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FIELD SERVICE REPRESENTATIVES

ENGINE RELIABILITY AND EROPS

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"Time is money" that is why each heavy maintenance event is expected to be as short as possible and must go according to schedule. While we all realise how important reliable initial provisioning and replenishment reviews for spare parts are, provisioning of them for heavy maintenance may be either underestimated or considered impossible.

Why does mystique surround our daily work of assessing maintenance costs and especially material requirements and investments?

How can we satisfy all the requirements of engineering and material planning departments without losing sight of the economic aspects?

This article gives you an insight of what is possible.
THE "JUST-IN-TIME" CONCEPT

What does just-in-time mean for material provisioning other than for a production line?
- Only a fashionable term?
- A modern phrase for efficiency?
- Today's reality of material management?

For an airline it means low maintenance cost through reduced inventory levels and frequent replenishment reviews.

Due to the increasing number of heavy maintenance checks, just-in-time for Airbus Industrie means an unusually high spares demand for first-time-ordered parts which have to be identified and manufactured at short notice.

Figure 1 shows that the number of heavy maintenance events will more than quadruple by the year 2000.

Not only the increasing number of heavy maintenance checks but also the ageing Airbus fleet is a challenge to everybody involved in material provisioning activities.

Here the just-in-time concept combined with a sound, reliable heavy maintenance forecasting will help to control the cost of heavy maintenance checks.

Clear objectives are required to make the concept work:
- Frequent stock analyses and updates considering latest parts consumptions, fleet composition with clear indications of future events and requirements.
- Consideration of operators' and Airspares' previous experience of heavy maintenance checks.
- Increase of the availability of spare parts at the operator's facility.
- Reduction to a minimum of priority orders during each check.

From our frequent evaluations and comparisons we have results which are quite different from those originally expected. Analyses of 27 D-checks conducted by ten operators showed that there is very little repetition of spare parts required on these checks.

Figure 2 shows that for all the Airbus Industrie proprietary replacement parts requested during the 27 checks, 66% of them were required only once. In fact less than 1% were required more than seven times.

Studies for standard hardware, components and breakdown parts showed almost identical results, as did analyses of the checks by geographical region and by operator.
So in the interest of simplicity we have chosen to show only the total results for all 27 checks in figures 3 to 6.

**INFLUENCING FACTORS**

The following factors have been identified as having a significant influence on material requirements and creating the differences in material consumption between heavy maintenance events:
- General maintenance policy – in-house maintenance, sub-contracted maintenance, airline pooling, maintenance planning, block or equalised-check concepts, embodiment of modification service bulletins.
- Level of training and experience of personnel.
- Facilities and environmental conditions.
- Commonality of aircraft in an airline’s fleet.
- Capacity and capability of Planning and Engineering departments.
- Availability of GSE and tools.
- Level of investment in spare parts.
- Quality of technical documentation.

These factors have to be considered when analysing stock holdings and material recommendations so that reliable information can be provided.

**MATERIAL CONSUMPTION**

A more detailed breakdown of the material consumption was made by ATA Chapter. The ATA breakdown (see figure 3) shows that although there is a low repeatability between the Airbus proprietary parts used, three main groups can be identified:
- Equipment/furnishing – chapter 25
- Doors – chapter 52
- Fuselage – chapter 53.

The large percentage of cabin interior items (chapter 25), which are generally customised, confirms the necessity of an early identification through cabin inspections, and provisioning of such items.

Material consumption by part number (figure 4) shows that nearly 40% of all part numbers are Airbus proprietary parts and another 40% are standard hardware. The latter yields 75% of all items used (figure 5).

*Do you realise that the non-availability, ordering and handling of standard hardware alone leads to additional costs?*

Material consumption by cost (figure 6) indicates that for 16% of
the cost, 75% of material requirement could be covered.

**MATERIAL REQUIREMENTS**

All the evaluations have shown a clear indication of five categories which must be looked at separately before heavy maintenance can begin. For a widebody D-check we can expect, on average, the following material requirements:

- **High consumption parts** – parts which are frequently used in maintenance and are called up on most checks.
- **Customised cabin interior parts** – parts of the commercial cabin interior which are frequently called up but which may differ due to customisation (colour, patterns etc.).
- **Cargo compartment parts** – including roller-tracks and ball-mats which are requested on most checks but differ due to customisation.
- **Structure overhaul parts** – parts which are seldom requested.
- **Corrosion repair parts** – such as seat tracks and extrusions which are seldom requested.

**CONCLUSION**

Forecasting and provisioning of material for heavy maintenance is, as we know, no easy task. Every airline fleet and every aircraft in the fleet must be looked at separately. It is a challenging task for spares engineers and requires the joint skills and close cooperation of operators and Airbus Industrie alike, the common goals being:

**LOW AIRLINE INVENTORY**

and

**LIMITED AOG/CRITICAL ORDERING**

and

**ON TIME COMPLETION OF EACH LAYOVER**

**PROVISIONING FOR HEAVY MAINTENANCE**

For further information or a customised recommendation please contact AIRSPARIES, Department A1/S1A13. Telex: HAMASLH Telecopy: +49 (40) 50 31 68
At the end of April 1988, a picture was flashed round the world, in newspapers and on TV, which shook the aviation industry to the core. It was a photograph of an Aloha Airlines aircraft, on a scheduled passenger flight in the Hawaiian islands, from which a large portion of the upper fuselage, aft of the cockpit, had detached in flight. One of the first, and as it turned out, most significant aspects of this accident was that this aircraft had accumulated nearly 89,000 flights since it was introduced into service in April 1969. In the face of the sometimes hysterical media hype, the reaction of some senior US politicians and worries of the travelling public, the aviation industry moved swiftly to avoid further occurrences.

The other significant aspect of this accident was its cause, which was established by the US National Transportation Safety Board (NTSB) to have been "the fuselage failure initiated in the lap joint along stringer 10 left; the failure mechanism was a result of multiple site fatigue cracking of the skin".

There is much more in the report than that simple statement and the author strongly recommends anyone involved in the maintenance of aircraft structures to read it. Another significant but not so well known fact is that operators and manufacturers had begun addressing the issues of high-time aircraft long before the Aloha accident. Everyone in the industry remembers the Lusaka accident in 1977, where the right hand horizontal stabiliser of a jet transport detached in flight.
This accident led to the damage tolerance concept now used for design and repair of aircraft and which was used to develop the A300 Supplemental Structural Inspection Programme (SSIP), probably known better to some of you as the Supplemental Inspection Document (SID) programme. This programme is specifically aimed at dedicated inspections of structurally significant details, over and above those inspections already called for by the MRB document.

In the aftermath of the Aloha accident, it became clear that even with the SID programmes in place, further action was needed. What that action is, and what it is designed to do, is described below.

Before going into detail however, the reader should be aware of what constitutes an "ageing" aircraft. Many years ago, it was common enough to retire an aircraft after 5 to 10 years active service. Today, this is no longer the case. The growth in demand for seats means that passenger aircraft remain in service much longer than their designers originally intended. It is not unusual to see 25-year-old aircraft operating daily just like their brand-new sister ships. Furthermore, they can operate perfectly safely, bringing benefit to operators and the travelling public alike. It is projected that by the year 2000 there will be approximately 3000 jet transport category aircraft aged between 20 and 30 years in active service.

The Airbus fleet has not reached anything like these figures (see figure 1), but Airbus Industrie are involved, as you will see.

**THE AGEING AIRCRAFT ISSUE**

In June 1988, the FAA and the ATA sponsored an international conference on ageing aircraft and cited "recent events" which raised concerns within the FAA that the safety of the ageing air transport fleet and experience with SID programs should be re-evaluated.

This led to the establishment of a complete structure to examine these issues (see figure 2), and the creation of working groups and task units to examine in detail the development of ageing aircraft programs. Initially named ageing aircraft task force, the activities are now known as the airworthiness assurance task force, this being a much clearer definition of what the tasks really are about. Due to the limited number of aircraft involved (243 active A300B2 and B4) compared with aircraft like the B727 or DC9, the Airbus task unit was part of a group which also dealt with Fokker F28, Lockheed 1011, BAC 1-11 and Con-

**A300 AIRWORTHINESS ASSURANCE TASK UNIT**

The A300 Airworthiness Assurance Task Unit was composed of airlines, regulatory bodies and representatives of Airbus Industrie partner companies.

Airlines participating (Continental Airlines, Eastern Airlines, PanAm, Deutsche Lufthansa, Korean Air, South African Airways and Thai International Airways) represented about 30% of A300 operators. 60% of the aircraft in service and included almost all high-time aircraft. Deutsche Lufthansa represented the A300 members of the ATLAS group (Air France, Alitalia, Iberia and Air Inter).

