CoA Memo No. 77

REPORT ON VISIT TO FOUR NORTH AMERICAN AIRLINES

22nd July to 6th August, 1965

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Acknowledgements

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Summary

The object of the visits was to discuss the current state-of-the-art with the Engineering Departments of several North American airlines which were known to be leading the field in the application of certain advanced techniques. In the limited time available it was decided to confine the talks mainly to those topics on which the chosen operators were known to have had unique experience.

This note is presented in chronological sequence and is only intended to be a record of the information gathered; no derivations, or comparisons with other operators, are made.

United Air Lines were visited first and reliability programmes are detailed, although the application of critical path techniques to aircraft and engine overhaul is summarised. Continental Air Lines are noted for their use of the continuous maintenance philosophy, and this is reported next. The third visit was to Air Canada where talks ranged from the applications of operations research and electronic data processing (EDP) techniques to aircraft evaluation procedures. Finally the PanAm aircraft system reliability programme is reviewed, together with a note on their general EDP engineering and maintenance activities.

A bibliography is given, although it should be appreciated that some of the items listed contain information which may be commercially secure.

United Air Lines Engineering and Maintenance Base, San Francisco - Friday 23rd July and Monday 26th July

F.S. Nowlan	Manager, Planning and Operations Analysis Division
T.D. Matteson	Manager, Operations Analysis Section
H.F. Heap	Manager, Performance Analysis Section
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Reliability Programmes

The basic concept on which the United Air Lines reliability programmes are based is that scheduled component overhauls are virtually never necessary. This implies that TSO, reliability and safety are not directly related to each other, as has usually been assumed in the past. In general no relationship between TSO and overhaul cost has been found, although a very small increase in maintenance costs with increasing component time has, in many cases, been established. The fact that little useful information is obtained from serviceable time-expired components is also noted in the light of conventional "time extension by sampling" schemes; here again the emphasis is on inspection and servicing on a routine basis with overhaul having no association with a time limit.

Only a small number of components on United's jet fleets are controlled by individual time life. For example on the DC-8 and B-720 aircraft approximately 80% of components are lifed on a multiple airframe basic check period basis (or, in some cases, the engine overhaul period), 19% are on condition and about 10% are individually time lifed. On the 727 aircraft, the numbers on multiple BCP and on condition will be about the same, with again a very small percentage on time life control.

As the BCP is progressively increased, the multiple BCP lifed components are automatically carried along. However the FAA requires that individual justification is needed for all components with failure rates of 0.5 or greater per 1000 component hours. As United point out, this is not very rational as such components fail on average every 2000 hours in any case and most BCPs are now around 6000 hours.

The small number of individually time controlled components have detailed records based on "tag" returns from premature removals. A removal rate plot is derived every three months in order to compare the performance of the units with the standard. These high accuracy records are kept in hand written form by aircraft history, and component history as well as punched cards for analysis purposes.

/Cross-checks...

Cross-checks on serial numbers and TSO are also made.

For the vast majority of components where trend analysis is required, but the records are not required for control purposes, it is found that about 90% of the information is usable for reliability calculations i.e. in 10% of cases the records on individual component removals and replacements on a given aircraft are incomplete.

The usual way of performing a mortality analysis on the individually lifed components, so as to show that wearout does not exist, is simply to use the cumulative conditional probability. Starting with zero at the upper limit of the vertical scale, the failures per period, which itself may be between 100 and 400 hours, are plotted against TSO. The information is considered reliable if at least 20 points are available, although it must be emphasised that as TSO increases fewer components survive and the points become less reliable. If a straight line can be fitted to the experimental data, it indicates an exponential failure distribution, although the line may well be steeper during an early infant mortality period. A probability of survival curve can then be constructed from this data.

United emphasise the difficulty of fitting classical mathematical distributions to such data owing to limitations on sample sizes and discontinuities caused by checks, overhauls and modifications. It was also noted that despite the success of the reliability programmes, there were still many individuals within the airline who needed convincing about the validity of using statistical techniques. The educational process is continual and the Operations Analysis Group always use experimental results in graphical form directly to try and prove their point.

The FAA have tried to encourage the use of chartrooms for the display of data from reliability programmes (paragraph 8 of Handbook for Maintenance Control by Reliability Methods, FAA Advisory Circular No. 120-17[1*]). However, United have resisted this and submit monthly and/or quarterly reports together with open invitations for the FAA to attend occasional meetings. The airline prefers this approach as it would still be required to present reports based on chart displays. Consequently it does not consider that the overhead required to maintain such chart rooms could be justified.

Some thought has been given to the introduction of an all-embracing programme for the complete airline engineering activity, without reference to a performance standard. The possibility of this idea arises from the accumulation of knowledge on the basic independence of TSO and reliability, coupled with the fact that more effort is being given to monitoring component conditions and also that higher levels of failures are now able to be sustained. An esoteric measure such as the money spent on non-routine maintenance might even be the indicating factor in the programme.

