

# Developing Alert Level for Aircraft Components



Wai Yeung Man and Eric T. T. Wong

**Abstract** In the aircraft industry maintenance is considered to be one of the key contributors to business success of an air carrier. By this, efforts are made to achieve maximum aircraft utilization with a reliability level as high as possible and minimal operating costs. As a result, aiming to increase profitability, and monitoring the reliability of an aircraft, its components and systems is of great benefit to aircraft carriers. As per Hong Kong Civil Aviation Department (HKCAD) requirements, all registered aircraft must have an approved maintenance schedule (AMS) to ensure aviation safety. In the AMS, system or component reliability plays an important role in condition-monitored maintenance program. To assist in the assessment of reliability of aircraft components, alert levels are established for the components which are to be controlled by the program. An alert level can help the operator to monitor engineering performance of an aircraft system or component during routine operations. Besides a consideration of the quality management processes to be contained within the AMS, this paper illustrates the development of an alert level for a helicopter air-conditioning system (ACS). The function of an ACS is to regulate the temperature, humidity, and air flow inside the helicopter. The reliability of the ACS is therefore important to an air operator. Once the alert level is triggered, approved maintenance actions need to be executed, such as component repair or replacement. In this paper, ACS of the helicopter McDonnell Douglas 902 Explorer was chosen to illustrate the development of an alert level for the purpose of improving operational performance.

**Keywords** Helicopter air-conditioning system · Reliability · Alert level

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W. Y. Man (✉) · E. T. T. Wong  
Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hong Kong, China  
e-mail: [wai-yeung.man@connect.polyu.hk](mailto:wai-yeung.man@connect.polyu.hk)

E. T. T. Wong  
e-mail: [mmttwong@connect.polyu.hk](mailto:mmttwong@connect.polyu.hk)

# 1 Introduction

In the early days of aviation, commercial airlines concerning with in-flight failures and component reliability developed maintenance schedules to help prevent costly occurrences. As aviation grew and advanced air transport technology arrived, safety, reliability and economics became important in order to attract passengers. It is obvious that to achieve a controlled balance between safety and economics, civil aviation regulatory authorities need to ensure minimum standards are maintained and a level playing field exists for fair competition among operators.

What to maintain, when to maintain and how to maintain, are the keys to the content of the maintenance schedules and a worldwide platform for airlines, aircraft manufacturers and regulatory authorities to share experience and knowledge on these particular issues in respect of new aircraft is being developed. Some commercial air transport operators may choose to maintain their aircraft in accordance with a maintenance program. This is a real-time system which consists of a maintenance schedule and a group of review and management procedures to ensure that it remains realistic and effective.

The Air Navigation (Hong Kong) Order 1995 [AN(HK)O] requires that an aircraft registered in Hong Kong in respect of which a certificate of airworthiness is in force, shall not fly unless it has been maintained in accordance with a maintenance schedule approved by the Hong Kong Civil Aviation Department (HKCAD) in relation to that aircraft. The term maintenance schedule [1] means the maintenance schedule together with any associated program, such as the reliability program, necessary to support the maintenance schedule. As the aircraft consists of an airframe, engine, propeller and other equipment, there are various sources of operational information. Not only will there be details of ‘what and when’ but also ‘how’ the parts are to be maintained; there are also details on the types of task that are to be performed. Such kind of details are published by the original equipment manufacturer (OEM) who may also be the type certificate holder (TCH) of that product. In aviation a type certificate is issued to signify the airworthiness of an aircraft manufacturing design or “type”. The certificate is issued by a regulatory body, and once issued, the design cannot be changed. The certificate reflects a determination made by the regulatory body that the aircraft is manufactured according to an approved design, and that the design ensures compliance with national airworthiness requirements.

As data will be obtained from several manuals, there will be a collection of tasks to be accomplished at varying intervals. These intervals can be based either on flying hours, flight cycles or calendar time and sometimes there are combinations of these. It is quite often inconvenient to take each task as it comes and accomplishes it; it is usually expedient to parcel the tasks into packages of work that can be carried out when it is convenient to do so, but at a frequency not exceeding the approved intervals. The general rule that can be applied for compiling work packages is that tasks can quite often be done earlier than when recommended. They can only be done later with agreement of Hong Kong Civil Aviation Department and only in exceptional circumstances. So, for tasks that have more than one frequency in terms

of flying hours, flight cycles and calendar time, then the event that occurs first is normally the governing one.

The frequency of maintenance tasks is affected by the way the aircraft is to be operated. When the TCH recommendations are first compiled they would have in mind a 'typical' flight profile for the aircraft type; any deviation from this may need an adjustment on the basic recommendations. For example, an aircraft may have a 'typical' flight profile of three hours for every cycle while another may be of three cycles every hour. It can be seen that in these cases a schedule based solely on flying hours may mean the first aircraft is maintained too often and the other not enough, so, with the help of the TCH, usually a schedule can be developed for any particular type of operation.

The area of operation is another important consideration, for example operating over salt water may require special tasks, such as engine compressor washes and other maintenance, to be done on a more frequent basis. Similarly, operation in sandy areas or off rough strips may affect the tasks required. Likewise, the age of an aircraft may affect the number and frequency of tasks, particularly if it has ageing structural inspections and significant repairs.

Once established, an owner or operator may wish to amend the maintenance schedule due to addition or deletion of tasks or change of task interval. This can be done with the aid of an amendment to the maintenance schedule, which has to be submitted to HKCAD for agreement and subsequent approval. Doing tasks less frequently requires suitable justification in order that it may be approved. Proof that safety will not be compromised must be provided. Maintenance programs supported by a reliability program will have an advantage as they will readily be able to show how often a task has been performed without deterioration of the component or system.

Maintenance programs have long been based on the traditional method of maintaining safety margins by the prescription of fixed component lives and by aircraft 'strip-down' policies. The call for changes to the basic philosophy of aircraft maintenance has been greatly influenced by the present-day economic state of the industry as well as by changes in aircraft design philosophy allied to progress in engineering technology. These changes have, in turn, resulted in the necessity for the management and control of expensive engineering activities to take a new and more effective form. It is from this background that a maintenance process known as condition-monitored maintenance (CMM) has evolved. CMM [1] uses data on failures as items of 'condition' information which are evaluated to establish a necessity for the production or variation of hard time and on-condition requirements, or for other corrective actions to be prescribed. Failure rates and effects are analyzed to establish the need for corrective actions. Indeed, CMM can be used in its own right to identify the effects of deterioration, in order that steps may be taken to maintain the level of reliability inherent in the design of the item.

