ICAS-86-5.7.2

THE AIRLINE ENGINEERING ROLE IN THE MANAGEMENT OF SAFETY

D.K. Craig, British Airways PLC, Heathrow Airport, London, UK

To be presented at the 15th Congress of the International Council of Aeronautical Sciences, London, UK on September 7th - 12th 1986.

ABSTRACT

The paper outlines the contribution the Engineering Department of a major International Airline makes in the maintenance and enhancement of Safety Standards. The areas to be covered are: the innovative approaches to the identification of maintenance requirements; the progressive maintenance programmes for the future; the introduction of enhanced safety standards through the airline; development of techniques such as Engine Health Monitoring, NDT and AIDS; and the improvements in quality standards of staff.

1. INTRODUCTION

The aim of the airline, through the development of its Maintenance Programme, is to produce a cost-effective programme which meets the requirements of safety, product performance and maintainability.

"It is the responsibility of the manufacturer to produce an aircraft which is designed to be safe and maintainable at an economical cost".

Therefore, with adequate design, the objective of a scheduled maintenance programme is to realize and maintain the inherent standards of safety and reliability which were designed into the equipment, by the most cost effective means available .

Time has not changed the objectives of airworthiness; what has changed however is the size, complexity and increased performance of aircraft, together with improved design techniques and a more knowledgeable approach to the control of aircraft maintenance. As a result, the traditional methods of maintaining safety margins by the prescribing of fixed component lives and aircraft strip-down policies have been proven to be ineffective as a means of preventative maintenance and also very uneconomical.

"The practice of over-maintaining aircraft does not improve the safety margins - indeed, it is possible it will achieve the reverse".

1.1 Initial Programme

With the advent of the B747 project in the late 1960s, the airline industry believed that a more quantative approach to the development of an initial maintenance programme was possible.

Consequently, a disciplined, maintenance analysis suitable for aircraft systems, powerplants and structures was developed within the combined aircraft/airline industry. The analysis, which was first developed for the B747, was recognised by the regulatory authorities, and this document became known as Maintenance Steering Group 1 (MSG1). The experience gained using MSG1, was used to update the document and delete certain B747 specific information so that a universal document was produced which could be applied to any new aircraft type, hence MSG2.

MSG2 was primarily concerned with prior-to-service maintenance programmes based on the design of the aircraft and did not take account of in-service operational experience or equipment development to modify the programme after the aircraft entered service.

Several events and developments in the late 1970s provided the stimulus for a new look at MSG2 and the areas that were likely candidates for improvement.

New regulations, such as the structural damage tolerance rules in FAR 25.571 for one, required a new approach to developing structural inspections. In addition, many new ideas were produced by a thorough analysis of the maintenance programme development process carried out by United Airlines under contract with the U.S. Department of Defence. These were published in a document entitled Reliability Centered Maintenance (RCM) in 1978.

In 1979, with two new Boeing aircraft on the drawing board, (the 757 & 767), the industry felt that the timing was right to develop MSG3, utilising some of the new ideas to provide for the then current state of advanced technology and including the requirement of the revised FARs.

MSG3 was accepted by the regulatory authorities and has provided considerable improvements particularly in relation to:-

(i) Better identification of safety versus economic considerations.

(ii) A structures programme related to detectability of defects.

(iii) Better assessment of identifying the effectiveness of maintenance tasks.

Each scheduled maintenance task is generated for an identifiable and explicit reason. The consequences of each failure possiblity are evaluated and the failures are then classified according to the severity of their consequences. Then for all significant items - those whose failure involves safety or has major economic consequences - proposed tasks are evaluated according to specific criteria of applicability and effectiveness.

The resulting initial programme should include all tasks necessary to protect safety and operating reliability, and only the tasks that will accomplish this objective with no unnecessary repetition or overlaps.

1.2 Maintenance Review Board Process

Since the early 1970s it has been a requirement that the Certificating Regulatory Authority for each aircraft type issues a Maintenance Review Board report concurrent with type certification, identifying the initial maintenance requirements for that aircraft type. The method of compiling these requirements is defined in FAA.A.C.121-22 and CAA BCAR A6-4 Supplement 2, with the responsibility being delegated to an Industry Steering Committee (ISC). This committee is made up of representatives from the launch customers (Airlines) and the manufacturers' engineering personnel. Working groups of airline and manufacturer specialist engineers are assigned to analyse each aircraft system and the whole aircraft structure using the MSG3 analysis. The initial proposals are submitted to the authorities by the ISC.