Although there is no immediate move in this direction, it seems likely that political pressure for such a scheme may come from the FAA as it would

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*Such numbers refer to the Bibliography on page 22.

encourage the FAA "audit concept". This concept is an attempt to reduce the number of FAA surveyors in local offices and to have a smaller number of specialists who would have very large areas of responsibility. At the present time no airline is organised to accept the audit concept on a working basis as they all have individual schemes that have been mainly negotiated with local FAA personnel.

The Reliability Controlled Overhaul Programme (RCOH)[2/] was originated in 1958 and applies to components which are basically electronic. A component is qualified for the programme when a mortality analysis shows that the component's reliability does not deteriorate with time, although the failure rates involved might be relatively high. Recently a new criterion is also being used which simply states that the MTBF must be 0.5 or more of the authorised TBO for the previous six-month period.

Currently the RCOH programme is being rewritten so as to comply with FAA Advisory Circular on Maintenance Control by Reliability Methods. Approval is expected within the next two months. After this time, it is hoped to rapidly increase the number of components on the scheme from the current number of 6 to approximately 100 within a period of 6 months. Having demonstrated the ability to control such components from a knowledge of MTBF only, it is hoped that the requirement on detailed mortality analyses will be dropped and only MTBF derived from premature removal reports will be required. However care will still be taken to hold component lives when less than a required sample size are reaching the currently established life.

The Turbine Engine Reliability Programme (TERP)[3/] was preceded by the FAA/Industry Propulsion System Reliability Programme (PSRP), which itself was started at United in December, 1961. The original programme was noted for being the first FAA proposal which recognised the essential independence of TBO and reliability. It established a comparative measure of reliability from the in-flight shutdown rate and permitted rapid time extension programmes whilst providing for review of corrective action if an "alert rate" was exceeded. The general success of this programme is given in more detail in UAL Report No. POA-85[2/].

TERP has been developed from PSRP in order to fully utilize the large samples generated by the vast size and variety of the UAL jet fleet. Actuarial techniques are used and continuous ageing, subject to sampling of the oldest units, is the basis for evaluating the powerplant age/reliability characteristic. Responsibility for the control of the periodicity of the "engine heavy maintenance" inspections is transferred to UAL.

The primary performance standard is still in-flight shutdowns, although premature removals are used as a secondary standard and data is also regularly reviewed on engine condition surveillance and reliability analyses. Information for the condition surveillance is derived from both steady state in-flight monitoring and engine overhaul shop inspection reports. The continuous sampling rate is based on fleet size and the amount of engine hours operated. Engines not sampled continue to age until performance indicates the need for an overhaul

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time limit.

Performance standards for all engines under this programme are 0.3 shutdowns and 0.5 premature removals per 1000 engine hours of operation. The ageing process only stops if these standards are not met and a critical mode of failure appears to be time related with no immediate engineering fix being available.

The Component Reliability Programme (CRP)[2/] was developed to rapidly investigate the age/reliability characteristics of major mechanical components, without degrading in-service reliability. It was started in February, 1963 and uses the experience gained under PSRP. There are six components on this programme and it is expected that the total number will never exceed about 20. The plan is that components will graduate onto the RCOH programme from CRP or alternatively reach fixed, but very high, TBOs.

The basic difference between this programme and TERP is that components are not inspected under CRP whilst they are installed and therefore the control needs to be more stringent. TBO is controlled by conventional probability curves and ageing must only stop if an MTBF of 0.5 or greater of the authorised TBO is not achieved.

To enter this programme components must have high overhaul cost, excellent engineering support, negligible change in failure rate with increasing age and complete time monitoring. A sampling scheme is operated on high time components and mortality analyses and prepared quarterly. Monthly meetings are held in order to decide whether it is necessary to impose time limits on any components in the programme. To date this has usually only occurred because the required sample reaching the current TBO was not achieved and a temporary hold on the TBO is made until more experience at that TBO is accumulated e.g. cabin turbocompressors are being held at 8,900 hours and Freon compressors have just started to age again after a hold at 6,600 hours, both components having shown improved reliability at these lives compared with the original low TBO conditions.

The Component Reliability Engineering Evaluation Programme (CREEP)[2/] is a joint manufacturer/operator effort on the components of the Boeing 727's environmental control system. It functions within the currently approved component TBOs and is essentially a design evaluation project. The manufacturer sends representatives to the operator on a scheduled basis in order to study and discuss current problems.

Test and Replace As Necessary (TARAN)[4,5/] provides a means of rapidly identifying the optimum overhaul frequency, if it exists, for each hydraulic system component and eliminates lowtime precautinnary removals that are typical of most time extension programmes. It had its origins some three years ago as United became increasingly dissatisfied with the traditional approach to setting somewhat arbitrary component lives, particularly on hydraulic items. However the "on condition" approach was only acceptable to the FAA if monitoring was incorporated.

/Basic principles ...

