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AIR & SPACE
CHALLENGES FOR FRENCH
SOVEREIGNTY AND FREEDOM
OF ACTION

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Editorial

There are many factors today that have an effect on the stability of our planet, and indications are that France and Europe will in the future, even more than now, suffer from changes concerning the equilibrium worldwide.

We are fully aware here and now of the decisive role of aerospace power. In this ever-changing environment, it will become the beating heart of the independence of assessment that underpins our freedom of political decision. It will confer upon us mastery of airspace, the pre-requisite for our liberty of action on the ground, at sea and in the skies. It will allow us to have the essential reactivity we need to defend our strategic interests and our power, ultimately in the defence of France and Europe, wherever it proves necessary.

The main challenge for our future is now the long-term ability to align our military capabilities with our ambitions in both European and worldwide contexts. It concerns strategic stakes of anticipation related to the future of our sovereignty and the degree of dependence on our alliances and—the bottom line—to the strategic independence of France and Europe in political, industrial and military affairs.

This 53rd International Paris Air Show, the *Salon international de l'Aéronautique et de l'Espace* au Bourget, offers the occasion to consider issues surrounding the future of aerospace in general. With that in mind, I offer my gratitude to all involved in producing this special supplement to *Revue Défense Nationale* dedicated to air and space power, for their commitment and their ideas in support of our consideration of these matters.

Général de brigade aérienne Guillaume LETALENET
Director of the Air Force centre for studies, reserves and partnerships (CERPA)

Summary

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Air Power Serving the Protection and Freedom of Action of our Country

Philippe LAVIGNE

Général d'armée aérienne, Chief of Staff of the French Air Force.

A little more than a century after the advent of air power at the time of the battle of Verdun, the Air Force today takes part in daily activity for the protection of our citizens and in France's commitments to the benefit of international security. It contributes to ensuring the sovereignty of our country and supports its freedom of action.

Our sovereignty is expressed notably through the command of our airspace: controlling access to it and detecting and identifying every aircraft in it is indispensable for the protection of our territory and for the security of everyone. In time of peace, it means being ready to face a hostile act such as the attacks of 11 September 2001 in the United States. Every day we come to the aid of aircraft in difficulty because of technical or human failure, or of some meteorological issues. That is why our airmen constantly scan their radar screens and why, by day and by night, our crews remain ready on their bases to take off to ensure our country's intervention capability, so essential to our security. Today, and even more so in the future, the challenge of exercising our sovereignty in our airspace will become even more determining, given the constant increase in the flows of aeroplanes crossing our territory and in the number of drones overflying us.
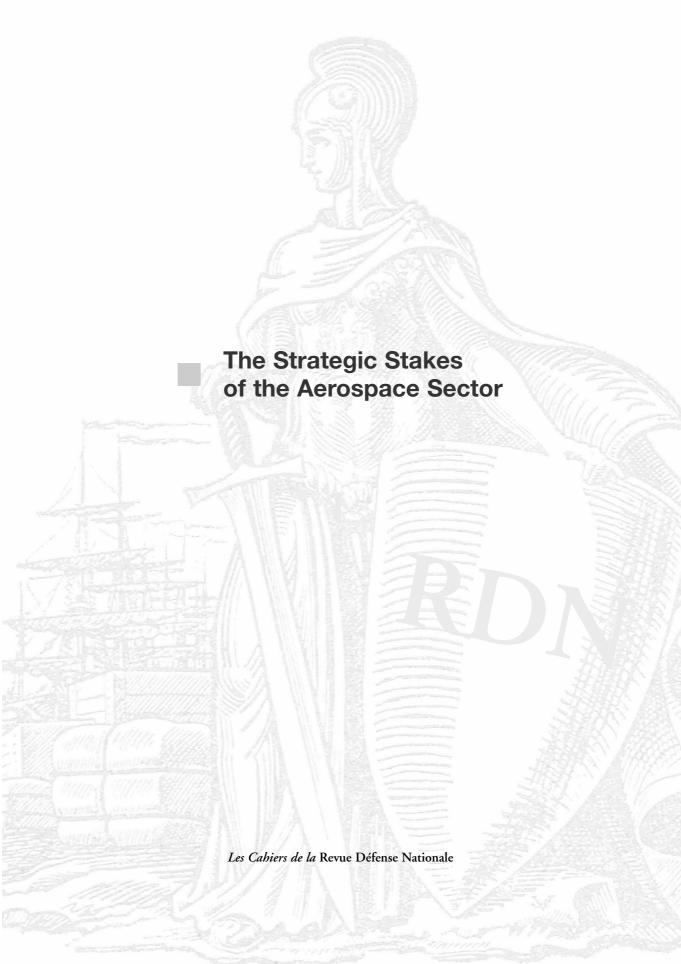
The Air Force also participates in the protection of France through its capacity to deter any major attack against its territory, its populations and its vital interests. That is the aim of the other permanent posture, nuclear deterrence. The Air Force has constantly maintained this posture since 1964 with its combat and refuelling aircraft. This function is in essence political, since it constitutes the ultimate guarantee of the security of our country. Internationally, the airborne component of the nuclear force, the *Forces aériennes stratégiques* (FAS), alongside the seaborne component, the *Force océanique stratégique* (FOST), embodies the sovereignty of France that was so cherished by General de Gaulle, and whose principle has been reaffirmed by every Head of State of the Fifth Republic. It presupposes a capability for intervention everywhere in the world, which is maintained by regular and demanding training in the acquisition and mastery of air superiority, and also for penetration in depth to the heart of heavily defended hostile territory.

Operation *Hamilton*, a strike against Syrian chemical sites, approved by the President of the Republic in the spring of 2018 and which faced the defences of a regime that maintains constant links with Russian forces, is an illustration of this. It demonstrated the capability of our country to coordinate in just a few days a large-scale, complex intervention combined with our American and British allies. It was also a reminder of the eminently political nature of air forces, affording France the ability to bring weight to an international conflict involving the major powers. Finally, this strike showed that a particular intervention can be conducted by air from national territory with no imprint on the theatre of operations.

The Air Force, a first response force, is also able to conduct long-term operations day and night for limited cost of deployment, as has been demonstrated since 2014 in Operations *Chammal* in the Levant and *Barkhane* in the Sahel. Its determination support to local and French ground forces aids the fight against the roots of Jihadist terrorism to guard against its extension into Europe.

The Air Force is reactive, multi-role and flexible, and free from the limitations of borders: it permits the rapid deployment anywhere of the power of our nation. Supported in particular by sovereign defence industry, it affords our national authorities a key asset in bringing French will to bear throughout the world. ◆

The Strategic Stakes
of the Aerospace Sector

French Aerospace DTIB:
A High-Stake Strategic
Defence Capability

Joël BARRE

Délégué général de l'armement (Head of defence procurement).

S trategic independence is the result of a will to possess the ability to pursue a defence and security policy freely and autonomously. This principle is manifest in the sovereign control of extensive military capabilities whose assurance over the long-term requires that the Defence Technological and Industrial Base (DTIB) that produces, maintains and improves them be considered as a defence capability in its own right.

The choices made in France have created a defence industrial policy, which is guaranteed by the Directorate-general of armament (*Direction générale de l'armement*—DGA), which is also a key player.

In contrast to the civil market, the defence market is very closed for several reasons. Above all, development and production function according to a regime of authorisation that *de facto* puts limits on the players. Exports are controlled: in principle they are prohibited other than by explicit state-approved exception. Retaining control of the national asset that defence industry represents is also the subject of great attention to foreign investment in France, strengthened further by the recent PACTE law.[1]

Clients tend to be states and few in number. The arms market is one of small volumes, long development cycles[2] and even longer equipment life. The products are more and more complex, high-tech and with specific requirements for performance, reliability and sourcing. These limitations imply close scrutiny of the DTIB in order to respond to the needs of our forces in development and production and also for maintenance in operational condition.

The French DITB is a top-notch technological ecosystem, able to produce almost all of our defence needs, that covers the whole of the chain of added value. It has major project leaders, many qualified as system managers and integrators, and a network of sub-contractors on several levels, such as successful ETI, SME and

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(1) *Plan d'action pour la croissance et la transformation des entreprises* (Action plan for growth and transformation of businesses).
(2) Development of Rafale started in 1986, with entry into active service in 2001 for the first standards.

start-ups,[3] that bring innovation and in some cases represent over 80 per cent of value added and contribute to the competitiveness of our major industrial groups.

The DITB is not limited to the industrial sector however: it obviously includes public and private research laboratories and public bodies, such as ONÉRA and CNES[4] for the aerospace sector, which bring their skills and experience as much to the lowest TRL[5] as to the most complex systems.

Technological advance is a measure of operational superiority, and demands research at a low TRL, in particular in areas unique to military applications ('non dual') such as supersonic aeronautical propulsion and the missile sector, which require significant financial investment. These studies do eventually have some fallout in the civil sector, and inversely technological advance is acquired through innovation in matters that are of interest to both civil and military markets.[6]

Through the DGA, the Ministry for the armed forces ensures development and maintenance of competences key to national defence over the long term. The levers that define this policy are of several types:

- Direction given to defence research and innovation via the Defence innovation agency (*Agence de l'innovation de Défense*—AID),
- Governance of industrial firms through administration committees for public concerns or by investment from the *Definvest* fund,
- Establishment of cooperation policies for armament programmes and for industrial organisation, an example being MBDA,
- Procurement policy by public orders in the fields of innovation as well as in armament programmes and operations,
- Support to exports via the network of armament attachés in our embassies and at high-level meetings,
- Support to SME through the SME action plan to ease their access to the armed forces' Ministry's markets by simplifying procedures, helping them to export, guiding them in their requests for European funding and looking after their contractual relationships with the major leading groups in the defence markets.

The main players in the aerospace DTIB[7]

The French aerospace industry employs 195,000 staff in France and had a turnover of 65.4 billion euros in 2018,[8] of which, 77 per cent came from the civil

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(3) *Entreprises de taille intermédiaire* (ETI)=Intermediate-sized enterprises; SME=Small and Medium Enterprises.

(4) *Office national d'études et de recherches aérospatiales* (ONÉRA)=National office for aerospace studies and research; *Centre national d'études spatiales* (CNES)= National centre for space studies.

(5) Technology Readiness Level.

(6) Typical examples would be aeronautical propulsion and the link between space launchers and ballistic missiles, for which R&D enjoys significant cross-fertilisation.

(7) This list is not exhaustive: the reader is asked to excuse the simplification made here.

(8) Source: *Groupement des industries françaises aéronautiques et spatiales* (GIFAS), the French aerospace industries association.

sector and 85 per cent was from exports. Dassault Aviation and the Airbus, Thales and Safran groups are the principal system engineers and integrators within the defence aerospace industry. Directly or via cooperation between companies they therefore constitute the fundamental structure of the ecosystem.

Airbus, the biggest aerospace and defence group in Europe,[9] is organised into three divisions:

– Airbus Commercial Aircraft, in charge of commercial aircraft.

– Airbus Helicopters (AH), world leader in civil and public service helicopters (40 per cent of the market), and 4th in the world for military helicopters.

– Airbus Defence & Space (ADS) is built around 4 main areas of interest: military aircraft, space, pilotless air systems and communication-intelligence-security. ADS is world number two for satellites.[10] Its flagship defence programmes are the A400M transport aircraft, the multi-role tanker transport A330 MRTT, the European MALE drone (Medium Altitude, Long Endurance), and for our foreign partners, the Eurofighter.

Dassault Aviation (DA)[11] is one of the world leaders in business aviation with its Falcon range, but is above all the project manager for the Rafale combat aircraft for which development of standard 4 is underway. DA's competence extends also to aircraft (*Atlantique 2*), for missions of intelligence gathering and maritime patrol, and to combat drones with the European cooperative technological demonstrator nEUROn.

The Safran group[12] has broadly three main areas of activity:

– Propulsion: military engines (M88 for Rafale and TP400 for the A400M) and civil ones (CFM56, LEAP with the US company General Electric), turbojets (helicopters and cruise missiles) and electrical propulsion for satellites.

– Aeronautical equipment (in particular pods, undercarriage, electrical systems, power transmissions and cabling), which includes a wide range of the activities of Zodiac, whose purchase and merger was successfully achieved at the beginning of 2018.

– Defence and electronics: inertial navigation, optronics, avionics and defence systems, in particular AASM,[13] and the Sperwer and Patroller drone systems.

ArianeGroup,[14] a Franco-German company and subsidiary of Safran and ADS, was created on 1 July 2016 on merger of the launch activities of the two owning

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(9) With nearly 130,000 employees and a turnover in 2018 of 63.7 billion euros.

(10) In 2017 the turnover in space matters was of the order of 3 billion euros, with activity divided across three countries, France, Germany and the United Kingdom.

(11) In 2018 DA's turnover was 5 billion euros, and it had 11,400 employees.

(12) Safran's turnover was 21 billion euros in 2018 (including Zodiac Aerospace's share) and it employs over 55,000 staff in 57 countries of which, 35,000 in France.

(13) *Armement air-sol modulaire* (Modular air-ground armament).

(14) With turnover of around 3.6 billion euros in 2018, ArianeGroup employs 9,000 staff, mainly in France, but also in Germany.

companies. With it, France has a European and world-level champion in the field of launchers which gives it independent access to space. It is also the project manager for the M51 ballistic missile, one of the pillars of French deterrence.

Thales is the main European industry in the defence electronics sector.[15] The group's skills range from supply of components, equipment and subsystems to systems project management in strategic areas such as EW, tactical communications and missile electronics. It is also developing its activity in civil aeronautics as a supplier of civil and military Flying Management System (FMS) equipment.

A world player in satellites, Thales Alenia Space (TAS)[16] provides, as does ADS, management of both space and ground components of satellite systems. These two specialists are now associated in the creation of our most recent independent capabilities.[17]

This all-round look at the great masters of integration would not be complete without mention of the missile company, MBDA.[18] Present in four European countries (France, United Kingdom, Italy and Germany), it equips all European aircraft with the Meteor long-range air-air missile. MBDA is driving hard for stronger integration between France and the United Kingdom with centres of excellence that lead to mutual dependence, a successful example of controlled rationalisation of industry on the European level.

DTIB challenges in aeronautics

Civil aeronautical activity is growing strongly and has to deal with increasing its delivery rate to match that of worldwide air traffic. Taking into account the global situation, reduction in the environmental impact of each aircraft is a specific challenge that puts engine manufacturers under the spotlight. Such challenges are not limited to big companies, as they affect the entire sub-contracting chain with its associated financial and HR investments.

The increasing number of aircraft poses questions on adaptation of the associated MRO workload.[19] Through the Directorate of aeronautical maintenance (*Direction de la maintenance aéronautique*—DMAé), the armed forces Ministry is committed to restructuring the industrial landscape of military aeronautical support. It remains to be seen if the same will apply to the civil sector, in which industrial concerns are reforming and in which aircraft fleets are growing.

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(15) Defence activity before acquisition of Gemalto, represented about half its turnover of 15.86 billion euros in 2018. The group employs some 64,900 people across the world, of which 34,500 in France.

(16) TAS, a joint enterprise of Thales (67 per cent) and the Italian Leonardo (33 per cent), has a turnover of some 2.4 billion euros and over 7,500 employees.

(17) On *CSO* (*Composante spatiale optique*—space optical component), *Syracuse IV* and *CÉRES* (*Capacité d'écoute et de renseignement électromagnétique spatiale*—capability for listening and gathering of electromagnetic intelligence from space).

(18) A subsidiary of ADS (37.5 per cent), BAE systems (37.5 per cent) and Leonardo (25 per cent), MBDA employs 10,500 people and has a turnover of 3.2 billion euros.

(19) Maintenance, repair & overhaul.

With regard to combat aviation the challenges are many: short-term ability across the entire production chain to satisfy export clients by an increase in production rate and adaptation of industry needed to respond to the demands of offset linked to exports, whilst at the same time maintaining over the medium term the key design office skills required on a European scale for the Future combat air system (FCAS, *Système de combat aérien du futur*—SCAF). Among other things, the latter will be composed of a new combat aircraft, the New Generation Fighter (NGF), which will be outfitted with advanced survivability and manoeuvrability capabilities that will call upon brand new technologies including artificial intelligence (AI) to assist its aircrew in understanding the combat picture and taking the right decisions. The NGF will be accompanied by unmanned remote carriers that have a degree of autonomy. FCAS will have to provide the political decision-maker with freedom of action through its ability to acquire and maintain air superiority in post-2040 conflict situations. Spain has recently joined what was begun as a Franco-German bilateral project, whose success will depend among other things on the capability to build industrial agreements that respect requirements for sovereignty and are concerned for the best use of established competences, yet are open to new technologies and industrial innovation.

The helicopter sector is being severely hit by a reduction in demand from the oil rig business and is relying on renewal of the range of helicopters currently in service. Development of the H160, successor to the *Dauphin* family, has meant that engineering expertise has been retained in the civil field within AH and its main partners, Thales for modular avionics and Safran Helicopter Engines for the turbine engines. The helicopter of the future will be driven by the civil need, from which defence can benefit: increased speed without detriment to payload, reduced environmental impact, better noise reduction reduced operating cost and more. The move to standard 3 of the Tigre, the development of a Special Forces version of the NH90 and work on the forthcoming HIL[20] will in the short and medium terms mean we can keep our design office competences up to better levels in matters regarding the strictly defence sector, such as self-protection, weapon and fire control integration and sensors. The MALE Eurodrone programme being developed in cooperation with Germany, Italy and Spain is important for the sector and will offer Europe control over the intelligence that is so important for its independence of appreciation of a situation and decision. Through this project the DTIB has to demonstrate its capability to enter the worldwide order of battle in this highly competitive sector.

The technological studies in the SDAM[21] project for vertical take-off drones will capitalise on the competences of a particular SME, Guimbal, which is an excellent example of SME creativity, and will bring together the bigger project leaders, AH and Naval Group, with the support of Thales and Safran.

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(20) The *Hélicoptère interarmée léger* (HIL), the light joint helicopter, is derived from the H160 and will be produced in several standards.
(21) *Système de drone aérien* pour la Marine (Air drone system for the Navy).

DTIB challenges in space

The worldwide positions won by TAS and ADS through their competences are being called into question by the increasing number of new players in Europe, with OHB, and also by private interests in New Space. The French DTIB nevertheless has the capability to respond to these challenges, for example through the work being conducted by CNES in cooperation with Nexeya that aims to provide a nano-satellite platform able to fulfil requirements of future constellations, and by the gamble taken on by ADS to industrialise satellite production (OneSat). Accepting that image resolution has limits, reduction in delays to revisit a point and correlation of information from different wavelengths are operational challenges of greater importance to defence space observation. The technological challenges that will have to be met relate in particular to digitisation of satellites and their payloads, optical telecommunications, technologies that bring operational superiority (especially infrared, hyperspectral imaging, penetrating radar frequencies, waveforms and accuracy of positioning), and those that contribute to the resilience of our operational systems, such as anti-jamming. Which is not to forget other technologies that will ensure the integrity and durability of our assets such as those relating to orbiting services.

For its part, ArianeGroup has to face up to reduced costs of launch that have appeared with players in New Space who benefit from sizeable institutional contracts incomparable with European industry. That will be *Ariane 6*'s short-term challenge.

Research into hypervelocity is now a technological challenge that has to be followed up thoroughly. Solutions will draw on studies by ONÉRA on supersonic propulsion and super-ramjets. ArianeGroup, responding to a DGA requirement, is getting ready for the challenge to produce a manoeuvring hypervelocity glider demonstrator (V-max).

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The French aerospace DTIB is flourishing. It includes not only the major industrial companies but also the precious ETI and SME that are permanent sources of innovation. As ever, the big boys overshadow the small ones but it is only when they all work together as an ecosystem that they can collectively rise to the challenges.

The project managers of the DTIB are European leaders who justify prime places in cooperative programmes such as the European MALE drone and the FCAS.

Cooperation is explicitly sought after by France and is all the more encouraged on a European level with the establishment of Permanent Structured Cooperation (PESCO) and the European Defence Fund (EDF), which are leading to identification of common technological and capability priorities and substantial funding for collaborative projects.[22] Cooperation between states implies the same between their companies and will bring with it industrial rapprochement. Such industrial consolidation has

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(22) The EDF could receive some 13 billion euros for the period 2021 to 2027.

strategic, economic, technological and operational interest and helps achieve European sovereignty.

We will first have to work towards creating added value in Europe that will be shared across our increased independence, operational and technological superiority, export competitiveness and employment. Whatever happens, the opportunities afforded to the French DTIB must be seized upon to strengthen the major industrial groups and the entire ecosystem that surrounds them. ◆

Ten Proposals to Consider
in Forming a Space Defence Strategy

Philippe STEININGER

General, military advisor to the president of the national centre for space studies (CNES).

Whilst military history seems to be stuttering its way to extinction, extra-atmospheric space is at last being recognised as a zone of confrontation. In some ways we currently regard space as we once regarded aviation just before the Great War. At that time, the majority of military commanders still only saw the flying machine as a supporting tool for ground operations among others. Yes, its usefulness for gathering intelligence, communication and directing artillery fires had been recognised, but more offensive missions for aviation had not been considered. The First World War rapidly altered opinions by demonstrating in particular the need to *fight* in the skies in order to impede the enemy and to conduct one's own operations. Materiel was therefore adapted to this new mission, men trained for it and *ad hoc* organisations established to manage it.

At the outset of battle of Verdun, the Germans had mastery of the air and were able to stop static balloon deployments and French aviation missions. The command therefore no longer had a precise picture of the front line and its artillery lost effectiveness. It was then that an anxious but far-seeing Pétain spoke to his head of aviation saying, "Rose, clear the sky for me! I'm blind (…). If we are chased from the sky, then it's simple: Verdun will be lost". Whilst nobody today contests the advantage in having space assets for the conduct of military operations, they are as vulnerable as were the aircraft and the balloons at Verdun, given that a number of nations possess means of action in space which could potentially target them.

Where and when will be our next 'Verdun', that test in which a military commander might say, on the lines of Pétain in 1916, "Clear space for me, I am blind, I can't communicate any more, my forces don't know where they are and can no longer fire with accuracy"?

Wisdom dictates that we should look closely at the ways and means capable of substantially reinforcing the security of our space operations since, were conflict to break out, inability to control space risks military rout. It is with this in view that ten proposals are presented below for consideration in forming a strategy for space.

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1. All countries are concerned by the exploitation of inner (or *circumterrestrial*) space, which is common property. Regulation of space activity needs therefore to have a multi-lateral approach even though an infinitesimal minority of states have complete control of it.

In less than half a century space has entered the daily life of humans by bringing them a considerable number of services. Humans resort to space-based systems to communicate with each other, for the accurate synchronisation of some of their activities, for better knowledge of their environment and even for preservation of the planet. Given that, it is hardly surprising that more and more countries are showing interest in space, witness a constant increase in the number of national space agencies. Add to this shared interest the fact that extra-atmospheric space has no respect for the principle of territorial sovereignty and the consequence must be that any attempt to regulate human activity in space has to be multilateral in nature.

Shared interest and a multilateral approach are therefore key elements to any policy on space. But if extra-atmospheric space is presented as property common to all humans, it has to be said that it remains an environment access to which is extremely selective and which only very few powers are able to conquer. It is a fact that fewer than half of all countries possess orbital platforms, even though all benefit from space-related services. Moreover only some 3 per cent of countries have autonomy of action in space, meaning that they are capable of designing, producing, launching and setting orbital platforms to work on a regular basis. On a more strategic level, it might be considered that a little more than just one per cent of countries could be considered as genuine military space powers, those which have added a coherent space element to their defence policy linked to independent capabilities for space surveillance, launching, a range of supplementary services and activity in space. These few countries enjoy a strategic advantage over others and find themselves in a position that history has afforded but very rarely.

2. No military space power can exist unless supported by civilian industry and competences in the sector.

In 1965, France became the third space power when it put the *Asterix* satellite into orbit with the *Diamant* launch vehicle. What is less known is that with that same activity, our country began trials of a ballistic missile intended for its nuclear deterrent force, which had been developed in parallel with the *Diamant* vehicle. This glance at history is a reminder that duality was at the heart of space activities as they began— and it still is, as demonstrated by the simple fact that all defence satellites have been put on station by civilian launchers, and that the services provided by the *Galileo* constellation of satellites will very soon find military applications. And what goes for France goes also for all space powers, from the United States, which entrusts major military contracts to the company Space X, through Russia and India to China.

Fact is that the capability to design, produce and launch orbital systems constitutes a distinguishing factor in the evaluation of a country's 'space power'. And yet these are the same assets and competences that are mobilised for both civil and military

aspects of space activities, something ever more true when relating to a medium power like ours, which is not in a position to spread its effort. From that point of view we can only be pleased about the presence in our country of an effective industrial ecosystem that in space matters ranks on a worldwide scale, along with the repeated successes over several decades of the *Ariane* launchers, which owe much to French expertise.

A truly sovereign military space strategy is conditioned in the long term by the vitality of that industrial ecosystem which supports it. Their joint future merits adoption of measures to maintain competences and the industrial base.

3. An orbital platform does not operate like an aeroplane. It does not fly, as such, and is physically accessible only to a very limited degree. Furthermore, it is subject to Kepler's laws throughout its operational life.

An often-made error is to envisage space operations in the same way as air operations, as if satellites behaved like aircraft, and yet the latter allow a wide range of manoeuvres and offer the great advantage of being in permanent contact with their users. None of that applies to an orbital platform: its dynamics are subject to Kepler's laws, which constrain its ability to manoeuvre, and for the few years of its operational life it is stationed far from its operator in a barely accessible and aggressive environment which precludes virtually any maintenance operation.

Space operations need therefore to be understood in the context of the three major constraints affecting them which, although seemingly evident, are too often forgotten:

• Above all, a satellite rotates around the earth and does not 'fly'. Given that, changing an orbit consumes a lot of energy, and arranging an r/v with another orbital platform can be achieved within a given plan if programmed before launch, but is hard to arrange thereafter if not.

• Next, a satellite has little on-board energy available, between 2 and 20 kW for a standard satellite, which amounts roughly to what is available in an apartment. For a nano-satellite, the available power amounts to just a few watts. Operational possibilities are therefore very limited.

• Finally, a satellite is far removed from its operators—typically between 300 and 36,000 km (roughly 180 and 22,500 miles) away—in a barely accessible environment, which complicates any intervention on the said satellite.

4. Everywhere on earth can be seen from space.

One consequence of the laws of space mechanics is that at some moment every point on earth is visible from a space platform in polar orbit, and another is that a large area of the earth's surface can be permanently visible from a satellite judiciously positioned in geostationary orbit. Whilst numerous operational opportunities are offered by these facts, they are at the same time limited by the same space mechanics, which

mean that permanence and accuracy of observation work in opposition. Put another way, a distant geostationary orbit at around 36,000 km/22,500 miles from earth offers permanence to the detriment of accuracy (and of latency, if considering communications), whereas for a polar orbit, the lower it is, the more accurate it is, but any observation is only fleeting, to the extent even of being stealthy.

Improvement in the performance of detection devices is the lever that allows the situation of the geostationary satellite to be corrected. In time such improvement should allow observation of the earth from that orbit with a degree of accuracy that would have certain operational interest. With regard to polar orbits, this improvement in detection devices adds to the altitude of the orbit as another parameter leading to improved observation quality. Improvement in the persistence of the observation is made by increasing the number of orbital platforms. It is because of this that numerous plans for constellations of low-orbit observation satellites are being developed, since they additionally afford a considerable capacity for revisits.

The result of this situation is that hiding a military manoeuvre will in the short term become extremely difficult because of the presence in space of a multitude of highly effective military and civilian detectors. For the military chief, this means that surprise will no longer come so much from concealment, but more from speed of execution, control of information, decoys and deception.

5. Freedom of access to space is the prerequisite of any space strategy.

This proposal, a truism, is worth advancing given its strong relevance and that the requirements stemming from it are structural. Forty-five years ago our country was forced to understand the meaning of lack of freedom of access to space when the United States refused permission for the commercial exploitation of one of our satellites that was due to be launched by an American rocket. France learned from the incident and offered Europe a launch vehicle that it had designed. This was the start of the Ariane programme, which for the past forty years has ensured Europe's independence of access to space.

The other key element of autonomous access to space is having a launching base on one's own territory. Conscious of the strategic challenges presented, our country quickly took the decision to equip itself with sovereign launch facilities and dedicated considerable effort in that direction. Since its creation in 1964, the space centre in Guyane (French Guiana) has been a visible demonstration of the French will to possess independent access to space. It allows our country to launch military satellites from a very advantageous geographical position in terms of performance whilst protecting our secrets and freeing us from any constraint linked to export.

The United States, Russia, China, India, Japan and other countries well understood that independent access to space was a condition for all space activities. It is therefore in this context of greater competition that we have to consider the preservation of the European launch capability and the upkeep of the European spaceport.

6. *Circumterrestrial* **space is a transparent environment for those who possess the right means of detection. Knowledge of the situation in space is primordial among military space missions.**

The positivist Auguste Comte argued that we need knowledge so we can anticipate in order to be in a position to act. (savoir pour prévoir afin de pouvoir). Mastery of space does not escape the logic of this situation, and indeed begins with knowledge of the activities being conducted there, sometimes just a few hundred kilometres above our territory.

Space surveillance responds in practice to two needs: that of removing as far as possible from orbital systems the risk of collision with other platforms or space debris, and that of establishing a situation in space with the aim of preserving our interests. Whilst radar is the most appropriate way of keeping watch over low orbits, higher orbits can only be observed by optical means. It is almost impossible to hide in space, and once detected, an object can be tracked—all the more easily, given that orbital movements are broadly predictable.

Surveillance of space is the cornerstone of space security in its three aspects of detection, identification and tracking, which is why it is a high priority to possess independent and robust assets for space surveillance in order to assess the threats to satellites and to take appropriate protection measures.

7. Digital data is both fuel and product of all space activity.

The space environment is one of collection and transit of data. On this we should not forget that each of us, every day, uses information from several dozen satellites to communicate, navigate, inform ourselves about the weather, and to search for information on internet. Economic activity is also partly dependent on space assets, and it is in that way that some stock and share trading organisations link their activity to a common time reference supplied by satellites. Regarding the military field, it takes little imagination to realise that were satellites to fail, there would no longer be any significant operations, since the element that in great measure gives Western forces their superiority would disappear.

Digital data has well and truly become both fuel and product of space activity. That being so, the security of the data is very closely linked to the cyber-security of its environment. Taking into account the threats observed in cyberspace, protection against cyber attacks on the entire chain of a space system—ground and satellite segments—needs to be very meticulously controlled.

8. The centre of gravity of a spatial vehicle is on the ground.

Orbital platform attacks may, using different methods, be initiated from the ground, from space or within the atmosphere. The methods are all technically very demanding and require considerable, specialised expertise. It would seem easier to attack the platforms by setting about the ground elements upon which they depend—

exist, even—in some conventional manner. This goes for the industrial base that produces them, and even more so their launch, control and exploitation infrastructure in which there is little redundancy, and which makes them relatively vulnerable.

The corollary of recognition that the space environment has become one of confrontation, even of conflict, is establishing redundancy in, and protection of ground-based space infrastructure.

9. Destruction of a space vehicle by impact will in time affect the capabilities of all players, including the aggressor's.

A physical attack on a satellite runs a high risk of creating space debris, which represents a danger to all orbital systems, including those belonging to the aggressor. In 2007, the intentional destruction by the Chinese of one of their satellites created thousands of particles of debris which today pose a significant risk to low-orbit satellites. Moreover, the impact on satellites of munitions fired from earth or from low altitude tends to throw the debris 'upwards'. This means that such destruction of a satellite in a very low orbit (under 400 km/250 miles) might be considered non-problematic since the debris created would be rapidly consumed by the atmosphere, but is in fact quite the opposite, since the reality is that far higher orbits become lastingly polluted. This fact helps to reduce the probability that an offensive act in space would be in the form of a destructive shot. The risks of non-destructive offensive acts against satellites are therefore greatest, taking the form, for example, of EM pulses, jamming, lasers or degradation of certain components of the platform. Nevertheless, the main risk remains that of computer attack on a satellite's control chain, which might go as far as taking over control of the satellite.

Having the capability to destroy satellites in orbit with kinetic weapons is of greater value to a country which itself possesses few space assets. In this case it would have a sort of equalising power when compared with more advanced military powers: a paradoxical situation in which it is able to hold mastery over highly developed space techniques without being capable of exploiting the potential of them. Thus a country little advanced in space technology but which began to develop kinetic anti-satellite weapons should be very closely watched.

10. Attrition of space assets produces short-term irreversible effects which can only be compensated by a number of prearranged resilience measures.

The production and launch cycle of satellites is currently still very lengthy even without taking into consideration the costs involved. It follows that a lost satellite cannot be replaced numerically in a timescale compatible with normal operational requirements unless a similar model is held in reserve and there is a suitably reactive launch capability, both of which are beyond the financial scope of almost all countries. Besides that, it is clear that when faced with attrition, a constellation offers the best guarantee of resilience.

Against the same background, attrition of space assets should also be seen as being applied to ground infrastructure and equipment, including launch bases, satellite ground segments or space surveillance assets.

Faced with the possibility of attrition of its space assets, a wise country would well beforehand set in place resilience measures that would be activated according to need and rely in particular on international cooperation and use of civilian systems.

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Strategic thinking today on space is largely confined to inner, or *circumterrestrial*, space, to which the ten proposals presented here should be considered as applicable. In the future, discussion should be on what is possible in that space between the earth and the moon, then outer space, and further proposals considered. ◆

Space Cooperation in Europe:
Great Success in the Civil Field,
Little Developed in the Military Field

Gérard BRACHET

Former Director General of CNES, the French Space Agency.

European cooperation in space affairs had some difficult teething troubles in the nineteen sixties and seventies, a period noted for the coexistence of two organisations, the European Space Research Organisation (ESRO), exclusively dedicated to scientific research in space, and the European Launcher Development Organisation (ELDO), dedicated to development of the launcher *Europa*. Unfortunately the latter saw nothing but setbacks during its development and was abandoned in 1972. This failure was attributed to a weak programme management though in the end led to a positive outcome in the French proposal to develop the *Ariane* launcher in a far more technically-orientated programme to be directed by the French Space Agency (*Centre national d'études spatiales*—CNES) on behalf of the European Space Agency (ESA).

Creation of the ESA and the success of inter-governmental cooperation

The ESA was decided upon in 1973 and became effective in 1975. It took on the ESRO's scientific programmes and in particular introduced the notion of optional programmes in which only interested member states could choose to participate. In 1973 this new notion facilitated commitment to the *Ariane*, *Spacelab* (West Germany) and *MAROTS* (United Kingdom) satellite programmes. Other satellite programmes with applications such as *Meteosat* (meteorology) and OTS/ECS (point to point tele-communications) also benefited from the flexibility of the ESA convention that introduced and intelligently managed these optional programmes for which the guarantee of in-country industrial contracts was the best argument for convincing member states to participate financially. The latter point is worthy of analysis across the entire range of programmes of the European Space Agency, including the compulsory scientific programme to which all member states contribute according to their GDP.

This scientific programme is also worth a particular look, since it has allowed Europe to play a leading role in astrophysics and in exploration of the solar system virtually without a hitch, placing the European scientific community on the same level as the American one despite the considerable difference between the financial assets that NASA and ESA commit to these activities.

This organisation has worked well since its creation and has led to commitment to new programmes such as (regarding earth observation alone) *ERS-1* and *2* radar satellites in 1981 and 1984, launched respectively in 1991 and 1995, then the highly ambitious *ENVISAT*, decided upon in 1992 and launched in 2002 which until 2012 supplied improved radar data of the same type as ERS as well as new information on the chemistry of the atmosphere related to depletion of the ozone layer and greenhouse gases. It also led to the decision to develop the METOP polar orbiting meteorological prototype satellites requested by the meteorological services, and a number of programmes for validation of new satellite telecommunications technologies.

In October 1995, during a difficult ESA council meeting at ministerial level in Toulouse, Europe's participation in the International Space Station (ISS) project was agreed, a decision that felt more political than technical but one supported vigorously by Germany. Europe then committed to supplying one of the modules of the station (*Columbus*, which was launched in 2005 and has been operational since then) as well as the Automatic Transfer Vehicle (ATV), a huge, unmanned cargo vessel weighing over 20 tons for the regular resupply of the station. There were five ATV launches by *Ariane 5* from 2008 to 2014, which among other things served to pay in kind Europe's share of the operational costs of the ISS.

For launchers, the decision mechanism for the ESA's optional programmes authorised development of new versions of the *Ariane* launcher, *Ariane 4* in 1984, launched for the first time in 1988 and exploited with great success up to 2003, then *Ariane 5* in 1987, whose first launch in 1996 was a failure, but after being quickly overcome went on to conduct an impressive series of successes—more than 100 by April 2019. This excellent result is perhaps the origin of a degree of relaxation of European vigilance: from 2005 to 2010 Europe paid insufficient attention to rekindled competition in the United States with the arrival of SpaceX and its Falcon launchers. As a result the preparation of the following generation started late and it was only in 2014 that the ESA Ministerial Council launched development of *Ariane 6*, this time with a completely renewed industrial organisation based on the new company Ariane-Group, which brought together the ballistic missile and space launcher teams from Airbus, and the space rocket engine teams from Safran. *Ariane 6* will be in two versions, 62 and 64 (2 or 4 additional propulsors), and will operate from the European spaceport in French Guiana, within the Guiana space centre the (*Centre spatial guyanais*—CSG).

A little-known but remarkable dimension of this European effort in space cooperation has been its capacity to conceive and organise bodies able to take over from the ESA in exploiting the systems it has developed. It was in this way that Eutelsat for telecommunications satellites (privatised at the beginning of the century), the European inter-governmental organisation EUMETSAT for meteorological satellites and Arianespace for commercialisation of launching services using *Ariane*, progressively took over the exploitation of satellites and launchers that had been developed under the auspices of the ESA. Arianespace is a particularly interesting case since on creation in 1980 it was the first company in the world to offer a commercial

satellite launch service. At that time, NASA was responsible for American launchers operating for civilian applications, including launches of non-American satellites, and the Department of Defense (DoD) was responsible for operating launchers for its own requirements.

The ESA is an inter-governmental organisation quite independent from the European Union. It has non-EU member states such as Switzerland and Norway, and the United Kingdom intends to remain a member even after Brexit, should the latter occur. Its success comes from the confidence of its member countries in the management of programmes by the Agency's technical teams. In particular they are very attentive to commitments regarding the geographical benefits of programmes, occasionally to the detriment of a programme itself. The ability of the ESA to manage these constraints to the benefit of everyone whilst generally keeping to cost and timetable targets is a reason why a number of European countries has expressed a wish to join the Agency over the years. From eleven at its creation in 1975 it had twenty-two member countries in 2018. Such expansion has only been possible by great attention being paid to the increasing ability of new member countries' industries, which has occasionally led to inefficient doubling up of critical competences in Europe. This trend towards scattering of teams and industrial sites goes against the overall competitiveness of European space industry as a whole, but is probably the price to pay for a truly inclusive approach to the development of a European space organisation which does not leave by the wayside those countries that have decided later than others to invest in the sector.

The European Union becomes interested in space

The gradually increasing EU interest in space matters only really began at the beginning of the nineteen-nineties. Until then only the European Commission's 'research' directorate kept an eye on how EU member states' space ambitions were developing: it did not intervene, since they had already taken the initiative to create the ESA.

That said, the Joint Research Centre of the European Commission was already very involved through its space applications institute at Ispra in Italy. For several years the institute's teams had been studying practical applications of remote sensing imagery from space. The most remarkable among these was the MARS programme in direct support of the Common Agricultural Policy, which generated statistics on the agricultural production of all member states from analysis of imagery from the American *Landsat* satellites and later, from 1986, from the Franco-Belgian-Swedish *SPOT* satellite. The institute was also working on satellite surveillance of tropical forests and oceans in close cooperation with a number of research laboratories and teams spread across the whole of Europe. This work was directly related to studies into global changes that were developing rapidly in the nineteen eighties and nineties.

During the same period, the European Commission was involved via its environment and external relations directorates in preparation and negotiations regarding international conferences on the reduction of greenhouse gases which were to culminate

in signature of the famous Kyoto Protocol in 1997. These negotiations highlighted that, while Europe's desire to reduce its production of greenhouse gases was real, it did not really know how to go about doing it or how to measure independently on a world-wide scale the rates of production and absorption of these gases—particularly carbon dioxide. It therefore became important that the EU negotiators were correctly informed through observation from space of progress made in the key parameters used to measure climate change. This necessary connection between highly advanced research and the world of regulators and politicians was the origin of the EU's *Copernicus* programme that was first known by the name Global Monitoring for Environment and Security (GMES) and which was set in motion in the early years of the century after publication of the Baveno Manifesto in 1998.[1]

The EU undertook a considerable part of the financing of the programme, to the tune of nearly 8 billion euros. It has an entire series of operational observation satellites developed under the aegis of the ESA and sent into orbit from 2014. At the beginning of 2019, seven Sentinels are being exploited and others are being prepared. It is a very fine example of efficient cooperation between the EU, which is financing the major part of the programme, and the ESA, which is managing the development of satellites entrusted to industry, the operations in orbit and the ground assets needed for the reception, storage and distribution of a quite considerable mass of data. The budget planned by the European Commission for *Copernicus* over the period 2021-2027 is 5.8 Billion euros.

The EU's other main space programme is the *Galileo* positioning and navigation satellite constellation, better known to the public at large because of its services similar to those of the American GPS. Its origin is interesting: for the EU it was a question of reducing economic dependence on GPS, which had become excessive by virtue of GPS's monopoly and the complete absence of commitment by the US government to the continuity and integrity of the civilian GPS signal. The latter was offered free to the rest of the world, it is accepted, but was not backed up by the slightest guarantee. The economic impact of this system is considerable for applications are multiplying at an astonishing rate, well in excess of the wildest dreams of the (military) founders of GPS. The question of dependence on it is therefore even more relevant, since it is a unique system whose primary objective is above all military—civilian use comes a second.

The European Commission's initial proposal for the *Galileo* programme was drawn up in 1999 by its transport and energy directorate, and called on a public-private partnership for the deployment of a constellation of thirty satellites whilst the development cost for the first four prototypes and a third of the deployment cost would remain chargeable to the EU budget. The scale of financing needed for the deployment and the uncertainty over return on investment led to an impasse and the approach was abandoned in 2007, after which the EU took on the total deployment

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[1] Global Monitoring for Environmental Security: A manifesto for a new European Initiative, brochure published by the Joint Research Centre, Ispra, October 1998.

cost of *Galileo* of nearly 11 Billion euros. The European Commission delegated to the ESA the technical management of the development phase of the programme on the condition that it obey EU management rules, which are different from those of the ESA and which exclude the guarantee of geographical benefits. Division of the industrial work into six main sections in effect made the ESA the overseer of development and validation of the system and as a result the single entity in a position to guarantee its performance.

Today after many delays (including *Soyuz* putting two of the satellites into incorrect orbits) and several other concerns in particular over on-board atomic clocks, 26 satellites are currently being exploited out of the 30 planned, and another 12 are under construction. Since the end of 2016, some of *Galileo*'s services have been operational, including the free Open Service. The performance is remarkable, with instantaneous positional accuracy of about 1.5 metres (5 feet), which is better than that for GPS (2.5 to 3 metres/8 to 10 feet for bi-frequency receivers[2]) and far better than the Russian *GLONASS* and the Chinese *Beidou*. The Public Regulated Service, reserved for EU member states' governmental services, is not yet ready: its initial operational capability should be available from the beginning of 2020. It is also planned to introduce a free high-accuracy service that will offer positioning to 20 centimetres (8 inches) and a 'certified' positioning service in a few years' time that may be charged for. Additionally the *Galileo* satellites carry equipment for the reception and retransmission of 406 MHz maritime and aeronautical distress transponders that ensure the continuity of the international *COSPAS-SARAST* system that was set up at the beginning of the nineteen-eighties by Canada, the United States, France and the Soviet Union. *Galileo* improves the service significantly by reducing the time for detection from several hours to 10 minutes and by allowing the SAR services to benefit from the accuracy of its localisation function.

After numerous ups and downs and delays, the European *Galileo* system is therefore on the way to achieving the operational stage and from now on the GSA[3] and the European Commission are studying desirable developments for services that might be included in the second generation of *Galileo* satellites. The budget planned by the European Commission for the *Galileo* programme for the period 2021-2027 is 8.25 Billion euros.

A fair measure of the credibility that *Galileo* has now achieved can be found in the fact that most so-called GPS chips in portable telephones currently on the market are in fact GPS+*Galileo* chips, able to handle signals from both constellations of satellites. The GSA reckons that today over 700 million terminals worldwide are equipped to receive *Galileo* signals and that the figure will exceed a billion by the end of 2019.

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(2) Which are in fact only a small share of the GPS receiver market, most being single frequency.
(3) European Global Navigation Satellite Systems Agency.

What about European cooperation in space systems for defence?

In the field of space systems that serve defence needs, in which the ESA cannot intervene since its constitution forbids it, member states of the EU tend to define their needs and develop their systems on a purely national basis. The British were first to deploy a system dedicated to their armed forces, the *Skynet* telecommunications system, which is now in its 6th generation (*Skynet 6*). France followed with its *Syracuse* satellites (*Syracuse III* today). Italy with the *Sicral* satellites, and Germany with the *SATCOMBW* satellites have done the same, as has Spain. Attempts to arrive at a common definition of needs and communications security requirements have never managed to achieve agreement on a single shared system. From the economical and operational points of view it is in any case far from certain that such a solution would suit military needs, given the very wide geographical variation in intervention areas for the forces concerned. Moreover the need for bandwidth regularly exceeds the capability available. This very rapid growth in the telecommunications needs of the armed forces is in part linked to the growing use of drones in operational theatres whose observation data collected has to be sent back to base, and communication with which has to be performed in real time.