Although CMM accepts that failures will occur, it is necessary to be selective in its application. The acceptance of failures may be governed by the relative unimportance of the function, or by the fact that the function is safeguarded by system redundancy. To assist in the assessment of reliability, alert levels are established for the items which

are to be controlled by the maintenance program. When the alert level is exceeded an appropriate action has to be taken. It is important to realize that alert levels are not minimum acceptable airworthiness levels. Alert levels should, where possible, be based on the number of events which have occurred during a representative period of safe operation of the aircraft fleet. They should be updated periodically to reflect operating experience, product improvement, changes in procedures, etc.

When establishing alert levels based on operating experience, the normal period of operation taken is between two- and three-years dependent on fleet size and utilization. The alert levels will usually be so calculated as to be appropriate to events recorded in monthly or three-monthly periods of operation [2]. Large fleet will generate sufficient significant information much sooner than small fleets. Research on helicopter alert levels is scarce and it was not based on actual operating data. This is mainly because they are proprietary information.

## **2 Hong Kong Government Approved Maintenance Activities**

HKCAD approves three primary maintenance activities. They are Hard Time, On-Condition and Condition Monitoring.

### **(i) Hard Time**

This is a preventative process in which known deterioration of an item is limited to an acceptable level by the maintenance actions which are carried out at periods related to time in service (e.g. calendar time, number of cycles, number of landings). The prescribed actions normally include servicing and such other actions as overhaul, partial overhaul, replacement in accordance with instructions in the relevant manuals, so that the item concerned (e.g. system, component, portion of structure) is either replaced or restored to such a condition that it can be released for service for a further specified period.

For example, on the McDonnell Douglas helicopter model MD902, rotating swashplate assembly and non-rotating swashplate assembly are life limited to 7285 h and 1800 h respectively. Non-rotating swashplate is located directly above the mixer and below the rotating swashplate. The non-rotating swashplate is constructed of forged 7050 aluminum alloy. It receives collective and cyclic inputs and coordinates longitudinal and lateral flight control. It also transmits the control inputs to the rotating swashplate via the swashplate bearing.

Rotating swashplate is located directly above and assembled to the non-rotating swashplate by the swashplate bearing. The rotating swashplate transfers control inputs to the pitch links. It is in five-star configuration and made of forged 7050 aluminum alloy.

Rotating swashplate keeps rotating at 392 rpm once engines start, driven by a main rotor driveshaft. Non-rotating swashplate sliding up and down, tilting left and right frequently during flight. They are the most critical controls of the helicopter. When

the prescribed time reaches, the mentioned parts have to be replaced. Otherwise, the helicopter is not airworthy (Fig. 1).

(ii) On-Condition

This also is a preventative process but one in which the item is inspected or tested, at specified periods, to an appropriate standard in order to determine whether it can continue in service (such an inspection or test may reveal a need for servicing actions). The fundamental purpose of on-condition is to remove an item before its failures in services. It is not a philosophy of “fit until failure” or “fix and forget it”.

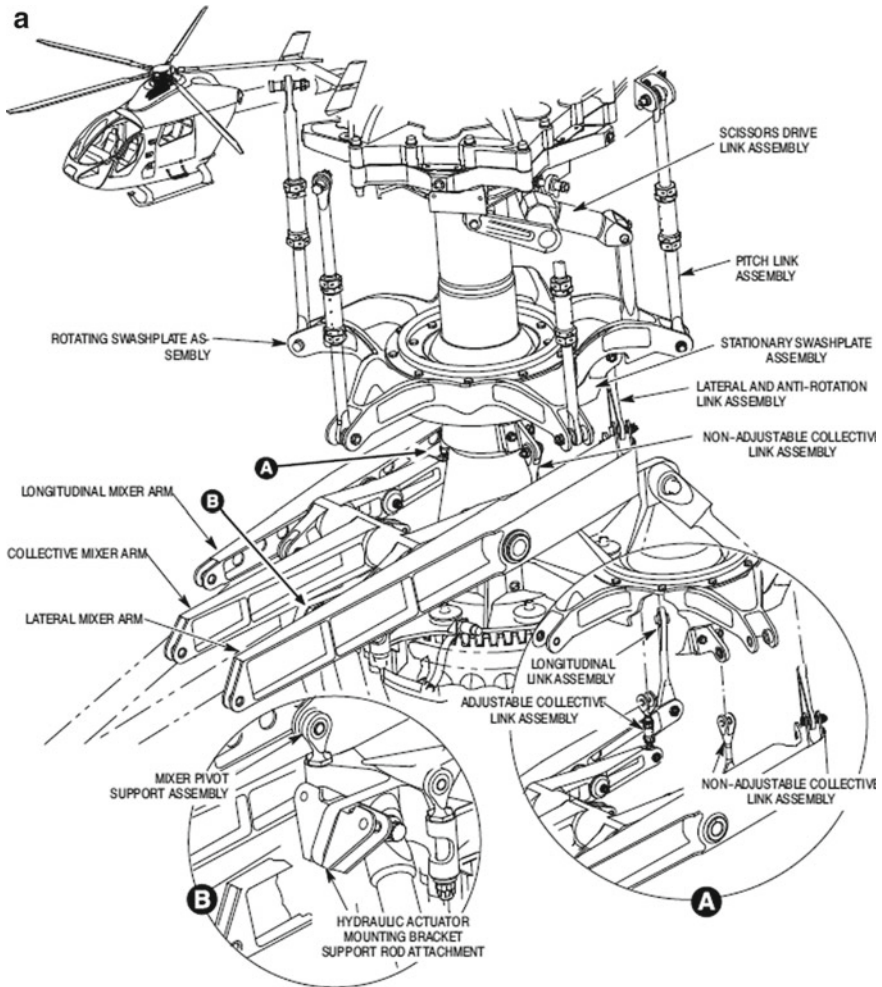
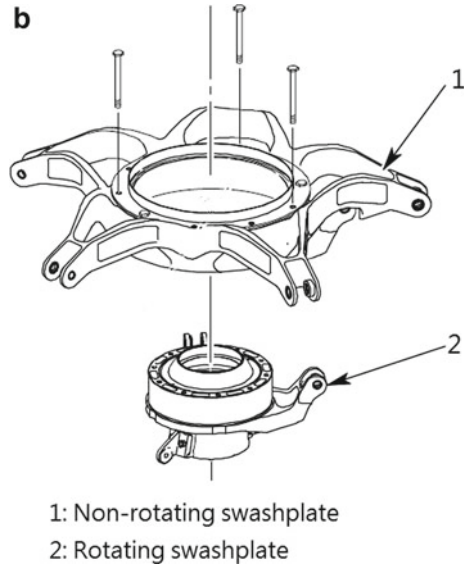


Fig. 1 a Rotating and non-rotating swashplate assemble. b Rotating and non-rotating swashplate

