Availability Improvements in New Transport Aircraft – The Case of the A400M

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ABSTRACT

This paper presents the improvements in aircraft availability implemented for the Airbus Military A400M transport aircraft, a European multinational procurement programme managed by the Joint Organisation for Armaments Cooperation (OCCAR). After introducing the reader to OCCAR and the A400M programme, it explains the maintenance and support concepts used to improve availability and reduce costs, such as a commercial approach, the optimisation of the scheduled maintenance programme, extensive use of on-condition maintenance, the application of a Maintenance-Free Operation Period (MFOP), common support solutions, and innovative support concepts. It also explains the technological measures applied during the design of the aircraft to improve availability, such as computer-aided design, damage-tolerant design, onboard systems integration, and increased components reliability. It also shows that availability cannot be dissociated from costs, and that a higher operational availability and lower costs can have organisational, but also industrial, effects that could lead to increased efficiency of the Forces, but also of the European defence industry.

1.0 INTRODUCTION

The A400M programme is a cooperative European programme between seven European nations and managed by the Joint Organisation for Armaments Cooperation (OCCAR) for the acquisition from Airbus Military of a military transport aircraft system in response to common military requirements. As a new programme built on a commercial approach, it is bringing together many improvements in Aircraft availability. This paper, after introducing the reader to OCCAR and the A400M programme, will present the maintenance and support concepts, as well as the technological measures applied in the programme to improve aircraft availability as compared to current platforms.

However, despite the fact that effective operations and national security drive requirements for increased availability, the latter cannot be considered in isolation from Whole Life Cost (WLC), especially in these times of reduced defence budgets. A balance therefore has to be sought between increased availability and optimised costs, and this paper highlights how this is envisioned to be achieved for the A400M.

2.0 THE JOINT ORGANISATION FOR ARMAMENTS COOPERATION (OCCAR)

OCCAR, which is the French acronyms for *Organisation Conjointe de Coopération en matière d'Armements*, is an international organisation created by a treaty (the OCCAR Convention) signed in 1998 by France, Germany, Italy and the United Kingdom. OCCAR gained its legal status in January 2001 at the end of the ratification process of the OCCAR Convention, and has since then welcomed Belgium (in 2003) and Spain (in 2005) as Member States. In addition, OCCAR includes an Executive Administration (OCCAR-EA) made-up of staff members recruited within its Member States.

The mission of OCCAR is to facilitate and manage collaborative European armament programmes and technology demonstrator programmes. For that purpose, OCCAR aims to be a centre of excellence, and first choice in Europe, in the field of the collaborative acquisition of defence equipment. The activities of OCCAR are based on five principles defined in the OCCAR Convention:

- The achievement of cost-effectiveness over the whole life of the system procured;
- The harmonisation of requirements, methods and technology across the Participating States and industries in each programme;
- Contributing to the building of a competitive Defence Technological and Industrial Base (DTIB) in Europe;
- The renunciation of the *juste retour* principle of fair industrial return that led in the past to many less-than cost-effective work allocation decisions among countries, in favour of a global balance across programmes and over the years; and
- Openness to other European countries, under which States that are not Members of OCCAR may participate in programmes managed by OCCAR. This shows that OCCAR is far from being a “closed club”, contrary to some other international organisations.

OCCAR currently manages seven programmes of various sizes and covering a wide array of system types. Each programme is managed by a Programme Division that, together with a Central Office located in the OCCAR headquarters in Bonn, form OCCAR-EA. The graphical representation on Figure 1 represents the programmes managed by OCCAR, their size and costs, and the location of their Programme Division.

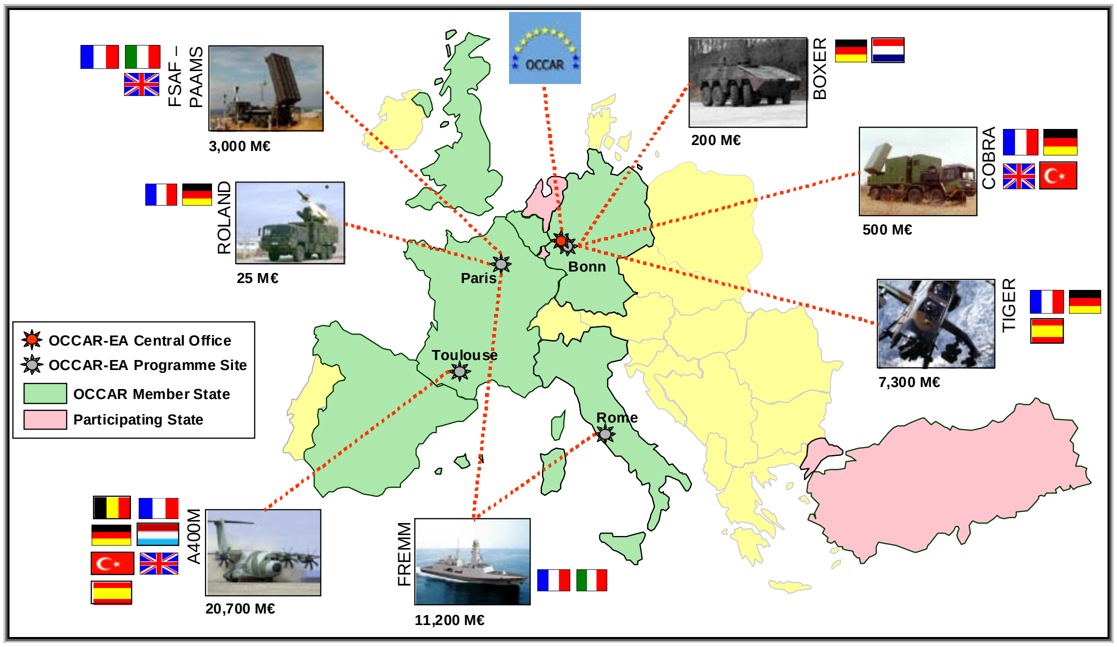


Figure 1: OCCAR Programmes, Estimated Total Costs, and Participating States.

It is interesting to note that the global overhead of OCCAR-EA compared with the costs of the programmes it manages is only about 1.1%, while its yearly turnover for each of its 200 full-time employees is about 15.1 million euro. Since 2005, OCCAR-EA is certified ISO 9001:2000 by the German accreditation authority TÜV.

OCCAR maintains close links with other international organisations in the field of defence in Europe, such as the European Defence Agency (EDA) and the NATO Maintenance and Supply Agency (NAMSA), which supports OCCAR-EA in spares management on a number of programmes.

3.0 THE A400M PROGRAMME

3.1 The Programme and the Aircraft

The A400M programme (formerly known as the Future Large Aircraft, or FLA) is a cooperative European programme between Belgium (representing also Luxembourg), France, Germany, Spain, Turkey and the UK for the acquisition of a military transport aircraft system in response to common military requirements. Built on a commercial approach, the aim is to produce and deliver the aircraft and the appropriate support at fixed price conditions through a single-phase contract including development, production and initial support at minimum life cycle costs. The Participating States have contracted to procure a total of 180 aircraft: Germany 60, France 50, Spain 27, the United Kingdom 25, Turkey 10, Belgium 7 and Luxembourg 1. Development and production was launched in May 2003, the first flight is scheduled early 2008, and the aircraft will be delivered between 2009 and 2021. Following the launch of the programme, South Africa ordered 8 aircraft and Malaysia 4.

The Airbus Military consortium, comprising Airbus, EADS, TAI of Turkey and Belgium's FLABEL, is the programme prime contractor and is located in Toulouse and in Madrid. It has subcontracted the management of development activities of the A400M to Airbus, and uses the existing Airbus production centres plus the facilities of its industrial partners, most notably the single final assembly line located in Seville (Spain). Airbus Military is also responsible under the prime contract for the delivery of the necessary support products and services, such as technical documentation, spare parts, Ground Support Equipment (GSE), training and training aids and maintenance and support services.

The A400M itself is a four engine strategic and tactical military transport aircraft capable of carrying troops and/or cargo loads, performing airdrop, and acting as a tactical air-to-air refuelling tanker. It is propelled by four 10,000 shp TP400-D6 engines manufactured by Europrop International (EPI) and FH386 propellers manufactured by Ratier Figeac (RFHS). The aircraft performances will include a high cruise speed of Mach 0.68 to 0.72, a cruise ceiling in normal operation of 37,000 ft, a range from 1,700 NM (at maximum payload) to 4,100 NM (for ferry flights), a MTOW of about 136.5 tonnes and a guaranteed maximum payload of about 32 tonnes.