In this somewhat national landscape of military space telecommunications there is one exception worthy of note. France and Italy have been able to reach agreement on a common high-data rate telecommunications satellite, *Athena-Fidus*, which was put into orbit in 2015 and whose exploitation and capacity are shared by the two countries' armed forces.

At the EU level, the European Commission is trying to put a satellite system in place for the governmental telecommunications of those member states which wish to have secure communications without being prepared to invest in their own system (*GOVSATCOM*). It remains to be seen whether the attempt will come to anything.

The other privileged area of space systems that support defence and security is observation for reconnaissance and intelligence uses. Satellites in low orbit are a precious source of observation by virtue of their ability to overfly anywhere in the world and of their being out of reach of the law in their extra-atmospheric space environment. France was the first country in Europe to acquire such systems when in 1986 after the demonstration launch of *SPOT-1* in February of that year it decided to put in place the optical reconnaissance satellites *Helios 1A* and *1B*, launched respectively in 1995 and 1999. Spain and Italy contributed to the programme (7 and 14 per cent respectively) though Germany was hesitant invest in this area and the German Ministry of defence preferred radar observation. A decision was forthcoming at the end of 1999 and its constellation of five *SARLupe* radar satellites made by OHB in Bremen was put into orbit in 2006-2008. In between times France had greatly advanced in the preparation of its satellites of the following generation *Helios 2A* and *2B*, but Italy was giving priority to its national dual use radar observation satellites *COSMO-SkyMed* (launched between 2007 and 2010) and did not participate in *Helios 2*. On the other hand Spain confirmed its participation but at the lower level of 2.5 per cent. Belgium and Greece also decided to contribute but they too at the modest level of 2.5 per cent each.

Helios 2A was launched in 2004 and Helios 2B in 2009. France and Germany signed a reciprocal agreement for access to *SARLupe* and *Helios 2* (the Schwerin accord) that allows the two countries to exchange a part of the capacity of each system. A cooperation agreement in the form of shared system capacity between the Italian *COSMO-SkyMed*, the French *Helios 2* and *Pléiades*, dual capability satellites then being developed under the auspices of Cnes was signed in January 2001 during the Franco-Italian summit in Turin. *Pléiades 1* and *2* were put into orbit in 2011 and 2012, and benefit from the most advanced of observation technologies, which make them much more compact and thus far more agile. They presaged the Ministry of the armed forces' *CSO* satellites that will take over from Helios 2. *CSO-1* was launched in December 2018.

CSO refers to the *Composante spatiale optique* (Optical space component) of a European system called *Multinational Space-based Imaging System for Surveillance, Reconnaissance and Observation* (*MUSIS*), which was conceived by the partners in extant programmes, Germany, France, Italy, Spain, Belgium and Greece. In 2009 they had asked the European Defence Agency (EDA) to take on this concept as one of the Agency's category B programmes. This attempt at coordination of reconnaissance satellites at the European level did not succeed, and seeing the lack of progress France decided to go ahead with developing the *CSO* satellites in 2015. France asked Germany to participate financially by purchasing the third flight vehicle, which would give it direct access to the optical constellation. Germany did not, however, give up on its interest in radar observation techniques and went forward with the *SARah* satellites, successors to the *SARLupe*. Italy has done the same with its *COSMO-SkyMed Second Generation* (CSG) and Spain is not being left behind: its Paz national radar observation satellites were launched in 2018 and the Ingenio optical one is planned for launch in 2019.

To sum up, in the field of observation for reconnaissance and intelligence purposes there is a considerable diversity of effort in Europe. This results from a very national approach to these activities due probably to a combination of the traditional culture of management of intelligence that does not really open it to cooperation in any usual sense, and protection of national industrial interests.

Until recently the European Union did not interfere in matters of defence and foreign policy but has for some time via its satellite centre at Torrejón de Ardoz in Spain played an important role in awareness and training on the exploitation of images from reconnaissance satellites. That centre was in fact created by the Western European Union (WEU) in 1991: its member states were impressed by the capability demonstrated from 1986 of the newly-orbiting civil SPOT satellite to collect images of the nuclear power station at Chernobyl, one of whose reactors exploded on 26 April of that year. Thereafter, two parliamentary reports from the WEU, written by Fourré and Malfati and published in 1988, highlighted the interest for Europe to acquire the capability, though without immediate effect. The first Gulf War in 1991 inspired the WEU Council to review the recommendation and rather quickly decided on the creation of the satellite centre, voted the finance and began the construction at Torrejón. It was

never intended for the centre to have its own observation satellite but to exploit images supplied by civilian satellites such as *SPOT* and the American commercial satellites that from 1998 supplied high-resolution images, for use in intelligence on behalf of member nations. Access to classified images collected by French, German and Italian military satellites was the subject of particular and restrictive agreements which for long limited the centre's access to such imagery.

The satellite centre was inaugurated in 1993 and was authorised to receive *Helios 1* images from 1996. It was transferred to the EU on 1st January 2002, and has since been called the European Union Satellite Centre (EU SATCEN). It should be noted that because of its mission focused on defence and security needs, it is not part of the European Commission but reports to the European Council. Like the EDA, its operation is more inter-governmental in nature, in contrast to the usual common approach within the European Union.

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This exposé would not be complete if it failed to mention, even briefly, satellites for gathering EM intelligence with which currently only France has experimented in orbit, with the four *ESSAIM* micro-satellites launched by *Helios 2* at the end of 2004 and also the four *ELISA* electronic intelligence satellites, launched at the same time as *Pléiades 1* in 2011. The next step is to put into service the *CERES* (*Capacité de renseignement électromagnétique spatiale*—Space electromagnetic intelligence capability) operational constellation, planned for 2020. These systems are not open to cooperation. ◆

The International Landscape of Military use of Space
Technological Upheaval and Continuity of Power

Olivier ZAJEC

Lecturer in political science at the University of Jean Moulin-Lyon 3.

In January 2019, the African Union (AU) announced to the rest of the world its desire to create an African space agency modelled on the European Space Agency (ESA), with its headquarters in Egypt, whose head of state, Marshal Al-Sissi, has been president of the AU since February 2019. For such an entity to operate effectively, a great number of diplomatic difficulties internal to the AU will have to be ironed out. The symbolism of the announcement is extremely important: setting up an African space agency is one of a number of signals indicating that the strategic race for extra-atmospheric space is no longer to be limited to a select club of technologically advanced countries. This development is all the more significant given that the stampede we are seeing is not limited to civil uses of space.

By dint of the intrinsically dual nature of investment in space, any extra-atmospheric technological advance is likely to carry with it a direct or indirect military dimension, whether or not it is actually admitted by the states concerned. A recent article reminds us that the first satellites for radio-navigation (GPS and *GLONASS*), now indispensable for public use, were in fact military programmes.[1] Hence, and just to stay with African examples, Nigeria's new capacity for space observation offers its security forces the facility to obtain satellite imagery that allows the country to track down Boko Haram jihadists and insurrectional groups which are appearing in the oil-bearing delta region in the south of the country.[2] The Moroccan earth observation satellite *Mohammed VI-B*, launched by Arianespace from Kourou in French Guiana on 20 November 2017, gives Rabat the ability for better control of its land management programmes and also secure surveillance of its borders in one of the most unstable regional environments.

Space might therefore seem, on first sight at least, to be more and more open to everyone internationally—the military included. Yet is space really on track to

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(1) GARDIEN Damien, HAINAUT Béatrice and BOUHET Patrick, *La guerre dans l'espace. Quelles possibilités dans un futur proche ?*, *Défense et Sécurité Internationale* (DSI), No 135, May-June 2018, p. 77 (www.areion24.news/).
(2) CIYOW Yassin, *L'Afrique à la conquête de l'espace*, *Le Monde*, 26 April 2019 (www.lemonde.fr/economie/article/2019/04/26/l-Africa-a-la-conquete-de-l-espace_5455038_3234.html).

achieving real strategic equality that could see outsiders catch up with the traditional powers in terms of extra-atmospheric military status? About ten years ago, when referring to a multi-polar space race, some analyses were already questioning just to what extent the end of space shuttles and the financial crisis would sound the end of American hegemony in space.[3] Here we should probably beware of a number of illusions: whilst the number of new entrants has increased exponentially over the past decade with some quite significant technological work, albeit to differing degrees, the rapid changes in the world space hierarchy should nevertheless be viewed with prudence, particularly in the field of military applications. Multi-polarity here is not necessarily synonymous with true polyarchy.

To illustrate the geopolitical changes, and also what has remained permanent regarding power in this new global military space landscape, we will here first summarise the progress and initiatives among players in the extra-atmospheric domain then come back in the second part to the adaptations and breaks with the past made by the traditionally dominant players in the sector, among which are the United States, Russia, China, Japan, India and the European Union.

Progress and initiatives of the new entrants: effective, but still limited multi-polarity

Space activity, especially its military applications, is particularly intense in the Asia-Oceania region. Apart from the advanced countries of India, China and Japan, the main players now emerging in the region are Australia, South Korea, the UAE, Vietnam, North Korea, Pakistan, Singapore, Malaysia, Israel, Iran, and Indonesia. Within this already large group, which is growing larger year by year, it would be appropriate to consider separately those countries that possess independent means of launching, which are (for the moment, at least) North Korea, Israel and Iran. These three countries share a strategic characteristic in that they have a military nuclear capability or are suspected of seeking to have one. In the group of Asian countries that are emerging in both space and nuclear fields only Pakistan, which has declared it has possessed atomic weapons since the tests in 1998, does not yet have its own independent capability of access to space.

Israel, which has nuclear weapons though does not officially admit it, is an actor in space and although not top rank nevertheless stands out markedly in that trio. The first Israeli achievements in the field of satellite reconnaissance date back to the nineteen-eighties and the *Ofeq* programme. Since then progress has been striking, in particular in the field of high-resolution imagery satellites. Most have been put into low orbit by the *Shavit* launcher, designed on the *Jericho II* missile, from the launch site at Palmachim. Despite the failure in April 2019 of the *Beresheet* (which means 'Genesis' in Hebrew) lunar programme, Tel Aviv, which maintains close links with the

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(3) Verschuuren Pim, *Géopolitique spatiale : vers une course à l'espace multipolaire ?*, *Revue internationale et stratégique*, No 84, April 2011, p. 40-49 (www.cairn.info/revue-internationale-et-strategique-2011-4-page-40.htm).

Americans and the Indians in these issues, is keener than ever to boost its regional dominance and not to let Iran catch up in space matters.

For it is indeed the case that Teheran is also advancing in military use of space. In 2003 the Iranians created a national space agency attached, as political control would have it, to a 'supreme space council', itself part of the Ministry of information and communication technologies. Despite two recent aborted Iranian launches in January and February 2019, the Israeli researchers Kevjn Lim and Gil Baram wrote a quite alarming report in *Foreign Policy* saying that the Islamic republic was advancing towards mastery of the final frontier,[4] in particular since the successful independent launch of the *Omid* satellite in 2009, followed by four later successes.[5]

Moving to the difficult case of North Korea, whilst the current state of negotiations between Donald Trump and Kim Jong-un are part of a clear background of ballistic issues that attract the attention of the media, North Korea's extremely active space activities are less in the limelight. After three failures in 2006, 2009 and at the beginning of 2012, a first North Korean satellite was successfully and completely independently put into orbit in December 2012. The launcher used (*Unha-3*) is thought to be a derivative of the *Taepodong-2* intercontinental missile. According to the Space Threat Assessment 2018 report by the Center for Strategic and International Studies (CSIS), North Korea has yet to develop anti-satellite weapons, although its capability for direct kinetic weapons could progress in the coming decade.[6]

The other Asian outsiders, whilst not immediately seeking true independence in launch capability nevertheless have more and more impressive niche capabilities. Australia, which didn't even have a national space agency until 2018, has since announced that it wishes to double the number of employees in the sector by 2030. A recent agreement signed with Boeing will allow the Australian space sector to develop, particularly in satellite navigation and extra-atmospheric surveillance.[7] South Korea's military space programme only really started in 2006 with the launch of its first communications satellite. The very recent *Project 425*, composed of four radar observation satellites and an optical observation satellite, illustrates Seoul's growing ambitions in the field of space intelligence even if the launch capabilities required remain external to the country: in particular, South Korea uses the services of Arianespace. Supported by major local industries like Korea Aerospace Industries, the national effort is towards achieving complete strategic independence. Although launching has up to now relied upon Russian technology, in November 2018 Seoul successfully tested a rocket motor for its fully national three-stage launcher, the *Korea Space Launch Vehicle-2* (*KSLV-2*), planned for 2021.

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(4) LIM Kevjn and BARAM Gil, *Iran Is Mastering the Final Frontier*, *Foreign Policy*, 14 March 2019 (https://foreignpolicy.com/2019/03/14/iran-is-mastering-the-final-frontier/).
(5) *Omid* (which means *hope* in Farsi) was put into orbit by the *Safir* (= *ambassador*) launcher. The new Iranian *Simorgh* launchers that appeared in 2010, seem to be modelled on the North Korean *Nodong*.
(6) *North Korea Overall Space Capabilities*, *in* HARRISON Todd, JOHNSON Kaitlyn and ROBERTS Thomas G., *Space Threat Assessment 2018*, CSIS Aerospace Security Project, April 2018, p. 20 (https://aerospace.csis.org/wp-content/uploads/2019/04/SpaceThreatAssessment2019-compressed.pdf).

Singapore, Malaysia, Indonesia and Vietnam, whilst progressing, are not on the same level as Australia and South Korea. Indonesia stands out by the long history of its space programme, which began in the nineteen-sixties and which today appears overtaken by progress in Vietnam. The latter dynamic newcomer originally counted on the United States, France and Belgium to produce its satellites, but in 2017 announced its aim to produce its own programme independently from 2022. Hanoi does not hide the clear military nature of its projects, justified by growing disquiet resulting from the impressive Chinese launch into space activities. It seems that a geopolitical axis of space cooperation is now developing between Vietnam, Indonesia and India who share sentiments regarding Beijing that range from prudent suspicion to out and out mistrust.[8] Malaysia has been following the same path as Vietnam since its space agency was set up in 2002. It is increasing its international cooperation to progress in the field of communications, notably with the *MEASAT* fleet in partnership with Boeing. Among this outsider group of ASEAN member countries, Singapore is probably the one that stands out most because of the leverage effect of its considerable investment in innovative space technologies.[9] The local space sector has been lively since 2013, supported by some thirty companies and dynamic universities with satellite programmes, high among which is the Satellite Research Centre of Nanyang University of technology. One of the objectives of this island city-state seems to be to have a position in the field of micro and nano-satellites and in time to put them into orbit with its own lightweight launchers, benefiting from its favourable position close to the equator.[10] At the other end of the South-Eurasia rim, the UAE emerges as the most audacious player in Middle-Eastern space geopolitics.[11] *KhalifaSat*, the first autonomously constructed satellite, was launched October 2018 by the Japanese H2 rocket. The national plan for the promotion of investment in space, announced at the end of January 2019, is only the latest stage of a conscious plan to see Abu Dhabi launch its first mission to orbit Mars in 2020!

On other continents, other than in the established West, progress has been more contrasted. In comparison to the Asian 'tigers', South America has yet to see any space 'jaguars' other than Brazil, which has been constantly purposeful in the field and which in 2018 organised a development committee for its space programme in order to have a better structure for creating continuity of innovation between its public and private actors. The Brazilian Air Force is coordinating efforts as well as playing a major role in the field. Across the Atlantic, Africa is in the introductory stages, investing symbolically with its pan-African initiative, even if more tangible programmes are currently being driven on a national level from Nigeria to Morocco, passing through Kenya.

(7) WEITERING Hanneke, *Looking Up from Down Under: Australia Partners with Boeing to Boost Its Young Space Program*, *Space.com*, 13 April 2019 (www.space.com/boeing-partners-with-australian-space-agency.html).
(8) In 2018, India and Vietnam signed a memorandum of cooperation to improve their relations in space matters.
(9) *Cf.* SARMA Nandini, *Southeast Asian space programmes: Capabilities, challenges and collaborations*, ORF (Observer Research Foundation) Special Report, 7 March 2019 (www.orfonline.org/).
(10) TEO Gwyneth, *Singapore companies shoot for the stars as space technology gets more accessible*, *Channel News Asia* (*CNA*), 5 June 2018 (www.channelnewsasia.com/).
(11) FOUST Jeff, *UAE to establish Space Investment Plan*, *Space News*, 22 January 2019
(https://spacenews.com/uae-to-establish-space-investment-plan/).

All these emerging countries are progressing in space through the use of their own satellites, the future production of their own launchers or the development of ever-more ambitious space defence programmes, and yet the vast majority remain dependent on launchers controlled by other powers. For a few years yet the services of access to space offered by the Americans, Russians, Europeans and Indians will remain indispensible. The first Tunisian satellite, *Challenge One*, to be operational in 2020 is an example. The ambitious programme aims to add to this first element a constellation of thirty satellites which will work in the field of security among others. The fact remains that this launch will be performed by the Russian company GKLaunchServices, itself a part of the Russian space agency *Roskosmos*.[12]

From the point of view of access into orbit, the New Space companies of course offer outsiders an interesting alternative including for the military use of space. Though private and in the main American, these new players keep have close strategic ties with Washington, which can influence their choice of clientele. It is therefore likely that any real change in the international geopolitical space hierarchy will come in particular from the acquisition of independence of space industrial and technological bases by those outsider states. In Asia, South America and Africa, the new geopolitics of space that are beginning to be reshaped by the emerging players briefly described here will depend as much on the availability of technology afforded by a New Space that is for the moment Western-dominated as by the quest for autonomy of those emerging states that wish to draw on regional cooperation and private development opportunities to boost their freedom of independent strategic action.

The multi-polar shift in extra-atmospheric power balances will therefore be gradual, and the often-predicted 'space catch-up' will in reality be far more incremental given the simultaneous progress being made by the traditional players in military space affairs that must be taken in to account. The latter are far from passive spectators of a multi-polar cauldron of activity that they would be happy to observe and no more: on the contrary they are progressing in great leaps, conscious of needing to keep a major step ahead or, in the case of the United States, to secure absolute domination of the coming new strategic frontier.

Progress by the dominant players in space

The twentieth century chequerboard of power has clearly added a fourth strategic dimension that is no longer content simply to supply support services to the first three (air, land and sea) but now puts itself on the same level as them precisely because it has itself become a theatre for potential conflict. Conscience of this new state of affairs brings with it the widespread intensification in space ambitions whose abundant dynamism has already been mentioned. And yet this new strategic pattern in the international space landscape, though shaped to some extent by the appearance of new players, remains driven in the main by the progress made by the major powers in the

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(12) *Le premier satellite tunisien sera lancé par une fusée Russe en 2020*, *Agence Africa*, 2 April 2019
(www.agenceAfrica.com/16232-le-premier-satellite-tunisien-sera-lance-par-une-fusee-Russian-en-2020.html).

field—the United States, Russia, China, Japan, India and the European Union. The geopolitical rivalries between these top-ranking players motivate and underpin moves of the pieces on a chequerboard of military space whose easier access to technology is not in fact leading to any change in the balance of power.

In Asia, political rivalry between China and Japan is therefore one of the driving forces behind a new space race between the leading actors. The supporting cast is expected to line up behind these two self-proclaimed leaders, as illustrated by the recent creation of two regional cooperation organisations supported respectively by Tokyo and Beijing, which are *de facto* rivals: the Asia-Pacific Regional Space Agency Forum (APRSAF) for one, and the Asia-Pacific Space Cooperation Organization (APSCO) for the other.[13] India, the traditional actor in space which has been recording the most significant progress for the past year, is effusing to follow this lead and is presenting an independent and increasingly credible alternative in power and influence on the regional level. In particular it started 2019 with the wonderfully successful launch in January of two surveillance satellites, one of which is said to have played a role in the striking and highly controversial anti-satellite test conducted on 27 March. This clear strategic signal, intended largely for the consumption of India's regional rival China, was only the start of a series of clearly military launches, planned throughout 2019 that will include putting new surveillance satellites into orbit, among which the *Radar Imaging Satellite* (*RISAT*) and *CartoSAT-3* series. Russia of course has a deal of scientific heritage in this field and appears also to be adopting an extremely offensive posture in the renewal of its extra-atmospheric activities.

Eurasian space geopolitics, which unfortunately we cannot develop further here is also giving rise to a purposeful and innovative dynamism in which China is without any doubt the major strategic stimulus. The effect of the centralised state is not the only aspect coming into play in this general re-launch, since private players in the space game are rapidly developing in India, Japan and China. New Space will not for long be limited to the well-known cases of American entrepreneurs like Bezos (Blue Origin) and Musk (Space X): we will probably soon see Chinese or Indian tycoons with no less ambitious and challenging visions. As in the American case, the clearly apparent links of strategic interest between the private visionaries of this Eurasian New Space and the states that accept and sponsor them are probably very close.

There seems to be a spirit of competitive imitation that is shaping the re-launch of the military and security aspects of space among the major Eurasian powers, which contrasts in large measure with the disparate appearance presented by the Western duo of the United States and the European Union. In Washington we are witnessing a new conceptual, doctrinal, technological, capability and economic build-up of a size not seen since the break with the former objective of space supremacy developed at the beginning of the century by the Bush administration. An overall strategy of space domination, founded on the concept of overmatch and repeated over and over again

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(13) *Asia in space: Cooperation or conflict?*, ORF, 11 October 2018
(www.orfonline.org/research/asia-in-space-cooperation-or-conflict-44890/).

in the Trump administration's new National Security Strategy,[14] is driving this strong-arm vision in which the announcement of the creation of a new space force is but one of the more visible of its structural aspects. We need to follow the reality of these developments with attention, since the United States seems set to remain the dominant player in the military space field for several decades to come.

In all this the European Union is the exception when compared to the group of uniformly dynamic leaders. It clearly holds on to its position from the point of view of its dual advances in space, witness the long-anticipated arrival of *Galileo*, and can count on solid and innovative industries but the fact remains that, beyond a France coloured by a politically acknowledged realism with regard to space matters, and an increasingly ambitious Germany, the EU seems unwilling to recognise all the consequences of the upheavals caused not only by the increasing number of secondary players keen on catching up strategically but also more fundamentally by the quantum leaps made by the traditional space powers. This problem in itself merits exhaustive study. Let us say simply that without more direct recognition by the continent of space surveillance or establishment of effective space deterrent capabilities, among others, it could well be that the EU finds itself in the worst of scenarios in which it drops from the top rank at the same time as the more dynamic of second rank players catch up as they move across that international space chequerboard mentioned before. Europeans have to avoid the one and slow down the other.

Herein lies the real challenge of making the leap together, to bring continued political and strategic weight by uniting the vital efforts made by each of the Union's nations with regard to military use of space. ◆

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(14) *National Security Strategy of the United States of America*, December 2017
(www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf).

Geopolitics of the Air
and the Destiny of Europe

Jérôme DE LESPINOIS

Lieutenant Colonel, Air Force centre for studies, influence and partnerships (CERPA).

Admiral Mahan and Halford Mackinder each spoke in his time of the geopolitical shake-up that was brought about by maritime transport and the railways. The tremendous growth of aviation also modified the power balances between countries, but it was after the Second World War that aviation really began to transform international relations by dint of the incredible acceleration that aviation afforded to technological progress. By way of example, in the nineteen fifties Raymond Aron[1] highlighted the extension of diplomacy brought about by the arrival of bombers that could reach the speed of sound and which had a range of several thousand kilometres. The ability for countries to exercise their political influence or military power thousands of kilometres from their home territory then revolutionised the field of inter-state relationships and led to building hitherto unknown diplomatic groupings.

Aviation in particular offered some states the modern means to pursue global policies. The navy had for centuries been their preferred instrument for expanding commerce and influence and in some cases for building vast empires. In some respects during the inter-War years and after the Second World War, aviation replaced the navy as the instrument of power on an international level.

General Gallois defined geopolitics as the study of the relationship between the conduct of power politics on an international level and the geographical framework in which it takes place.[2] As a new means of applying influence and coercion, air power overturns long-established forms of geopolitics and sets in motion a new order of space and time. That is not to say that it changes the nature of geopolitics as such, more that it establishes a new pattern. It is worth noting that the first geographers to be interested in political changes brought about by the arrival of the aeroplane published isochronal maps, the first types of which had been published in the eighteen eighties as charts that represented the contraction of space and time afforded by maritime transport.[3]

(1) ARON Raymond, *De l'analyse des constellation diplomatiques*, *Revue française de science politique*, 1954, vol. 4, n° 2, p. 237-251.
(2) GALLOIS Pierre-Marie, *Géopolitique : les voies de la puissance*, L'Âge d'homme, 1990, p. 37.
(3) BRETAGNOLLE Anne, *De la théorie à la carte : histoire des représentations géographiques de l'espace-temps*, *in* VOLVEY Anne, *Échelles et temporalités*, Atlande, 2005, p. 55-60.

This article does not intend to go back over the history of how the aeroplane changed international relations but to highlight the major characteristics of this new instrument of power then to outline European stakes in the changing power balances in the air domain.

The peaceful and coercive power of aviation

This new instrument of political power was developed by the principal countries before the Second World War, and authoritarian and democratic states alike put on countless demonstrations to show off their capabilities in the air. One of the most spectacular was the Marshal Italo Balbo's air cruise in which he took 24 Savoia-Marchetti seaplanes from Rome to Chicago. On 15 July 1933, the very day on which the fascists landed on Lake Michigan, in Rome Mussolini signed the Four-Power Pact with Germany, the United Kingdom and France to create at his initiative a kind of European management board through which the main Western European powers could deal with the big political questions of the day. The date had been carefully chosen and illustrates perfectly the link between air power and diplomatic influence. Other examples could be cited: the 'black cruise' of General Vuillemin's 30 Potez aircraft in Africa in November 1933, the record flight of a Mitsubishi plane from Tokyo to London in 1937, the demonstration of the brand new Boeing B-17 *Flying Fortress* bombers during a tour of Latin America in February 1938 and the Berlin to New York dash of the German four-engined Focke-Wulf 200 *Condor* in August 1938.

These demonstrations illustrate what General William Mitchell defined as the capability to act in the air, which means to transport all kinds of things in an aeroplane from one place to another, and since the air covers the entire earth there is nowhere that can escape the influence of the aeroplane.[4] This influence can be peaceful, limited to the economy, society or diplomacy but it can also be coercive through the use of armed violence. The civilising influence of aviation soon appeared after the beginnings of heavier than air flight at the turn of the twentieth century. It remains very present despite the fear of a knockout blow from the air, which was widespread the United Kingdom between the two World Wars. *Fortune* magazine published in April 1943 an article entitled 'The Logic of the Air', in which it described the aeroplane as an instrument of peace and prosperity: the logic of the air, it wrote, was founded on the fact that the air is an ocean of blue water accessible by every nation for commerce of every kind and for creating high strategy. It added that the former idea that led to the incorrect representation of a world divided between land and sea was as out-dated as the Great Wall of China.[5]

And yet while *Fortune* was pushing these pacific and rather utopian views, the US Eighth Air Force and Bomber Command were getting ready to launch the most ferocious air attack ever, to ignite a firestorm in Hamburg by a conscious mix

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(4) Quoted by COOPER John C., *The Fundamentals of Air Power*, in EMME Eugene M., *The Impact of Air Power*, Princeton, D. van Nostrand Company, 1959, p. 128.
(5) VLECK (VAN) Jenifer, *Empire of the Air. Aviation and the American Ascendancy*, Harvard University Press, Cambridge, 2013, p. 3.

of high-explosive bombs and incendiaries. Fifty years later, having abandoned carpet bombing and started favouring targeting of the adversary's centres of gravity with precision-guided munitions, aviation achieved spectacular success against Iraq in 1991 and again against Serbia in 1999 during Operation *Allied Force*, which almost exclusively used air power during a 78-day campaign of bombardment.

Today, however, it is the peaceful, economic and social aspects that are the most significant. In its civil form, aviation is a powerful sector of the economy, both industrially, with big aeronautical groups, and commercially, with airlines. But above all, air transport has become the powerful catalyst of the global village and of the globalised and connected society by encouraging trade and social and cultural exchange. According to the World Bank,[6] the number of people transported annually by air multiplied by 12.8 between 1970 and 2015, going from 310 million 3.9 billion, whilst during the same period air freight increased by 13.3 times, from 16 to 214 billion ton-kilometres. No other means of transport, land or sea, saw the same transformation. World maritime transport 'only' increased by a factor of 3 from 1970 to 2008, going from 2.5 billion tons to 8.3 billion, and the projections for 2020 are for 14 to 15 billion tons.[7] For world air traffic, the estimated annual increase is around 6 per cent, which would take the number of passengers to some 6 billion by 2030, in 60 million flights. Whilst care should be taken when comparing these figures, which come from different economic estimates, what can be said is that if globalisation resulted from 'maritime-isation', it also did so from 'aviation-isation' and that the size of the changes affect both the aviation and the naval sectors.

Asymmetrical distribution of air power

A nation's expression of air power is dual (its civil and military aspects), as General Paul Jacquin described in a speech in 1948[8] and more recently General Stéphane Abrial in *Concept de l'Armée de l'air* (Concept of the Air Force) published in 2006. Put briefly, it appears today to be divided between two main geographical areas, the United States and Europe, the rest scattered across other secondary centres, which include Russia, China, India, Japan, Turkey, Israel, South Korea, Canada and Brazil, each of which has its own characteristics. Among the latter could be considered the volume of commercial, military and tourist fleets, existence of national industry for making airframes, engines and equipment, size of the airport infrastructure, schools for aeronautical engineers, pilots and technicians, support from the population and an aeronautical culture.

The United States has been the foremost air power since 1945. In her book on aviation and the American domination, Jenifer van Vleck perfectly defines the role of aviation in American imperial construction from the nineteen forties when she writes

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(6) Data from the international civil aviation organisation, available on the site of the World Bank (https://data.world-bank.org/indicator/IS.AIR.GOOD.MT.K1?end=2017&start=1970&view=chart).

(7) Committee for foreign affairs, defence and the armed forces, *La Maritimisation* (Information report n° 674), Sénat, 17 July 2012, p. 14-15 (www.senat.fr/rap/r11-674/r11-6741.pdf).

(8) Général Paul Jacquin, *La notion de puissance aérienne*, *Stratégique*, n° 64, 1996, p. 53-84.

that international aviation politics formulated at the end of the war allowed the United States to develop freedom of commerce through an open door doctrine for commercial airlines, and in consequence the skies became the race track of American worldwide power. She adds that during the Cold War the needs of national defence led to regular public funding of the aerospace industry, and that airlines facilitated the international flow of American funding, consumer goods, tourists, technical advisors and arms.[9]

Aviation therefore plays a significant role in the constitution of the American sphere of influence during the Cold War, the more so since that ascendant extends onto the Rimland, which is in places at considerable distances from US soil and which can of course be reached by sea, but far more slowly than by air. General Curtis LeMay, USAF Chief of Staff from 1961 to 1964, put this logic of the air in military-messianic terms when he said: "If we maintain our faith in God, love of freedom, and superior global air power, the future looks good."[10]

US aviation was dominant during the Cold War and covered the entire range of air power. This was not the case for Europe, which remains an incomplete air power whose strength lies in the industrial success of Airbus, which builds half the airliners produced in the world, several flagship companies such as Dassault, Safran, Rolls Royce, Saab, Thales and Leonardo, and its commercial airlines. These successes are nevertheless somewhat delicate, as is the entire sector. A report from the Commission on strategy and prospection highlighted in 2013 a risk of disappearance of European companies as a result of changes in the air transport market.[11]

Today the worldwide distribution the commercial aircraft fleet seems fairly evenly balanced between Asia and North America (each with 30 per cent) and Europe (with 20 per cent). In 20 years' time, the fleet will have doubled and regional imbalances will gradually appear between the fleet in the Asia-Pacific region (37 per cent) and the other world centres, whose relative proportion will stagnate or reduce.

	Asia-Pacific	North America	Europe	Latin America	Middle East	Russia and Central Asia	Africa	Total
Evolution of the distribution of world commercial fleets								
2017	7,360	7,210	4,900	1,560	1,500	1,180	690	24,400
2037	18,200	10,390	8,880	3,580	3,890	1,970	1,630	48,540

That said, the swing of the commercial fleet's centre of gravity towards Asia-Pacific is above all a reflection of the development of Chinese economic power, since the major balances in world aeronautical production have not changed. Since the

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(9) VLECK (VAN) Jenifer, *op. cit.*, p. 7.
(10) ENGEL Jeffrey A., *Cold War at 30,000 feet: Anglo-American Technology Controls, Aircraft Sales and Trading with the Enemy at the Dawn of the Jet Age*, University of Wisconsin, Madison, 2001, p. 27.
(11) ABRAHAM Claude, *Les compagnies aériennes européennes sont-elles mortelles ? Perspectives à vingt ans*, Commissariat à la stratégie et à la prospective, 2013 (www.ladocumentationfrancaise.fr/var/storage/rapports-publics/134000597.pdf).

nineteen-eighties Europe and the United States have represented 70 per cent of world airliner production, a situation likely to continue and even become greater in the medium term because by 2025 Boeing and Airbus will probably control 40 and 38 per cent respectively of the world production of commercial aircraft. The Chinese COMAC, created in 2008 to build airliners, will only represent one per cent of the civil aviation market, in part owing to the production of its C919, a single-aisle aircraft that competes with the A320 and the B-737, the larger part of whose components are supplied by Western manufacturers.

Incomplete European air power

Europe will therefore remain a major centre for worldwide aeronautical production in the civil sector. The challenge is to add a military component to make it an overall aeronautical power, yet for the moment European aviation is seen purely as a civil and commercial enterprise that concerns only the airlines, infrastructure and organisation of the market, as stated in the EU strategy for aviation, published by the European Commission in December 2015.[12]

The European military aircraft fleet (planes and helicopters), in the broad sense of the 41 members of the European Civil Aviation Conference (ECAC—which includes Turkey, Georgia, Armenia and Azerbaijan), nevertheless remains comparable in size to that of the United States.

European military fleet in 2013[13]						
	Combat aircraft	Transport and tanker aircraft	Light aircraft and drones	Helicopters	Coast-guards	Total
ECAC	3,365	949	1,390	3,733	-	9,437
USA	3,393	2,264	2,778	5,277	200	13,912

This volumetric comparison gives only a partial indication and is not a real reflection of European aviation capacity. The low number of support aircraft—transport and tankers—and of drones illustrates the unbalanced nature of European air forces. Moreover, it is just a simple addition of the craft held by different countries in a geographical area that is not militarily unified. It should be added that more than 40 per cent of aircraft of the air forces of the 28 countries of the European Union have been manufactured outside the Union's borders, for the most part in the United States. This dependency is largely explained by the weakness of European military aeronautical industry: while in 2017 US aeronautical industry produced 538 military aircraft and helicopters,[14] European production was only 150. As a last illustration of Europe's weakness in military aviation, suffice it to say that of the 14,700 combat aircraft in

(12) *An Aviation Strategy for Europe* (http://eur-lex.europa.eu/).
(13) EUROCENTROL, *Military Statistics*, 2014, Version 1.0.
(www.eurocontrol.int/sites/default/files/publication/files/2014-military-statistics.pdf).
(14) AEROSPACE INDUSTRIES ASSOCIATION, *2018 Facts and figures. US Aerospace and Defense*, p. 4-5.

service in the world, 32 per cent are on us origin (F-5, F-16, F-15, F-18), 30 per cent Russian (MiG-21 and MiG-29, Su-27/30) and 6 per cent Chinese (F-7 and J-7).

In that regard, there has been no increase in the military aircraft fleets in Europe or North America (where the first has remained steady and the second has actually reduced), but Asia is not only seeing the growth in commercial fleets but is also developing its military fleet considerably. The growth in military aviation, that is, combat, transport, refuelling, training aircraft and helicopters, in the Asia-Pacific area was estimated at 1 per cent in 2015, 2 per cent in 2016 and 4 per cent in 2018.

For all that, the hierarchy in the various aviation capabilities put into service by different countries should be noted. Some possess essentially defensive capabilities intended to deny access to their airspace while others have force or power projection capabilities. Regional powers should also be distinguished from world powers: the former include states having the facility to employ an air force within their own airspace and in immediate proximity to their borders, and the latter, states that possess air forces that allow them to deploy beyond their regional power space, or a naval-air force or indeed a land-air force.

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At a time when air power is undergoing redistribution and major world geopolitical balances are being reformed, Europe appears to be an area relatively devoid of combat aviation. Even with some 2,000 combat aircraft today, it is only with difficulty that Europe could envisage very long air operations even if they are not excessively costly. Figures would indicate that after 11 days such an air force operating 2 sorties per day and suffering an attrition rate of 3 per cent would have lost 1,000 aircraft, and after a month only 300 aircraft would remain on line.

In the broader context in which 'the JSF/F-35 programme has considerably weakened Europe's industrial independence in combat aviation,'[15] the Franco-German project for the New Generation Fighter, which has been joined by Spain, appears to be a lifesaver for rescuing European air power from yet further weakening. As Air Chief Marshal Sir Arthur Tedder, Eisenhower's deputy in 1944 and Chief of the Air Staff (UK) from 1946 to 1950, said, "airpower is the dominant factor in this modern world and […] though the methods of exercising it will change, it will remain the dominant factor as long as power determines the fate of nations."[16] ◆

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[15] ACADÉMIE DE L'AIR ET DE L'ESPACE, *Quel avenir pour l'Industrie européenne d'aviation de combat ? Vers une mort annoncée ?*, 2011, 4 pages (www.europarl.europa.eu/).

[16] The French version of this was drawn from: TEDDER Arthur (Air Marshal), *La Puissance aérienne dans les opérations de guerre* (1947) *in* LESPINOIS (DE) Jérôme, *Anthologie mondiale de la stratégie aérienne*, La Documentation française, to be published in 2019.

Operation *Hamilton*…
Strategic Demonstration
and Air Power

Éric MOYAL

Lieutenant Colonel, Air Force centre for studies, influence and partnerships (CERPA).

A year ago, during the night of 13 to 14 April 2018, Washington, London and Paris launched *Hamilton*, an operation under French command to destroy Bashar al-Assad's stock of chemical weapons. These punitive strikes deep into Syrian territory were in response to the regime's attack against the civilian population in Douma on 7 April, which France, the United States and the United Kingdom had warned would not go unpunished. With Operation *Hamilton* France demonstrated its ability to enforce its red lines, and at the same time provided proof of its strategic autonomy, especially to Moscow which had had the military and diplomatic upper hand in the region since 2013.

From the military point of view, *Hamilton* was the outcome of complex work that resulted in the simultaneous firing of cruise missiles from the air and from sea.[1][2] The operation was a tactical success, since Syria no longer uses chemical weapons, and also a strategic victory, since this episode saw the return of the three nations to the power games being played out in Syria. It afforded the opportunity to explore the subtleties of a complex mission with overtones of a nuclear raid, and also the role of conventional weapons that might be considered to some degree strategic. *Hamilton* also underlined the importance of a modern, appropriately-sized Air Force.

Controlling risks and political decisions

Only an air raid would bring the guarantee of success to such a demonstration of power. France committed 20 aircraft to this night operation covering 10 hours and more than 7,000 km (4,350 miles). The combat aircraft made 3 in-flight refuellings before firing their cruise missiles from above international waters in the eastern Mediterranean, whilst the command and coordination of the three allies' assets was conducted from two French AWACS C2 aircraft.[3]

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(1) Missiles capable of complete flight under power: performance depends on speed, range, manœuvring capability and accuracy.

(2) From Air Force Rafale (9 SCALP—long range conventional cruise missiles), US B-1B and British Tornado. From French Navy frigates (3 naval cruise missiles) and US cruisers and submarines.

(3) C2 air (air command and control) in flight and on the ground is the keystone to combined and joint integration (coordination of firing from the air and from sea).

Before ordering the operation, the President of the Republic, Emmanuel Macron, needed assurance from the Air Force of the virtual certainty of success of the raid and a minimum risk of losses. For many this assurance was based upon historical knowhow gained from long-range air raids conducted by the air component of the nuclear deterrent and also on experience and expertise acquired from recent operations, as was also the case in Mali.[4]

The phase of flight up to firing, followed by the autonomous phase of the cruise missiles' penetration of defences deep into Syrian territory, was the sole way of keeping control of the risks involved—minimum exposure of the pilots and low collateral damage—while affording a very strong probability of destruction of the targets.[5] This mission profile, drawing on competences related to the nuclear deterrent role, was a demonstration of the progress made in the use of cruise missiles in conventional operations: similarities included the political dimension of missions, action far removed from national territory, personal presidential decision, reduced timescale for setting up the operation and the reversibility of action right up to the moment of firing.

Operation *Hamilton* is a reflection of the political will of the powers involved to conduct firm action without provoking escalation with Russia. There had been numerous prior warnings to the Syrian regime: whilst some diplomatic channels remain secret, there is little doubt that deconfliction mechanisms had been activated, since it was not in the interest of any of the protagonists to take another by surprise, thereby risking high-intensity combat.

Although it is understood that Russia was not too vehemently against the raid, it was expected that Moscow would show its ability to undermine the operation. The coalition also wanted to demonstrate its ability to act under all circumstances, including in defended airspace, by including air defence aircraft in the raid.[6] As it turned out, there was no compromise of freedom of action by firings from Russian fighters or frigates.

To achieve penetration of the cruise missiles into Syria up to their targets meant thwarting the most modern of Russian anti-missile systems,[7] since interception would have been especially bad for the image of the raid.[8] Russia attempted a deception manoeuvre by announcing several interceptions, which merely emphasised the coalition's ability for battle damage assessment and hence for contradicting the Russian claims. The actual use of anti-missile missiles remains uncertain: it was anyway not in Russia's interest to defend against the raid too strongly for fear of inciting escalation with the three countries involved.[9] The Russian reticence could also be construed as

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(4) Despite similarity in modes of action *Hamilton* had nothing to do with nuclear matters.
(5) This first operational use of naval cruise missiles did not offer the same combat proven guarantees. The strength of the air organisation made the risk acceptable in order to demonstrate a full range of options.
(6) Air superiority was ensured by French Mirage 2000-5 and American F-15 and F-16.
(7) Preparation of missile trajectories was an essential tactic to counter systems like the Russian S-400 and S-300.
(8) France admitted several technical problems—1 SCALP and several naval cruise missiles not fired—though they did not prejudice the operation since the number of missiles planned covered the possibility of failure.
(9) The use of GPS jamming or some other form of EW is far more likely.

not wishing to expose the characteristics of its own systems—their true performance, as much as their failings.[10]

Strategic operations that participate in a complex *dialogue of forces*

By these long-distance strikes the coalition brought about a strategic rebalance to the detriment of Moscow without having to put its entire force structure into action. The demonstration by Paris, Washington and London of their independence of decision-making and action was simple application of power projection, of which few states are capable. It counterbalances the idea that Moscow's unbridled use of force is effective in Syria. Beyond the destruction of the chemical weapon arsenal, *Hamilton* demonstrated that Western powers are capable of conducting a well-considered and controlled operation when certain red lines are crossed. That strategic message was addressed as much to Russia as to Syria.

Bringing that conflict into the logic of power play was a response to the need to re-establish the values of non-proliferation: weapons of mass destruction (WMD) cannot be used with impunity. These values are threatened for several reasons: they have been violated by Syria time and time again under the protection of a country— Russia—which has a special responsibility as a state possessing WMD and, moreover, as a permanent member of the UN Security Council.

Besides that, the legitimacy of any action being political and ethical, use of force limited to surgical strikes contributed to its strategic nature, the 'cleanliness' of action itself sending a message of moral and technical superiority.[11] It clearly under-lines the capability of those three powers to resort to military force, though in contrast to Damascus and Moscow they respect the laws of armed conflict and the lives of civilians when doing so.

There is of course the veiled message that nuclear deterrence was shaping this dialogue between nuclear powers. For France, it is in essence the only strategic domain. Deterrent logic is based on the fear of reprisals, and the airborne nuclear weapons are the visible part of deterrence.[12] Yet conventional capabilities that ally firepower, precision, autonomy, reactivity and range to some degree equally contribute to strategic action[13] and are priority matters for an ambitious power such as France.[14]

Cruise missiles are the state of the art in conventional strikes and their use in *Hamilton* should be seen in the light of their repeated use by Russia in the Syrian theatre, fired from its frigates and submarines. It is worthy of note that real operations

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(10) The more so given that these systems attract the attention of the West and are particularly sought after (Iran, India and Turkey have already acquired them). Therein lie both strategic and commercial stakes.
(11) There is solid proof of the use of chemical weapons by Damascus. Nevertheless the operation was not backed up by a UN resolution, which would in any case have been vetoed by Russia.
(12) Affirmation of will, demonstrated credibility of capability and re-establishment of deterrence (concept here replacing that of *final warning*).
(12) It is acknowledged that the notion of conventional strategic capability in no way implies any possible substitution of nuclear deterrent capability, which remains the ultimate guarantee of security.
(14) *Revue stratégique* 2017, Article 297 (www.defense.gouv.fr/dgris/).

and exercises that show off missiles potentially capable of carrying nuclear warheads have a particular significance for Moscow: those firings of the conventional version of Kalibr contribute to the credibility of Russian nuclear capabilities. It is therefore quite likely that the coalition raid was perceived by Moscow as a demonstration of the capacity of Paris, London and Washington to conduct a strategic operation technically comparable to a nuclear mission.

French air power beyond *Hamilton*

While the action of France in Syria is a reminder of the central position of air power in application of strategic independence,[15] its lessons should also serve to identify the challenges facing French air power. In a global context where strategies and tactics of anti-access and area denial (A2/AD)[16] have again become major concerns, two scenarios suggested in the review *Revue stratégique* in 2017[17] add to consideration of highest intensity crises in which activation of defences is able to constrain our freedom of action.

Credibility of our capability to recover territory of a NATO member annexed by Russia[18]

Politically, this scenario is a test of the principle of solidarity of NATO's Article 5 when faced by the only enemy capable of countering a latest-generation, effective A2/D2 structure. Strategically, one of the prime objectives of the belligerents would be to contain the conflict to the regional level and keep it below the nuclear threshold. That said, NATO would have to avoid the danger of self-censure through fear of escalation even when faced with a Russia that would probably not hesitate to communicate somewhat skilfully its tactical nuclear potential to intimidate the allies and thus deter them from reacting to the annexing of the territory.