As with all the other task units, the Airbus A300 task unit had a number of clearly defined objectives, which will be described in more detail later. It was tasked with:

- Reviewing structure service bulletins
- Developing a corrosion prevention programme
- Assessing repair quality
- Providing guidelines for structural maintenance
- Reviewing the SSIP

The last item was not in fact dealt with during the review as the programme has only recently started up, and there is insufficient experience at this time to permit an effective review.

One of the significant aspects of all task units was to develop the various programmes in the same manner. This was quite simply for reasons of commonality, thus allowing all airlines and regulatory agencies worldwide to have a common approach and understanding.

This led in some cases to extremely close cooperation between manufacturers who are otherwise competitors.
SERVICE BULLETIN REVIEW

One of the main conclusions from the NTSB Aloha accident report was that the previously accepted method of regular inspections on older aircraft is no longer acceptable as an alternative to modifications in areas susceptible to fatigue or corrosion (or both!) which could have an effect on structural integrity or airworthiness as the aircraft get older.

On this basis, a preliminary review of all A300 structure service bulletins was performed. This "short list", consisting of some 140 SB's, was then reviewed by the task unit in a series of meetings, always applying the following criteria:

- The area in question is difficult to inspect (possibility of finding a defect)
- Probability of occurrence (finding rate)
- Potential safety problem.

If the task unit considered that one or more of the above items applied, it meant that the SB concerned was a candidate for mandatory action.

The review of A300 SB's resulted in 4 modifications and 9 inspections being recommended to the steering committee for mandatory action (see figure 3). These were accepted and the French Direction Générale de l’Aviation Civile (DGAC) is presently drafting an Airworthiness Directive (AD) on the subject.

The four modifications represent about 350 man-hours of work and USD 6,000 in parts expenditure. The inspection work for the other nine items is in the order of 60-70 man-hours, repeated of course at various intervals. Alternative modifications are available for eight of these nine items.

Compared with some other manufacturers these figures may seem ridiculously low, but this is mainly because the A300 fleet is still rather young. Further reviews will take place over the coming years and the numbers will probably increase as the aircraft mature.

CORROSION PREVENTION

Another major conclusion, not only from the Aloha aircraft, but from worldwide surveys, was that corrosion is far more widespread and potentially more severe than previously thought. Although all manufacturers have corrosion inspection procedures in their maintenance programmes, they were considered insufficient in the light of recent events and thus the task units had to develop dedicated Corrosion Prevention and Control Programmes (CPCP) for each aircraft model.

The A300 CPCP is a "baseline" programme and sets out minimum requirements for typical operators to contain potential corrosion damage at an acceptable level. The programme applies to all areas of the aircraft and to all aircraft in the fleet.

The CPCP document, recently sent out to all A300 operators and their regulatory agencies contains detailed guidelines on how to implement the programme. Only the major points will be highlighted here.

- The programme is the result of task unit consensus, not dictated by any one entity.
- Alternate means of compliance are permitted; the baseline programme is for operators who do not have an effective corrosion prevention programme in place.
- Corrosion detected and above one of the levels given in the document may require adjustment of the programme (e.g. shorter interval).
- The programme has been mandated by DGAC, effective Nov. 1990.
- Reporting of corrosion findings to local authorities, where these exceed the level(s) defined in the CPCP, is mandatory. Airbus Industrie must also be informed.
- The programme is to be implemented on a minimum of one aircraft per year, and all aircraft in an individual operator's fleet must be inspected within the implementation age plus first repeat interval (see figure 4).
### REPAIR ASSESSMENT

The damage tolerance capability of repairs is also an item resulting from recent events. Today repairs which you find in the SRM have already had this principle applied before inclusion in the manual (or retrospectively in some cases). However, some repairs can deviate from these norms, partly because of evolution in the way repairs are designed, partly because of difficulties in interpretation of repair documentation and finally because not all repairs will have been performed in accordance with the instructions. One of the task unit's responsibilities therefore was to develop guidelines for operators to assess existing repairs, to ensure damage tolerance and therefore long-term integrity. Figure 5 shows how, in principle, a repair can be categorized. Each one of the four categories A, B, C, or D, determines the action required.

#### Repair categories

- **Category A** meets the intent of the design certification basis of the aircraft and requires no special inspection other than during normal maintenance.
- **Category B** meets the design certification basis of the airplane. However, it must be inspected periodically beyond normal maintenance requirements to ensure structural integrity.
- **Category C** meets the design certification basis of the aircraft. However, the repair is clearly of a temporary nature and to ensure structural integrity requires periodic inspection in addition to normal maintenance and must be replaced or upgraded to category B or better within a certain time limit.
- **Category D** does not meet design requirements and/or exhibits structural degradation. Must be upgraded to category C or better by replacement or repair, before further flight.

#### Figure 5

Repair assessment programme

1. **Operator locates 100% of repairs by visual inspection and conducts records search**

   - **Stage 1**
   
     - **Is repair on structure that does not require special inspection?**
       
         - **YES**
           
           - Continue with normal maintenance
         
         - **NO**
           
           - **Stage 2**
             
             - Apply guidelines to categorize repairs
               
               - No further action required
                 
                 - **Cat. A**
                 
                 - **Cat. B**
                 
                 - **Cat. C**
                 
                 - **Cat. D**
                   
                   - Repair prior to further flight
             
             - **Stage 3**
               
               - Can guidelines be applied to determine inspection interval and/or removal time limit?
                 
                 - **YES**
                   
                   - Apply guidelines
                 
                 - **NO**
                   
                   - Contact Airbus for recommendations
The guidelines (document) for the A300 fleet are presently under detailed review and are expected to be issued by mid 1991 and cover about 60% of repairs. The document will be further expanded to cover 95% of all repairs during the first quarter of 1992.

**MAINTENANCE PROGRAMME GUIDELINES**

Modern transport category aircraft are designed to meet continued structural airworthiness requirements for an indefinite period. However, this is only valid if maintenance programmes are in place that ensure continued structural integrity (e.g. ultimate strength, damage tolerance). For this reason, the AATF set up an ad-hoc committee to establish guidance material for use in developing maintenance programmes for older aircraft. The AATF has recommended that the ATA controls distribution and revision of these guidelines, that the FAA include some of them in Advisory Circular 120-17A and that aircraft manufacturers include them in the Maintenance Planning Document (MPD) for each aircraft model.

These guidelines will contain a number of recommendations on aspects of the programme becoming applicable to aircraft as they age, including such items as setting up engineering facilities, training of maintenance personnel, phasing of check intervals, age exploration, sale/lease of aircraft and many other items too numerous to mention here. Figure 6 gives a typical example of how an efficient maintenance programme can cut downtimes for aircraft if an ageing programme is introduced before the aircraft actually become old.

There are other examples of this nature and all operators are strongly recommended to study these guidelines carefully. Presently the document is in draft form for consideration by the AATF and Airbus Industrie plans to include it for issue by the end of 1991.

Airbus Industrie considers that the maintenance programme guidelines and the CPCP are powerful tools for all airlines to ensure that aircraft "grow old gracefully".

**OTHER ACTIVITIES**

This article has given a reasonably full picture of Airbus Industrie's role in the AATF.

However, the foregoing is not all. The ATA and FAA have initiated studies into several other aspects of high time aircraft. These include fatigue testing, human factors (for example, it is known that lighting and access platforms have considerable influence on an inspector's ability to find a defect) and further research in non-destructive testing. These activities are ongoing and results can be expected to find their way into the system of aircraft structural maintenance in the coming years.

**CONCLUSION**

Although, as previously mentioned, the A300 fleet is still quite young, Airbus Industrie has participated actively in the setting up and implementation of continuing airworthiness programmes on the structure. There are some in the industry who believe that "mature aircraft" has a more positive sound to it than ageing aircraft. Perhaps, but the object of the exercise is continuing airworthiness, and with the programmes now being introduced the A300s will continue to operate economically and safely for many years to come.

This may be the end of the article, but it is certainly not the end of the story. All the subjects discussed will be reviewed by the various committees and working groups, which will result in further improvement to the mutual benefit of all concerned.
COMPUTER SOFTWARE IN AIRCRAFT
Airborne software is an increasingly large and important system element. However, it is only one element of the aircraft systems, and only one element of the aviation software environment. Consequently, it must be considered similarly to the other system and software elements, and cannot be considered in isolation. It is commonly appreciated that there are no such things as systems which are free from risk, but only systems that reduce overall risk and improve overall performance. The apportionment of risk varies with the systems, some of which contain software.

