Development of an aircraft systems dispatch reliability design methodology

M. Bineid and J. P. Fielding
Aerospace Engineering Group, School of Engineering
Cranfield University,
Bedford, UK

ABSTRACT

This paper describes the development of a generic aircraft systems dispatch reliability design methodology (ASDRDM) that has been developed for use during early phases of the aircraft systems design process.

The methodology incorporates prediction of both reliability and maintainability through the aircraft design hierarchy, down to component level. It can be applied at the early design stage, but can also be used for advanced design phases and can use generic or actual failure rate and mean time to repair data. It allows designers to modify system architectures and component reliability and maintainability characteristics. The paper shows the validation that has been performed, and its use is demonstrated by a case-study.

NOMENCLATURE

A/C	aircraft
ASDRDM	aircraft systems dispatch reliability design methodology
ATA	Airline Transport Association of America
AUC	Air Transport User Council
EUROCONTROL	European Organisation for the Safety of Air Navigation
ISL	International Society of Logistics
ITA	Institut du Transport Aérien.
K	constant value = 0·5
LRU	line replaceable unit
MEL	minimum equipment list
MTBF	mean time between failures
MTTR	mean time to repair
MTBUR	mean time between unscheduled removals
N	number of components of a sub-system
NPRD	non-electronic parts reliability data
R&M	reliability and maintainability
SAE	Society of Automotive Engineers
SR	scheduled reliability
λ	failure rate
λ_{ia}	the allocated failure rate for the *i*th component
$\lambda_{sr(sub)}$	the failure rate requirement for the sub-system (can be obtained from historical data for a similar aircraft system or from the system manufacturer)
λ_{ip}	the predicted failure rate for the *i*th component, which could be obtained from historical data for a similar aircraft/system.*
λ_{sp}	the total predicted failure rate for the components in the sub-system = $\sum_{i=1}^{N} \lambda_{ip}$
μ	repair rate

**The component predicted failure rate data can be obtained from historical data for similar components or from other sources such as NPRD-95[25] and Relex[24] software library.*

Paper No. 3063. Manuscript received 20 January 2006, accepted 27 February 2006.

https://doi.org/10.1017/S0001924000001251 Published online by Cambridge University Press

Table 1
Average punctuality and delay time

	Eurocontrol Area	USA
Departure punctuality	74%	74%
Average delay time (>15 minutes)	39 minutes	44 minutes
Arrival punctuality	73%	77%
Average delay time (>15 minutes)	43 minutes	53 minutes

1.0 INTRODUCTION

One of the value drivers in the civil aircraft industry is the dispatch reliability of aircraft, also termed operational reliability. The former is defined as the percentage of scheduled flights which depart without having a technical delay of more than 15 minutes, or a cancellation.

Increased dispatch reliability reduces flight delays and cancellations, resulting in greater operational efficiency, flexibility and customer satisfaction. Therefore, increased dispatch reliabilities result in reduced costs and increased revenues.

Aircraft dispatch reliability is affected by technical and non-technical factors. The former are strongly affected by decisions made by designers, whereas the latter are governed by other aspects, which include those managed by the operators, such as maintenance, logistics, operations, and management. This paper will address only technical factors that can be influenced by aircraft designers, which account from some 20% of all delays[6].

1.1 Magnitude of delays

A study performed by Eurocontrol to analyse the average delay time in some of the European and USA airports for the year 2000 showed that around 26 % of the flights were delayed with average delay times of 39 and 44 minutes[17] as shown in Table 1.

The American Bureau of Transportation Statistics[4] showed that flight delays were a major concern, especially during the high season, with figures of up to 33%.

CAA data[12] shows the statistics of the average delays of all flights in the United Kingdom. These showed that the percentages of delays were around 30% for scheduled flights and 35% for charter flights. The aircraft average delays were 12 and 20 minutes, for scheduled and charter flights respectively. These delays are the times that occur after the 15-minute window, which means that the total delays were some 27 minutes for scheduled flights and 35 for the charter flights.

1.2 Delay costs

Current aircraft delay costs are already very high, with some conservative estimates, putting them in the region of €86 to €108·6 per minute of delay, and the annual delay cost between €6·6bn to €11·5bn for air transport delays in Europe[17].

Omari[23] stated that the cost of delays and cancellations are in the region of 2% of the annual total revenue. The Air Transport User Council (AUC) data base showed that 22% of the 2000/2001 total passenger's written complaints were for flight delays[1].

The current situation is expected to further deteriorate because air transport passenger numbers and cargo shipments are increasing continuously, with over a billion passengers per annum in recent years[20]. This growth is expected to continue, as the world's population is increasing and more people want to travel. This expected growth requires more flights and/or larger aircraft, resulting in a very difficult challenge for the aircraft industry to produce the required number of flights at the required times. Aircraft delays will further aggravate this problem.

The costs of delays are of two types, namely direct and indirect costs. The direct costs include a number of obvious elements that range from lost ticket sales, the cost to passengers for lost connecting flights, maintenance costs, providing meals and hotels for the passengers during the delay, through to the airport fees.