Such a recovery operation would probably start with a big air campaign commanded by the United States. Although imposing on a European scale, the contribution of French air forces to this high-intensity combat is unlikely to be significant in overall size nor would it be decisive. Whilst A2/AD does not represent a solid barrier for France, the conventional capability of the Air Force would highlight its limitations.[19]

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(15) The 2013 *Livre blanc* (Defence white paper) (https://fr.calameo.com/read/000331627d6f04ea4fe0e) and *Revue Stratégique, op. cit.*, Article 275.

(16) For France, A2 and AD are two different postures, usable together to create a strategy. A2 works on the politico-strategic level through the use of long-range offensive systems that threaten the points of entry to a theatre and of long-range defensive systems that oblige air and naval assets to penetrate several layers to gain access. AD is of interest to the tactical level via offensive and defensive systems (which may be mobile and not evenly distributed) that are capable of hindering freedom of movement in all three environments within a theatre. It leaves open the possibility to conduct operations in defended areas if a variable level of risk is acceptable.

(17) Context relates to the resurgence of Russia or China and smaller regional powers that benefit from the proliferation of ever more effective missiles.

(18) A Ukraine-type scenario applied to NATO, which often serves as a hypothetical high-intensity example. *Revue stratégique, op. cit.*, Article 140.

(19) See: NATIONAL DEFENCE AND ARMED FORCES COMMITTEE, Hearing of General François Lecointre (*Chef d'état-major des armées*—CÉMA) on the draft finance law 2019, *Assemblée nationale*, 18 October 2018 (www.assemblee-nationale.fr/15/cr-cdef/18-19/c1819015.asp).

In a case where the scenario moves towards escalation of the conflict, France would probably envisage concentrating its air assets onto the home-based deterrent function because it does not possess the critical size to affirm its autonomy in any way other than to consider the re-establishment of deterrence as a means of stabilisation or setting an upper limit to the escalation.

This scenario militates for strengthening our air forces. It underlines that in a highly demanding campaign we have to have available sufficient resources to ensure our solidarity in the long term. The challenge would be to preserve the credibility of the national deterrent, both independently and as a contribution to NATO's deterrence.

Ability to conduct conventional reprisals of a strategic nature against a threatening medium-sized state (or a proxy)

If France were threatened unacceptably, or even attacked, by a state possessing modern offensive and defensive missiles[20] there would be more uncertainty about the outcome of the confrontation than about the decisive character of the demonstration of power of which we would be capable. The adversary would test our determination in the face of a considerable risk of losses and the probability of lesser success than in operation *Hamilton*.

An autonomous and potentially long air campaign in an average A2/AD environment[21] would be a challenge. In the first place, AD air defences would have to be neutralised according to the modes tested in Syria, though on a larger scale. The size of the air force and stock of ammunition would directly affect the strength of our reaction.

Just as *Hamilton* demonstrated our capability to accomplish conventional missions in fulfilling a strategic function, France would seek to keep well away from nuclear matters even in the case of a missile reaching its territory and which might wrongly be seen as a failure of deterrence.[22] Our limited anti-missile defence capacity[23][24] could therefore increase in importance in the face of proliferation of increasingly effective ballistic and cruise missiles. It would allow for local protection of certain sites and, on occasion, provide options to guard against unfounded doubts about our deterrence.[25]

This scenario could in the medium term become a revelation of France's strategic autonomy and serve at the very least to define the size of our air and anti-missile capabilities. An insufficiently significant demonstration of power, an even moderate level of losses in its conduct, or a resort to the nuclear question would all amount to victories for the adversary.

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(20) *Revue stratégique, op. cit.*, Articles 140, 151 and 152.
(21) A few high-tech systems and a greater number of more basic ones positioned in layers.
(22) An expression often used in US and NATO writing but refuted by France, whose doctrine retains deliberate ambiguity on what might be considered failure of deterrence.
(23) Ten *Mamba* held by the Air Force: dual use systems effective in anti-air mode and against some missiles under some conditions.
(24) The concept of theatre anti-missile defence, hence deployed according to need (cf. NATO's TBMD mission), which is different from permanent anti-ballistic missile defence (cf. NATO BMD).
(25) It is not realistic to promote an anti-missile shield, but defensive options can play a strategic role in a given theatre.
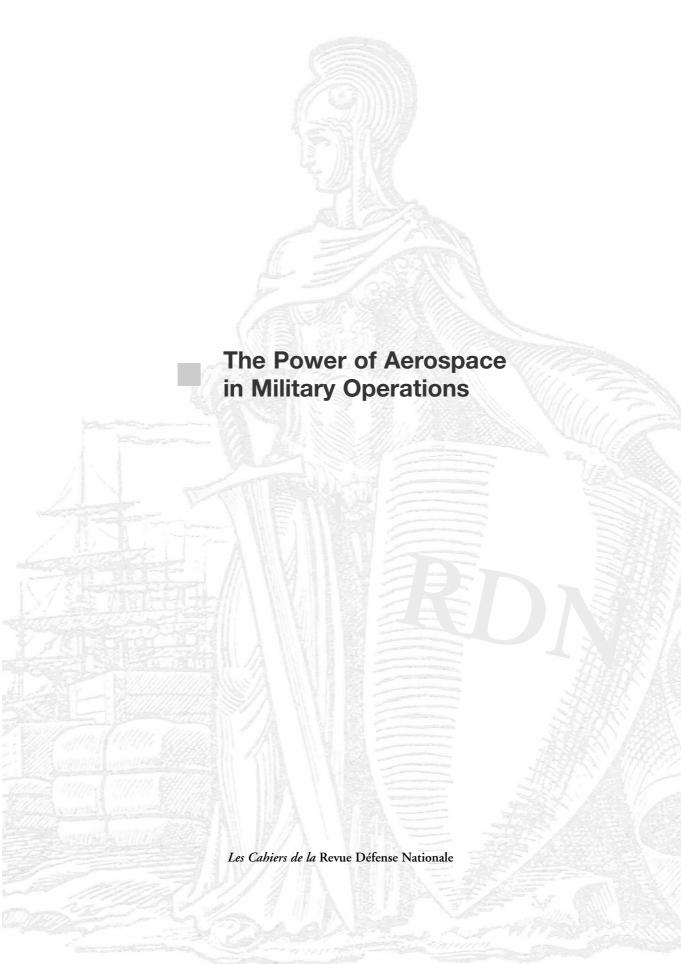
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- *Hamilton* shows that when facing A2/AD the pairing of combat aircraft + cruise missile confers a strategic dimension on air power and justifies political decisions in favour of these modes of action, especially for a demonstration of force. In the medium term, the increasing capability of numerous players supports this trend.

- The concepts and tactics that the Strategic air forces (*Forces aériennes stratégiques*—FAS) bring to the conventional forces underline the importance of deterrence in stimulating innovation. It is also the proof that certain closed areas are evolving. The strategic aspects of the conventional arms race are accentuating this movement.

- Faced with the challenges of dissemination, notably of anti-air defence systems, exceptional technical knowledge such as in the field of hypersonic missiles should continue to be developed because it will shape the dialogue of power. Cyber matters, space, offensive and defensive electronic warfare and, in the medium term, artificial intelligence, are all areas of innovation of capital importance to air operations in an A2/AD environment.

- Faced equally with modern defences, the quantitative reduction favouring the qualitative increase that high-performance, though increasingly expensive combat aircraft offer cannot be the sole solution. The critical size that corresponds to military ambition, particularly in initial entry air capability, must be supported precisely by simulation. It is not contradictory to promote more rudimentary vehicles and complementary modes of operation in scenarios where the cost of high-tech weapons would be prohibitive.

- The sovereign nature of a demonstration of power is compatible to some extent with a European dimension, as much to gain legitimacy of action as to boost the European defence technological and industrial base (EDTIB) for missiles. We need to add to our consideration of cooperation on key capabilities that would not weaken our national sovereignty in operations, examples being space exploration and the Future combat air system (FCAS, *Système de combat aérien du futur*—SCAF).

- The proliferation of offensive missiles opens up opportunities for adversaries who find themselves faced with ineffective anti-missile defences.[26] The effect on public opinion of a missile landing on France would certainly be prejudicial to deterrence. The NATO pattern of deterrence and defence, based on an appropriate combination of conventional, nuclear and anti-missile defence capabilities[27] would merit adaptation to our national level particularly through reinvestment in anti-missile and anti-air defence, both doctrinally and in terms of capability. ◆

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(26) Superiority of the most modern offensive missiles, and the possibility of saturation of defences with more rudimentary capabilities.

(27) This combination was mentioned in declarations from the 2012 Summit of Chicago, § 54 (www.nato.int/), through to that of the 2018 Summit of Brussels, § 34 (www.nato.int/).

The Power of Aerospace
in Military Operations

Space: a Strategic Issue and a New Warfighting Domain

Michel Friedling

Général de brigade aérienne, Commandant interarmées de l'Espace.

S pace is a strategic issue, mostly unknown to the citizens. While the dependence of our societies, economies, citizens and military operations on space has never been greater and continues to grow, the risks, threats and vulnerabilities in space have never been so important and are constantly growing. Formerly the object of a relatively peaceful strategic competition, space becomes a field of confrontation and weaponization of space is an ongoing process. It must now be considered as a domain and as a component like the land, maritime, air or cyber domains and components. Evolutions of our doctrine, capabilities and organization are inevitable.

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The French know little but space is essential to their daily lives and the prosperity of our economies. On a daily basis, French people use satellite services very often without knowing it. Ordering a VTC, withdrawing cash abroad, communicating with loved ones when traveling far, checking the weather of the day, getting to an appointment with the GPS of a car, watching a game of the cup of the world of football taking place on another continent, finding the nearest petrol station with a Smartphone or finding the nearest self-service bike depend on satellites and space services.

But space has also become unavoidable for the environment or the economy. Satellites make it possible to evaluate global warming, to measure climate change, to observe ecosystems, to know biodiversity. They make it possible to optimize the use of agricultural land, regulate and control the exploitation of fisheries resources, and measure and control deforestation or coastal erosion. Many space applications can help us to know the evolution of the environment and to design and implement preservation, good management or preservation measures. The space industry is developing à la carte services in fields as diverse as precision farming, with monitoring of drought levels and crop yields, optimization of meteorological accuracy, and road or air traffic management, monitoring of energy or transport infrastructure, filling of car parks or state of offshore platforms. In a more general way, space is essential to the good functioning of our globalized economies because it allows the exchange of information in near real time, secure banking transactions and their synchronization.

The applications are endless and the perspectives huge. On April 9, 2019, at the 35th Space Symposium in Colorado Springs (USA), a true international space show where the most eminent personalities speak on the subject of space, the acting US secretary of Defense Patrick Shanahan began his speech by comparing the role that space will play tomorrow for the prosperity of the United States to the one played by the oceans in past centuries. US secretary of Commerce Tim Ross added shortly after, according to estimates by the Commerce Department, the space economy would represent $1 to $3 trillion according to the assumptions by 2040, against $400 billion in 2020 with known market sectors such as space communications, Earth observation, navigation and weather. But also new market segments such as space tourism, robotics, in-orbit services, space debris removal and mining of planets and asteroids.

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Indispensable to our economy, to the proper functioning of our societies and to the everyday life of the French, space is equally important to the exercise of our strategic autonomy by the capacity it offers to our authorities to decide and transmit their decisions sovereignly. The French decision not to follow the United States in their intervention in Iraq in 2003 rested in particular on the capacity of France, thanks to its observation satellites, to independently assess the evidence concerning the detention and the use of weapons of mass destruction by Saddam Hussein.

It is also indispensable for the planning and conduct of our military operations. Our space defense capabilities allow our staffs and forces, in the homeland and on all our theaters, on land, at sea and in the air to see, listen, understand, communicate, navigate, locate and deliver armaments with a formidable accuracy in all weather.

From the beginning, space was considered a pillar of national strategic autonomy. The observation was initially used for strategic purposes for political and military decision-making, for nuclear targeting or for monitoring compliance with nuclear disarmament treaties. In the 1980s, the doctrine "Observe Listen Communicate" was defined and a space office created within the joint staff. During the first Gulf War, France understood the potential of space for the conduct of operations and not only for its contribution to the strategic decision. Spatial imagery, a necessary tool for politico-military decisions of strategic level, saw its use gradually go down to the lowest operational levels. In operational level staffs, then in components and even in units deployed in the field. The very recent case of Operation *Hamilton*,[1] which refers to the strikes carried out by France with the United States and the United Kingdom on April 1, 2018 against Syrian sites, is a perfect example. Space capabilities have been critical for policy-making, targeting, planning and execution.

Space support for operations covers intelligence, targeting, communications, positioning and navigation, plus meteorology and geography. With a little over €3.6bn over the duration of the Military Procurement Law voted in July 2018, all the military

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(1) See the article by Lieutenant Colonel MOYAL in this volume, p. 47-52.

space assets dedicated to support operations and authorities will be renewed, with increased performances. The *CSO* observation satellites will replace *Helios 2*, the *Syracuse IV* communications satellites will replace *Syracuse III* and the *CERES* constellation will be commissioned.

Dedicated to military observation, *CSO* is a constellation of 3 satellites placed in polar orbits of different altitude. Focusing on coverage, theater acquisition and revisit, the reconnaissance mission is filled by two satellites at an altitude of 800 km. The Identification mission, provided by the third satellite at 480 km altitude, benefits from the highest level of resolution, image quality and analytical accuracy. Completely deployed by the end of 2021, the *CSO* system will maintain sovereign access to optical imaging, in clear daytime or at night, with unsurpassed sensor performance and acquisition capacity. France opens the *CSO* capacity to its European partners to play the complementarity of the sensors and federate a space Europe Defense. Thus, in the broader context of the *MUSIS* program,[2] bilateral agreements ensure Germany and soon Italy a right to use the *CSO* system in exchange for access to their radar satellites. In the same way, the provision of the Kiruna Polar Station gives Sweden access to *CSO*.

Syracuse IV will constitute between 2021 and 2035 the heart of the long-distance communication capacity necessary for our military operations and the command of the deployed forces, in autonomy. It is structured around a three-component system. The space segment with two geostationary satellites launched in 2020 and 2022 will operate in the X and Ka bands. The user ground segment (SSU in french) will rely on an existing fleet of ground and naval ground stations to be reused, adapted and supplemented, including aeronautical stations, to meet changing needs. An operator ground segment will manage the network of communication means constituted by the user ground segment and the other satellite communication systems of the French department of defense.

CERES will finally equip the armed forces with an operational space eaves dropping capability in complementarity with the non-space capabilities already implemented in this area. *CERES* will detect and locate a wide variety of radar or telecommunication transmitters on almost the entire globe. The analysis of the data collected will provide information on areas in which we are today almost blind and fuel the strategic, operational and tactical levels. The rarity of such a capacity and the expected performance of the *CERES* system will make it a real asset for the French forces and more generally for France by increasing its autonomy of appreciation.

To these capacities will be added the services provided by the European constellation *Galileo* for navigation, the images of the *Pléiades* satellites and their successor, an access to the images of the radar satellites *SAR-Lupe* (ALL) and *COSMO-SkyMed* (ITAL), those of the satellite dual *ATHENA-FIDUS*[3] (with Italy) and access to *SICRAL 2* (ITA) services.

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(2) Multinational Space-based Imaging System for Surveillance, Reconnaissance and Observation.
(3) Access on THeatres for EuropeaN Allied forces nations-French Italian Dual Use Satellite.

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But the context changes radically. While the dependence of our societies, economies, citizens and military forces on space has never been greater and growing, the risks, threats and vulnerabilities in space have never been so important and are constantly growing. Risks are caused mainly by the vertiginous increase in the number of objects in space with an unparalleled densification of outer space. In 1957, the launch year of *Sputnik 1* by the USSR, the Earth had only one object in orbit. Today, there are more than 1,700 active satellites, an estimated number of more than 6,000 in 2025, and between 15,000 and 20,000 debris larger than 10 cm, plus several hundred thousand pieces of debris larger than one centimeter. At the same time, several major space powers have developed capability since the end of the 2000s to neutralize enemy space capabilities, with some acceleration for about five years. Threats to our space capabilities are proven. Cyber threats, sabotage, jamming, intelligence, denial of service, partial physical incapacitation or total destruction: these threats are varied and some are already operational. Thus, the Russian satellite *Luch Olymp*, cited by the minister in September 2018, approaches communications satellites to capture the communications flows. Several anti-satellite missile fires have been observed since 2007 with a Chinese demonstration against one of their satellites in 2007, followed by an American demonstration in 2008 and more recently by India in March 2019. Other anti-satellite capabilities are more experimental. For example, satellites in geostationary orbit that are thought to be able to damage and desorb other satellites using articulated arms or directed energy weapons, or space vehicles capable of carrying military payloads and to approach non-cooperative spatial objects. Some hostile actions may also be carried out by satellites having the appearance and missions of a civilian or scientific satellite. This makes aggression difficult to characterize and attribute and is a real concern for the future given the proliferation of non-state space actors.

As space is thus not only a major economic issue but also an environment whose mastery is essential to military operations, strategic competition in space becomes confrontation with new modes of action. It is certain that a confrontation between powers with space capabilities will extend to the space domain from the very first hours, each seeking to deny the adversary the use of its space capabilities and deprive it of the decisive advantage of freedom of action in and from this domain.

Space is no longer just a domain to support military operations, but is already and will be more and more a warfighting domain, just like the land, maritime, air and cyber domains.

In this context, it is essential to review our doctrine of the use of space. A true concept of military space operations is emerging. It can be defined as all activities carried out by or for the benefit of the Ministry of the Armed Forces in, to and from space to ensure the availability, monitoring, safety and security of national space capabilities and services, or national interest. Military space operations consist not only in operating capabilities to provide services in support of government authorities or military operations, or in contributing to the security of the territory and populations, but also

in necessary actions to protect our means and discourage aggression against these capabilities. Such a doctrine could be articulated around the traditional functions like ISR, support to military operations, Space Situational Awareness (SSA), and potentially new functions such as the action in the space.

SSA is a priority. Monitoring space and acquiring the knowledge of the space situation is a prerequisite for any exploitation of the space domain and in particular for the conduct of military operations, as well as for the implementation of a military space policy. The SSA responds to a military requirement that is the need to assess the threats that space-based space systems may pose to space on our national space capabilities, and, on the ground, our territory or forces deployed. This need is fundamental to attribute a hostile or unlawful act to its author and allow the political authority to take the appropriate measures. The SSA also addresses a need to prevent collision risks in space between active satellites and other objects, including space debris. We must therefore be able to detect, characterize and track all space objects that may pose a risk or threat. The surveillance radar *GRAVES* implemented by the Air Force, the *SATAM* radars also implemented by the Air Force, the *GeoTracker* and *TAROT* telescopes today provide an initial surveillance capability unparalleled in Europe. It remains insufficient, however. France must build, with European partners, a real capacity in this field. A reflection on a global architecture combining complementary sensors such as radars (to succeed the *GRAVES* radar), telescopes, imaging radars, monitoring systems in orbit to monitor and monitor all objects of military interest in outer space.

But if we want to be able to protect our space capabilities, we will have to go beyond that. At the request of the President of the French Republic and the Minister of the Armed Forces, all possibilities have been studied in this field, from reactive launchers to reusable space vehicles carrying a variety of payloads.

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In parallel, many questions appear. How to define and characterize behaviors and actions in Space, as a nation or as a member of a coalition? How to characterize a hostile intention, a hostile or dangerous act, especially below the threshold of armed aggression and how to respond to it? What rules of engagement, including peacetime? How to interact with the adversary, as a nation or as a member of a coalition? What reversible actions or non-reversible actions to be conducted? How to define and conduct a warning action in space? What capacities must be defended? With which level of priority? The national interest is not limited to military capabilities but also includes commercial or civilian capabilities, sometimes multinational or even foreign, within and outside the coalition, how to defend these capabilities? How to formalize cooperation with commercial operators? Their conditions of use should be clearly defined and robustly agreed to cover the entire spectrum. In particular, in what situations and under what conditions would a transfer of authority be necessary?

An immense field of thinking opens consequently to the Ministry of Armed Forces. It is now necessary to design coherent decision and command chains in national

and with our allies and partners to ensure the concentration of efforts in the diplomatic, informational, military and economic fields. It is necessary to establish and promote rules of behavior and measures of transparency and trust in order to promote a responsible use of Space. We must develop a common dialectic, not only with the allies, but also with other nations, including potentially adverse ones, to preserve, amend or elaborate norms and also minimize, in peacetime, the risk of misunderstanding between parts. Spectrum-wide capabilities and a range of options are needed to be able to act in a continuous, flexible and proportionate manner, especially in the face of an adversary who intends to remain below the threshold of armed conflict or in the event of a characterized hostile act. Finally, there is a need for better collaboration between the cyber and space domains, and more generally, between the different components in operations that will be more than ever multi-domain.

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To conclude, the challenges are considerable and the issues all the more complex as the space is experiencing a revolution that, while carrying the risks mentioned above, offers many opportunities. The digital revolution and the new economy applied to space are a chance. They offer new, more flexible, more responsive, more innovative services that can be used by the Armed Forces. Because acquisition and capacity development modes are changing for these capabilities and services, moving from a long-time logic with perfect control of risks to a logic of shorter time, experimentation, demonstrators, with acceptance of a measured risk, even that of a defined need by walking, iteratively. These two approaches are complementary. For complex space systems, the risk management approach is inevitable given the financial stakes. For new capabilities, the call for innovation, the emergence of a truly innovative space ecosystem in France and an iterative approach based on demonstrators implementing technologies in the commercial sector will be assets for France, our Armed Forces and our military operations. ◆

State Activity
in the Air

Christophe MICHEL

Colonel, Head of the inter-ministerial mission for air safety and security of the General secretariat for defence and national security (SGDSN).

Activity of the state in the air is often thought to be limited to security and air safety, and yet it is remarkable for the many fields with which it interacts. Development of national economic and industrial structures at a time of ecological transition, the importance of the air sector for tourism, town and country planning, international trade and maintenance of stock levels are just some of the areas for which the highest levels of security and safety are required. So long as all the players concerned by the development of the air sector coordinate their policies, state activity in the air contributes to facilitating national growth.

Defence and national security

The Prime Minister is the guarantor of governmental action in the field of defence and national security and is in charge of national policy on the matter. He calls on the administration and the armed forces to carry out this policy and together with other concerned ministers he assumes responsibility for it before parliament. National security policy cuts across the major traditional ministerial functions, including defence, foreign policy and domestic security.

The aim of the national security strategy is to identify all threats and risks likely to affect the life of the nation, and in particular protection of the population, integrity of the territory, preservation of vital interests the continued functioning of institutions of the Republic. It determines the responses that the public powers must make to them. The Prime Minister is supported by the General secretariat for defence and national security (*Secrétariat général de la défense et de la sécurité nationale*—SGDSN), which coordinates preparation of measures in accordance with the national security strategy and which ultimately puts them into practice.

Starting with analysis of the threats that could prejudice national interests, the SGDSN is responsible for devising the response of the state. Its action is divided into security measures that range from the long-term prevention of malevolent acts to the shortest possible notice reaction required to counter aggression.

Policy for air security

For matters in the air, the Prime Minister is assisted by an Inter-ministerial committee for air security (*Commission interministérielle de la sûreté aérienne*—CISA) that sits twice a year. Under the authority of the Prime Minister's principal private secretary, the CISA brings together representatives of relevant ministries and directorates general and of the Air defence and air operations command (*Commandement de la défense aérienne et des opérations aériennes*—CDAOA). It is the decision-making body that ensures coherence of national policy on security and air defence. Working from the decisions of the CISA, the Prime Minister delegates to the SGDSN the responsibility for overseeing inter-ministerial coherence in the measures to be taken, in order that the level of protection afforded to vital interests against a malevolent act is constantly improved. Seen through the prism of the threat, the air environment stands out by virtue of its globalisation, the intrinsic vulnerability of aircraft, the high number of passengers transported, the violence of accidents—the majority of which lead to catastrophes that cause numerous victims, its high level of media interest, the serious economic consequences of an incident and also the psychological impact on the population that suffers an attack.

Because of this, the state is prepared to react immediately to any aggression towards the air sector. With a set of permanent security measures available to him, and taking account of the assessment of any particular threat, the Prime Minister can decide on the activation of the governmental plan of response to a crisis in the air sector as soon as the situation demands. *Piratair-Intrusair* measures add to those that might be applied form the moment the integrity of an aircraft or its passengers is threatened, an airport installation is targeted or an intrusion into airspace is established. A malevolent act could be of any nature: hijacking of an aircraft, hostage-taking, attack within an airport's infrastructure or cyber attack on air navigation systems, to mention but a few.

It is a peculiarity of the air environment that the Prime Minister himself assumes operational responsibility. In this regard he has a direct link to the commander of the CDAOA, represented by the High authority for air defence (*Haute autorité de défense aérienne*—HADA), in order to decide upon immediate air security measures, for which the combat aircraft and helicopters of the Air Force are the strong arms. Given how quickly a crisis develops in the air environment, it is through this reactivity that the state can permanently ensure the protection of national airspace and French citizens.

If proposed by the SGDSN, he could also decide to activate the Inter-ministerial crisis cell (*Cellule interministérielle de crise*—CIC) in order to concentrate the efforts of all ministries and operators on resolution of the crisis. The CIC unites experts from ministries and administrations, and also the CDAOA, to maximise the effectiveness of assets and to offer the highest authorities of the state the best response to the aggression suffered by the air sector. The CIC is permanent liaison with the departmental prefect concerned, who is the director of operations in his area in accordance with his territorial responsibilities.

Action of ministries and central administrations

The Directorate general of civil aviation (*Direction générale de l'aviation civile*—DGAC), an administration of the Ministry for ecological transition, brings together all the services of the state whose functions cover the regulation and supervision of air security, air transport and civil aviation activity in general. On the first point, it is responsible for air traffic control, supporting R&D in aeronautical construction and for the certification of aircraft. Regarding safety, with the support of domestic security forces and the facilities provided by the operators, it ensures that the best level of passenger and freight checking is performed, starting as far as possible upstream of any journey to the moment of embarkation in the aircraft.

Principally through use of its specialised forces—the border police and the Air transportation gendarmerie (*Gendarmerie des transports aériens*—GTA)[1]—the Ministry of the interior ensures the safety of civil air transport in their respective areas of responsibility. With support from the intelligence services, domestic security forces supervise the day-to-day security of passengers and freight from airport screening inspection points through to aircraft parking aprons.

Once the aircraft is in the air, the Air Force takes over responsibility for it as part of the CDAOA's safety mission. The latter must at all times and in all places keep watch on national airspace and ensure that no flights there present any risk, not only to aircraft and their passengers but also to third parties on the ground. As required it activates Air Force intercept units, to bring aid to an aircraft in distress, to remove doubt from an uncertain situation or to put an end to any threatening situation. It also provides the search and rescue service for aircraft in uncertain situations and in distress in national territory.

The National centre for air operations (*Centre national des opérations aériennes*—CNOA) is the Air Force organisation that permanently guarantees the integrity of national airspace. It verifies the correct allocation of military air assets, and that they are appropriate for detection of mobile contacts, their identification or interception in the air. It maintains close links with civil aviation, the national police force, the national gendarmerie and the customs authorities, and also with all bordering foreign military authorities and NATO. This gives it the ability to coordinate and optimise its actions with partners, and ultimately to offer the Prime Minister the best response to a crisis situation, whatever the circumstances.

In the field of civil security the Ministry of the interior's Directorate general for civil security and crisis management (*Direction générale de la sécurité civile de la gestion des crises*—DGSCGC) operates dedicated air assets. Helicopters and aircraft can be committed at short notice as soon as a crisis poses a risk to the population. Closely followed by the media in summer, the specialised aircraft for fighting forest fires are put under the responsibility of the prefect of the department from the moment they are committed. The highly reactive equipment of the DGSCGC can usefully benefit

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(1) A peculiarity of the GTA is that it comes under the DGAC for its employment.

from optimised freedom of action once the CNOA is in a position to ensure it exclusivity in its manoeuvre area.

The Directorate general of the national gendarmerie (*Direction générale de la Gendarmerie nationale*—DGGN) has aircraft for its public security duties, which can also be brought into action for the resolution of a civil security crisis. They are particularly adapted to rescue and intervention missions in specialised environments, such as at sea and in the mountains.

The Directorate general of customs and indirect taxation (*Direction générale des Douanes et des droits indirects*—DGDDI) is a further actor in the air. Responsible for monitoring flows of freight, it has responsibilities for air freight and passengers' luggage too. In cooperation with the border police it ensures personnel checks at the boundaries of the Schengen area. It has a range of helicopters and aircraft in addition to its ground and maritime equipment.

Whenever state action in the air has implications beyond our borders, the Ministry for Europe and foreign affairs is called in. It is informed if French interests are threatened in a third party country, and support from the embassies is then sought. It will also be informed when foreign interests are threatened in France, for example when a foreign-flag airline is concerned or when there are foreign passengers in a French plane.

Perspectives

Contrary to the maritime and ground environments, which have dedicated prefectural authorities, other than for the activation of the CIC the air does not enjoy the sort of arrangement capable of federating the air assets of all ministries in order to optimise their use. That said, the CDAOA has capabilities and prerogatives that allow it to initiate protection measures from the very first moments of a crisis. This opportunity, probably insufficiently used, requires better communication with territorial civil authorities. The will to unify efforts is seen in the field of development of national civil aviation, for example, through the re-establishment of the High council for civil aviation (*Conseil supérieur de l'aviation civile*—CSAC) announced by the Minister of transport during the closing speech of the Air transport conference last March.[2]

Nevertheless no dedicated body exists for handling the totality of matters concerning the air sector, whether those arising from safety and security, development of French aeronautical structures, promotion of industry or ecological transition. Such a high-level body could contribute to strengthening national strategy for the air sector. It would usefully complement the work of the Council for aeronautical research (*Conseil pour la recherche aéronautique*—CORAC), which is already helping development

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(2) Élisabeth Borne (Minister of transport), *Conclusion des Assises nationales du transport aérien – Présentation de la stratégie nationale du transport aérien*, Paris, 8 March 2019 (www.ecologique-solidaire.gouv.fr/conclusion-des-assises-nationales-du-transport-aerien-presentation-strategie-nationale-du-transport).

of the aeronautical industry with regard to the commitments made by France to ecological transition.

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The continuing development of the air sector should encourage us to continue this line of thought. The International Air Transport Association (IATA) forecasts a doubling in the volume of passengers carried in the world over the next 20 years. In Europe this growth will lead to fundamental adaptation of the rules governing air traffic circulation through the Single European Sky initiative. The drone and space markets are in full growth with regard to the services they will be able to offer in the near future: wider use of high performance pilotless aircraft with greater endurance and payload, and the multiplication of state and private players going into space should incite France—a pioneer nation in aeronautics—to improve relationships between national players in order to respond to the challenges to come and to guarantee the success of its activity in the air. ◆

Air, Space
and Ground Action

Michel Grintchenko

Général de division, commanding French Army aviation (ALAT).

The Army is a major player in the third dimension: it has its own light aviation section (*Avitation légère de l'Armée de terre*—ALAT) whose 300 aircraft cover the whole range of *aérocombat*—air combat in support of ground operations. It is a European reference in this field, capable of conducting long, high-order operations in either French national or coalition formats, following national or international modes of operation.

It also has for a considerable number of years been recognised for its expertise in the world of airborne drones and was a pioneer with its use of the CL89 and 289. Today, it operates some thirty of the Sperwer interim tactical drone system (SDTI)[1] and just under a hundred Tracker intelligence-gathering drones (DRAC)[2]. It will soon have the Patroller, more than a hundred Spy Ranger intelligence mini-drones (SMDR)[3] and a host of contact mini-drones. The Chief of the Army Staff will then become the employing authority for more than 1,000 airborne drones in addition to the helicopters and other aircraft of the ALAT, with all that implies in terms of training, management of airspace and, of course, aeronautical security.

The artillery should also be mentioned since it too uses a lot of airspace, with firing trajectories that occupy impressive volumes. The trajectory of the 120 mm mortar, with a range of some 10 km (6 miles), exceeds 4 km (13,000 feet) in altitude; that of Caesar[4], whose range is up to 40 km (25 miles), can have a trajectory close to 20 km (65,000 feet) in height. The LRU,[5] with its 80 km (50 mile) range, requires clearance of a mush larger airspace. Furthermore, the Army regularly uses the third dimension tactically, for its parachute units for example, and logistically for the positioning and support of deployed forces. It is not obsessed by action on the ground: its eyes are constantly looking upwards, be that for establishing communications, obtaining images from different sensors or for action within the electromagnetic spectrum.

The future of the Army is therefore intimately linked to space and aeronautics from the point of view of capability as well as in its manner of conducting operations.

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(1) SDTI = *Système de drone tactique intérimaire*: Sagem Sperwer.
(2) DRAC = *Drone de reconnaissance au contact*: EADS Tracker.
(3) SMDR = *Système de minidrones de renseignement*: Thales Spy'Ranger.
(4) Trucks fitted with an artillery system.
(5) LRU = *Lance-roquettes unitaire* (An MLRS system).

A modern army, actor in an air-ground environment

Anything relating to the air and to space immediately inspires in the collective imagination an impression of modernity and high technology. It reduces ground combat to rustic simplicity: a form of warfare that has developed little since the era of trenches and puttees. It is as if the vigour in the army comes from its speed of movement alone. That impression could not be more wrong!

The French Army today develops the warrior spirit so essential to the fighting soldier by drawing on the traditions of his or her arm, mastery of high technology and an unfailing will to dominate the adversary. Moreover, it is fully engaged in the twenty-first century notably with the Scorpion programme. Scorpion is a good example of collaborative combat, the system bringing together captors and effectors in a theatre intranet, which in real time allows the instantaneous transmission of alerts and the reticulation of units. It opens the way for even better exploitation of opportunity through use of artificial intelligence. Scorpion puts the Army firmly in the world of high technology.

The army's zone of action extends from the ground to the lower layer of air-space, which is quite naturally an extension of ground manoeuvres, and which is why we speak today of air-ground action. The Army has the right assets for optimum management and organisation of this space, such as surveillance radars and coordination systems. It is also able to defend it by sharing its air defence with the Air Force. The subject becomes even more complex given that with few fixed and mobile assets we have to protect moving force concentrations whose very movement increases their need for protection as they advance. This supporting defence manoeuvre requires close coordination between assets operating in the third dimension (CI3D), including where necessary those of Air Force, such as the medium range ground to air system SAMP[6] and the Crotale new generation short range anti-air system SACP NG[7]. CI3D is for the Army a field of strategic competence that is shared with the other armed forces.

An army that depends on space

All modern combat depends to a great degree on satellite data with its accuracy, high information rate and security. It is essential to highly precise positioning of units, particularly for Blue Force Tracking[8] and for firing certain munitions. It also adds value to information that combines positional data with digitised terrain data derived from satellite imagery. The Army makes great use of long-distance satellite communications, which are both secure and resilient. With Syracuse IV, a high data rate system, it can instantly share images, video and alerts. Additionally, the element of intelligence that comes from space or transits through it should not be forgotten.

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(6) *Système sol-air moyenne portée.*
(7) *Système d'arme anti-aérien à courte portée Nouvelle génération*: Thales-MBDA Crotale.
(8) A system for GPS localisation of friendly forces.

Future command systems, in the air and on the ground, will need to make the very best use of informational superiority. The Army would therefore count on the Air Force to fight the battle in space to protect our satellites and if necessary disable others. At the same time, the Army intends to develop its capabilities to benefit fully from equal shares of the services supplied by space assets such as Comsat (communication by satellite), which should be fitted to its aircraft and larger drones.

Mastery of air-ground combat

Following this look at capabilities, we come to the way combat is perceived. The synergy between ground and low-flying airborne assets has led to formalising the concept of aérocombat, air combat in support of ground operations, which is the ALAT's preferred mode of operation. By combining the advantages of each component committed to an action (the agility of helicopters, power of ground-ground artillery, infantry and the engineers' ability to hold, clear and service ground, for example) the Army possesses agile and powerful units capable of conducting decisive action. Following Admiral Labouerie's principles of warfare (uncertainty and striking force), *aérocombat* units can operate more than 500 km (300 miles) from their bases. They dominate the enemy by their ability to seize, defend and hold individual points, particularly during the final shock of the last 50 metres of contact across which everything is played out.

These bold operations are not conducted in isolation, of course: they need the support of assets coming from the other services—the air force or the navy—to ensure air superiority, bring extra pressure to bear locally or to halt an enemy seeking to counter-attack.

It serves no purpose to set and compare the services one against the other by awarding some form of certificate of excellence to one or another of them, since in combat all actions have to be complementary in space, time and effect.

Nevertheless combat assets are rare and often over-stretched. We would need to use them massively everywhere in order to have an advantage over an enemy who would understandably seek to disperse them in order to dilute our efforts. The forces therefore need to identify those capabilities that would lead to better effectiveness of key units by developing real force multipliers. These are the capabilities that allow adjustment of force balances, whose mathematical rigour is a basis for tactics. Overall for the attacker, experience shows that a ratio of 3 to 1 is needed to hope for success, but if we are capable to move a section of our troops to where the front line could be breached, we would not hesitate to attack locally at a ratio of 10 to 1! Napoleon did precisely that on his battlefields when he gained great victories although in a position of overall inferiority in numbers—he applied extra power where he had decided to crush his enemy. The key issue here is tactical mobility, which can mean avoiding combat in certain places in order to saturate the enemy in others where he has to be defeated. That is even more true today, when far smaller armies are spread over vastly greater battlefields. With Scorpion the Army is basing its future on tactical agility

whilst being sure that air assets, whether from the Air Force or the Army, are excellent force multipliers.

Different services, different constraints and different logic

The differences between these two services nevertheless become sensitive on occasion, especially when they are fighting over budget shares for apparently similar systems and when major political choices have to be made. Before contrasting them, however, it is worth understanding what distinguishes each in order to assess what each offers that is complementary and irreplaceable. The two are linked in victory but each has to operate in a different domain. The army acts in a determined timescale in a space where the outcome of the battle will be decided. In 1940 the Battle of France was lost at Sedan between the 10th and 15th May, when the *Wehrmacht* broke through the front. It was never possible to recover the campaign after that, since once a combat unit exploits a breakthrough, all powerful means possible will be brought to bear, creating carnage on very weakly defended targets. Command posts and logistic depots are destroyed, their loss meaning the vital supply line to 1st echelon units dries up and chaos and disorganisation are increased. The outcome of war for an army is therefore linked to a particular place and time that cannot be moved. Moreover, it can only with great difficulty dodge its enemy once contact has been made. Back to 1940: several months later, the Battle of Britain serves as an example of a very different success. The Royal Air Force had suffered three months of tactical defeats, being unable to stop the *Luftwaffe* from bombing London and other parts of England, and yet in the end it was the RAF that enjoyed victory. As in naval warfare, air warfare is a question of fleet work and of maintaining combat potential. Those services are able to avoid combat, to choose their moment and wear down their adversary in a war of attrition. For them, he only ceases to be a threat once his firepower has been destroyed.

Thus there are two very different ways of achieving victory or suffering defeat, and they mould the mentalities of each service. Nevertheless both of these facets of war have to be won. The easiest way is to do them successively, but destruction of enemy fleets before commitment to combat on the ground is a theoretical prerequisite rarely found in history. Most often everything needs to be done at the same time, but there is a risk of losing priorities regarding the manner of conducting operations. That said, opposing the conduct of air and ground operations must be avoided, since they both support the same battle. No war is won without rupture and exploitation on the ground, just as no battle is won on the ground while the enemy air force remains able to counter ground action. The same rationale is valid for the navy, where there can be no victory on land without freedom of action at sea. What is important is that each should do what it is best at: the air battle should be conducted according to the logic of the air whilst that on the ground should follow the logic of the ground. This requirement that each understand the peculiarities of the other led to the creation of joint force command structures, within which each of the different reasoning processes can be expressed.

Complementarity in approach

The way that conduct of operations is viewed depends also on a special culture, shaped by confidence in technology and the manner of grasping reality, putting it into context and deriving from it a succession of actions. In this era of high quality imagery from satellites and aircraft, and capabilities for listening, exploitation and understanding from human and technical networks, there is great temptation to think that we know a large part of reality and to consider that what we know is, in fact, reality. But that is to forget that concealment is part of warfare! Think of the deception operations—stocks of rubber tanks and wooden aircraft—that made the Germans believe that the Normandy landings were only a diversion. Today, big data and artificial intelligence lend themselves perfectly to modern methods of deceiving the enemy by distorting his analyses using false data. Illusion is part of warfare, and that must drive us to confirm again and again, permanently, all the information received via the different methods in order to avoid being misled.

Once what is known is confirmed, it is converted into objectives to be destroyed according to a methodical campaign aimed at breaking down that which allows the enemy to exist and often, unfortunately, which allows the population to live. The planning cycle gets under way and the spiral continues until the required level of attrition has been reached. In a given action we can destroy the known part of the enemy's combat capability yet are shocked by the collateral damage we wreak at the same time on the civilian population. But what can we do to destroy the unknown part, that hidden by the enemy? What do we do to avoid generations of combatants rising up against us, revolted by the dehumanisation of war? Doesn't brutality incite resistance and revolt?

We need to know how to get out of impasses and to give new wind to a campaign by flushing out the enemy from where he is dug in, provoking him and pushing him to make a tactical error. That is what was decided during the war in Libya in 2011 where, after a very effective air campaign, the land battle had stalled and had put the local population in danger. The deadlock was broken by a succession of raids from the sea led by the ALAT. In a cat-and-mouse game, helicopters defeated the forces loyal to Gaddafi, forcing them to make errors and to reveal themselves. We had to get into the mentality of the combatants, and to accept very high risks, in order to destroy almost 400 vehicles, that means two brigades, which led to breakthrough of the front and ultimately the end of the conflict.

The symphony of fires

When the soldier is in contact with his enemy on the ground, he can find himself rapidly pinned down by enemy fire. Incapable of manoeuvre, he must expect relief to come from elsewhere. His salvation might come from another unit forcing the enemy to move: very often that will result from indirect fires from artillery or aircraft. It is all rather on the lines of a musical score—just as each instrument in a orchestra has to play its phrase at the right moment and in the right key, so here each arm is directed to produce something particular in the right place at the right time. The air

force delivers particular types of fire—massive, brutal and powerful. The artillery is able to produce various effects, dropping shells in clusters, on a line or perhaps creating a perimeter around a unit we might wish to protect. The shells explode on impact to destroy solid matter or before impact so its splinters break up what is poorly protected. They can be explosive, smoke generating, illuminating or, for greater precision, guided.

Each system can therefore produce a special effect with the common aim of eliminating the enemy's will to fight. The question remains, though, who is the composer of this symphony and who conducts the orchestra? Those who tend to plan everything to excess would allot these roles to headquarters staffs far removed from those in contact, leaving only a technical role to those on the front line. Others would prefer to leave decisions on fire and manoeuvre to the person in command of the action at the time. The debate continues in the knowledge that the best solution is that which produces the best effect at the chosen moment. During the engagements in Libya, the ALAT had the advantage of 'cockpit delegation', which authorised aircraft captains to decide for themselves which targets to engage and when to open fire, whereas other components had to obtain specific authority for each firing, thereby missing the fleeting moment when the enemy imprudently revealed himself. Delegation of firing authority and the concept of fire manoeuvre form an essential element of effectiveness in combat.

Mastering the interface between two environments

Units deployed on the ground hold the terrain, but have only a very limited view of the overall situation, being blinded by topography and by the smoke that rapidly appears during combat. Aircraft have limits, too: they cannot stay too long in these dangerous zones where they are in the enemy's firing range. The fast-moving craft needs to receive information on his target and the tactical situation to facilitate his attack, and the same goes for indirect fires, which have to be guided constantly onto targets that might move or reveal themselves. Today's preferred positioning of guidance cells is on the ground, but consequently they suffer the same limitations as the deployed units, so there is an compelling need to create the ability to see from above in order to direct fires. In the war in Indochina it was precisely that problem which led to the development of artillery observation aviation, responsible for holding the sky, as it were, and being for the artillery units and airmen the eyes so essential for the success of their missions. This requirement is today partially satisfied by drones and by the ALAT. The need is sure to increase in the years to come, conferring an essential role on this interface between two environments. The effectiveness of the entire combat outfit will depend upon its quality.

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France is a military nation that counts. It has a comprehensive army, capable of conducting independent operations and of bringing weight to bear in the conduct of coalition operations. A faithful ally and a permanent member of the UN Security Council, it upholds its military rank and does not refuse to pay the price in blood.

A deeply humanist nation of human rights, France knows that war is but a temporary disturbance in the life of a society. It knows it has to wage it when necessary, to win it rapidly if possible and to conduct it with humanity in order to try to reconstruct just as rapidly a state of harmonious coexistence. That is why the French Army does not shirk from commitment when necessary to what is difficult, in order to save lives and control the crisis. It does so with the entire support of other components of French forces or of its allies by developing the greatest synergy and complementarity possible, particularly where favoured by programmes developed through multinational cooperation.

A modern army that is totally committed to operations in the third dimension, the French Army is therefore an entirely natural and structural player at the *Salon Aéronautique* at Le Bourget. ◆

Cyber and Military Action
in the Air and in Space

Didier Tisseyre

| Général de brigade aérienne, Deputy chief of cyber defence.

Globalisation and the digital transformation of society have led to the creation of a space in which almost all human activity can be seen: cyber space. Its characteristics offer great chances—economic, scientific and cultural in particular—since they increase trade, in turn favouring progress and the creation of wealth. And yet precisely because it potentially reaches all who connect to it and all deployed systems, it is also a world that attracts envy, and is favourable to crime, espionage, influence, sabotage and destabilisation. It is therefore an environment of conflict, which means that security and defence are at stake.