Figure 2 shows a graphical representation of the A400M.

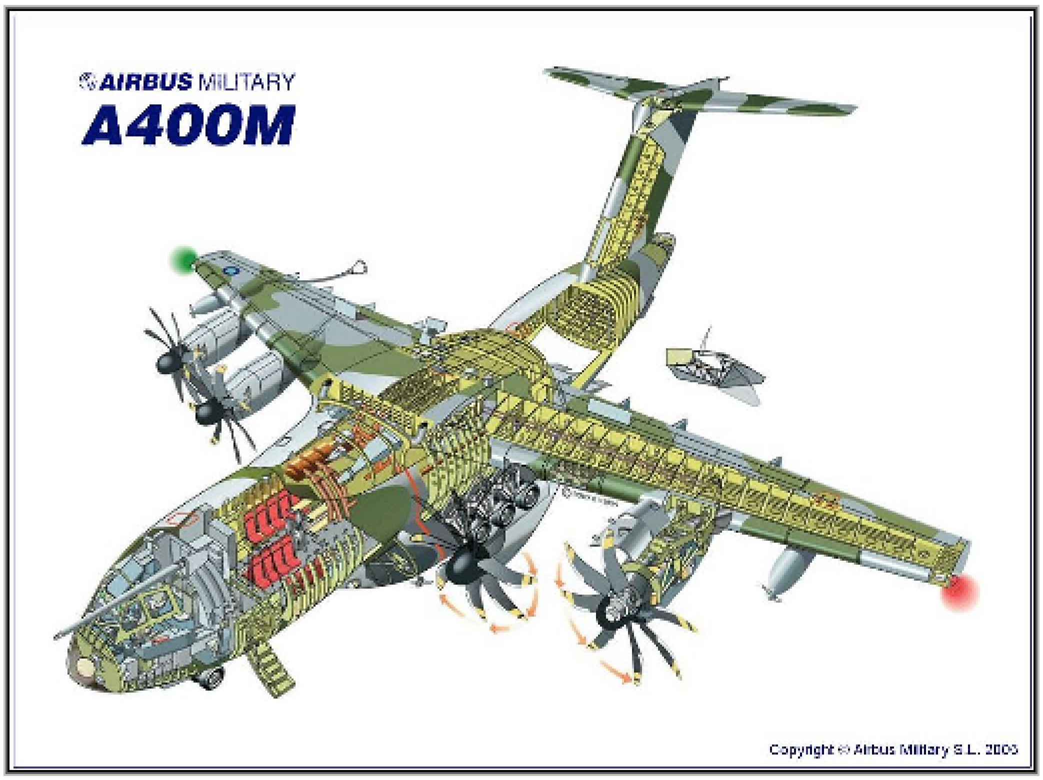


Figure 2: A view of the A400M Military Transport Aircraft.

The aircraft in its basic configuration is referred to as the Common Standard Aircraft (CSA), but the delivered A400M will include the installation of, or provisions for, additional optional systems that will be different for each Participating State and depend on the specific role of the aircraft. However, the aircraft configurations are about 90% common.

The aspects of the aircraft relevant to civilian certification will be certified by the European Aviation Safety Agency (EASA), while the whole aircraft, including the military systems, will be certified by a multinational military body set-up specifically for the programme, the Certification and Qualification Organisation (CQO) and comprising representatives of the Military National Airworthiness Authorities (MNAA) of the Participating States.

Management of the A400M programme has been entrusted to OCCAR by the Participating States. It is the first programme to be incorporated in OCCAR from the start of its development phase. As such, it constitutes a pilot programme to demonstrate in a practical way the validity of the OCCAR principles. The A400M Programme Division is composed of about 30 staff members supported by experts from the Participating States, and is located in Toulouse, France.

The A400M programme is intended to remedy one of the currently identified European armed forces capability gaps, namely the ability to project quickly and effectively armed forces into overseas theatres of operation. As such, it will replace the existing fleet of C-130 and C-160 of the Participating States. It should also strengthen the European DTIB.

3.2 Key Performance Indicators and Modelling for A400M

The management of OCCAR programmes is based on a set of High-Level Objectives (HLO), which enable OCCAR to develop and implement a programme management aligned with the principal aims of the Participating States. These HLO include Key Performance Indicators (KPI) that define system performance, schedule objectives (defined for each national fleet as the date of initial capability and that of full capability), and financial objectives covering both the development and production phase costs as well as the Whole Life Cost (WLC) of the fleet.

Availability has been especially considered in the modelling of the programme cost objectives. The A400M WLC has been projected in a MS Excel-based model called A400M LCC Toolsheet (the resulting file is about 25 Mb in size, which gives an idea of the dimensions of the features included). The development of this model was based on an Airbus Military tool, but was further performed in cooperation with experts from the Participating States and OCCAR, and validated and verified independently by the Pricing and Forecasting Group (PFG) of the UK Defence Procurement Agency (DPA), thereby providing the users with a guarantee that the working of the model is not biased. This model is now widely used in the Participating States to predict WLC, calculate budgets, and perform simulations on the impact on WLC of differing operating assumptions.

The A400M LCC Toolsheet uses the target operational availability of the fleet (input by the user) to calculate the necessary human resources to support it in-service, as well as the required spares availability. On that basis, it optimises the pack of spare parts that would be required to achieve that target. Despite the fact that operational availability is not a guarantee under the DPP Contract, each Air Force has defined a target operational availability for its A400M fleet that it can enter in the A400M LCC Toolsheet as an input. The user can then immediately know the cost impact of his or her requirements related to availability. Figure 3 show an extract of the spares availability sheet of the A400M LCC Toolsheet. In that example, the target operational availability was set at 90%, leading to a required spares availability of 93.96%, which is then allocated among the aircraft systems.

A400M Life Cycle Cost - Target Spares Availability.

Target Spares Availability (As) **93.96%** *(See below for derivation)*

ATA	DESCRIPTION	URR/1000FH	URR		As Target
21	Air Conditioning	4.253	0.00425276		0.9957495
22	Auto Flight	0.135	0.00013519		0.9998646
23	Communications	1.043	0.00104317		0.9989557
24	Electrical Power	5.707	0.00570742		0.9942997
25	Equip & Furnishings	1.055	0.00105515		0.9989437
26	Fire Protection	0.525	0.00052474		0.9994746
27	Flight Controls	1.838	0.00183774		0.998161
28	Fuel	3.453	0.00345316		0.9965473
29	Hydraulic Power	1.099	0.00109948		0.9988994
30	Ice & Rain Prot	0.482	0.00048238		0.999517
31	Instrum/Record	1.534	0.00153441		0.9984643
32	Landing Gear	8.400	0.00840043		0.9916214
33	Lights	3.249	0.00324917		0.9967509
34	Navigation	2.845	0.00284486		0.9971546
35	Oxygen	1.268	0.00126825		0.9987305
36	Pneumatic	3.057	0.00305674		0.996943
38	Water/Waste	1.266	0.0012661		0.9987327
49	APU	1.625	0.00162488		0.9983738
52	Doors	1.252	0.00125214		0.9987466
53	Fuselage	0.011	1.1463E-05		0.9999885
54	Nacelles	0.015	1.4791E-05		0.9999852
55	Stabilisers	0.571	0.00057145		0.9994278
56	Windows	0.038	3.8495E-05		0.9999614
57	Wings	3.793	0.00379303		0.9962081
			0.04851742	77.96%	
61	Propellers & G'box	3.057	0.00305739		0.9969424
71	Propellers & G'box	3.057	0.00305739		0.9969424
72	Engine Core	1.459	0.00145927		0.9985394
73	Engine Fuel/Cont	2.713	0.00271302		0.9972863
74	Engine Ignition	0.325	0.00032451		0.999675
75	Engine Air/Deice	0.398	0.00039807		0.9996014
76	Engine Controls	0.172	0.00017178		0.999828
77	Engine Indicating	0.851	0.00085127		0.9991477
78	Engine Exhausts	0.222	0.00022211		0.9997776
79	Engine Oil	1.256	0.00125629		0.9987425
80	Engine Starting	0.208	0.00020823		0.9997915
			0.01371933	22.04%	
99	0	0.000	0	0.00%	1
		TOTAL	**0.06223675**	**100.00%**	**93.96%**

DERIVATION OF TARGET SPARES AVAILABILITY
(based on projected scheduled maintenance programme)

	Scheduled Interval				
A Check / A Multiple	**5**	*months*	*Annual utilization*	**660**	*FH/ac/year*
Light C Check / C Multiple	**15**	*months*	*Average mission length*	**3.01**	*FH/cycle*
Intermediate heavy C Check	**6**	*years*	*Unscheduled removals*	**66.45**	*/1000FH of which 70% = AOG*
Full heavy C Check	**12**	*years*	*Average time to rectify*	**3**	*MMH/removal*

	Down-time		Annual down-time				
A Check / A Multiple	**1**	*days*	2.40	*days*			
Light C Check / C Multiple	**5**	*days*	4.00	*days*			**Operational Availability (Ao)**
Intermediate heavy C Check	**18**	*days*	3.00	*days*			
Full heavy C Check	**32**	*days*	2.13	*days*		Target Ao	**90.00%**
Scheduled maintenance down-time TOTAL			**11.53**	***days =***	3.16%	of 365 days	**96.84%**
Unscheduled maintenance down-time TOTAL			**3.84**	***days =***	1.09%	of remaining	**98.91%**
						Target Spares Availability (As)	**93.96%**

Figure 3: A400M LCC Toolsheet Spares Availability Calculation (Example).