Basic principles of TARAN are:-

(a) **to do system monitoring in-situ wherever possible, thus minimising the** exposure to infant mortality caused mainly by external leakage

(b) to carry out a pre-overhaul test, thus identifying unjustified removals and enabling true component performance to be established, and

(c) not necessarily to carry out a 100% teardown on justified removals.

The in-situ monitoring is concerned with measuring internal leakage rates and the first problem was to set the level at which the component was deemed unacceptable. This performance standard was initially established in conjunction with the manufacturer. Typically, factors of 4 on design leakage rates in, say, spoiler actuation valves were found to be quite acceptable. These factors were kept on the conservative (low) side and experience was then established on the fleet by measuring leakage rates and comparing them with design values when the appropriate system was "squawked" by a flight crew. The factors were then modified, usually upwards, based on this experience.

Leakage profiles of the appropriate components on each aircraft are accumulated; in fact on the Boeing 727s the first points on the profiles are now established on delivery of the aircraft. Depending on experience, some components are monitored only at the basic check period which may be as high as 6000 hours. In these cases the leakage factor is kept conservative (low) and sometimes monitoring is carried out at mid-overhaul periods. When it is established that a component is deteriorating, a leakage check may be performed at 1000 or 1500 hour intervals.

Using accurate flowmeters at various test points it may only be possible to isolate a trouble area which involves two or three components. In these cases United have developed test gear that enables the offending component to be isolated without disconnection of the hydraulic piping. Liquid nitrogen is applied externally on the line, just upstream of each component in turn, so as to create a solid plug of hydraulic fluid.

Another device used as a standard piece of ground equipment at the dock depends on measuring the time/temperature relationship of a cooled plug of fluid. A carbon dioxide bottle has an extension, with an integral thermocouple, which can be clamped to the hydraulic line. Another thermocouple is positioned externally at a set distance downstream (actually 4 inches). Both thermocouples are connected to a timer control box which is basically a voltmeter calibrated in flow rates for various sizes of hydraulic tubing.

This leakage check is performed some 2-6 weeks prior to the aircraft input for the basic check. The shop floor man uses the flowmeter test equipment which actually only registers scale readings so as to discourage him from trouble-shooting. These readings are then passed to a technically qualified planning engineer. His full time job is to convert the readings to leakage rates, develop the profiles and, when necessary, to write the job cards and request predraw of

/of the components ...

of the components that have exceeded the leakage limits. This procedure eliminates a fundamental disadvantage of "unmonitored on condition" maintenance.

Engineering meetings are held at 30 day intervals to discuss troubles and review a report on irregular removal rate (IRR) data which is the alert signal for all components on the TARAN programme. Quarterly meetings, involving the shops, aircraft overhaul, inspection and quality control, are used to monitor overall progress by reviewing component history cards to select TBSM limits if they exist, and to pinpoint potential problem areas. Reports on both meetings are sent to the FAA who are also invited to observe the quarterly sessions.

Under TARAN there have been less unscheduled component changes and now the IRR has, in most cases, also shown a downward trend compared with the non-TARAN experience on the same aircraft. Thus even the line stations are beginning to benefit from the programme.

Considerable labour savings have been immediately apparent in hydraulic system overhaul. These range from an average saving of about 1000 man-hours on the DC-8 system which is scheduled at a multiple of 4 times the BCP (i.e. every 24,000 hours) to an estimated 1,800 man-hours saved on the 727 system which is currently listed at 2 BCPs (i.e. every 12,000 hours). These savings are based on aircraft overhaul and component shop time but, with United's ultimate fleet strength of about 120 727 aircraft, the overall return is large. However, the increased overhead needed to run a TARAN system, although relatively small in this case, must be remembered when estimating nett gains.

The Boeing 737 hydraulic system will be very similar to the 727's, so that most of the techniques developed for the 727 will be used directly on the new aircraft. It is claimed that the DC-9 is the first aircraft in which the TARAN concept is built into the aircraft. Apparently the TARAN specifications have been bought from United by Sud, for incorporation into Concorde. In fact the TARAN approach has been such a success that United are planning to sell it to other operators in order to help recoup their development costs. Such a deal may include not only specifications and manuals, but also test gear and the training of personnel.

The Application of Critical Path Techniques to Aircraft and Engine Overhaul[8]

The critical path technique was first becoming widely accepted in industry at the same time as the early jet aircraft were taking considerably longer than the 7 days out of service that United had planned for their overhaul. This was in late 1961 and the work was planned on a 5 day dock visit plus 2 days ramp time for engine running, check out and flight test. The scheme theoretically gave most dock men a conventional working week, although work was of course, continuous throughout the 24 hour period.

/At this ....

At this time the average out of service time for overhaul was about 2 weeks and aircraft were having to be taken out of the bay before the overhaul was completed owing to the limited bay space available. Under this pressure, considerable effort was made available in order to try something new.

Seven network charts of the important areas of the aircraft were evolved, these being the hydraulic system and control surface rigging, cockpit, engine, air conditioning, fuel, radio and electrical systems and cabin. The non-routine work presented problems but the jub of "planning foreman" was instituted with the object of using the charts to run the overhaul. Lead mechanics, whose job is to decide the fix and write the process on a ticket, were asked to give information as to where the non-routine jobs fitted on the charts. However, they declined to co-operate. Nevertheless enough information was obtained at this stage to try out the method for several months.