Interactions between cyber space and the other spaces (ie land, maritime, air and space) are many and on several levels. Cyber is therefore a transverse space, able to reach all the others. Like the ground and maritime spaces, air and space are highly computerised, thus contributing to the efficiency of military action in those environments. That computerisation then itself becomes a new source of vulnerability. Are we then condemned to suffer, when faced with sure risks and proven threats (*Winter is coming*, as in *Game of Thrones*!), just hoping that our defences hold out? Is there not a strategy for better management of these risks and for countering these threats? Could we not turn these vulnerabilities to our advantage to preserve our freedom of action and independence, and to contest those of our adversaries?

To counter the risks that stem from cyber space and which could limit military action in the air and in space we need on one hand for our systems to have genuine, operational cyber defence that relies upon a permanent cyber defence posture, and on the other to have the capability to plan and conduct defensive and offensive military operations in cyber space, both in external theatres of operation and in the defence of the forces' digitised systems. And though seeming a contradiction in this environment of hyper-technology, it is the intrinsic qualities of the human being, when set to work within the framework of that new technology, that will drive our response to the challenges posed.

To back up these analyses and proposals let us look at the characteristics of cyber space and the vulnerabilities induced into military action in the air and in space, then at the capabilities we have to develop for our defence and to enable us to conduct operations in cyber space.

Benefits of digitisation and dangers of cyber-space

Mass digitisation of information, the exponential development of calculating power, the interconnection of networks and the falling cost of the associated technologies have led to the transformation of all human activity. Computerisation of processes optimises activities and new uses see the light of day, freeing us from traditional prescriptive, regulatory frameworks. States, administrations and historical players in certain sectors are therefore disappearing, to be replaced by direct relationships between users and suppliers of services. Digitisation increases opportunities and contributes to the development of progress. Internet is the symbolic example of this worldwide web, connected by cable or waves, and plugged into by numerous private and public networks. Initially limited to information and communication systems, digitisation has been broadly extended to remote control of automated systems through Supervisory Control And Data Acquisition (SCADA) and, in the field of defence, to command and control (C2) systems and hence to almost all weapon systems.

Worldwide interconnection of digitised systems has created a completely artificial cyber 'space' in which everyone can potentially interact with everything. In view of the profound transformation of society that accompanies its deployment, we could say that it amounts to the digitisation of physical spaces (land, sea, air and space) in a rather philosophical, conceptual sense. It is a higher-level space since it penetrates all the others and can act in them. In another universe we might argue that it is a space, like Tolkein's ring, to rule and control everyone. Although sometimes seen as a single entity, cyber space is far from homogeneous and is often described as three layers on top of each other—physical, logical and semantic (or cognitive, or social). The first is made of computer materials and components and the networks that link them, which could be cables, fibre-optics or electromagnetic waves. The second is the collection of digital data, its handling processes and flows of data being exchanged, which are activated in the physical layer. The third layer brings together that which is exchanged in cyber space between humans—ideas and sentiments for example—in particular via avatars (digital identities) set up by users. These three layers are interdependent and any action on one of them could have consequences on the others. It is possible to hide a user's real identity and traces in order to remain anonymous and/or furtive.

Our companies and administrative bodies make massive use of cyber space in support of their activities and are becoming dependent on it. At the same time its boundaries and structure continue to evolve. Other than its physical aspects it has no real limits, geographical characteristics or political or legal boundaries that would connect it to states and thereby define notions of territoriality or sovereignty. Because states are in essence absent from cyber space it is difficult for them to play any stabilising role. The real influence, on both economic and social levels, comes from the major companies associated with the digital world, such as the GAFAM,[1] BATX[2] and NATU[3] groups. Others are revolutionising entire areas of activity: Elon Musk, for

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[1] Google, Amazon, Facebook, Apple and Microsoft.
[2] Baidu, Alibaba, Tencent and Xiaomi.
[3] Netflix, Airbnb, Tesla and Uber.

example, with New Space and SpaceX. Clearly it is no longer states that are initiating or supporting the development of technologies, among which those essential to aerospace activities, nor are they controlling their availability: that all now lies in the hands of private interests.

On Internet everyone, whatever his motivation, can potentially transmit information or software almost instantaneously to a great mass of addressees or in a more targeted fashion. Tools exist to protect against malware but few, if any, protect against broadcasting of false information—fake news—aimed at manipulating opinion.

Vulnerabilities impacting military action in air and space

A major constraint on cyber space is the frequent need for updating of hardware and software owing to their rapid obsolescence. Because of the reliance on open architectures, mechanisms need to be added to ensure confidentiality, availability, integrity and the traceability of data and its handling. The complexity of development and parametering of the hardware and software associated with those mechanisms means that vulnerabilities can be discovered, which once in the public domain lead to distribution of corrective patches that are not always installed as quickly as they should be. Therein lie opportunities for the attackers, some of whom even set traps in those patches in order to infect the machines. Indeed, some manufacturers are accused of deliberate infection of the material or software that they sell, to the advantage of the state to which they belong—the debates over Kaspersky and Huawei being examples.

The worst scenarios see attacks on the digital systems of civil or military vehicles in flight (aircraft, helicopters, drones and missiles, for example) or of spacecraft (satellites and rockets). With no need to have anyone on board it is possible for pirates to take over control remotely to make the vehicles crash, collide in flight or be used as flying projectiles as in the terrorist attacks of 11 September 2001. In other scenarios there is some form of intrusion into an air traffic control system to disrupt it by masking, adding or moving tracks. Up to now the few successful attacks that have been made public concern flight reservations systems or handling of customers' accounts and their only impact has been financial or on company image.

Because of interoperability and interdependency, risks to civil activity inevitably weigh on military activity too. Everything that is connected to or within the aircraft physically or by radio, or even asynchronously by a removable device, could be used as an entry channel for a cyber attack. New generation systems for air traffic management in the context of single European or American skies are based on satellite links and interconnection of systems that assemble information relating to the aircraft and its environment and are therefore a greater source of cyber vulnerability. Robustness and resilience in the face of an attack on a system are major challenges for all public and private organisations, such as airlines, airports, air forces and the missile, launching and satellite sectors.

Cyber attacks affect military action in the air and in space even more so: on one hand the Air Force's missions of defence of airspace and surveillance of exo-atmospheric

space, and on the other, defence of its own air and space capabilities. It is therefore essential to analyse these risks and threats very well, especially to evaluate their possible impact on our systems since these are now 'systems of systems' that rely on complex architectures. They integrate many constituent digital elements, airborne or on the ground, including data links and various sensors. The C4ISTAR (Command, Control, Communications, Computers, Intelligence, Surveillance, Target Acquisition) concept well illustrates the operational gain afforded by the digital technology that allows these functions to be brought together, something unimaginable back in the days of manual and analogue information handling. Tactical data links are another major advance for the coordination of combat and optimum allocation of targets. For France, these advances are being implemented in collaborative or connected combat, part of the major Future combat air system project (FCAS, *Système de combat aérien du futur*—SCAF), which brings together sixth generation aircraft and a wide range of inter-connected and interoperable elements such as drones. And yet this very interconnection facilitates penetration by an attacker. The same goes for the entire range of satellite systems used by military bodies (for observation, listening, communications and positioning and navigation, for example), all of whose components and functions are potentially vulnerable to attack even via their ground segments. Their cyber security is a major issue since today there is no military operation that does not requires the support of space assets.

Cyber-defence operations and military action in air and space

Whilst cyber 'weapons' hardly revolutionise the principles of war, by the same concentration of effort and economy in use of assets they open up new perspectives for states and armed groups through their unconventional and hybrid use alongside traditional weapons and action. The Internet allows anyone to overcome issues of time, distance and borders to destabilise a state by targeted or wider broadcasting of information or transmission of malware. Globalisation, which offers easier access to high technology, and the dependence of Western society on information technology lead to counter effects in cyber space. The use of cyber space adds to the difficulty states have in creating an appropriate response in an environment in which the boundaries between peace, crisis and war are less clear than they once were. There is no internationally recognised definition that clarifies whether a cyber attack can be considered 'armed aggression', which would entitle legitimate defence under the terms of Article 51 of the UN Charter, or collective defence under NATO's Article 5. Cyber attacks and strategies of influence on social networks therefore bring a level of asymmetry that profoundly modifies the framework of international relationships.

Quite apart from the technical impact, proliferation of threats, the variety of modes of action—often furtive and difficult to attribute to an originator, and the multitude of possible targets, the ability of cyber attacks to produce worldwide effects from limited resources lead to serious operational challenges. They involve the freedom of action of armed forces and national sovereignty. Our adversaries are in a position to put credible attack strategies into effect against our forces and defence industry. Organisational measures and local protection techniques are no longer sufficient and

need to be complemented by a form of overall reactive and dynamic cyber defence that forms part of a permanent cyber defence posture. It would be structured on an operational chain of command with specialised human and technical assets. We must anticipate adverse modes of action, detect and define them, assess their likely impact and react in order to preserve as best we can our operational advantage. It is a cycle comparable with that of air defence, though adapted to cyber space. Since a cyber attack could be wide ranging and arrive via indirect channels, it is essential that all players share the same operational picture so they can respond collectively to crises.

Within the Ministry for the armed forces the Cyber defence command (*Comcyber*) is responsible for conducting operations in the Defensive information battle (*Lutte informatique defensive*—LID) according to a policy of end-to-end coordination based on a principle of subsidiarity. Each major body in the Ministry—forces, directorates and services, for example—establishes LID arrangements within its area of responsibility, overseen by a technical and operational structure, one of a number of Security Operations Centres (SOC). The LID analysis centre (CALID) a sub-unit of *Comcyber*, ensures wide-ranging technical oversight and assembles and shares information on the cyber pictures produced by all the SOCs or by its own assets. *Comcyber* is at the head of the LID chain and has an operations centre which directs the work of the CALID and the SOCs to ensure broad operational oversight. Comcyber receives complementary information from national and international cyber security, cyber defence and intelligence partners, and is party to the cyber threat state and to newly-discovered vulnerabilities so it can ensure best effectiveness of the chain.

Actions in cyber space should now be considered as genuine operations, and their design and conduct need to follow the same types of process as traditional military operations. They draw on C2 assets to ensure coherence and effectiveness of manoeuvres. Whilst they can be conducted independently following their own objectives, the advantages of cyber operations are often greater when they are combined with traditional operations such as assisting an in-depth air attack by masking it from radars more discretely than would be the case with jamming.

Offensive operations can also allow paralysis of the adversary to avoid or limit combat. This possibility is well illustrated by the theory well known in aviation circles of the American John A. Warden, who describes the enemy as a system of five rings.[4] The rings—fielded military, population, infrastructure, system essentials and leadership—can be attacked individually or collectively through cyber space. Additionally, through the use of influence operations on social networks, the population ring becomes the target of choice for acting indirectly against the leadership ring.

France considers that the military Offensive information battle (*Lutte information offensive*—LIO) broadens the palette of military options. It can be combined with or take the place of other military capabilities and contributes to acquiring and

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(4) WARDEN John, *Air Theory for the 21st century*, in SCHNEIDER Barry R. and GRINTER Lawrence E., *Battlefield of the Future, 21st Century Warfare Issues*, Air War College, Studies in National Security n° 3, p. 103-124 (www.airuniversity.af.edu/Portals/10/CSDS/Books/battlefield_future2.pdf).

retaining military superiority in the defence of our interests and preservation of our sovereignty. Its peculiarities generate constraints for its use, however. Its use must be controlled and involves political, legal and military risks. As with any weapon of war, LIO is subject to the principles and rules of international law, particularly humanitarian law regarding proportionality, distinction and discrimination, as well as to national laws and regulations. It is therefore only used in cases where the rules of engagement (ROE) are very restrictive, and any risk of compromise, abuse, collateral damage or fratricide must be avoided.

The development of military cyber defence advances hand-in-hand with new skills that are specific to cyber matters such as threat analysis or *Threat Intel*, a strategy for detection of attacks on IT, cyber patrolling and hunting on networks, digital forensic investigation, reverse engineering of codes, management of cyber crises, mass data analysis, the laws of armed conflict and those controlling the digital world. A cyber combatant is neither a specialist in IT, nor in communications nor intelligence nor even a social engineer or a pure 'soldier'. He is a combination of all of these, which means ever more focused training that is continuous, modular and alternating in partnership with the civilian academic and industrial world to ensure improved competence appropriate to the profession. Yet in addition to the knowledge required, there needs to be a mentality particular to work in cyber space. This means a preference for those born in the digital world—digital natives, as it were—with the minds of hackers (ethical ones, of course!) and a strong ability for self-learning, able to 'play' with their computers in order to meet the challenges with passion. Indeed, some among the self-taught are the best performers. Recruitment and retention of qualified personnel are essential to the performance of military cyber defence.

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The air and space, like other environments, benefit from what digitisation brings them, but they suffer equally from the vulnerabilities associated with the cyber environment. To control the major risks and counter the known threats it is essential to have a highly operational approach to cyber space and to establish a permanent cyber defence posture to defend our weapon and information systems. We also need to know how to seize the opportunities offered by cyber space within a strictly controlled framework in order to conduct offensive operations. Such operations might be conducted alone or combined with other forms of action since they bring a significant operational advantage to both strategic and tactical levels, which mean that balances of forces can be reversed and the adversary paralysed. The human remains very much at the centre of such an organisation because his capacity for adaptation, his reactivity and diversity of thought, together with his sense of commitment make the difference when facing up to the rapid developments now taking place in cyber space. ◆

Multi-Domain Operation (MDO): On Ward!

Olivier Jean-Louis

Project Coordinator (Joint & Multi-domain C2), Supreme Allied Commander Transformation (ACT), NATO.

We know that our purpose is a just and moral one, for we seek only peace with freedom and we can succeed in this great endeavour only if each and every one of us is willing to give the full measure of courage, sacrifice, work and vision, not in a divided effort but working together in pursuit of our common goal. (Dwight D. Eisenhower)

A complex and ever-changing environment yet to come

Over the last two decades of conflict adversaries have closely studied western countries at war through operation led by nations, coalition or international organisations like NATO,[1] European Union (EU) or United Nations (UN). The numerous operations (UNIFIL,[2] *Atalanta*,[3] KFOR,[4] ISAF,[5] *Enduring Freedom*,[6] NATO Traning Mission–Iraq,[7] *Unified Protector*,[8] and others) these countries have been

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Preliminary note: This product is designed to provide an independent opinion. It does not necessarily represent the opinions or policies of NATO and/or the Nations quoted in the article.

(1) At present, North Atlantic Treaty Organization has 29 members. In 1949, there were 12 founding members of the Alliance: Belgium, Canada, Denmark, France, Iceland, Italy, Luxembourg, Netherlands, Norway, Portugal, United Kingdom and United States. The other member countries are: Greece and Turkey (1952), Germany (1955), Spain (1982), Czech Republic, Hungary and Poland (1999), Bulgaria, Estonia, Latvia, Lithuania, Romania, Slovakia and Slovenia (2004), Albania and Croatia (2009), and Montenegro (2017).

(2) The United Nations Interim Force in Lebanon (UNIFIL) is a peacekeeping mission established on 19 March 1978 by UN Security Council Resolutions 425 and 426, to confirm Israeli withdrawal from Lebanon which Israel had invaded five days prior, restore international peace and security, and help the government of Lebanon restore its effective authority in the area.

(3) The EU Naval Force-Somalia (Operation *Atalanta*) was launched on 8 December 2008 and is conducted in accordance with UN Security Council's resolutions. The Operation has been extended until December 2020 and has the following objectives: 1-Protects vessels of the World Food Programme and other vulnerable shipping; 2-deters, prevents and represses piracy and armed robbery at sea; 3-monitors fishing activities off the coast of Somalia, and 4-Supports other EU missions and international organisations working to strengthen maritime security and capacity in the region.

(4) The Kosovo FORce (KFOR) is a NATO-led international peacekeeping force which is responsible for establishing a secure environment in Kosovo.

(5) The International Security Assistance Force (ISAF): was a NATO-led security mission in Afghanistan, established by the United Nations Security Council in December 2001 by Resolution 1386, as envisaged by the Bonn Agreement.

(6) Operation *Enduring Freedom* (OEF) refers to the U.S. led combat operation which supports the Global War on Terror (GWOT) active in Afghanistan, the Philippines, and parts of Africa. The operation was intended to bring stability to Afghanistan and to prevent the emergence of terrorist cells in the region.

(7) The NATO Training Mission-Iraq (NTM-I) was established in 2004 at the request of the Iraqi Interim Government under the provisions of UN Security Council Resolution 1546. NTM-I was not a combat mission but was a distinct mission, under the political control of NATO's North Atlantic Council.

(8) Operation *Unified Protector* was a NATO operation in 2011 enforcing UN Security Council resolutions 1970 and 1973 concerning the Libyan Civil War and adopted on 26 February and 17 March 2011, respectively.

involved in enabled their adversaries to know quite well their modus operandi and why it is successful applying operations concepts that emphasize joint and combined operations; technological dominance; global power projection; strategic, operational, and tactical manoeuvre; effective joint fires; sustainment at scale; and mission command initiative. Adversaries have analyzed, systems, capabilities, and tactics attempting to minimize their disadvantages in every domains.

At the same time, emerging technologies like artificial intelligence, machine learning, nanotechnology, robotics, and quantic computing, are profoundly anchored in the reasons why the characteristics of modern wars are fundamentally changing. These technologies are developed and their military applications become more and more well-defined. These evolutions have the potential to revolutionize battlefields unlike anything since the integration of aviation which began the era of combined arms warfare. Strategic competitors rely on these emerging technologies to develop capabilities to fight in all domains – land, air, sea, space and cyberspace. In this new realm great powers compete to achieve their strategic goal and the current military problem remains to maintain the ability to defeat multiple layers of stand-off in all domains in order to maintain the coherence of operations.

The NATO Strategic Foresight Analysis[9] (report published by ACT[10] in 2017) and the most recent Framework for Future Alliance Operations (FFAO, 2018) mention a number of commonly-accepted indicators of what the future might look like, noting that the environment is complex and ever-changing. The future will likely bring a wide range of new threats coming from emerging technology or from new, creative, and innovative tactics, techniques, procedures, capabilities, or doctrine. Without suffering the cost of research and development, hostile actors can capitalise on technological advancements and translate them into capabilities that engender threats to other nations. Examples of areas where technology could revolutionise warfare are subsurface and subterranean operations, swarm techniques, space based weapons, directed energy, autonomous systems and sensors, quantum computing, unmanned systems, electromagnetically launched projectiles, renewable energy, artificial intelligence, biotechnology and nanotechnology. Technology will also change the way information will

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(9) The SFA Report identifies trends that will shape the future strategic context and derive implications for the Alliance out to 2035 and beyond. It provides an iterative assessment of trends and their implications to understand and visualise the nature of the dynamic and complex security environment. The SFA is the initial phase of the ongoing Long-Term Military Transformation efforts at ACT and sets the intellectual foundation for a follow-on report, the Framework for Future Alliance Operations. The SFA Report examines the main trends of global change and the resultant defence and security implications for NATO, highlighting challenges as well as opportunities. It is structured along the following themes: political, human, technology, economics/resources and environment.

(10) Allied Command Transformation's mission is to contribute to preserving the peace, security and territorial integrity of Alliance member states by leading the warfare development of military structures, forces, capabilities and doctrines. The mission must enable NATO to meet its level of ambition and core missions.

From its inception in 2003, ACT demonstrated the importance placed by NATO Nations on the roles of transformation and development as continuous and essential drivers for change—drivers of change that will ensure the relevance of the Alliance in a rapidly evolving and complex global security environment. ACT is organized around four principal functions: Strategic thinking; Development of capabilities; Education, training and exercises; and, Co-operation and engagement. These functions are reflected in the composition of ACT which has its Headquarters in Norfolk, Virginia and three subordinate entities in Norway (Joint Warfare Centre), in Poland (Joint Force Training Centre) and in Portugal (Joint Analysis & Lessons Learned Centre).

be disseminated and will probably require changes in how military organisations are managed and structured, as well as how decision-making is conducted. Additionally the technical capacity to monitor actions, almost without geographical limitations, gives global audiences access to the gigantic information flow related to a conflict. Hence, the fight for creating perceptions becomes an essential part for future conflicts. Bottom line, it seems fair to conclude that the nature of war and conflicts will become even more complex and will change even more rapidly than it does nowadays.

One step further in effects based operations

Kinetic aspect will still remain where traditional kinetic effects are used to disable and destroy. However, arising abilities to act through new domains implies to change modus operandi. For instance, the cyber domain which is reasonably familiar now (although it is still maturing) is a critical enabler for capabilities in the kinetic fields. Command and Control of military forces, designed primarily to achieve kinetic effects, still needs to implement cyber and related new tools to achieve their objectives in the designated domains. At the same time, kinetic forces should guarantee coordinated and combined operations can take place with forces designed to primarily operate in the cyber domain. In this new framework the C2-approach may not need a drastic change, although it will necessitate some adjustments. These adjustments might include: process changes to take benefit from any capabilities provided by advanced technology, and generation of staff, tools and techniques to operate in all domain.

Prevailing in future operations means a joint force is able to accomplish assigned missions and affect the will of the adversary through a combination of multi domain effects. Multi-domain operations are not just operations led in one domain with the support of services from the others (e.g. an air campaign enhanced with support of assets and effects on the ground, at sea or in space and cyber). Multi-domain operations must provide the ability to generate offensive and defensive capabilities from all domains in order to create complex dilemmas for an adversary at a tempo that they can't respond to. One of the best examples for how multi-domain operations can solve current military problems is that of suppression of enemy air defences. In the multi domain operation concept, a joint force will have the ability to conduct that mission from platform on the ground, at sea, in air, space and cyber to independently generate effects in those domains to create more problem for the adversary.

C2 development: what's the next step?

This shift to multi-domain operations is going to take time as some facets still need to be thought through. As an example, one of the critical one is determining what a command structure under MDC2[11] will look like. Without a foundational level, the best ideas will just crumble the whole architecture. These foundations could include elements such as Multi-domain operations concepts, C2 and MDO experts, MDC2 tools.

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(11) MDC2: Multi domain command and control.

This updated framework of action will provide the joint force commander the ability to face new challenges. Knowing that separate operations centres will not serve the need for future wars, he will persistently need an appropriate cross-domain information sharing between air, land, maritime, space and cyberspace. To that aim, development of a Multi Domain Command and Control capabilities which will impeccably support analysis, fusion and sharing of information for the benefit of all domains of operation will be indispensable. To execute capabilities across all of the domains, command and control structure that can seamlessly exercise the appropriate kind of weaponry will be key. To get there, C2 system interfaces must evolved beyond their current capability and road-blocks to sharing must be removed. If one component wants to build a single global network linking Air, Sea, Land, Space and Cyberspace, it must first pursue further in sharing proprietary data and remove existing barriers. Once this new environment is firmly in place, then they can begin to build in multi-domain C2. At that juncture, when multi-domain C2 capabilities exist, multi-domain operations will become achievable.

In this new realm Artificial Intelligence (AI)[12] could also be fundamental to converging capabilities across all domains. An important implication for future military commanders will be the expected interaction with intelligent support systems that have the ability to explain themselves. Research is now being done to allow AI-applications to explain out-comes or decisions. Justifying one's decisions and explaining "why" is already important, and may in the future become even more important with the proliferation of AI-applications. Trust in the supporting system, either with human staff or a different level of AI-algorithms, is essential for a Commander. This will also have implications for the delegation of authority and assigning tasks during the command and control process. The technological opportunities will outpace the social acceptance of AI-based authority. Careful and closely monitored delegation of both tasks and authority with future commanders is expected to be required.

Human capital: the centrepiece

Nevertheless in human-machine teaming, human factor will hold a central position. Joint forces will necessitate adequate training to be able to think outside the box for doing MDC2 using personnel from all branches. Services have to work to build a C2 workforce (officers and enlisted) to engrain the expertise and proficiency at a career level rather than see personnel cycle in and out on short term rotations. Combination of effects will imply to comprehend all domain characteristics and to acquire the ability to decide and act adequately. For instance, real time situational awareness and subsequent responses will probably play a crucial role when carrying out operations in space, cyberspace or air. Hence, any movement towards multi domain

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(12) "AI will profoundly change military organizational planning and coordination. The implementation of AI in the battlefield would mean advancing into a "hyper war" where current decision-making processes could be disrupted by the enormous speed of development and the ability of machine learning by AI applications. It is, therefore, key for the Alliance to implement AI applications into their militaries' planning, operations, and coordination". KARLIJN Jans, *NATO Needs to Get Smarter About AI*, *Atlantic Council*, July 10, 2018 (www.atlanticcouncil.org/).

must be with change in how we develop our personnel. If an MDC2 career concept took further form, for it to succeed it must ensure personnel are truly joint-trained and joint-minded, while retaining the expertise in their component capabilities. This requires exposure to the full spectrum of joint capabilities in both educational and operational settings, and experiences in the future MDC2 environment.

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To tackle the lack of "Jointness" of Air Forces the TSSG[13] has proposed the creation of specific career path devoted to developing operational level staff to not only fight jointly but to understand how to employ the spectrum of Joint capabilities across a multi-domain environment. Similarly, the US Air force will work to build a C2 workforce cadre of officers to engrain the expertise and proficiency at a career level rather than see personnel cycle in and out on short-terms rotations. While an interesting concept, this idea is contrary to what some authorities espouse. That's, a future operational level staff (Joint) must be comprises of expert in each of the single service capabilities, rather it takes years of tactical/tactical-operational level experience to develop. So, what can be done to creat more highly capable Joint officers while keeping a balance with their parent Service's core competencies?

To improve its Jointness, and to improve the effective use of air power in a Joint environment as the first step towards multi-domain operations, threatened nations must be able to address two questions:

1. How do they train air component commanders to plan air campaigns and to plan the Air power contribution to a joint campaign?

2. What needs to be done to tailor any existing training/exercises to better prepare commanders to plan for, and exercise, Air power in Joint campaigns?

These inquiries and wished-for way ahead seem to be relevant for all other services. A Multi-domain campaign will only become achievable once joint forces are effectively trained for multi-domain operations and adequately equipped with multi-domain C2 capabilities. In addition to these MDO experts and MDC2 tools, a foundational level including elements such as Multi-domain operations concepts will be key.

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(13) Comprising US, UK and France Air forces, the Tri-lateral Strategic Steering Group has investigated the concept of multi-domain warfare. According to their studies future adversaries will blend conventional, asymmetric and hybrid capabilities across each of the traditional physical domain (Air, Land and Space) plus Cyber and Space, they postulate that a more comprehensive approach to dealing with this security is needed to operate in this type of multi-domain environment. Furthermore they assert that not only is this multi-domain operations concept a potential for the future but that element of it already exist with the US, British and French national perspectives on warfare today.

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Five Myths About the Anti-Access/Area Denial Threat

Corentin Brustlein

Director of the Security Studies Center, French Institute of International Relations (Ifri).

In just a few years, concerns about "anti-access" and "area denial" capabilities (A2/AD) have erupted into French-speaking strategic debate. The concept of "anti-access" strategy first appeared in the United States in the decade following Operation *Desert Storm* in Iraq in 1991 and was soon bracketed together with that of area denial. Whereas an anti-access strategy aims at constraining the ability of projected forces to penetrate a theatre of operations, area denial aims at limiting the freedom of action of such forces once they are present in the theatre. Although the two issues can be distinguished in conceptual, capability or operational terms, both come down to a single concern: states in growing numbers are currently looking to constrain the freedom of action of expeditionary powers in distant theatres.

Over the past two decades the development and diffusion of air-, sea-, ground- and space-based interdiction capabilities have given form to this strategy. Surface-to-air and anti-ship systems, underwater mines, surface-to-surface cruise and ballistic missiles, electronic warfare capabilities and other anti-satellite assets are part of the options available to those who wish to hinder expeditionary powers. In that sense, the strengthening of A2/AD capabilities is a reflection of the progress that miniaturisation of electronics has led in the field of conventional weaponry, in turn opening up an era in which major powers have lost the monopoly of long-range, precision-guided, conventional strike capabilities.

The French 2017 *Defense and National Security Strategic Review* and the military programming law covering the years 2019-2025 both identified A2/AD as a threat to France, and the number of studies dedicated to this problem has increased significantly in recent years in parallel with renewed strategic competition between the major powers in the Baltic, the South China Sea and the Eastern Mediterranean.[1] Despite this growing attention, a number of myths and misunderstandings of the problem posed by A2/AD have remained. This article looks at five of those myths in order to encourage even deeper debate about a threat that will weigh upon our defence strategy for a long time to come.

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(1) *Revue stratégique de défense et de sécurité nationale*, 2017 (www.defense.gouv.fr/dgris/); Report annexed to law No. 2018-607, the military programme for the years 2019 to 2025, 13 July 2018 (www2.assemblee-nationale.fr/).

A2/AD is yet another American obsession which should not worry France

The US strategic community produces numerous concepts whose pertinence to France sometimes appears somewhat relative. Several factors can explain this tendency. First, the US strategic community relies on permanent renewal of concepts while the French system is notable for its continuity in principles over years. Second, many US concepts are both tainted by a highly technology-centred strategic culture and regularly used by Washington as a medium of influence over its allies—within NATO in particular, where US military concepts often lead to the identification of new requirements that only the acquisition of US equipment can meet. For those reasons they are often met with scepticism by the French defence community. Third, and finally, the problems of a military superpower permanently acting on a global scale unsurprisingly differ from those facing France, whose responsibilities and assets are far more limited. The increasing centrality of A2/AD in transatlantic discussion is a perfect reflection of some of these tendencies. And yet it would be wrong to infer from all of this that the increasing dissemination of interdiction capabilities should not concern France or Europe.

While the threat posed by A2/AD appeared as a US-focused preoccupation, it should matter to all military powers concerned by their future external freedom of military action. Numerous countries in the world—most, in fact—are not expeditionary military powers and focus their defence strategies towards the protection of their own territory. Conversely, a limited number of states have chosen to develop and maintain capabilities for intervention in distant theatres of operation. France has multiple interests abroad (such as allies and friends, nationals living overseas, or strategic supply routes) and thus, like the United States, United Kingdom, Russia and, more recently, China, is one of those states which have invested heavily in order to be in a position to deploy military forces overseas independently and on short notice, even in contested environments[2]. It is one of the rare European countries that have the ability to conduct initial entry operations and as a consequence would see its security severely degraded if stronger sea and air interdiction capabilities led to a sharp increase in the risks and costs of its military actions. France has to be concerned by the growth of A2/AD capabilities, all the more so since its force structure and numbers have been pared down time and time again to the minimum, meaning that they can no longer respond to the challenges posed by this type of threat by relying on superior numbers.

A2/AD capabilities can create impenetrable areas

An A2/AD strategy relies on a number of weapon systems developed since the 1980s, whose increasing range and accuracy offer an ability to create havoc over areas of unprecedented dimensions. Yet how is it possible to assess the extent of the threat that such systems pose to expeditionary forces? The default method has been to assume perfect systems effectiveness and to estimate the size of the threat envelope by taking

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(2) Corentin Brustlein, "Entry Operations and the Future of Strategic Autonomy", Ifri, Focus stratégique, no. 70bis, 2017.

the maximum theoretical range of their missiles (surface-to-air, anti-ship or surface-to-surface) as the basic reference datum. Measured in that way, the area covered by the Russian S-400 surface-to-air system would extend up to 400 km (250 miles) from the borders of any possessor country—in other terms, to the maximum theoretical range of a missile that could be fired by that system. Once the same logic is applied to all types of anti-ship and surface-to-surface missiles, extremely vast areas appear impenetrable, an impression enhanced by the way chosen to represent these areas graphically in the form of range circles with clearly-defined limits.

This representation of the A2/AD threat distorts perceptions in multiple ways. First of all, in real operational conditions, a missile of any type will only rarely be in a position to strike a target at its maximum range[3], and in any case cannot be deployed very close to a border without being itself exposed to counter-strikes. Moreover, although reconnaissance and surveillance capabilities have benefitted from major advances over the past thirty years they still do not render the maritime and air approaches to any territory transparent. Mobile targets remain difficult to track in real time, and radar beams are constrained by geography and can be countered by electronic warfare assets.

Consequently, even if deploying A2/AD systems allows the creation of contested areas, the latter are not homogeneous in space or time, nor are they impenetrable. The threat level can indeed be very high in the immediate proximity of an adversary's territory, but it will decrease with distance and will remain limited by the geography of the theatre and the frequently constrained availability of costly, and therefore few in number, long-range systems.

Entering an area protected by A2/AD assets is not impossible in absolute terms, but implies taking risks, which will be more or less acceptable depending on the circumstances. Whether or not an expeditionary force can penetrate an A2/AD defensive posture is therefore a function not only of the geography and balance of forces but also, and perhaps especially, of the importance of the stakes for each both the defender and the attacker. Certainly even a weak anti-access posture could contribute to discourage political decision-makers from initiating operations if the interests are deemed too limited. On the other hand, were the major—even more so the vital—interests of France to be threatened, the stakes involved would justify accepting the risks and losses that go together with operations in heavily contested environments, whether the task is the suppression of enemy air defences, the destruction of adversary's long-range reconnaissance and strike capabilities or, in extreme circumstances, to conduct a nuclear strike.

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(3) There are many reasons for that fact: it is very difficult to detect, identify and track targets at long range, and the longer the range at which a target is engaged, the longer the time it has to react, and the more options it possesses—such as moving out of the area exposed to the defender's missiles.

**A2/AD is a radical departure from the art of warfare /
A2/AD has always existed**

Two extremes need to be avoided when studying the consequences of the emergence of A2/AD strategies and capabilities: one is to see it as a fundamental break with the art of warfare, the other is to deny A2/AD any form of novelty and importance. Either type of extreme judgment would be dangerous: one would lead us to mobilise too much attention and too many resources in responding to a challenge that represents only a part of the range of future threats; the other would lead us to neglect a structural trend likely to have a considerable effect on our external freedom of action.

It is quite clear that there are aspects of continuity between the A2/AD threat and past military experiences, and in the long term sources of continuity probably outweigh the sources of novelty. Some environments have always been more contested than others—ground terrain to start with. Does that mean A2/AD is simply one more step in the never-ending struggle between the sword and the shield and, more generally, the offense-defense balance? Whilst the metaphor illuminates a part of the problem, it does not take into account the non-technological dimensions of the problem and hence its true extent. A2/AD has become a concern shared by both France and the United States not only because technological developments could open up again a new era marked by the superiority of the defensive form of warfare, but most importantly because the combined effects of the wider dissemination of advanced weapon systems and a change in the balance of power on a global scale could affect more than just our capabilities at the tactical level: this new reality will weigh also on the strategic level, on our decisions to resort to armed force to protect interests abroad. After thirty years of foreign military interventions that were only so frequent because of the technological and operational superiority the West enjoyed over its adversaries, we cannot assume that even a marginal loss in our external freedom of action would be without incidence on how we conduct our foreign policy and protect our interests.

Conversely, the emergence of A2/AD is not revolutionary in itself. Beyond even ground warfare, having one's freedom of action challenged is not new and has clearly been the norm over the past centuries. The ever-reducing number of symmetrical conventional conflicts from the mid-1970s, and the weakness of the adversaries against which Western expeditionary powers operated from 1990 to date, distorted perceptions by allowing pundits to believe that it was normal to use force without any risk of significant losses. The reality is that, on the scale of past centuries, the post-Cold War era constitutes an exceptional period during which the external freedom of action of a small number of states was both undisputed and hard to challenge. A2/AD is therefore less a revolution in the art of warfare than a return to a norm we had forgotten. This is not without consequences when preparing for the future: while modern capabilities pose, due to their range and precision, a number of hitherto unseen challenges, some militaries are not starting from scratch to counter them and as a matter of fact the generation of officers who currently hold the most senior positions began their careers by preparing for major conventional war in Central Europe. Innovation to counter A2/AD implies designing systems, organisations and operational concepts that

will allow us to stay ahead of the adversary in both current and future technological and socio-political conditions yet at the same time re-learning lessons from the past. Renewed great power rivalry and the wide availability of precision-strike technologies should encourage us to re-examine loss rates and the dynamics of high-intensity combat during the wars in Vietnam and the Falklands, as well as those between Israel and its neighbours.

Anti access is a natural monopoly of our potential adversaries

The countries most often cited as incarnating the threat posed by A2/AD capabilities and strategy are China, Russia and, to a lesser extent, Iran and North Korea. Yet are the United States and its NATO allies really incapable of setting up a similar strategy of regional interdiction? It is a fact that the capabilities associated with A2/AD strategies have been developed in response to the West's highly visible superiority in the air and naval environments so feared in Moscow in the second half of the Cold War. Setting aside the peculiarities of each conflict, the 1991 Gulf War and air operations in the Balkans in 1995 (*Deliberate Force*) and 1999 (*Allied Force*) and during operation *Enduring Freedom* in Afghanistan in 2001 sent a very clear overall message throughout the world: if US air superiority is not challenged, defeat is certain. Since strategy is a dialectic, any demonstration of force also serves as a step towards effective an adaptation by the adversary: whereas *Desert Storm* can be seen as a reminder of the need to impede the large-scale deployment of a coalition into a theatre of operation, *Allied Force* highlighted the existence of options which can reduce the effectiveness of air power thought the use of basic surface-to-air systems and clever tactics. In short, it is the concentration of military power and of expeditionary capabilities in the hands of the West that explains the growing interest for A2/AD from the 1990s. This same historical legacy led Western forces to look for options to preserve their own external freedom of action instead of investing in the type of defensive capabilities that would be the most needed to implement an A2/AD strategy.

The current change in the balance of forces at both the global and regional scales ought to lead us to reconsider these choices and to reinvest in defensive postures neglected for so long in our capability development plans. Doing so appears doubly rewarding: the interest shown by Russia and China in strategies of territorial *fait accompli* relies on their ability to generate a favourable balance of force at a regional level, particularly close to their own national territory. Strengthening A2/AD capabilities in countries closest to Russian and Chinese territories—those most directly exposed—would improve their defensive capacity, thus increasing the costs of direct aggression. Furthermore, hand-in-hand with Russian strategic resurgence and increasing Chinese power is a strengthening of their expeditionary capabilities, as demonstrated by Moscow in Syria and by Beijing through its increasing naval presence in the Indian Ocean and the Mediterranean Sea. Renewed effort towards development of Western interdiction capabilities would offer a broader range of possibilities to constrain Moscow and Beijing's external freedom of action. In short, there is no mystery surrounding the assumed effectiveness of Russian and Chinese interdiction strategies: they are the product of long-established advantages associated with the defensive form

of warfare and of substantial, targeted investments in niche capability areas such as surface-to-air and anti-ship missiles, deep strike capability, long-range detection and surveillance assets and electronic warfare. Reversing the trend in order to constrain these countries' freedom of action is perfectly doable; it requires combining targeted investment, strategic adaptation and the preservation of non-proliferation norms aimed at limiting the availability of advanced weapon systems.

Europe has no role to play to counter A2/AD

Because of the influence of the United States and of its historical position opposing Russia, it is not surprising that NATO has seized the issue of A2/AD since 2014 and the annexation of Crimea. The thinking on that matter has largely been led by the United States and remained virtually absent from any European debate on defence. The situation can be explained in several ways, European military operations being focused on the lower end of the conflict spectrum either by European reluctance or through fear of duplication with NATO. And yet several factors really ought to incite Europe to grasp the challenge posed by A2/AD capabilities.

First, weapon systems making A2/AD strategies possible (surface-to-air defences, surface-to-surface and anti-ship missiles, etc.) are not limited to just those countries already mentioned. The trend toward their diffusion is far wider, not only because numerous countries wish to be protected against Western militaries but also because the general improvement in the range of modern weapon systems *de facto* offers those who possess them a significant interdiction capability. The direct consequence is that the areas neighbouring Europe will become militarily an increasingly disputed environment. Secondly, Europeans still depend hugely on the United States to preserve their own capacity for action in these increasingly contested areas. European forces are either entirely lacking or insufficiently equipped in capabilities such as deep strike, suppression of enemy air defences, information superiority at the theatre level and space surveillance. Without having to consider a severing of the transatlantic link that would lead to the disappearance of the Alliance, the growing tension between China and the United States could prevent the latter from being as able to support the Europeans as it has been in the recent past. If France, the most capable and independent expeditionary power in Europe, still has to rely upon US intelligence and logistical support when conducting initial entry operations, what will be left of the European ability to operate effectively in the absence of US leadership and forces? It is therefore crucial that Europe grasp the issue of entry operations in contested environments by making good use of the new instruments currently being put in place that are aimed at supporting the growing European ambitions regarding defence: the European Defence Fund, Permanent Structured Cooperation, Coordinated Annual Review on Defence and the European Intervention Initiative all offer opportunities for Europeans to better adapt to the problem posed by A2/AD, and in doing so contribute to the emergence of European strategic autonomy. ◆

Air Surface Integration,
the Basis for Air-Ground Combat

Thierry SUTTER

| Colonel, Air Force Staff.

*If you can knit up the power of the Army on the land and the power of the air in the sky
then nothing will stand against you and you will never lose a battle* (Field Marshal Bernard Montgomery).

Air Surface Integration (ASI) appeared about ten years ago in the framework of joint operations and since 2017 has had its own doctrine to define its boundaries: ASI is the collection of processes set in motion by several components during the planning and conduct of operations that combine the operational activities of air, ground and/or maritime assets with aim of fully exploiting the complementarity between components thus allowing accumulation and conjugation of the effects produced by each in order to improve the effectiveness of manoeuvres at the tactical level and the overall efficiency of the joint force.[1] ASI includes Air Land Integration (ALI) and Air Maritime Integration (AMI).

The ASI concept is not really new, since it goes back to the beginnings of exploitation of airspace in time of war and the increasing presence of the air component as the third armed force. Despite that, it is still too little used in operations, largely through lack of knowledge, and is even considered by some to be too novel. A few significant events illustrate its origins:

• The success of Operation *Overlord* in June 1944, with 11,000 air sorties on D-Day in Close Air Support (CAS) of ground forces and Air Interdiction (AI) on the rear lines to allow consolidation of the bridgehead by slowing down the arrival of German forces, was in part the consequence of lessons learned since 1943: *Army and Air Force commanders must work in closest consultation throughout all stages of the formulation and execution of the plan, to ensure that the land and air operations interact to the best advantage* (General Ira Eaker, United States Army Air Force, 1943).

• With the experience acquired in post-Second World War conflicts and a need to reinforce coordination of joint force action, in 1956 the Air Force began to create specialised units, the air parachute commandos (*Commandos parachutistes de l'air*— CPA), to facilitate the interface between air and ground during firings and intelligence action.

The Cold War environment pushed this concept onto a back burner for several decades. Today's renewed interest in ASI and its incorporation into doctrine is above all the result of feedback from operations conducted in a very changed environment:

• In their feedback from Operation *Anaconda* in Afghanistan, US armed forces reported from 2002 that insufficient coordination between land and air components posed a problem, essentially because of the lack of frequent and formalised contact between specialists in the two components' staffs.[2]

• After operations in Iraq (Operation *Telic*) and Afghanistan, the British armed forces took note of a loss of capability to conduct integrated air/ground operations, and that led to the Coningham-Keyes project, aimed at developing ground-air-sea interoperability through the introduction of tools, procedures and training.[3]

• In Afghanistan, French Special Forces always favoured a high level of ASI to achieve the effects required of their combat or intelligence gathering activity, and to optimise use of the available air assets. This is a particular reason why the Special Operations Command is today at the forefront of experimentation and of the progress that is being achieved in the field, from both tactical and technical points of view.

• Closer to home, during Operation *Inherent Resolve* (OIR) in the Levant, coalition forces fighting Daesh took fully into account the feedback from past operations and set up an ASI chain which allowed efficient management of available assets, including aviation, artillery and Special Forces.

Several things arise from recent operational experience. The first is that no operation today can be conducted without use of the air. The second, that the air is a uniform and continuous, but also complex space that offers the flexibility that favours a combination of military activities. The third is that the air is the sole space that can guarantee reactivity for action in depth. That said, it needs skilled management in both planning and conduct of operations by true experts in the matter.

What Does Air Surface Integration Actually Cover?

Feedback from the preceding examples shows that in order to optimise employment of effectors and captors and to fully exploit the complementarity between components a joint operation cannot be designed today without enhanced integration of firing and intelligence activity, and of the mobility of the different components, in both planning and conduct phases. This is supported by a number of determining factors.

First of all, ASI has to **respond to changing threats and the current operational environment** (asymmetric operations, hybrid war, anti access and action in depth, for example) by controlling the entire combat space. For the air, it must guarantee the air

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(2) Headquarters, United States Air Force, *Operation Anaconda, An Airpower Perspective*, 7 February 2005 (https://apps.dtic.mil/dtic/tr/fulltext/u2/a495248.pdf).
(3) See in particular Wing Commander S.P. Kilvington, *Delivering effective Air-Land Integration (ALI) in the next war: what enduring lessons can UK Defence draw from historical and contemporary operations to generate and maintain an efficient, joint ALI capability that is fit for future conflict?*, 2003 (www.raf.mod.uk/).

forces the capacity to conduct all of their missions including those that need interaction with ground forces (the changing proportion of missions between CAS and AI, deliberate and dynamic, and control of fires).[4] Reactivity and the ability to concentrate action in space and time, dimensions in which the combination of capabilities of the air forces with those of ground forces is often decisive, must permit coverage of large operational spaces while ensuring management of considerable overlapping of forces on the ground, avoiding counter-productive action and fratricide and being able to respond to transient threats.