In addition, spares optimisation is also performed by the subject matter experts of the OCCAR Central Office using the commercial off-the-shelf OPUS 10 tool (from the company Systecon in UK). That tool, based on a different routine than the A400M LCC Toolsheet, specifically performs spare parts package optimisation based on the required operational availability. This allows the comparison of the results of both models for a detailed analysis of the initial provisioning recommendations of the company, thereby providing the nations with an alternative source of information to support their decisions.

It is common knowledge that, whilst the In-Service Support (ISS) phase of a programme amounts to more than 50% of its WLC, decisions made during feasibility, definition and specification phases define about 80% of the platform’s WLC. Therefore, support has to be considered as early as possible in the life of a programme, and this is the case for the A400M. Support considerations are an integral part of the concurrent engineering design of Airbus through a process called Supportability Engineering (SE), similar in objectives to the Logistic Support Analysis (LSA) process. This process is explained in more details in § 5.1 below.

For that purpose, Airbus is using a dedicated Excel-based model called Operational Reliability Analyser (ORA) to support system design by analysing the operational availability consequences of both system architecture and components Reliability, Maintainability and Testability (RM&T) characteristics. Based on that analysis, supportability engineers can influence system design if the current solution would not lead to a satisfactory availability result that cannot be otherwise compensated. We will come back later in this article on the practical impact and use of this tool.

3.3 Operational Availability and/or Operational Reliability?

Because of the reference of the ORA tool to “operational reliability”, now is probably the time to highlight a fundamental difference between the way civilian and military people approach aircraft availability.

Despite what some would like to think, military aircraft are mostly underused. The expected usage of the A400M varies from nation to nation, but averages 650 Flying Hours (FH) per year per aircraft. In contrast, a civilian airliner is used for more that 2000 FH per year per aircraft, or about 6 FH per day. These aircraft are designed to carry on their missions (up to four or six per day) despite the occurrence of faults, which are only repaired by mechanics during the night. In contrast, military aircraft are generally waiting to be used, but when that need arises, a maximum availability is expected because the vital interest of the State, and indeed human lives, are at stake.

This explains why civilian and military operators use different metrics to calculate the availability of their aircraft. Civilian companies such as Airbus use the concept of Operational Reliability (OR), defined as *the percentage of flights without mission loss* and equivalent to the military term Mission Reliability. A mission loss will be declared if there is a delay of more than 15 minutes in the mission departure time for technical reasons, or if the mission has to be interrupted (on ground or in flight). The contractual Operational Reliability requirement for the A400M is set at 98.7%.

By contrast, the concept of operational availability for military operations is usually defined as *the time during which the aircraft is available for a mission* (either on mission or on standby) over the total time (including corrective and preventive maintenance time and the administrative and logistic delays). This figure is not only linked to technical factors such as RM&T data, but also to the efficiency of the support system. As stated above, each Participating States has defined a non-contractual target for the operational availability of its A400M fleet, and most require a 90% figure, which would already be a major improvement compared with existing systems.

The different usage concepts between military and civilian aircraft clearly explain this difference. What counts for a civilian airliner are the so-called “revenue flights”, and companies whose aircraft are waiting on the tarmac for revenue flight or of which the support system cannot ensure that revenue flights are carried out will soon face bankruptcy. The management aspects of availability are dealt with through the company balance sheet. On the other hand, whilst Mission Reliability is also an important parameter for the military, because of a much more fluctuating military usage, and because the issue of balance sheet is superseded by the operational requirements, the military is much more orientated toward availability over time, whether or not a mission is expected… because in the military, when mission are important, they are often unexpected.

The personnel working on the A400M programme, both military and civilian, had to come to a mutual understanding of both these points of views.

4.0 MAINTENANCE AND SUPPORT CONCEPTS TO IMPROVE A400M AVAILABILITY

4.1 Commercial Approach

The Statements of Principles of the Future Large Aircraft (FLA) defined as early as 1997 that the programme (now the A400M) was to be managed in accordance with a "commercial approach". This is one of the key characteristics of the A400M programme.

Under this commercial approach, the prime contractor has the freedom to decide on design and manufacturing sources for airframe, engine and equipment, choosing those that provide best value for money together with acceptable capability and quality. The prime contractor is to use best commercial practice in the management of the programme to ensure that design and manufacturing are properly and efficiently integrated. Government participation is then limited to ensuring that the work is being conducted in accordance with these principles.

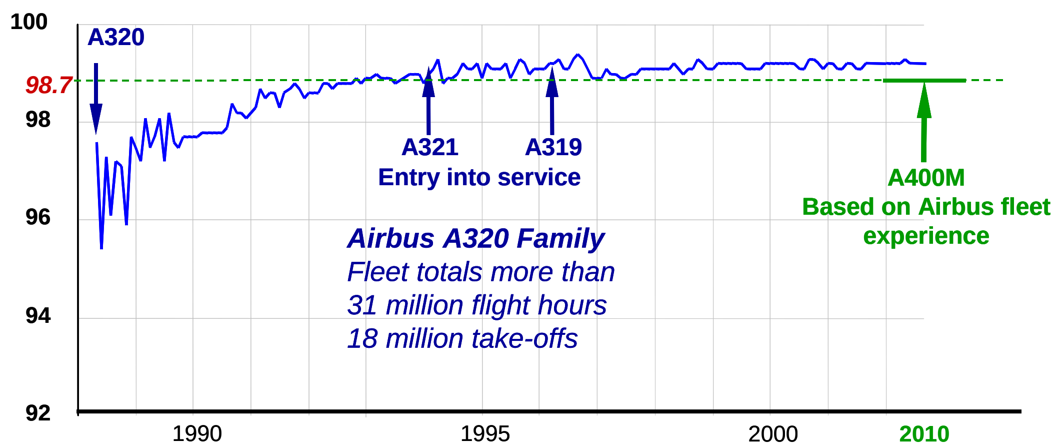


Figure 4: Airbus Fleet Operational Reliability (in %).

The commercial approach is intended to ensure that the A400M can be purchased, operated and supported at minimum WLC. Under these principles, the prime contractor is free to design and manufacture a product that meets the contractual requirements of the Participating States and satisfies the widest possible market at costs that are internationally competitive. This requires best international practice in management, design, development, production and support and the competitive allocation of sub-contract work. Participation in the programme is to provide the Nations' industries with work opportunities (under the Global Balance principle mentioned above), as long as they do not create significant adverse impact on the economy of the programme and if they are competitive in quality, price and delivery.

Despite not being explicitly mentioned in the original definition of the commercial approach, aircraft availability is one of its key elements. This approach intends to build on the record of Airbus that, for its fleet of commercial airliners, is able to achieve an Operational Reliability of more than 98%, as shown on Figure 4 for the A320 family.

4.2 Optimised Scheduled Maintenance Programme

It has been showed extensively that an optimised scheduled maintenance programme is one of the keys to cost reduction and availability increase. Studies performed by the US Air Force have shown extensive differences between the workload of scheduled inspections of the traditional aircraft of the '60 and '70 such as the DC-8, and that of more modern aircraft, such as the Boeing 747 or the DC-10, for which the scheduled maintenance programme had been defined using the Maintenance Steering Group 3 (MSG-3) process. For the A400M, these gains are expected to be even bigger, as shown on Table 1.

Table 1: Scheduled Maintenance Gains through MSG-3 Process.