Airborne software, like other system changes, is used where its benefits outweigh its disadvantages, notably to improve human factors, which are involved in most aircraft accidents. The timescales involved extend over many decades, and involve a large number of suppliers.

Airborne software is produced in accordance with uniquely severe aviation standards, more severe that those understood to be presently used in other aspects of aviation related software or in other safety critical industries. These standards ensure that very great efforts are made to aim at freedom from errors, but freedom from faults is not assumed, and thus fault consequences are assessed and dealt with on a continuing basis, as is the practice in other aspects of aviation systems. A number of powerful tools have been developed to facilitate software development and compliance with these standards.

For decades airborne software has been contributing, and continues to contribute, towards making aviation more efficient, and above all, safer.

**INTRODUCTION**

It would not be appropriate to address the subject of airborne software without placing it in context. After all, airborne software is only one of many elements that affect and make up air transport.

Perhaps the most important element, although it is an implicit one, is man's ability to manage risk to his advantage. Another element is all the various other kinds of software that surround aviation, and make it possible in the form we know today.

Yet another set of elements are the systems that are used on aircraft to make them safe, economical and attractive, and airborne software has been part of these for a long time. In fact, it entered service with the airlines over 20 years ago, in 1968. So in a sense, we can say that airborne software has come of age.

The context in which airborne software is used has a logical consequence in the somewhat unique way in which it is produced, in the severe standards, and the tools that we use to help us meet and exceed these standards.

**AIRBORNE SOFTWARE**

- **ENVIRONMENT**
  - Risk reduction
  - Aviation-related software

- **AIRCRAFT SYSTEM**
  - Design for safety
  - Software as a part of the system

- **PRODUCTION**
  - Standards
  - Tools

**RISK MANAGEMENT**

It is not commonly appreciated that almost all of man's decisions contain an element that affects the risk to him, to others, and to property. Let us take an example that is simple, even seemingly absurd, the decision as to whether to go out or to stay at home, and which has been immortalised in the lament "Nowhere to go but out, nowhere to stay but in"! The risks that we run when we go out are well known, ranging from the consequences of taking a friend to a poor film at the cinema, to the risks associated with cold or with sunny weather, passing by way of the risk of financial loss due to a poor business decision, being involved in a car accident, having a crane fall over on one, or being robbed.

The risks of staying at home are pushed back deeply into our subconscious mind, and we have the saying "It's as safe as houses". However nothing could be farther from the truth. In one country (France) 22,000 people died in domestic accidents in one year, twice as many as in road deaths.

If one fails to go out and get enough exercise, one increases one's risk of cardiovascular disease. Fortunately, being bored to death by a poor book is a metaphorical risk. The near certainty of financial ruin if one stays at home persistently rather than going out to one's place of work is very real however. Even crime has to be considered, although the risk of being assaulted by a worker in the fast-increasing burglary profession is quite small; the initial suspects in a murder include the person that discovered the body, and the family of the victim. Most murders occur at home. It's not so simple, is it?
"Nowhere to go but out..."  
→ Risks:  
. Icy pavements  
. Transportation accidents  
. Freezing / sunstroke  

...Nowhere to stay but in"  
→ Risks:  
. Cardio-vascular disease  
. Domestic accidents

**TECHNOLOGICAL CHANGE**

It is accepted that there are no such things as risk-free systems. Those of us who remember the "zero defects" drive also remember it as an unattainable aim, in other words a myth, and the same holds good for risk, as we saw in our simple, domestic, example. In a sense, we are pilgrims on the path to unattainable perfection, and our particular pilgrimage aims at eliminating risk. But since we cannot attain this aim, we minimise risk.

In the air transport industry, for years we have been using both experience-based and analytical methods to reduce risk and to evaluate how successfully we have been. When introducing technical change we do so because the new system is better than the old one and this is also true in terms of risk. Let us take a few examples.

On the whole, automotive transport is safer than horse-drawn transport ever was, largely because an automobile does not bolt like a horse does occasionally, or throw its rider. A similar improvement has been achieved in aircraft flying controls. The hydraulic systems used now on large aircraft enable precise, crisp control leading to easier and safer handling. Similarly, the use of digital equipment, with its software, has enabled safety-related improvements to be made that would not have been feasible with the older analog technology.

When new technology is being introduced, an achievable target is for the improved system to have a risk that is a fraction of the risk associated with the system it replaces. The way that the different risk elements are apportioned will vary: one may choose a sharp reduction in the human-factor risk and little change in the mechanical-failure risk, for instance.

**"There are no such things as risk-free systems"**  
(Prof. Nancy Leveson, University of California at Irvine)

→ Zero risk, like zero defects, is a myth.

In fact, we aim to eliminate risk but cannot do so, so we minimise it:

- Experience-based and analytical methods
- Benefits of technological change (intended to) outweigh disadvantages also in terms of risk.

Examples are:

. Automotive vs. horse-drawn transport
. Hydraulic vs. manual flying controls
. Digital vs. analogue equipment (with software)
. When introducing new technology, an achievable target is a fraction of the previous risk...

**ENVIRONMENTAL SOFTWARE**

Software is used in many aviation-related applications. The choice is extremely vast, and to illustrate the point it is sufficient to consider some of the computer systems used in the operation of an airline: all of these use software. The applications range from commercial to operational, with most being a mix of the two.

Computer reservation systems are familiar to most people by now, and computer systems that match claims for lost bags with descriptions of "ownerless" or "no-destination" bags in airport baggage stores world-wide are becoming a fact of life for the traveller. They are remarkably good, and the risks are mainly financial: however the associated risks of high blood pressure should not be neglected!

Computer cargo routing systems are in some way similar to computer reservation systems. They ensure that cargo is routed into the proper containers and then onto the proper flights. The difference is that cargo, unlike people, comes in widely differing weights, and that these weights are used for the computer generated loadsheets that tell the crew how heavily their aircraft is loaded and how it is balanced fore-and-aft. Fortunately, these parameters, although important, rarely become critical.

Computer performance calculations ensure that the aircraft is not too heavy for the runways in use during the conditions of the day; computer flight plans route the aircraft properly through three-dimensional airspace so that the flight has enough
The use of computers in aviation is widespread, and the transition from commercial to operational systems is critical for safety. The following table highlights some key areas where computer systems are employed:

<table>
<thead>
<tr>
<th>FROM COMMERCIAL TO OPERATIONAL...</th>
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<tr>
<td>Computer reservation systems</td>
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<td>Computer lost baggage recovery</td>
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<td>Computer cargo routing</td>
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<td>Computer load sheet</td>
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<td>Computer performance calculations</td>
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<td>Computer flight plans</td>
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<td>computers have uniquely</td>
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<td>severe standards</td>
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**SYSTEM DESIGN FOR SAFETY**

Any system, whether on an aircraft or elsewhere, consists of several elements which need to be considered together. Let us look at the way that these elements can act as balances and checks for each other on an aircraft.

The human beings who form the aircraft’s crew, if provided with adequate information and time, can deduce system malfunctions and isolate or override the malfunction so as to maintain safe operation. They remain the most flexible response to many situations.

The aerodynamic surfaces of an aircraft can be moved to compensate for imbalances, and are subdivided so that the inadvertent extension of, say a spoiler, may be counterbalanced by an aileron so that the flight may safely proceed to its destination.

Mechanical systems may contain force limiters or cams to counteract the effects of jamming or faulty operation. Hydraulic systems may act by a “majority vote” to counter a movement caused by a fault.

Similarly with the electrical and electronic systems. The computer software and the data bases can help to protect crews from inadvertent incorrect actions or to assist them in working around systems and operational problems.

The way that these systems are designed is evolutionary; it is most rare for an entirely new feature to be added, with no precedent.

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**AVIATION SYSTEM**

**DESIGN FOR SAFETY**

This system is a whole, it has several components:

| Human, aerodynamic, mechanical, hydraulic, pneumatic, electrical, electronic, software, data base  |
| System designs are based on previous, similar systems (revolution). Revolution is rare          |
| (Not all systems have all these components)                                                   |
| Design for safety uses the properties of the various components as checks                     |

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**THE SOFTWARE EVOLUTION**

Perhaps an illustration of a couple of aspects could serve to show how the process usually works.

The electronic control of engines is a good initial example. Most engines used to have totally hydromechanical control systems to adjust the fuel flow, the guide vanes, and the air intakes and reheat for supersonic engines.