The less obvious costs are the indirect costs, which can sometimes have very significant effects. These include the ferry flight for repair, replacement costs, and most importantly, the damage to the airline's reputation. This last cost is very hard to restore, and can seriously affect the future of the airline.

Current evidence strongly suggest that if future aircraft are allowed to have current aircraft dispatch reliability levels, the number of delayed passengers and cargo will make it very difficult for airport facilities to operate, and air transport operations will be jeopardised.

1.3 Previous aircraft dispatch reliability design methods

Although aircraft operators recognise the importance and impact of dispatch reliability, they have not been able to address it effectively, as the above evidence has shown. The major problem facing the aircraft operators is the fact that aircraft dispatch reliability is a design requirement that is difficult and costly to improve for in-service aircraft and must be built-in to the design from the outset. Design improvement actions and corrective techniques can help to improve existing aircraft dispatch reliability, but at very high cost and to a very limited level.

Taking into consideration the evidence suggesting that around 85% of the life-cycle costs of an aircraft are determined at the project stage (conceptual and preliminary) with a further 10% decided during detail design stage[18], the solution to the aircraft delay problem is to have aircraft designers design the desired dispatch reliability into the aircraft in the design stage.

The most important benefit of up-front dispatch reliability analysis is that the aircraft system designers will be able to perform thorough analyses to evaluate alternative approaches and explore different options during the design cycle, to arrive at a superior design. Through this process, engineers and designers can quickly investigate many design variations and evaluate a range of ideas that would not be practical to test in hardware.

Aircraft systems have a very significant effect in the aircraft design, because their mass accounts for about one third of the aircraft's empty mass, and more than one third of the development and production costs of a medium civil transport. This ratio can be even higher in the case of military aircraft, and aircraft systems account for some one third of the direct operating costs and direct maintenance costs[26].

There has been little design effort by aircraft manufacturers towards early design for dispatch reliability, because of its difficult nature and lack of suitable design methods.

Current methods to improve designs at later stages include the introduction of system modifications, improvements in maintenance procedures, enhancements to the quality of maintenance work and the introduction of new maintenance aid computer programs. The cost of performing such actions is in most cases very high and requires considerable resources. Some, or all, of these actions might improve the situation, but they cannot replace design for inherent dispatch reliability.

The literature on aircraft system design methodologies for dispatch reliability usually show comparison techniques between previous and new aircraft designs, using a baseline aircraft as the main vehicle for addressing dispatch reliability in the design[2,7,15]. Most of these techniques rely on proprietary data that are not available in the public domain. They are applicable for later design stages. This dependence on the comparison method limits its use. Because of its type-specific nature, it cannot be applied to a wide range of aircraft designs, and does not allow for technological improvements. It also has the disadvantages of limited accuracy and needs excessive analysis time.

For the above reasons, a new aircraft systems dispatch reliability design methodology was required to give a realistic approach for the design for dispatch reliability, at both the early design phases, and throughout the design process.

https://doi.org/10.1017/S0001924000001251 Published online by Cambridge University Press

1.4 Methodology requirements

Both military and civil aircraft require such a methodology, because dispatch reliability is important for both of them, and is affected by similar factors.

In summary, the requirements for the methodology were:

- independent of particular company data
- generic for both civil and military aircraft
- appropriate for use during the conceptual design phase
- uncomplicated to use
- address both reliability and maintainability

2.0 DESCRIPTION OF THE METHODOLOGY

2.1 Methodology assumptions

The developed methodology used the following assumptions, the detailed justification of which is shown in Bineid[6]:

1. Aircraft components exhibit constant failure rates.
2. Aircraft components exhibit constant repair rates.
3. Only the technical factors that affect dispatch reliability were considered in this methodology.
4. Qualified personnel and suitable spare parts are available for conducting maintenance tasks.
5. Failure rate data were obtained from the mean time between unscheduled removals (MTBUR), and when this was not available, mean times between failures (MTBF) were used.
6. All aircraft sub-system/component structures were modelled as series configurations. Any other types of arrangement were converted to series configurations.
7. In the construction of the reliability block diagram (RBD), LRUs (components) on the MEL were considered as actively redundant.
8. No common cause failures were considered in the RBD failure rate calculations.
9. System dispatch reliability was equal to the multiplication of the sub-system dispatch reliability estimations.

$$Dispatch\ reliability_s = \prod_{i=1}^{n} Dispatch\ reliability_i \quad \ldots (1)$$

10. The system failure rate was equal to the summation of the sub-system failure rates.

$$\lambda_s = \sum_{i=1}^{n} \lambda_i \quad \ldots (2)$$

2.2 Methodology description

Reliability and maintainability (R&M) are the main elements that govern aircraft technical dispatch reliability, and there are two main design approaches to predict them. The first utilises a bottom-up approach whereby the designer selects or designs components based on their performance characteristics, and then works upwards towards the system level. With this approach, the designer is not aiming at specific R&M targets and waits for the system behaviour to be acceptable in terms of meeting R&M requirements targets.