1.3 How is Safety Defined?

In the terms of the safe operation of the aircraft, once the design has been certificated, the adoption of MSG3 by the regulatory authorities has allowed airlines to identify those failures and subsequent consequences which have to be prevented to ensure continued, safe operation. In which case, an aircraft can be considered to be safely maintained if the failures of systems or structural elements, which could result in serious/catastrophic consequences and might cause the loss of the aircraft or injury to the occupants, are prevented.

As expected in the design of modern civil aircraft only a small percentage of maintenance tasks are for safety reasons. For example, these equate to only 9% of the total systems maintenance tasks specified in the B757 MRB.

The airlines however, feel that there is still room for improvement in aircraft design to reduce the possibility of such safety critical failures and hence the need for safety-related maintenance tasks. In this respect, the MRB activity and system design certification should be better co-ordinated.

1.4 Maintenance Programmes

Initial Maintenance Programmes established through the use of MSG3 are based on three primary maintenance processes. These are:- hard-time, on-condition and condition monitoring.

With less than 10% of the items needing a hard-time operating limit to reduce the risk of failure, the maintenance programme relies heavily on applicable, on-condition inspections/tests to remove an item prior to its failure, or detect deterioriation before it becomes serious. This is backed up by the airline Condition Monitoring/Reliability programme, (which has to be approved by the regulatory authority), to measure the effectiveness of the overall maintenance and operational standards.

1.5 Condition Monitoring (Responding to Experience)

A condition monitoring programme has two basic functions:-

(1) To provide a statistical summary of aircraft fleet reliability and thus the effectiveness of the way in which maintenance is being carried out.

(2) To provide significant and timely technical information by which improvement of reliability may be achieved through:- changes to the programme, or to the practices for implementing it, or by modification action to reduce the failure rate.

Because of differences in the size and structure of the various airlines the organisation of any programme is generally individual to each operator.

Within British Airways, a closed loop "Condition Monitored" control system (see fig 1) is in operation with a continuing review by Engineering Management to ensure that aircraft technical performance is satisfactory and reaction to any deterioration is both timely and effective.

MAINTENANCE CONTROL PROGRAMME

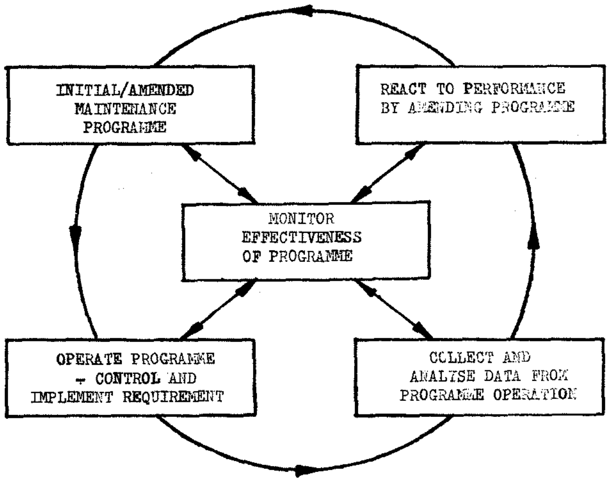

Fig. 1

Typical parameters monitored would be:-

> Aircraft technical delays, engine inflight shut downs, aircraft system performance, component reliability, repetitive defect occurrences and air/ground incident reports.

In order to ensure that the levels of safety are not being eroded however, it is a requirement that a technical investigation is carried out for each reported, mandatory occurrence arising from a technical problem on the aircraft, with the objective of identifying the cause and recommending any action which would prevent a recurrence.