A gradual change is occurring with the introduction of electronics. The first electronic control system which controlled the hydromechanical actuators went into civil service in 1956, on the Bristol Britannia's Proteus engines. Twenty years later, digital electronics entered the scene, controlling the variable air intakes needed for supersonic flight for Concorde’s engines. In 1984, the first engine which used digital electronics to control its functions went into service on the Boeing 757. This was the Pratt and Whitney PW 2037. In all these cases the engine would not work unless a significant part of the electronics remained operative. There were also other intermediate steps, as well as military applications.
The use of electronics to control the movement of hydraulically-powered flying controls is not new either, although its history is a little shorter. The first civil aircraft to use analog electronics in its flying controls was Concorde, again in 1976. The system is analog, and the aircraft remains controllable with the back-up mechanical controls. Digital controls entered service for the first time on the A310, where the slats, flaps and spoilers are controlled using digital computers. All these controls are duplicated. The ailerons act as a backup to the spoilers, and the aircraft may be landed with an abnormal slat or flap setting in the same way as any other aircraft. The result is a more agile aircraft, with fewer control surfaces needed. Digital technology was extended to the primary flying controls of the A320, which entered service in 1988. There are multiple (electronic) mutual backup systems, and the aircraft remains controllable with the backup mechanical flying controls. As for the engine controls, there have also been other intermediate steps, both civil and military.

### Engines
- 1956: analogue electronic engine controls
- 1976: part-digital electronic engine controls
- 1984: full authority digital engine controls
- Other intermediate steps

### Flying Controls
- 1976: analogue primary controls mechanical back-up
- 1983: digital secondary controls mechanical back-up
- 1988: digital primary control mechanical back-up
- Other intermediate steps

### Civil Examples of Software Evolution

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**Airborne Software Development**

The first recorded use of airborne software by a civil operator occurred in January 1968, when Litton LTN-51 Inertial Navigation Systems entered service on a version of the Boeing 707. This event quietly marked its 21st anniversary not long ago. Digital computer systems have since then gradually appeared in an ever-increasing variety of applications. The total size of the software installed is not easy to determine, but a few examples are shown below.

On the whole, airborne software has been near doubling each two years, as new aircraft appear. Computers, with their software, are becoming all-pervasive. For instance, if you flush the lavatory on a modern aircraft, you use a microcomputer.

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**Software's Contribution Towards Risk Reduction**

Many examples could be cited: a couple will suffice to illustrate the theme. Navigation blunders occur occasionally, when erroneous navigation data is used or entered by a crew. The use of digital systems that accept "pre-recorded" data bases has enabled many of the causes of error to be removed, and has thus reduced the frequency of blunders. The digital electronic map displays which have come into use since 1982 help further, since the crew may visualise the navigation data in use.
in an easily understandable form.

Another example is that of the software in the electronic flying controls. This has enabled characteristics to be built into aircraft which prevent the crew from inadvertently exceeding the controllability limits of the aircraft. The effect of the anti-lock braking systems fitted to many modern cars, trucks and buses is similar. The ordinary user can safely control the vehicle to the limit of its capabilities, immediately, without fearing loss of control due to extreme conditions. Another benefit has been smoother control, enabling a more comfortable flight and reducing crew fatigue in turbulence.

Both these examples illustrate improvements in human factors, which are involved in some 60% of aircraft accidents at present, according to industry statistics.

### EXAMPLES OF SOFTWARE CONTRIBUTION TOWARDS RISK REDUCTION

**Area navigation systems**
- Pre-recorded databases have nearly eliminated navigation blunders

**Flying controls**
- Loss of control has been prevented

→ **Airborne software frequently helps to improve human factors.**

### SOFTWARE REQUIREMENTS

The requirements for airborne software are effectively dictated by the nature of the product i.e. airliners. The timescales are those of the aircraft industry. An aircraft takes some two to four years to design, and may remain in production for some twenty years in various developed versions. Many of the aircraft made will remain in service for some twenty years - more in some cases. For instance, the first A300B2 entered service in 1974, and we even now have production schedules for delivery of the A300-600R, a direct derivative, until well into the 1990s. Another example is the DC-3, which entered service in 1936, and of which many examples are still in operation more than 50 years on. Most of them were initially manufactured around 1943-1945, more than 40 years ago, as military variants such as the C-47 or Dakota, and subsequently converted to civil use.

It is interesting to place this in perspective. A person who takes part in the design of an airliner towards the end of his career can expect to have his (or her) great-grandchildren, and sometimes great-great-grandchildren use the aircraft that he helped design, some 40 years later - a sobering thought. Of this time, some 2 to 3 years are spent in design of the airborne software, and updates to this design are made from time to time for up to some 30 years, mainly to adapt to different features introduced in new models of the aircraft, either during manufacture, or by retrofit and in service.

On a typical large airliner, over 35 suppliers provide programs of up to one million bytes each, for a total of about 4 million bytes of program per aircraft. Many of the units which incorporate this software are installed in dual or triple configurations - making for some 10 million words of software in each aircraft. Future aircraft entering service in 1992 and 1993 are estimated to use about double these totals.

The software is developed to severe standards, such as are not yet used in any other industry, including the nuclear power industry. These standards cover design, documentation, verification and certification.

In certain applications, use is made of functionally similar programs that are produced by two, three or four independent teams. This technique is known as N-version programming, and is an example of dissimilar redundancy.

### ON-BOARD SOFTWARE EQUIPMENT

- **Industrial timescales.**
  - 2-4 years for aircraft design.
  - 20 years in production.
  - 20 more years in service.
  - 2-3 years for software development, up to 30 years for modifications.
  - More than 35 suppliers involved.
  - Selected use of dissimilar redundancy.

- **Large size:** up to 1 million words per system, up to 10 million words per aircraft.
- **Severe standards:**
  - Structure design.
  - Documentation.
  - Verification.
  - Certification.

### SYSTEM SAFETY ANALYSIS

When discussing the way airborne software is used, it is useful to bear in mind how an airborne system is designed and its safety established. Some of the methods of designing systems have been covered previously, and the designs are such that the probability of causing an accident due to faults in any one of the systems is less than
one in 1000 million \(10^{-9}\). In other words, one could expect to have one such occurrence less frequently than once per 300 years in a fleet of 1000 aircraft, on average. There are many different ways of designing such systems, but they all use a similar method of demonstrating that this \(10^{-9}\) per hour target has been met or exceeded. This is called the System Safety Analysis, and has been in use for many years in one way or another, for all types of system, including ones containing software.

A System Safety Analysis is a methodical process which resolves a number of issues. When a fault is being considered, one examines whether it can occur in combination with other faults, and how rarely in each case. The consequences of the faults are assessed, as a function of the phase of flight – some faults are innocuous in cruise, but could be highly hazardous during take-off or landing, for instance. In this way, limitations on the use of the system may be properly established. The resources that may be called upon to counter the fault are also considered. These may be the crew, or other systems, and so on.

An important element in the assessment is the time available to counter a fault. For instance, an engine failure must be recognised and compensated for very quickly during the take-off, but more time is available in the cruise. The mission duration is also of importance: if an aircraft is designed for an average mission of seven hours, it can be assumed that more things can go wrong than if it were for two hours, other things being equal. So the system design may be adapted so that the probabilities return to an acceptable level.

One also considers what kinds of faults may occur and remain undetected in normal operation, and one determines maintenance actions to be applied at specified intervals to prevent such hidden failures occurring with an excessive probability. Again, a similarity can be found in the automotive industry - most car owners' manuals and overhaul manuals specify that the brake fault lamps and detectors be checked at certain intervals.

As part of this System Safety Analysis, one considers the defects which may be caused by improperly developed software. At present, it is not possible to use quantitative methods, since there is no reliable way of demonstrating that a program is free of faults to a given probability. So one uses qualitative methods, depending on past experience to guide the assessment. This method is giving results which are proving satisfactory.

**SYSTEM SAFETY ANALYSIS**

- Formal demonstrations of fault characteristics.
- Target is \(10^{-9}\) per hour (or better) accident probability. (less than once per 300 years for a fleet of 1000 aircraft).
- Software defects are considered:
  - No quantitative methods available.
  - Qualitative methods used.

**WHY SOFTWARE STANDARDS?**

It has been seen that there is nothing more special about software than about any other element of a system. A badly designed piece of structure, a badly designed hydraulic union, a badly designed radio amplifier or bad software can all have similar consequences, at one time or another. So it is pertinent to show the reasons why software standards are needed.