Type of Preventive Maintenance	*Traditional*	*Modern*	*A400M Expected*
Structural inspection	4,000,000 MMH	66,000 MMH	9,000-20,000 MMH
Hard-time overhauls	339 items	7 items	None
Turbine shop maintenance	-	50% DMC reduction	-

MMH: Maintenance Man-Hours DMC: Direct Maintenance Costs

The scheduled maintenance programme of the A400M is therefore defined in close collaboration between Airbus Military, Airbus, OCCAR, the airworthiness authorities and the Participating States based on the MSG-3 process. Under this process, each Maintenance Significant Item (MSI) and Structure Significant Item (SSI) is analysed based on its criticality, architecture and RM&T characteristics in order to perform only the scheduled maintenance activities that are absolutely necessary for the safety and economics of operations.

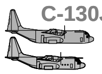
As many as 10 Maintenance Working Groups (MWG) have been set-up to perform that analysis for all of the systems and the structure of the aircraft. These MWG are provided with detailed architecture and design information by industry, including the results of the Maintenance Task Analysis (MTA) and Failure Modes and Effects Analysis (FMEA) – which, under the Airbus procedures, also covers criticality – as well as recommendations for the scope and schedule of maintenance tasks. As the MWG are manned jointly by experts from industry and from the Air Forces, the latter have the opportunity to feed into the process their experience of military aircraft maintenance and operations.

This process will lead to the approval of a common A400M maintenance programme by the civilian EASA and the MNAA of the Participating States working together within the CQO. This maintenance programme will then be customised to meet the specific needs and operations to each Participating State.

The expected scheduled maintenance gains from that activity and from the other improvements that we will detail below can be seen on Table 2, the source of which is Airbus Military based on publicly available data.

These gains translate directly into an increased operational availability. However, it is clear that the A400M MSG-3 process is still ongoing and that its results will affect these figures.

Table 2: Expected Scheduled Maintenance Downtime.

	Maintenance Intervals				Maintenance Downtime in 5 years
	Line (A-Check)	Light C-check	Heavy C-Check	Effect	
 C-17	60 Days	18 Months	36 Months (sampling)		**~ 150 Days**
 **A400M**	**150 Days**	**15 to 24 Months**	**72 Months**		**~ 50 Days**
 **C-130J / C-130J Str.**	120 Days	12 Months	60 Months		**~ 120 Days**

During the in-service phase, the operation and maintenance data will be collected by the Participating States and passed on to AMSL to allow for the revision and evolution of the initial maintenance programme. These evolutions will also take into account the evolutions in the configuration of the aircraft. The Participating States have agreed to manage these further evolutions of the maintenance programme in common, which should increase interoperability. This feedback loop will allow for the optimisation of the maintenance programme over time. In that sense, the MSG-3 process for the A400M will continue during the whole aircraft life.

4.3 Extensive Use of On-Condition Maintenance

Monitoring systems on board of the aircraft may supplement or even replace periodic inspections that are part of the scheduled maintenance programme. Automatic monitoring of the aircraft allows replacing certain tasks at pre-determined intervals by on-condition maintenance, thereby extending the service life of some items by avoiding premature replacement. An assessment of aircraft status and the need for maintenance action in such cases will be determined by monitoring dedicated parameters to identify the need for maintenance action before an anticipated failure occurs, and monitoring performance or systems configuration degradation to enable maintenance to be undertaken before a critical loss of function occurs.

Degradation of a mission-critical system, otherwise transparent to the crew, is detected by the monitoring system, which predicts a *schedule interval* during which a maintenance action will be required. For the duration of this interval, maintenance action may be deferred to the most convenient time, and aircraft operation may continue with a high degree of confidence that a mission loss or further degradation will be avoided. Despite the fact that this might lead to the removal of a component that still has some potential, it allows performing the corrective maintenance activity when the aircraft is on standby or preferably during a scheduled inspection, thereby avoiding mission loss or to have to remove the aircraft from the flight line. The schedule interval can be defined based on parameter or configuration requirements as shown in the example of Figure 5, which should be self-explanatory.

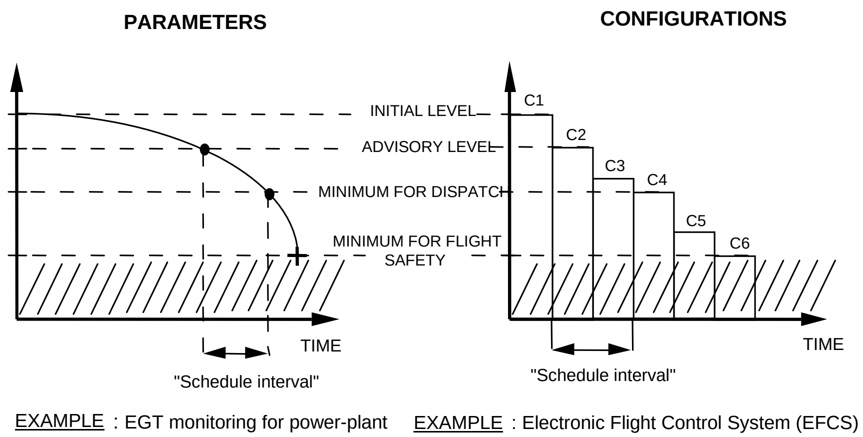


Figure 5: On-Condition Maintenance – Examples of Schedule Interval Definition.

On-condition maintenance, used for a long time on Airbus aircraft, is being systematically applied for all the systems and the structure of the A400M when flight safety allows it. For that purpose, the integrated avionics of the A400M is equipped with an Aircraft Integrated Monitoring and Diagnostic System (AIMDS) that centralises the control of built-in test equipment (BITE) of all systems on each aircraft, detects system faults and provides failure messages in plain English, and also collects and records engine, APU and critical systems data. This data can then be analysed using the Maintenance Data System (MDS), which is explained in more details below, to enable prognostics, trend analysis, maintenance planning and health and usage monitoring.

In addition, the extensive use of Integrated Modular Avionics (IMA) and redundant architecture makes easier the continuation of operations with degraded configurations. This feature is also explained in more details in a further section of this paper.

The dramatic reduction of hard-time overhauls brought by on-condition maintenance on modern aircraft and on the A400M is highlighted in Table 1 above. The operational availability gains of such maintenance concepts are obvious: repairs can be deferred to a convenient time (either during scheduled maintenance or at a time when the aircraft is not operated), and ongoing missions can be completed without endangering flight safety.

4.4 Maintenance-Free Operating Period (MFOP)

One of the key requirements of the A400M is its Deployment Reliability, defined as the probability that one aircraft operated and maintained in accordance with standard conditions will complete a planned deployment period, using only spare parts contained in a transportable deployment kit. The Deployment Reliability of the A400M is guaranteed as 90% for a deployment of 15 days.

In order to satisfy this requirement with limited deployment kits and personnel, Airbus Military has the objective to provide the users with a Maintenance-Free Operating Period (MFOP) of 15 days. The MFOP is defined as a period of operation during which an aircraft is able to carry out its assigned missions without the need for any maintenance except pre-defined flight servicing (e.g. generic visual inspection, replenishment) and role change activities. During an MFOP, faults may occur in the aircraft but they must not require corrective maintenance action until the aircraft returns to the base. Once the MFOP is complete, an aircraft may have to be restored to its fully serviceable state at a suitable location (maintenance recovery period).

Because of redundant architecture and of the application of on-condition maintenance techniques, any faults occurring during the MFOP (but not affecting the mission) may be deferred to the maintenance recovery period.

The current design activities performed by Airbus Military show that it will not be possible to achieve a 15 days MFOP with 90% certainty, although an MFOP of 15 days if still possible (with a lower probability) and the guaranteed Deployment Reliability mentioned above can still be achieved using the spare parts of the deployment kit. This shows the difficulty of an MFOP, even with a modern aircraft.

Another requirement of the A400M is that no preventive maintenance is required during deployments of up to 90 days, with 150 days being the objective. This requirement is taken into account both in the design of the aircraft, but also of course in the maintenance programme definition process.

In addition, a number of supportability guarantees are provided by Airbus Military: a mean time between critical faults of 225 flying hours, an average of 10 Maintenance Man-Hours (MMH) per flying hour for all levels of maintenance over the aircraft life (assuming a typical maintenance labour efficiency of 75%), a maximum elapsed time for servicing and maintenance activities of 40 minutes active maintenance time on the flight line, as well as other guarantees such as maximum parts costs per flying hour and no fault found rate. These guarantees aim to support the objective of improved availability.