A computer programme was used on an IBM 1410 machine to generate the standard critical paths in each network and list the jobs in a sequence of increasing slack for use by the foreman. These networks were posted at the dock, but little co-operation from the dock personnel resulted. Also a computer run was organised twice daily but the "backroom operation" involved too many people. Consequently, when combined with the difficulty of getting up-to-date information from the lead men, it was abandoned.

However, the elapsed times on overhauls were by now approaching the 5 day target. Experience showed that such areas as the hydraulic system and control surface rigging were always critical. Eventually the process reverted to being run by hand completely. Networks were replaced by Gantt charts and then by job cards positioned in sequence on conventional schedugraph boards. These were based on the critical path experience and they allocated more effort to the newly established critical paths.

Simultaneously a new aircraft overhaul manager was assigned to the job and he proved to be a powerful influence in coordinating these new schemes and achieving the 5 day target with reasonable regularity. Unusual events could, of course, upset the standard work pattern but, because of their uncommon nature, such events rapidly become known to all on the dock and a critical path review could be established on the spot.

Four docks are now in use and the 5 day period has been achieved regularly for some 24 months on DC-8 s and 12 months on 720 s. In fact the first overshoot from this target figure in 1965 occurred during my visit. This was due to spar cracks being found in both wings on a 720 overhaul.

Considerable thought is now being given by United on how to get the SST out-of-service time down to 5 days as quickly as possible. An on-line computer may be used for scheduling, with constant feedback of routine and non-routine work, together with a resource allocation plan.

/Similar .....

Similar critical path experience has been gained in the turbine engine overhaul shop which works a 5 day week, basically with two shifts. Average times for turbine engine overhauls have been reduced from around 35 days to 20 days. Each job is on an IBM card together with the latest possible starting time. Knowing the time taken for each job the computer is used to find how much each foreman is behind schedule. This has proved to be a powerful motivation tool. At present no account is taken of the available manpower in the shop, but a resource allocation programme is currently being built into the system.

Continental Air Lines Maintenance Base, Los Angeles
Tuesday, 27th July

J.F. Martina	Assistant Vice-President, Maintenance
K.W. Roberts	Production Planning Manager
C.A. Ptashinski	Training and Publications Manager

Fully Equalised (or Continuous) Maintenance System

Basically the maximum out-of-service time for all Boeing aircraft is confined to the 12 hours between 8 p.m. and 8 a.m. However, this downtime is measured from block to block and therefore includes two 45 minute periods for the normal turnround activities and towing of the aircraft from, or to, the passenger terminal ramp. Thus a nominal 10 hours is available for hangar and run-up work, of which some 8 hours is usually spent in the hangar.

Further restrictions on the flexibility of this arrangement arise from the prohibition of engine running during the late night and very early morning. Small changes also occur in these timings as Summer schedules change to Winter, and vice versa, and occasionally if the fleet size alters significantly; otherwise the shift pattern is adjusted to meet the flight schedules.

The majority of maintenance personnel are therefore on a permanent nightshift and they receive the appropriate incentive rate. Only by gaining sufficient seniority can a man move into a more desirable shift, although this problem does not appear to be great as the situation is made clear when he is hired. Moreover the Los Angeles area has a vast labour potential in aeronautical skills.

The production scheduling of routine work is based on computer outputs which indicate component lives in a "time remaining" sequence for the next 3 months. The complete data system covers some 1300 items of which about 50 refer to "on condition" components and some 250 to structural overhaul and special inspection schemes. This system is also used for trouble rate analysis as well as routine work scheduling.

The necessity to avoid labour saturation in critical areas on the aircraft is, of course, paramount. Continental claim, however, that more flexibility exists to accomplish this objective than with block overhaul systems. Perhaps the greatest emphasis is placed on the fact that each crew working on the aircraft knows that all work must be completed by the end of their shift. No "handovers" are involved and each man is under constant pressure and has the satisfaction of being able to see the aircraft being rolled out at the end of his particular shift.

Before each input to the Base meetings are held some 24 hours and 12 hours ahead, the latter actually involving lead mechanics. These meetings

/finalise .....

finalise the detailed planned content of each work package, based on the computer cards and modification requirements. The necessary work on each input is scheduled first and then optional work is listed towards the end of the shift. However great care is taken in order to achieve realistic planning of workload for the input. At present no display of any sort is used on the dock. A production foreman administers control at the dock itself and a production co-ordinator acts in an advisory staff capacity with the object of co-ordinating activities with the plan.

The actual check periods for all Boeing aircraft are nominally 205 and 615 hours although there is little difference in the work content of the two. In practice the 205 hour check is usually carried out at around 185 hours. With utilisations of around 13 hours per day, each aircraft visits the dock about every 7 days. This arrangement is matched to the fleet size of 13 Boeing aircraft and the Base capacity of two bays, overhaul work being carried out during the 90/95 hour visit.