Firstly, it has to be realised that a listing of computer code is a somewhat more indigestible form of information than the schematic diagram of an analogue electronic circuit which performs the same functions. An incorrect connection on the schematic stands out like a sore thumb to the experienced designer. An incorrect letter or numeral in a software listing may represent an instruction whose results are very different from those intended - and is not easy to spot during verification.

Secondly, airborne software is a marriage of two technologies: aeronautics, with its emphasis on critical systems, and the disciplines needed to ensure their safety, and computing (or data processing) with the emphasis being very rarely on critical systems in scientific, commercial or process control applications. Many of the people who write airborne software came from the computing "world".

Thirdly, the rapidly reducing cost and volume of digital computing is allowing the use of software to perform more and more complex functions, which were not previously practicable in most cases.

The creation and enforcement of airborne software standards allows the critical-
WHY SOFTWARE STANDARDS?

Cross connections are highly visible inside (analogue) electronics—less so with computer software.

On-board software marries two technologies: aeronautical and computing.

Many programmers came from the computing world (scientific, commercial, process control) and are usually inexperienced in critical applications.

Reducing cost and volume allows functions of greatly increased complexity.

→ Software standards allow transfer of aeronautical disciplines to the "ex-computing" people, alleviate complexity's potential for error.

SOFTWARE STANDARDS

Nowadays, most airborne software complies with standard DO-178A, laid down by the Radio Technical Commission for Aeronautics (RTCA), or with equivalent standards such as EUROCAE’s ED-12A. RTCA is a voluntary industry body, which is entrusted by the US Federal Aviation Administration with much industry standard making in this field.

The Special Committees which define the standards have as their participants people with appropriate qualifications and experience from the regulatory bodies, the aircraft operators, the aircraft and avionic manufacturing industry and elsewhere. DO-178A is itself derived from a previous standard, DO-178 and is in the process of being updated (to DO-178B), in order to incorporate increasing experience and knowledge.

DO-178A defines three levels of software.

● Level 1 is aimed at critical applications, and aims at being error-free. However freedom from errors is not assumed: the fault consequences are assessed and dealt with on a continuing basis, as is the practice in other aspects of aviation systems. The standards are extremely severe, and require the structure of the software to be simple and deterministic— in other words what is happening inside the software at any given moment is entirely determined by the "outside world" system inputs which supply the data which it processes. The structural simplicity is required so that the interconnections between the software elements can be assessed with a reasonable effort. The standards impose a formal methodology, which covers quality planning and assessment; the software design process; the test plan and results; the certification process and the tools used. The documentation generated as a formal record of this process is impressive.

● Level 2 is aimed at essential, rather than critical, applications. The standards are comparable with Level 1, but less documentation is required.

● Level 3 is aimed at simpler or non-essential functions, which aim mainly at comfort and economics. This is the least stringent of the three levels, and is similar to good commercial software.

Dissimilar redundancy is used in conjunction with Level 1 or 2 software as an additional precaution in many full-time critical systems such as flying controls and in some critical systems such as the automatic landing system.

⇒ RTCA DO-178A is an industry and certification standard.

THREE LEVELS OF SOFTWARE STANDARDS

- Level 1
  - Used in critical applications
  - Aims at being "error-free"
  - Severe standards
  - Deterministic, simple structure
  - Format software methodology:
    - Quality
    - Test
    - Tools
    - Design
    - Certification
  - Extremely well documented

- Level 2
  - Used in essential applications
  - Standards comparable to Level 1...
  - Well documented

- Level 3
  - Used in non-essential applications
  - Least stringent—similar to good commercial software
WHICH LEVEL OF SOFTWARE?

The level of software to be used is not determined by the "diktat" of any single party. A collegiate approach is used by the airframe manufacturer (who deals with the supplier) and the major certification authorities. For the A320 these were the Joint Aviation Authorities (JAA), itself a college of the CAA, DGAC, LBA and RLD, and the FAA. Normally, certification for export to countries with other authorities is covered by the usual procedures, which do not result in changes to software levels. After certification (and entry into service) any modifications to this software are designed to the same standard as the original software used.

→ Software level is determined as a function of application and airline requirements by teams comprising:

- The airframe manufacturer
- The major certification authorities:
  CAA (UK), DGAC (F), FAA (USA)
  LBA (FRG) RLD (NL).

→ Software modifications are the same level as original software.

CRITICAL SYSTEM SOFTWARE

Airborne software has strict requirements, starting with the methodology to be used. A commonplace comment that applies to commercial computing is "rubbish in - rubbish out", meaning that if you go about writing a program or entering data in just any old way, you will be justly rewarded for your efforts (or rather lack of them). There is a converse comment applicable to level 1 software, this is "Quality in - quality out". Quality is built in right from the start, before a single line of program is written. The development process is split into orderly phases, determined right from the beginning, and quality plans are determined so as to assure its incorporation, and to control that it has been incorporated. This includes formal documentation for the extent of testing.

The consequences are threefold: simplicity, simplicity, and yet again, simplicity. That is to say, the complex software is broken down into simple, understandable building-blocks, and the way that these blocks inter-relate with each other is kept as simple as possible. The software is kept deterministic; it does not have obscure or ambiguous internal states, since these are entirely determined by its input data, which the real world supplies. The structure is simple and operates in real time, and has very few interruptions. In other words, all the inputs used are scanned periodically, and acted upon in the same way, computing cycle after computing cycle; the practice of carrying out part of the computation routinely, and interrupting it to process a changed input is not used here.

The result is that each software module can be tested easily, and so can its interconnections, thus enabling the whole of the software to be tested in a methodical way. Another result is that if it is necessary to update a software module at some time, it can be tested independently, as can its interconnections. Since the interconnections are part of a logical scheme, the functions affected by the changed module can be verified, and one can better verify that the other functions are not affected by the change.

Methodology requirements:
- Development formally split into orderly phases
- Formal quality assurance and quality control activities
- Formally documented test coverage

Consequences:
- Straightforward architecture
- Deterministic
- Simple, real-time structure
- Built from simple modules with few interfaces

→ Better testability

→ Modifications can be demonstrated to affect only the intended function and not the others
AN EXAMPLE

The A320 flying control system contains a number of computers, which can be used to illustrate the preceding descriptions.

The Spoiler and Elevator Control computers (SEC) are typical and can be used as an example. There are three identical SEC computers on each aircraft, each controlling different a spoiler pair and elevator hydraulic controls. There are two sets of hydraulic controls per elevator, and one set per spoiler pair. The aircraft may also be controlled by ailerons in the roll axis, and these are controlled by the Elevator and Aileron Control system (ELAC) which also provides a back-up for the elevator control. It is seen that back-up can be provided by the other SECs and the two ELAC computers. There is also a mechanical back-up control system which can be used to control the aircraft.

The software of each SEC consists of 180,000 bytes of program, divided into two dissimilar lanes. A disagreement between these lanes would result in shutdown of the SEC lane affected, control being retained through the other SEC channels and the ELACs. The software operates in real time. In other words, the controls will always move an imperceptibly short time after a control stick is moved. This contrasts with many commercial computing systems, which operate either on a batch processing basis (like credit card statements) or on a near-real-time basis like bank cash dispensers, which may take a few moments to check the bank card validity by phoning up a remotely located mainframe computer. Such delays would be intolerable in a vehicle control system.

The documentation required to codify the quality assurance requirements, to describe the software, to define what tests are required and to document the results is impressive: 16,800 pages, which on standard office paper would form a pile as tall as some adult human beings. About 90% of this documentation is solely for quality purposes, including testing.

CRITICAL SYSTEM SOFTWARE EXAMPLE

Sub-system:
- A320 spoiler and elevator control system (SEC)

Software features:
- 180,000 bytes (words) of level 1 software
- Dissimilar redundancy
- Real time

Backups:
- Elevator and aileron control system
- Other SEC lanes
- Mechanical control

Documentation:
- Quality assurance
- Software description
- Software testing
- Software inspection/quality control

Total SEC software documentation is 16,800 pages long, of which over 90% is solely for quality purposes, including testing.

DISSIMILAR REDUNDANCY

Unlike in labour relations, redundancy in the engineering sense is frequently desirable. If a function is redundant, it is one of a set of functions which can perform a particular task. The number of such functions (or degree of redundancy) desirable to achieve a given economic or safety goal can be adjusted by the system designer. The redundancy may be similar (like the dual hydraulic brake systems on most cars) or dissimilar (like the hydraulic brakes and the handbrake or electric brake on a truck or bus).

In the software applications one sees on civil aircraft, the term dissimilar redundancy is usually used to describe two (or more) lanes of similar function, but made rather differently. These can be compared, and be arranged to shut down a subsystem if they disagree.