The successful achievement of those guarantees will be verified during an In-service Reliability, Maintainability and Testability Evaluation (ISRMTE), whereby in-service data will be collected by the Forces during a period of about two years and transmitted to Airbus Military for the calculation of the actual in-service parameters. These calculations will be reviewed by the Participating States and OCCAR, and any negative deviation from the guaranteed values will lead to remedial actions such as retrofits. The management of this ISRMTE still has to be defined, but this process has been started by OCCAR-EA.

4.5 Common Support Solutions

Some ways to improve availability and reduce costs do not necessarily involve an impact on the aircraft design or operation and maintenance procedures. One of these is the search for an agreement amongst the Participating States to perform support in common, thereby sharing resources and achieving increased efficiencies as well as economies of scale.

A detailed analysis of the impact of common support on A400M WLC, with the operational availability considered as a constant, have led to the conclusion that substantial gains could be made from common support solutions such as common maintenance leading to economies of scales, pooling of spare parts, spare parts lateral support between the Participating States, common configuration management to share the non-recurring costs of modifications, and performing training mostly in common centres. Based on an A400M WLC comparator for non-common solutions for the whole fleet of 180 A400M (no variation of price and no discounting), the gains from common support and optimised support concepts are shown on Table 3.

Table 3: Potential WLC Gains of A400M Common Support.

Expected Gain from Common Support	*Of WLC*	*Of Support Costs*
Total Maximum WLC Gain (least expensive solutions)	7.15%	14.30%
Total Expected WLC Gain (most cost-effective solutions taking into account operational and policy criteria)	3.98%	7.96%

Although these results may seem limited, one should remember that – as a general rule – 80% of the WLC of a platform is defined by the feasibility, definition and specification phases. Only about 10% of the WLC can be affected by support concept decisions. Additionally, it should be noted that in some cases the benefits of common support are already realised in the A400M development and production contract, such as through common design authority services, common training device development and common central services for technical support and material support.

In addition, certain common support decisions can increase operational availability at times when it is needed the most. For instance, cross-maintenance, in which the mechanics of a Participating State would be allowed to maintain an aircraft of another Participating State, could be an extremely useful tool during deployments. In addition, spare parts lateral support between Participating States can be used in order to restore an aircraft to operation more rapidly than if the part had to be flown from the home base. In that sense, the participation of countries such as South Africa to these common schemes can be beneficial, as a number of operations of European States are conducted in Central Africa. In addition, these common processes are not especially difficult to implement.

However, common support in general (especially common contracting) often requires the Participating States to review some of their internal procedures and practices, and the agreements that will in fact be reached among the Participating States remain to be seen.

4.6 Pragmatic Support Concepts and Innovative Contracting

Another way of optimising the availability of the A400M at lower costs is an adequate choice of support concept by the Participating States. Within the scope of the A400M programme, support concepts are defined as the *allocation of work between the military services and industry*. A generic terminology has been agreed to identify support concepts within the programme, as shown on Table 4. ML1 (meaning Maintenance Level 1) covers line maintenance and servicing. ML2 on aircraft covers light scheduled inspections, while ML2 off aircraft includes the replacement of Line Replaceable Units (LRU) modules and parts in specialised workshops. ML3 on aircraft covers the heavy structural and corrosion inspections and ML3 off aircraft includes the repair of modules and parts in workshops.

Table 4: A400M Support Concepts.

Support Concept	Maintenance Level Performed By	
	Nation	**Industry**
Total Support	Some ML1 and all support to deployments	ML1 to ML3 on aircraft and off aircraft
Baseline Plus	All ML1	ML2 and ML3 on aircraft and off aircraft
Baseline	ML1 and ML2 on aircraft	ML2 off aircraft, ML3 on aircraft and off aircraft
Baseline Minus	ML1 and ML2 on aircraft and off aircraft	ML3 on aircraft and off aircraft
National Depot	ML1 to ML3 on aircraft and/or off aircraft	Support as required

In addition, some Participating States are moving away from the ownership of spare parts, instead choosing to rely on a spares lease option whereby spare parts would be owned, and even managed, by industry. Technicians from the forces would provide industry with a failed part and receive a functional one through a 'hole in the wall' located on the air base. The management of the whole supply chain behind the 'wall' would then be the responsibility of industry.

Because of the optimisation of the A400M maintenance, studies have shown that the most cost-effective support concept for the Participating States is either the *Baseline* (for larger fleet) or the *Baseline Plus* (for smaller fleet), meaning that most of the LRU repairs (including the engine) should be contracted to industry. This on the one hand moves away from the old support concepts applied by the military, where military depots were responsible for most of the maintenance, and on the other hand places more dependency on industry to ensure aircraft availability. This is rendered possible by the changes in the threat and in the multinational security environment since the beginning of the '90s, but security of supply remains a potential issue.

Most Participating States are likely to follow the conclusions of these studies and to reduce drastically the maintenance activities performed in-house and, as a consequence, the needed resources. However, in order to ensure aircraft availability under these concepts, innovative contracts have to be put in place. This process is ongoing, but most Participating States are currently looking to contract for availability, pooling and leasing spare parts, and even in some cases (notably in the UK), partnering contracts with industry. These contracts, obviously, can be negotiated and concluded by OCCAR, thereby providing the expected gains of common support. The most complex issues being discussed for these contracts are the responsibility allocation between industry and the Participating States for any unavailability, the management of the deployment kits to be used in operations, and the coverage of changing environmental conditions in the contract prices.

This process will have a significant impact on the European industry and on national depots. An analysis of the industry workload in terms of dock occupation for on-aircraft maintenance (in the case of the Baseline support concept) performed by the Participating States and OCCAR based on the available data shows the results of Figure 6. It confirmed the results of a similar study performed earlier by Airbus Military. These figures cover the industrial workload for heavy systems, structural and corrosion inspections, as well as the resulting corrective maintenance and routine service bulletins implementation.

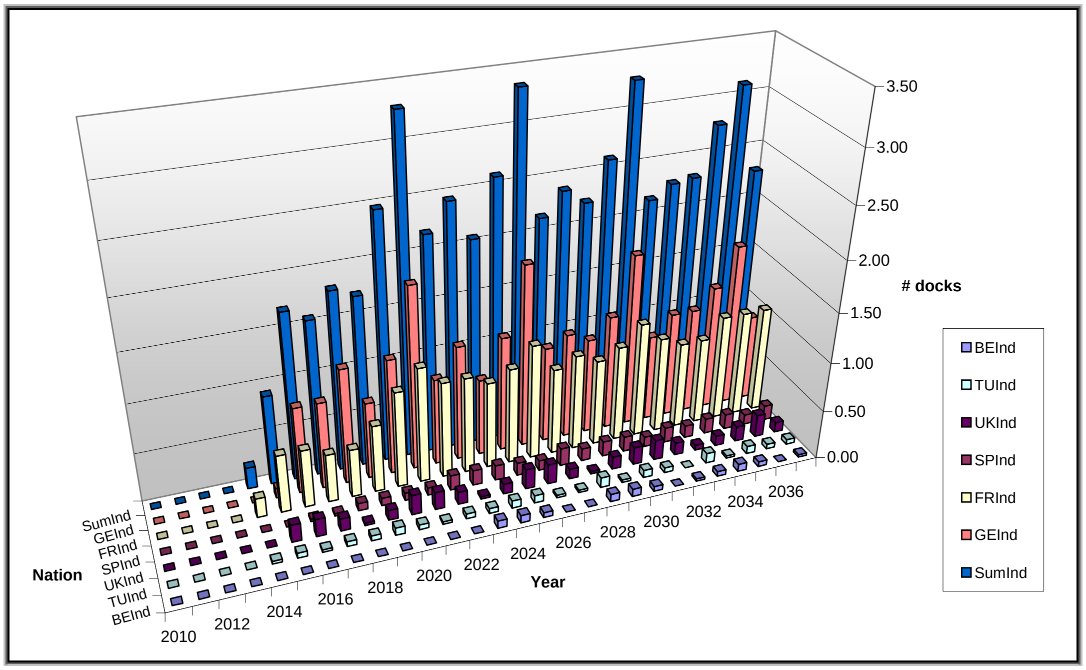


Figure 6: Estimated Industry Maintenance Docks Occupation (Baseline Support Concept).