Each night it is usual to have one aircraft on overhaul work and one on check work, although the system allows flexibility and variations are readily made to suit changing situations. No concession system on component lives is granted by the FAA and consequently the maintenance plan must allow for the possibility of an aircraft missing a planned input. Occasionally it becomes necessary to take the maintenance crew to an alternate field if Los Angeles is fogbound for a long period.

Test flights are minimised by, for example, never installing two zero-time engines and also by reworking original control surfaces whenever possible. Cabin refurbishing is usually accomplished within the 10 hour period, although external paintwork has to be done piecemeal. However, care is taken to keep the port side of the aircraft in good condition as this is seen more by the passengers as they get in and out of the aircraft. Modification work is very rigorously controlled and a recent example of a major programme which is being accomplished during a series of visits to the Base is the installation of TV equipment.

Since the Boeing fleet was started in 1959 Continental claim that all aircraft on domestic operations have flown on every day since delivery, except during one major modification programme and other "very exceptional" circumstances. Such circumstances have mainly resulted from certain mandatory airworthiness modifications and the very occasional discovery of spar cracks. The main reason why this record does not completely apply to the 707-320C aircraft on international duties is that the structural inspection of the wing forgings requires the removal of the centre fuselage fuel tanks. This operation cannot be completed within a 10 hour hold (these tanks are not required for the 707 domestic services and have been removed to facilitate this inspection).

The early 707 s had the fin extension and rudder boost modification carried out by TWA in one week as the necessary shop capacity exceeded that available at Continental's Base. The 720 aircraft were also out of service for a week when American fixed the leading edge corrosion problem which involved

/the removal .....

the removal of the leading edge glove between the fuselage and the inner pylons.

Obviously the scheduling of all work within some 10 hours gives rise to many problems. However the record speaks for itself and in May 1965, for example, the four 707 - 320C aircraft on MATS work each averaged 14.11 hours per day and one aircraft accumulated 484.17 hours in that month. On domestic operations the 720 fleet averaged 12.33 hours and the 707's recorded 13.05 hours. All utilisations quoted are flying hours, which are about 0.95 of block hours for Continental's services.

It is interesting to note that some airlines, including British United it is believed, have purchased many of Continental's continuous maintenance system concepts from them.

In summary it can be said that the system works successfully owing to a combination of the following reasons:

(a) Continental is a small enough organisation for the medium of rapid personal communications to be highly effective;

(b) a comparatively high technical delay rate of approximately 5% is accepted (a maintenance downtime even shorter than 10 hours has been used but, among other difficulties, even higher technical delay rates resulted);

(c) Continental's route network is fairly dense and all aircraft visit the Los Angeles Base frequently; and

(d) large labour resources of the necessary skills are readily available.

SAE/ASME/AIAA Fourth Annual Reliability and Maintainability Conference, Los Angeles[9]
Wednesday to Friday inclusive, 28th to 30th July.

Air Canada, Montreal - Monday and Tuesday, 2nd and 3rd August.

C.H. Glenn	Director of Operations Planning
A.M. Lee	Director of Operational Research
J.W. Norberg	Director of Maintenance Production Services
I.S. MacDonald	Project Engineer, Aircraft Evaluation
P.J. Jeanniot	Superintendent of Management Services
T.E. Truscott	Superintendent of Maintenance Training
G. Haigh	DC-9 Power Plant Engineer

Electronic Data Processing and Operational Research[11]

In Air Canada computers are used for:-

(a) large volume information processing;

(b) the transmission and processing of operational information accurately at high speeds ("on-line" applications); and

(c) complex calculations and detailed simulations arising from O.R. projects which could not economically be done manually.

The relative size of these three types of use are noticeably changing; increasing attention is being paid to on-line applications in both Sales and Operations Departments, so that category (b) has a growing weight. In addition, applications of category (c) in the areas of planning and management decision are assuming greater importance (the so-called "management science" applications of computers).

Recently an investigation into Management Information Processes was started and Sales and Operations, being the two largest Departments, will be investigated initially. This study will involve the identification of information. what form it should take, where it should flow, who should read it and how it should be organised. Air Canada consider this to be an area in which there is vast scope for improvement.

It is interesting to note that an exchange agreement is operated with United Air Lines. United has released to Air Canada a crew scheduling programme in exchange for Air Canada's Operations Schedule Simulation. This simulation is being extended to handle all fleets simultaneously and to take into account the

/effects of ....

effects of weather and connecting flights.

The main areas in which Air Canada is using EDP are summarised below on a Departmental basis. Where applicable, brief comments indicate the status of these applications and this can be considered as an extension and updating of Appendix I of J.T. Dyment's paper on The Tools of Airline Management 12/.