This design technique has been used extensively in the past but has proved to be unsuccessful with regard to R&M[8]. This was because no objectives were set for dispatch reliability, and the resulting designs reflected this.

The second approach follows a top-down approach, whereby the designer works from the system level down to the required component level. This approach gives the designer control over the required R&M characteristics, but, it will not ensure a successful design with regard to dispatch reliability, unless it is directed towards a specific dispatch reliability target.

The methodology developed in this research adapted a two-way system approach, to concentrate on the design parameters of reliability and maintainability. The first way proceeds from the top level down to the component level by allocating the required dispatch reliability values from aircraft level through system level, and to the component level. The second way predicts dispatch reliability from the bottom level using initially-chosen components to iterate to meet the top-level targets.

The methodology flowchart is shown in Fig. 1, and consists of the following steps:

1. Allocation of dispatch reliability for individual aircraft systems. This could be performed by using one of the following methods:

- Dispatch reliability prediction method developed by the authors[5].
- Historical data for similar aircraft/systems
- Comparison method
- Any other available methods, such as stated customer requirements.

2. Construction of the aircraft's system reliability block diagram (RBD) based on the initial system design architecture.
3. Allocation of the aircraft system failure rate requirement $(\lambda_{sr})_s$, from historical data or by extrapolation of test results for new components.
4. Allocation of the sub-system failure rate $(\lambda_{sr})_{sub}$ based on the system architecture and using the Relex RBD package[24].
5. Allocation of the component failure rates (λ_{ia}) by using the combined allocation method, as shown in Equation (3). This method combines the Equal and ARINC methods which should overcome some of the first method's tendency to over-simplification, but not to give too much dependence on predicted component failure rates, as is possible with the later. The failure rate allocation used for this work was a derivative method using part of Boyd's[9] combined method, where the value of the constant K is equal to 0·5. This is because it is the value where the two allocation methods are combined and their advantages are utilised to the optimum.

$$\lambda_{ia} = \lambda_{sr\,(sub)}\,(K / N + (1-K)\lambda_{ip} / \lambda_{sp}) \quad \ldots (3)$$

6. Calculation of the components' allocated mean time between failures ($MTBF_I$) by using Equation (4).

$$MTBF_{ia} = \frac{1}{\lambda_{ia}} \quad \ldots (4)$$

7. Dispatch reliability allocation for the aircraft's sub-system/components (LRU), performed using Equation (5).

$$DR_{ia} = \sqrt[n]{DR_s} \quad \ldots (5)$$

8. Prediction of the component mean time to repair $MTTR_I$ by using MIL-STD 472[14].
9. Calculation of the predicted component dispatch reliability (DR_{ip}) by inputting the calculated $MTBF_I$ and $MTTR_I$ into Equation (6).

$$DR_{ip} = \frac{MTBF_i}{MTBF_i + MTTR_i} \quad \ldots (6)$$

10. Comparison of the predicted component dispatch reliability (DR_{ip}) and the allocated dispatch reliability (DR_{ia}). If the predicted dispatch reliability is equal or greater than the allocated dispatch reliability, and the difference between them is less than (0·085), this means the design is acceptable and the process moves to Step 11. If not, it is necessary to return to Step 2.

https://doi.org/10.1017/S0001924000001251 Published online by Cambridge University Press

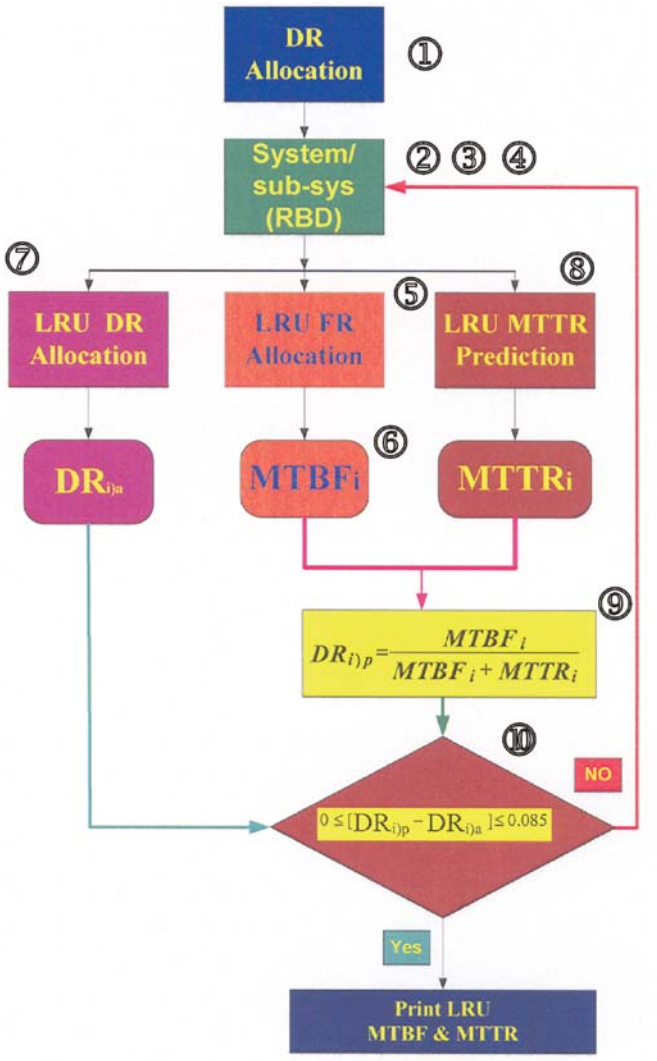


Figure 1. Methodology flow chart.