Then, it has to **take into account new capabilities** (drones, missiles), **the multi-role nature of new aircraft** (like Rafale) a**nd new equipment**, which undeniably improve effects. In particular it means preparing for the arrival of the next generation, the Future combat air system (FCAS, *Système de combat aérien du futur*—SCAF). Modern multi-role aircraft mean that a succession of different tasks can be fulfilled during a single mission as a function of real-time need, for example, a sequence of CAS, AI, offensive counter-air, show of force and ISR missions.[5] The same goes for platforms conducting ELINT/IMINT,[6] airborne C2,[7] electronic warfare or transport, which are increasingly multi-mission. The most recent equipment also allows sharing of a common tactical picture, easing exchanges between the components as well as between airborne elements and the ground segment. This includes laser designation pods for Non Traditional ISR (NTISR)[8] tasks, the real-time retransmission of video data to forces on the ground, the evolution of information and communication systems in general and the wider use of tactical data links in particular. They also augment the effects brought to bear by the air component in asymmetrical operations: adaptability and accuracy of mission equipment and airborne sensors, improvement in high-altitude drops of personnel or materiel, and improvement in platforms and their persistence, including armed drones, C3ISTAR,[9] ALSR,[10] and C-160G/CUGE.[11]

Finally it concerns the **essential optimisation of C2 and air and ground segments to increase their effects**. Optimisation is imperative for greater effectiveness of assets that today have better performance and are more diversified (missiles and drones), but are also fewer in number and operating in more complex intervention frameworks. It also needs to be applied to C2 and working practices in order to achieve flexible processes and to guarantee the freedom of action of the players involved. There is a real need for tools to aid decision-making that can absorb the multiplicity of information, merge it and ensure its continuous, secure transmission to the deciding authorities.

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(4) Standard NATO terms to describe missions. CAS=Close Air Support; AI=Air Interdiction.

(5) Intelligence, Surveillance and Reconnaissance.

(6) Intelligence from electromagnetic (ELINT) and imagery (IMINT) sources.

(7) Command and Control.

(8) These include 'unconventional' ISR assets, and cover capabilities fitted to some aircraft of the special operations command.

(9) Command, Control, Communications, Intelligence, Surveillance, Target Acquisition and Reconnaissance.

(10) *Avion léger de surveillance et reconnaissance* (light surveillance and reconnaissance aircraft).

(11) *Charge utile de guerre électronique* (Live EW load – the future C-160 system to replace the Transall).

ASI therefore responds to the double aim of overall conceptualisation of manoeuvre and achievement of more rational use of available airborne effectors to reach the objectives, be they strategic, operational or tactical. If on first sight this appears to relate mainly to opening fire, it concerns intelligence and mobility action just as much. Since its end state is the effectiveness of the joint force and the guarantee of its unity of action, it clearly goes beyond the limited vision of an air-ground bubble that constrains the air component to a simple support role.

Some Fundamental Principles

ASI is an important part of an overall approach that stimulates synergy between effectors and exploits the complementarities between the components to the benefit of the manoeuvre, with the desired military effects top of its priorities, of course. It requires dialogue between the components and above all mutual knowledge and confidence among the players. Whilst it is at the tactical level that it produces the most convincing results, it does not only apply there: indeed, it is applicable across all domains of operations. Moreover, it is essential to develop technical and organisational interoperability and joint processes.

Technically it relies on all components' synchronised and coordinated planning and conduct of operations. Hence the aim is to optimise the contribution of air and surface assets (including artillery and missiles) by better understanding between the players involved so that air manoeuvre can play its full part in the overall joint manoeuvre. This will require an integrated tactical approach and instilling an 'ASI state of mind' based on:

– Joint operational processes for planning and execution to optimise the use of the capabilities and effects of the players and to identify new modes of action hitherto little considered because of systematic resort to organic assets to produce the desired effects in the right place and at the right time.

– Synchronisation of processes for the conduct of the different forces to adapt their tactical manoeuvres dynamically when the situation demands.

– A shared tactical picture, especially when live firing in a situation where force units overlap each other. Joint, reactive prioritisation is needed to ensure correct understanding of the need. To this end, digitisation of the battle space is fundamental, as are tactical data links.

ASI should be based upon a recognised community of experts in the third dimension that is integrated into the operational structure via a command chain appropriate to each theatre that is able, for example, to set up links from the Combined Air Operations Centre (CAOC) to the Joint Tactical Air Controller (JTAC) on the ground.

These fundamental principles, whilst already essential to current operations, will have to be fully taken into account in developing the future capabilities of FCAS,

Scorpion[12] and the joint fire support project (*Appui feux interarmées*—AFIA).[13] Though especially adapted to military operations, the principles are transferable to other environments, notably civil and other security forces.

Some Challenges to Overcome

Although coherent with the current operational and technological environment, ASI still has a number of hurdles to be overcome before it can be adopted universally.

The principal hurdle is **adaptation of current C2 structures**. OIR coalition forces in the Levant today have adopted a joint C2 organisation close to the Joint Battlespace Management (JBM)[14] concept, which favours choosing the most effective effector to reach a target. Nevertheless this principle is not yet in general use within the French forces operating the Sahel other than the Special Forces, which already have ASI experts in their task force command structures. Recent conflicts in the Levant and in Ukraine have show the importance of managing effectors much more efficiently when faced with anti access situations which affect all components, or with hybrid war environments where the solution lies in part in the reactivity in transferring effort from one effector to another. ASI suits these contexts well since, apart from facilitating the coordination of effectors for much greater tactical effectiveness, it optimises the choice of principal effector right from the planning phase. On the other hand it is primordial that each component be led from within and that it has its own authority for action in order to optimise the effect of the manoeuvre delegated to it. This also implies that the command responsibilities of each component should be backed up by higher-level assurance that its efforts are integrated to the benefit of the joint manoeuvre right down to the lowest tactical level. That in turn requires the presence of experts from each component in all levels of the C2 structure if there is to be true ASI capability. The experience of the Air Force in the sky makes it the natural choice for the integrator of effects coming from the third dimension.

The second of the challenges is **changing the culture of the entire operational chain**, which is still dominated by organic thinking. History shows that the latter acts as a brake on adoption of ASI. Because of that, it seems essential that personnel be subjected to the culture change from the very first cycle of their training so that they think in terms of overall effects, rather than tactical or local ones—an ASI state of mind needs to be inculcated from the start. Conscious of this necessary change, the Air Force has committed to instilling this culture in its initial officer training schools and throughout officers' careers.

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(12) *Scorpion*: *Synergie du COntact Renforcé par la Polyvalence et l'InfovalorisatiON* ([approximately] Contact synergy reinforced by multi-tasking and improved quality of information), a programme to create a flexible tactical combat system for all current and future operational missions of the Army.

(13) Future replacement for the Army's current *Atlas* (*Automatisation des tirs et liaisons de l'artillerie sol/sol*—automation of artillery ground-ground fires and liaisons) system.

(14) The Joint Battlespace Management concept looks for better added value in the use of all the assets committed, together with their coherent, efficient and realistic integration from the very start of operational planning.

The third challenge is the creation and maintenance of **a pool of real experts in the field**. This is not only to guarantee expertise in the C2 structures, but also among the engaged troops. This is already the case in fire support, with advanced tactical controllers and the JTAC, but is less so in other segments of ASI, such as mobility and intelligence. Currently, only Special Forces can guarantee the permanent presence of such expertise in the manner of the US forces' Combat Control Teams. Whilst air Special Forces already have specific ASI training, with regard to the wider need a bigger reservoir of qualified, trained and updated specialists should be generated. For that, we must have qualifying training that is performed within the centres of xpertise, rather in the way that the Air support training centre (*Centre de formation à l'appui aérien*—CFAA) does for JTACs. Again, with its expertise in the domain, the Air Force seems the right choice for ensuring appropriate training.

The last challenge is not the least: we must **possess equipment optimised for ASI**. Ensuring high-performance ASI requires near-real time dialogue between the various players on the ground and in the air, itself quite constrained by discrimination and security needs. In turn, this implies having a service that can optimise airborne effectors and captors, and can optimise in near-real time the benefits of each of the components in a joint force operation, from the tactical to the strategic level, and especially in a highly contested environment. In the end, it is a matter of offering the command a reactive and permanent system that can handle the multiplicity of data.

Connectivity is the cornerstone of ASI, and yet it is too limited today. Its job is to facilitate the collection and merging of databases (from ground, air or space units, cartography, altimetry and so on), and to update all information in near-real time (friendly and enemy positions, data from captors) in order to maintain an updated plot and guarantee the link between the information collected and the communication systems for broadcast to the community. Technically this requires high performance sensors, standardisation, security, permanence and fluidity in the data exchanged between information systems as well as almost direct transmission from source to receiver. Furthermore, although national autonomy is sometimes considered a measure of security, a system verging on the autocratic is unthinkable today and interoperability with our allies remains essential, at the very least by intermediary technical bridges. Put simply, that means exchanging information and data between domains, each having its own codes, standards, logic, technology, procedures and restrictions in a joint or multinational operational context—which underlines the complexity of the challenge. It will also be necessary to ensure interoperability between different generations of materiel in order not to create a two-speed ASI. The building blocks already exist to ensure minimum capability yet the greater amount has yet to be developed in partnership with the university and industrial worlds. The declared openness of the Ministry for the armed forces—and in particular the special operations command and the Air Force— with regard to innovation is a great advantage in constructing arrangements optimised for ASI and for preparing for the future. Artificial intelligence, Big Data and enhanced reality are promising areas of technology. The development of mixed structures dedicated to ASI on the pattern of the operational laboratory for research into the air-ground interface (*Laboratoire opérationnel de recherche sur l'interface AIR-SOL*—

LORIAS) in Orléans,[15] which combines university, industrial and operational worlds, is a significant advance in specialised R&D, itself a measure of recognition of the need.

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Air Surface Integration is the result of feedback from experience and is perfectly adapted to current types of conflict. It enables enhancement of effects from the components of a force, optimising the overall manoeuvre. Its wider application calls for better appreciation now of its important role in the current operational environment, for above all it represents a major pillar of projects like SCORPION, FCAS and AFIA. With its experience in the third dimension, the Air Force has a major role to play as the integrator of effects. ◆

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(15) A digital 'design house' that discovers promotes and guides creators of innovative companies.

Transport Aircraft and Helicopters at the Centre of Operations:
Transformation and Adaptation of Air Force Projection Capabilities

Nathalie Picot and Christophe Piubeni

| Lieutenant Colonels, Plans office of the Air Staff (EMAA).

In words attributed to Winston Churchill, war is a transport operation—he who transports best will win. Whether overland as when, in his Russian campaign, Napoleon led over 650,000 men to the gates of Moscow in 1812, at sea as at Midway, where no fewer than seven aircraft carriers went into battle several thousand miles from their home ports in 1942 or by air to resupply and defend Na San, in Indochina, at the end of 1952, possessing the capability to project greater force and power has tipped the balance of many a campaign. Land and sea transport allow large volumes of material and men to be moved, but slowly: projection by air is the fastest method and is able to overcome numerous risks and constraints. This capability now dictates the initial size of any military engagement into a theatre of operation—its reactivity, in large measure, its durability and resilience, too. Projection by air is therefore fundamental for the forces.

Originally, transport aircraft and helicopters were used in the main for force projection missions—for positioning troops and materiel on the ground—and only later became essential elements for power projection. Today they are used to bring firepower by air at all times and to all places in hitherto unexpected ways, even in the most challenging of environments. The Air Force has developed its concepts of use of its projection assets in the face of today's ever-wider range of commitments regarding mobility and support, and has acquired multi-role equipment. The progressive renewal of these capabilities after 2025 is a major challenge for the French forces in an aggressive strategic environment and at a time of budgetary constraint.

The perpetual swing between force and power

Projection is a highly particular art of war, which remains the prerogative of the great powers. It is essential for offensive warfare, which Clausewitz regarded as far more difficult to conduct than defensive warfare since it requires assets to be transported onto enemy territory far from our rear bases, which in turn stretches out the force considerably. On the other hand, projection arouses uncertainty in the enemy,

preventing him from organising and concentrating his forces either for fear of their destruction or because of the risk of not defending the right area.

This capability has two distinct parts: one is the progressive projection of the force, the phase in which troops are deployed and materiel brought forward, the other the projection of power, which leads to concentration of fire or a particular combat action.[1] For projection, the Air Force has been continually innovating to be in a position to deploy the mass and firepower necessary for victory.

The conflict in Indochina was effectively the birthplace of French tactical transport aviation. There, it conducted numerous missions in support of forces under direct enemy fire, including replenishment, parachute drops and immediate redeployment of forces. Following the success in 1952 of the battle of Na San, an outpost based around an airstrip, there was that at Diên Biên Phu. Fully aware of the vital importance of that airborne umbilical cord, General Giap plastered the runway to make it unusable, thus condemning the transport aircraft to perilous air-drop missions under the fire of ground-air artillery hidden in the hills surrounding the hollow in the landscape. Between February and May 1954 over 50 per cent of air missions over the hollow were conducted by transport aircraft, with an average of 50 sorties daily resupplying the remote camp. Despite foul weather, very basic navigation instruments and old, hard to maintain materiel, the Air Force improvised and innovated unceasingly throughout the conflict in order to complete its missions.

At the same time, the helicopter was first used close to combat for casualty evacuation and observation, in particular the Hiller 360 in 1950. The see-saw between projection of force and of power first appeared for the helicopter in Algeria. By the end of the conflict, more than 350 helicopters had been engaged in all types of mission—transport, observation, airborne command post—and the first *Mammouth* armed helicopters had been seen.

Because of their extent, ruggedness of conditions and the level of engagement, operations in both Indochina and Algeria became the birthplaces of robust and multi-role projection assets that could land on basic landing strips. Of these assets, the Air Force ordered 208 Noratlas, which was the pioneer of tactical air transport with its high wings and rear-opening hold.

The nineteen seventies and eighties were the years of the Franco-German Transall C-160. Twice the weight of the Noratlas, it could carry twice the payload twice as far and yet could still land on rudimentary clay airstrips. It shone especially in the operation on Kolwezi in 1978 and in its use as an airborne command post in Operation *Lamentin* in Mauritania against the *Polisario Front*.

After that period, the range of modes of action developed by the transport and helicopter fleets of the Air Force was fully mature, covering action in depth, casualty

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(1) BRUSTLEIN Corentin, *Vers la fin de la projection de forces ? La menace du déni d'accès*, *Focus stratégique* No 20, Ifri, April 2010, p. 11 (www.ifri.org/fr/publications/enotes/focus-strategique/vers-fin-de-projection-de-forces-i-threat-deni-dacces).

evacuation, material drop, in-flight refuelling for the Transall and self defence, among others. But the changing geostrategic context altered the stakes. The first Gulf War was a turning point for the Air Force's transport and helicopter fleets, which had to adapt if France were to keep its rank as a framework nation and its capability for first entry.

For one thing, it highlighted the lack of strategic projection: the ruggedness of the Transall was adapted to tactical missions but its radius of action and carrying capacity had become insufficient to support major, long-distance deployments. This situation imposed a resort to chartering civil craft and to turning to our allies for support.

For another, helicopter Combat Search and Rescue (CSAR) became a completely separate mission during Operation *Daguet*. Account being taken of the size of the friendly air force and of the adverse ground-air defences, every CSAR mission must be coordinated with fighter-bombers to ensure its protection—and in a very short timescale, too. The Air Force experimented with this mission using two *Pumas* stripped of much equipment, which in January 1991 recovered a downed US Navy pilot from Kuwaiti territory. It marked a turning point in the ways of planning and conducting this mission, which requires specialised materiel and aircrews to act in depth over enemy territory in coordination with fighter and bomber aviation. This gave birth to the *Caracal*, a helicopter derived from the CSAR-dedicated *Cougar* and converted for the power projection mission. It is an armoured helicopter with side-looking weapon and self-protection facilities, and is able to refuel in flight. It is adapted to operation in hostile territory, able to carry a commando and with its modernised avionics and Forward-Looking Infra-red Radar (FLIR) its ability to operate at night means it has also been adopted for special operations.

Counter-insurrection and anti-terrorism conflicts became more general over the following decade, which again changed the types of mission in theatres of operation. It became necessary to be able to act reactively, in isolation and wherever needed as is the case for special operations, and also in direct support of ground units, notably with the Transall's integrated C3ISTAR observation and coordination capabilities. These conflicts also had the peculiarity of occurring more often in urban or suburban environments, which require robust helicopter operational capabilities to limit the time spent under enemy fire and avoid recurrence of dramatic situations like that in Somalia in 1993. The Caracal is entirely adapted to these missions.

With regard to the vehicles to be transported, anti-guerrilla modifications and reinforcement of armour all add weight. The VAB troop transporter, which as built weighed 12 tons, now weighs over 17 tons in some configurations and can no longer be carried by the Transall. Its successor, the *Griffon*, will weigh 20 tons empty. This has a major impact upon air transport and justifies the dimensions and performance of the A400M *Atlas*.

The past 70 years have therefore seen development in projection missions for military transport and helicopters: they are now more exposed and closer to combat, and combine the roles of force projection, observation, coordination of action on and onto the ground, communications relays and power projection action with

ever-increasing requirements of range and robustness. This increase in importance and the multi-role capability of transport craft and helicopters is now necessary to cover a range of operations that continues to broaden.

In a disputed air environment

Combat...

The improving strength of powerful states and the better equipment of certain non-state groups are leading to an increasingly disputed air environment, which threatens the use of air power. Adapting our assets to this new state of affairs is therefore essential to guarantee our ability to carry out our projection missions and necessitates three main capabilities: endurance, connectivity and reactivity.

Endurance means avoiding threats, remaining longer in an area and penetrating deeper into enemy territory. Connectivity is needed for coordination of dedicated protection assets and sharing of the general tactical picture via data links (currently Link 16), and also to be able to operate in an environment in which satellite navigation might be jammed (the Navwar scenario). Lastly, reactivity sets the speed at which a situation that could turn unfavourable can be stabilised by, say, controlling the escalation of a conflict, pinning down an enemy or resupplying ammunition.

The A400M *Atlas* has all the qualities needed to provide these three capabilities. The technological leap from the Transall is comparable to that from the Jaguar to the Rafale. The A400M can carry double the payload of its predecessor in a quarter of the time and yet retains the ability to land on rough ground. With its four metre-wide hold, it can transport all in-service types of helicopter as well as the newest ground equipment directly from France to operational theatres.

The A400M can be integrated perfectly into complex missions even, in disputed airspace. Its exceptionally robust flight controls and advance terrain mapping facility allow it to fly with great agility just 150 feet above the ground and below the radar horizon; its powerful turboprop engines mean it can also fly at high altitude, out of range of the majority of ground-air systems and at speeds that ease its integration with escorts. Its fuel capacity gives it long range but also means it can refuel combat aircraft in-theatre if required.

Its secure communications fit, tactical and satellite data links and the navigation system of the A400M now mean aircrews are able to conduct missions in the Levant in complete safety by day and night (using night vision goggles and FLIR) while being perfectly integrated into allied operations. Developments in avionics now underway will allow secure transmission of data via military satellite links and also for the aircraft to perform autonomous approach, without support from the ground, even in an environment with heavy jamming.

Lastly, its reach, coupled with its centralised mission preparation system allows planning and conduct of a tactical mission, which might involve departure from its base in Orleans for a five-hour logistic round trip to land a 20-ton load at the heart of

the Sahara-Sahel region. This new aircraft therefore means major airlift operations can be conducted directly from France while remaining in constant contact with the command and control centre via satellite link, which is in contrast with an operation on Timbuktu in 2013, where is was necessary to gather together a mixed fleet of C-160 and C-130 operating out of Abidjan, to communicate on HF and this, without any overall air picture. The aircraft has exceptional potential and will soon be committed to Special Forces work. In the longer term, the Air Force envisages using it to conduct firing actions using dedicated on-board armament and its intelligence-gathering equipment, after transfer of the special air forces' C3ISR capability from the Transalls.

...and rescue[2]

At the other extreme of the range of operations, we need to be saviours in the sky, as it were, at all times and in all places. The ability to operate rapidly over great distances in time of peace, during a catastrophe, a crisis or in conflict contributes unquestionably to the resilience of the state.

In time of peace, aircraft and helicopter projection assets can maintain governmental alert states and also protect the population, major events and sensitive sites by their permanent operational and search and rescue (SAR) missions. For them, the three key elements of endurance, connectivity and reactivity are just as important. Endurance means that the periods of in-flight surveillance of sites or events can be lengthened. Connected helicopters can anticipate the arrival of civil air traffic, identify individual planes and coordinate interception and interrogation. Reactivity is intimately linked to the speed that is needed to intercept then constrain airborne threats or offenders at a safe distance from the sites to be protected. These missions are essential to the maintenance of sovereignty vis-à-vis airborne craft operating at lower speed than combat aircraft, and thus they can maintain a high level of security over sensitive or strategic installations, such as the space centre in French Guiana.

In overseas territories where there are few civil protection assets, the CASA CN-235 can land easily, including on remote atolls. This very agile light cargo plane, with its low operating cost contributes to missions of presence, land and maritime surveillance and maritime counter-terrorism. The addition of an optronics ball has become essential to these multi-role missions.

France has around 1.5 million expatriates, of which a third are in potential crisis areas that demand assets capable of intervening rapidly, whatever the conditions. Events over the past few years were a reminder that we had to be able to intervene in just a few hours to protect our citizens. In February 2008, when the town of N'Djamena was under fire, rotations of C-160 ensured the evacuation of hundreds of French people to Gabon. More recently, following the damage wreaked in September 2017 by hurricane *Irma* on the islands of Saint Martin and Saint Barthelemy, France

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(2) This reflects Colonel Brunet's adage (*Combattre et sauver*—he started the use of armed helicopters during the Algerian war), which has become the motto of the Air support and projection brigade (*Brigade aérienne d'appui et de projection*—BAAP) of the Air forces command (*Commandement des forces aériennes*—CFA).

mobilised its projection assets (Air Force A400M, CASA and *Puma*) to evacuate victims and transport freight: in all some 3,000 people were evacuated to mainland France and 100 tonnes of freight were delivered to the area.

These projection assets can also cover casualty evacuations. Being closest to the combat, the helicopters are able to evacuate the wounded rapidly to a basic landing site or to a medicalised version of the CASA, where medical teams would take over to transport them to a more appropriate structure. Depending on the state and number of wounded, a medicalised *Falcon* or an A330 MRTT outfitted with a Reanimation module for long-range patient evacuation (*Module de réanimation pour patient à haute élongation d'évacuation*—MORPHÉE) would repatriate them to main-land France within 24 hours. In the longer term, there could be real-time transmission of the wounded patients' vital signs, which would improve their medical transfer from the moment of landing.

Future programmes and projects

To maintain its capabilities for force and power projection in the face of future threats, the Air Force is studying what will need to change in its fleets, notably in terms of action in depth in high-intensity environments, of networking and of heavier arming of its platforms.

For helicopters, the next standard of the *Caracal* will concentrate on the protection and self-defence aspect. For tactical superiority over a zone, the plot heli-copter has to be escorted by another asset with equivalent reach and heavy firepower. The armament of the *Caracal* is therefore an essential complement to combat aircraft for the conduct of special action in depth. The projected *Caracal Mammouth* will be fitted with axial armament that would answer this need. In the longer term, repla-cement of the *Caracal* fleet is expected around 2035 as part of a joint programme. This new-generation helicopter will continue to have capabilities for in-flight refuelling, protection self-defence so that it retains the reach needed for missions deep into the enemy's layout.

The Joint light helicopter (*Hélicoptère interarmées léger*—HIL) will replace the Air Force's current *Fennec* fleet around 2030. It is intended for air security missions, SAR, fire support and intelligence and will benefit from major advances in endurance, connectivity and reactivity. Its in-depth capabilities are essential and have to be cohe-rent with those of other aircraft types, which is why the HIL will be equipped for in-flight refuelling, with ad hoc data links and axial armament.

In arming transport aircraft, advantage is going to be taken of the endurance and payload offered by the A400M. It will probably need to be able to launch swarms of drones, and offer new modes of offensive action or observation.

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Military air transport is particularly dynamic in its search for new concepts and will in the future be more and more capable of opening up strategic space[3] as a function of its central role servicing all types of mission in operational theatres. Current and future materiel brought in to service, along with various projects now in their study phase, are opening up a new era with regard to our airborne force and power projection capabilities, among which are the mid-life renovation of the *Caracal*, A400M developments and the capacity boost that the future HIL will bring. Yet it is not just a question of machines: it is the skills of our men and women that enable us to conduct missions in times of peace as well as of war. The new dynamism of modernisation and operational commitment also means that we will be able to retain these talents. In the spirit of Clausewitz, to reach great goals we must dare to do great things. ◆

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(3) MARGERIDE Jean-Baptiste, *La dilatation de l'espace stratégique par le transport aérien*, *Stratégie* No 59, 1995-3 (www.institut-strategie.fr/strat_059_MARGERIDE.html).

Modernisation
of the Air Force *MCO Aéronautique*

Laurent LHERBETTE

Général de division aérienne, Deputy head of Activity, Air Staff (EMAA).

I n January 2018, the Minister of the armed forces agreed a transformation plan aimed at improving the performance, efficiency and governance of Aeronautical maintenance in operational condition (*Maintien en condition opérationnelle*—MCO). MCO in the Air Force is of primordial importance, for it is an essential determining element in the success of any operation, a key factor in operational readiness and, perhaps less evidently, in the morale of personnel. The Air Force and all state and industrial players in the MCO structure are therefore fully mobilised to ensure the success of the plan and that it rapidly brings positive results within tightly controlled costs. For its contribution to this reform, the Air Force has initiated the NSO 4.0 project, which will look at modernising the level of operational support (*Niveau de soutien opérationnel*—NSO) within its field of responsibility to ensure the Air Force's capability to fulfil all its missions in all places and in all circumstances.

MCO is not an end in itself—its sole objective must be to make materiel ready and in the right state for going into combat. It therefore contributes to airmen's operational readiness, a direct responsibility of the Chief of the Air Staff (*Chef d'état-major de l'Armée de l'air*—CEMAA), and to the faultless conduct of the permanent missions of the Air Force—deterrence, permanent posture of security and various alert states—its commitments to external operations and its contribution to action in our overseas territories and in foreign countries.

MCO consists of ensuring maintenance of equipment and integrating logistic functions (supplies, storage and distribution of spare and exchange parts) with technical functions (follow-up and handling of technical issues). Maintenance activities are divided into different levels of technical work (NT1, 2 and 3, where NT is Niveau Technique, technical level), and are carried out at two levels of support responsibility: the operational level (NSO), which is performed by the forces, and the industrial level (*niveau de soutien industriel*—NSI) which for the state is performed by the Industrial aeronautical service (*Service industriel aéronautique*—SIAé). Private NSI is operated by private industries.

Success of this plan to improve MCO performance relies on a number of players with complementary responsibilities:

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Level of support	Level of technical work	Who?	Examples of types of intervention
NSO (Operational support)	NTI 1	Forces	**Readiness and maintenance on line:** – daily visits before and after flight; – replacement of units on line where allowed.
	NTI 2	Forces or SIAé or private industry	**Maintenance on line or off line (hangar):** – periodic visits of aircraft (short duration); – periodic maintenance visits for instruments, accessories and equipment; – replacement of units that are repairable in workshop; – fitting technical updates on-site; – fitting/removal of engine modules.
NSI (Industrial support)	NTI 3	SIAé and/or private industry	**Maintenance requiring industrial backup:** – major visits or repairs to aircraft (long term); – repair or major overhaul of engines; – industrial maintenance of on-board equipment (general overhaul); – application of technical developments (capability upgrade work or equipment retrofits).

• **Project managers** (EMA, DGA, EMAT, EMM and EMAA[1]) prescribe the need[2] and allocate the financial and state-employed human resources. For the Air Force, CEMAA is responsible for the operational readiness of the forces placed under his authority and for the MCO of the materiel being operated. He exercises his responsibilities through the EMAA and the DRHAA.[3] Within this framework, the Major General of the Air Force (MGAA) is responsible for the air operational programme budget, of which 74 per cent is dedicated to the Materiel maintenance programme. The Air Force is also the employing authority and is also the responsible body for maintenance of airworthiness.

• **Associate project management** is delegated to the Directorate of aeronautical maintenance (*Direction de la maintenance aéronautique*—DMAé), which draws up an MCO strategy that ensures the overall coherence of MCO activity, and proposes it to the Chief of the Joint Staff (*Chef d'état-major des armées*—CEMA). It also negotiates and steers maintenance contracts, and is responsible for part of the technical (OGMN[4], authority for technical teams) and logistic (management of property and materiel, and end-to-end logistic coordination) functions. For budgetary issues it is responsible to the MGAA for steering the operational units' MCO within the Air Force.

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(1) *État-major des Armées* (Joint Staff), *Direction générale de l'Armement* (Procurement organisation), *État-major de l'Armée de terre/de la Marine/de l'Armée de l'air* (Army, Navy and Air Force Staffs respectively).

(2) Covers a number of documents including the Objectives and performance contract (*Contrat d'objectifs et de performance*—COP), which together define the needs and priorities of the forces.

(3) For MCO the Air Force HR directorate (DRHAA) manages operational staff as part of operational support or on behalf of other employers within the Ministry.

(4) *Organisme de gestion du maintien de la navigabilité des aéronefs d'État* (OGMN)—Organisation for the maintenance of airworthiness of aircraft belonging to the state.

• **The technical authority** is the DGA, responsible for technical management of materiel throughout its life. For this, the DGA draws up with the forces a support strategy for each new fleet and takes on the initial support. Together with the DMAé, DGA is also responsible for keeping watch over and dealing with obsolescence.

• **Project management for NSO** is delegated to organic commands of each armed force, which employ their technical units and exercise in part the responsibilities of the OGMN and as a maintenance organisation. For the Air Force, the principal headquarters staffs in charge of the NSO are the CFAS and the CFA.[5]

• **Project management for NSI** is given to:

– SIAé, the state-owned operator, so that the Ministry for the armed forces can retain its expertise and capabilities for design and direct industrial-level intervention for industrial maintenance for which outsourcing is not possible or desirable. SIAé works on a number of fleets including those of the Air Force, both old (C-160 *Transall*, C-130H *Hercules*, Mirage 2000, *Puma* and Alphajet) and recent (A400M *Atlas*, Rafale), as well as on equipment that includes motors, electrical and mechanical assemblies, security, rescue and survival materiel, radomes and ground radars.

– A range of private sector industries that includes essential constructors and major aeronautical equipment manufacturers (Dassault, Airbus, Safran, Thales, MBDA and others) and also to top-ranking maintenance experts such as Air France Industries, Sabena Technics and TAP Air Portugal.
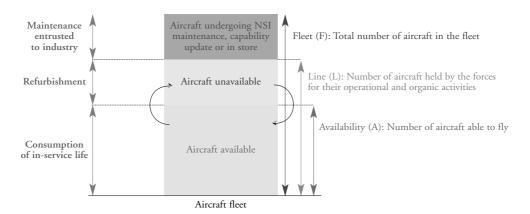
The overall performance of MCO depends on good coordination and the actions of each of the players. It is measured by results achieved in air activity, the amount of materiel made available to the forces (the line mentioned before), in daily availability and in control of cost. (See diagram below)

Within a given budget, **air activity and availability are the most visible parameters** of MCO performance. Activity comes from aircraft outfitted in the configuration needed for them to fulfil their mission—with laser designation pods and radar, for example. Other than its contribution to activity, availability contributes to the completion of all types of mission including maintenance of alert states and the various readiness states of the airborne component of the deterrent. The volume and quality of this air activity allows us to:

– **Conduct air operations** of prime importance: the permanent security posture, fight against *Daesh* in the Levant or against terrorism in the Sahel, retaliation strikes after the use of chemical weapons in Syria (Operation *Hamilton*[6]) and policing the sky over the Baltic are just some examples;

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(5) *Commandement des Forces aériennes stratégiques* (CFAS)—Strategic air forces command; *Commandement des forces aériennes* (CFA)—Air forces command.
(6) See the article by Lieutenant Colonel MOYAL in this volume, p. 47-52.

Modernisation
of the Air Force *MCO Aéronautique*

Maintenance entrusted to industry

Refurbishment

Consumption of in-service life

Aircraft undergoing NSI maintenance, capability update or in store

Aircraft unavailable

Aircraft available

Aircraft fleet

Fleet (F): Total number of aircraft in the fleet

Line (L): Number of aircraft held by the forces for their operational and organic activities

Availability (A): Number of aircraft able to fly

– **Fulfil operational requirements** that are demanding in terms of volume, range, reactivity and duration of action, such as protection of national territory, nuclear deterrence, knowledge and anticipation, crisis prevention and management, national emergencies and commitment to major operations;

– **Ensure the operational readiness of crews** so that they can carry out the above missions.

Achieving a balance here between NSO and NSI is essential to the performance of MCO. Keeping NSO correctly sized in relation to operational requirements is the guarantee that the Air Force can fulfil its missions in all places, in all circumstances and within cost limits. Close to the aircraft and fully focused on support of operational requirements, NSO contributes directly and decisively to the Air Force's missions 24 hours a day, 7 days a week. It is staffed by military personnel, which counts much for its reactivity, autonomy, resilience and controlled cost, whatever the circumstances or theatres of operation.

To ensure this capability, the Air Force and its military personnel must continue to master a number of skills and essential knowledge, such as:

• The operation and maintenance of combat aircraft, some aircraft transport, special fleets and helicopters and also their equipment, armament and certain other material used in the aeronautical environment, the intensity of which varies with how each fleet is used and the skill level required.

• The operation and maintenance of aeronautical information and communication systems, including surveillance and approach radars, systems for operational command and control and ground-air defence equipment, following the same approach as for aircraft.

• Some logistic activity: here again within a boundary that depends on competences that are organically essential. In any case, commitment to external operations (*Opération extérieure*—OPEX) requires retention of military assets.

• Support of techno-logistical or embarked information systems.

• A level of technical expertise to contribute to maintenance and verification of airworthiness.

• Technical functions, comprising fleet management and organisation of tasks, and preserving associated capabilities for arbitration, in which the operational aspect must unquestionably remain *primus inter pares*. Behind this lies recognition of occasional inability to achieve the overall availability of assets to conduct priority missions. Keeping these functions within the Air Force is therefore logical and essential.

To judge by the very good levels of availability on OPEX, productivity of Air Force military manpower is very satisfactory.[7] Similarly, apart from OPEX, NSO performance in generating training activity is above 70 per cent, which means that for every ten aircraft held by the forces, seven can be put on line daily to contribute to an operational mission or operational training. Moreover, every military person working for NSO is also a combatant as well as a high-level technician. He or she divides active time between pure production, as it were, dedicated to MCO (80 per cent) and the requirements of military life (20 per cent).[8]

Since 2007 the Air Force has reduced its air manpower dedicated to aeronautical maintenance by 27 per cent through passing more MCO activity to private firms. NSO has been optimised and rationalised along the following lines:

• **The boundary of NSO encompasses NTI1 activities and some NTI2 activities considered strategic** for combat system fleets whose use is exclusively military: Rafale, Mirage 2000, Alphajet, C-130H and J *Super-Hercules*, C-160, C-135, CASA CN235, A400M, *Puma*, *Fennec*, AWACS and A330 MRTT (Multi Role Tanker Transport). Strategic NTI2 activity includes, for example upkeep of engines, mission equipment or OAE[9] that the forces would have to deal with themselves on OPEX. Retention of these technical skills means NSO incorporates certain types of preventive maintenance visit. This arrangement leads to deeper knowledge of the aircraft and involves activity that helps training of mechanics. It assumes high skill levels in the key repair activities essential for regenerating availability whilst on operations.

• **The boundary of NSO focuses on NTI1 and some NTI2 activities** for fleets that have very sensitive operational tasks but which are limited in number, or those which are technically close to their civilian equivalents, such as *Caracal* and the DHC6 *Twin Otter*, and soon the ALSR,[10] CUGE,[11] Reaper Block 5 and the European MALE drone (Medium altitude, long endurance).

• **There is no NSO** (i.e. all maintenance is passed to civilian industrial contractors) for the majority of flying training, strategic transport and governmental

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(7) The availability on OPEX is over 80 per cent overall and even over 90 per cent for combat fleets.
(8) Combat training, exercises, missions and permanence, among others.
(9) Organes, accessoires et équipements. (Instruments, accessories and equipment, mentioned in the table above)
(10) *Avion léger de surveillance et reconnaissance* (Light surveillance and reconnaissance aircraft).
(11) *Charge utile de guerre électronique* (EW payload), future system to replace Transall C-160 *Gabriel*.

transport aircraft, including Grob G120, Embraer 121 *Xingu*, Pilatus PC-21, A310, A330, A340, TBM 700, Falcon and *Super Puma*.

The Ministry's MCO transformation plan looked first at NSI, considered as one of the causes of under-performance to be treated as a priority.[12] On the basis of the report by IGA Christian Chabbert, this priority is being dealt with by seeking **optimisation of contractual strategy** with the following objectives:

– limit interaction between the different players (*verticalisation*);

– make industry responsible for a greater scope of activity (*globalisation*);

– give them greater visibility (**long-term contracts**).

This optimisation of contractual strategy could in some cases result in new transfers of NSO activity to the NSI. Nevertheless we need to look on a case-by-case basis at the impacts of such a move on operational effectiveness, which means ability to fulfil operational commitments, deployment capability and durability for example, and also on overall efficiency—extra costs weighed against against HR advantages.

With regard to its contribution to the transformation plan, and in pursuance of the NSO rationalisation effort made in recent years, the Air Force has initiated the NSO 4.0 project, which aims to identify new pathways for optimisation in accordance with the current MCO transformation plan. The work brings together all MCO actors, and has been entrusted to two Air Force NSO managers (CFA and CFAS), and is looking at the 3 principal areas of activity in the forces:

1. Production activity in the maintenance of aircraft;

2. Upkeep and operation of materiel used in the aeronautical environment;

3. Logistic movement.

Taking account of the many recommendations that have been made in all the audits, enquiries and special studies on MCO, particularly those arising from IGA Chabbert's report, the NSO 4.0 project covers four principal headings:

1. **Organisation**, aimed at consolidating organisations, notably by precise definition of the limit of the NSO baseline in terms of the HR, technical assets and skillsets to be retained.

2. **Sequencing**, aimed at improving coordination of all MCO players on air bases, by better association of industrial concerns whilst keeping within the forces the responsibility for decision-making, which ultimately has to be guided by the rhythm and demands of operations.

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(12) For the Air Force, this means C-130H, *Puma*, Mirage 2000, A400M and some equipment, such as laser designation pods.

3. **Lean Management**, to delete low-value tasks, optimise the sequencing of maintenance operations, recover training margins and follow the best industrial standards.

4. **Performance measurement**, aimed at consolidating tools for performance measurement, verifying project results and the effectiveness of actions.

Management of change is a fundamental aspect of this major project. In particular, getting personnel on board is a strategic challenge, and to respond to that the following four areas in particular will be developed: communication; look-ahead management of workforce, jobs and skills; partnerships (with education, private industry and state MCO actors) and innovation.

The spirit of innovation will be aided by the NSO 4.0 project's use of opportunities arising from technology, reviewing of processes and organisations and constitution of a live network within technical units. This network will be linked to action initiated by the recently launched Agency for defence innovation (*Agence pour l'innovation de Défense*—AID) so that budding new ideas can blossom and bear fruit.

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MCO is a major element of the armed forces' capability to attain their required level of readiness and fulfil their operational commitments. Its success comes from the motivation and commitment of all the players concerned and who contribute to it. With regard to its cost, we need to take up every opportunity offered by technical innovations, organisational changes and possible optimisation in order to keep cost under control yet without reducing the capability of the forces to *Se Préparer, Agir et Durer*.[13] ◆

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(13) This is the motto of the Air forces command (*Commandement des forces aériennes*—CFA), meaning [approximately] 'prepare, act and remain'.

Future Challenges for the Use
of Force in the Air and in Space

Challenges for the Future
of Space Defence

Xavier Pasco

| Director of the foundation for strategic research (FRS).

T he anti-satellite test conducted on 27 March 2019 was presented by the Indian Prime Minister, Narendra Modi, as a source of great pride for his country. It was evidence, moreover, of the renewed interest in space shown by numerous governments over the past few years. Such interest takes on many forms, from the emergence of 'new space' to the publicised re-launch of the lunar exploration programme, as well as increasingly evident strategic and military power struggles that are clearly the reason behind that most recent event in India.

Donald trump's announcement of a space force to prepare the United States better for conflicts that might involve space assets to some considerable degree has helped to dramatise these changes. It is nevertheless true that more worrying events have been concentrated into the past twelve years than had been in the previous two decades. The destruction in 2007 by the Chinese of one of its own satellites fundamentally changed the US image of an adversary who was seeking to take on the role of strategic equal that Russia could no longer play. Conscious of not wanting to let such an idea take form, the United States performed the same type of test a little over a year later. The year after that, two satellites, one Russian, the other American, collided and created a considerable quantity of debris. The Chinese experiment in 2007 nevertheless retains the record for pollution with its high altitude interception, which produced debris that continues to present a danger to other objects in space. The much lower-altitude US test would not have been so polluting. The recent Indian test, though inspired by US prudence, would seem to have created a little more pollution in high orbits.

This hitherto unseen activity reveals increased militarisation of space whilst diplomacy struggles to make any advance in the process of controlling weapons in space. Counterspace programmes and the notion of space deterrence are now common currency in the United States. They refer to strengthening of all aspects of space surveillance assets, to creating better resilience to the consequences of possible attacks on satellites, and also to acquiring new methods of in-orbit intervention such as manoeuvrable satellites capable of action against other objects. Clearly the United States is not the only country to play this game: China and Russia have also tested systems of like types.

These developments are of course worrying at a time of an increasing number of private players, some of whom are promising to put thousands of satellites into

orbit. There are numerous projects that foresee such constellations as increasing the frequency of observation of the earth, for example, or creating telecommunications networks in low space orbit. Carried along on the wave of unequalled growth in the past few decades of the information and Internet industries, these projects are looking to generate revenue despite their still somewhat hypothetical business models. The interest shown by the super-rich and by the greatest global businesses of course gives a certain form to these enterprises. For example the latest player, Jeff Bezos, head of Amazon, one of the biggest commercial players on Internet who also presides over Blue Origin, his spaceflight company, currently forecasts the future launch of over 3,200 satellites to reduce the digital gap. The idea here is to reduce costs, in particular by his own company performing the launches. In parallel, the satellite infrastructure could in this specific case serve to increase the services offered by Amazon—already in strongly increasing demand—by reliance on a well-established clientele and on strengthening its fidelity via these new services offering worldwide access and low communication latency.

The emergence of similar players in China, supported in considerable measure by the state (as in the United States, incidentally) will in time make these changes more credible. Seen against a background of wishing to show that in this field of technology *made in China* means quality, the perspective of a strong demand for satellite technologies coupled with the most modern information technology capable of helping domestic modernisation across the Chinese continent could well prove the country's major asset.

So it is that the space landscape is in the process of fundamental change, with major geopolitical consequences. We need to abandon the idea of a select club of a few 'space' nations and adopt one of the increasing coexistence of continuing massive public investment with a greater number of private efforts. This situation is bound to offer new opportunities in the fields of defence and security. As the latest issue of the US *National Security Strategy* explained, this evolution is naturally an integral part of the defence policy of the country: *Governments and private sector firms have the ability to launch satellites into space at increasingly lower costs. The fusion of data from imagery, communications, and geolocation services allows motivated actors to access previously unavailable information. This "democratization of space" has an impact on military operations and on America's ability to prevail in conflict.*[1] But this new balance will also present a number of challenges. Objects in space will increase in number and will offer the opportunity for many activities, both commercial and military, the consequence of which will be a less and less easily predictable environment.

It is against this new background that the world's defence efforts in space seem now to be changing direction. The idea of the importance of satellites for military operations has been acquired through conflicts over the past years. That message having been received, it is now protection and resilience of space assets that come into

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(1) *National Security Strategy of the United States*, December 2017, p. 31 (www.whitehouse.gov/).

question. This is officially the case for France, as the Minister for the armed forces, Florence Parly, declared in her keynote speech in September 2018.[2]

Knowledge of the situation in space becomes a condition for exercise of sovereignty

Knowledge of the space situation has become one of the clearest priorities of space powers, as much for controlling the risks of collision as for evaluating hostile satellite manoeuvres. The United States has planned to invest one billion dollars annually in the issue at least until the middle of the next decade. The investment is to improve the performance of detection devices and data handling facilities in order to respond to the need to detect and classify increasingly smaller objects. The US authorities are aiming for an order of magnitude improvement in their capability for detection and tracking (that is, from 20,000 objects classified to over 200,000) and aim also to be able to distinguish fragments smaller than 10 cm (4 inches) which is the detection threshold of current systems. Whilst lagging behind, Russia and China also have a number of different optical and radar assets, which allow them to evaluate low and geostationary orbits with precision.

The considerable growth in the population of small objects in orbit expected over the coming years will enormously complicate the task. Apart from the question of detecting objects, it is the quality of defining their location, and cataloguing based on certain identification, which will pose the biggest problems.

At a time when space systems will evolve in a much more grouped fashion, probably with more manoeuvrable objects, maintaining an operational space situation will present new challenges. Additionally, current debate across the Atlantic is now on the difficulty of modernising data handling systems to be capable of exploiting the technical performance of the new American Space Fence.[3]

Accurate knowledge of possible actions in space, and intentions behind them, add to the difficulty. Still in the United States, orbital surveillance assets, specialised satellites which observe low orbits or which visit geostationary satellites, have officially been in place for several years.[4] The US Air Force (USAF) is in energetic debate regarding continued effort in low orbit and considers that these systems are essential complements to ground assets. It has put the development of the next generation SBSS into the hands of Boeing. It is not a question of simply surveying space but of classifying the events that occur there and attributing any attacks to their perpetrators. For all that, one of the delicate tasks will be to distinguish possible hostile action from

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(2) *Espace et Défense*, CNES, Toulouse, 7 September 2018 (www.defense.gouv.fr/).
(3) See CLARK Colin, *What About JMS? Air Force Reanimates 'Old Clunker' Space Tracking System, Breaking Defense*, 8 April 2019 (https://breakingdefense.com/).
(4) This concerns respectively the *Space Based Space Surveillance* programme, which led to the launch of the first satellite in 2010 (and is today the subject of reconsideration of pursuing the effort), and the *Geosynchronous Space Situational Awareness* Program, which led to the launch of the first two satellites in July 2014 and the following two in August 2016. Two more are planned for launch in 2020.

unexpected accidents, and the assessment of intentions must by definition be performed with great caution.