Engineering (1) Engine Component Recording and Forecasting Systems consist of a recording function for updating and history, and a retrieval function for general surveys and population travels. Manual records are no longer kept for all serialized engine components and blades for Conway, Tyne and JT3-D3 engines. Daily reports of flying time are used to generate inspection reports for engine removals and to assist in forecasting removal times and component usage. The forecasting simulation permits long range (5 year) forecasting of the consequences of various strategies involving engine life policy, modifications, life development and repair and overhaul policies. It is planned that this programme will cover all aircraft components within the next two years.

(2) Aircraft Log Book Information System (ALIS) is currently concerned with variances between actual and expected fuel consumption derived from log book information taken during cruise conditions. This is part of the general Aircraft Integrated Data System (AIDS) which will most probably be a digital system with punched data tapes being ripped off and transmitted from each line station to a central organisation. Emphasis will be placed on shortening the feedback time of information to make trend analysis effective. Although the 40 odd parameters will initially be chosen primarily for crash recording purposes, this is seen to be the first step towards effective maintenance recording. It is expected that the system will be fully operational on the DC-9 aircraft by the end of 1966.

(Eventually it is envisaged that an integrated on-line computer system for maintenance activities will have inputs based on the two systems outlined under items (1) and (2) above).

(3) Engine Repair and Overhaul Simulation (EROS) is well known. It forecasts the number of scheduled and unscheduled engine removals in order to provision for spare parts, establish manpower and production requirements and to check the adequacy of spares holdings.

Based on EROS, with inputs of fleet introductory pattern, utilisation, MTBR and mean shop turnround time, the complete initial provisioning for the DC-9 has been developed from grids of these input variables. This has given rise to an automated parts catalogue which is compatible with the ATA 100 and 200 specifications and the inventory control process.

A further development of EROS dealing with the complete aircraft (AROS), and including a resource allocation of hangar labour, is currently being studied.

(4) Labour and material reporting is carried out daily, under various combinations of skills and time periods, for control purposes.

/(5) ....

(5) Automated Budget Analysis by Category Usage System (ABACUS) is in regular use and determines optimum staffing levels for the major workshops taking into account the necessary balance of skills, labour rates, idle time, temporary staff, overtime, training costs etc.

(6) Other applications are concerned with routine information, costing and monitoring processes.

Sales Department expects to realize two objectives in regard to EDP applications, namely (i) greater efficiency in processing basic information compared with manual systems and (ii) the timely provision of selected information to ensure that alternative strategies can be considered and best decisions made.

In fact, the largest expansion in EDP work and O.R. techniques is now taking place in Sales. Even the difficult but fundamental problem of how much money to spend on salesmen and how much on advertising (and where) is being tackled by field experiments each costing around £30,000. Experience is being accumulated from the measured responses to these experiments and it is hoped that in two years time the company will be using the results for executive decisions.

(1) Electronic Reservations and Records Systems (ReserVec and ReseRec). ReserVec maintains records of seats by flight and date, suggests alternatives if no space is available and includes automatic processing of waiting lists and follow-up information in strict order of priority. ReseRec is just becoming operational and is a computer based passenger name record system for check-in and ticketing purposes.

(2) Planning (a) Long Term (up to 10 years ahead) involves traffic forecasts from an econometric model using about 50 external variables between each city pair. This will shortly operate on a routine 6-month cycle, although some skilled human intervention from economists will still be needed in the final interpretation of results.

(b) Intermediate (6 months to 2 years ahead) uses exponential smoothing and depends only on the history of past traffic. It is operating on a monthly routine. A self-checking process involves the calculation of the variance between the latest data and a forecast for that period based only on previous data. If this variance exceeds certain limits, the programme may be readjusted by a market analyst to give greater emphasis on the more recent data. This check allows for unpredictable situations such as local political disturbances.

(c) Short Term (present to 4 months ahead) is based primarily on advanced booking information and predicts, every month, requirements for extra services and financial forecasts to determine the policy on short period loans and borrowings.

(3) Staffing simulations for telephone sales offices, sales counters and gates to meet given standards of performance have been completed. Tables are now used to find the number of people required on a given shift in order to satisfy specific demands.

(4) Passenger and cargo tariffs calculate the official fares and rates.

/ (5) ....

(5) Sales Analyses summarise and analyse each month's sales.

Operations (1) Operations Schedules Simulation is being extended to cover all fleets simultaneously and to consider the effects of weather and connections. This very complex simulation will be put on a CDC 3600 computer. The schedules are coded and kept up to date in punched card form and meal costs, crew pairings, flight records, operating plans and timetables will be generated automatically.

(2) Crew Scheduling programmes construct crew cycles from the flight schedules. Pilot contract limitations, safety restrictions and effects of delays are taken into account so as to minimise costs and optimise the ratio of flying time to time on duty. This is an example of the use of integer linear programming. Currently it is partly operative and an adaption of it for cabin crew scheduling is working. By the end of 1966 the complete process will be on the computer and this will be one of the major routine EDP applications in Air Canada.

(3) Aircraft weight and balance for each flight is being investigated as a potential EDP application.

