In the last issue of the FAST magazine the carriage of perishables and livestock was discussed. In this article a more specific challenge to the cargo smoke detection system, caused by excessive humidity, is examined.

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The market forecast indicates that transportation of cargo is the fastest growing area of aviation, with the world’s freighter fleet growing at an annual average of 6.7% until 2015. A large amount of the cargo carried will be moisture and heat carrying, e.g., animals, fruit and vegetables. This moisture and heat has the potential to be released over the period of time that the cargo remains in the hold. Operations in hot and humid environmental conditions can also lead to occurrences of the same phenomenon. With the opening of the cargo doors there is an influx of hot and humid air. This affects the environmental conditions within the hold in the same way as the presence of heat and moisture producing cargo. False smoke alarms may occur in both circumstances due to interference of condensation with the smoke detection system.

The condensation formation may be affected by the ventilation and heating options for the cargo hold taken by the operator. There are several options for ventilating and heating the cargo bays. In the forward cargo bay there is a basic option for ventilation, and temperature control and/or ground ventilation can also be installed. In the aft compartment ventilation is a basic option and in the bulk cargo bay ventilation is fitted on all aircraft. In the bulk cargo bay heating and/or ground ventilation can also be installed.

The ventilation systems for the forward, aft and bulk cargo compartments all have the same architecture. Two fans are fitted, one to draw air into the compartment and one to draw out air. The expelled air is ducted towards the outflow valve, which ensures that most of the air is not recirculated. Since this is only operative in flight there is an extra option to enable ventilation on the ground.

The option for heating the bulk cargo bay consists of an heating element heating the incoming air. There is no true regulation of the system; it is only possible to heat the bulk cargo compartment, and there is no facility for cooling the compartment. This system differs from the forward cargo bay system, which allows true temperature control, with heating and cooling of the compartment.

Both heating and ventilation should ensure that in-flight spurious smoke warnings due to condensation are prevented (since the detectors will be warmed by the heated circulating air and the ventilation will help reduce the amount of water vapour in the air). However, in cases of the carriage of extreme humidity producing cargo, in-flight spurious warnings due to condensation may still occur. Also, with the cargo hold at a nominal temperature of 20°C, condensation formation is still possible if the cargo doors are opened in very hot and humid conditions, where 20°C may be below the dewpoint temperature of the outside air.

Condensation forms because the detectors are cooler than the air entering the cargo hold, either because of ventilation in the hold, or because of the cold soak during a long flight. When the hot and humid air enters the cargo bay a disparity occurs between the relative humidity within the hold and the temperature of the detectors. This may lead to the situation where the dewpoint temperature of the humid air is above the temperature of the detectors. In these conditions condensation can form on the grid in the measuring chamber of the smoke detector. The condensation causes a change in the current in the measuring chamber, which is the criteria for giving a smoke alarm. These false alarms occur on long range aircraft of all types, this formation of condensation being exacerbated by the length of time a long haul aircraft may be airborne.

Over the duration of the flight, if no cargo ventilation is present, the humidity level in the cargo bays will increase while the temperature of the smoke detectors drops. This provides the perfect conditions for condensation to form.

A solution has been developed by Airbus Industrie to prevent spurious alarms due to condensation occurring on the A330 and A340 aircraft.

<table>
<thead>
<tr>
<th>CARGO COMPARTMENT MODIFICATION OPTIONS</th>
<th>A330-300 /A340-300</th>
<th>A340-200</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forward compartment</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventilation (basic option)</td>
<td>Mod 40096</td>
<td>Mod 40186</td>
</tr>
<tr>
<td>Temperature control</td>
<td>Mod 40097</td>
<td>Mod 40188</td>
</tr>
<tr>
<td>Ground ventilation</td>
<td>Mod 40220</td>
<td>Mod 40220</td>
</tr>
<tr>
<td><strong>Aft compartment</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventilation (basic option)</td>
<td>Mod 40098</td>
<td>Mod 40190</td>
</tr>
<tr>
<td><strong>Bulk cargo compartment</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventilation</td>
<td></td>
<td>Mod 40099</td>
</tr>
<tr>
<td>Compartment heating</td>
<td></td>
<td>Mod 40221</td>
</tr>
<tr>
<td>Ground ventilation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**SYSTEM OPERATION**

The lower deck cargo compartment (LDCC) smoke detectors on the A330s and A340s are installed in pairs. Each pair of detectors is supplied with power by a dual redundant power supply (see Figure 1). One detector in the pair is installed on the Smoke Detection Control Unit (SDCU) loop A, the other on loop B. To trigger an alarm a signal from each detector in the pair is needed. However, if one loop is not functioning, a signal from only one detector is able to trigger an alarm. The SDCU tests each loop to check whether it is functioning before it acts on a smoke alarm from a single smoke detector. When a smoke alarm is generated by the SDCU the ventilation and heating systems (if installed) will be closed automatically.

The detectors used on Airbus aircraft are of the ionisation type that detect both visible and invisible fire aerosols (particle diameter between 0.01 m to 10 μm). The ionisation detector utilises the phenomenon that air ions are attracted by smoke particles. The electrodes set up an electric field and the air between the electrodes is ionised (made electrically conductive) by a weak radioactive source (refer to Figures 2 and 3 for schematic diagrams of the smoke detector operation). These ions move under the influence of the electric field, setting up an ionic current. Smoke particles are too large (up to 1000 times larger than the ions) to be ionised and also attract the ions present between the electrodes. These resulting heavy ions are virtually immobile, reducing the ionic current, which as a consequence increases the electrical resistance of the measuring chamber. An imbalance is now present between the measuring chamber and a reference chamber. This imbalance in voltage is amplified and compared to four different threshold levels:

- **The smoke threshold.** The voltage at which the detector recognises that smoke is present in the measuring chamber and gives an alarm signal.
- **The prefault high threshold.** The voltage at which the detector senses a rise above the normal operational voltage range.
- **The prefault low threshold.** The voltage at which the detector senses a fall below the normal operational voltage range.
- **The fault threshold.** The voltage at which the detector gives a fault signal.