Fig. 1 (continued)



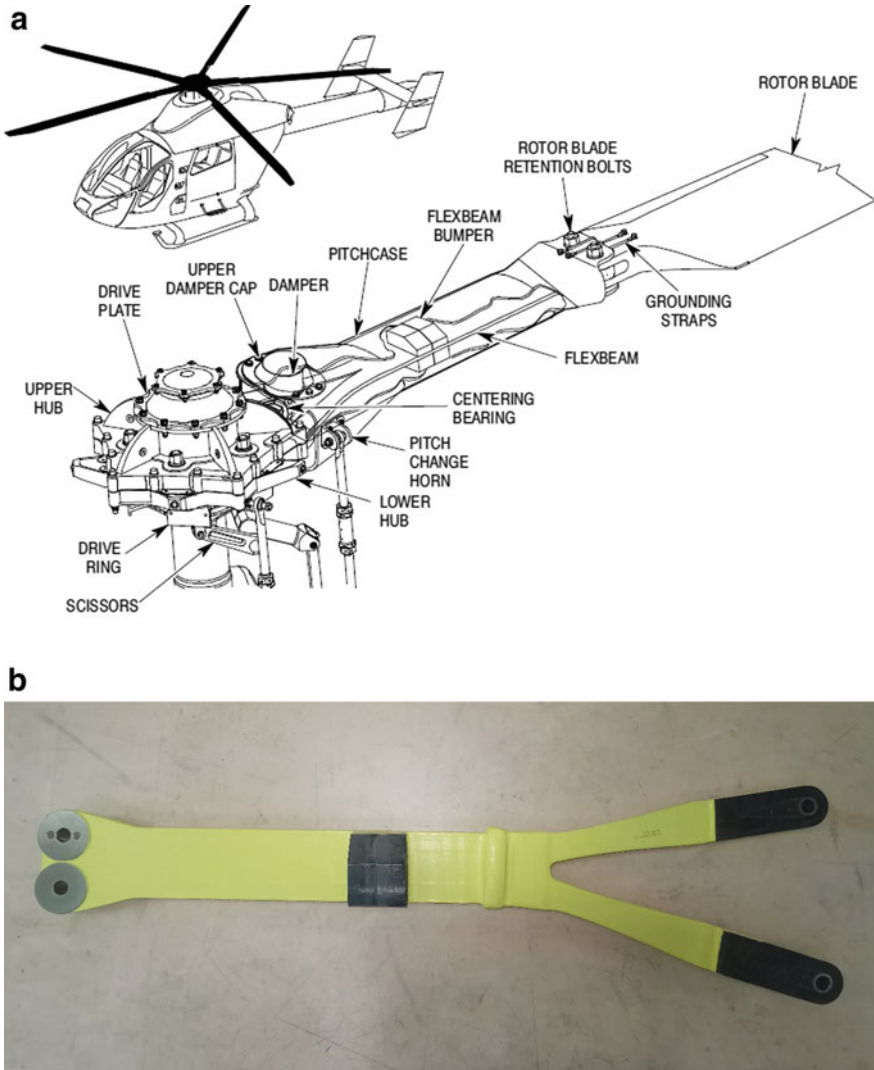
For example, on helicopter model MD902, flexbeam assembly and main rotor centering bearing assembly are on-condition items. They are inspected every 50 and 100 h. If damages are found on the mentioned items, they may be repaired or replaced depending on the nature of the damages. Otherwise, the helicopter is not airworthy. For the flexbeam, if a crack is found more than 2 inches, it needs to be replaced. For centering bearing, if cracks, rubber particles, housing not aligning with center bushing or separation between elastomeric material and the housing are found, it needs to be replaced.

Flexbeam is attached between the rotor blade and the main rotor hub. Flexing of the beam allows rotor blades to move about the feathering, flapping, and lead/lag axes without the need for hinges. The flexbeam is a composite structure made of laminated fiberglass. Flexbeam attachment points are hardened stainless steel bushings embedded in the laminate. An elastomeric flexbeam bumper is bonded around the flexbeam to reduce flexbeam deflections during rotor starts and stops.

Centering bearing is installed at the hub end of the pitchcase. The centering bearing fits onto a snubber bolt in the lower hub half and provides a fixed feathering axis for the rotor blade. The centering bearing is captured between an upper and lower elastomeric damper assembly that help the flexbeam dampen out the lead/lag motion of the rotor blade (Fig. 2).

### (iii) Condition Monitoring

This is not a preventative process, having neither Hard Time nor On-Condition elements, but one in which information on item gained from operational experience is collected, analysed and interpreted on a continuing basis as a means of implementing corrective procedures. Condition monitoring is repetitive and continuous, the key



**Fig. 2** **a** Flexbeam and centering bearing illustration. **b** Brand new flexbeam assembly. **c** Cracked flexbeam—out of tolerance (more than 2 in.)—unserviceable. **d** Cracked flexbeam—within tolerance (less than 2 in.)—serviceable—keep monitoring (a little black dot was marked to indicate the propagation of the crack). **e** Centering bearing

factor in its use being the introduction of aircraft embodying failure tolerant designs, which allow for replacement of some traditional failure preventative maintenance techniques by non-preventative techniques. Condition monitoring is not a relaxation of maintenance standards or of airworthiness control. In fact, it is more demanding