(4) Flight planning to calculate optimum flight paths has not received any detailed study as the number of alternative routines are comparatively small on Canadian domestic operations. The main choice is usually restricted to the selection of flight level. Also the relatively low frequency over the North Atlantic does not warrant the required effort at present.

(5) Teletype switching is a major on-line system which was implemented in December 1964 when the company started to use a new computer controlled fully automatic teletype system. Subsequently it has been interconnected with similar systems operated by ARINC in the U.S.A. and the Caribbean. It will soon be linked with the U.K. through the BOAC centre in London.

Purchases and Stores. Most applications of large volume information processing in this Department are concerned with Inventory Control.

(1) Daily inventory and order record for the 125,000 items stocked at Dorval which generates action notices, punched order cards, receiving cards, location cards, stock value adjustment cards, accounts payable cards, output for the Finance Department and various reports.

(2) Monthly calculation of inventory parameters for the 115,000 expendables at Dorval i.e. forecast consumption, procurement time consumption, protection stock, reorder point, economic order quantity and deviation.

(3) Line station items and quantities of spares required at each station are updated every month.

(4) Other applications such as initial provisioning (see item (3) under Engineering) annual inventory, parts catalogues and rotable/repairable inventorying.

/Finance ......

Finance and Accounting. (1) Revenue information system.

(2) Payroll/personnel records information system.

(3) Statistical information system.

(4) Financial forecast system.

(5) Many smaller applications involving financial analyses and personnel records.

Aircraft Evaluation

Air Canada's approach to maintenance costs in aircraft evaluation is interesting. As the engineering accounting system is based on the ATA 100 specification 13/, information on current and past aircraft is used to predict future aircraft maintenance costs for individual systems. These predictions are made by a committee with members drawn from various departments in order to remain unbiased.

Most items are established as a cost per hour to cover labour and materials for each ATA system, together with an appropriate learning curve. Obviously some items are costed on a per flight basis (flaps, undercarriage) and some on both a per hour and per flight basis (engines).

There are of course, difficulties and exceptions to such a comprehensive system. For example, some hangar labour costs are difficult to allocate by ATA chapter and the use of "pool" spares complicates the accounting process. Exceptions to the prediction process are naturally made when items on the new aircraft are radically different from current practice. Also, for a few systems, cost formulae have been developed (e.g. wheels, tyres and brakes maintenance costs are based on the governing parameters of weight, speeds, landing and take-off distances).

These costs aim to represent stabilised conditions several years after the introduction of a new type. Thus in the case of the DC-9 all costs will be on an ATA chapter basis from the initial provisioning stage and the evaluation figures will also be used as target values to be achieved as soon as possible by the respective departments.

Other interesting facts were:-

(i) the aircraft purchase price is negotiated with the manufacturer by the Engineering Department;

(ii) great emphasis is being taken on the inventory for the DC-9 to account for the fleet introductory pattern; and

(iii) Purchases and Stores Department negotiate warranties directly with the manufacturer.

Pan American World Airways, New York
Thursday, 5th August

E.M. Fessenden	Manager of Maintenance Administration
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Aircraft System Reliability Programme 18,19,20/

The PanAm system reliability programme is a direct extnesion of the original FAA/Industry Turbine Engine Reliability Programme "alert" concept. It was started in February 1963 as a six months' trial on five selected DC-8 systems. The DC-8 aircraft was chosen as it represented an established and stable fleet.

Care is taken to define precisely each system and failure mode. As a specific example of this, a failure in the fuel quantity indicating system is defined as "when a flight crew reports an inaccurate reading on any one or more tanks on any one flight leg". Service analysts use master documents with the agreed definitions to interpret which of the reported snags in the flight logs are to be classified as failures. The actual "alert" values were set by researching the previous two years operations and listing the defined failures; this information was then converted to failure rates of unscheduled removals per 1000 flying hours, and a process of judgment used to finalise the "alert" figure.

Each month the reliability of the systems in the programme is reported to the FAA using a three-months' running average. As long as the reliability is under the alert value, PanAm are free to extend the TBO of components in the system without prior FAA approval. However there are, of course, other criteria involved. The complexity of the component and the applicability of the criteria to that specific component decide which of them will be used. These criteria are:-

(1) total unscheduled remove rate; (2) confirmed failure rate;
(3) routine service inspection review; (4) specific sampling inspection;
(5) functional check (normal operation); (6) ground functional check;
(7) overhaul discrepancy findings; (8) TSO scatter analysis;
(9) preoverhaul bench check.

If the alert value is exceeded a report must be submitted to the FAA outlining the appropriate action that is to be taken . Currently there are ten DC-8 systems and subsystems on the programme.

It is appreciated by PanAm that a fundamental stage in this process is the choice of the alert value, and also that this choice is the least scientific part of the exercise. This was highlighted after the trial programme

/had been .....

had been operating very successfully for about a year on the fuel quantity indicating system. At this time there was a major reshuffle of aircrews and immediately the indicating system failure rates were considerably above the alert value for several months. Gradually the rates dropped comfortably below the alert value before any (of the suggested) modifications could be incorporated in the fleet. This experience also indicated the need for careful definition of "failure".