11. The MTBF and MTTR are inserted into the spreadsheet. The EXCEL optimisation process was used to achieve optimum results. The objective was to determine the target level of dispatch reliability for all components, i.e. that which was greater or equal to the allocated component dispatch reliability, and hence the best sub-system and system dispatch reliability. The optimum component MTBF and MTTR data are printed in a table for all components of the whole system.
In Step 11, changing the design to achieve the required dispatch reliability could be performed by one or more of the following options:

- Fault avoidance, i.e. making the less reliable components more reliable
- Fault tolerance, i.e. introducing redundancy for the less reliable components
- Increasing the maintainability for the less reliable components, i.e. reducing the mean time to repair.

Note:

(a) The margin between the predicted and allocated dispatch reliability was set to a specific value to prevent over-designing with regard to reliability and maintainability, which, if it happens, will mean extra cost without justification. This value was set to be (0·085) to make the difference between the allocated and the predicted component dispatch reliability as low as possible. It was defined after many dispatch reliability analyses, which showed that it was the minimum possible value. It is possible to set the difference gauge to any desired value, if there is justification.

(b) The methodology makes provision for reliability and maintainability trade-off studies by sorting the components according to their failure rates. Those components with a high failure rate would be designed with better maintainability characteristics. The sensitivity of an improvement of system maintainability to the improvement of component maintainability is proportional to the failure rate of the component.

3.0 VALIDATION

The developed aircraft systems design methodology for dispatch reliability (ASDMDR) was validated by a case study in which a twin-engine long-haul aircraft was studied. The aircraft mean time between unscheduled removals (MTBUR), mean time between failures (MTBF), mean time to repair (MTTR), and dispatch reliability data were obtained or predicted.

The fundamental argument here was that if the methodology works for any particular aircraft system, it should do the same for any other aircraft system, because the methodology has no steps or rules that are specific to any one system, sub-system or component.

A hydraulic power system was selected for this study, due to the availability of information.

Four cases were planned for the examination of the effectiveness and applicability of the methodology. These were chosen to represent different data availability scenario, as below:

(a) Applying the methodology using real values for the failure rates, together with predicted values for the mean time to repair (MTTR) and dispatch reliability.

(b) Applying the methodology using real field data for failure rates, MTTR, and dispatch reliability from an aircraft operator (A)

(c) Applying the methodology using real field data for failure rates, MTTR, and dispatch reliability from an aircraft operator (B)

(d) Applying the methodology using generic data from the Nonelectronic Parts Reliability Data (NPRD-95)[25] for the failures rate and predicted data for the MTTR and dispatch reliability. This scenario was potentially the least accurate, as it used the least reliable reliability and maintainability data sources.

A schematic diagram of the hydraulic system was obtained, which showed that it consisted of three sub-systems, right, left and centre. All sub-systems must be operative in order for the aircraft departure to take place. This means that from a dispatch reliability perspective all three sub-systems were in series configuration.

3.1 Validation process

The validation process was applied for all the three hydraulic sub-systems as described in Section 3.2 below and followed the following steps:

1. Running the methodology using data sources for MTBUR, MTTR and dispatch reliability for the four cases. The outcome of the design methodology was the sub-system design decisions, which determined the success of the design, based on a comparison between the predicted and allocated dispatch reliabilities.
2. Comparing the four output parameters.
3. Analysing the result.

https://doi.org/10.1017/S0001924000001251 Published online by Cambridge University Press