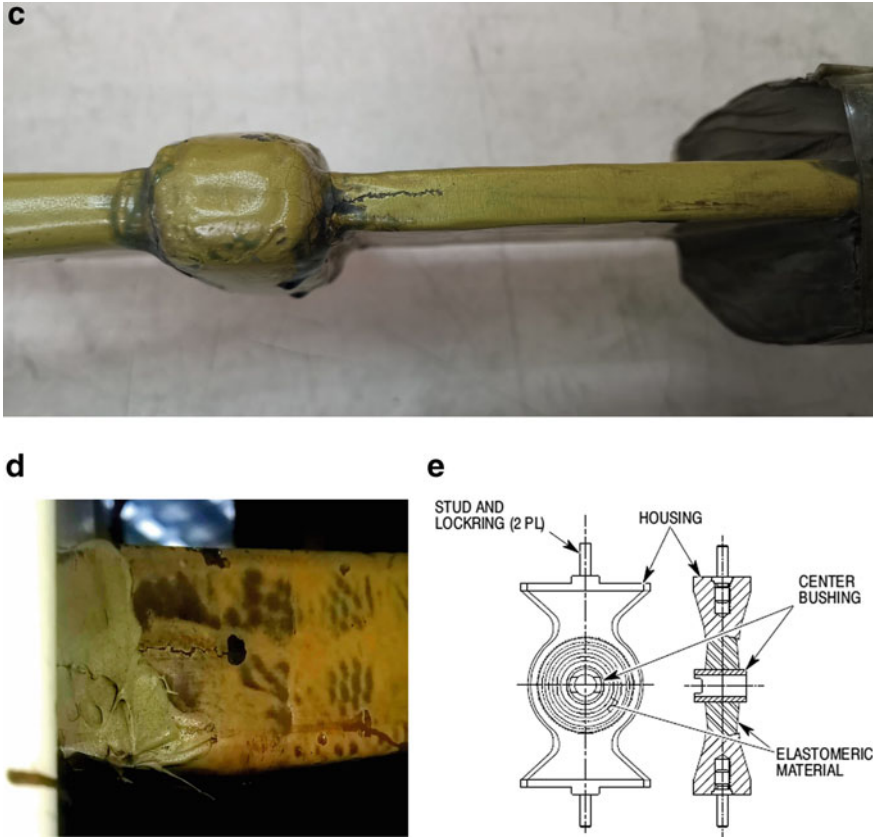


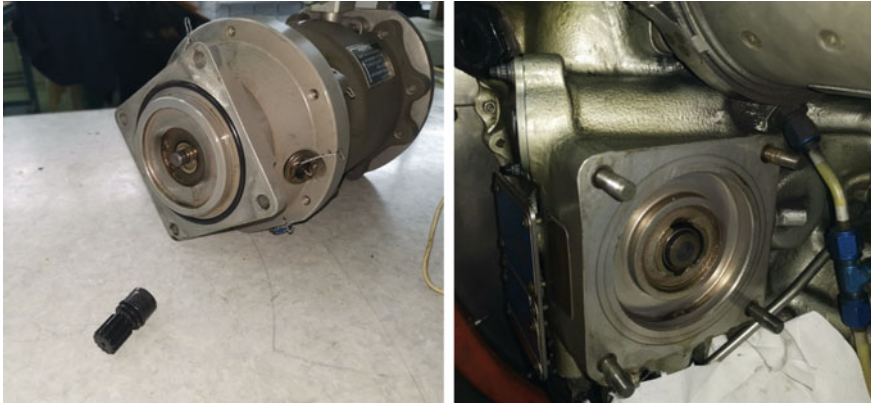
Fig. 2 (continued)

of both management and engineering capabilities than the traditional preventative maintenance approaches (Fig. 3).

### 3 Condition Monitored Maintenance Program

A maintenance program which provides for the application of Hard Time, On-Condition and Condition monitoring program is known as a Condition Monitored Maintenance Program (CMMP). There are two basic functions. Firstly, by means of the statistical reliability element, to provide a summary of aircraft fleet reliability and thus reflect the effectiveness of the way in which maintenance is being done by means of statistical reliability element. Secondly, to provide significant and timely technical information by which improvement of reliability may be achieved through changes to the program or to practices for implementing it. A properly managed





**Fig. 3** Compressor split shaft separated from internal drive shaft

CMMP can contribute not only to the continuous airworthiness, but also improve the fleet reliability, produces better longterm maintenance planning, and of course, reduces the fleet operation and maintenance costs.

The key factors leading to a successful CMMP are the manner in which it is organized and the continuous monitoring of it by professionally qualified personnel. Within the CMMP, each reliability program has a controlling body, usually known as reliability control committee and it is responsible for the implementation, decision making, and day-to-day running of the program.

The reliability control committee would ensure that the reliability program establishes not only close co-operation between all relevant departments and personnel within the organization, but also liaison with other appropriate organizations. A typical communication and data flow chart is shown in Fig. 4:

The committee will have full authority to take actions to implement the objectives and processes defined in the CMMP. Normally, the quality manager or engineering manager will lead the committee and responsible to the Director of HKCAD for the program operation.

The committee should meet frequently to review the progress of the program and to discuss and resolve, if any, current problems. As the reliability program is approved by HKCAD, formal meetings with HKCAD will be held at agreed interval to assess the effectiveness of the program.

## 4 Data Collection

As mentioned at the beginning, aircrafts/components operation data are needed for preparing the reliability program. Due to the complexity and variety of the reliability program, there are different ways to collect data.

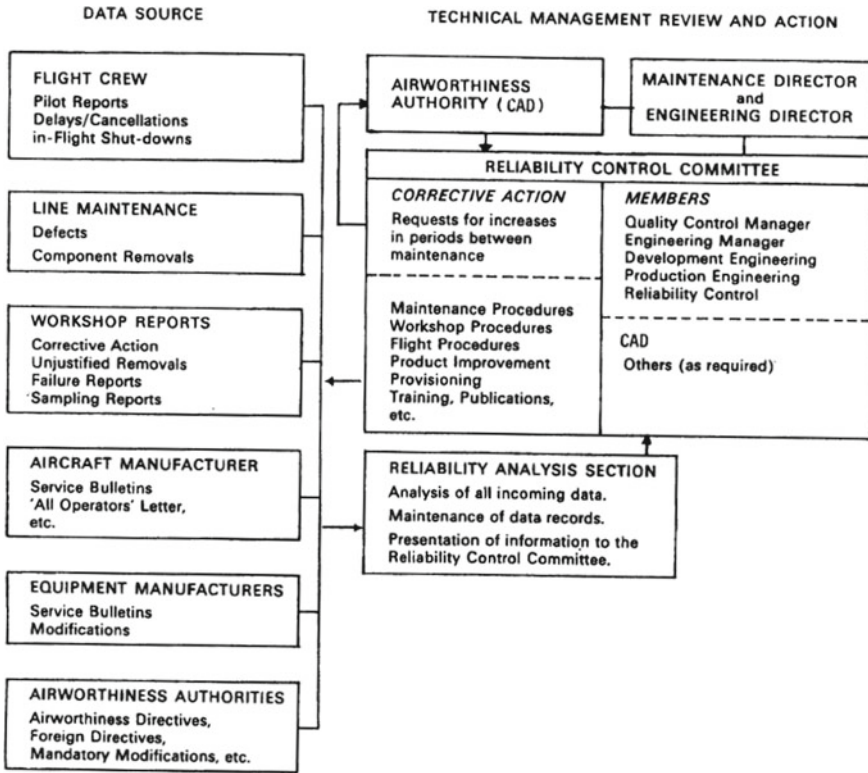


Fig. 4 A typical communication and data flow chart (Source CAD 418 [2])

(i) Pilot Reports

Usually known as “pireps”, are reports of occurrences and malfunctions entered in the aircraft technical log by the flight crew for each flight. Pireps are one of the most significant sources of information, since they are a result of operational monitoring by the crew and are thus a direct indication of aircraft reliability as experienced by the flight crew.