The reference chamber in the detector is present to allow for differential pressure and temperature changes ensuring that the detectors operate with the same sensitivity in flight and on the ground.
The investigations into the spurious smoke alarms due to condensation were mainly concentrated with two operators, one operating in the Middle East and one in the Far East. Questionnaires were also sent to other A330/A340 operators susceptible to spurious warnings to discover how widespread the spurious alarms were. Some common factors high-lighted in the replies to the questionnaire allowed Airbus Industrie to suggest some short term solutions to help reduce delays and inconvenience. An effective short term solution was drying the smoke detectors with a hot air source, but this was a maintenance burden and not practical for the operators in the long term. It was also suggested that the cabin should be heated to the maximum temperature (28°C) if no passengers were present on the flight, to have the cargo ventilation, if installed, on at all times and to heat the bulk cargo hold, if possible.

In January 1995 testing took place on an A340 to define the environment and to determine the effect of localised heaters on the smoke detectors. One of each pair of detectors was instrumented to measure temperature, humidity, sensitivity and smoke indication. The cabin temperature, aircraft skin temperature and the ambient conditions on the ground were also recorded for each flight.

In total five flights were made, the first between Hong Kong and Osaka and the other four between Singapore and Hong Kong. The last two flights made were with heaters fitted in smoke detectors 1WH and 7WH (the two detectors seen as being most susceptible to the formation of condensation, see Figure 4 on the following page). This susceptibility to condensation when the cargo doors are opened was shown by information previously taken during the investigation. This susceptibility is probably due to proximity to the door.

The conditions on the ground (temperature approximately 25°C, relative humidity 50-100% throughout the test period) did not lead to any false alarms, but enough data was collected from flights 2 and 3 to be able to conclude that there was a direct, although small, influence of hot and humid conditions on the smoke detector sensitivity signal.

On flight 2 the sensitivity dropped. The signal moved from -4.6V to -4.9V on 1WH (the detector was not heated on this flight, -4.5V being the normal signal and -6.0V a smoke alarm), while on flight 3 the sensitivity dropped, the signal changing from -4.9V to -5.2V on 3WH (an unheated detector).
Airbus currently uses the ionisation type of smoke detectors but is also undertaking a review into the latest technology optical smoke detectors. The Scattered Light Detector is the optical smoke detector which is most suited for the use in cargo holds. The photodiodes used in these detectors are semiconductor devices for detecting and measuring radiant energy (as light) by means of its conversion into an electric current.

The photodiodes and LEDs are arranged so that light from the LEDs does not fall on the photodiodes under normal conditions. The optical properties of some types of fire aerosol lead to a scattering of the emitted light, some of which will fall on to the photodiodes. This increase in the amount of light detected by the photodiodes causes a change in the electric current output by the photodiode.

Airbus Industrie is currently examining new advances in optical smoke detector technology.
power sources (ground power, APU and engines). These fluctuations could cause the heater coil to act as a solenoid, producing a magnetic effect that could either cause a loss of smoke indication capability or false smoke alarms. The electronic filter prevents such adverse side effects.

The evaluation units were tested for six months in operational conditions. At the end of the evaluation period it was judged that the heater coil was successful in preventing spurious smoke alarms. During the six months no spurious warnings had occurred, against what could normally be expected (between three or four spurious smoke warnings per month to three or four per week, depending on the operator and the environmental conditions).

The cargo smoke detectors are an essential component of the fire protection system, but are susceptible to false alarms if the conditions in the hold are hot and humid. Long range aircraft of all types suffer from this phenomenon, but Airbus has solved the occurrence of false alarms by introducing heated smoke detectors.

There were two main requirements for a new detector:

- The relative humidity within the smoke detector measuring chamber had to be reduced without compromising the detectors’ effectiveness.
- The dewpoint temperature of the detector had to be raised above the dewpoint temperature within the cargo bay.

Both of these requirements could be solved by heating the smoke detector to a nominal temperature above ambient conditions. The new detector included a heater coil that was capable of causing electromagnetic interference. A filter was therefore added to the design to protect the detector from the effects of electromagnetic induction.

Six months of testing took place to ensure that the heated smoke detectors would enter service without the need for further modification.

The main uptake of the modification by operators has been in the Far and Middle East, since many European operators have not experienced problems with the cargo fire detection system. This is due to the less extreme environmental conditions encountered in Europe and as the man-hours required for the wiring modification are fairly substantial it is not seen as economical to perform this modification.

Airbus has successfully solved the occurrence of spurious alarms due to condensation on its long range aircraft. There have been no reported smoke alarms due to condensation from operators who have the heated smoke detectors fitted to their A330 and A340 aircraft.
The concept of on-board centralised maintenance was developed with the A320. The aim was to provide maintenance teams with diagnosis of faults in plain English, through a single location in the cockpit, with homogeneous access to the maintenance information related to the various electronic systems. As a highly interactive tool, the Centralised Fault Display System (CFDS) has evolved with in-service experience, which has also benefited the A330/A340 Central Maintenance System (CMS) (described in FAST 16, April 1994) in terms of homogeneity of interfaces and definition of layout, reports and messages.

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The CMS in the A330/A340 family is based on the same core principles and basic functions as in the A320 family: fault monitoring and diagnosis is undertaken by the Built In Test Equipment (BITE) of each system; a dedicated computer, Centralised Fault Display Interface Unit (CFDIU) on A320 and Central Maintenance Computer (CMC) on A330/A340, concentrates the messages sent by the BITEs, edits maintenance reports and provides an interface to the operator with the maintenance part of the connected systems; a Post Flight Report is generated after each flight; it lists the ECAM warnings and maintenance status triggered during the last flight, as well as the corresponding fault messages produced by the BITEs; test capabilities and access to additional systems maintenance information are provided through the System Report/Test function.