The reality is that the principal function of these accelerated developments in the field of space surveillance is to reduce uncertainties. Space remains a vast area that is difficult to watch over, and these national efforts will in any case go along with a certain level of cooperation between states to contribute to a genuine stabilisation of military activity in space.

Lastly, the increasing number of private players who propose their services for some state-level space activities should be noted. In the United States again, the number of offers of private services for space surveillance has increased markedly. In 2016, the USAF even let a contract to Applied Defense Solutions Inc. (ADS) to obtain Space Situational Awareness (SSA) services directly. The mission of ADS, at the head of an industrial consortium is to input data coming from private sources to the recently-established National Space Defense Center—the Pentagon's nerve centre for these matters—to feed simulations and exercises that are carried out there. In this case, the private player plays the role of aggregator of the now many sources that exist outside military institutions. Other companies, such as Leolabs, ExoAnalytics and Analytical Graphics Inc. (AGI), are today front-line players in space surveillance in the United States and the world.

The example of the last company mentioned is enlightening. AGI was first recognised on the publication of its star software, well known to space surveillance specialists, Satellite Tool Kit (STK), which has since become Systems Tool Kit insofar as it now integrates all airborne mobiles as well as satellites in orbit. Almost all satellite operators now use this software. Building on the ubiquity of its software solution, AGI has developed as an operator of space surveillance systems for a range of clients, with support activities conducted for the Pentagon as well as for the consortium of operators of geostationary satellites, Space Data Association (SDA). Finally, AGI today operates the Commercial Space Operations Center (COMSpOC), which draws on a network of several dozen telescopes and a few radars for low orbit observation. In this way, and in just a few years, the company has become a major player in the field.

In France, the company ArianeGroup today has a network of telescopes, GeoTracker, made up of instruments in Europe and Australia, and used for tracking catalogued objects or others specifically selected.

In fact, GeoTracker is one of the rare industrial sources in Europe capable of tracking traffic in geostationary orbit.[5] The system is complemented by a trajectography laser capability that can now pinpoint the positions of tracked objects in low orbit.

Clearly, the ground gained by these types of player in a fast-changing orbital landscape will not be without consequences on the role of states and on their limits of action. From the states' point of view, identification of the key functions relating to

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[5] A demonstration of tracking of the mobile Russian satellite *Lutch* on its geostationary arc by *GeoTracker* was also publicly presented by ArianeGroup (Conference FRS, 4 December 2017).

tracking objects and to their classification will be what guarantees their sovereignty of decision-making in the space field.

Safety in protection

Protection of satellites against risks and threats figures is a further key element that features in all current documents concerning space strategy as the first condition for a space defence policy. As a first step, such protection could come from hardening of national satellites against attacks from lasers or EM radiation, from increasing the manoeuvrability of satellites, from redundancy of ground stations or from a capability to launch and replace satellites rapidly. It could also take the form of using satellites of sufficient performance yet at a lower cost, which means they could then be deployed in greater numbers, thus representing a less vulnerable target. This same logic leads to consideration of housing defence-related payloads on civil and commercial satellites, which would also make their targeting more difficult.[6]

Again, as for space surveillance, the very notion of protection from natural risks or intentional threats relies on the multiplication of commercial, observation or telecommunications systems and on their fitting into multi-mission infrastructures, which in some cases could even be in multi-ownership. It would also benefit from cooperation between countries able support each other in time of need through the loan of certain capabilities.

All that said, the effects are never unambiguous. The anticipated multiplication of micro or nano-satellites with greatly increased performance and which could bring greater resistance, will also transform fundamentally the occupation of space and is in itself a possible source of threat, for example, from the simple fact of an increasing risk of debris out of control, or from strategies of deliberately hiding hostile actions within increased traffic.

It is therefore no coincidence that Space Traffic Management (STM) is now the subject of numerous lectures by experts and appears in negotiations on future international regulations. For space nations, one of the major challenges in the coming decade consists of establishing sufficiently transparent rules of conduct to allow closer and closer identification of everyone's actions in order to ensure a form of international security whilst authorising resort to the many assets that could be deployed in case of national need.

Have the ability to act so as not to have to act

The theoretical resilience that would mean resorting to more and more satellites is part of the broader principle of space deterrence, for some years already the subject of lively debate among experts across the Atlantic.[7] Taken up again by the Trump Administration, this principle of deterrence is aimed mainly at convincing

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(6) This refers to *Hosted Payloads*, now seen as a factor of resilience in the United States.

a potential aggressor of the pointlessness of an attack in a context where space resources are less and less rare, which would make unimaginable the very idea of victory in space. Military systems remain targets, however, and the deterrent effect consisting of minimising advantages to the attacker is but one aspect of the strategy. Space deterrence is therefore complemented by a discourse on a capability to respond to any identified attack '*at a time, place, manner, and domain of our choosing*' as declared in the national security document already mentioned.[8] Thus the space environment might not be the only one concerned by a riposte, were one to be decided.

The anti-satellite interceptions performed in recent years have also been intended to demonstrate possible response capabilities, though they are probably more demonstrations than truly operational activities: they do not represent the only options for action either. Capabilities for action are varied and will probably be more widely employed as their technology becomes accessible and also if they are less likely to put the users on the accused's stand. Jamming and cyber-attacks are clearly ready-made technical candidates. The use of an anti-satellite missile is naturally immediately observable with the demonstration of a hostile act or of a deliberate escalation. It is also a highly visible symbolic act and might suit a political need. There are other advantages, too, of having the capacity to deprive the adversary of his capabilities by actions that are difficult to detect, and possibly temporary, as much from the point of view of initiating them as from the political point of view. Analysis of programmes known as counterspace, in the United States in particular, shows that we should expect the development of varied ground and space techniques aimed at producing a graduated effect on an adversary's assets. These many techniques range from computer or EM radiation attacks to prevent the use of space materiel in chosen zones, to manoeuvres in space to disrupt the adversary, and do not necessarily involve destruction by collision. Directed energy weapons—lasers or high-power microwaves—might also be favoured space weapons of the future.

Complementing defence by some form of collective security

Development of technologies, and the variety of possible actions in space that they engender, shows the limits of any defence policy that is founded solely on the fight against clearly identified hostile military action. The risks to satellites can have

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(7) HARRISON Roger G., SHACKELFORD Collins G. and JACKSON Deron R., *Space Deterrence, The Delicate Balance of Risk*, *Space and Defense*, Vol. 3 No 1, summer 2009, Eisenhower Center for Space and Defense Studies, p. 1-30 (www.usafa.edu/app/uploads/Space_and_Defense_3_1.pdf);

MARQUEZ Peter, *Space Deterrence, The* Prêt-à-Porter *Suit for the naked Emperor*, in *Returning to Fundamentals: Deterrence and U.S. National Security in the 21st Century*, The Marshall Institute, 2011, p. 9-19 (www.law.upenn.edu/);

MORGAN Forrest E., *Deterrence and First-Strike Stability in Space, A Preliminary Assessment*, RAND Corporation, 2011, 59 pages (www.rand.org/content/dam/rand/pubs/monographs/2010/RAND_MG916.pdf).

See also more recently, HARRISON Todd, COOPER Zack, JOHNSON Kaitlyn and ROBERTS Thomas G., *Escalation & Deterrence in the Second Space Age*, CSIS, 3 October 2017 (https://csis-prod.s3.amazonaws.com/).

(8) Any harmful interference with or an attack upon critical components of our space architecture that directly affects this vital U.S. interest will be met with a deliberate response at a time, place, manner, and domain of our choosing, *National Security Strategy of the United States*, *op. cit.*, p. 31.

numerous sources and it is probably illusory to think that they can be protected by a single strategic capability-based strategy, even if such a strategy is necessary.

That is the reason why the main space powers, the United States in the forefront but China and Russia too, have in parallel adopted very active positions in advancing international space law. Regulation of space activity currently depends on a single principal text, the 1967 UN Space Treaty, which forbids putting WMD into orbit but little else regarding space weapons.[9] Conscious of developments in the space environment, the increase in the risks of confrontation and of potentially disastrous collective consequences, the principal countries are all in agreement that the texts should be developed in the sense of shared responsibility and greater transparency. The difficulty for each of them to equip itself in advance and completely against all types of attack of course makes a choice of cooperative strategies inevitable. Despite that, negotiations are essentially stalled over competing strategies, some involving proposals for new treaties, others for simple collective agreements. As ever, the devil is in the detail with, on one hand, proposals for treaties that are hardly operable (for example, since they avoid regulation of certain technologies) and on the other, a move towards texts that lack legal commitment and which reduce their value for numerous countries.

And yet this challenge of creating an international community at peace in space would seem to be the priority for the coming decades and defence effort should be coupled with greater diplomatic effort to ensure complete legitimacy, and therefore complete effectiveness. ◆

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(9) United Nations, Office for Outer Space Affairs, *United Nations Treaties and Principles on Outer Space and related General Assembly resolutions* (www.unoosa.org/pdf/publications/st_space_11rev2E.pdf).

The Challenges of Innovation
and Modernisation
of the Air Force From Now to 2030

Frédéric Parisot

Général de division aérienne, Deputy head of preparation for the future in the Air Staff (EMAA).

If you don't take change by the hand,
it will take you by the throat. (Winston Churchill)

O ver the past decade the world has seen profound changes and an upheaval in international balances that have led to a more unstable strategic environment. That there is a return of power politics is undeniable, but at the same time armed groups are benefiting from the endemic weakness of some states to extend their area of influence or control, the ramifications of which affect our democracies and endanger the stability of wide geographical areas. These changes are leading to a more dangerous world: because it is more mixed and more unpredictable, it poses new challenges for us. At the same time, and whereas for decades technological progress has been fairly steady, we are now witnessing a great acceleration in innovation especially in the field of digital technology, which forces us into continual processes of step-by-step change for the development of our future capabilities. Our potential adversaries having caught up, preserving our advantage means we have to improve the agility and performance of our air forces and our organisations.

A rapidly changing environment

For over twenty years, Western air forces have enjoyed unchallenged technological and operational superiority in the absence of credible air and ground-air threats in theatres, in which the majority of missions has concerned the fight against terrorism. Their principal advantages are speed, reach and firepower, and these air forces offer an immediately and permanently available asset to military and political authorities that can act rapidly, flexibly, reactively and, if needed, deep into the adversary's territory. This was clearly demonstrated in Operation *Hamilton* into Syria in April 2018.[1] Additionally the air arm offers the ability to perform the entire range of its missions while limiting its ground footprint, thus limiting risks and losses while controlling collateral damage by the accuracy of the weapons it carries.

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(1) See the article by Lieutenant Colonel Moyal in this volume, p. 47-52.

The environment in which this air force operates is nevertheless undergoing profound changes. At the upper end of the spectrum the major powers have considerably increased their investment in defence to provide better capabilities in both quality and quantity. In parallel, regional powers are benefiting from a proliferation of high-performance weapon systems and are developing Anti Access/Area Denial (A2AD) strategies based on the combined use of integrated long-range anti-air systems, EW assets, jamming of GPS and recent or modernised combat aircraft. Airspace is therefore more and more disputed. The advanced integration of such systems risks seriously calling into question the mastery of airspace enjoyed by Western air forces, which it is now wrong to consider unchallenged. The dividends of air superiority were garnered by all Western countries, a situation which has led to reductions in the strengths of air forces by 30 to 50 per cent in the course of the past thirty years.

For France, the capability for initial entry, including in depth into the adversary's layout, is the basis of the airborne element of our nuclear deterrent. In the range of missions we have to carry out, these are considered the most dangerous. At the other end of the scale are the most likely missions, those against irregular adversaries using asymmetric and agile modes of action, which include hiding within concentrations of population, brief offensive actions followed by rapid dispersion, the combined use of low-cost weapons and freely-available high-tech equipment such as mini drones, IEDs and effective communications equipment. This combination of assets, unconstrained by ethics or rules means they can reduce the effect of the Western technological advantage. Their action is often supported by effective propaganda on Internet, digital warfare waged on social media and the use of terror on civilian populations.

Another notable development in the environment is the increasing number of players in the aerospace domain at a time of increasing civil and military traffic and the multiplication of drones of all sizes, whilst operations are conducted in zones that broadly have no limitation on non-military activity. This increases the difficulty of detecting and classifying everything that flies, when to control the environment it is of primary importance to identify all mobile objects in order to ensure the security of the force and of the populations under protection. The air arm must therefore take into account these constraints when conducting its operations in much more contested and congested airspaces.

In addition to that, the range of threats has greatly widened because of the development of information technologies. These afford new weapons for our enemies to use such as cyber attacks and attacks on systems that support positioning and coordination functions—the NAVWAR scenario. They also allow the enemies to optimise the use of their weapon systems and to update them rapidly. Here, irregular adversaries have far greater agility than regular forces since their capability developments do not have to conform to any standards in contrast to Western forces, whose systems must always follow an ever more onerous regulatory framework and abide by demanding qualification regulations that retard developments.

Our space assets, which have long been considered invulnerable, can now be the targets of aggression given that they constitute the essential capabilities for the

conduct of modern military operations in intelligence gathering, long-distance communications and navigation, and are the source of environmental data.

The Air Force must take into account this new environment to ensure it retains air superiority in the long term—an essential prerequisite to any military action. As Field Marshal Montgomery famously remarked, if we lose the war in the air, we lose the war and we lose it quickly.[2]

This means we must modernise our equipment and rethink our modes of action, the way we function and our processes.

The imperative modernisation of our equipment and necessary development of our modes of action

Faced with these new threats and given the decisions that have for too long been put off, renewal of our equipment has become necessary. This has already been set in motion by the Military programming law for the period 2019 to 2025, which dedicates considerable effort to the improvement of capability in the air.

In first place, intelligence: external operations show every day how essential this is for the conduct of military action against the transient adversaries of current conflicts. Such effort is also made necessary by the strategies adopted by a number of powers that use proxies or strategies of ambiguity. In order to act, one has to decide. To decide, one has to understand the situation and limitations of the protagonists. Intelligence is therefore as essential in the preparation phases as it is during the action. By 2030 our medium altitude, long endurance (MALE) drone capability will have doubled, going from 4 Reaper to 8 systems on arrival of the Euro-MALE. For light surveillance and reconnaissance aircraft (*Avions légers de surveillance et de reconnaissance*—ALSR) the effort will be greater still, passing from 2 aircraft in 2020 to 8 in 2030. This equipment will considerably increase the intelligence capability of the forces in permissive theatres of operation, particularly in the Sahel-Sahara band in support of Operation *Barkhane* and also in the Levant. For strategic intelligence gathering, the two EW-fitted C-160 *Gabriel* planes will be replaced by three new systems fitted with appropriate captors.

Air transport capacity will also be improved throughout the period of the military programming law. By 2025 there will be 25 A400M *Atlas*, 4 C-130J *Super-Hercules* of which, 2 with in-flight refuelling capability, and 14 modernised C-130H. The A330 MRTT (Multi Role Tanker Transport) programme will also update an in-flight refuelling capability that has passed its best: for this, 12 *Phénix* will be delivered by 2025 (from an eventual total of 15) which will also allow an increase in the strategic transport capability. In 2030, the Air Force will bring renewed projection capabilities into service, thereby depending far less on chartering, and will have the assets appropriate to the new types of theatre, especially for special operations.

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(2) Field Marshal the Viscount Montgomery of Alamein, *The Role of Science in Warfare of the Future*, *Egineering and Science*, December 1954, pp. 20-28.

In the foreseeable environment in which air power will operate, its survivability and overall effectiveness will depend more and more on networking. The Air Force is therefore completely committed to developing connectivity. Collective combat will make coordinated and concentrated action of assets more effective, in turn enabling weapon systems to work together to win the day. The rapid dissemination of information within a combat cloud will accelerate manoeuvres in the air and rapidly overcome the adversary: the air forces must draw on the digital revolution, already widely used in the world of economics.

The F4 update of the Rafale, which began at the end of 2018 will over the coming decade lay the first brick in building the structure of connected combat by expanding its means of communications and giving it the software tools to allow network operation. The ability to operate when faced with new threats will also be boosted by improvement in the aircraft's protection system, its sensor suite and the armaments it will carry. This work will also lead to the development and testing of the initial capabilities in terms of equipment and services necessary for the development of the connected collaborative combat that forms the hub of current Franco-German thinking[3] and which are intended to lead to the definition of the Future combat air system (FCAS, *Système de combat aérien du futur*—SCAF), which should enter service around 2040. In addition to that connectivity, some sixty Rafale are planned to be delivered between now and 2030. These deliveries are essential for the renewal of a third of our combat aviation fleet, taking into account the planned service life of Rafale of 30 years. In addition to the Rafale, the connectivity will link the MRTT, electronic warfare planes, the MALE drones and C2 (command and control) assets.

This interconnectivity of air assets must be developed hand-in-hand with reinforced C2 capability: it will be the digital backbone that links C2 with the forces in action and will bring progress that has been made in the civil sector in management of vast databases and will facilitate the rapid and optimised handling of considerable flows of data. From that will come acceleration of decision-making processes up to almost real time so that the enemy might be engaged at the right time with armaments most appropriate to the environment and to the military effects desired, as well as automation of air traffic control procedures that are under increasing pressure. Some processes that are currently not well optimised, since they rely on conventional analytical methods based on experts' skills and knowhow, will be improved by the use of digital methods: in-flight refuelling plans, general coordination of action and direction of sensors. Possession of such equipment means shortening timescales for planning and for the various teams involved to adapt more rapidly to unexpected changes through the use of targeted aids to decision-making, which ultimately lead to more agile command and control. Connectivity therefore has a major stake in operational effectiveness and will need to be deployed as and when advances are made in the digital world.

Moreover, gaining control over new areas of conflict requires our weapons systems to be made secure against potential cyber attacks and also that we develop our

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(3) Spain is now joining this project.

means of action in digital matters and in the electromagnetic spectrum. In the range of weapons that might be used in air operations we now also need to consider cyber weapons. It is worth noting in passing that the modes of action in these two fields are similar, from which comes the notion of multi-domain operations. Cyber attacks could well be linked with EW attacks in a few years' time.

On another point, the separation between atmospheric and extra-atmospheric space is tending to become less distinct: we now have to conduct aerospace manoeuvres by expanding our fields of action in the areas of surveillance, protection and action to take into account the ever-greater contest in the space domain and the appearance of systems that bring together these hitherto separate spaces.

As well as these major programmes for combat and transport aircraft and for in-flight refuelling, the other aircraft fleets should not be forgotten. We now have to prepare the modernisations that must take place during the next decade—renewal of light helicopters, of the Alphajet, the AWACS system (Airborne warning and command system), and the ground-air component. The demands placed on the Permanent posture of air security (*Posture permanente de sûreté Air*—PPS-A) and air defence of the territory mean that modernisation of our search radars needs to be pursued, too, as does that of radio and air operations control systems, whose mobile versions support operations. Taking account of the changing nature of the threat, the protection of advanced air bases and deployed forces requires reinforced ground-air defence, to be achieved principally through the current modernisation programme of the SAMP/T and the replacement of Crotale.

Development of these capabilities is of priority in a European context and has to result in the maintenance of a very high level of interoperability with our allies, since it is clear that future operations will continue to be for the most part in coalition.

Modernisation of equipment and improvement in the agility of C2 will nonetheless not compensate for the difficulties that flow from the reduction in the size of our fleets over the past twenty years. When supporting more difficult operations in more challenging environments in which attrition is inevitable, the criterion of numbers again becomes important. We need strength in numbers to absorb the shock if we are to cover all eventualities and to do so in the longer term. The size of fleets will therefore probably have to be revised upwards in the coming years if France is to maintain its capability for first entry in high-end conflicts.

Renewal of function and processes

This essential modernisation must be accompanied by reform of our practices made possible by the digital revolution, and first in line should be human resources.

The new generations have different aspirations regarding quality of life at work and the social responsibility of companies, and will have a very different perception of their professional career from that of those who went before. They will be quite happy with the digital world yet will be a resource hard to capture in a tense job market,

particularly in the digital, data and maintenance sectors, all of which are essential for the Air Force. Beyond the need to offer more dynamic and more individual career management for airmen, we need to go out and capture those essential skills—and retain them. We will have to create new trades or transform existing ones. A number of studies highlight that some 65 to 85 per cent of available jobs by the year 2030 do not exist today. The Air Force will not escape the great change that information technologies will bring and will have new needs in the fields of artificial intelligence, encoding, network management and data handling, not to forget cyber and space matters.

This transformation will also require adaptation of our training cycle, which will make greater use of the progress made in digital matters. The coming years will also see a complete revision of the training of aircrews, which has already started with the entry into service of the Pilatus PC-21 training aircraft for training combat pilots. Greater call will be made upon simulation, using the rapidly growing technologies of serious gaming and video games.

It will undoubtedly affect our procurement processes, too. In parallel with the long processes associated with renewal of our major equipment our operational superiority can only be ensured if we use our ability to benefit from innovation and put it into service quickly. The incremental development of aeronautical programmes has for long allowed us to update platforms with technological improvements, although in general a considerable number of years is required to develop, qualify and then deploy a new standard. The challenge now is to reduce the time to make innovations available by the use of more open architectures that allow speedier introduction of new digital applications and facilitate the handling of technical obsolescence whilst at the same time maintaining a high level of security of the core systems. The introduction of recent technological innovations must also be feasible during the development phase of new equipment, which often takes from five to ten years. In this, industry has to help us by avoiding proprietary standards.

As well as these major weapons programmes, the Air Force will favour open innovation, be it from the acquisition of technology coming from the civil world or from ideas from airmen themselves. The system whereby the basic military requirement is expressed and we then wait until defence industry responds to it, is no longer the only way: we now need to cross cultures and be open to innovation, with ideas coming from within or outside the Air Force, if we are to be more agile and have a greater facility for adaptation. That means we have to promote a culture of risk-taking, something not traditionally in the genes of the aviation world, and of willingness to call accepted principles into question since invention, in the spirit of Albert Einstein, means 'being different'. But innovation also means accepting that mistakes will be made. The release of energy therefore comes from acceptance of seeing some projects failing to come to fruition and some ideas not being transformed into reality whilst at the same tile accepting questioning of established principles: being too selective at the outset tends to limit innovation. And yet airmen are often best placed to offer solutions to the real problems that they encounter daily doing their job. Once these ideas are assembled, transforming them into something greater will become one of the major

challenges of the policy of innovation if today's momentum is to be maintained. Creation of the Defence innovation agency (*Agence de l'innovation de défense*—AID) is a promising move, supported by the Air Force.

All of our current processes, as well as operational innovation, will benefit gradually from the increased activity afforded by the arrival of digital equipment; activity whose inspiration will come from the vitality of the sector and from the delegation that offers greater decisional flexibility. They will also be aided by the independent and reactive capability for creation and support of *ad hoc* digital applications that respond to needs at unit level as well as at the higher echelons.

Over the past ten years-or-so the network of air bases, critical to the operation of the Air Force, has been rationalised. Reorganisation of these bases will continue over the coming years to become 'functional centres', their modernisation meaning they can encompass the new capabilities planned in the military programming law, thus confirming their role as melting pots of open innovation (by smart base initiatives, for example) by dint of their geographical connection with local economic structures and the innovative spirit of their personnel. In return, new technologies and innovation will lead to improvement in the operational capabilities of the air bases and in the airmen's quality of life.

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Faced with an upsurge of threats and a rapidly changing environment in a world in which technology is transforming society and established rules, we are at the beginning of a decade which will be crucial for the modernisation of the Air Force and its ability to act rapidly, independently and in all places as an extension of political policy. The many missions conducted recently by the Air Force in Australia and in the Southern Indian Ocean demonstrate that no point on the planet is inaccessible for combat or transport aircraft in a few dozen hours. After years of under-investment despite sustained operational commitment since 1991 the current military programming law allows for the renewal of essential worn-out equipment. Hand-in-hand with this modernisation must be a major transformation of processes and modes of operation such that the increased complexity of new systems does not slow their development.

The next decade will also be essential in shaping the one that follows, which will have to respond to two major—though not the only—challenges: renewal of the airborne component of the deterrent and the entry into service of FCAS around 2040—little more than 20 years away.

The Air Force is preparing for it. ◆

Future Challenges
for the Air-Carried Component
of the Deterrent

Bruno MAIGRET

Général de corps aérien, Commander of the Strategic Air Forces (FAS).

Among the missions given to the armed forces, the Air Force in particular, there is one whose history and culture is deeply embedded in that of our airmen: nuclear deterrence. Originally conceived as a collective effort between the armed forces, the procurement organisation (the *Direction générale de l'armement*—DGA), the Atomic energy commission (now called the *Commissariat à l'énergie atomique et aux énergies alternatives*—CEA) and industry, united towards a common goal, it was an effort without precedent, a national ambition that forms the basis of our defence and the ultimate guarantee of the survival of the nation. Supported by successive Presidents of the Republic for nearly 60 years, it involves commitment at all levels—political, strategic, operational, industrial and research and development (R&D). The armed forces' role in this coherent chain of responsibilities from the highest level of the state down to the operators is to offer to the President of the Republic a variety of possible actions in order to guarantee constant freedom of French action. From the point of view of the Strategic Air Forces (*Forces aériennes stratégiques*—FAS), this effort is now, and will continue to be, a matter of operational effectiveness and demonstration. In this regard, the challenges that face the permanent airborne component are inseparable from those facing the Air Force as a whole and are related to that national ambition: it is important therefore that the objectives and motivation of that ambition are well understood, so in dealing with the issues of those future challenges we need first to explain the 'grammar' of the nuclear business—something that changes slightly with each era and each system. Thereafter we'll look in detail at how the Air Force carries out the mission that falls to it now and into the future, of giving the President of the Republic the 'language' he needs for deterrent dialogue.

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Any consideration of deterrence has to start with the historical and conceptual fundamentals that guide French effort in the subject. Deterrence is above all a national ambition and a key element in French defence policy. It was derived from the chord struck between *the levelling power of the atom* (expression after Pierre-Marie Gallois) and the trauma of the strategic shock of the German invasion, which gave rise to the

expression *June 1940: never again* and made even more necessary by the nuclear black-mail that overshadowed the Suez Crisis in 1956. The decision to provide the nation with nuclear power was derived from de Gaulle's '*certain idea of France*'. Post-war politicians launched into this titanesque adventure in the name of safeguarding the sovereignty of France and preserving its freedom of action. The magnitude of this nuclear adventure, as its name suggests sets deterrence as a characteristic element of French identity. It was the backbone of French industry in the years following the War and the nuclear ambition gave France a coherent vision and the ability to once again become a major power. That coherence applied across complementary civil and military programmes, access to space, ballistic launch vehicles, independence in generation of energy and naval propulsion, the national aeronautical industry and high-tech defence aeronautics, to mention just some. This preamble is important for understanding what it all really means, when embarking upon discussion of nuclear matters. Far from a simple element in the range of possible defence strategies, deterrence in France is thought as consubstantial with the idea of *The Nation*, and its post-war manifestation in the current Fifth Republic. It is not some simple attribute of power but the ultimate guarantee of the survival of France as a *sovereign nation*, in the words of its founding fathers (albeit tautologically).

Once the step in the nuclear direction was taken, thinking and contexts evolved and France took on a kind of *nuclear grammar* (expression after Bruno Tertrais). Doctrinal concepts use this grammar to create a set of rules and laws that govern interactions between the various deterrent elements and the geostrategic situation.

Deterrence starts once one is able to bring to bear a sufficiently credible threat to force the adversary into a cost-benefit calculation that will decisively alter his action. The key element of nuclear grammar is therefore political, technical and operational *credibility*. The central concept of any deterrent strategy relies on five doctrinal notions which, although they evolve over time and with changing contexts, remain essentially stable.

• **National independence** could be understood as a multi-stage rocket: it is manifest in issues of programmes, R&D, implementation and in the decisional process at the top of which is the Head of State. It is both a means and an end.

• **Permanence** is the notion that determines the format of the armed forces responsible for putting deterrence into effect. It is made necessary by virtue of the political credibility that it carries. Given the size of the stakes involved, only special, regularly trained forces, used to handling nuclear devices and to very high intensity engagements, are able to achieve the required threshold of operational credibility.

• The notion of **unacceptable damage** is the centre of the nuclear issue and ensures that the doctrine avoids any drift of nuclear use towards possible use on the battlefield. Whilst it is true that the role of the forces, particularly that of the air-carried component, exists to offer options to the President of the Republic, it is imperative it remains a step into the unacceptable.

• **The vital interests** that deterrence defends give rise to a sort of material and immaterial sanctuary with vague and changing outer limits whose definition is the sole prerogative of the President. The absence of definition of these boundaries avoids any attempt to undermine deterrence. The related concept of a warning strike complements this notion to avoid an adversary from mistaking our intentions.

• Lastly, **strict sufficiency**—both words are important—is the expression chosen to express the fact that French effort, especially in the size of its nuclear arsenal, is of a magnitude to guarantee unacceptable damage today and in the future. Moreover, the notion of limitation carries with it a stopping point in any escalation of weapons whilst reinforcing the credibility of a system in which each piece is carefully though out in order to give it a particular effect.

Returning to the fundamental element, credibility, and to its operational aspect, it is worth noting just how the two components—seaborne and airborne—complement each other in guaranteeing that the President of the Republic has the ability to inflict that unacceptable damage. This complementarity arises from the different military effects that ballistic and aerobic missiles bring. It underlines the difference between the two forces. Whereas the Ocean-going strategic force (*Force océanique stratégique*—FOST) concentrates on the invisibility and permanence at sea of the submarine, the FAS focuses on procedures for increasing visibility that can be open and demonstrative.

Their modes of action complement each other in their manners of penetration and in the modelling used in planning between determinist planning on one hand, based upon calculation and a military strike plan on the other, less able to be modelled yet one which relies on broad strategic concepts such as concentration of fire, exploitation of the adversary's weaknesses and saturation of defences. In any case, the two components come together through the guarantee of their effectiveness: the submarine by its discretion and the FAS by its permanent operations of show of power and nuclear raids.

To complement this broad look at our deterrent it is worth looking at duality, one of the characteristics of the permanent airborne component. This peculiarity is historical: Mirage IV have been employed since 1971 on reconnaissance missions, and tanker aircraft deliver fuel to all operational theatres: only a minority of these missions is conducted for the FAS. Such duality is inherent to the concept of use of the airborne component and affirms its credibility by demonstrating the skills of aircrew and command and control structures. In moving to an all-Rafale era, the FAS have achieved a further step in this duality. Whereas the Mirage IV and Mirage 2000N were aircraft specialised in the nuclear mission, and only occasionally used for conventional missions, the Rafale was built as an all-role aircraft: there is nothing to distinguish a FAS Rafale from a conventional Rafale. Because of this, the combat craft of the FAS can be, and are, employed as much on conventional missions as on their principal, nuclear one. The arrival of the A330 Multi-Role Transport Tanker (MRTT—*Phénix*) from October 2018 highlights this duality even further. These replenishment aircraft

can now simultaneously deliver fuel and transport personnel and/or freight over very long distances.

Not content with just showing the operational credibility of assets, duality offers the President the means for deterrent dialogue with an adversary. Whether in Poker operations or by the fact that the FAS participate in all external operations—Operation *Hamilton*[1] is an example—even in time of peace the air component allows us to show our operational abilities very clearly in the protection of French interests.

In taking the necessary step back to observe this overview of deterrence the reader will understand how the challenges taken up by the Strategic Air Forces are never uniquely tactical. They carry with them that national ambition that relies on the entire state and industrial structure of our deterrent.

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Thus the Air Force, through the strong arm of the FAS, holds the major structural responsibility of giving the President of the Republic his deterrent dialogue and guaranteeing his freedom of action. The air component is therefore always working to ensure these options are available to the decision-maker whilst at the same time maintaining the duality and ability for demonstration that is in its genes, along with its complementarity with the FOST. Throughout the history of the FAS, such effort has always required advancing along two lines in particular: operational effectiveness and demonstration thereof—two key elements of credibility.

The FAS are today harvesting the fruit of ten long years of modernisation. The effectiveness of the three systems ASMPA[2]+Rafale+*Phénix* has achieved remarkable results with regard to the golden rules of the 'three Ps'—*précision, pénétration, portée* (precision, penetration and range). The performance of the missile, regularly evaluated during the forces' test firings, is ensured by 40 years of French expertise in ramjet technology. The ability of Rafale to change instantly from an air-air role to an air-ground one is a major advantage in terms of organisation and doctrine of use. Its low altitude, all-weather, high-speed penetration performance is one of the key points in the credibility of the system. In addition, the renewal of our tanker fleet means a greater fuel load and better availability, together affording the long-range action required by the President of the Republic, in accordance with the doctrine of deterrence at all levels and in all places.

All that said, the operational effectiveness of the air component does not come solely from the FAS. During a nuclear raid the entire Air Force takes part. The successive operations of the FAS, which have continued uninterrupted for over 55 years, have integrated nuclear weapon-carrying aircraft under the permanent responsibility of the FAS with protection and support assets that usually come under other command structures. This close integration of conventional and nuclear assets is strengthened

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(1) See the article by Lieutenant Colonel Moyal in this volume, p. 47-52.
(2) *Air-sol moyenne portée amélioré* (Improved medium range air-ground missile).

further by the multi-role aspect of the Rafale, and supports the Air Force's expertise in high-intensity engagements.

The principle of a nuclear operation relies on the effect of mass. Aircraft depart in cells, each grouped around a tanker, before leaving it to attack in a pack. The size of the raid can be altered to suit the President's requirements but in any case the raid has with it its means of protection. It therefore offers the flexibility and robustness required to establish a deterrent dialogue. Integration of the FAS into the Air Force underpins the latter's mantra of *firm*, *fast* and *far*.

Looking to the future, the principle of guaranteeing penetration relies on always being a move ahead in the game of sword versus shield. This implies dedicating enough support to R&D in order to stay on the right side of the technological barrier. That is why the air component's future challenges concern the entire spectrum of penetration, from the tanker via the combat craft to the missile itself. Here again, history is enlightening when looking at these issues for the future. When deterrence started, in order to overcome Soviet anti-air artillery defences and interceptors we had to fly very high and very fast. Thus Mirage IV became the first aircraft in the world able to fly at twice the speed of sound and to maintain this speed at an altitude of 13 km (43,000 feet). Later, the interception of Gary Powers' U-2 in 1960 made the world acknowledge a new vulnerability as defence systems developed. It sounded the end of very high altitudes and later of the gravity bomb. From then on the concept of penetration relied on terrain following, later complemented by the cruise missile. In the future the progress being made in Anti Access/Area Denial (A2/AD) systems will force re-evaluation of our doctrine in the knowledge of a single truth: that no armour is without its faults. To achieve the right future force size in accordance with the concept of strict sufficiency it is important to understand fully the enemy defences, which in turn imposes upon us a considerable intelligence and anticipation effort. Seen from today's point of view, it is probable that ASN4G[3] will be a very long-range missile, able to fly higher than the adversary's interceptors and at hypersonic speeds, and will be hyper-manoeuvrable.

Following the fundamental characteristics of the airborne component, we'll need to think about interoperability and even commonality of FAS assets with those of the conventional forces. Hence the reason why thinking on the Future combat air system (FCAS, *Système de combat aérien du futur*—SCAF) is from the outset integrating deterrent requirements. This recognition is setting another new ambition that is to ensure mastery by the Air Force of high-intensity combat.

Finally, and more generally, deterrence encourages the link between the Air Force, defence industry, R&D and the rest of the aviation world. Looking beyond the usual horizon of conventional weapons programmes, given that deterrence is a living beast that evolves slowly, the guarantee of penetration to which we are committed and which comes from what the American call the refusal of a fair fight, dictates the need for keeping a technological step ahead and forces us to look to the future with some

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(3) *Air-sol nucléaire de 4ᵉ génération* (4th generation nuclear air-ground [missile]).

uncertainty. Paraphrasing what President Mitterand said long ago to researchers at the CEA, if we find difficult we'll have to look harder. This sort of 'forward imbalance' is integral to the history of the FAS and is the backbone of the French aeronautical industry. Just as Mirage IV led to Concorde, the ASN4G, FCAS and the future nuclear carrying vehicle will be the stimuli that push our engineers and researchers to develop completely new technology by which France will remain a world leader in the aeronautical sector. Beyond the purely military weight behind mastery of nuclear weapons, the industrial capabilities it carries with it are essential contributions to preserving our country's rank among world powers.

To be effective is a challenge: to demonstrate it, a necessity. Demonstration of operational performance of the Air Force establishes the dialogue with the adversary and sets the thresholds of escalation that force him to give in.

Such a demonstration is addressed mainly to a single audience: a (or any) potential adversary. It is based on an operational posture concept that consists of having a determined number of assets available in set timescales. These stages of increasing readiness form the basic rhythm of FAS operations. They are regularly exercised for demonstration purposes and are part of the central business of the permanent airborne component. These readiness operations are the backbone of the deterrent, underlining the need for the air component command to be both operational and organic, reliant upon proven skill in C2 and supported by the operations centres of the strategic air forces (*Centres des opérations des Forces aériennes stratégiques*—COFAS I and II). Knowing permanently the state of the forces, availability of assets and preparation of crews is a necessity inseparable from maintenance of the posture that allows the FAS to maintain the balance of activity between periods of operational preparation, conventional operations and nuclear operations. Experience in this control of activity gives the FAS the ability to conduct two major types of operation.

The first, that of increasing readiness, can be done discreetly or openly according to the President's directive. The recall of aircraft to the homeland, and deployment or gradual increase in alert state of forces over their alert areas, which could be programmed as a function of times of satellite passes, send a quite explicit message to those who listen.

The second type of operation, the nuclear or conventional raid, might also include test firings by the forces. Following the principle of demonstration by element, each segment of the deterrent mission is demonstrated several times a year. The clearly demonstrated long-range nature of operations, the level of adverse defence reproduced and the absence of impasses in the scenarios are all visible measures of operational credibility. To mention one recent example, during Operation *Excalibur* a Rafale B aircrew demonstrated its ability to conduct a 12-hour raid in a scenario with realistic opposition before firing an ASMPA missile, carrying out all that was expected of it. The fields covered by these various demonstrations are therefore well in accordance with the three Ps rule with here, the particular addition of 12 hours' worth of reach, equivalent to some 10,000 km (6,200 miles).

This requirement for demonstrability propels the Strategic air forces into a field of operation that is the essence of the Air Force's skill, power projection, and the need to extend continually the FAS's range of action concentrates effort on that mission. The duality means conventional forces can also benefit from advances required of the nuclear mission, especially in capability terms. Replacement of the C-135 tankers by a more agile, robust and better-performing fleet of 15 *Phénix*, currently gradually joining the ranks, means it will be possible from 2022 to deploy 18 Rafale and their support crews anywhere in the world in 48 hours. This hitherto unknown capability is a real game changer and for conventional commitments will contribute directly to providing the political decision level with the possibility to conduct high-intensity operations 20,000 km/12,500 miles from mainland France, independently or in coalition.

There is another side of the duality coin: though useful for the Air Force and the FAS, since bringing together conventional and nuclear forces builds up efficiency and performance of air combat arrangements, there is a minimum level below which the accumulation of operational tasks could bring the whole edifice tumbling down. Their very multi-role nature means that FAS assets are called upon to fulfil a number of missions and hold a number of alert states, including the permanent posture of security, reconnaissance missions, power projection and operational exercises. This is all very virtuous and improves the competence of the Air Force overall yet tends to limit the availability of assets for conducting organic personnel training—improving skills and tactics, for example. In the same way, a fleet whose dimensions are derived from the lowest common denominator of the missions given to the Air Force could in the case of high-intensity conflict end up leading the decision-maker to keep back his assets for the ultimate, nuclear mission.

In short, below a certain level what was virtuous can become counter-productive. Instead of offering options and guaranteeing freedom of action to the Head of State, the structure could push him towards rattling the nuclear sabre too soon. Duality is therefore a double-edged sword and the issue of the format of forces and numbers of aircraft remains critical despite the efficiencies engendered by multi-role fleets.

The permanent air-carried component has today reached maturity and remarkable coherence. The challenge remains to maintain that 'forward imbalance', thus preserving the technological and operational advance over our potential adversaries. Demonstration of our effectiveness through duality inspires the performance of the entire Air Force. The logic of will pitted against will continues to be the sole consequence of any geostrategic situation: hence it is vital not to be constrained by any weakness. On the other hand the argument has to follow the doctrine of strict sufficiency and unacceptable damage: misrepresenting it could have fatal consequences.

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The Strategic Air Forces carry a national ambition consubstantial with the Fifth Republic, and are at a pivotal point in their history. After ten years of transformation that have allowed them to develop their duality, the FAS are approaching the

future as carriers of a number of challenges that concern not only the Air Force but also the overall military-industrial complex. Permanence, the cornerstone of the FAS's existence, applies also to the sword versus shield argument that underpins all techno-logical progress. The very principle of deterrence implies always being beyond the adversary's range in the debate, which for research and development means always looking ahead. Duality raises different stakes, essentially issues of format of forces. Beyond these matters we must recognise that the real success of the FAS comes from their complete integration into the Air Force. The permanent deterrence mission gives structure to the Air Force in terms of its ability to project power and will in the future contribute to the projection of forces: the venerable Boeing tankers that 55 years ago helped France become a nuclear power have been waiting as impatiently as our airmen for the arrival of the *Phénix*. ◆

Air Security
of the Homeland in 2030

Benoît D'ABOVILLE, ADER7

T he growth of air traffic in Europe has direct implications on overflights of our territory, making adaptation of our current structures for controlling airspace more urgent. The common objective of the Single European Sky (SES) is the defragmentation of national airspaces and optimisation of air pathways, both civil and military. Future management of the Permanent security posture (*Posture permanente de sécurité*—PPS), which is the responsibility of the Air Force, will inevitably be affected by it and will have to take into account the growing threats from drones and terrorism. To respond to these issues, a new 'policy for the sky' needs to be established, which includes space aspects as well as those arising from the new arrangements for air traffic management to be effective by 2025.

The Permanent security posture—a developing mission for the Air Force

The Permanent security posture is a mission for military aviation and is essential for the air security of our territory. It is a truly permanent function, and a demanding one too, operating 24 hours a day, 7 days a week, wholly operationally and financially undertaken by the Air Force in collaboration with the Directorate general of civil aviation (*Direction générale de l'aviation civile*—DGAC). It is extremely reactive, able to respond to the requirement of rapid decision-making and to obtain in a very short time the political authorisation to act, including from the level of the Prime Minister.

The PPS is a high-performance structure that has no real equivalent in any other European country. Its field of action embraces a wide range of situations—accidental, intentional or otherwise:

– non-respect of filed flight plans and of limited flying areas,

– surveillance of overflights by apparently suspect aircraft,

– assistance to aircraft in difficulty,

- prevention of intrusions into national airspace by foreign aircraft attempting to gather intelligence, intimidate or spark off politico-military escalation,

- airborne surveillance and protection of events of high political or media value,

- surveillance of the Kourou rocket launch area when space launches are in progress.

The number of alerts and interventions has increased recently, with over 400 in 2018 divided roughly half and half between loss of communication and overflights of prohibited zones. Russian aircraft activity on the boundaries of our national airspace has also increased. Air surveillance of territory will inevitably see considerable change from now to 2030, going from identification and detection of aircraft by national civil and military assets to wholly computer management of flight paths of connected objects, which will be to a large degree centralised in the new Single European Sky system. Additionally, interaction between air security and anti-terrorist action in its various forms needs to be strengthened. It needs also to be able to counter the problem posed by the development of drones.

An overall approach to territorial air security, justified by the terrorist threat and the proliferation of drones

Terrorism

The interaction between the territorial air security organisation and the fight against different forms of terrorism, which includes security of airports and air bases and the future proliferation of drones, has recently been strengthened. Because of the SES, it needs to take into account a new division of roles for the identification and management of aircraft.

The link between terrorism and the opportunity of attack on air facilities, which are by their nature easily damaged, is now well recognised even if, for example, lessons from the affair of Air France flight 0963 from Algiers, hijacked on 24 December 1994 by members of an armed Islamic group and stopped in Marseille while the group prepared to crash it onto Paris, were not at the time recognised for what they were, though they presaged the attacks of 11 September 2001.

The risks of intrusions onto airports and air bases, and the vulnerability to Manpads[2] of aircraft landing or taking off, were long ago identified, and measures since taken notably in the field of intelligence, the surveillance of people in airports and the security of public accesses. They presuppose considerable inter-ministerial preparation and closely coordinated action. They are in part financed by the airlines, which pass the cost on to their passengers.

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(2) Man-portable air defence systems—ground-air missiles launched from the shoulder.

Drones

The issue of the growth in intrusions of drones into restricted spaces and a spectacular increase in the number of incidents in the air pose increasing security problems. The Air Force is not currently officially in charge of preventing accidents with drones—it is the responsibility of the *DGAC* and operators of sensitive sites—yet in terms of various conventions it will inevitably become involved in cases of accident.

The European Aviation Safety Agency (EASA) is forecasting a tripling of incidents involving drones compared with the period 2011-2015. A similar evolution is anticipated in the North American continent. In France, we have already seen the near collision of a drone and an Airbus A320 on its approach to Charles-de-Gaulle airport on 19 February 2016 and an intrusion into the nuclear power station at Bugey on 3 July 2018. More recently, in the United Kingdom, Gatwick airport was temporarily closed on 19 December 2018, stranding 110,000 passengers.

Moreover the number of drone operators has rapidly increased. From about 50 in France in 2012, we had more than 5,000 operators using 10,000 drones in 2018. Looking at 'leisure' drones alone, over half a million have been sold in France since 2016. Controlling this market is difficult, with ways and means that are insufficiently harmonised between European countries despite the efforts of the European Commission and the European Defence Agency (EDA, which has also created a working group on autonomous drones) to come up with common rules. Step by step, France has been putting national legislation into effect.[3] The maximum altitude permitted in European Union countries is 150 metres/500 feet and a number of obligations are planned, though discussions continue, to cover registration of the drone device, identification of the user and his pilot training, the means of maintaining contact with the device and a ban on night flying.