(ii) Engine Unscheduled Shut-Downs

These are flight crew reports of engine shut-downs and usually include details of the indications and symptoms prior to shut-down. When analyzed, these reports provide an overall measure of propulsion system reliability, particularly when coupled with the investigations and records of engine unscheduled removals.

(iii) Mechanical Delays and Cancellations

These are normally daily reports, made by the line maintenance staff, of delays and cancellations resulting from mechanical defects. Normally each report gives the cause of delay and clearly identifies the system or component in which the defect

occurred. The details of any corrective action taken, and the period of the delay are also included.

(iv) Component Unscheduled Removals and Confirmed Failures

At the end of the prescribed reporting period the unscheduled removals and/or confirmed failure rates for each component are calculated to a base of 1000 or 500 h flying, or, where relevant, to some other base related to component running hours, cycles, landings, etc.

(v) Miscellaneous Reports

A variety of additional reports may be produced on a routine or non-routine basis. Such reports could range from formal minutes of reliability meetings to reports on the sample stripping of components, and also include special reports which have been requested by the maintenance management.

## 5 Alert Level Development

To assist in the assessment of reliability of aircraft components, alert levels are established for the components which are to be controlled by the program. Alert level is an indicator which when exceeded indicates that there has been an apparent deterioration in the normal behavior pattern of the item with which it is associated. When an alert level is exceeded appropriate maintenance actions should be taken as soon as possible.

When considering data based on components, it is useful to note that where a maintenance program is introduced to an aircraft fleet for the first time and in the early 'settling in' period, the number of failures which are not confirmed after an unscheduled removal can be as high as 40% for all components taken together. For individual components this can range from 5% for landing gear and flying control components to 65% for some communications and avionic components; thus, indicating the need for inclusion of data on both unscheduled removal and confirmed failure of components.

Typical acceptable procedures for establishing alert levels are outlined below. It can be seen that the resultant alert levels can vary according to the method of calculation, but this need not necessarily be considered to be of significance.

For each of the following sample calculations, a minimum of twelve months' operating data has to be available.

(i) Method 1

The three-monthly running average data for each system (or sub-system) is averaged over the sample operating period and is known as the Mean; the Mean is multiplied by 1.30 to produce the alert level for the given system. This is sometimes known as the '1.3 Mean' or '1.3 x' method.

## (ii) Method 2

The Mean, as in Calculation 1, plus 3 Standard Deviations of the Mean.

## (iii) Method 3

The mean, as in calculation 1, plus the Standard Deviation of the 'Mean of the Means', plus 3 Standard Deviations of the Mean.

## 6 Recalculation of Alert Level

If a significant change in the reliability of the particular item is experienced due to known actions such as modification, changes in maintenance or operating procedures, alert level of that item has to be recalculated. Any significant change in alert level requires written approval from HKCAD.

## 7 Corrective Actions

Corrective actions taken to improve the reliability of systems and components, and ultimately that of the fleet, will vary considerably and may typically include one or more of the following:

- (i) Changes in operational procedures or improvements in fault finding techniques.
- (ii) Changes to the scope and frequency of maintenance processes which may involve servicing and inspection, system tests or checks, overhaul, partial overhaul or bench testing or the introduction or variation of time limit, etc.
- (iii) Modification action.
- (iv) Non-routine inspections or adjustment.
- (v) Change of materials, fuels and lubricants.
- (vi) Use of different repair agencies.
- (vii) Use of different sources of spares.
- (viii) Variations of storage conditions.
- (ix) Improvements in standards of staff training and technical literature.
- (x) Amendment to the policy/procedures of the reliability program.

## 8 Essential Qualities of the CMMP

Condition monitored maintenance/reliability programs can vary from the very simple to the very complex, and thus it is impractical to describe their content in detail.

However, for HKCAD approval the CMMP has to be such that the considerations listed in (i)–(ix) are adequately covered:

- (i) It generates a precise, specific and logical Quality assessment by the operator of the ability of the organization to achieve the stated objectives.
- (ii) It enables the director, as the airworthiness authority, to accept initially, and, with subsequent continued monitoring, to have confidence in, the ability of the organization to such an extent that the director can renew certificates of airworthiness, approve changes to the maintenance schedules, etc., in accordance with evidence showing that the objectives of the program are being achieved.
- (iii) It ensures that the operator provides himself with quality management of his organization.
- (iv) It provides the operator with a basis for the discharges of his moral and legal obligations in respect of the operation of aircraft.
- (v) It enables the Director to discharge its duties and legal obligations in respect of the maintenance aspects of airworthiness, and, where applicable, to delegate certain tasks to the operator.
- (vi) The manner of presentation has to be acceptable to the Director.
- (vii) With (i)–(vi) in mind, it states the objectives of the program as precisely as in possible, e.g. “maintenance of designated components by reliability management in place of routine overhaul”, “condition monitoring as a primary maintenance process”, etc.
- (viii) The depth of description of the details of the program is such that:
  - (a) The details can be understood by a technically qualified person.
  - (b) Those factors which require formal CAD acceptance of any changes are clearly indicated.
  - (c) All significant non-self-evident terms are defined.
- (ix) In respect of individuals or departments within the organization:
  - (a) The responsibility for the management of the program, and
  - (b) The procedures for revision of the program, are clearly stated.

## 9 Assessment of CMMP Document

Following questions have been suggested by HK CAD to assist the air operator in making a preliminary assessment of the adequacy of the CMMP document:

- (i) Is the document to be physically contained within the approved maintenance schedule? If it is to be a separate document, is it satisfactorily linked with, and identified within the approved maintenance schedule?

- (ii) Are the objectives of the program clearly defined? e.g. “maintenance of designated items by reliability management in place of routine overhaul”, “confidence assessment of overhaul periods”, “airworthiness/economic quality management of maintenance”.
- (iii) Does the approved maintenance schedule clearly state to which items the program is applicable?
- (iv) Is there a glossary of terms associated with the program?
- (v) What types of data are to be collected? How? By whom? When? How is this information to be sifted, grouped, transmitted and displayed?
- (vi) What reports/displays are provided? By Whom? To Whom? When? How soon following data collection? How are delays in publishing controlled?
- (vii) How is all information and data analyzed and interpreted to identify aircraft actual and potential condition? By Whom? When?
- (viii) Is there provision within the organization for implementation of corrective actions and is this identified within the document? How are implementation time periods, effects and time for effect manifestation provided for?
- (ix) Is there a requirement that the approved maintenance schedule be amended, and is the method of doing so included in the program, e.g. variation of time limitations, additional checks?
- (x) Is there a requirement that maintenance manuals be amended and is the method of doing so included in the program, e.g. maintenance practices, tools and equipment, materials?
- (xi) Is there a requirement that the operations manual/crew manual be amended, and is the method of doing so included in the program, e.g. crew drills, check lists, defect reporting?
- (xii) What provision is made for corrective action follow-up and for checks on compliance with original intention, e.g. those which are not working out in practice, spares provisioning, timetables for the incorporation of modifications?
- (xiii) Who is responsible for the management of the document?
- (xiv) Is there a diagram of the relationship between the departments and groups concerned with the program and does it show the flow of condition monitoring data, its handling and the prescribed reaction to it?
- (xv) Are all of the departments involved in the program included and are there any responsibilities not allocated?
- (xvi) What quality management processes are contained within the program in respect of:
  - (a) Responsibility for the document itself and the procedure for its amendment?
  - (b) Monitoring of the performance of the program by statistical reliability and other methods?
  - (c) Committee consideration of program implementation and monitoring of performance?