In practice, the software is written by two independent teams, and the hardware is frequently also different, using two different varieties of processor. The function to be implemented can also be described in two different but functionally identical ways. This is because many mathematical expressions can be expressed in different orders or ways which are exactly equivalent.

Since the error content of each level 1 set of software is ideally zero, it follows that the likelihood of finding a pair of similar errors in both sets of software becomes very much lower still, although the total number of errors may increase because the total amount of program is double the size. However, these remaining unlikely errors would result in sub-system shutdown, which is tolerable in many cases, whereas sub-system misbehaviour would not be.
A corollary is that the technique may only be applied where system loss is acceptable or when a back-up is available.

Examples where dissimilar software redundancy has been used by Airbus Industrie are automatic landing systems (since 1981) and flying controls (since 1983). Other airframe manufacturers are following suit.

**DISSIMILAR REDUNDANCY**

- Uses two different sets of software and hardware
- Result of computations compared; if different, sub-system is automatically switched off
- Software designed by two different teams
- Used as an additional precaution where system malfunction could cause unacceptable consequences, but where other backups are available if sub-system loss is allowable

**SOFTWARE TOOLS**

In addition to the normal software production tools used by most suppliers, there are a number of tools which are designed for the production of software for critical and essential functions. Automatic code generation is used by several suppliers to actually write the program, starting with the specification supplied by the airframe manufacturer. The advantage of automatic code generation is that it can be carried out in a systematic way, and that the program which writes the code can be written to comply with the DO-178A requirements.

Computer-aided specification writing is used by the airframe manufacturer to generate the software specifications. This is a user-friendly system which ensures that the specifications for any different types of systems software are unambiguous. It incorporates a number of checks, for instance verifying that conflicting or incomplete statements are not made. The system interfaces with some suppliers' auto code generation tools, thus facilitating their operation. Lastly the specification output can be used to configure simulations of a system well before the airborne computer can be made available.

Another software tool category is the use of analysis and parameter injection tools, which can be used to access or modify parameters inside computers at will during system development and flight test.

**Computer aided specifications, used by the airframe manufacturer:**

- "SYSTEMATIC SPECIFICATION WRITING"

  - User-friendly
  - Unambiguous, multi-use
  - Incorporates inconsistency, other error checks
  - Facilitates auto code generation
  - Allows system simulation

**Automatic code generation used by suppliers:**

- "SYSTEMATIC SOFTWARE PRODUCTION FROM SPECIFICATION LEVEL"

  - Analysts and parameter injection tools, used by the airframe manufacturer during development, enable computer parameters to be accessed/modified at will.
  - Examples are GALA (Sextant) and PASTEL (Aerospatiale)

**SOFTWARE TOOLS**

**CONCLUSION**

It has been seen that airborne software is only one element of the aircraft systems, and only one element of the aviation software environment. Consequently, it must be considered similarly to the other system and software elements, and cannot be considered in isolation.

Airborne software is produced in accordance with uniquely severe aviation standards, more severe than those understood to be presently used in other aspects of aviation software or in other safety critical industries.

These standards ensure that very great efforts are made to attain freedom from errors, but that freedom is not assumed. Fault consequences are thus assessed and dealt with on a continuing basis, as is the practice in other aspects of aviation systems.

In a nutshell, for decades airborne software has been contributing, and continues to contribute, to making aviation more efficient, and above all, safer.
A single in-flight engine shutdown (IFSD) which causes an airline to alter the affected aircraft's schedule or route, just one shutdown, might obliterate an entire year's operating profit the carrier would expect with that aircraft. This costly nature of IFSD events is discussed as part of periodic seminars United Technologies' Pratt & Whitney hosts for operators of twin-engine aircraft powered by Pratt & Whitney's JT9D-7R4 engines. Reduction of this engine series' IFSD rates is the main topic. The seminars are an element in Pratt & Whitney's expansion of its basic JT9D engine model reliability program. The expansion, initiated in 1989, is focusing specifically on JT9D-7R4 twin-engine operators. Representatives from these airlines, Airbus Industrie, and Boeing Commercial Airplane Group attend the seminars. Twin-engine aircraft powered by JT9D-7R4 engines are the Airbus A310, A300-600, and the 767; 144 of these aircraft were in service as of October 1990.

EXPANDED RELIABILITY PROGRAM

Under the expanded reliability program, a special Pratt & Whitney team has been formed to reduce in-flight shutdowns, and therefore operating costs and maintain competitiveness for the 21 airlines with the JT9D-7R4 twin-engine series; nearly 400 engines are involved. The IFSD-reduction team is multi-department in structure, comprised of more than 50 members from 15 in-house functions, including several customer support and engineering disciplines. Subcommittees work on a cross-functional basis. The team meets daily to review the status of solutions to previous causes, or potential causes, of IFSD events and to analyze any new events carefully and quickly for new causes. For each actual or potential IFSD cause, the team determines a corrective action and adds it to the operator's implementation plan. During its analysis of an IFSD, the team obtains reports and data describing the event.

Pratt & Whitney field offices provide extensive data for analysis, including the engine operating mode just prior to the event, a summary of maintenance data and supporting pertinent data. The event is categorized with known causes or is identified as a new cause of an IFSD. If there is a new cause of an IFSD, the team identifies a permanent correction, or an interim action, then issues appropriate documentation and updates existing corrective actions in a manual, known as the "pink book", which has been distributed to all JT9D-7R4 twin-engine operators. Aircraft manufacturers, Pratt & Whitney suppliers, and the JT9D-7R4 twin operators also participate in the analysis and corrective-action process. The original "pink book" stemmed from a substantial review beginning in 1987 of a data base of historic JT9D-7R4 IFSD events. Airbus and Boeing collaborated in its preparation. Actual or potential IFSD causes were listed, with available corrective actions.

ETOPS REQUIREMENTS

The Pratt & Whitney team has a target of 0.02 or fewer total in-flight shutdowns per 1,000 revenue operating hours in 1991, matching the required reliability rate for 180-minute ETOPS (extended-range twin operations) certification. Airbus A310 and A300-600 aircraft have received 180-minute ETOPS certification from France's DGAC (Direction Generale de L'Aviation Civile), with approval by Britain's CAA (Civil Aviation Authority) and the United States' FAA (Federal Aviation Administration) expected before the end of 1990. This certification was based on the availability of corrective actions for historic, actual or
COSTS OPERATORS

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IFSD causes. Approval for a specific airline to fly ETOPS routes will be based on its demonstrated fleet reliability and its incorporation plan for these corrective actions.

Even though all 21 JT9D-7R4 twin-engine operators will not necessarily have a requirement for ETOPS certification, the benefits of reduced operating costs reflected in an improved IFSD rate should be attractive to every JT9D-7R4 operator. Any improvement toward the 0.02 level reduces costs, increases profits and results in a more-competitive position. Operator expenses are reduced by prevention of the multiple costs of an in-service engine shutdown. Low total IFSD rates also allow operators to fly more direct routes over long distances (ETOPS) if appropriate to the route structure, further reducing operating time and expense. Engine improvements that have a favorable impact on the total IFSD rate, frequently result in fewer delay-and-cancellation and operating-discrepancy events; another economic benefit.

IFSD COSTS

The cost of an IFSD can be startling, as was revealed at one seminar. Airline attendees estimated the cost at anywhere from $5,000 to $5 million. One-third of the 24 respondents, however, placed associated direct losses for each shutdown at more than $1 million, not including the more-indirect costs of customer dissatisfaction. The average of all the estimates was $850,000. An airline's average annual profit per aircraft, in comparison, was estimated in an industry study at about $639,000 depending on aircraft size, route structure, passenger load and other basic operations factors. Shutdowns can result in such costly procedures as diversions, jettisoning of fuel, air turnbacks, delays and cancellations. Repairs required because of any of these events add to the cost. The cost of customer dissatisfaction to the operator is more difficult to quantify but is just as real. High IFSD rates also can result in loss of, or failure to obtain, ETOPS operating approval. For those operators desiring ETOPS approval for certain routes, inability to gain the certification can result in higher fuel and operating costs, increased flight times, and a competitive disadvantage. Engine-related events, including surges, account for about 45 percent of all in-flight shutdowns for the entire JT9D-7R4 twin-engine aircraft fleet. Maintenance-related errors account for an estimated 15 to 20 percent of the IFSDs and the remainder is attributed to operations errors, the aircraft and the nacelle.