An example of the effectiveness of this condition monitoring is shown by the following graph (Fig.2):-

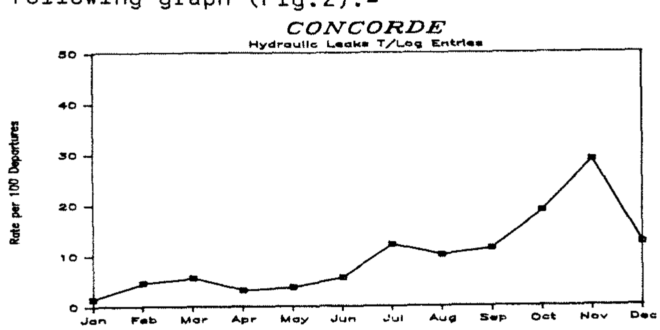

Fig 2

This graph illustrates a problem which was associated with hydraulic leaks on the Concorde aircraft and demonstrates an increasing trend which was identified, allowing timely corrective action to be instigated.

ATA Chapter 29 delay rate (3 month moving average) started to climb in June 1984 and was seen to be significant in the monthly reliability report. The delays over a period were reviewed and the rising trend attributed to an increase in the number of hydraulic leaks. Other ATA Chapters involving hydraulic components were reviewed and similiar trends relating to hydraulic leaks were identified from other parameters monitored, e.g., Pilot Reports, Air Safety Incidents, etc., which by themselves were not readily discernible.

To provide an effective monitor of the total picture, all Pilot Reports concerning hydraulic leaks involving ATA Chapters 27, 29, 32 and 71 were coded together and monitored monthly as shown on the graph.

The continuing rising trend was quickly traced to an age related deterioration of the neoprene and nitrile hydraulic seals, operating at higher temperatures and pressures than conventional aircraft such as the B747.

The following corrective action was instigated:-

(a) A rapid, seal-change programme was established for the major components affected, (PFCUs, Ramp Actuators etc)., based on critical time since fit periods. Longer term, the neoprene and nitrile seals were replaced by "Viton" seals which can withstand much higher temperatures.

(b) An hydraulic leak check was added to the Maintenance Schedule at a Service Check 1 period (100 hours).

As a result of this action the hydraulic leak problems have decreased to much lower and hence acceptable levels and, although the scheduled leak check has been retained, it is now carried out at periods of 250 hours.

1.6 Communication

Any system which depends upon the collection and analysis of data depends upon the adequacy of the raw data. Within the airline maintenance field the communication between the flight crew and the maintenance crew, using the aircraft Technical Log, is vital. Deficiences at this time are likely to inhibit a timely or effective response, and the lack of clear, precise defect - reporting can cause unnecessary difficulties in troubleshooting.

Furthermore, good communication is not only essential within individual airlines but throughout the industry as a whole.

> "An unknown serious problem should be one which has never arisen before".

2. INTRODUCTION OF ADVANCED TECHNOLOGY

In order to provide a safe, reliable and financially viable service, the airlines are always searching for new methods and techniques - not only to reduce maintenance costs but also to enhance the safety standards. There has been considerable progress in engineering technology which has been utilised and pioneered by various airlines to the benefit of all.

The application of this increased technology by the airlines has meant that the aircraft are maintained more effectively and precisely, whilst also increasing operational capabilities.

These achievements have resulted from the introduction of techniques such as the following examples which are currently in use by British Airways:-

2.1 Engine Health Monitoring

This technique was developed to permit early detection of a deteriorating engine condition, thus enabling engines to be removed at the optimum time before they fail in an expensive or even catastrophic way.

Objectives

(1) To minimise consequences of failure by:-

- (a) Reducing inflight shutdowns.
- (b) Reducing secondary engine damage and hence overhaul costs.
- (c) Enabling engine changes to be scheduled.

(2) Helping manufacturers to determine the precise cause of failures and hence to introduce early solutions.

The activities involved in Engine Health monitoring, apart from routine boroscope and visual inspections, include:-

(1) Oil System

- (a) Magnetic chip detectors routinely monitored by a specialist section.
- (b) Filters.
- (c) Spectrographic oil analysis.
- (d) Oil consumption monitors.

(2) Gas Path (AIDS monitor)

- (a) Rotor speed trending.
- (b) EGT trending.
- (c) Fuel flow trending.
- (d) Vibration trending.
- (e) EPR/N2 relationship.

This detailed monitoring has not only enhanced safety standards by reducing the number of inflight shutdowns but has reduced maintenance costs quite considerably.