- (d) Consideration of reports on incidents and accidents and other events which can affect airworthiness?
- (e) Program management and discipline?

To illustrate the development of alert levels for an aircraft system and its application in aircraft maintenance, a case study based on the MD 902 Explorer helicopters is shown below.

## 10 Case Study

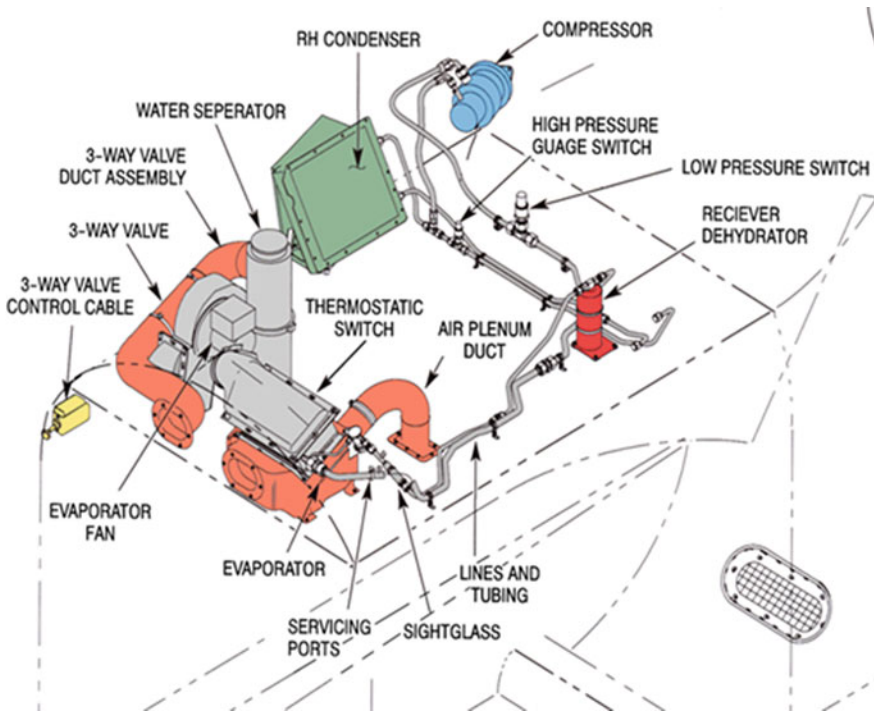
Heliservices (HK) Ltd, the sole provider of rotary-wing services in Hong Kong, offers a wide range of aviation services including aircraft charter for sightseeing and VIP services, filming and photography, lifting works, powerline maintenance and methodical inspection. Heliservices also provides aircraft management and maintenance services and unmanned aerial systems (UAS).

Heliservices operates a fleet of three MD 902 Explorer helicopters. Each helicopter has an air-conditioning system mainly consists of a compressor, evaporator, condenser, receiver dehydrator, thermal expansion valve and pressure sensors. The air-conditioning system (ACS) supplies ventilation, temperature, and humidity control to the helicopter. In this case study the ACS of the MD 902 are chosen to evaluate the operational improvement opportunities.

From past record, the ACS has a high failure rate. Without ACS, passengers and crews experience a discomfort journey. To provide enjoyable journeys, operation department often needs to reschedule the flights for engineering department to rectify any defects relate to ACS. Alert level was chosen to monitor the system or component performance so that an optimal time for maintenance can be agreed between operation and engineering department. It was found that most of the time, ACS defects were mainly due to compressor failures.

## 11 Helicopter Air-Conditioning System

The effect of aircraft cabin temperature and ventilation on crew performance has long been a subject of aeromedical study by flight physiologists and physicians alike. Air conditioning systems for helicopters have been around for a long time. Some systems in fact still operate with the old CFC-12 (R12) refrigerant, while the newer vapor-cycle systems are serviced with the more environmentally friendly HFC-134a (R134A). For the MD902 Explorer, air-conditioned air is routed through the fresh air vent system gaspar assemblies. The cockpit has four gaspar assemblies and the cabin area has six. The air conditioning system is a vapor-cycle type system that provides conditioned air to cool the cockpit and cabin areas.



**Fig. 5** MD902 air conditioning system layout

This section provides a general overview of a typical vapor-cycle air conditioning system and how it functions. This type of system operates in a closed loop, in which the refrigerant absorbs heat from the cabin and rejects it into the outside air. The refrigerant then returns to the cabin to repeat the cycle. The operation of the system is described below and involves these major components: compressor, condenser, receiver-dehydrator, and evaporator (Fig. 5).

The compressor receives through the suction port low pressure heat laden refrigerant vapor from the evaporator. The compressor pressurizes the refrigerant depending on system demand. This increases the temperature of the refrigerant. At this temperature and pressure the refrigerant is above its boiling point. The compressor then discharges it out of the discharge port.

The superheated refrigerant then flows into the condenser. In the condenser the high pressure vapor condenses into a high pressure liquid. This is achieved by using a fan to force air over the surface of the condenser enabling heat to transfer from the refrigerant to the outside air thus reducing its temperature. Ideally, only refrigerant in the form of a high pressure liquid leaves the condenser outlet.

The high pressure liquid refrigerant flows into the receiver-dehydrator which stores, dries and filters the liquid refrigerant. The liquid refrigerant then flows from the receiver-dryer to the expansion valves. The expansion valves change the refrigerant



into low pressure, low temperature liquid by lowering the pressure using a variable orifice. The orifice has high pressure on one side (from the receiver-dehydrator), and low pressure on the other side (evaporator and compressor), and allows a small quantity of refrigerant to flow through it. The sudden drop in pressure and temperature causes some of the refrigerant to vaporize. The low pressure, low temperature liquid then flows to the evaporator where the heat is transferred from its surface to the refrigerant through vaporization. The heat comes from inside the cabin and is blown over the evaporator's surface. Once the refrigerant has completely vaporized and reached its saturation point it should still be able to carry more heat.