One can see that, should each Nation contract nationally, only France and Germany would be able to provide their national industry or national depot with a reasonably constant on-aircraft maintenance workload, but that workload would be much lower than for the current fleet (maximum two aircraft in maintenance at any one time). All the other nations would only require partial use of one maintenance dock over time in their industry or national depot, the most extreme case being Belgium, which would likely only need the use of a maintenance dock for about one month per year.

Moreover, would industrial on-aircraft maintenance be contracted in common (thereby allowing for efficiencies in maintenance dock occupation), only three maintenance docks would be required in industry for the whole A400M fleet. To that figure must obviously be added the requirements deriving from incidents, operations and major modifications, but even this would keep the figure much lower than the current maintenance docks requirements of the existing aging fleet of C-130 and C-160.

In order to achieve these efficiencies, mandated by reduced defence budget, not only will the military have to modify their fundamental views of aircraft maintenance (a process that is well underway in most Participating States), but also the European defence industry will have to produce the required synergies. Even though this could lead to mergers and more focus on core business, this can only lead to a more competitive European DTIB, which is one of the principles and aims of OCCAR.

5.0 TECHNOLOGICAL MEASURES TO IMPROVE A400M AVAILABILITY

5.1 Computer-Aided Design

In addition to maintenance and support concepts, technological measures can be used to improve aircraft availability, or maintain the same availability at lower costs. Based on the Airbus experience, a range of these measures has been used on the A400M.

The concurrent engineering process of Airbus includes a process called Supportability Engineering (SE) that aims to include supportability considerations into the design of an aircraft. All design information is stored in a Digital Mock-Up (DMU) that allows not only a visual representation of the aircraft and its systems, but also to perform analyses of supportability. An example of DMU picture is shown on Figure 7.

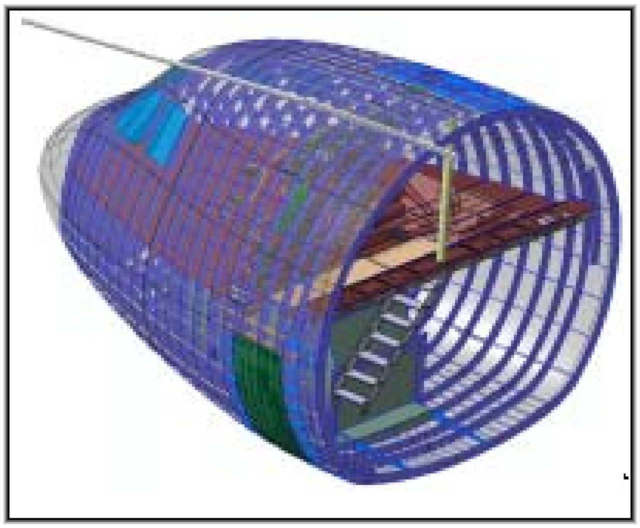


Figure 7: A400M DMU Extract (Forward Fuselage and Cockpit).

A graphical representation of the SE process is shown on Figure 8. Based on the supportability needs of the customers (in this case, the Participating States), a support specification is agreed which, together with in-service experience from other military and Airbus aircraft, leads to the systematic identification of supportability requirements. For the A400M, the support specification is an integral part of the procurement contract. The supportability requirements are reviewed by the experts of the Participating States and OCCAR-EA within the scope of the supportability assurance process. They form the basis upon which the aircraft will be designed for supportability through a supportability analysis.

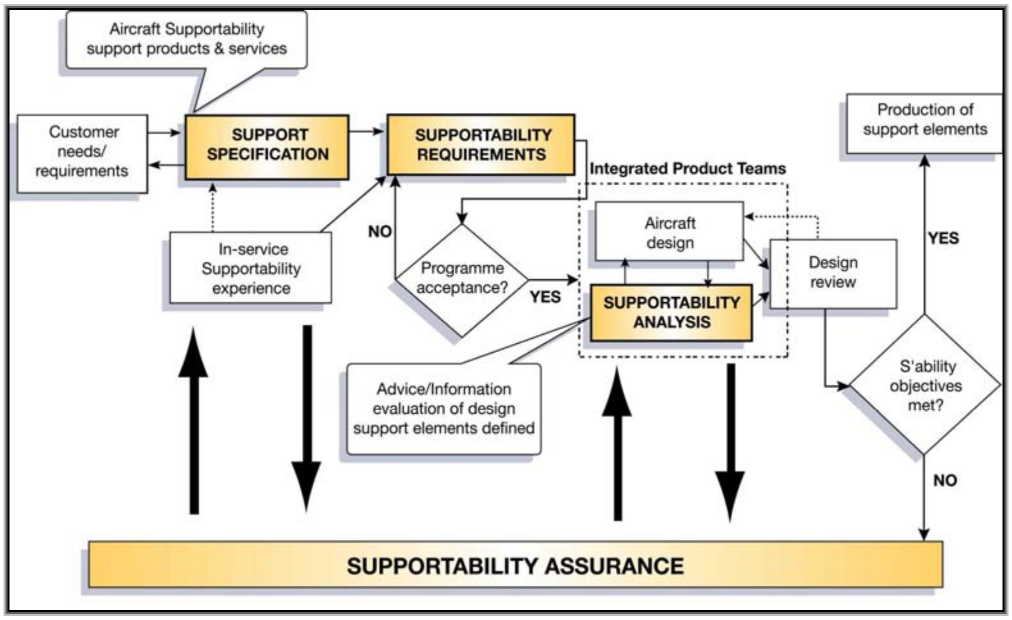


Figure 8: The Airbus Supportability Engineering Process.

The supportability analysis is divided into two main phases. In the first phase, during the Qualitative Maintainability Analysis (QMA), all parts are checked for accessibility and ease of removal. When the removal of a part would be too complex or require the removal of too many other parts, the supportability engineers request a change in the installation design. In a second step, the Maintenance Task Analysis (MTA) finalises the list of maintenance tasks and their Ground Support Equipment (GSE), tooling, procedure and manpower/duration requirements, all the time verifying that these are within the supportability requirements and related contractual guarantees, and would lead to an optimised availability. These two phases can be performed concurrently for various systems.

During the whole supportability analysis phase, any supportability issue that would influence the design is reported to the design teams and discussed. The design is modified whenever necessary to improve supportability (an example of such design modification is shown below). The Participating States and OCCAR are involved in the supportability analysis through a supportability assurance process where customer involvement allows advising the Airbus engineers on the specifics of military operations (e.g. the consequences of landing on rough strips), as well as providing assurance to the customers that the design is progressing as planned.

The results of the SE process are compiled in computer databases in a similar way as the LSA Report (LSAR), which are accessible to the customer and constitute the basis for the authoring of the Interactive Electronic Technical Publications (IETP), which will replace paper documentation for the A400M.

Of particular importance is the use of the DMU to perform verifications of adequate maintainability. Human beings (male and female, with and without NBC clothing) are therefore modelled in the DMU in order to verify accessibility and maintainability during the QMA. An example of this is shown on Figure 9, which identifies an accessibility issue for the removal of the aircraft right battery. This led to the relocation of the banister that was blocking the access. If this action had not taken place, the replacement of the right battery would have required additional maintenance, and would have negatively affected operational availability.

During the MTA, tooling is modelled into the DMU to verify the adequacy of the installation and removal procedures of each maintenance task.

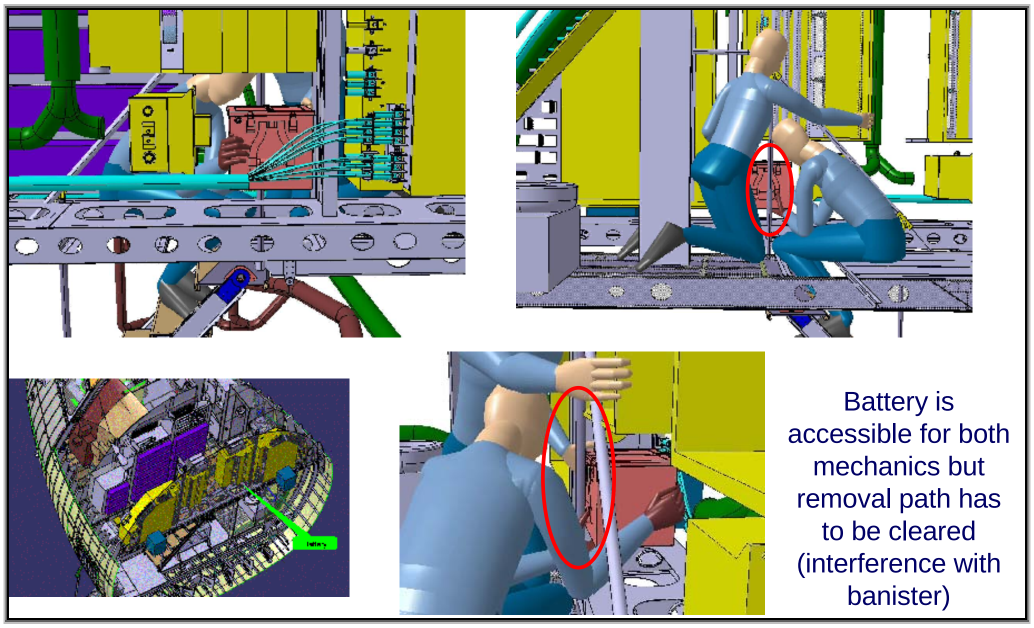


Figure 9: Example of Qualitative Maintainability Analysis using the A400M DMU.