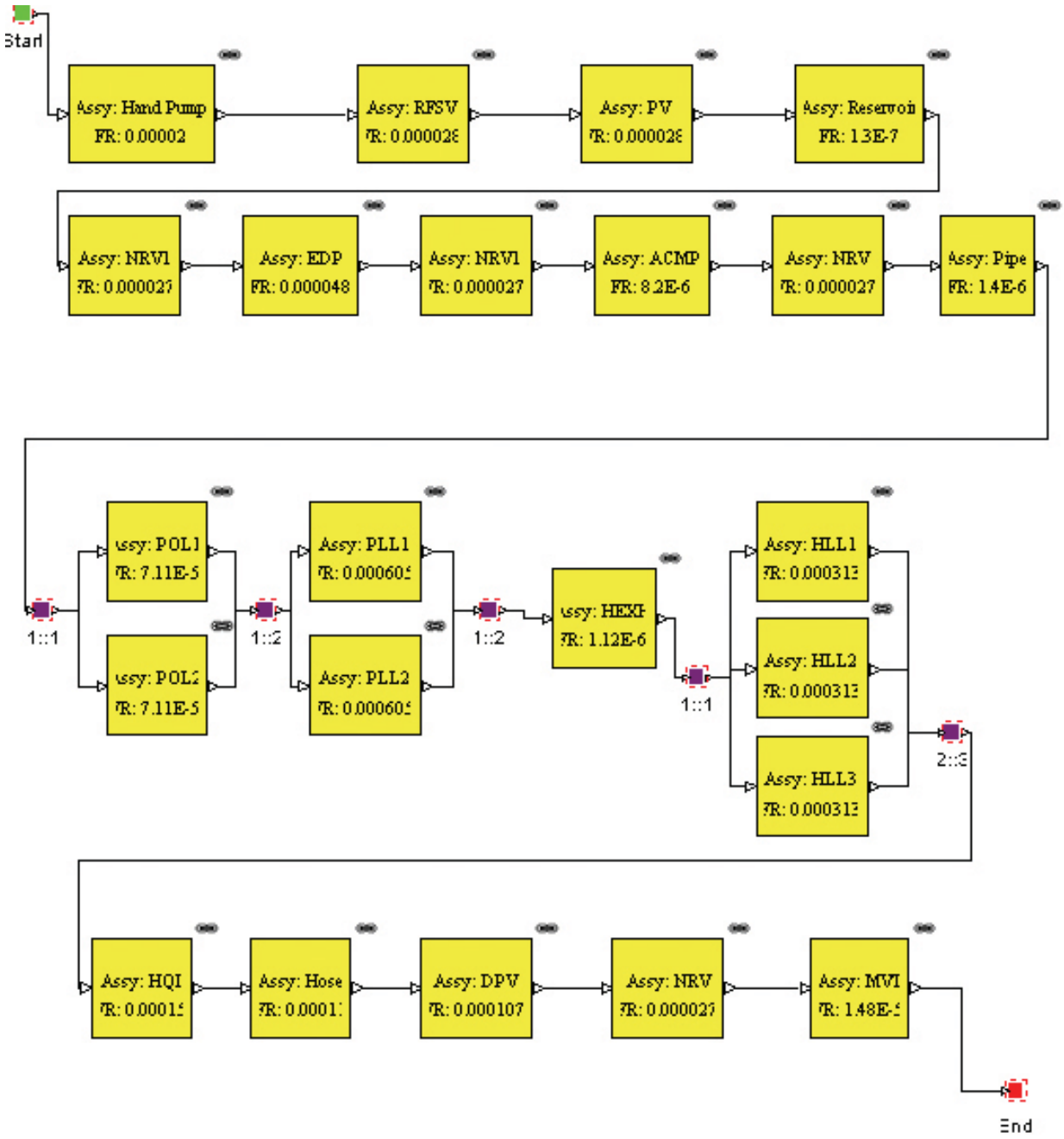


Figure 2. Right-hand side hydraulic sub-system RBD (case 1).

3.2 Methodology process implementation

The following methodology steps were performed for each hydraulic sub-system; in accordance with the process shown in Fig. 1:

1. For the first and fourth case, the required dispatch reliability value was defined by using the prediction method developed by the authors[5]. For the remaining two validation cases, dispatch reliability was obtained from real field data.
2. Construction of the right-hand side sub-system reliability block diagram (RBD) was prepared by using Relex software, as shown in Fig. 2. In this step, the general LRU information such as weight, location, accessibility and interchangeability were obtained and documented, as they were required for prediction of MTTRs.
3. Allocation of the aircraft system failure rate requirement was based on historical data, or predictions, depending on the cases used.
4. The sub-system failure rate was allocated using the system architecture, as shown in the RBD.
5. The combined method was used to allocate component failure rates.
6. The components' allocated MTBFs were calculated, using Equation (4).
7. The methodology was then used to allocate individual LRU dispatch reliability values using Equation (5), resulting in Table 2.
8. Prediction of the LRU mean time to repair (MTTR) was performed using MIL 472 for the first and fourth cases. For the other two cases, MTTRs were obtained direct from the operators' databases.

https://doi.org/10.1017/S0001924000001251 Published online by Cambridge University Press

Table 2
Allocated LRU dispatch reliability (case 1)

No.	LRU	Dispatch Reliability Allocation
1	Hand Pump	0.999985081
2	Reservoir Fill Selection Valve (RFSV)	0.999985081
3	Pressure Valve (PV)	0.999985081
4	Reservoir	0.999985081
5	Non Return Valve (NRV)	0.999985081
6	Engine Driven Pump (EDP)	0.999985081
7	Non Return Valve	0.999985081
8	Aircraft Motor Pump (ACMP))	0.999985081
9	Non Return Valve	0.999985081
10	Pipe	0.999985081
11	Pump Overheat Light (POL1)	0.996200000
12	Pump Overheat Light (POL2)	0.996200000
13	Pump Low Light (PLL1)	0.996200000
14	Pump Low Light (PLL2)	0.996200000
15	Heat Exchanger (HEX)	0.999985081
16	Hydraulic Low Light (HLL1)	0.975400000
17	Hydraulic Low Light (HLL2)	0.975400000
18	Hydraulic Low Light (HLL3)	0.975400000
19	Hydraulic Quantity Indicator (HQI)	0.999985081
20	Hose	0.999985081
21	Depressurization Valve (DPV)	0.999985081
22	Non Return Valve (NRV)	0.999985081
23	Moisture Vent Trap (MVT)	0.999985081