The individual freedom of the operator should not be excessively constrained by over-heavy legislation, which would risk putting the brakes on development of the technology to the advantage of other countries which are also drone manufacturers—China, for example. It is nevertheless essential to manage this new popularity of use of airspace. Developments now envisaged by drone operators, such as urban taxis, parcel delivery and inspection of depots, make it hard to anticipate the problems that will be posed regarding sharing of airspace: we can be pretty sure, though, that they will be quite different from those we now know.

The Directorate general for armament (*Direction générale de l'armement*—DGA), is, like its foreign equivalents, exploring different approaches to achieve early detection and destruction of drones, including anti-drone rifles, lasers, trained birds of prey, jamming navigation systems, capture nets and cyber intrusion. Up to now no system has proved entirely successful even though several countries, France included, have ordered materiel from private firms and continue evaluation of its effectiveness.

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(3) In particular the law of 24 October 2016 and the decree of 18 May 2018 which distinguish different categories of drone by weight (under/over 800 grams). Ministerial instruction 5050 of 10 May 2016 aims at devolving responsibilities for protection measures.

Progress in Artificial Intelligence (AI) will lead to greater reactivity in the automatic piloting of drones, which will nullify to a large extent the current methods of jamming its communications and drive us more towards provision of kinetic means. In parallel, innovative technologies are worth a look particularly since perfection of anti-drone measures interests the Ministry for the armed forces not only for air security if the territory but also for external operations, as has already been seen during coalition operations in Iraq and Syria.

The risks related to terrorism and drones are yet another reason for ensuring the adaptation of the country's radar cover, especially at low altitude, even if detection of drones remains very difficult. The evolution of threats means consideration has to be given to very fast, stealthy targets and also to small, slow ones. Experiments are currently taking place on equipment for managing drones close (5 km/3 miles) to an airport.

The development of drones and its consequences therefore presents a triple challenge for the Air Force:

• Public opinion would not understand if effective measures were not adopted by the Air Force for the anti-drone battle nor that responsibility for that battle remains essentially in the hands of the managers of critical installations such as nuclear power stations and aerodromes. The current PPS arrangement can only respond in a limited manner to the need: Mirage and Rafale aircraft are too fast over the zone, whilst helicopters with on-board marksmen aiming to intercept slow targets do not always have the speed needed to get to the intercept point in time.

• The place and role of the Air Force itself in an inter-ministerial anti-drone organisation cannot be dissociated from the airspace security management policy. For the moment, effort is focused on low altitudes but in the future some drones will cruise at altitudes approaching those of commercial flights.

• Future management of the *PPS* should explicitly take into account problems relating to interference from drones, whatever their flying altitude. For the Air Force this would be a formal extension of responsibilities, which supposes political and legal endorsement as well as allocation of the assets required. It would confirm and boost the role of the Air defence and air operations command (*Commandement de la défense aérienne et des opérations aériennes*—CDAOA). Operational management of the PPS, hence of the active measures then needed would remain unchanged from the current arrangements.

New forms of European airspace management—
a major challenge for military aviation

Across the world, the annual growth in air transport is around 5 per cent, and air traffic doubles every 12 to 15 years. It has been recognised that this pattern is incompatible with the way air traffic is controlled in Europe and in the United States. A move towards total digitisation of airspace management within the Single European Sky programme is therefore inevitable, in view of this forecast increase in traffic.

Removal of national airspace boundaries and computerisation of air corridors has been underway in the EU since the beginning of the century as the various stages of the SES have progressed, including the current version, Single European Sky 2+. This movement today seems irreversible, supported as it is by the airlines and the European Commission. The SESAR programme,[4] to which Thales is one of the main contributors, is financed by the Commission and is at the centre of defining new IT systems. Things are now progressing rapidly and involve also the activity of military air forces in Europe and those of EU partners, including, of course, the Air Force.

Detection of aircraft and drones displaying suspect behaviour will be done not only through their flight plans but also by following their movements in real time using information combined from civil and military radars. At the same time this has to avoid impacting the freedom of manoeuvre of military aviation with regard to exercise and training areas, the confidentiality of their activities and the management of flights and deployments without prior notice. Moreover, by virtue of its geographical position at the crossroads of European air lanes, France has a particular responsibility and is a key element in any future arrangement.[5]

Given that, the presentation in Brussels in December 2018 of a common attitude among those responsible for European countries' military air fleets was an important step: two officers, one French the other German, both deputy commanders of their respective air defence and air operations commands and speaking on behalf of 'the European military air community' indicated in particular that:

– Military activity is not responsible for delays and congestion in European skies, because of a number of measures that have already been adopted.

– The 'the European military air community' is a party to the SES, even if it only represents a minor proportion of the use of airspace (about 11 per cent), and has its own particular needs, costs and security considerations.

– European ATM (Air Traffic Management) could be an advantage for purely military activities in an increasingly complex environment but brings with it a need for special training of aircrew.

– Civil-military interoperability is already compulsory and military organisations are already a step ahead with regard to digitisation of operations in the SES area.

– Cyber-security is a common concern for military and civil organisations.

– Drone navigation must be integrated into the SES area.

– Any defragmentation of air traffic operating space and possible delegation of tasks to independent bodies must include contractual obligations on priorities for military access.

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(4) Single European Sky ATM (= Air Traffic Management) Research.

(5) Since the summer of 2018, France has become the target of a campaign led by the airlines, regarding its responsibility for accumulations of delays suffered by passengers in peak periods for commercial traffic. Strikes by the French air traffic controllers and the obsolescence of French and German management systems have been denounced by the press and by the airlines. cf: FINANCE COMMITTEE, *La modernisation des services de la navigation aérienne* (Information report No.568), Senate, 13 June 2018 (www.senat.fr/rap/r17-568/r17-568.html).

Moreover NATO, which has drawn up over 300 STANAGs[6] for joint exercises and the activities of member nations, among which is which the US Air Force, the largest military air fleet in Europe in terms of number of flights, has specific interests to be taken into account in the new organisation for ATM in Europe.

Airmen therefore have a positive attitude towards SES whilst making their particular needs known, including flexibility of the structure to ensure movement of aircraft, training and organisation of missions (including the PPS), confidentiality, cybersecurity and the financial and technical sustainability of the adaptations required. Clearly, putting new SES systems into place relies on optimisation of flight paths and the regular flows of commercial traffic, with military activities way behind them, given the current order of priorities—and, incidentally, such military activities that are unprogrammed and unannounced principally because they are arranged in response to an emergency, and for which confidentiality is a major consideration, affect only a very minor proportion of the European air traffic that has to be managed.

Specialists in SESAR and at the European Defence Agency (EDA) estimate that the technologies developed for ATM will be able to respond simultaneously to civil and military needs. New infrastructure will ensure the interface between satellites, instruments in flight and ground stations and should allow optimisation of areas requested by the military bodies for their specific needs. For major events, a part of airspace will always be able to be mobilised to deal with a real or simulated crisis situation.

The PPS will have access to more information: today, the flight path is known from the flight plan filed before departure, whilst SESAR will afford exchange of data on the flight path in real time, directly from the instruments on board the aircraft concerned. It will be accessible by both civil and military competent authorities. The system is not aiming to achieve total autonomy in an aircraft's flight management but, as it enters service step by step, a gradual increase in the automated assistance to pilots and air traffic controllers. The operator remains in the loop constantly and can intervene directly on the flight path if need be, even if that becomes more and more the exception.

The consequences on the employment and training of both civil and military air traffic controllers should not be over-dramatised: the development of the system will occur progressively over a minimum of 10-15 years. In principle there is no negative impact on employment, though the profession will evolve towards system management, rather like that of pilots on modern aircraft. The Air Force personnel management plan will nevertheless need to take these developments into account.

Setting up a SES is inseparable from a common approach to space management and surveillance

New civil and military ATM systems, in Europe and in the United States and progressively in the rest of the world, will depend heavily on communications that use

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(6) Standing NATO Agreements.

space relays. There is a close link between setting up of the SES and the capability of European countries to manage the security of their space networks and therefore to possess in particular the space surveillance assets of the system. There is the obvious question of vulnerability of guaranteed communications with satellite platforms (cyber attacks, physical strikes, solar storms or satellite breakdowns, for example), as for the majority of modern transmissions. Washington and Brussels are both preoccupied by the matter: the strategy being followed is to provide for resilience of the network by redundant systems, ensuring backup of an all-satellite system.

Another component of resilience of space communications used for ATM must be the establishment of an effective space surveillance system that can detect and attribute responsibilities in the case of breakdown. Whilst it is for now the United States which supports the majority of space activities (financially, at least, since the US Agency could soon be privatised), Europe will have increasing need to furnish its own assets for permanent up-to-date mapping of space.

The financial aspects

The costs of adaptation of military air fleets for these new systems are very difficult to estimate at this stage. Yet this adaptation can only be done slowly, probably over a period of at least 10 to 15 years. Already in the United States, where the Federal Aviation Administration (FAA) is imposing measures to ensure interoperability with the NexGen system, there have been major slips with respect to the original planned timescale. Only around 20 per cent of commercial fleets were so equipped in 2018. In any case, distinction should be made between the fitting new equipment to aircraft and the adaptation of ground infrastructure.

• On the basis of financing projects submitted to the EDA, the cost for modernisation of interoperability between civil and military control centres is estimated for all EU states put together at between 1 and 2 billion euros, and for France at 300 million euros for the initial phase.

• For aircraft, it is difficult to make the distinction between modernisations directly relating to adaptation to SES and those which correspond to equipment that would anyway be installed. Furthermore, costs of modernisation of flight systems vary considerably according to the timescale chosen for update of the aircraft. Current interoperability requirements are likely to evolve over the next ten years, particularly in the light of technological progress.

• Handling of confidential military data will not, in principle, be affected directly by the System Wide Information Management (SWIM) system of the SES. A military cloud will have to be established with effective electronic firewalls.

According to these estimations the overall cost of adaptation to SES over the 10 to 15 years being considered could reach 5 billion euros, not including infrastructure.

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We now need a new policy to respond to the triple challenge of terrorism, the problems arising from the increasing number of drones operating in shared airspace and the establishment of the Single European Sky. It needs to be coherent with the various aspects of space policy, particularly with regard to surveillance of space, and as the policy is developed it must be remembered that one of the important applications of space surveillance is the future management of air traffic.

The financial aspect reinforces this need: some arbitration will be required to allocate the costs of this transformation between civil and military bodies and to decide upon what parts of infrastructure to retain, modernise or abandon.

Under these conditions, the contribution of the Air Force to the overall policy governing airspace management, itself coordinated with space policy, is sure to be a major issue for the years to come. ◆

The Future Combat Air System (SCAF):
A European Defence Policy That is Moving Ahead

Jean-Pascal B RETON and Eva P ORTIER

Respectively Général de division aérienne and Ingénieur général de l'armement, Directors of the Scaf project

C ontest for space, and especially airspace, is becoming more hard-fought as a result of anti-access and area denial (A2/AD) strategies. A2/AD strategies are now keeping our forces at bay through a combination of firm defence action, attacks and harassment at hitherto unknown levels: such strategies are now established in the new battlefields of space and cyber space.

In attacking outer space, the enemy seeks to deprive us of our long-distance communications, our navigation and synchronisation systems, and of our strategic means of gathering intelligence.

With cyber attacks he targets our means of coordination and command, and even our highly computerised and increasingly interconnected weapon systems themselves. Whilst this interconnection leads to substantial growth in sharing of information, it adds growing complexity in establishing precise and up to date data on the origin of the threat. This state of affairs could in time deprive us of our freedom of military action. Indeed, as General Philippe Lavigne, Chief of the Air Staff, reminded everyone during a parliamentary hearing on 17 October 2018, freedom of action in the air is a prerequisite for our protection and to any freedom of military action in the air, on the ground and at sea.[1]

The primary challenge for future combat aviation is therefore to preserve its capability to achieve and retain air superiority independently or in coalition in order to be able to act in the third dimension from bases on land and also from sea, from new generation aircraft carriers. This is why navalisation of future platforms needs to be taken into account from the outset of the design.

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[1] N ATIONAL DEFENCE AND ARMED FORCES COMMITTEE, on the hearing of General Philippe Lavigne, CEMAA, on draft finance law for 2019, 17 October 2018, Assemblée Nationale
(www.assemblee-nationale.fr/15/cr-cdef/18-19/c1819013.asp).

FCAS, a system of systems based on a new combat aircraft

To rise to these challenges from 2040, the construction of the Future combat air system (FCAS, *Système de combat aérien du futur*—SCAF) firstly needs to recognise a changed pattern of affairs. The current notion of the duel, which relies on superiority of different elements considered separately—a confrontation of two aircraft or of an aircraft and a missile—will be replaced by a capability to deploy groups of mixed platforms within much greater overall units, all closely interconnected and able to conduct a coordinated manoeuvre whilst and maintaining their effort in the long term. The FCAS concept comes down to an open system that combines different assets working in collaboration, whose type and number may change with time. For example, a FCAS will be able to bring together future combat aircraft or legacy aircraft (Rafale for France, Eurofighter for other nations), unmanned platforms (Remote carriers, MALE[2] drones and satellites), and tanker, communications relay, C2 or transport (A330 MRTT or A400M) aircraft.

In France the FCAS is represented as a system organised in two concentric circles. The first brings together the platforms that will be in direct contact with enemy threats: it will contain but not be limited to new generation combat aircraft with their own armament, cruise missiles operated from various types of platform (aircraft and ships), unmanned remote carriers each with a degree of autonomy, armed MALE drones and maritime patrol aircraft.

The second circle supports or is supported by the action in the first, according to the needs of the mission. This much larger circle includes air assets (advance warning aircraft, tankers, EW platforms, transports and helicopters), maritime assets (including new generation aircraft carriers, anti-air frigates and multi-mission frigates), land-based assets (ground-air defence systems, close air support or TACP and Special Forces, for example), space assets (communication and intelligence satellites) and the various command and control centres (C2 and JFAC[3]). These assets and their different degrees of interconnection form a system of systems, which must continue to evolve with changing needs and as missions unfold.

With this background, establishment of the FCAS requires new weapon systems to be developed that are resilient to the types of threat envisaged, whilst at the same time allowing for incremental adaptation of the current air combat system. That is why SCAF will be designed around a multi-role combat aircraft adapted to the air threats to come, which exploits the potential of artificial intelligence (AI) and networked combat assets such as cruise missiles and other weapons and drones of various types, as the Minister for the armed forces, Florence Parly, indicated in 2018.[4]

Looking ahead to 2040, at the centre of the first circle of the FCAS the new combat aircraft, the New Generation Fighter (NGF), will have advanced capacity for

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(2) Medium Altitude, Long Endurance.
(3) Joint Force Air Command.
(4) Florence PARLY, Communiqué following the Franco-German council of ministers 'European defence advances', 19 June 2018 (www.france-allemagne.fr/).

survivability and manoeuvrability that will call upon ground breaking technologies. It will have on-board AI capability to assist the aircrew in their understanding of the situation, conduct of the mission and decisions to be taken. The NGF will be accompanied by unmanned vehicles that will have a degree of autonomy. These remote carriers will be both effectors and captors and will bring new capabilities for saturation, neutralisation of enemy defences and intelligence.

Apart from the platforms that will constitute the FCAS, its system of systems design will rely on a level of data exchange never before achieved. That will require networking of all players involved as well as judiciously dispersed data handling capabilities. The use of AI to handle this mass of data and in particular to detect weak signals will be essential. The control and security of data handling and exchange is fundamental and poses a significant challenge for sovereignty, yet that must not inhibit the search for a very high level of interoperability.

To ensure the superiority of our weapon systems, ground breaking technologies have to be developed: this is not a question of simply developing existing or emergent technologies but of going out and searching for ones that have yet to appear. Capturing innovation is therefore one of the structuring principles of the FCAS project. Initial steps in this direction have already been taken: they will be developed further in particular via the Defence innovation agency (*Agence de l'innovation de Défense*—AID) in liaison with the major industrial groups.

What the FCAS brings to current combat aviation

The major evolution that the FCAS brings when compared with current combat aviation is its *ab initio* concept of a system of systems. Connecting all players together will bring the informational superiority that is essential for keeping ahead of our adversaries: it is a question of knowing more quickly in order to decide more quickly and affording optimised use of the different vectors available to act effectively whilst controlling collateral damage. This is connected collaborative air combat.

In order to achieve this goal and to assist the human in the decisional loop as much as possible, we will nevertheless need to advance in technological maturity and intensify our research. Work to this end has begun with the Man Machine Teaming (MMT) project, put out to contract at the beginning of 2018 by the Procurement organisation (*Direction générale de l'armement*—DGA). Improving man and machine interfaces and drawing on AI-related technologies, the project aims to redesign the cockpit of future aviation, making it a cognitive air system.

To do this we need to answer the fundamental question of assessing the level of autonomy we afford weapon systems and the operational effects we expect of them. The key issue is to keep man at the centre of engagement decisions, which is a measure of respect for the ethics of the combatant and the laws of armed conflict. With regard to these needs, the role of MMT is to identify the group of technologies that might be integrated into this cognitive air system and to develop some of them further. For this, the project is calling on a French ecosystem of start-ups; SMEs and

research bodies. The move is structured around six themes: the virtual assistant and the smart cockpit, man-machine interactions, mission management, intelligent sensors, captor services and support. Initial results are expected from the end of 2019.

The new vectors will be adapted to the threat foreseen for 2040 by increased survivability and effectiveness brought about by their physical structures—shapes and materials—and addition of active measures such as electronic warfare. They will be designed from the outset with expansion capacity so that they can always be kept a step ahead of the enemy forces' capabilities. Man-machine cooperation and the massive exploitation of data using AI will allow more rapid, appropriate decision-making and offer new concepts of use such as coordinated flights of unmanned vectors.

Challenges for defence

With the FCAS, the challenge for the French Air Force and the Navy is therefore above all to be able to guarantee national independence, especially for their mission of the airborne element of the deterrent, and to face up to the threats envisaged around 2040. In this way, the freedom of action of political decision makers in time of crisis will be preserved.

The choice of the new vectors must align with our ambitions and our means. Future equipment must be able to confront the most contested of environments and also to conduct low-intensity operations at acceptable acquisition and operating costs. Training and support of these new platforms are fully taken into account in the concept studies.

The ambition of the FCAS makes it a precursor project for the entire Ministry of the armed forces. For example, it interacts with the major project for the successor to the aircraft carrier *Charles-de-Gaulle* that was started by the Minister for the armed forces in October 2018. It is also the first project conducted from its initialisation phase by a dedicated and integrated team that brings together operational personnel and those of the DGA. The team is working in close coordination with key French industries operating in the field of combat aviation in France. In this way, the project is an example of the capability approach sought by the Minister for the armed forces.

At the centre of the FCAS, the NGWS—a European cooperation project

On 13 July 2017, the French President and the German Chancellor decided to set in motion common consideration for the renewal in 2040 of the Rafale and Eurofighter fleets by the 'Next Generation Weapon System (NGWS) within a Future Combat Air System'. Under French leadership, the NGWS project will focus on the NGF, the accompanying unmanned platforms (uniting the various remote carriers) and the connectivity that links them.

The interests of each nation, industrial in particular, are taken into account. This will be based on appropriate organisation of the partner states, both for the plat-form aspects and all of the equipment aspects, including EW, sensors and security, that

are essential to the performance of the NGWS. Sharing of responsibilities between industries and states will be clearly established, particularly regarding aspects of certification, airworthiness, security and end-to-end performance measurement. The organisation must be open to addition of new partners.

NGWS is a truly European project aimed at pursuing the development of European defence, strengthening its sovereignty and ensuring the future of its defence industry. It is therefore open to any European country that wishes to join—as Spain has recently done. To this effect, a common operational vision (HL CORD[5]) has been agreed by the Chiefs of Defence Staffs of the three countries and confirmed in a letter of intent signed by their Ministers on 14 February 2019 in Brussels.

Establishing contracts with the various industries will be the responsibility of the DGA on behalf of all the partners. For running those contracts, a multi-national Combined Project Team (CPT) will be set up in France from October 2019. It will bring together in the Paris region some thirty personnel from the participating countries, drawn from the world of armament projects (DGA and its foreign equivalents) and from the operational environment.

The starting point, the Joint Concept Study

As announced by the French and German Ministers at the beginning of February, cooperation began with the award on 31 January 2019 to Dassault and Airbus of a first contract for architecture and concept studies for the NGWS. This common study, which began on 20 February 2019, aims at defining the operational need and refining the characteristics of the new weapon systems that will be developed together. The study is organised around combined state/industry 'round tables' and is planned to last 2 years: its end state is to propose consolidated ideas to the highest political levels in the participating countries so that they can decide finally on the concept to be developed.

These studies are looking as a priority at defining operational scenarios that shape the nature of conflicts and threats around 2040. They will serve as filters through which the different concepts will be passed. The ability to fulfil the assigned missions will be evaluated against a list of strategic functions identified as structural. In parallel, balanced evaluation criteria will be established to classify the concepts as a function of the quality of their response to different scenarios. These criteria will cover varied domains—operational, programming, technological, sustainability and cost, among others. Finally, the different platforms and their interconnection that come out of previous national studies will be incorporated into this initial operational evaluation.

In parallel with these conceptual studies, detailed technological route maps will be created in order to steer the project and prioritise where effort is to be made to meet the 2040 timescale.

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(5) High Level Common Operational Requirement Document.

R&T: key to success of the project

The FCAS will call upon numerous new and ground breaking technologies. Before being able to decide on their integration into platforms they need to achieve sufficient maturity to establish their performance, risks and costs.

For this, research and Technology (R&T) work is essential for the preparation of trials in the laboratory, on the ground and in flight. In parallel with this traditional scheme of system design, demonstrations that put the overall set of systems to work will combine simulation with real equipment in live trials and potentially in operational condition. In this way it is envisaged that demonstrators will be developed for NGF (first flight planned for 2026) and remote carriers, as well as iterative demonstrations of the system of systems. They will be complemented by other demonstrations of motors, sensors and stealth. All of these trials will be in a coherent digital environment that will allow establishment of the best compromise of overall performance achievable, and will benefit from the short cycle and opportunities offered by that environment.

Nevertheless, to be ready for 2040 analysis of projects of similar size, such as Rafale and Neuron, has shown that R&T work has to be started now. Informed discussion has started between states and industry with the aim of launching as soon as possible a first R&T study phase common to all concepts. It will be followed by other sequences of studies that will take their steer from the initial conclusions.

<p align="center">⁎
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The return of military powers or the appearance of new ones, the evolution of threats carried along on a wave of staggering technological development, and A2/AD strategies are all going to challenge our capability for action if we do not react, and threaten the security of the French population and our interests of power. To remain in the strategic race we have to react now—and that means investing positively for the future.

This rapidly changing environment points to a change in pattern for our air power: operational superiority can no longer come simply from elements considered independently but from the ability to use them collectively and more effectively than the adversary. That means more quickly and more accurately and with effort sustained over the longer term.

Since our principal partners are faced with the same issues, the challenge must uphold our ambition for greater affirmation of European strategic independence. Beyond the political objectives, sharing of development costs of a modern air combat system, and the need for interoperability are invitations to look for and seize opportunities for partnership. Such cooperation under French leadership has been established between France and Germany, and extended to Spain through the ambitious project for the Next Generation Weapon System within a Future Combat Air System based on a genuine system of systems at the centre of which is a new generation combat aircraft and partially autonomous effector drones. ◆

Collaborative combat:
Keystone of the Air Combat System
for the Next Twenty Years

Olivier Fix

| Colonel, Air Staff (EMAA).

For over fifteen years Western air forces have enjoyed total freedom of action in operations conducted in the main against irregular adversaries in unstable areas. They have been able to put permanent pressure on those adversaries everywhere in a theatre and to give effective support to forces on the ground. Resurgence of threats to that power could yet alter the physiognomy of future conflicts.

Russia and, in lesser measure, China have developed effective ground-air systems of significantly increased range compared with those used at the beginning of the century. In modernising their organisation these countries have pushed ahead with integration of these weapons into robust, coherent and resilient defence systems that have considerably improved their capabilities for defence. These assets, when associated with broadly modernised combat air fleets, are contributing to the establishment of A2AD (Anti Access/Area Denial) strategies aimed at depriving Western air forces of their freedom of action, which it would now be rash to take for granted. These two countries are progressively exporting this equipment to a growing number of regional powers, or are supporting them directly through deployments, as in Syria.

As a result, the liberty to conduct operations can henceforth be challenged, whether in military confrontations, even limited ones, against these powers or in regional conflicts where these systems are present. In this context, military effectiveness will depend on optimum coordination of effects in order to recover, then retain sufficient freedom of action to achieve the objectives set at the political level. Collaborative combat, which enhances the intrinsic capabilities of each system taken individually, will then be essential if we are to win the day. The connectivity underlying this is a fundamental pillar for future capabilities, which absolutely must be considered, developed incrementally then tested over the next decade in order to maintain superiority in the years 2030-2040.

Combat zones ever more contested

To ensure freedom of action in the air, on the ground or at sea, it is essential to have air superiority: it is a prerequisite to any sizeable military operation from the gathering of intelligence, to deployment, during the engagement with the adversary

and through to stabilisation. Air forces therefore play a key role in the conduct of joint operations in contested environments.

Performance of defences will generally improve well before 2030 through a combination of materiel with complementary performance in multi-layer architectures, those with short or very short-range systems of low lethality but high resilience because of their mobility, protecting highly effective though more static, and therefore more easily detectable, strategic launchers. This generation of defences is already allowing these major powers to protect their centres of gravity and also to extend their intercept capability beyond their borders by virtue of their very long range, which leads to aggressive creation of sanctuaries of bordering territories in a strategy of ambiguity, as in Ukraine in 2014.

In the case of future crisis, even in a limited regional conflict, an adversary possessing such systems would potentially be in apposition to protect both his rear and his front lines and to project a highly-contested volume of airspace ahead of his positions. Allied air defence would have to operate without any depth of field, therefore conceding, even if temporarily, some freedom to the adverse air assets to limit our own air and ground forces. In such a case the adversary would degrade our ability to gather intelligence and limit our capability for action against his rear bases, supply lines and front line formations. Air and ground combat would only be made harder.

Despite this reinforcement of defences, combat aircraft supported by the other components will continue to occupy a central position in the battle for freedom of manoeuvre because of their reach and capacity to concentrate effects rapidly, and their survivability. It is precisely because of this that one of the principal missions of the Future combat air system (FCAS, *Système de combat aérien du futur*—SCAF), which should enter service around 2040, will be to ensure air superiority.

The challenge of collaborative combat

Given these developments, modes of combat action developed up to now are no longer sufficient to gain the advantage in a hotly contested environment. It needs permanent adaptation of both force and mission, of ability to penetrate and operate inside the threat envelope, to be in a position to constrain the adversary, to regain then retain local air superiority to reverse the balance of forces, then once again be able to act on his rear and his centres of gravity. Against this background the logic of a simple duel between platforms is no longer valid: henceforth collaborative combat is the order of the day with platforms cooperating with each other using enhanced connectivity that allows them together to be part of an overall system whose combined performance is greater than the sum of its parts.

This new approach means considerable investment in development of connectivity between airborne platforms and also with systems operating on the ground and at sea. Central to future collaborative air combat in the near future is the F4 standard Rafale, and in the longer term, around 2040, the FCAS. But what advances are needed to achieve this objective? What capabilities have to be developed?

Enhanced connectivity at the centre of these developments

To be able to operate in contested environments and to reverse the balance of force we have to ensure the survivability of the assets committed and to outdo the adversary by more agile manoeuvres. To do this, linking all players together is primordial if their joint performance is to be markedly increased. The development of enhanced connectivity within the overall air combat system (*Système global de combat aérien*—SGCA) clearly involves improvement in the means of communication and also in handling of an increasing volume of data to speed up decision-making, in turn necessitating development of dedicated tools based upon artificial intelligence.

In the past the SGCA was connected to other forces' systems and to those of allies by slow and limited methods which left much to human intervention. Although successive developments have led to improvement in radio communication and tactical data links that allow greater exchange of formatted data without the use of voice, the air combat system still relies on a disparate collection of weapon and communication systems, each designed independently then put together by piecemeal adaptations. With that goes major limitation in its capacity for development, which considerably inhibits integration of new digital devices. Current exchange of data remains limited in volume, between a limited number of players and often at very limited data rates. In short, the capability for coordination, sharing of information and adaptation remain limited and far short of what is needed if we are to benefit fully from the massive data flows that are part of the rapid developments afforded by the digital world.

Current connectivity therefore inhibits development of closer collaboration between weapon systems, between sensors,and communication and with munitions to improve agility and overall performance of SGCA, and prevents us from having informational superiority over the adversary. It requires a step change in dimension if we are to fight more effectively in these contested areas where the threat is permanent.

The ability to detect and engage air threats or targets before being detected and engaged oneself relies in particular on a capacity for rapid handling and correlation of information of varied quality and quantity. New information technologies being developed in the civilian world afford solutions to the growing challenge of short-cycle handling of vast quantities of data dispersed across numerous systems. Four digital technologies lie at the heart of future connected collaborative combat: networked assets for medium and long range digital transmission, cyber security, analysis of masses of data (Big Data Analytics) and artificial intelligence (AI). As long as it is adapted to the specific requirements of air warfare, exploitation of big data offers sight of opportunities for major developments in the balance of forces in favour of he who first uses it to his advantage.

The advent of an air combat system designed as a network will be a fundamental factor of superiority in the conception of air missions, since it will increase the collaborative combat capacity of the various components' contributions by merging the capability of each sensor or weapon independently of the platform carrying them. Such is objective of the Air Force's *Connect@Aéro* initiative, which aims at ensuring

coherence in capability to the benefit of connectivity across the entire system in order to enhance the effectiveness of the air forces.

Rafale F4: a first step towards connected collaborative combat

The ambitious aims of the future F4 standard of the Rafale are coherent with the anticipated development of threats for around 2025. The Minister for the armed forces, Florence Parly, declared this new standard "a technological leap, an industrial leap and a strategic leap".[1] It is the first move towards the FCAS, which is planned to enter service around 2040, and lays the technological foundation stones of the connectivity essential to support collaborative combat at that time.

The F4 standard will introduce genuine collaborative combat capability by sharing information obtained from active and passive sensors. Radars working in collaboration will have increased detection capability against stealthy targets and those operating at very low altitude and masked by topography. The standard is also intended to permit sharing of effectors in order to achieve better survivability of assets. Hence an air-to-air missile could be launched from one Rafale and guided to its target by another. Other, passive, captors will also be able to share their data within a patrol to enhance a tactical picture shared instantaneously among all the aircrews. These transmissions will be made by radio software.

One of the peculiarities of the air arm is the great distance between the various assets participating in a given mission. Rafale will therefore be able to exchange information permanently via SATCOM with MRTT replenishment aircraft flying in safe zones, with the CUGE[2] system for updates on the situation, with a drone or a command centre to receive target designation. Today a not insignificant number of missions is conducted without contact foe lack of appropriate means of exchanging information at long range, thereby penalising the reactivity of SGCA.

To benefit from the mass of data coming from these captors, the most relevant data will be grouped together in a combat cloud to be shared by all platforms, thus giving an informational advantage over the adversary. The multi-level communications server intended to be integrated into the F4 standard will channel information flows, distribute information as needed and ensure security of communication. For the F5 standard, already in the definition phase, data exchange will be even more secure.

Integration of AI in the future standards of Rafale is another essential step in the direction of collaborative combat. It will allow the automation of certain time-consuming tasks of information handling and network management currently performed by personnel. AI in captors will perform image interpretation to make possible real time merging and exploitation of all available data. The power of the algorithms used

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(1) Florence Parly, speech at Dassault Aviation in Bordeaux-Mérignac at the launch of the F4 standard, 14 January 2018 (www.defense.gouv.fr/actualites/articles/la-ministre-des-armees-lance-le-nouveau-standard-f4-du-programme-rafale).
(2) *Charge utile de guerre électronique* (Live on-board EW equipment – the future system to replace the Transall).

will simplify the aircrews' decision-making process by presenting analysed options via a virtual assistant, in turn increasing the agility and reactivity of the air combat system.

To the fight the growing cyber threat the Rafale will be fitted with a specific, inviolable on-board digital architecture.

For all these reasons deployment of the F4 standard is necessarily ambitious and will lead to the broadest possible update of this combat aircraft so that France remains a front-line player, able to follow developments in the threat until the entry into service after 2030 of the following standard.

A necessary development in armament

Another element of collaborative combat necessary for the recapture of contested areas is a capability to saturate the adverse system by sheer numbers using intelligent weapons that cooperate amongst themselves. Their connectivity will mean they can operate autonomously in packs, or swarms, yet be synchronised in the face of the threat, able to change trajectory simultaneously, and play on dispersal in airspace then rapid concentration onto a target area to surprise and saturate defences then reach the designated targets according to the priorities set.

At the same time, there will be far greater resort to autonomy when employing them: modes of automatic target detection and reconnaissance will mean possible targets to engage will be transmitted back to aircrew and the virtual assistant will propose the best choice of engagement as a function of measurable criteria whilst leaving the aircrew the final decision to engage. The pilot will always remain in the loop when engaging a target.

Connectivity and autonomy are therefore two major paths for progress in developing air-ground weapon systems and ensuring strong penetration capability. In a highly contested environment the saturation effect will require the use of a considerable number of munitions, given that some of them will be intercepted. Connectivity and autonomy must therefore be developed according to need to keep costs to a level consistent with the concept of employment whilst allowing the forces to generate sufficient stocks. Therein lies the challenge for future developments related to the future air-to-ground weapon (*Armement air-sol du future*—AASF). This programme will set in motion a new approach to operating in swarms to surpass the performance currently achieved and will provide the forces with an initial SEAD-DEAD[3] capability that is essential for acting in a highly contested environment. AASF will capitalise on technological developments that afford the ability to counter an adversary's Navwar[4] assets and will be required to ensure coherence of action between the very long-range strike made possible by the future generation of cruise missiles (the FMAN-FMC programme)[5] and the strike at just a few tens of kilometres that exists today. These

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(3) Suppression of Enemy Air Defence-Destruction of Enemy Air Defences.
(4) Navigational warfare, which incorporates PNT, meaning Position-Navigation-Time.
(5) *Futur missile antinavire-Futur missile de croisière* (future anti-ship missile-future cruise missile).

developments require work on the links from aircraft to munitions and between muni-
tions, on increasing useful ranges, on the variety of military effects on offer and
on-board intelligence to achieve the desired saturation effects.

These developments in connectivity will allow particular tasks to be assigned
to certain munitions or sub-systems to aid the SGCA: decoys, remotely carried consu-
mable effectors which could conduct reconnaissance or offensive jamming tasks to
enhance the agility of the system and the penetration capability of vehicles such as
munitions committed to the final engagement.

<div align="center">⁂</div>

The whole range of technological building blocks needed for reinforcing
collaborative combat have therefore to be developed on Rafale over the coming decade
if they are to be proved operationally and have future updates prepared before their
integration into FCAS. The Rafale F4 constitutes a first stage of a revolution which
will shape the air combat system of tomorrow. But success will only be achieved if
connectivity genuinely leads to linking all players together. That is the whole point of
the Air Force's *Connect@Aéro* initiative.

Beyond the necessary development of collaborative combat, gaining air super-
iority in future confrontations will be a strategic challenge by virtue of the influence it
brings—witness the skirmishes seen in the air over Syria, harbingers of violent enga-
gements. Furthermore, the notion of attrition could return, albeit rather forgotten for
the past forty years: it will require some thought on the size of combat fleets in an ever
more unstable strategic environment. ◆

Artificial Intelligence Serving Airmen, or How Human Intelligence is the Future of AI

David Pappalardo

| Lieutenant Colonel, Plans office of the Air Staff (EMAA).

Artificial intelligence (AI) is one of the four technologies at the heart of digital transformation of the Air Force as the Future combat air system (FCAS, *Système de combat aérien du futur*—SCAF) is being developed, in parallel with its use in the massive amount of analysis of data (big data analytics), in connectivity and in cyber-security. By combining the calculating and storage capacity of computers with the ability of human intelligence to adapt itself, this transformation is aiming to create a truly cognitive air combat management system.[1]

In the world of AI, connectionism and machine learning have progressed markedly as a result of huge increases in calculating power.[2] The ability to handle vast quantities of information in a very short time is now excellent, and compensates for human limitations such as memory, attention, calculating ability and anticipation in situations where there is an excess of information (*infobesity*!) and where speeding-up of decisional processes is necessary. And yet these digital technologies remain limited to effecting specific, identified tasks: the notion of AI being able to perform better than its creator is a complete myth, as is the much vaunted technological *Singularity* from which it is derived.[3]

For that reason, the planned cognitive air combat system neither breaks with humanism nor leads to the semantic dead end of anthropomorphism. Since AI does not have the human ability for lateral thinking, questioning whether machines can think is about as relevant as asking whether aeroplanes know how to fly.[4] On the contrary, AI needs to allow the airmen to concentrate on his main tactical and operational combat tasks, which gives rise to a counter-intuitive paradox: the more we advance in AI, the more man is able to fulfil his potential, given that he is relieved of the simplest analytical tasks. Since he is able to understand both context and higher-level issues, the airmen will always bring good sense, intuition and the ability

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(1) Ferrari Vincent, *Prise de décision et numérisation de l'espace de bataille : l'exemple du C2*, French Air Force Research Centre, May 2017.

(2) They represent the most remarkable progress yet in supervised learning by networks of neurones fed with vast quantities of data.

(3) Ganascia J.-G., *Le mythe de la singularité : faut-il craindre l'intelligence artificielle ?*, Éditions du Seuil, 2017, 144 pages.

(4) This paraphrases the mathematician Edsger W. Dijkstra, whose comparison was whether submarines can swim.

to adapt when faced with the unknown. Man is very much the future of AI within the cognitive air combat system of the future.

The Air Force is therefore moving ahead with great determination on the road to developing AI, whose numerous fields of application range from predictive maintenance to the management of multi-agent systems within the Man-Machine Teaming project.

AI and the Performance of Maintenance in Operational Condition

In the short term AI and big data analytics together offer decisive opportunities on the economic, industrial and practical levels to increase the availability of fleets and, in fine, the overall performance of maintenance in operational condition (*Maintien en condition opérationnelle*—MCO). Three channels of effort have been identified within the Air Force—predictive maintenance, its corollary *logistique 4.0*, and robotisation of maintenance operations.

Digital technologies will allow optimisation in the planning of maintenance tasks with regard to operational requirements by substituting the conventional, correctional approach with one that is diverse and predictive, intended to 'make danger predictable'.[5] This will be achieved by aggregating and correlating data from different sources: from the maintenance and service units of the Air Force, from industrial concerns in general (integrators, builders and sub-contractors, among others), and also the data coming directly from the digital twins of connected aircraft. These virtual twins, taken from the Internet of things, should allow data analysis in real time through the use of AI machine learning techniques and its ergonomic presentation on a three-dimensional, enhanced-reality display. Such projects are being studied for natively connected aircraft for use from around 2030. The principal purpose of this value-added data is to improve the management of fleets and to anticipate maintenance operations including the pre-positioning of spare parts.

Optimisation of logistic support is a natural corollary of predictive maintenance. AI and big data should lead in the short term to optimisation of logistic flows through use of better real-time capability for anticipation of demands, stock levels, state of materiel and driving replenishment pipelines.

Robotics and additive manufacture are progressively modifying line maintenance of aircraft. For example, automated drones are currently under study for inspection of areas of aircraft that are difficult to access—from above or even within the airframe. Furthermore, 3D printers will in time allow some parts to be manufactured within the country or in the theatre of operations, where the logistic flow is often limited.

Management of the Mass of Operational and Intelligence Data

Apart from MCO, the strategy for adoption of AI must start with control of data. From intelligence to planning and conduct of operations, insertion of AI must

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(5) Choain Christophe, *La course au numérique est en marche*, *Epidosis* No. 48 by Cesa, July 2015.

of necessity respond to the problem of the information deluge. In particular the amount of information available (the *infobesity* mentioned above), the multitude of players involved and the improvement in performance in general all pose a number of challenges to the command. Faced with this problem, the real question concerns the data rather than the algorithm. Digital technologies have become essential for the analysis of vast quantities of data, to consolidate the information extracted and then to distribute the knowledge acquired in order to decide and act with clarity.

IA and Sensors

The first step is to integrate AI into the sensors of the different weapons systems in a 'data and services' approach. Current effort is on the tools to help handling and exploitation of information in order to achieve better discrimination and identification of potential targets through use of automatic target detection and recognition algorithms.

For example, the Rafale F4 standard will integrate this type of algorithm into its TALIOS targeting pod[6] for optronics, its RBE2 radar[7] for radar imagery and, in the longer term, into SPECTRA[8] for electronic warfare. Similarly, work is in hand to improve terrain interpretation and detection of anomalies arising from wide-field surveillance of medium altitude, long endurance (MALE) drones—the Wide Area Motion Imagery (WAMI) System.

Allocation of importance to the transmitted data is also of great importance in an operational environment constrained by the techniques used—for example, a given pass band is finite, so data rates remain limited and are never as high as those of fibre-optics—and also by the threat of contest within the EM spectrum.

If initially identified by AI, priority information could be transmitted as rapidly as possible whilst that of lesser importance or criticality could be stored, indexed and archived for later exploitation.

The Problem of Infobesity in Intelligence

The second step acknowledges the problem of *infobesity* in intelligence, where issues of criticality, integrity, validity and sensitivity of information are exacerbated. The challenge, then, is to exploit more effectively and independently a great, and greatly increasing, mass of data with ever-limited human resources. The use of AI and big data analytics is therefore needed to automate the most common types of data handling and to optimise the collation of data coming from multiple directions and sources. The final objective is to refocus human endeavour onto high added-value functions of expertise such as decision-making, high-level analysis, creation and conceptualisation.

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(6) Targeting Long-range Identification Optronic System.
(7) RBE2: *Radar à balayage électronique 2 plans* (Two-dimensional electronically scanned radar).
(8) SPECTRA: *Système de protection et d'évitement des conduites de tir du Rafale* (System for protection and avoidance of enemy fire control for Rafale – in short, the advanced EW suite).

Digitisation of Operational Command and Control (C2) Structures

Lastly here, the ability to put AI into effect efficiently is a major challenge in the management of an increasing flow of data in air operational command and control structures. Management of combat space will therefore need ever more efficient real-time coordination and sharing of information—the notion of the Common Relevant Operational Picture (CROP). To have success in operations in distant theatres and over long periods, forces will need digital assets that are compatible with real-time transmission of information so that the entire command chain can operate at the required tempo.

The Air Force is making such moves towards digitisation of its command structures, supported by the technologies associated with AI—the e-JFAC concept.[9] Progress in digital technology should enable C2 Air to:

- **Automate general tasks** of airspace management and coordination.
- **Have available dynamic, resilient and connected databases**. Resilience comes from spreading of data (between aircraft, air bases and command centres), from its transmission and from functional applications with or without connectivity.
- **Give sense to data** by optimisation of man-machine interfaces, to redirect human effort onto the most useful information, which means the human will remain in the loop, or in close supervision of it (on the loop), as required and as a function of context and operational tempo.
- **Assist manoeuvre planning** by offering relevant modes of action. AI will then be able to enhance the traditional techniques of serious game by increasing the available possibilities, anticipating the probable behaviour of the adversary and increasing the chances of facing him with a dilemma.
- **Assist conduct of a manoeuvre**, by following divergences from the plan and by proposing reactive changes in the face of contingencies.

Thereafter, the involvement of AI in C2 Air should lead to shortening the OODA loop, particularly in air operations evolving well away from decisional centres.

Connected, Collaborative Air Combat and Virtual Cognitive Assistance[10]

In the face of growing anti access/area denial (A2AD) strategies, conducted in and from airspace will increasingly be regarded from a multi-domain point of view, within which its collaborative dimension will be one of the measures of freedom of military action.

Networking of different airborne weapons systems centred on the Rafale and the future Next Generation Fighter (NGF) will make new modes of collaborative

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(9) JFAC being Joint Force Air Command.
(10) FAURY Étienne and PAPPALARDO David, *L'intelligence artificielle dans l'Armée de l'air*, Special edition of *Défense & Sécurité Internationale* (DSI) No 65 (*Intelligence artificielle – Vers une révolution militaire ?*), April 2019.

combat possible, which will in turn increase the intrinsic fighting strength of the platforms. But there again, connected, collaborative air combat will also necessitate piloting of ever more complex systems. AI has therefore to allow the creation of a genuine virtual cognitive assistant to the aircrew, whose double aim is aiding decision-making and piloting of complex systems.

Aids to Decision-Making

Within the Man Machine Teaming (MMT) study programme, co-directed by Dassault and Thales, the aim of studying this virtual assistant is to make it proactive, by suggesting changes in the operational states of objects, and also reactive, by continually choosing the best function or the best resource to obtain the desired change of state. It will have to interact and work in an intuitive and natural manner with the aircrew if it is to help them in their missions. This means capabilities to adapt displays and alerts to the tactical situation and to the cognitive workload of pilots, assist the reconfiguration of systems following breakdowns and faults, improve prediction of the chance of success of a weapon firing, adapt navigation as the tactical scenario develops and more yet.

Management of complex systems and autonomy[11]

Connected, collaborative air combat will go hand-in-hand with strengthened partnership between human operators (whether embarked or not) and the autonomous functions within a system of systems. This partnership must improve the effectiveness of the mission above that which the traditional manned craft could achieve by itself. To achieve this, the virtual cognitive assistant must be in a position to respond to demands placed upon it, to anticipate needs and to act autonomously, though in coordination with the overall system.