The maintainability of the A400M will be verified jointly by personnel from AMSL and the Participating States during maintainability demonstrations that will be performed first on digital mock-ups and then on the flight test aircraft. A number of maintenance tasks will be selected for verification by OCCAR and the Participating States, and the performance of these tasks will be verified in terms of interchangeability, elapsed time, required resources, and adequacy of the technical documentation.

The DMU allows optimising the equipment installation. In addition, during the SE process, the architecture of the systems is also defined in order to guarantee aircraft availability. This is done within Airbus by using an Excel- and Cab Tree-based tool called Operational Reliability Analyser (ORA), as we mentioned above. The main interface sheet of the ORA tool for a specific system of the A400M is showed on Figure 10.

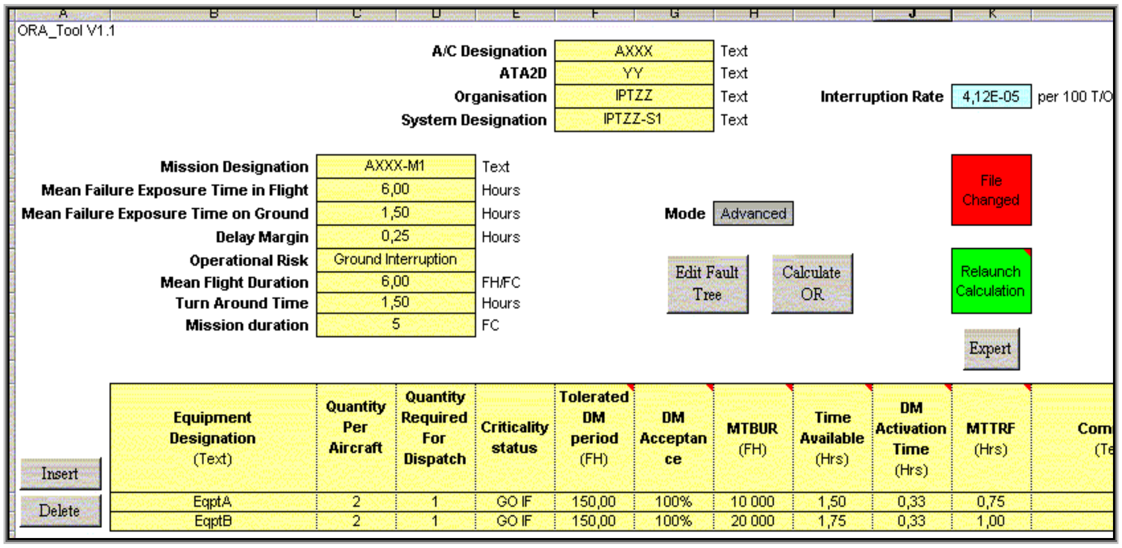


Figure 10: Example of ORA Main Interface Sheet.

The operational reliability guarantees at the aircraft level are allocated as reliability targets at the system level based on the experience of the design teams. By modelling the systems architecture and the RM&T data of its components within ORA, the supportability engineers of Airbus can calculate reliability projections and assess if the system as a whole could meet the target. If this is not the case, the architecture of the system and/or the requirements for its individual equipment would be reviewed, potentially leading to modifications of the specifications used for the selection of the equipment suppliers. If this cannot solve the discrepancy, the target allocation may be reviewed at the system level, and a target reallocation between systems can then be agreed.

On that basis, the supportability engineers can support the definition of the most efficient system architecture, define the components reliability requirements and make simulations to verify compliance with the contractual requirements. In that sense, supportability is a key part of the concurrent engineering design process of Airbus.

5.2 Damage Tolerant Design

Scheduled maintenance programmes are defined and applied to protect an aircraft from environmental damages (corrosion), accidental damages, and fatigue damages. For the latter, the *damage tolerance* concept has been introduced in the late ‘70s. Based on the improvement of inspection techniques and increased knowledge of the propagation rates of cracks in metallic structure, it has been possible to ensure continued airworthiness through more focussed inspections.

Fatigue and damage tolerance stress analysis and tests are performed as part of the design, certification, and during the in-service life of any new aircraft model. The resistance of structures to cracking, and the behaviour of the structure in presence of cracks are investigated during these processes. This is done using computer models but also full-scale fatigue tests, where actual aircraft parts mounted in a test rig are subjected to stress similar to that experienced during more than their whole life. For the A400M, discussions are ongoing to define if these full-scale tests should simulate up to three times the expected aircraft life of thirty years. Figure 11 shows a digital mock-up image of the full-scale fatigue test of the new Airbus A340-600.

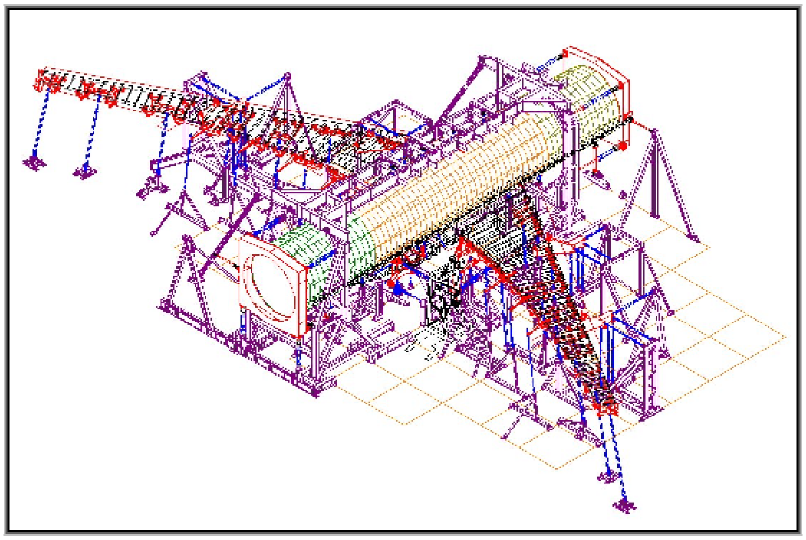


Figure 11: Airbus A340-600 Full-Scale Fatigue Test.

The scheduled maintenance tasks for fatigue damage are generally provided with an inspection threshold, and repeat interval. This is based on the fact that it will take a certain time before a crack initiates and starts to grow. Inspections will be repeated so that a crack exceeding the detectable crack size will be discovered before it may reach its critical size under limit load.

Inspection tasks are defined based on assumptions regarding aircraft usage. These cover average mission profiles, including phases between take-off and landing; average aircraft weights, speeds, altitudes, distances per flight stage, etc. and their variation. Therefore, a mix of missions with different parameters has to be considered, and this is especially true for military aircraft, for which the mission mix is much wider than for airliners. The results of the fatigue tests will be used to calibrate the A400M Life-Time Monitoring System (LTMS), discussed below, that will be used to predict the needs for structural inspections based on the actual aircraft use.

This concept is being applied for the design of the A400M structure, based on various operating assumptions provided by the experts of the Participating States, and the 'fatigue consumption' for the Structure Significant Items (SSI) can then be calculated during the aircraft design phase, allowing to define the best structure to meet the mix of missions. Figure 12 shows an example of this analysis based on C-160 data. The A400M full-scale fatigue tests, which are part if its certification process, are scheduled to be completed in January 2011.