9. The LRU mean time to repair, allocated failure rate and allocated dispatch reliability were fed to the master calculation sheet and the LRU predicted dispatch reliabilities were calculated.
10. The design decision was undertaken at this stage for all LRUs. The right-hand hydraulic sub-system methodology design decision output is shown in Table 3.

The design decisions were based on the LRU dispatch reliability comparison process. This is a process that compares the predicted and allocated dispatch reliability, and if the predicted dispatch reliability is equal or greater than the allocated dispatch reliability, it is categorised by the tag 'GOOD', as the design meets the required target. If not, it is categorised by the tag 'Try again', the design methodology process returns to Step 4, where a solution will be sought and the methodology steps repeated.

3.3 Validation results

The right and left-hand hydraulic sub-systems on the aircraft were identical, thus the results were identical.

In an ideal situation, when dispatch reliability, mean time between failures, and mean time to repair are all real and accurate data, the result should show that all LRUs pass the design criteria. This is because their dispatch reliability targets were attained. Any case result was judged against this criterion.

The validation results were calculated by comparing design success percentages on the predicted dispatch reliability, relative to the allocated (required) dispatch reliability. The required, predicted and design success percentage for the four validation cases are presented in Table 4.

In the first validation case, where dispatch reliability and mean time to repair (MTTR) were obtained by prediction, and failure rates were collected from aircraft operator data, the result revealed that all LRUs, except two, passed the design requirement. These were the engine driven pump (EDP) and depressurisation valve. The success of the design methodology can be calculated as the percentage of the predicted dispatch reliability, relative to the required reliability. The resulting design success percentage for the first case was 99·96%. This is an encouraging result as it used predicted MTTRs, combined with real failure data.

In the second and third cases, all the three variables were real field data from aircraft operators. For case b, the results showed that only one LRU failed to pass the design criteria. This was the engine driven pump (EDP) and the design success percentage for this case was 99·973%.

The engine driven pump (EDP) and the hose item failed the design criteria for Case c. The design success, however, was more than 99·968%.

As expected, both of the above cases gave very good results, as they used the best possible data sources.

On the last validation case, four LRUs failed to meet the design criteria. These were the engine driven pump, aircraft motor pump, heat exchanger, and the warning light (HQI). The design success was about 99·93%. This gave the worst predictions, as expected, because it used predictions for MTTR and only generic reliability data. Nevertheless, this performance is more than adequate for initial design purposes.

4.0 DISCUSSION

The data collection was a very difficult and time-consuming task. Airlines vary in their reporting practices and in the completeness of their reports, and many airlines do not keep an organised and ready to use record of the MTBF, MTBUR & MTTR.

Detailed information about aircraft sub-system failure rate is very scarce and operators usually report failure rates by individual LRU and not for the entire sub-system. It was observed that considerable scatter occurred in the published aircraft failure rate data, and significant knowledge is essential in the selection of suitable data.

Mean time to repair (MTTR) prediction was performed using MIL472[14]. This was created many years ago, but because it deals with human capability, which that has not changed, it is still a suitable method to predict MTTR. However, the use of this technique needs considerable experience of the users, in order to produce rational predictions.

The methodology was designed to be used by aircraft system designers who have adequate knowledge about their components, thus reasonable engineering judgment is expected.

The methodology is workable using either MTBUR or MTBF and it is to the user's discretion to choose either of them.

Computer aided design programs can be of great help to the designer in many ways. In particular, they enable designers to assess component maintainability features that affect component mean time to repair (Fig. 3). This will allow them to improve their design to achieve better MTTR.

https://doi.org/10.1017/S0001924000001251 Published online by Cambridge University Press

Table 3
Right-hand side hydraulic sub-system methodology design output (case 1)