The refrigerant continues to flow through the remainder of the evaporator coils absorbing more heat and becoming slightly superheated. Thus, air is blown through the evaporator, has its heat extracted/transferred to the refrigerant, resulting in cooled air being ducted into the cockpit and cabin through strategically placed air outlets.

The low pressure low temperature slightly superheated vapor refrigerant flows to the compressor and the cycle repeats itself.

The fresh air vent system provides outside airflow into the cockpit and cabin areas. Outside air enters the fresh air ducts and is available to the cockpit and cabin areas by manual adjustment of gaspar assemblies that provide flow volume up to 20 cubic feet per minute. The cockpit has four gaspar assemblies and the cabin area has six. An integral two-speed vent fan can sustain fresh airflow at up to 180 cubic feet per minute [3]. Vent fan control is provided from the cockpit (Fig. 6).

## 12 Compressor Failures

As mentioned above, defects of the compressor have contributed to the failure of air conditioning system. The compressor internal drive shaft is connected to the waisted spline input shaft by a shear pin. If excessive torque is caused by the compressor or gearbox problem, the shear pin is sheared so that damage will not be transferred to the engine (Figs. 7, 8).

## 13 Alert Level Calculation

The number of air-conditioning compressor failures were collected among the fleet covered each 500 flying-hour period from January 2014 to December 2017. By using method 3 (The Mean plus the Standard Deviation of the 'Mean of the Means', plus 3 Standard Deviations of the Mean) as shown above, the alert level was calculated to be 12.7. This means that whenever there are 12.7 failures or more per 500 actual flying hours, appropriate maintenance action needs to be done. Detailed calculations are shown in Table 1:

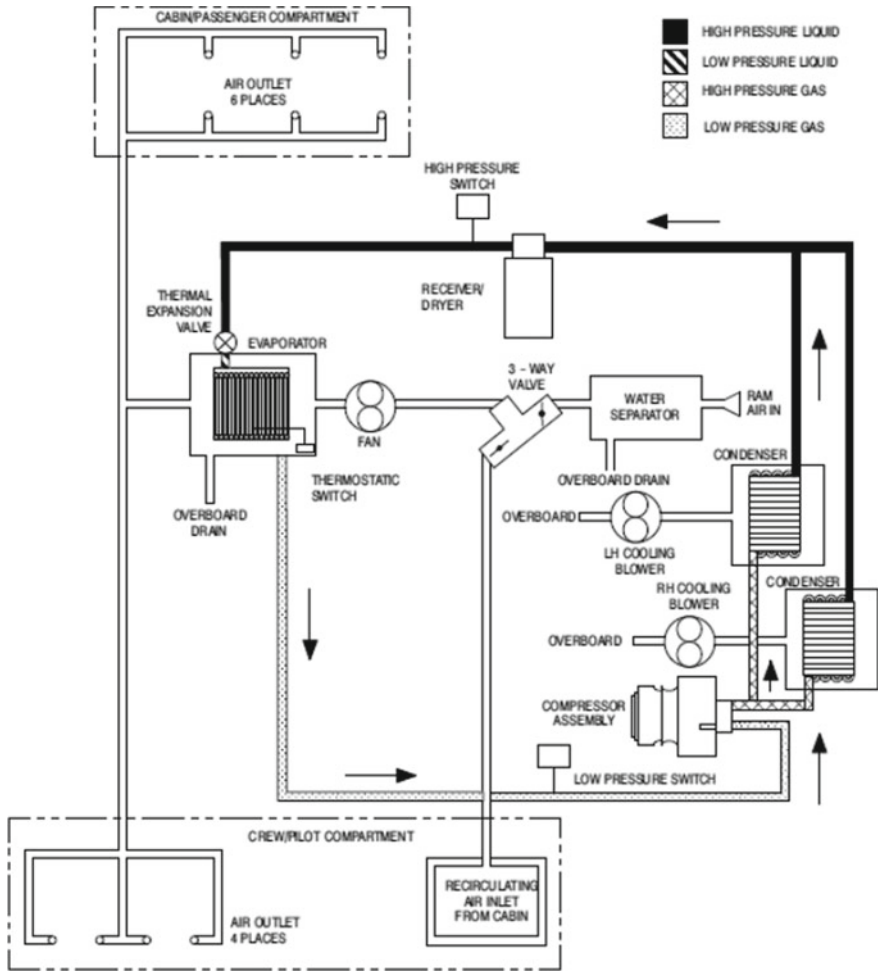
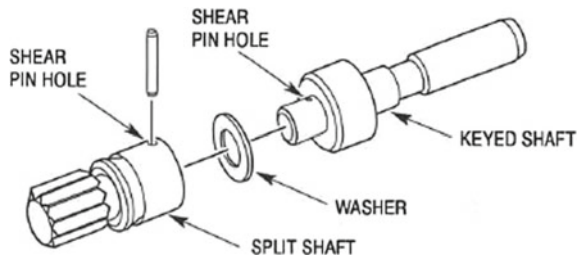
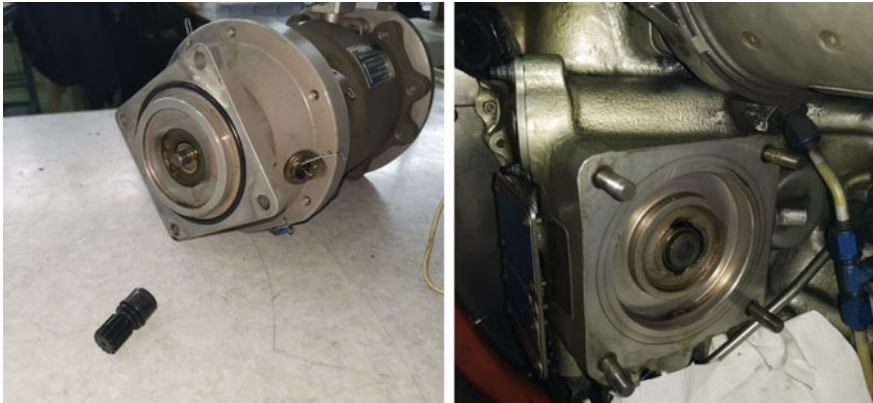


Fig. 6 MD902 air conditioning system operation [4]