In addition to these basic functions, Airbus Industrie, in cooperation with the A330/A340 operators, has developed a batch of new features to enlarge the capabilities of the Central Maintenance System - The A330/A340 CMS Option Package (Figure 1). This package can be divided into three categories:
- features improving the Trouble Shooting process by providing additional information such as flags and advisories on the Post Flight Report (PFR) and new means of transmission: information downloading on to a disk, and sending BITE reports following uplink requests from the ground;
- the Servicing Report gathers a number of parameters, such as oil/liquid levels, status of filters, pressures, etc., with the aim of reducing the servicing workload;
- the Configuration Management Reports allow the airline to know which part numbers, serial numbers and databases are fitted on their aircraft; every configuration change is also detected, memorised and transmitted in real time.

A Post Flight Report (PFR) (Figure 2) basically contains ECAM Warnings and Maintenance Status in the “cockpit effects” column; the associated fault messages are displayed on the same line, in the “faults” column.

When an event occurs in flight, it is reported by the crew in the log-book. If it corresponds to an ECAM Warning, it is easy for the maintenance personnel to retrieve it on the PFR. Then, the correlated message in the “faults” column precisely identifies the faulty Line Replaceable Unit (LRU).

**Figures 1**
Central Maintenance Computer optional functions

<table>
<thead>
<tr>
<th>MAINTENANCE MENU 1 / 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>POST FLIGHT REPORT - - - - - - PRINT *</td>
</tr>
<tr>
<td>AVIONICS STATUS - - - - - - PRINT *</td>
</tr>
<tr>
<td>SERVICING REPORT</td>
</tr>
<tr>
<td>DUMP: ← SEND: →</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MAINTENANCE MENU 2 / 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLASS 3 REPORT</td>
</tr>
<tr>
<td>REPORTS PROGRAMMING</td>
</tr>
<tr>
<td>DATA BASE MANAGEMENT</td>
</tr>
<tr>
<td>AVIONICS CONFIGURATION REPORTS</td>
</tr>
<tr>
<td>DUMP: ← SEND: →</td>
</tr>
</tbody>
</table>

**NEW FEATURES**
- **Servicing Report:** List of servicing parameters for 10 items (engines, IDG, APU, Landing gear...)
- **Avionics Configuration Reports:** List of P/N, S/N and DB/N of systems connected to the CMC
- Dump of CMS Reports on a disc through the MDDU
- BITE reports transmission upon Uplink Request

**MODIFIED FUNCTIONS**
- **Post/Current/Previous Flight Report:** Flag and Advisories
- **Reports Programming:** SRR and Configuration Change Report automatic PRINT/SEND/DUMP programmation.
- **Data-base management: two new data-bases** Customised thresholds/Comments for SRR, and diskettes configuration data-base
If an event is not related to an ECAM Warning, the correlation between the log-book and the fault message on the Post Flight Report is done with the UTC (GMT), the flight phase and the ATA Chapter of the affected system.

The innovation of the CMS Option Package is the recording, in the PFR “cockpit effects” column, of the red flags and the advisories displayed during the flight on the Primary Flight Displays (PFD), Navigation Displays (ND) and System Displays (SD). The 37 new “cockpit effects” increase the number of cases where a direct correlation between the PFR and the log-book is possible, giving less room for interpretation and more room for efficiency.
With the development of data processing applications on standard Personal Computers (PC), the need for maintenance information exploitable on a PC is rising. This is the reason why CMC and BITE reports can now be directly transferred to a diskette inserted in the Multipurpose Disk Drive Unit (MDDU) in the aircraft.

This diskette must contain a configuration file, prepared with the ground software Maintenance Option Tool (MOT) (see Figure 3). Data can be manually transferred using the DUMP line key from CMS menus on the Multi-purpose Control and Display Unit (MCDU), or automatically downloaded at the end of the flight (Post Flight Report, Servicing Report). A command file can also be prepared with MOT, in order to automatically transfer selected reports, upon insertion of the diskette into the MDDU.

Quick access to maintenance information can be difficult, when the cockpit is crowded during turnarounds. Besides, trouble-shooting of an aircraft at an out-station sometimes requires the competence of main-base engineers,
and would be much facilitated if they had the possibility of accessing the maintenance reports and system information in real time. This is the reason why new uplink requests have been defined, which can specify the exact BITE report that is needed. These commands are sent by radio (ACARS) from the main-base ground station to the Central Maintenance Computer; the latter initiates a dialog with the requested system, simulates the line keys in order to give access to the specified report, and retransmits it via ACARS in the same format as a usual SEND from the cockpit (see Figure 4).

As with direct access through the MCDU System Report/Test, the BITE uplink requests are inhibited in flight, and the System Dual Access (i.e. conflicts when a system is being accessed from several peripherals) is managed by the CMC. Of course, any command corresponding to system tests is automatically rejected by the CMC, in order to ensure a totally safe use of this feature.

The purpose of this Maintenance Servicing Report is to gather parameters from various systems involved in periodic checks and which might lead to the following report pages:

**SERVICING REPORT**

The purpose of this Maintenance Servicing Report is to gather parameters from various systems involved in periodic checks and which might lead to the following report pages:

**Figure 5**

Example of Servicing Report pages
to a servicing action. Once again, by concentrating the information on a single report, the aim is to simplify maintenance and to save time. This is particularly valuable when the aircraft is operated with short turn-arounds, and when specific regulations, such as for ETOPS operations, require additional checks.

The Servicing Report (SRR) is available on two formats:
- **the full mode SRR** is a two page report (Figure 5), which lists all the following parameters, should they require a servicing action or not:
  - engines,
  - IDG,
  - APU,
  - hydraulic,
  - fuel,
  - landing gear,
  - oxygen,
  - doors and slides bottles,
  - water/waste,
  - air conditioning.
- The monitored parameters are:
  - levels of oil, fuel, water, and hydraulic fluid,
  - status of filters,
  - pressures of bottles, tires, reservoirs,
  - chip detection, etc.

- **the coupon mode SRR** presents only the systems which have at least one parameter requiring a servicing action. A summary is always issued first, in order to indicate the status of each system: OK or CHECK. This summary is followed by a variable number of “coupons”, each of which gives the servicing parameters of the systems declared “CHECK” in the summary (see Figure 6).