No.	LRU	Failure Rate per hour	MTBF	MTTR (Hr)	Predicted Dispatch Reliability	Allocated Dispatch Reliability	DESIGN DECISION
1	Hand Pump	0.00002	50000.00	0.47	0.9999905	0.999985	GOOD
2	Reservoir Fill Selection Valve (RFSV)	0.00003	35714.29	0.40	0.9999889	0.999985	GOOD
3	Pressure Valve (PV)	0.00003	35714.29	0.40	0.9999889	0.999985	GOOD
4	Reservoir	0.00000	7692307.69	1.01	0.9999999	0.999985	GOOD
5	Non Return Valve (NRV)	0.00003	37037.04	0.47	0.9999874	0.999985	GOOD
6	Engine Driven Pump (EDP)	0.00005	20833.33	0.76	0.9999637	0.999985	Try again
7	Non Return Valve	0.00003	37037.04	0.47	0.9999874	0.999985	GOOD
8	Aircraft Motor Pump (ACMP))	0.00001	121951.22	1.71	0.9999860	0.999985	GOOD
9	Non Return Valve	0.00003	37037.04	0.47	0.9999874	0.999985	GOOD
10	Pipe	0.0000014	714285.71	0.92	0.9999987	0.999985	GOOD
11	Pump Overheat Light (POL1)	0.00007	14064.70	0.69	0.9999508	0.996200	GOOD
12	Pump Overheat Light (POL2)	0.00007	14064.70	0.69	0.9999508	0.996200	GOOD
13	Pump Low Light (PLL1)	0.00061	1652.89	0.36	0.9997808	0.996200	GOOD
14	Pump Low Light (PLL2)	0.00061	1652.89	0.36	0.9997808	0.996200	GOOD
15	Heat Exchanger (HEX)	0.00000	892857.14	1.16	0.9999987	0.999985	GOOD
16	Hydraulic Low Light (HLL1)	0.00031	3194.89	0.30	0.9999049	0.975400	GOOD
17	Hydraulic Low Light (HLL2)	0.00031	3194.89	0.30	0.9999049	0.975400	GOOD
18	Hydraulic Low Light (HLL3)	0.00031	3194.89	0.30	0.9999049	0.975400	GOOD
19	Hydraulic Quantity Indicator (HQI)	0.00002	66666.67	0.33	0.9999950	0.999985	GOOD
20	Hose	0.00001	90909.09	0.13	0.9999986	0.999985	GOOD
21	Depressurization Valve (DPV)	0.00011	9345.79	0.15	0.9999836	0.999985	Try again
22	Non Return Valve (NRV)	0.00003	37037.04	0.47	0.9999874	0.999985	GOOD
23	Moisture Vent Trap (MVT)	1.48E-05	67567.57	0.73	0.9999893	0.999985	GOOD

The ASDRDM enables the following activities:

- Aircraft system design optimisation based on the dispatch reliability criterion.
- A comparison method for discrimination between different design options

It can be used for any type of aircraft and is applicable for both civilian and military aircraft, where operational readiness is the criterion for the latter, rather than dispatch reliability.

It should be noticed that the degree of accuracy of the methodology depends on user skill and the accuracy of the data fed into the methodology.

ASDRDM users should always consult maintenance technicians during the component MTTR prediction to benefit from their accumulated experience of maintainability aspects, which can be of crucial important for the ASDRDM effectiveness

The methodology makes provision for a reliability and maintainability trade-off studies by sorting components according to their failure rates. Those components with a high failure rate could be designed with better maintainability characteristics.

It is possible to use the ASDRDM at very early design stages when very little information about the exact number and type of components on sub-system/system is available. This can be achieved by making some assumptions, about these components and implementing the

Table 4
Validation results

Validation cases	No. of Failed LRUs	Required dispatch reliability%	Predicted dispatch reliability%	Success %
Case a	2	99·972*	99·940	99·960
Case b	1	99·976**	99·949	99·973
Case c	2	99·969***	99·938	99·968
Case d	4	99·972*	99·900	99·930

** From the authors' prediction methodology(5)*
*** Actual dispatch reliability data from operator A*
**** Actual dispatch reliability data from operator B*



Figure 3. 3D view of a design(13).

https://doi.org/10.1017/S0001924000001251 Published online by Cambridge University Press

ASDRDM using to them and checking later, when more information becomes available.

ASDRDM is an independent approach that does not rely on confidential data. If such data, are available, results should be more accurate.

In general, a reduction in LRU mean time to repair (MTTR) would reduce it's delay rate, thus dispatch reliability will be improved. However, this is possible only as long as the component MTTR is equal or less than the allocated turn-around time plus 15 minutes. A reduction on MTTR below 15 minutes will not improve dispatch reliability, and the designer should look for other improvement solutions, such as enhancing reliability or/and changing system architecture.

5.0 CONCLUSIONS

- Very few aircraft dispatch reliability design methodologies exist, and they use the comparison technique. They are unable to address dispatch reliability requirements effectively because they depend on old design data to drive the new design, rely on proprietary data that are not available in the public domain, and can be used only for similar aircraft types.
- The developed methodology is a step towards producing better designs for dispatch reliability. The main objective of the methodology was to provide aircraft system designers with an effective design tool that would help them to design and evaluate their designs from the dispatch reliability point of view during the early design stages. The methodology has demonstrated its ability to achieve this objective.
- Several design iterations are considered during the conceptual design phase, thus requiring rapid reliability and maintainability analysis responses, which can be quickly accomplished, in a user-friendly manner, by using the ASDRDM.
- ASDRDM can be used to design for a specific dispatch reliability target for a whole aircraft, or to a specific aircraft system/subsystem.
- ASDRDM can also be used to determine component dispatch reliability, even if there is no defined dispatch reliability target, i.e. it can be used to predict component-level dispatch reliability.
- It is important to set an upper limit for the wished-for dispatch reliability. This is to prevent over-specifying dispatch reliability, which can increase the design project costs dramatically.
- ASDRDM allows quantitive investigation of three design approaches to reliability and maintainability. The first of these is fault avoidance, which involves making failed components more reliable. Secondly, fault tolerance, which involves introducing redundancy for the failed components. Third, improving the maintainability characteristics of the failed components, thus reducing the mean time to repair (MTTR). A trade-off study between the above three solutions should be conducted and the most cost-effective solution should be chosen.
- ASDRDM accuracy relies very heavily on the dispatch reliability, failure rate, and MTTR data and efforts should be exerted to find most accurate possible set of data and avoidance of seasonal variations.