Fig. 7 Shear pin of air-conditioning compressor drive shaft





**Fig. 8** Failure of compressor—shear pin broken; split shaft left in engine accessory gear

**Table 1** 2014–2017 MD 902 Explorer fleet air-conditioning compressor failures

Actual flying hours	Failures among fleet, (X)	$ X - \bar{X} $	$ X - \bar{X} ^2$	Mean of X, (Y)	$ Y - \bar{Y} $ , D	$ Y - \bar{Y} ^2$ , D <sup>2</sup>
0–500	0	3	9			
500.01–1000	5	2	4	2.5	1.3	1.69
1000.01–1500	3	0	0	4	0.2	0.04
1500.01–2000	2	1	1	2.5	1.3	1.69
2000.01–2500	9	6	36	5.5	1.7	2.89
2500.01–3000	3	0	0	6	2.2	4.84
3000.01–3500	1	2	4	2	1.8	3.24

$$N_1 = 7$$

$$\bar{X} = \frac{\sum X}{N_1} = 3.3$$

$$\sum |X - \bar{X}|^2 = 54$$

$$SD = \sqrt{\frac{\sum |X - \bar{X}|^2}{N_1 - 1}} = \sqrt{\frac{54}{6}} = 3$$

$$3 \times SD = 9$$

$$\text{Mean of mean of X} = \frac{\sum Y}{N_2} = 22.5/6 = 3.75 \approx 3.8 \text{ where } N_2 = 6$$

$$\sum D^2 = 14.39 \approx 14.4$$

$$\sum D = 8.3$$

$$\text{Standard deviation of Mean of Mean} = \sqrt{\frac{\sum D^2}{N_2 - 1} - \left(\frac{\sum D}{N_2 - 1}\right)^2} = \sqrt{\frac{14.4}{5} - \left(\frac{8.3}{5}\right)^2} =$$

0.4

$$\text{Alert level} = 0.4 + 3.3 + 9 = 12.7.$$

**Table 2** 2014–2018 MD 902 Explorer air-conditioning compressor failures

Actual flying hours	Failures among fleet, (X)	$ X - \bar{X} $	$ X - \bar{X} ^2$	Mean of X, (Y)	$ Y - \bar{Y} ^2$ , D	$ Y - \bar{Y} ^2$ , D <sup>2</sup>
0–500.00	0	3	9			
500.01–1000	5	2	4	2.5	1.1	1.21
1000.01–1500	3	0	0	4	0.4	0.16
1500.01–2000	2	1	1	2.5	1.1	1.21
2000.01–2500	9	6	36	5.5	1.9	3.61
2500.01–3000	3	0	0	6	2.4	5.76
3000.01–3500	2	1	1	2.5	1.1	1.21
3500.01–4000	3	0	0	2.5	1.1	1.21

This alert level cautioned the engineering department and her staff started observing pilot procedure of operating the ACS during power assurance check. It was noted that pilots used to switch on air-conditioning system during engine power assurance check, which engaged the compressor immediately, and this required single engine operation at 75% torque. Eventually a new procedure came up and pilots were instructed not to engage air-conditioning system during engine power assurance check.

Based on the new procedure and additional operating data, the alert level 11.8 was achieved. This drop in alert level means that the performance of the air-conditioning compressor was improved. In other words, the compressor has become more reliable. Again, detailed calculations can be found in Table 2.

$$N_1 = 8$$

$$\bar{X} = \frac{\sum X}{N_1} = 3.4$$

$$\sum |X - \bar{X}|^2 = 51$$

$$SD = \sqrt{\frac{\sum |X - \bar{X}|^2}{N_1 - 1}} = \sqrt{\frac{51}{7}} = 2.7$$

$$3 \times SD = 8.1$$

$$\text{Mean of Mean of X} = \frac{\sum Y}{N_2} = 25.5/7 = 3.64 \approx 3.6 \text{ where } N_2 = 7$$

$$\sum D^2 = 14.37 \approx 14.4$$

$$\sum D = 9.1$$

$$\text{Standard deviation of Mean of Mean} = \sqrt{\frac{\sum D^2}{N_2 - 1} - \left(\frac{\sum D}{N_2 - 1}\right)^2} = \sqrt{\frac{14.4}{6} - \left(\frac{9.1}{6}\right)^2} =$$

0.3

$$\text{Alert level} = 0.3 + 3.4 + 8.1 = 11.8.$$

## 14 Conclusion

Reliability engineering and maintenance are the source of aviation safety. They are one of the most important aims in the aviation industry. Modern reliability engineering is one way of reducing operating costs without compromising safety. Through Condition Monitored Maintenance, one can achieve better operational performance of aircraft systems at minimum costs.

In this chapter, an alert level was established based on the operating data of the chosen helicopter air-conditioning system compressor. Being cautioned by the high failure rate of the air-conditioning system, the maintenance engineering team proposed a new operating procedure for the helicopter pilots. For this new procedure, pilots were told not to engage air-conditioning system during engine power assurance check. Subsequently it was found that implementation of this procedure resulted in an improved utilization of the air-conditioning system, as evidenced through the new alert level - a reduction from 12.7 to 11.8. This case study illustrates that alert levels can be used to monitor and improve fleet operational performance effectively.

Notation	Description
D	Absolute value of the difference between mean of X and mean of mean of X
$N_1$	Number of ranges of actual flying hours
$N_2$	Number of values of mean of X
SD	Standard deviation
X	Number of failures among fleet
$\bar{X}$	Mean of number of failures among fleet
$ X - \bar{X} $	Absolute value of the difference between number of failures among fleet and mean of number of failures among fleet
Y	Mean of X
$\bar{Y}$	Mean of mean of X

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**Wai Yeung Man** Simon received the Bachelor's degree of electronic engineering from The Chinese University of Hong Kong in 2011. He furthered his studies in mechanical engineering at The Hong Kong Polytechnic University since 2018. Simon is particularly interested in aviation maintenance and engineering. He is currently a licensed avionics engineer at Heliservices HK Ltd. He is specialized in helicopter avionics systems inspection, troubleshooting, fault rectification and system modifications. He also holds a helicopter airframe and engine license.

**Eric T. T. Wong** Eric received his M.Sc. degree in Plant Engineering from the Loughborough University(UK) and Ph.D. degree from the Leicester University (UK). Prior to joining the Mechanical Engineering Department of the Hong Kong Polytechnic University, he worked for the Hong Kong Civil Aviation Department in the area of aviation safety. His research interests include: aviation safety management, risk modeling, and quality management. He is a Fellow Member of the Royal Aeronautical Society (UK) and a Founding Member of the Aircraft Engineering Discipline, Hong Kong Institution of Engineers. He has been the Treasurer of the Royal Aeronautical Society (Hong Kong) since its inception in September 1983. He was Vice-Chairman of the HK Institute of Marine Technology in 2002 and Program Chair of the ISSAT International Conference on Modeling of Complex Systems and Environments (2007) at Ho Chi Minh City, Vietnam. He is currently an Adjunct Associate Professor of the Hong Kong Polytechnic University and an Associate Editor of the International Journal of Industrial Engineering—Theory, Application and Practice.