It should be noted that every parameter is computed by the CMC with a particular logic, in order to always display the more significant value; for example, fuel & water levels are real time information, whereas engines oil levels are not shown in flight but presented in real time during five minutes on the ground, and then memorised until the next start. This logic allows minimisation of the errors introduced by the oil cooling and the gulping effects.

The Servicing Report can be customised, using files prepared with the MOT ground tool, and uploaded into the CMC:
- on every coupon, and after every item of the full report, spare space is avail-

![Figure 6 Servicing Report - Coupons](image-url)
able for the insertion of comments. These comments can be specific recommendations or information for the mechanics;

- the title of the complete servicing report and of the summary coupon can be modified;
- for every numerical parameter, maximum and minimum thresholds can be defined. If the actual value exceeds this range, the status of the system becomes CHECK, and a coupon will be triggered if the coupon mode is selected.

The Servicing Report can also be automatically printed and/or sent through ACARS and/or dumped on a disc, 10 minutes after engines shut-down, which is the delay needed to get stabilised oil levels.

**AIRCRAFT CONFIGURATION REPORTS**

The last feature of this option package is the capability of managing aircraft configurations. For that purpose, three reports have been designed, the Equipment Configuration Report, the Diskette Configuration Report, and the Configuration Change Report.

- The Equipment Configuration Report (ECR) gives in real time the complete list of part numbers (P/N), serial numbers (S/N) and, when applicable, database numbers (DB/N) of equipment connected to the CMC (Figure 7). This list is accessible from the MCDU, it can be printed, sent through ACARS, requested from ground with an uplink or dumped on a disk. It is automatically updated when new equipment is fitted on the aircraft.

- A Configuration Change Report (CCR) is created each time a part number or data-base number change is detected by the CMC. It can be automatically printed/sent/dumped, allowing the responsible ground staff to be aware in real time of any configuration change. For each modified equipment, the CCR remains accessible from the MCDU, as long as the change has not been validated through a specific menu with a password.

- The Diskette Configuration Report (DCR) is a list of the disks associated with the avionics; for each of them, the report provides the reference of the data they contain (Navigation data-bases, software loaded by disk, filter data-bases, etc.). The frame of this report is defined with the Maintenance Option Tool (MOT) ground software.

**CONCLUSION**

The new features developed in the option package of the A330/A340 Central Maintenance System, recording of red flags on Post Flight Reports, transfer of on-board data to diskettes, direct access from ground station to on-board data, and aircraft configuration reports, enlarge the capabilities of this trouble-shooting tool, which also becomes a servicing and a configuration management tool. Maintenance is simplified and time is saved.

This new step in modern maintenance confirms Airbus Industrie’s desire to develop powerful and efficient tools, which take full benefit from digital technology and adapt maintenance practices to the latest generation of aircraft.

*The A330/A340 CMS option package is available through the RFC/RMO procedure.
For more technical information, do not hesitate to contact AIRBUS INDUSTRIE, Customer Services, AI/SE-E54
Tel: +33 (0)5 61 93 29 42, or your Customer Support Manager.
The modification is covered by SB 45-3005 and 45-4005.*
This article is an extract of a brochure of the same name which covers the complete Airbus aircraft family.

Today’s tough competitive environment forces airlines to reduce their operational costs in every facet of their business. Every method to achieve this goal has to be envisaged, safety and accident prevention permitting of course, as these are prime factors in any aircraft operation. A wide variety of different aspects have to be taken into account in this process, such as Air Traffic Control, engine deterioration, flight operations management, instrument accuracy or aerodynamic deterioration.

The purpose of this document is to examine the influence of aerodynamic deterioration.

by Jean-Jacques Speyer
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The manufacturer does its best from the development phase onwards to foresee all potential deteriorations and adopt designs which are the least sensitive to in-service deterioration and by continuous research and modification programmes, to keep the aircraft deterioration processes within acceptable bounds. The operator’s responsibility is to maintain his aircraft in good condition and make sure that it is utilised in the most satisfactory conditions possible.

Unfortunately, in the life of an aircraft, degradation is likely to occur. An aircraft is normally expected to increase its drag by up to 2% within five years if not properly maintained. Indeed, many aerodynamic elements may increase drag and their cumulative effect can introduce a significant cost increase. Simply adopting corrective action in order to repair these items, could lead to excessive maintenance costs. Therefore, the effect of deterioration has to be traded-off against the estimated maintenance cost, in order to check whether it is cost-effective to carry out corrective measures. Cost-benefit analysis is the only practical way of keeping an aircraft operationally efficient.

Airbus Industrie has carried out numerous performance audits in co-operation with airlines which, implicitly, have made a very useful contribution to this document.

The information in this document will help the aircraft operator adapt its maintenance programme, balancing financial aspects, such as increased fuel consumption against maintenance costs. It should enable operators to determine whether corrective actions are financially pertinent, despite short-term maintenance costs. Considerable longer-term expense may thus be avoided at relatively low cost. And strategic maintenance actions rather than detailed, dispersed and costly repair jobs may be more easily decided upon and justified.

**GENERAL**

**Aerodynamic deterioration**

Some of the most severe penalties in terms of fuel consumption are caused by increased drag resulting from poor airframe condition. Normal aerodynamic deterioration of an aircraft over a period of time can include the incomplete retraction of moving surfaces, damaged seals on control surfaces, skin roughness and deformation due to bird strikes or damage caused by ground vehicles, chipped paint, mismatching doors and excessive gaps. All these items are potential money wasters. Each deterioration incurs drag increase, and this increased drag is accompanied by increased fuel consumption.

**Sensitivity classification**

The fuel burn penalty caused by drag-inducing items is largely dependent upon the location and extent of the problem; different areas of the airframe are more or are less sensitive to alterations in their optimum aerodynamic smoothness. Bearing this in mind, a zonal classification can be established for drag sensitivity over the whole aircraft (see Figure 1).