The expanded JT9D reliability program is addressing all IFSD categories with the intention of expediting the incorporation of available corrections and improving maintenance procedures and training. The JT9D-7R4 twin-engine aircraft first obtained ETOPS certification in April 1985. The overall JT9D-7R4-powered twin-engine fleet reliability has improved every year since 1986, however the IFSD rate in 1988 was still 0.063 (events per 1,000 hours), while the target reliability rate goal for 180 minute ETOPS operation is 0.02. This trend is shown in the bar chart on page 24. The 0.02 rate is attainable for the JT9D-7R4 series under the Pratt & Whitney plan. It does, however, require the cooperation of the aircraft manufacturers and airlines. IFSD reduction is a "win-win" situation for everybody.

CORRECTIVE ACTIONS

Pratt & Whitney has had corrective actions available for some time for many of the JT9D-7R4 in-flight shutdown events attributed to the engine. Interim or final corrective actions existed or were developed for 26 of 31 identified parts problems, and 19 of these existed prior to 1989. Implementation of recommended actions should be accelerated, and this is being promoted by the Pratt & Whitney IFSD-reduction team in the seminars. A "single-point" contact - generally a manager of either maintenance or engineering - at each of the JT9D-7R4 twin-engine aircraft operators and at Airbus and Boeing is helping to coordinate plans on all actions required to achieve the 0.02 reliability goal. The single-point contact at the
Airlines, Airbus and Boeing is a key part of the expanded JT9D reliability program. The contact will be working directly with the IFSD-reduction team and the on-site Pratt & Whitney representative to achieve the reliability goal and will be a pipeline for Pratt & Whitney communications on in-flight shutdowns.

1991 set as target for 2.20 IFSD goal for JT9D-7R4

- Engine - Stability
- Engine - Other
- Nacelle / EBU / Aircraft
- Maintenance / Operations

The actions recommended in the pink book are effective. Airlines that have followed them have seen a drop in their in-flight shutdown rates. More operators need to do likewise. The highest levels of incorporation tracked to date are between 60 and 70 percent, reached only by a small percent of the fleet, typically ETOPS operators. The IFSD rate for the ETOPS demonstration fleet - 43 aircraft with eight airlines - dropped substantially in 1989, from an average of 0.035 in 1988 to 0.023, and is currently (through October 1990) at a rate of 0.02. As a matter of fact, the entire Airbus A310 fleet, including a relatively small number of ETOPS operators (15 aircraft) has a current IFSD rate of 0.017.

Other improvements in IFSD rates have been realized since 1988. The entire 767 rate is currently 0.025, down from 0.069 in 1988. The A300-600 rate has increased to 0.176 from 0.086, but more than fifty percent of these events had been recorded by one operator. A fleet management plan has been developed for this operator. The overall IFSD rate for the entire JT9D-7R4 twin-engine fleet has improved to 0.035 from 0.063. Pratt & Whitney data show that there were 47 actual JT9D-7R4 events in 1989. If corrective actions available as of January 1989 had been incorporated, there would have been 23 events; additional corrections introduced during the year, if implemented, would have lowered the total to 16. To meet the 0.02 IFSD target level, 18 shutdowns are allowed in a year for the entire JT9D-7R4 twin-engine aircraft fleet.

In addition to promoting acceleration of the rate of implementation, Pratt & Whitney is asking the 21 operators to help in its investigation of any new shutdowns. Pratt & Whitney needs to be informed immediately of an IFSD and to receive any parts that might have caused the event. Pratt & Whitney will respond with help within 24 hours of the event. The sooner Pratt & Whitney is informed of the problem, the easier it will be to prevent a repetition. Pratt & Whitney also is working to improve its dissemination of recommendations to operators. The data base is being improved to group repeat causes of events and to have the data in a more action-oriented form.

Steps have been taken to improve the timeliness of service bulletins, Pratt & Whitney's primary recommendation document. Bulletin writers now are located alongside the engineers who design the improvements in order to document the changes faster. A new computer system has been installed to improve the number and format of illustrations in the bulletins. A special team has been formed by Pratt & Whitney in response to operator expressions of the need for clearer understanding of the reasons for service bulletins, installation requirements, and expected payback, to name a few. The team is working to address all of the operators' needs.

**TRAINING**

Pratt & Whitney also is expanding its training of airline personnel in engine maintenance and shop procedures, with emphasis on IFSD prevention. This includes distribution of videotapes and printed material and more training of airline personnel at the Pratt & Whitney Customer Training Center in Wethersfield, Connecticut. Pratt & Whitney also is assisting in recurrent training of airline personnel on a periodic basis. An intensive effort is under way to work directly on-site with the mechanics performing flight line maintenance on JT9D-7R4 engines for the 21 operators. A subcommittee of the IFSD-reduction team spends a week at each location to assist and observe the mechanics. General procedures and instructions are reviewed, and tools and fixtures are checked to ensure they are the proper ones. Emphasis is being put on getting feedback to Pratt & Whitney of any problems the mechanics might be having with Pratt & Whitney hardware. The subcommittee, usually comprised of three or four persons, is drawn from Pratt & Whitney's maintenance engineering, technical support and engine nacelle groups and customer training center.

**FLIGHT CREW PROCEDURES**

In addition to its efforts to help reduce IFSD events attributable to maintenance errors, Pratt & Whitney has another subcommittee in the field working on reducing in-flight shutdowns caused by flight crew errors. The most common problems occur with misinterpretation of procedures or instrument indications, leading to an unnecessary engine shutdown. Pilots, for example, sometimes shut down an engine when it fails to respond to a throttle-advance for more thrust. They do not realize that a heavy drain of bleed air from the engine may have cut acceleration margins. Similarly, in the event that the Electronic Engine Control had been inadvertently left off and then switched on at high engine power, the adjustment from the mechanical to the electronic control schedule could result in rapid deceleration and produce an engine stall. One planned course of action is to revise some of the procedures now listed in flight crew manuals, working in concert with Airbus and Boeing. Pratt & Whitney is committed to further improvement of the IFSD rates and a lowering of operating costs by achieving or bettering ETOPS requirements for power plant reliability. Higher reliability will contribute to higher profitability for JT9D-7R4 operators.

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The information presented in this article is intended to reflect the views of position of Airbus Industry, who accepts no liability or responsibility whatsoever for the content thereof. This article has described the actions of one engine manufacturer to improve the reliability of their engines to make them suitable for ETOPS. The next issue of FAST will carry an article covering the effects of ETOPS on aircraft systems.
Developments in digital electronic technology have led to very significant benefits for aircraft maintenance and engineering personnel. The ability to monitor and record hundreds of parameters simultaneously from the major components, and particularly the engines, is probably the most significant development in the monitoring of system performance and the trouble-shooting of faults since the invention of flying machines. Simple trouble-shooting information provided by the Centralised Fault Display System can be read in clear language on the multipurpose control and display units in the cockpit, an operation which was described in the article "On-line maintenance on A320" in FAST no. 8 of July 1987. However the recording and monitoring system in the A320 can provide a considerable amount of complementary information mainly of interest to the engineering staff in an airline. This article provides some details on the system to enable these engineers to understand its operation better.

by Pierre Valin-Saunal  Airbus Product Support  Indicating / Recording Systems

A320

IMPROVED TROUBLE-SHOOTING

The impact of modern data recording and monitoring systems
Recording of certain data has been required by the Airworthiness Authorities for many years but it is only recently that this same data plus many others have become easily available to aid maintenance. The aircraft data recording system available today consists of two sub-systems:
- the basic Digital Flight Data Recording System (DFDRS),
- an optional Airborne Integrated Data System (AIDS).

**DFDRS**

This sub-system (figure 1) includes the Flight Data Interface Unit (FDIU), and the Digital Flight Data Recorder (DFDR) (figure 2). Since the data are also useful for trouble shooting and determining other maintenance requirements they can be duplicated in an optional QAR. Read-out of the QAR tape is performed at a ground station.

The FDIU acquires data from digital buses to ARINC 429 standard, and then builds them into a DFDR frame at 64 words per second. The primary use of the information stored in the DFDR is for accident and incident analysis so it has to comply with extreme survival requirements, which as a result makes the data difficult to extract.

**AIDS**

The two main components of this sub-system (figure 1) are the Data Management Unit (DMU) (figure 2) and the Digital Access Recorder (DAR). It should be noted that the DAR and QAR are physically the same recorder. When linked to the FDIU it is known as a QAR, and as a DAR when linked to the DMU. Both the QAR and the DAR (same part number) can be installed, or one only which can be installed in either position, as the operator requires, for trouble shooting purposes.