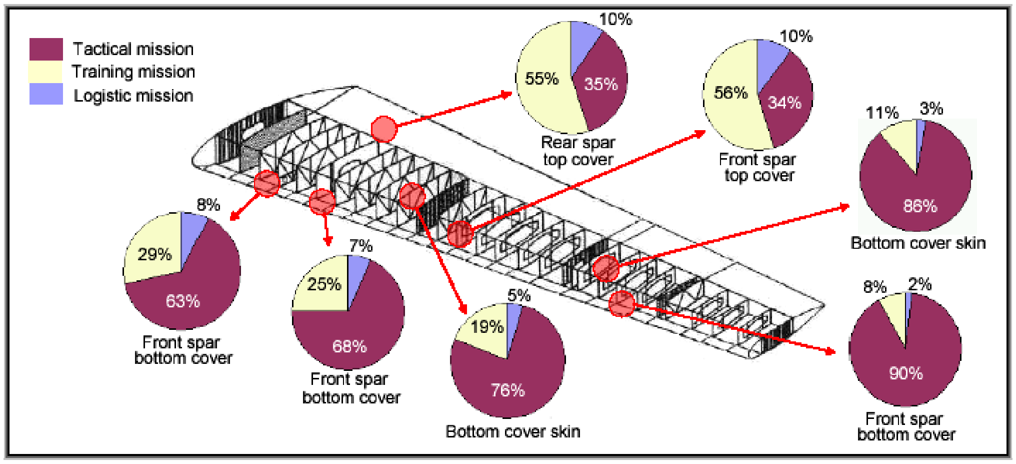


Figure 12: Comparison of Fatigue Consumption in Wing SSI.

During the in-service phase, actual operational and maintenance data will be collected in order to fine-tune the scheduled maintenance programme. This data collection will partly be based on onboard data collection and diagnostic systems that are described in the next section of this article.

5.3 Onboard Systems Diagnostic Integration

Another way to improve operational availability is to reduce the time required for corrective maintenance. In addition to an efficient system installation, which reduces the duration of components replacement, maintenance time can be reduced by improving the diagnostic capabilities of the aircraft. As we have seen before, the AIMDS of the A400M is used to centralise the control of BITE, detects system faults and provides failure messages in plain English, and collects and records engine, APU and critical systems data, thereby enabling trend analysis and maintenance planning.

This data can be either analysed on board of the aircraft, or analysed more deeply on the flight line by using a Portable Multi-purpose Access Terminals (PMAT) that allows ground crews to interrogate the AIMDS via plug-in points inside and outside the aircraft to facilitate a more in-depth analysis of failures. In addition, the PMAT will provide access to the Interactive Electronic Technical Publication (IETP) of the aircraft for troubleshooting and corrective actions.

The PMAT can download the AIMDS data and upload it into a Ground Support System (GSS) that includes both a Mission Planning and Restitution System (MPRS) and a Maintenance Data System (MDS). These systems, developed by Airbus Military for the A400M based on existing systems (in the case of the MDS, the AirNav system developed by Airbus for its commercial customers), will allow to store the data in a database, manage the performance of corrective actions on the aircraft, and schedule the preventive maintenance tasks. It will present the aircraft status in real time and perform other functions such as engine health monitoring. In addition, studies are being conducted to allow the transmission of maintenance data from the aircraft in flight to the ground via a data link, which would allow a more efficient management of maintenance activities on the flight line and increase operational availability. Such methods are already in use by some civil airlines.

A schematic representation of the functionalities of the A400M MDS, showing its external interfaces and main functions can be found on Figure 13.

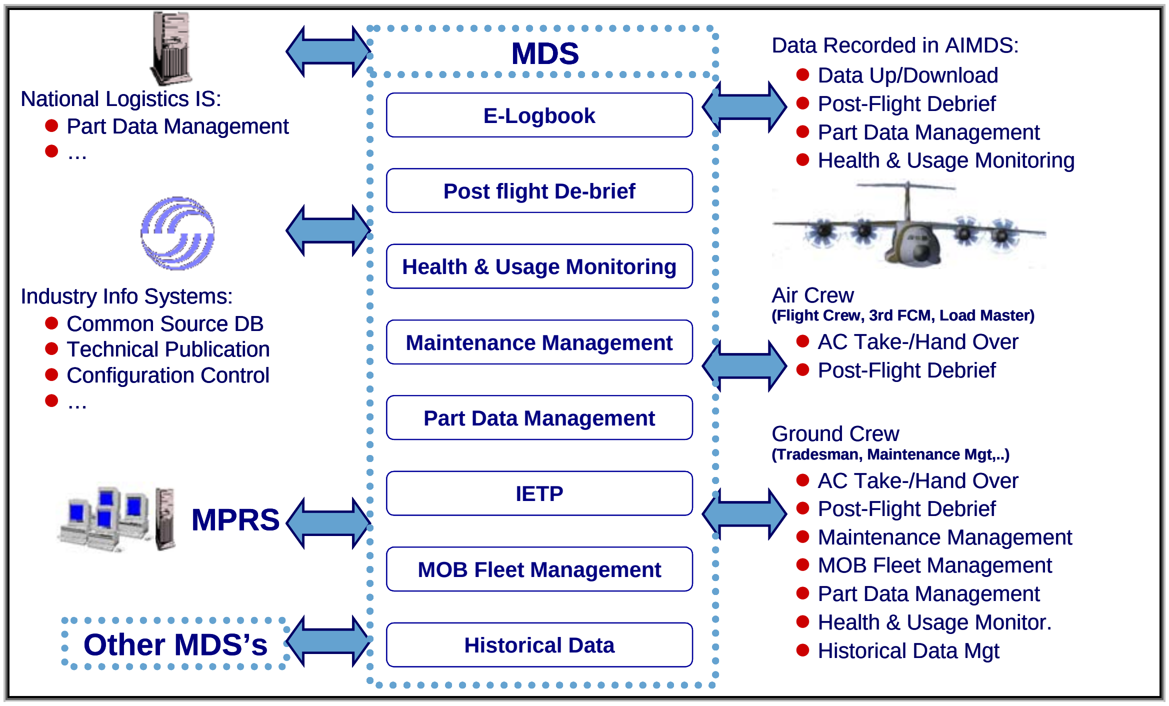


Figure 13: A400M MDS External Interfaces and Main Functions.

In addition, the aircraft may be equipped with an optional Life-Time Monitoring System (LTMS), for which an added option exists to perform direct measurements via strain gages. This system will record aircraft structural loads, including overloads, hard landings and total cycles accumulated, enabling operators to track aircraft utilization and associated fatigue. This will allow the operators on the one hand to plan their on-condition maintenance more efficiently, but also to review the scheduled maintenance programme if required.

5.4 Increased Components Reliability and Systems Redundancy

The RM&T characteristics of aeronautical parts, especially electronic components, have dramatically increased over the last decennia. The A400M design is based on these highly reliable components, which will reduce maintenance downtime and thereby increase availability while reducing WLC. In addition, a number of systems will benefit not only from the Airbus design methods and tools, but also from the experience of other recent Airbus programmes, such as the A340-600 and the A380. A number of A400M systems will be based on the design of similar systems in these aircraft. Whenever possible, Commercial Off-The-Shelf (COTS) or Military Off-The-Shelf (MOTS) components are used.

Moreover, the redundancy and possibilities of reconfiguration of the aircraft systems will provide increased operational availability by allowing the A400M to be operated normally with a number of failures. As an example, the aircraft will be equipped with four V/UHF voice radios, while only two are required by international civil aviation regulations for a normal logistic flight in civilian controlled airspace. Moreover, the critical systems can reconfigure automatically in case of failures, thereby easing the burden to the aircrew.

In addition, the aircraft structure will make intensive use of composite materials, which is expected to reduce the requirements for inspections for corrosion and fatigue.

6.0 CONCLUSIONS

The A400M is one of the key multinational aeronautical projects in Europe, compensating the air transport capability gap of the European Air Forces and enhancing the competitiveness of the European DTIB. To that end, it provides an opportunity to implement many improvements in the operational availability of the European air transport fleet, as well as optimising their WLC. This paper has highlighted these improvements, both in the area of maintenance and support concepts and of technological measures.

We can see that many of these improvements complement each other, and have both a managerial and technological components, so that none of these two should be considered separately. In addition, we have seen that operational availability cannot be dissociated from the related costs, and that the A400M attempts to strike a balance between these two critical factors. Moreover, the experience gained with civilian aircraft can certainly be used for the benefit of military aircraft.

By using the military experience of the European Air Forces and the aircraft design experience of Airbus, the A400M should be able to reach the optimum of operational availability and costs for the benefit of the European military, thereby helping to bridge its air transport capability gap and helping to optimise the competitiveness of the European defence industry.