Zone 1 surfaces require high aerodynamic smoothness because they are endowed with high local flow velocities and very thin boundary layers which are very sensitive to small local disturbance. Zone 3 surfaces are much less sensitive because of lower flow veloci-
ties and thicker boundary layers, and disturbance on these parts of the airframe does not produce high aerodynamic resistance to the airflow. Also, the transition from laminar to turbulent boundary layers having occurred earlier, zone 3 is less sensitive to aerodynamic irregularities or excrecences. Finally, zone 2 surfaces represent an average between these two extremes.

The localisation of zones 1, 2 and 3 for A300/A310 are shown in the figure. The zones differ slightly for the other Airbus aircraft.

**Figure 1**
Drag sensitivity zones (A300/A310)

- **Zone 1** High sensitivity
- **Zone 2** Medium sensitivity
- **Zone 3** Low sensitivity

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**Fuel penalty calculation**

It is possible to determine drag increase, generated by particular items, with wind-tunnel measurements or analytical techniques. The drag increase is then converted into terms of increased fuel burn - in US gallons per year per aircraft - but the reader must keep in mind that the values given correspond to an aircraft which is in accordance with specific assumptions. These assumptions refer to each type of aircraft of the three Airbus families.
and include annual flight hours based on airline statistics.

The drag increase can also be expressed in US$ per year per aircraft, the fuel price being based at US$0.60 per gallon. Note: fuel prices have increased by about 30% in the last year. Since calculation assumptions may vary significantly among individual operators, tables giving a corrective factor - to apply to the fuel penalty to be derived from the operator's annual flight hours - is given for each type of aircraft, in Figure 2.

### Airframe maintenance

For a specific corrective task, man-hours required can significantly vary from one airline to another, and from one type of repair to another. The calculation method adopted in this document is simply an estimation partly based on measurements. These tasks should have been carried out assuming a regularly maintained aircraft, operated under normal conditions and with an average daily utilisation, having maintenance /corrective actions carried out in a hangar with good environmental conditions. All necessary standard and special tools, as well as ground support equipment, skilled maintenance personnel and appropriate maintenance documentation should also be available.

The values presented herein (men and manhours) are based on these assumptions and are intended to reflect operational reality as closely as possible.

Total maintenance costs, for both on-aircraft and shop tasks, include overhead and burden costs for maintenance planning, engineering orders, safety equipment, facilities and supervision. An acceptable rate per manhour covering all these aspects is US$50. Serving as a benchmark, this value corresponds to an average cost covering skilled working personnel.

### Adapted maintenance programme

As stated above, the degradations that are likely to occur stem from two main sources (excluding incidents or handling) : either mechanical wear or corrective actions which have not been properly executed. Although ill-considered or superficial repair may have negligible effect on performance, some tasks have to be carried out with special care, given their positive impact on fuel consumption.

As mentioned before, despite the efforts of maintenance organisations and manufacturers, deterioration can occur. It may have significant effects on consumption in spite of having only a slight influence on drag. One way to determine these effects is to use the Aircraft Performance Monitoring (APM) software. This programme calculates deviations in Specific Range and, to some extent, helps to determine how much these discrepancies stem from engine degradation and how much from a lack of aerodynamic cleanliness. Inherently, the program does not really differentiate between apparent and real drag.
For instance, higher drag may be concluded from APM results but could, in fact, reflect lower thrust at N1 (or EPR). Also bleed leaks can affect apparent aerodynamic deterioration through N1 deviations by biasing the N1/thrust relationship if they are not accounted for. For these reasons, values given by the APM software have to be considered with great care.

Nevertheless, they can trigger an alarm at a predetermined loss of Specific Range in relation to the initial aircraft drag condition, and an unscheduled check could be launched to detect the type and location of any drag rise. This unscheduled check could be a line check walkaround associated with an overwing in-flight check observing and photographing control surfaces, preferably by means of a telephoto or zoom lens. The association of both types of check constitutes an Aerodynamic Inspection. The items to be observed are shown in Figure 3. This Aerodynamic Inspection, which would take only a short time to perform, should be done by skilled personnel as for example aerodynamics or performance engineers, able to interpret secondary effects (e.g. leakages) and to determine the corresponding deviations (as well as being able to conduct performance audits).

When both the type and extent of the deterioration are known, the following tables (example shown on Figure 4 on the following page) could be used to determine what should be repaired and what may be ignored, for financial reasons. Repair times should be scheduled during night-time periods, time permitting, otherwise the task has to be included in a scheduled check.

The Aircraft Performance Monitoring software has the advantage of potentially triggering an Aerodynamic Inspection just when it is needed, thus avoiding unnecessary inspection.

If the APM software is not used, the Aerodynamic Inspection could be scheduled, for instance, at the occasion of a “C check”.

Although this approach may confirm discrepancies, not all may be identified. In this case direct measurements in the suspected area should be made, such as prescribed in the Aircraft Maintenance Manual. This second way is more expensive but it may offer better drag reduction results.

In a third stage, if the drag reduction seems insufficient, the airline may then ask Airbus Industrie for a Performance Audit.

These three approaches should help any airline to alleviate excessive fuel consumption.

Figure 3
Flying control surfaces
The purpose of the following is to give a fuel penalty and maintenance cost comparison for the items studied. Values given in this particular section correspond to the smaller fuel penalties applicable to all Airbus Industrie aircraft. They are intended to make the reader more sensitive to fuel penalties / maintenance cost comparison and to sort out a few general conclusions which pertain to all Airbus Industrie aircraft.

**Misrigging of control surfaces.**

These items correspond to specific control surfaces misrigging (see Figure 5). They incur one of the largest fuel penalties, while the cost of the corrective actions, by comparison, is negligible. Indeed, one spoiler extended by 15mm over a 1 metre spanwise length leads to more than US$ 6,000 penalty per aircraft per year (see Figure 4 above). Similarly, an outboard slat misrigging causes nearly US$ 11,000 penalty per aircraft per year. Furthermore, flap misrigging - or especially rudder misrigging - can lead to a slightly lower, but still considerable, fuel penalty. Another sensitive item which is generally forgotten is misalignment at a flap track fairing which may cost nearly US$ 1,000 per aircraft per year.