Recently, PanAm have found a very good correlation between the number of defined failures and the total count of flight log entries. It is hoped that the FAA will soon accept new (higher) alert values based on "total counts" as this will save considerable interpretation time. Furthermore negotiations are in hand with the FAA to extend this programme to virtually all systems on all PanAm aircraft by the end of this year. In this extension it is hoped that the previously mentioned nine evaluation criteria on individual components will eventually be dispensed with.

Currently the flight logs of the latest 15 months of operation on a one-third sample (i.e. 20 aircraft) of the Boeing fleet are being researched in order to establish alert values based on "total counts" for all the Boeing systems. Consideration is being given to using a 3 standard deviations (99%) performance standard in setting these alert figures.

Only exceptions to this all-embracing programme will be items such as emergency gear and in-flight entertainment equipment on which insufficient history exists to enable alert values to be selected; engines will also continue to be controlled by the Propulsion System Reliability Programme. The ultimate goal is the extension of this concept to routine servicing periods and structural items, using work content as the alert figure.

The alert programme and individual time control on components contrast sharply with United Air Lines' reliability programmes and multiple basic check period system of component life control. PanAm consider that they have been subjected to tighter control by local FAA personnel and they suggest that this was a major contributory cause to these differences. A further consequence is that PanAm operate a sophisticated computer component control system covering all time lifed units. This forms part of the extensive engineering EDP system described below, a by-product of which is further reliability information in the form of actuarial analyses. Such analysis is carried out on the components of the 10 DC-8 systems covered by the FAA system reliability programme, but it is being extended to all time controlled units.

EDP Programmes for Engineering and Maintenance[21/]

The EDP Maintenance Time Control System has been gradually built up over a period of some 4 or 5 years and it controls all scheduled work that must be accomplished by a specified hourly time limit. An Aircraft Detail File contains information on each component installed on a particular aircraft by

/serial .....

serial number and also on routine maintenance work. With some 250 Boeing 727 components currently being inserted there will be about 1000 types of components on the File. This information is updated as routine work is accomplished or when components are changed and a listing of time controlled components is also made each week for reference.

A Master Data File contains constant information for components and routine work related to a type of aircraft and is updated each week. Currently some 77,000 items are listed and modifications are also being included in the records.

Each time a component is replaced and the Detail File is updated, historical records are produced for reliability analysis (as detailed below) and part time component records are printed as cards for all components that can be repaired and installed with time on the components. These cards are used to carry forward, at installation, the time since overhaul so that the remaining life may then be utilized.

When an aircraft is scheduled for a check, the computer interrogates each item on the Detail Tape and determines whether the work must be accomplished on that check or a subsequent one. The necessary reports to perform the check are then produced. This is done some 3 weeks ahead for an overhaul (6000 flying hours) or 1 week ahead for an equalised check (600 flying hours).

A check work list report notes all scheduled work that must be accomplished using numbers which refer to instruction cards giving full details of the work. After the check, the installation information is recorded on the report and it is used as source data for updating the Aircraft Detail records. An aircraft workload projection report gives the man-hours required by skill for the next check and future equalised checks up to, but not including, the next overhaul. A material requirements report lists all material scheduled for the upcoming service and is used to arrange predraw of material from stock. Finally a shop forecast report indicates component requirements on specialist shops, both on the upcoming service and also for the next 6 months period.

In order to co-ordinate the total work scheduled for an aircraft check, an aircraft modification scheduling and compliance programme was started 12 months ago and should be complete in another 6 months time. At present it is used for overhauls only. The requirements for the system are similar to the time control system except that the format of the reports differ and modifications are not repetitive.

Reliability analysis and shop findings reports are generated each month as by-products of the time control system. The shop data adjusts premature removals to confirmed failures. For the preceding six months the premature removals are accumulated within the 100 hour intervals in which they occurred. With fleet sizes of about 15 to 20 aircraft for each of the major Boeing variants and the DC-8, all producing about 3600 hours per aircraft each year, it was noted that a three month historical search was changed to a six

/months ....

months period after experience was gained with the reliability programme. The components presently installed, and those removed that successfully traverse each interval, are also accumulated.

From this data the following two component probabilities are derived:-

(a) conditional probability of premature removal (P_c) - this is a 100 hour interval probability calculated by dividing the number of premature removals (and confirmed failures) within a 100 hour interval by the number of components that successfully traversed that interval. However, where the numbers are very small two consecutive six month periods may be used, together with 200 or 300 hour intervals; 100 hour scans may be retained early in the component's life if infant mortality predominates;

(b) probability of survival (P_s) - this is a cumulative probability and the P_s of an interval is calculated by subtracting the P_c of that interval from unity and multiplying that number by the P_s of the preceding interval.

This reliability information has apparently been used quite successfully to measure the effectiveness of modification programmes, although it is now felt that TSI (time since inspection) may be a more useful parameter to use in the analysis than TSO (time since overhaul).