2.2 AIDS (Aircraft Integrated Data System

The majority of British Airways aircraft are equipped with an expanded Flight Data Recording system, known in the industry as AIDS.

British Airways uses the system extensively to monitor its operation in three basic areas. These are:-

2.2.1 Flight Operations Aircraft Handling

Results are regularly discussed with Flight Training branch. Feedback to and from crew on specific points is obtained, on a confidential basis, for any interesting/important aspect arising from the programme. Training videos are also made to stress any important points learnt in the programme.

Environmental conditions are also monitored, i.e. turbulence, wake encounters.

ATC problems are also reviewed.

2.2.2 Technical Support

Example include: engine problems, autoland integrity and performance assessment, air safety investigations, etc.

2.2.3 Maintenance

Assisting in defect investigations on other aircraft systems.

AIDS is also used in research projects in conjunction with the Civil Aviation Authority (windshear, cruise height excursions, etc.), Eurocontrol, Meteorological Office and, of course, aircraft and component manufacturers.

Data is processed within British Airways on (DEC) PDP 11/73 Computers. Today much of the processing, is largely auotmatic and output tabulations are by "exception" only.

2.3 Autoland

British Airways very much pioneered the introduction of autoland into normal passenger operations.

Many of our aircraft, like TriStars and B757s can land in virtually zero visibility, thus reducing the number of diversions, and providing savings in time and inconvenience to our passengers, and increased safety.

The world's first-ever, fully automatic landing by an aircraft on a scheduled passenger flight was by a BEA Trident 1C on June 10th 1965. Since then, British Airways has achieved more than 1500 autolands in Category III conditions (when visibility is at a minimum), and more than 4000 in Cat. II limits when visibility was down to 400 metres.

These developments have increased all-weather operating capabilities, putting less strain on flight crews and airline operations, thus enhancing safety standards and regularity in unfavourable conditions.

2.4 NDT (Non Destructive Testing)

B.A. uses NDT technology to support other inspection techniques to assure structural integrity of airframes, engines and system components.

Techniques employed include: X-Ray, Gamma Ray, eddy current, ultrasonic thermography and boroscope.

Among recent developments has been the BA design of a semi-automatic, eddy-current wheel inspection machine which, since its introduction in 1979 has virtually eliminated in-service wheel failures due to fatique cracks and, is now widely used by airlines all over the world.

NDT is also used extensively in the auditing of long life structures which, in the case of the B.747, can mean up to 150 different NDT techniques per aircraft input.

To achieve this level of production, computer-based eddy-current and ultrasonic instruments have been introduced and high speed eddy-current probes have been designed.

Liquid crystal and CRT (Cathode-Ray Tube) impedance plane analysis techniques are now commmon- place for the examination of multi-laminate structures, and for fatique cracks with and without fastener removal.

Work is also continuing on the examination of composite structures after lightning strikes and the routine examination of composite structures on B.737 and B.757 aircraft, for delamination, fluid ingress, impact damage, and fatique cracks.

In the workshops, an automatic fluorescent, electrostatic penetrant line is to be introduced in the wheel-bay, to be shortly followed by an automated magnetic particle line for the inspection of undercarriage components.

On the engine front, an Iridium 192 radioactive isotope, gamma ray technique has been used for the internal inspection of engine components, hence avoiding the need to dismantle the engine, making NDT a very cost-effective way of ensuring structural integrity.

3. CONTROL OF THE STANDARDS

CAP 360, (a CAA publication) identifies the standards required of an Airline Engineering Organisation in support of an Air Operator Certificate. These standards fall into two basic categories:-

(1) The adequacy of the company organisation and procedures to support the intended operations.

(2) The approval of suitable personnel.

3.1 Company Organisation and Procedures

Historically, the quality standards were controlled by a separate group of Quality Inspectors, whose function was to examine the aircraft or component undergoing an overhaul in order to identify any deterioration or defects. The Inspectors would then recertify the units as serviceable, once rectification action had been accomplished to an acceptable standard.