The Aerodynamic Inspection could be done in flight, simply by a visual inspection from the passenger compartment and by photographing control surfaces by means of a telephoto or zoom lens.

For a misrigged control surface, the associated corrective action cost is negligible and should indeed be undertaken.

**Absence of seals on movable sections**

Seals on movable sections are very important and should not be forgotten. The spanwise slat seals are mandatory for the optimisation of the wing supercritical airfoil. One metre of missing seal incurs a penalty of US$ 2,300 per aircraft per year. The chordwise flap seal, which may seem to have a rather negligible effect, causes more than US$ 3,000 extra cost per aircraft per year. However, the worst penalty would result from a missing fairing.

**Figure 4**

Cost of misrigged flying control surfaces (A300/A310)

<table>
<thead>
<tr>
<th>Control surface</th>
<th>Penalty in US$ gallons per year</th>
<th>Penalty in US$ per year</th>
<th>Aircraft Maintenance Manual</th>
<th>Corrective action</th>
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<tr>
<td></td>
<td>Excess gap 5mm</td>
<td>Excess gap 10mm</td>
<td>Manual</td>
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<td>Slat 1 (per metre)</td>
<td>3,850</td>
<td>2,310</td>
<td>27 80 00 27 81 00</td>
<td>2 5 250</td>
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<td>5,190</td>
<td>3,110</td>
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<td>490</td>
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<td>2 6 300</td>
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<td>1,840</td>
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<td>1 2 100</td>
</tr>
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<td>810</td>
<td>490</td>
<td>27 11 00</td>
<td>1 3 150</td>
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<tr>
<td>Rudder</td>
<td>1,350</td>
<td>810</td>
<td>27 21 00 27 24 00</td>
<td>2 4 200</td>
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<td>Misalignment at flap track fairing</td>
<td>680</td>
<td>410</td>
<td>05 25 30</td>
<td>2 5 250</td>
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</table>
**Figure 5**
Misrigging of control surfaces

**Slat**

Slat at 15° (gate 2) position

Correct dimension

**Flap, aileron, rudder**

Excess gap

**Spoiler**

Excess gap
and rubber seal at the fin/fuselage junction (US$ 3,500).

The check can be done from the ground during the Aerodynamic Inspection, preferably with extended control surfaces. With retracted control surfaces, the same check could be done by analysing leakage traces on the wing surface below the seals.

The associated corrective action costs are negligible and such action should be scheduled.

**Missing parts**

Missing parts are given in the Configuration Deviation List showing missing parts which must be replaced as soon as possible. A missing access door can cost over US$ 6,000 per year which provides adequate motivation to minimise the period of loss.

**Mismatched doors**

A step on the forward fuselage surface is much more penalising than one on the rear. Misalignment of forward doors must be monitored very carefully; a 10mm forward cargo door step imposes a US$ 2,300 annual penalty, although the associated corrective action costs US$ 650.

During the Aerodynamic Inspection, the door can be checked by standing under it and observing the line where it meets the fuselage. Due to pressurisation, the cabin door must be slightly out of flush with the fuselage. In other words, the door must be 2-3 mm inside the fuselage when checked on the ground (see Maintenance Manual).

The decision - to repair or not - is not easy, knowing that an estimated rigging cost could be much higher, especially if insufficiently skilled personnel are available.

The decision is a matter of judgement by each operator.

**Missing door seal section**

A missing door seal section has two effects: it disturbs the external flow and causes a slight leakage which has to be compensated for by an increase in engine compressor air bleed. In addition to the fuel penalty, a stress-provoking low-frequency whistling sound is audible in the cabin which could possibly annoy passengers.

Preferably, the inspection should be done with the door opened, looking for damaged sections of the seal. With a closed door, the same verification could be done simply by analysing dirt traces on the fuselage.

Since this leakage may increase with time, even if corrective actions are quite expensive, this work should be implemented to remove the risk of further deterioration which would lead to the aircraft being grounded eventually.

**Surface deterioration**

**Skin roughness**

Surface deterioration can lead to significant fuel penalties, especially if the skin is rough or dirty. For a complete aircraft - in the worst case - the penalty can be as high as US$ 60,000 per aircraft per year. Another serious penalty would certainly be on the airline’s commercial image!
Skin dents

Simple dents also cause some fuel penalty which are not costly in terms of fuel consumption (US$ 100 per aircraft per year in the worst case) but are very expensive to repair. If the dent is within the Structural Repair Manual tolerances, no action is necessary for purely aerodynamic reasons.

With repeated «loaders’ assaults», scuff plates are frequently dented and generally present a step, generating high fuel penalties, but corrective actions are not particularly time-consuming.

Unfilled butt joint gap

Unfilled butt joint gaps in aircraft skins are not very expensive in terms of excess fuel consumption (US$22 per aircraft per year in the worst case).

**CONSEQUENCES OF HASTY REPAIRS**

Sometimes, in an operational environment, the purpose of a repair is simply to keep the aircraft in service and to avoid grounding it. Repairs may have been done without taking into account the consequences of increased fuel consumption.

Overfilled butt joint gap

If a butt joint gap is overfilled, the penalty can be significant on the wing upper surface (US$330). A repair which is not properly carried out can lead to a heavier fuel penalty than existed prior to the repair (from US$14 per aircraft per year for an unfilled butt joint gap to US$500 for an overfilled gap on the upperwing in the sensitive zone 1).

External repairs

In the same way, external patches induce more drag, especially on the wing upper surface (US$640). It is normally difficult to replace an external patch by an internal one, but if access has already been gained during an inspection, installing an internal patch could be preferable, since it also has less impact on an airline’s commercial image.

Paint peeling

On the other hand, for visually improving the commercial image, some fleets are often hastily repainted without bothering to properly prepare the surface. Additional paint layers cause increased aircraft weight and the surface is less smooth due to paint steps. Over a short time, paint may peel, with dramatic drag effects, and severe risk of corrosion.

In order to prevent paint problems, proper preparation has to be carried out before any refresher coat is applied.