AIDS is dedicated to engineering tasks and ground-based
analysis and is organised around the DMU which interfaces with the other units shown in figure 3. Approximately 3000 digital parameters from 38 computers in the aircraft are fed into the DMU.

Based on these parameters the DMU performs several tasks, the results of which are either found on the DAR cassette, on the aircraft printer or MCDU screen or, if they are downlinked, through the Aircraft Communication Addressing and Reporting System (ACARS), directly at the computer in the airline ground station.

**DMU CAPABILITIES**

The DMU is a computer which collects and processes digital parameters and creates various reports on the condition of the aircraft. In addition it can be programmed in the aircraft by the airline engineering personnel to cope with particular applications or trouble shooting procedures. The DMU is programmed through the MCDU. Its functions can be categorised as:
- general,
- monitoring,
- real-time parameter reading,
- programmable.

**General functions**

The general functions performed by the DMU without any programming or operator actions consist of collecting basic data to be used by the other DMU modules, such as:
- Flight phase detection - The DMU divides the flight leg into logical segments where tasks like DAR recording and the generation of reports are triggered.
- Pre-event buffers - Whilst the recording of events is of significant importance, it is more important to know what happened before and after the event. So, each time a particular event defined in the DMU as a trigger condition for a report or to start the DAR occurs, the DMU can provide the values of the stored parameters for the printed reports (from 20 seconds before the trigger) and for the DAR (from 120 seconds before the trigger) for a determined period after the event.

**Monitoring functions**

These functions are mainly for engineering staff. Some reports are automatically processed by the DMU in order to allow:
- Engine Condition Monitoring (ECM),
- Aircraft Performance Monitoring (APM),
- APU health monitoring.

Thirteen different reports can be generated by the DMU. Numbers 01 through 11 are dedicated to monitoring aircraft performance and engine condition, and numbers 13 and 14 to APU health. All these reports are generated when their trigger conditions are verified by pre-defined DMU algorithms.

**Specific functions**

**Engine conditions and aircraft performance**

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**APU health monitoring**

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**Three free programmable reports**

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**Optional to AIDS**

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Note: 03, 08 and 12 are not used.
A report can be used in several ways, as shown in figure 4. It can be automatically printed on the on-board printer. If requested the print-out can be coded in Optical Character Reader (OCR) mode which is useful when the processing of the report is computerised. This possibility avoids the need for manual insertion of the data into the ground based computer. An optical pen can perform this task. An example of a printed report is given in figure 5.

A second possibility is to have the report down-linked automatically by ACARS. The report is then forwarded to the airline computer by the ARINC or SITA ground networks. This is the quickest way for a report to be processed.

Today the reports which lend themselves best to ground-based computer analysis are numbers 01, 02 and 04. Numbers 01 and 04 provide the inputs for the engine manufacturer's condition monitoring software called GEM for CFMI engines and COMPAS for IAE engines. The software enables the deviations between measured engine parameters to be compared flight after flight. In the short term this trend monitoring will quickly inform the airline of any engine deficiency. In the long term engine deterioration can be analysed and monitored and a schedule for engine maintenance can be established. Report number 02 provides the inputs for Aircraft Performance Monitoring (APM). The APM software is developed by the aircraft manufacturer to provide information such as specific range of the aircraft.

A registered change may be an indication of deterioration of engine performance or increase in aerodynamic drag caused, for example, by badly rigged moving surfaces.

A similar monitoring function exists for the APU.

**Read-out of parameters in real time**

These functions are mainly for maintenance staff.

One of the advantages of digital technology on the A320 is the ability to read the parameters available to the DMU in real time. These parameters can be called up on the MCDU under two headings, alphanumeric and label call up.

- **Alphanumeric call-up**

  Of the 3000 parameters available, 200 are defined with an alphanumeric code which can be typed on the MCDU to display the parameters in engineering units. Typical alpha codes are:
  - ASN for APU serial number, and
  - BLST for bleed status.

  These 200 parameters are mainly related to engines, APU and airframe surface deflections.

  In the example shown in figure 6 engine EGT has been requested. A maximum of five parameters can be displayed simultaneously.

- **Label call-up**

  Parameters which are not provided with an alphanumeric code can be selected using a parameter reference (equipment
number, system number, label number, Source Destination Identifier (SDI, etc.) which is the basic characteristics of any ARINC 429 digital word. Since the data is displayed in binary and decimal values a simple computation has to be made to convert those parameters into engineering units. A maximum of two parameters can be displayed simultaneously in this mode. In the example shown in figure 7 data for the Engine Control Unit is provided.

**Programmable functions**

The DMU can be quickly adapted to different monitoring or trouble-shooting situations by programming either the free reports or the DAR frame recording.

- **Free programmable reports**
  Three free programmable reports, numbers 16, 17 and 18 are available. Their start/stop conditions can be manual or automatic. The automatic start/stop modes should be programmed by the airline. The start/stop condition is a logical combination of trigger conditions which also have to be programmed. For example see figure 8.

  Once the start conditions have been programmed the contents of the report must also be defined. A maximum of 12 parameters of 60 data sets each can be programmed in each of these reports. The time interval between each data set is adjustable from 0.01 to 99 seconds.

  Pre-event data can be incorporated into the programmable report. These reports can be printed or downlinked.

  Programmable reports provide the airline with the functions of a small logic analyser which is a powerful trouble shooting tool. The results are immediately available and their time and size capacities make them interesting because significant amounts of data acquired before and after the event can be monitored.
**Figure 9**

Recorder speed selection

- **DAR speed selection**
  - YES: Selected speed = 256 w/s
  - NO:
    - DAR frame format
      - 64 basic DFDR words
      - 192 free programmable words
    - DFDR parameters requested
      - YES: 128 w/s DAR frame
        - 64 basic DFDR words
        - 64 programmable words
      - 64 w/s DAR = today QAR
        - with the 64 DFDR word
      - NO: DAR frame
        - 128 or 64 w/s programmable
    - IF 64 w/s selected
      - DAR = programmable QAR

**Figure 10**

Synoptic of ground analysis stations

- DAR tape
  - Reader
    - Serial data
  - Clock
  - Storage capacity:
    - 64 words/sec.
    - 128 words/sec.
    - 256 words/sec.
    - (12 bits = 1 word)
  - DECOM
  - COMPUTER

- DAR frame programming

  This function allows any parameters which are available in the DMU to be recorded in the DAR. Contrary to the DFDR, the DAR frame can be defined for specific monitoring by programming the DMU. Three different recording speeds can be selected: 256, 128 or 64 words per second (figure 9) which allows recordings for periods between 12.5 and 50 hours.

  The DAR can be started or stopped either manually or automatically depending on the flight phase, or by a programmable start/stop logic in the same manner as for free programmable reports.

  DAR programming is useful when large quantities of data have to be monitored over a long period. However the data are only available when the DAR cassette is read at a ground station, as shown in figure 10.

**CONCLUSION**

The digital electronic systems in modern aircraft such as the A320, A321, A330 and A340 offer greatly enhanced trouble shooting possibilities. The DMU is a real help in monitoring aircraft behaviour and in particular engine and APU performance. The significant advances are the flexibility offered to engineering staff to programme the DMU to provide supplementary and very detailed information on a wide variety of events.

Mechanics can also benefit because the on-board read-out facilities allow fast monitoring of data and provide information in addition to that provided by the CFDS.
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Engine reliability and E.R.O.P.S.

EROPS has become a well-known acronym in recent times.

One interpretation, Engineer Repairs or Passengers Swim, could have come from the shut-down of an engine on an early flight from Paris to Dakar which required the direct intervention of the flight engineer. The intervention was unsuccessful, leading to the passengers swimming 35 minutes later (and perhaps to the reduction in the perceived need for flight engineers in the cockpit).

A happier in-flight intervention occurred during the first non-stop transatlantic flight by an aeroplane, in June 1919. One of the two-pilot crew was obliged to leave the cockpit to clear impacted snow and ice from the engines, which brings to mind the other acronym, ETOPS, Engines Turning or Pilots Swimming.
Everything about the Airbus aircraft, from maintenance to cargo handling, has been thought through to minimise turnaround time.

An on-board maintenance panel in an A310 gives quick troubleshooting and testing. The wide-body fuselage gives easy access and all avionics are located in a single bay.

Standard containers mean standard ground equipment and procedures.

Passengers board and leave by the left hand side while all servicing is on the right hand side which avoids congestion.

And as well as taking up less time on the ground the A310 takes up less space – up to 20 per cent less per passenger than comparable aircraft.

Which makes the A310 as popular at crowded airports as it is with busy ground crews.