For example, combat in numbers (packs of manned platforms, combat drones or remote carriers) will offer the effects of saturation, which will make neutralisation of ground-air defences of an A2AD network easier. Collaborative autonomy will in this case allow overall coherence of flight trajectories—avoidance of collision and assessing the performance of the saturation effect—in particular for stealthy elements and in a Navwar context.[12] Besides that, it will improve the survivability of the overall unit by assigning designated tasks to certain consumable elements to the benefit of the whole pack. This approach is to wear down the opponent, as distinct from the classical duel in the sky, which very often needs more expensive technology and which is difficult to guarantee over the long term.

The arrival of cognitive virtual assistants and the collaboration within a system of systems that goes with it will, in short, empower air strategy with ubiquity through

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(11) Pappalardo David, *Combat collaboratif aérien connecté, autonomie et hybridation Homme-Machine : vers un "Guerrier Centaure" ailé ?*, *DSI* No 139, Jan-Feb 2019, p. 70-75.
(12) Navigational warfare, which incorporates PNT, meaning Position-Navigation-Time.

recreation of the mass that is essential to open the spatial and temporal doors to air superiority in the face of enemy defences.[13]

Protection: the Sole Solution to Counter Adverse AI

The advent of AI is not only a source of opportunities, it is also harbinger of new threats. No longer can anyone claim to beat AI at chess or *Go*. If strategy is, according to Coutau-Bégarie, a debate between opposing forces in a conflictual environment, the armed forces have to be in a position to face the adversary with a higher intelligence, able to operate at a higher speed over a broader spectrum.[14][15] The Air Force, itself facing growth of this new form of conflict, needs to be in a position to counter massive, synchronised, sudden and autonomous attacks, be that in cyberspace, for the analysis of weak signals, or in the face of a saturating swarm attack of mini drones or cruise missiles. In particular, the threat of a swarm of hostile mini drones against an air base or other sensitive site poses a real challenge to national ground-air defence capabilities: the miniaturisation of these technologies and their easy availability is making the threat from Low, Slow, Small (LSS) drones ever more credible and dangerous.

At the other end of the spectrum the emergence of a hypervelocity threat by its very nature means we have to possess defence systems that are more and more automated and reactive, given the short reaction times afforded.

Education and Training

As a final point, AI must play a key role in transforming and improving the training of airmen in all their operational functions. On the individual level, AI will be able to stimulate active and interactive learning through personalisation of syllabi, hence creating a sort of virtual coach. Regarding virtual operational preparation, AI will facilitate generation in the various simulation tools of representative, threatening virtual opponents.

On the level of the Air Force as a whole, AI collation of data from doctrine, training and operational feedback should lead to better performance evaluation, and short-cycle identification of channels for improvement. AI and massive, coordinated data handling will then help the Mont-de-Marsan Air Warfare Center (*Centre d'expertise aérienne militaire*—CEAM) to become a creditable battle lab, capable of developing tactics, techniques, procedures and doctrine and being in a position to advise the operational chief and the staff headquarters.

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(13) MALIS Christian, *Horizon 2030 : réflexions prospectives sur le combat terrestre*, *Revue Défense Nationale* No 778 March 2015, p. 105-112.
(14) COUTAU-BÉGARIE Hervé, *Traité de stratégie* (7th edition), Economica, 2017.
(15) PAPPALARDO David, *DSI*, *op. cit.*

The airmen shall not be the subject of the algorithm

In conclusion, and following in the footsteps of one philosopher and expert in autonomy, to see robots as mirror images of what we should be is an error. The manner in which we program them or the information that we 'teach' them will reflect our prejudices, our cognitive biases and all that ought to change in our societies. Robots will not create a perfect world for us.[16] AI and robots will not create a perfect world for the Air Force either. They bring us many promising things but do not announce the end of the airmen within the FCAS. To this end, the Air Force is developing a voluntarist strategy with neither false modesty nor excessive hope but always with responsibility. Its main factors are:

• **Critical acknowledgement of data as the basis of AI**: it is essential to store, archive, structure and add value to data by setting up adapted infrastructure and rationalising our processes.

• **Acceleration of application and adoption of AI**, not only with regard to the technology, but also organisation and human resources, so we are not left behind. For the Air Force and air operations to take full part in the AI age, future systems architectures will need to be designed to cater for continuous digital development throughout their long lives (30 years for a Rafale). We must be able with ease to improve software and on-board data storage and calculating capacity, without having to requalify the entire aircraft. That will mean separation of flight and combat systems and dissociating hardware, software and data. That is in itself a revolution.

• **Hardening against the increasing cyber threat**: hence the need to retain non-connected modes of action and the ability to use fallback modes to maintain a certain level of resilience.

• **Strict ethical rules**. A machine can never be moral or ethical. But as Louis COLIN indicated, ethics remains pertinent in consideration of risk and in good governance of robotics for aggressive use.[17] Ethical action has to be made in consideration of the precepts of utilitarian ethics, in which an action is good when it produces the best possible consequences for the individuals or enterprises affected, and the ethics of responsibility, in which 'I respond to the consequences of my actions'.

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Given the stakes involved, the rationale of the air combat system must be shaped by three essential conditions: that the association of man with machine benefits from accuracy and speed of automation to increase many-fold the agility and creativity of human intelligence; that AI will not abolish human responsibility and will not remove the man from the decision process when committing to lethal force; and that engineers' ideas in design will not replace those of the airmen in the decision-making process. Man must never be subjected to the algorithm, but use it to improve his own performance. ◆

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(16) See: RUFFO DE CALABRE Marie-des-Neiges, *Itinéraire d'un Robot tueur*, Éditions Le Pommier, 2018, p.180.
(17) See: COLIN Louis, *Éthique des systèmes d'armes autonomes (dissertation)*, University of Cergy-Pointoise, 2018.

Remotely-Piloted Military Aviation: Permanence in Support of Action

Jérôme MARY

| Lieutenant Colonel, Plans office of the Air staff (EMAA).

F ollowing a twentieth century that led to the dominant role of aviation in military operations, the twenty-first is sure to see a notable increase in remotely-piloted military aviation. These airborne systems, often at a lower cost of ownership than their manned equivalents, were originally designed to carry out missions considered 'dull, dirty and dangerous'. In the air, their main *raison d'être* was to gather intelligence but their use has rapidly expanded as a result of progress made over the past twenty years, and they have become truly multi-role intelligence assets and valuable tools for tactical coordination. The Air Force now has considerable experience in the use of intelligence-gathering drones, and in particular, theatre or MALE drones.[1] Carried along by technological developments, remotely-piloted military aviation is moving progressively into new fields. Despite this increased call upon technology, man must remain the guarantor of supervised employment of his combat system and of its ethical use, and hence he must receive training appropriate to these challenges.

Development of drones and the advent of permanent airborne reconnaissance

Although from the nineteen-seventies on, some other forces operated drones like the Nord Aviation CT.20, Canadair CL-289 and Sagem Crécerelle, these unmanned vehicles then followed a flight plan programmed on the ground. Their mission was IMINT[2] reconnaissance of sites in support of the artillery, looking for enemy military units. The mission was conducted in contested airspace and remained conceptually close to the reconnaissance missions of the First World War. Here, the drone replaced man in what was considered 'dangerous'.

The Air Force's first steps towards the use of drones were made in the nineteen-nineties with the Israeli Hunter system. It was fitted with an optronic ball and a laser illuminator but was limited by its communications system to an operational range of 200 km (125 miles). Its heavier successor, the EADS/IAI Harfang, announced our country's membership of the MALE drone users' club, freeing us from limitations of operational range linked to line-of-sight communication. With this type of aircraft

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(1) Medium Altitude, Long Endurance.
(2) Intelligence from imagery sources.

dedicated to low-intensity or asymmetrical operations, the low level of air threat in some theatres led to designing an vehicle ideally adapted to long-endurance surveillance with medium-altitude flight for discretion and reduction in fuel consumption, low speed and straight, glider-like wings to increase endurance, a dome for the satellite aerial to allow piloting beyond line of sight (BLOS) and real-time transmission of information. Its level flight, low speeds and light load meant that the structural reinforcement needed for a combat aircraft, for example, could be dispensed with, allowing a greater fuel load. Moreover, the absence of aircrew saved weight and overcame the human physiological limits of over 20 hours' flying time. This type of drone therefore covered the 'dull and dirty' aspects.

Increased activity of the various types of drone operated by the Air Force is evidence of the success of the surveillance drone concept. After the Hunter (1,500 flying hours), the Harfang saw a dramatic increase in activity (15,000 hours in 10 years), which the MQ-9 Reaper built upon (25,000 hours after five years of use). In operational theatres, the need to gather intelligence totally discreetly, and without any change in the environment, is continually increasing. The increased capability of the drone that allows the permanent surveillance over areas of interest means that several crews are needed for each to allow for reliefs: this presents a major challenge to find the number of operational crews required. The next step will be the arming of drones in order to seize opportunities to act or to protect without delay during these surveillance phases. Such a capability was initiated by the US Air Force on its MQ-1 *Predators* at the beginning of the century.

Beyond the increase in drone activity lies a revolution in their use, which has expanded from the simple, occasional reconnaissance mission to seek out military materiel to that of constant surveillance of an entire environment, including the people in it.

Since operations in Afghanistan, all theatres now set us against irregular adversaries in counter-insurrection and anti-terrorist operations. Modes of action employed by the adversary include dilution among the population, hiding of depots and training centres and the combined use of rudimentary material, civil technologies such as GPS, and modern communication methods. It is no longer a question of simply performing reconnaissance of military materiel to detect and identify them to establish an order of battle but of using the persistence of long-endurance drones to survey areas and track individuals over long periods in order to understand their organisations and intentions. The operators' work therefore centres on the use of wide-field sensors to detect activity in incompletely covered areas, then establishing the patterns of life of individuals or groups of people with narrower-field sensors. The lack of anti-air threats coupled with this need for surveillance over the long term has ensured the primacy of the drone in intelligence gathering for low-intensity military operations. But when the adverse ground-air threat reappears, as it did in Georgia in 2008 and Ukraine in 2014, the use of this type of drone becomes far more complicated because of its vulnerability.

From surveillance to strike

In the case of asymmetrical operations, permanent occupation of airspace by surveillance or strike assets puts the enemy under immediate pressure and precludes any mode of action that is too obvious. For this, the MALE drone is a game changer, since it upsets the element of uncertainty: the insurgent who previously could secretly prepare an ambush by assembling forces or planting an IED without being seen, now risks permanent discovery. Arming of these aircraft has added a capability for immediate action that is complementary to other aircraft such as fighters and helicopters and allows for immediate strike if the latter are unavailable. The long endurance drone also allows the choice of the most opportune moment for an air attack against a transient, mobile enemy who exploits urban areas for hiding and therefore avoiding strikes because of the presence of civilians. In this, the rules of engagement that apply are identical for both manned aircraft and those whose crews are 'remote'.[3]

The crew at the centre of the MALE drone's capability

A crew of four people man a French Reaper for the conduct of its missions: a pilot, a sensor operator, an image interpreter and a mission commander. The first two take care of what is happening in the present time whereas the other two analyse the information gathered and prepare future action. During long missions, several crews relieve each other in order to remain attentive and efficient. The environment of a cockpit on the ground, being far less constraining than that of a combat aircraft, means much more analysis equipment can be incorporated; liaison officers can be present, too, in the case of certain operations. The crew is connected to different levels of command of forces via a wide array of methods and also has to hand an unequalled range of digital and informational resources to support its analysis capability, which often gives it a central role in intelligence and coordination of action.

Lethal operations of MALE drones are regularly challenged, broadly on the basis of two arguments, the first being the ease with which they would be able to achieve targeted neutralisations outside any standard legal framework. Yet the means (the drone) must not be confused with the one giving the order. The second argument is the 'robotisation' of the system, since these drones would lead to automating the decision-making processes leading to any neutralisation, and therefore dehumanising them. Now, drones like Reaper call upon certain automatic flight functions only—and even they are quite basic compared with those in airliners: the important functions of intelligence and targeting are entirely conducted by the crew. Man is permanently in the loop in real time, from identification of the target through to the strike, which is far more than for a cruise missile strike or artillery fire onto map coordinates. This advantage of the man in the loop has also led to a significant proportion of attacks conducted by combat aircraft and helicopters in the Sahel being guided by drone

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(3) Florence Parly, Minister for the armed forces, said in her closing speech of the *Université de la Défense* on 5 September 2017, that she wanted from the outset *to refute any possible confusion and to dispel possible fears. No, an armed drone is not a killer robot. They are two systems quite unlike each other. This decision* [to arm Reaper] *changes nothing in the rules concerning the use of force with regard to the law of armed conflict.* (www.defense.gouv.fr/).

crews. In this way, the technological developments that are entering service will contribute to boosting further the role of the unmanned aircraft in air-ground missions in permissive environments and to diversifying their use.

Rapid progress and more varied uses

There is considerable technological profusion in the field of surveillance drones, both small and large, and there is rapid progress in conceptual fields—those of new uses, platforms, automation of piloting, recovery, information handling and insertion into airspace. The Air Force is also interested in small drones for reasons that include a less rigid regulatory framework that facilitates innovation, civil and military uses generating real dynamism, and rapidly increasing performance in endurance, flight envelope and sensor quality which usefully complements that of the MALEs. It is envisaged that they could cover the particular operational needs of the Special Forces, as well as protection of sites, the anti-drone battle and exploration of technologies essential to future swarm systems. The essential tenets of their employment—since they are common to all drones—would also form the basis for operator training.

Much progress is also being made on optical and radar captors, or sensors, from the original narrow-field to the wide field now afforded by systems such as Wide Area Motion Imagery—WAMI, and also means for listening, systems for integration in airspace, armament and, of course, connectivity. In parallel with them, new capabilities are appearing: equipment for offensive EW, powerful lasers, acoustic buoys for maritime surveillance and more. Automatic data handling, especially through the use of Artificial Intelligence (AI), will also ease the crews' analysis work and their manipulation of sensors, which will lead to their even greater effectiveness.

The most symbolic area of interest, and with great potential for growth, is clearly that of unmanned combat air vehicles (UCAV). Nevertheless the survivability of platforms poses a crucial challenge that requires major compromises to be made in their design comparable with those of combat aircraft, and very precise coordination with other aircraft in flight. The timescale for the arrival of these drones is rather longer.

To be able to take on these developments, the MALE is, and must remain, a low-cost carrier of high-tech captors, or sensors: the flying vehicle itself does not present any major technical challenge in terms of flight envelope or carrying of passengers, in contrast to the captors and communication systems. The interest lies in fitting the widest possible variety of captors on a single platform, such as ELINT, SAR-GMTI[4] and optronic balls, thereby sharing implementation costs and greatly increasing the available capabilities for conducting a mission. It follows that it is essential to design platforms with reserves of volume and energy so that they can be fitted with extra facilities later during their service lives and also to reduce the time needed for qualification in order to introduce new technologies more rapidly. All these technical developments will lead to a greater range of their activity, which will include coordination of

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(4) ELINT=intelligence from sources of electromagnetic radiation/transmission; SAR=Synthetic Aperture Radar; GMTI=Ground Moving Target Indication.

reconnaissance and strike missions, jamming, maritime surveillance, destruction of some short-range ground-air sites, logistic transport and in-flight refuelling.

There is greater diversification in the use of mini drones, too. The forces are using them more and more to improve their capacity for surveillance and investigation and to guide commandos in their action. Aside from use in theatres of operation, the Air Force is acquiring them for use in ensuring protection of its sensitive sites.

The drone will also lead to the use of airspace virtually devoid of aviation today: the stratosphere, for example, offers undeniable operational advantages from which the Air Force could benefit. At these high altitudes of over 20 km (66,000 feet) it is possible to maintain electrically powered drones in flight for several weeks and in a few days reach areas far removed from the starting point. Since functions such as communications relays would become conceivable, they could complement our space capabilities over permissive or semi-permissive theatres.

This extension of the operational domain of unmanned aviation means a rethink of captors is necessary to ensure multi-sensor integration from the lowest levels of information gathering and instantaneous retransmission of pertinent intelligence both to the forces and to the highest strategic levels.

In spite of this profusion of innovations, the ability to use unmanned aviation in as flowing, flexible and reactive a manner as a manned aircraft does not exist other than with mini drones. Integration of drones into ever more congested airspaces and into air traffic generally therefore requires major effort to ensure the military freedom of action of our systems. The technological trend is also towards the reduction of some of the barriers to the use of small and large drones in terms of altitude, radius of action, autonomy and therefore of employment, even if the conditions of implementation related to their size will continue to maintain a degree of segmentation. One might then question what can be automated and what should be kept under human control? The question of automation is closely linked to the training of the crews.

Training: the crucial challenges

The first attempts at regulation[5] segregate drones by their size, even though technological developments are sure to render such segregation obsolete by the increasing ability of small drones to reach higher altitudes—over 2,000 metres (6,500 feet). Moreover, a large part of airspace is densely used and is subject to strict rules of navigation both over national territory and on operations, for which the operators have to receive adequate training. Piloting of unmanned systems must therefore be reconsidered: such is the objective of the Air Force's *Cyclope* project to create a joint Centre for drone crew initial and continuation training (*Centre d'initiation et de formation des équipages de drones*—CIFED) on its air base at Salon-de-Provence. This will offer common aeronautical training independent of the size of drones but adapted to the types of airspace

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(5) Decree of 17 December 2015, concerning the use of airspace by aircraft circulating therein with no person on board (www.legifrance.gouv.fr/eli/arrete/2015/12/17/DEVA1528469A/jo/texte).

in which they will operate and to the intended mission profiles. It is essential for air safety that airspace is managed according to common rules, hence the need for training that instils the fundamentals of coordination so that the operators can launch their drones into controlled airspaces.

The second element of training consists of specialised instruction on the conduct of systems, to give drone operators the ability to detect attacks on the integrity of their systems. Resilience will rely more than ever on the airmen at the controls who masters the precise functioning of his system: he or she is the one who can recognise failures and can take back manual control when faced with potential threats such as cyber attack, jamming, directed energy weapons, jamming of GPS and physical strikes. Cognitive science and ergonomics will be fundamental here: experiments being conducted at the Mont-de-Marsan Air Warfare Center (*Centre d'expertise aérienne militaire*—CEAM) need to put the human cognitive factor at the centre of man-machine interface design.

Man must also be at the centre of digital transformation, which is intended to add value for those who benefit from it—he armed forces and the centres of decision-making. Connectivity, collaborative combat and data links must not end up in a position where the data scientist or some other person in the development team becomes responsible for military action simply because he designed the AI-based interpretation system. Man must remain at the heart of the system, so that *he* is the decision-maker. The ergonomics and degree of autonomy afforded to the unmanned airborne vehicle must retain a human at the heart of the system—in the loop—so that through his combatant's ethics he is the guardian of the use of his combat system and of the level of violence employed.

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All these developments are promising, but we need to remain modest in any prediction of the future of military drones around 2035, since 90 per cent of the innovations to come in the fields of AI and robotics are still unknown. That said, there is a distinct trend towards increased use of drones in air, land and sea military systems. The over-complexity of systems, cyber threats and disputes in extra-atmospheric space (regarding communications and navigational positioning, for example) will have effects on all things entirely remotely operated or automated. We therefore need to learn how to manage the evolution of the technologies concerned and to guide the men and women who will operate these systems. The challenges to safety and security of operations will require robustly designed systems and training of military personnel in aeronautics, conduct of remotely-controlled systems and the ethics of the military in operations and, moreover, the time and means needed to do it. ◆

Air Force Air Bases
and the Challenges
of Threats and Future Operations

Bruno DE SAN NICOLAS and Bruno VALLOS

Respectively Colonel and Lieutenant Colonel, Air Staff plans office (EMAA).

Air bases, and the network of which they are a part, are major combat assets that allow the Air Force to conduct its permanent missions and at very short notice to project power or forces to give the political level the reactivity it requires. To continue to do this, like all of our armed forces they have to adapt to the new threats against them. The distribution of bases across national territory and on operations follows the principles that today define the Air Force's stationing plan.

During the night of Friday 13 April 2018, Operation *Hamilton*[1] was launched from a number of air bases. The operation showed the vital nature of the bases in the preparation and conduct of sizeable air operations. This operation, like the actions conducted at very short notice in Mali in 2013, brought out the importance to air power of the base network, and demonstrated its relevance and effectiveness.

Air bases today

The definition of an air base (from the *Code de la défense*[2]) covers it as a place for stationing of forces and means of material and personnel support divided into units. And yet the air base is not just an administrative notion, for it is at once a combat platform, an aerodrome from which operational missions of the Air Force are executed simultaneously,[3] a place of training and maintenance in condition of the air forces and a living area for airmen. It therefore fulfils many functions which confers upon it a central position in the organisation of the Air Force, as General André Lanata, former Chief of the Air Staff (*Chef d'état-major de l'Armée de l'air*—CEMAA), underlined when saying that functioning by air bases is the key to understanding the organisation of the Air Force, and that the air base constitutes an intrinsic part of

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(1) Joint US, French and British operation against the Syrian regime in Damascus and near Homs in reprisal for the 7 April 2018 chemical attack at Douma.

(2) Article R3224-11 of the *Code de la Défense* (www.legifrance.gouv.fr/).

(3) The airborne element of deterrence, the permanent posture of air security (PPSA) with combat aircraft and helicopters on alert, direct intervention from the mainland to theatres of operation by projection de forces or power and public service missions.

the 'combat instrument' of the Air Force. He added that the network of bases constitutes the linkage essential for reactivity, permanence and resilience of action.[4]

More broadly, air bases contribute to the resilience of the nation, taking part in crisis management and in the re-establishment of functions essential to the continuity of the state, witness the role played by the network of bases during major events such as natural catastrophes. After hurricane *Irma* in 2017, the Air Force rapidly set up arrangements to help stricken populations, dispatched masses of freight and conducted evacuations, working in particular from the air base BA367 in Cayenne.

Air bases are also protected areas in which public assets and services of the state can take temporary refuge, as was the case at Evreux during the riots in 2005, when the town's buses were sheltered there.

The network of air bases: principles of the stationing plan

The geographical distribution of air bases relies on a stationing plan which obeys several principles, some drawn from the lessons of history. The plan must above all ensure the continuity of permanent operational tasks.

Deterrence means having sites offering resilience of forces through dispersion of assets and redundancy in platforms such as operational centres. Some among these are hardened and underground, among them a large number of highly secure sites dedicated to redundancy in communications.

Air defence of the homeland is conducted via the permanent posture of air security (*Posture permanente de sûreté aérienne*—PPSA), which requires detection of all air threats and the immediate activation of reaction measures. This is achieved by surveillance of airspace, itself relying on networked radar and radio stations that cover the entire national territory and are linked to air operations command and control centres. This network has to take account of the physical and geographical reality of the territory to be protected and therefore requires the creation of numerous isolated sites positioned in the main on high points and which are attached to the nearest air base for their permanent support. This defence measure will soon be extended to cover space. Localisation of platforms housing air assets dedicated to the PPSA permit combat aircraft and helicopters to intercept any aircraft overflying national territory in a short space of time. We therefore need not only to have two air bases in each quarter of France able to accept weapon-carrying aircraft but also bases close to sensitive sites for accepting helicopters performing air policing tasks against the slowest aircraft.

In consideration of immediate strike missions conducted from national territory, the stationing plan has to take into account the need to disperse forces to ensure a high level of resilience when under direct threat, as well as the capability to refuel and re-arm units easily. Moreover, projection of conventional or special forces must be

(4) National defence and armed forces committee hearing of General André Lanata, Chief of the Air Staff, 19 July 2017, at the *Assemblée nationale* (www.assemblee-nationale.fr/15/cr-cdef/16-17/c1617006.asp).

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achieved from a network of adapted and secure military air staging points close to ground force bases and logistic depots in order to minimise transportation times which would otherwise prejudice reactivity.

For the permanent public service mission of search and rescue (SAR OACI[5] and maritime rescue) Air Force helicopters intervene on land and sea according to their areas of responsibility. Unsurprisingly, medical evacuation (Medevac) tasks require proximity to major military hospitals.

The distribution of air bases must also cater for the operational preparation of units. In order for operational potential not to be reduced by transit times and distances, bases are positioned as close as possible to designated air training areas and to firing ranges. These areas have to allow combat aircraft to fly supersonically and to be compatible with the performance of new generation munitions whose increased range requires ever larger dedicated airspace if realistic training is to be maintained.

In the search for optimisation of aircraft maintenance, logistic flows, support, simulation and personnel, aircraft of the same type are generally grouped together on a single air base. There is, however, a limit to this, as it affects resilience of the assets concerned and also has environmental impacts, not least being the noise disturbance. This is why there are as a general rule only two or three aircraft units stationed on each base.

Stationing of military assets inevitably means construction of often-vast airport infrastructure, special-to-type industrial installations for maintenance in particular, and restaurant and accommodation facilities that together offer permanent support to missions and alert postures. Some air bases in strategic positions require reinforcement in certain situations: they have aircraft parking areas and transit squadrons designed for these reinforcements, as at Solenzara in Corsica and Djibouti. Given all of these facilities, moving an air base is neither simple nor fast, and is often very costly.

Personnel conditions need also to be taken into account in the stationing plan. Proximity of an attractive centre of life and employment for family members contributes directly to the retention of personnel at a difficult time for human resources. Since air bases employ 1,500 to 5,000 military and civilian personnel, they are also ambassadors for the service, links between the forces and the nation and advantageous for recruitment.

These principles shape the network of air bases that gives the Air Force the capacity to fulfil its operational contracts—especially its permanent missions of deterrence and protection of the territory—and to achieve efficient operational preparation of its forces in a manner sustainable over the long term.

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(5) *Organisation de l'aviation civile internationale* – the International Civil Aviation Organization.

Air bases and future threats

Air bases at home and in operational theatres are effective military instruments but are also tempting targets, since aircraft are more vulnerable on the ground than in the air. This is why bases have to be able to counter threats of all types: from airspace, from the ground, the potentially saturating, the hybrid and the non-kinetic.

The threat from the air is of strikes by guided bombs and cruise missiles. That from the ground includes ballistic missiles, anti-tank missiles, artillery, rockets, mortar rounds and direct attacks by light, mobile commando-like units. The non-kinetic threat covers cyber or electronic warfare (EW) activity and action aimed at degrading satellite positioning signals and its consequences. Attacks by mini drones are one aspect of hybrid or asymmetric threats, along with terrorist attacks.

A few decades ago, these threats were largely the prerogative of state actors but with today's proliferation of weapons, non-state actors have the ability to acquire the means to impose at least some of them. The means are obtained either by capture from the arsenals of failed states or directly from regional powers which use the non-state actors as intermediaries.

Countering aerospace threats:
Anti Access/Aerial Denial (A2/AD)

Defence in depth, using an A2/AD-based system of defence, is the only way to counter threats from the air and to prevent adverse forces from attacking our air bases. This system of defence is defined by its capacity for detection, intercept and resilience.

When facing modern, fast, long range and potentially stealthy threats from airspace, we need the long-range detection that is provided by a multiplicity of sensors networked together to improve overall detection performance and to give us better sight of stealth vehicles. Intercept capabilities need to be spread geographically in order to cover each other and to provide multi-layer defence. This includes guns and long, medium and short-range missiles, and in this way the best means can be brought to bear as a function of the threat by a cost-effectiveness analysis. Resilience is inseparable from the interlinked network and the multi-layer aspect of defence: it is essential that defensive system continues to operate despite successful attacks against it, and this overall defence network depends naturally on that of air bases.

These composite, Integrated Air and Missile Defence Systems (IAMDS) aim also to cooperate with aircraft to prevent an adversary from evading interception, thus creating a robust posture of defence in depth.

Air defence weapons programmes such as the system for command and conduct of airspace operations (*Système de commandement et de conduite des opérations aérospatiales*—SCCOA 4 and 5) and the new generation, medium range ground-based ground-air system (*Système sol-air moyenne portée terrestre-nouvelle generation*—SAMPT-NG) will cover these needs in both quality and quantity. But qualitative superiority alone can no longer lead to victory when the adversary has access to assets

and knowhow that reduce the gap with ours. We therefore have to possess systems and weapons in sufficient quantity to afford us resistance and endurance. Modernisation will also take into account cyber threats and EW activity—the Trojan horses of modern combat.

Additionally, a forward air base with this type of defence is a thorn in the side of the adversary's structure that limits his freedom of action. Hence it is not only a defensive arrangement but an offensive one, too.

Countering drones

In parallel with conventional air operations, operations in the Levant over the past three years have witnessed increased use of drones by all parties. Used initially as machines for reconnaissance and coordination of action, they have since become weapons.

The size of a drone can range from a few millimetres, the nano-drone, to a wingspan of several tens of metres for the high altitude, long endurance (HALE) drone. Whilst large drones can be treated in a similar way to a conventional air threat, the smallest require adaptation of defence measures.

Mini-drones, by virtue of their size and the use of plastics, are almost invisible to radar. They navigate by GPS, move slowly at low altitude over a range of a few tens of kilometres. They are easy to put into operation, for which little training is needed. They can therefore be used for low-tech surprise attacks without exposing the operators. Basic drones carrying mortar shells were successfully used at the beginning of 2018 against Russian air bases in Syria in saturating attacks against parked bombers, which they succeeded in damaging.

The Air Force's anti-drone policy is being activated within the arrangements for protection and air security (*Dispositifs de protection et sûreté aérienne*—DPSA) and those for protection of the Armed forces ministry's sensitive installations, which include air bases. At their level, protection and ground-air defence squadrons are in charge of putting new detection and protection assets into action.

With regard to protection of installations, we have to ensure continuity between the centralised arrangement for air security, for which the Air defence and air operations command (*Commandement de la défense aérienne et des opérations aériennes*—CDAOA) is responsible to the Prime Minister, and which takes air threats into account, and the decentralised arrangements for security and protection that must counter the mini drone threat to sites. These two functions are closely linked in order to afford a permanent, seamless response appropriate to the threat.

In addition to active protection against aircraft and drones, the long-established rules of the art of protection of air bases have been retained: multi-layer ground defence in depth, hardening and dispersion of aircraft shelters to avoid mass destruction, protection of munitions and fuel dumps, and protection of personnel and intervention

forces. Helicopters on active air security measures patrols[6] and airborne gendarmes ensure protection beyond the physical limits of the base.

Advantages of drones in air base protection and defence

The PRODEF[7] challenge, recently organised by the Air Force and the Agency for innovation in defence (*Agence de l'innovation de Défense*—AID) has highlighted the possible contribution to the security and protection mission of new technologies such as patrolling or surveillance drones using artificial intelligence (AI) to detect suspect behaviour. The bases themselves are very active in this field. In 2016 the 'smart base' at Evreux organised the first 'hackathon' on security and protection. This demonstration gave rise to novel ideas for detecting possible threats to air bases, particularly through the use of digital methods. The Centre for military air experimentation (*Centre d'expérimentations aériennes militaires*—CEAM) is continuing trials aimed at using commercial drones in support of base surveillance capabilities.

The first are being put into service now and will in time allow surveillance rounds to be conducted, allowing detection, interception and identification of intrusions and *de facto* increasing the level of protection of the sites. It is even conceivable that drones be used to scare birds from runways. Clearly the combined activity of surveillance drones and the aircraft of the base requires the establishment of strict rules to ensure air safety.

Innovation is apparent everywhere in the drone and anti-drone sectors, and is led by the dynamism of the civil sector. The Air Force is closely following developments there from its Centre for drone excellence at the air base of Salon-de-Provence and from the CEAM at Mont-de-Marsan.

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Air operations can only exist because of the existence of air bases, either on home territory or deployed in overseas territories, in foreign countries or theatres of operation. They are the fundamental combat instrument of the Air Force and also the places for operational preparation, stationing of units and for the life of airmen. By their size, their level of protection and their role as logistic centres they easily accommodate joint organisations, particularly in-theatre.

In an unstable geostrategic environment, the Air Force seeks to maintain a stationing plan based on an appropriate geographical division of air bases that allows assets to be dispersed, affords sufficient resilience and retains the reactivity required for the permanent missions and for operations launched from the homeland, which for the past decade have increased in number.

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(6) In French this is *Mesures actives de sûreté aérienne*—MASA.
(7) Lagneau Laurent, *L'Agence de l'innovation de Défense lance un défi pour améliorer la sécurité des bases aériennes*, *Zone militaire-Opex 360*, 11 January 2019 (www.opex360.com/).

The essential protection of the bases takes account of the diversification of threats, especially the rapidly developing one coming from drones. But we also have to ensure the protection of our deployed bases against serious threats that were once the prerogative of states but which are now entering the arsenals of numerous irregular adversaries as a result of galloping proliferation.

The air base is a remarkable, reactive, high-performance and complex system whose 360-degree security has to be designed from a holistic point of view if we are to ensure continuity of operations whatever the situation. The Air Force is committing considerable effort to that security, effort that must be continued over the years to come, given the increasingly challenging nature of threats. ◆

New Perspectives
for Simulation

Tanguy Benzaquen

| Colonel, Air Staff (EMAA).

The most modern among air forces operate complex equipment with increasing levels of performance to respond to multiple threats. They often act in coalitions and in delicate strategic environments where error cannot be tolerated. Aircrews need to have a very high level of competence, acquired through a selective training process and maintained by demanding operational preparation that is representative of the type of current conflict in which they might be called upon to act.

This operational preparation is conducted mainly by aircrews' activity in the air and covers instruction, daily training and hardening for high-intensity combat. Each flight conforms to a programme that is part of the overall operational preparation cycle. In parallel, simulation has been used for over 40 years to teach the functioning of the aircraft, to make the pilots' gestures automatic and to standardise teamwork.

Recent technological developments in digital matters are continually improving simulation tools in terms of accuracy and networking, and hence immersion, at the same time rendering their use and management easier. They could be employed in many more tasks in simulation and lead to its much more widespread use. The Air Force has developed a far-reaching modernisation programme for its simulation equipment in order to face up to the major challenges of operational preparation. The major fields of application envisaged are massively networked simulation on the ground, offering complex tactical situations and realistic threats, together with simulation in the cockpits of aircraft in flight. The objective is to bring the two together to improve battle readiness.

Why train?

When flying in a cockpit at close to 500 knots, everything happens fast and each action could prove fatal: at the same time the physiological environment (pressure and effect of gravity) tends to reduce everyone's perception and cognitive capacities. To be the best in combat the operational preparation of aircrew is primordial.

There are three aspects to it: instruction, regular training and battle-hardening. Instruction consists of teaching the technical and operational functions of the aircraft in its normal and fallback modes, then acquiring competences such as aerobatics, blind flying, navigation, formation flying and basic combat manoeuvres. The second aspect

involves daily rehearsal of these actions to consolidate the competences at a more demanding level and in an environment more representative of real combat situations. This training covers activities that demand great dexterity, such as in-flight refuelling and live firing. It also maintains coordination of actions and flight trajectories of the team members, understanding of the enemy air picture in order to thwart his manoeuvres and the effective use of the few armaments available. The third aspect is battle hardening, which gives the aircrews the ability to manage complex combat situations in stressful, rapidly changing and unpredictable environments.

Operational preparation is an all-embracing process that brings knowledge, practice and experience whilst keeping up the individual physical qualities that are essential to flight. Moreover, the more complex the aircraft and the mission, the longer and more exacting the training and the more decisive the experience. To have crews able to fulfil all of its missions the Air Force has to provide for these three elements, which depend on several processes: knowledge of the aircraft and its mechanisation, standardisation of procedures, development end maintenance of the warrior spirit, ease and endurance in combat flight and the development of tactical sense, judgement, initiative and leadership. Currently only real flight can train all of these processes simultaneously and allow crews to perform to a high level when faced with the unexpected even when they are exposed to intense levels of stress. For this, they complete 180 flying hours annually. For the past 15 years, commitment to operations has led to a reduction in the proportion of operational preparation flying and an increase in flights over theatres. Whilst these missions are testing, they are centred on bombing (CAS[1] and AI[2]) in uncontested environments, and neglect other aspects of air combat, the acquisition of air superiority in particular.

In parallel with that, the aircraft has become more complex. Twenty years ago, each aircraft was specialised—for bombing (Jaguar, Mirage 2000N and 2000D), air defence (Mirage F-1C, Mirage 2000C), or reconnaissance (Mirage F-1CR). The specific nature of each mission and the equipment tended to separate the specialisations. With the advent of the fully multi-role Rafale, and the reduction in fleets, aircrews now have to be masters of all missions. On the multi-role F-15E *Strike Eagle*, US pilots fly some 250 hours annually. Budget constraints have held flying hours for Rafale pilots at 180 hours per year, as was the case for the previous generation of aircraft, complemented by 70 hours of simulation to master a far more complex weapon system and the full range of missions. The 180 flying hours are the foundation to ensure safety and endurance under the physiological demands of flight and to develop air sense. They are essential to the pilot for the ability to fly the aircraft while pulling 6 to 9 G, to understand the tactical situation, take the right decisions, coordinate the action of his team members and fire his weapon systems.

Apart from the operational preparation of aircrew, air-related training activity also has to cover the specific training for command and control of operations (C2) and

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(1) Close Air Support.
(2) Air Interdiction.

allow for rehearsal of real strike missions. It must involve all players in operations (from tactical to strategic levels) and ensure interoperability with allies.

Battle readiness—acquisition of the highest level of knowledge—comes up against constraints of availability of realistic environments: adequate training areas, representative air and ground-air training targets, electronic warfare systems, mission equipment and more yet.

Whilst simulation today is limited to mechanisation and standardisation, new technologies should permit its use in all aspects of operational preparation.

Advantages and limits of simulation

The remarkable teaching capabilities of simulation allow the acceleration of training cycles in particular. Unconstrained by availability or weather, it offers the possibility to focus on the important phases of flight and allows repeated practice of scenarios and alteration of chosen parameters. Replay of missions supports detailed debriefing and step-by-step improvement in performance. Simulation also allows exploration of dangerous situations that would be too risky to attempt for real, such as breakdowns and aggressive threats.

Simulation alone can help to remove some of the constraints on working up battle readiness, thereby complementing and enhancing real activity. Indeed, only the virtual world allows us to generate the level of threat met today in the most contested of environments.

Despite the lack of any indicator of the cost effectiveness of simulation, it is clear that increasing simulation activity means the length of training can be reduced and that a better level of expertise can be reached for the same amount of actual flying time. This mechanism is in place for Rafale pilot training and will continue with the arrival of the Pilatus PC-21 at Cognac. The US Air Force has trialled new methods with its Pilot Training Next programme, which by relying on massive use of free access to simulation has reduced the initial training time of combat pilots to a quarter of what it was. This experiment shows promise for acquisition of knowledge even though we need to wait for feedback from more consolidated experience, especially on the skills expected of a combat pilot.

Conformity of the simulator to the real system is in all cases fundamental to avoid a negative training effect caused by the time needed to adapt from any artificiality in the simulator to the real system. There are several levels of conformity between the two:

– High conformity: the simulator interface reproduces exactly the aircraft and its capabilities. This is the case for the A400M simulator and the Rafale simulation centres.

– Lower conformity: the simulation equipment reproduces a complex tactical situation almost identical to the real one, with sensations and a visual environment,

but the operator is not in a replica of his cockpit. This is the case for latest-generation flight simulation video games.

The prices of simulators vary as a function of the level of conformity, and given that the volume of activity that can be performed with any simulator has limits, it is the objectives of the instruction that will shape the simulation tools to achieve an appropriate level of conformity with real systems. For example, a simulator for basic teaching on the aircraft (say, normal and breakdown procedures and blind flying) and a simulator for advanced tactical training in a network will have very different requirements for fidelity of flight characteristics and representation of cockpit layout. Given budgetary constraints, the development of conforming simulators at reasonable cost is a major challenge for the simulation industry. On PC-21 there will therefore be three types of simulator, each adapted to a different phase of learning.

On the other hand, simulation now faces technical, human and financial difficulties: the slow development of simulation standards that follow those of the aircraft, difficult handling of obsolescence, limited performance of threat modelling thereby prejudicing realism, networking of simulators, security standards for information, lack of personnel for supporting missions and lack of simulators. These constraints reduce the added value of simulation in current training.

Nevertheless, progress in digital technology in the civil sector is cause for optimism *vis-à-vis* current constraints and gives hope for more widespread recourse to simulation in the future.

Technological developments and perspectives

Simulation already fairly well covers the fields of teaching the aircraft and its weapon systems. Investment now needs to be made in qualitative and quantitative improvement and in interoperability of simulation systems.

The movement towards all-digital simulators will lead progressively to dispensing with the use of real aircraft parts, which will ease updates as standards develop and will reduce markedly the costs of production and maintenance. The growing capacity of AI algorithms will make the behaviour of simulated targets more coherent and more easily modifiable (to make enemies more or less aggressive, for example), in turn making the objectives of the instruction easier to achieve. Improvement in the graphics of virtual and enhanced reality will afford a hitherto unequalled sensation of immersion in the scenario.

These new technologies are a sign of coming equipment that is adaptable, interoperable and natively able to exchange all types of data within dedicated networks.

Conventional simulators and distributed distance simulation

On each combat air base there are between one and four simulators, which do not allow for battle seasoning. The aim of distributed distance simulation (*Simulation distribuée distante*—SIM2D) is to connect the simulation centres of several bases for

simultaneous training within a single virtual scenario. But existing simulators were often developed by different industrial companies and were never designed to exchange information between them.

SIM2D aims therefore to connect them via independent multi-level bridges. In the short term, only the most recent can be connected (those for Rafale and Mirage 2000D). That is an important first milestone but the objective is interconnection of all operational players in the Air Force, including drones, transports, helicopters, air traffic controllers, personnel in operational control centres, ground-air defence operators and those responsible for air support.

Live Virtual Constructive Training (LVC), On-board Simulation and the DMOC

In parallel with developing SIM2D, the Air Force is continuing development work on hybridising LVC, which will enhance the tactical environment of air missions and hence aid optimisation of operational preparation. This hybridisation is operating today at an initial level and around 2025 will enable in-flight combatant training (live) against real or simulated threats generated by AI (constructive) or by piloted simulators (virtual).

Integration of simulation with embarked weapons systems is a prerequisite to ensure compatibility between real and virtual worlds. It means presenting to the crews, via the weapon system, simulated contact tracks as if they were real tracks, in a sense decoying the core system, since the simulated track is not in reality detected by the aircraft's sensors.

The bases of this technology have long been used on combat aircraft in training modes of fire. Many paths for progress exist, as offered by modern training aircraft like the PC-21, which exchange simulated contacts through data links between the aircraft. Similarly, the use of special pods brings a high degree of operational realism to training flights, in particular via the real-time replay of weapon firings. On-board simulation will be progressively introduced into F4 standard Rafale around 2025.

To gain full potential from SIM2D and LVC, in 2018 the Air Force has created the Distribution Mission Operation Center (DMOC). The aim is to make it the centre for preparation, operation and analysis of a simulated tactical environment by offering simulation sessions on demand. It lays the first brick in constructing future virtual training for multi-environment, connected collaborative combat which the Air Force will develop from now to 2040.

These solutions will give a new dimension to operational training by multiplying the number of participants and possible scenarios. In parallel with the work on SIM2D and LVC, new equipment is appearing which indicate significant change in the use of simulation.

Massive networked simulation

Massive networked simulation (*Simulation massive en réseau*—SMR) draws on the technology of serious gaming. It uses latest generation simulation software originally intended for public consumption that adheres to natively designed, advanced criteria for realism to allow many players in the same virtual space to interact with each other. With its simple, user-friendly interfaces it is quick and easy to operate, which ensures that personnel will be attentive to their work reducing the need for training staff.

The financial, technical and security constraints of information systems, which make the interconnection of different types of simulator a delicate matter make SMR appear as the most interesting way ahead for providing extremely effective mass simulation structures at reduced cost. Such simulation tools will cater for battle hardening for experienced crews in addition to conventional simulators.

They are being tested experimentally now in the Air Force. A proposal to proceed to full-scale work is being studied by the Defence innovation agency (*Agence de l'innovation de Défense*—AID), with the aim of introducing the initial capability at the end of 2019, at this stage on the Mirage 2000. It means that initial feedback will be rapidly obtained and used for the incremental design of future equipment.

For SMR to be developed, the industries that equip the Air Force will need to be involved in order to reproduce the flight characteristics of aircraft to the required level of fidelity. Development of these tools will in time be an advantageous complement to their simulators by providing an extra module that is adapted to high-level training thereby creating a full-ranging simulation structure.

Whilst the need for a high level of system conformity remains essential for instruction and basic training, the combination of haptic technology with virtual and enhanced reality means in the much longer term that current simulators' physical cockpits could be replaced by totally virtual ones from which crews will be able to operate all controls identically in manner to the real environment. This revolution will see lighter, less costly systems that afford a wide range of use, in turn opening the way to development of simulation systems for other specialisations, such as mechanics and commandos.

<div align="center">**⁎⁎**</div>

In response to changing training needs, the Air Force is progressing with the transformation of its simulation equipment by drawing on new technologies to generate significant developments in the uses and modes of working, ultimately to permit better fulfilment of its missions.[3] Whatever the benefits of virtual training, flying remains essential. Nothing can replace it for testing materiel, verifying the correct functioning of sophisticated weapon systems and especially for building air sense in the

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[3] Paraphrased extract of report annexed to law No. 2018-607 on the military programme for the years 2019 to 2025, 13 July 2018 (www2.assemblee-nationale.fr/documents/notice/15/projets/pl1013/(index)/projets-loi).

aircrews and mastering the physiological constraints of the real world, such as spatial disorientation, the gravity factor, combat stress, meteorology and its consequences on holding formation, danger from birds and de-confliction with civil air traffic.

Simulation is an essential complement to perfecting training and operational preparation: it allows accelerated progression and an increase in tactical skills, but it is neither palliative nor a cheap substitute.

Simulators need to evolve towards becoming faithful tools, easy to operate at the squadron level by the crews themselves. That will ensure that personnel are on-side, an essential factor for achieving the aims of increased activity and wider use of simulation. SMR is a promising way ahead for obtaining conforming, connected and immersive equipment at a moderate cost with which everyone will be able to train himself with greater ease and more often to the benefit of the performance of combat forces. ◆