3.2 Quality Assurance

In order to improve manpower efficiencies, the 'quality control inspection' function was reassigned to the similarly-qualified supervisors covering the defect rectification. This role then became 'dual function'; both the setting of the initial standard and the rectification and acceptance to the required final standard. A smaller, independant Quality Assurance group now monitored the 'dual function' concept on a sampling basis, to ensure the standards were not deteriorating.

3.3 Quality Audit/Control

British Airways have taken a further step in assigning the responsibility for quality to the groups primarily responsible for carrying out the rework. This step allocates the prime Quality Assurance function to the "doers" and to the Engineering management of the appropriate hangar or workshop area by the introduction of 'Self Monitoring Programmes'. A small, Quality Audit group additionally monitors the adherence of the work areas to the company procedures and declared self monitoring programmes. In addition, a small Quality Control group made up of specialist engineers monitors the overall effectiveness of the Maintenance Programme, further identifying any deficiencies which arise, carrying out investigations to instigate positive, corrective action as approriate.

The changes in quality control responsibilities have been made with the objective of properly identifying those who actually do the work and control the achieved standards, to then assign that responsibility as well as monitor the effectiveness by which the responsibility is administered.

3.4 Approval of Staff

Approval of completed work and certification of completed maintenance has become increasingly dependent upon the support from associated groups such as technical records, planning and control organisations in order that the approving person can certify that he has completed the required maintenance.

In line with this, and the increasing complexity of aircraft and the size of Maintenance Organisations, the requirements for staff approval have changed from the specific granting of a Licence (with aircraft type rating) by the CAA, to a system of company approvals built around a basic CAA licence (without type rating). The company Quality group now has control of the issue of approvals, both from a job function and the ability of the individuals being approved.

With the increased responsibility for approval of staff, the operator has more effective controls for restoring any deteriorating standards:-

(i) by additional training

(ii) by discipline

(iii) by removal of approvals

3.5 Motivation

With the knowledge that the work being undertaken and certified can have an effect on the safety of the aircraft, the approved person is well motivated to meet the desired standard and in reality he is the <u>only</u> person who can get it right.

The organisation can maintain this motivation by supporting him in the following areas:-

(i) Adequate spares and technical advice.

(ii) Company procedures/systems which assist not hinder.

(iii) Eliminating unnecessary tasks.

(iv) Not requiring certification of ambiguous tasks.

(v) Recognising the value of both formal and informal feedback from the workplace.

4. FUTURE TECHNOLOGICAL ADVANCES BEING CONSIDERED

There are four major areas of technology development for transport aircraft:- aerodynamics, structures, avionics (systems) and propulsion.

4.1 Aerodynamics

Computational fluid dynamics will become more and more common-place in the aircraft design process, leading to further improvements in aerodynamic efficiency.

4.2 Structures

Further reductions in fuel consumption can be achieved with new materials, such as lighter aluminium alloys and the application of advanced composites and plastics to primary structure as well as secondary.

4.3 Avionics

Aviation system designers have taken advantage of the tremendous development in computing power to provide aircraft with sophisticated systems for navigation, guidance, performance management and displays. These are being further developed to assist the pilot in maximising the operational efficiency of the aircraft.

Mechanical, cable - operated flight control systems will be replaced with electrical controls (fly by wire) on primary control surfaces. Fly by wire/fly by light has the potential for further reductions in weight and mechanical complexity.

Electro - hydraulics may replace conventional hydraulic system.

4.4 Propulsion

As we look to the future there are obvious advancements, whether they are turbofans or turopropeller combinations and positive reductions in fuel consumption will be achieved. With some of these arrangements will come major configuration changes, single-rotation and counter-rotation turbopropellers etc.

More effective turbine cooling and improved high temperature materials will be introduced. Further improvements in materials technology will permit even higher by-pass ratio turbofans.

4.5 The Future

The combination of all these technological developments will eventually make most of todays aircraft obsolete, if the cost of ownership can be kept small. Therefore, it is essential that the airlines, both individually and collectively, monitor the introduction of these advancements to ensure that the aircraft maintenance techniques and philosophies keep in step, thus preventing the introduction of super efficient aircraft which, although safe by design can not be maintained satisfactorily.

ACKNOWLEDGEMENT

The author would like to recognise Mr. Ray Glenister's very substantial contribution to the preparation of this paper.