Manhours for painting have also to be determined with great care because ground time due to paint drying has much more effect on aircraft operation than the simple manhour cost by itself.
The engine cowling, due to its location in a very sensitive zone, has to be observed with great care during the Aerodynamic Inspection. All surface discrepancies incur considerable drag.

Another item, which is less obvious because it is hidden, is the reverser door seal. The associated fuel penalty is very large and it can be observed by leakages on the engine cowling.

For copies of the complete document, please contact AIRBUS INDUSTRIE headquarters, Customer Services Directorate, Flight Operations Support Department, Mr Jean-Jacques Speyer, Manager Operational Evaluation

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CONCLUSION

The purpose of presenting the foregoing examples is simply to make operators and maintenance personnel more aware of drag-induced performance degradation on normal day-to-day operation.

Manhours for structural repairs must be determined with great care because significant differences exist, mainly depending upon the exact location of the deterioration. All these discrepancies can be observed very easily from the ground during the Aerodynamic Inspection.

It has been shown that many, but not all, aerodynamic degradations can be easily detected and cost-effectively repaired. The Aerodynamic Inspection will identify all of these degradations.

It ultimately becomes a matter of judgement for the airline to decide whether to rectify a fault or to ignore its effect. Nevertheless, all maintenance and operations personnel should be aware of fuel penalties which may stem from misrigged control surfaces, defective seals and the lack or aircraft cleanliness - especially at or near leading edges and forward sections of the aircraft.

Airbus Industrie is convinced that prevention is better than repair. Continuously monitoring aircraft aerodynamic efficiency, together with timely rectification of problems, is, without a doubt, the best approach to minimising unnecessary fuel consumption.
As a guide through this sometimes complex subject we can take some advice from the English traveller, Rudyard Kipling:

‘I keep six honest serving men
(They taught me all I knew):
Their names are What and Why and When
And How and Where and Who’

In this article Kipling’s servants will be employed to illustrate the range of spares issues facing an airline today.
In this article, Airbus Industrie with its considerable experience of airline needs, offers:

- help to reduce Initial Provisioning investment by 30%,
- to arrange spares access solutions to suit an airline’s business objectives,
- to assist reduce airline cycle times and assist repair and warranty management,
- dedicated heavy maintenance support,
- help to reduce aircraft Direct Operating Cost (DOC) by 2% through spares rationalisation.

In response to its customers’ changing business environment, Airbus Industrie has already:

- reduced its proprietary 1997 spares prices to 1991 levels,
- negotiated with major suppliers to minimise or freeze their price escalations,
- developed Just-In-Time delivery schemes to reduce leadtimes to a minimum,
- guaranteed its shop repair processing times backed-up by no-cost forward exchanges,
- introduced a dedicated supplier services support team.

WHAT ARE SPARES?

Apart from being widely noticed as a significant cost, spares tend to be perceived very differently by different departments within a classical airline organisation.

Senior management & Finance see spares as:

- A necessary evil
- An asset on the balance sheet
- An excess on the profit and loss account.

Engineering are concerned about:

- Aircraft dispatch on time from the hangar,
- Line maintenance,
- Never enough spares

Flight Operations experience:

- Lack of spares
- Nuisance of Aircraft deferred defects
- Operational interruptions

Inventory focus on:

- Satisfying maintenance needs
- Budget control
- Managing rotatable, expendable or consumable spares.

Commercial worry about:

- Passenger irritation
- Airline image
- Delays.

So who is responsible for the management of all this expense, irritation and frustration? The Supply department of course! Their task is to balance the wishes and service-level requirements of all departments of the airline against their own business objectives, planning and budget. The supply manager has probably achieved the best balance when all the other departments are slightly dissatisfied with him!

Spares Costs can be found in Direct and Indirect Operating Costs
WHY SPARES?

Ninety-nine percent of Airbus aircraft line replaceable parts - those listed in the Aircraft Illustrated Parts Catalog (IPC) - are subject to on-condition maintenance. This effectively means you have no guarantee of when, where and with what consequences they may fail. You only know that one day a part will fail in service, and in line with Murphy’s Law, this will probably be on a Friday afternoon and probably with a VIP or someone from the media on board. And when it happens the supply department takes a spare part from the store or, if none is available, loans, leases, or buys one.

**Spares Benefits:**
**Operational insurance**

The spare parts holding can be compared to an insurance policy covering the risk of operational disturbance. The benefits are a quick recovery from a damaging delay, passenger comfort loss or safety risk. However, it should be noted that all airline recorded technical delays, non-availability of spares is on average responsible for not more than 10% of them. The cost-benefit and dollar return on an investment in spares insurance is very difficult to measure.

To demonstrate the insurance idea, Airbus Industrie would like to introduce the concept of redundant or dormant inventory. This may be defined as the difference between the spares bought and those used during maintenance. The industry standard method of recommending spares results in the investment in spares increasing exponentially with the desired protection. This then leads to a vast increase in the level of redundant inventory. Today airlines, in conjunction with the manufacturers, look for less and less investment in spares as an attempt to control this redundancy.

WHEN TO HOLD SPARES?

Only when you need them!

In an ideal world that would be the answer with all things being equal, except they rarely ever are! The demand pattern for spares is erratic - a non-linear function of human inputs, technical faults, and logistical constraints:

- **What is the problem - is it a component failure**? (Judgement, skill/training, availability of necessary diagnostic tools).
- **Do we have a spare** - if we have, take it, if not, do something else (rob, borrow, substitute aircraft, defer, check the manual, see if the problem is somewhere else etc.).
- **Having bought an additional spare** the airline is stuck with it even if further demand may not justify the cost.

Logistics of spares on the line - where is the store (far away?), is there a storeman, do they have transportation? Car, bicycle or foot? The difference may be recordable delay.

The answer to this problem lies in having access to the right spares when you need them. Airbus Industrie can help provide this access.

HOW MANY SPARES?

The method used widely in the industry today for the calculation of the Initial Provisioning (IP) recommendation for Rotable components (i.e. those which are considered to be repairable for the entire lifetime of the aircraft) is as follows:

- Estimating the expected or average number of further on-aircraft failures which may occur for a part during the period after an initial removal has happened and while the failed part is away for repair, i.e. during the repair turnaround time.

This is calculated using the following formula:

\[
E = \frac{fh \times n \times N \times \frac{1}{MTBUR \times 365}}{TAT}
\]

where:
- \( E \) = the expected number of removals resulting from the calculation.
- \( fh \) = the flight hours per year per aircraft.
- \( n \) = the number of units per aircraft.
\[ N = \text{the number of aircraft operating}, \]
\[ \text{TAT} = \text{the turnaround time, i.e. the time taken from removal of the failed part from the aircraft until is available for re-use after repair}. \]

This formula therefore takes into account the fact that the part is repairable and so the coverage needed is when the part is out for repair. The TAT is therefore a very important parameter. It also assumes spares coverage for the first failure. This point is often overlooked.

With the expected demand, a recommended quantity for each part is calculated using Normal or Poisson probability distribution tables. Using a probability curve: if \( E \) is the average number of failures then how many parts \( R \) do I need to stock to ensure that 90% of the time I will have a spare in the store. Conversely, to ensure that only 10% of the time I will have no spare available.

The number of spares required can be reduced through managing the maintenance cycle for spares removed for repair. The airline controlled part of the cycle involves the removal, shipping to repair station, and the return to store after repairs. Within the repair cycle, opportunities exist for reducing the spares requirement through control of the Shop Processing Time.

**Airbus Industrie offers guaranteed shop processing times not average shop processing times and offers free of charge loans or exchange of replacement spares if it does not meet this guarantee.**

The demand for Expendable parts, items such as nuts, bolts, filters, lenses, bulbs and washers is predicted using a similar formula where the leadtime is substituted for the TAT as it is the leadtime which determines the float quantity.

**WHERE TO ACCESS SPARES?**

In the previous sections we have shown how the in-service demand for spares is non-linear, erratic and hard to predict, and subsequently how suppliers and operators try, despite the difficulties, to actually forecast spares’ demand.

The result is a large investment in aircraft spares worldwide. Industry studies report this at USD 45 billion with a holding cost of 20% per annum. This involves a huge cost and waste through duplication and inefficiencies.

The key to optimisation of the spares investment is balancing the cost against...
the risk of operational interruption and so relates to spares access. Ideally this means having the right spares when and where you need them and being able to give them back afterwards!

There are several different ways of solving the spares access problem, offering various advantages - financial, experience, demand-smoothing, strategic or flexibility.

Airbus Industrie can help operators obtain access to spares when needed through one of the above schemes.

**AND FINALLY WHO?**

Within Airbus Industrie, the Materiel Support Centre in Hamburg is responsible for the management of materiel supply to Airbus customers. Distribution is assured from five stores around the world, located at Hamburg, Washington, Singapore, Beijing and the newly opened Frankfurt store. Together they hold 130 000 Airbus Industrie Proprietary part numbers.

In addition to Airbus Industrie Proprietary Parts, there are numerous vendor parts installed on Airbus aircraft. Airbus Industrie is not the prime supplier of vendor parts. Taking a positive step towards cutting the cost of ownership of its aircraft, Airbus Industrie decided in 1989 to cease being the ‘middle man’ between vendor and customer. Instead, the vendor as the principal source of spares, provides the first line of supply and support. Nevertheless, Airbus Industrie will still provide the service if requested.

Other than the Original Equipment Manufacturers, there are a number of organisations which offer partial or total support for spares maintenance. These offer lease of spares, access to spares pools as well as component maintenance.

These organisations are typically airline maintenance divisions offering third party support or dedicated spares maintenance centres. Airbus Industrie provides assistance to operators to find the optimum solution for their spares needs.

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**CONCLUSION**

To conclude one can quote, again, Rudyard Kipling from his poem to the despairing Supply Manager:

“If you can keep your head when all about you are losing theirs and blaming it on you...”

...then you’ll optimise your spares holding and keep your costs down.
On the 1st of January 1997, Airbus Industrie has opened a new distribution centre in Frankfurt for large high cost spares. The new bonded store is located within the international airport at Frankfurt, one of Europe’s busiest passenger and freight hubs. This enables Airbus Industrie to offer a faster, lower cost, round-the-clock response to our customers’ needs for their spares.

The new store holds over 600 large spare parts including, among others, the parts traditionally known as ‘Insurance Items’. Parts stored are for example passenger and cargo doors, wingtips, flaps, slats, leading edges, and elevators. In all, there are some 392 part numbers held in this store. All parts are available for sale, exchange or lease to Airbus operators as and when required, saving the cost of having to purchase and store these bulky items “just-in-case”.

The opening of the Frankfurt store is yet another Airbus Industrie initiative to reduce the cost of ownership of Airbus aircraft.

Airbus Industrie will be holding its 4th Materiel Symposium in September. This symposium carries on the tradition of meeting with almost the entire Airbus operator and supplier community to discuss materiel issues.

The theme of this year’s symposium is

‘**Cost ↔ Service balancing, let’s keep up the momentum**’

reflecting the on-going pressure on the materiel supply chain to deliver more service while keeping costs down.

Through these Materiel Symposia’s Airbus Industrie obtains first hand knowledge of the problems and concerns of Airbus operators which is a major driving force in its efforts to serve its customers. Invitations are being sent to all our customers and suppliers to attend what, we believe, will be another dynamic and productive programme.
The British airship R-33 which was torn away from its mooring mast in a storm in 1925. A small crew were on board and managed to bring the airship back to its base, but it took them 29 hours.
# Resident Customer Support Representation

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32 FAST / NUMBER 21
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Protecting the atmosphere is a serious responsibility. Airbus Industrie has always believed in a healthy synergy between economic growth and the needs of the environment. This continues to be a major driving force in the design philosophy of our aircraft. In cooperation with the airlines, five ultra-long range A340s are equipped with sampling devices which measure ozone and water vapour concentrations every half mile flown in daily airline service. This initiative is producing millions of readings to assist research into atmospheric change. 

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