6.0 RECOMMENDATION FOR FUTURE WORK

- The developed ASDRDM should be extended into a computer program that contains a library of component failure rates, MTTRs and dispatch reliabilites. It needs to incorporate RELEX or similar software to benefit from their capability. The recommended software should have some visual demonstration capability to enable designers to assess maintainability characteristics. The proposed additional software will further speed up the design process and improve the accuracy of the methodology.
- Design solutions that would improve an item's dispatch reliability are likely to have cost implications, and require careful selections of available design solutions. Further research should be conducted into the cost implications of alternative design solutions and results incorporated into ASDRDM.
- Given that maintainability is major driver for dispatch reliability, more research should be undertaken to improve maintainability predictions, using the latest available techniques such as 3D simulations.

REFERENCES

1. *Charter Airline Delay Summer 2002*, 2003, Air Transport Users Council (AUC), UK.
2. *Comparison Procedure Direct Maintenance Cost: A300-A310*, 1981, Airbus Industries, France.
3. *Approaching Gridlock: Air Traffic Control Delays*, 1999, Air Transport Association of America (ATA), USA.
4. Flight delay, 2002, American Bureau of Transportation Statistics, available at http://www.bts.gov/programs/international/.
5. BINEID, M. and FIELDING, J. Development of civil aircraft dispatch reliability prediction methodology (V75), *Aircr Eng and Aerospace Tech*, 2003, UK.
6. BINEID, M. Aircraft Systems Design Methodology and Dispatch Reliability Prediction, 2005, PhD thesis, Cranfield University, UK.
7. BLACKMORE, D. and GEORGIADES, S. MD-80 Service Maturity Program, 1986, Proceeding from Annual Reliability and Maintainability Symposium, IEEE, USA.
8. BLANCHARD, B.S. *Maintainability: A Key to Effective Serviceability and Maintenance Management*, 1995, John Wiley & Sons, USA.
9. BOYD, J.A. Allocation of Reliability Requirements: A New Approach, 1992, Proceeding from Annual Reliability and Maintainability Symposium, IEEE, USA.
10. Summary statistics, 2002, Bureau of Transportation Statistics (BTS), available at http://www.bts.gov/ntda/oai/SummaryStatistics/.
11. *Condition Monitored Maintenance: an Explanatory Handbook*, 1978, CAP 418, Civil Aviation Authority (CAA), UK.
12. *Statistics on Punctuality of Flight*, 2003, Civil Aviation Authority (CAA), UK.
13. CATIA Image Gallery, 2005, Dassault Systems, available at http://www.3ds.com/.
14. *Maintainability Prediction*, 1966, Military handbook MIL-HDBK-472, Department of Defense, USA.
15. ELLIOTT, G.A. *Designing to Achieve Reliability and Maintainability*, 1985, The Institution of Mechanical Engineers, UK.
16. *Aircraft Delays*, 2004, Eurocontrol (European Organisation for the Safety of Air Navigation).
17. *Costs of Air Transport Delay in Europe*, 2000, Eurocontrol (European Organization for the Safety of Air Navigation).
18. HOWE, D. *Aircraft Conceptual Design Synthesis*, 2000, Professional Engineering Publishing, UK.
19. GAILLARD, W. *A Review of the Air Transport Industry*, 2003, International Air Transport Association (IATA), Canada.
20. JENKINSON, L., SIMPKIN, P. and RHODES, D. *Civil Jet Aircraft Design*, 1999, Arnold, UK.
21. METH, M. and GREENE, K. The operational readiness: the reliability and maintainability connection, 1984, Proceeding from Annual Reliability and Maintainability Symposium, IEEE, USA.
22. MOUBRAY, J. *Introduction to Reliability-Centred Maintenance*, 1997 Second Edition, Butterworth-Heinemann, UK.
23. OMARI, N. The Measurement and Control of Airline Fleet Dispatch Reliability, 1980, unpublished PhD thesis, Cranfield University, UK.
24. Relex, 2003, Relex Software Corporation, available at http://www.relex-software.com.
25. Non-electronic parts reliability data, 1995, NPRD-95, Reliability Analysis Centre, USA.
26. SCHOLZ, D. Aircraft systems-reliability, 2002, Mass, Power and Costs, European Workshop on Aircraft Design Education, Germany.
27. *Reliability Engineering and Management*, 1999, The International Society of Logistics, UK.

https://doi.org/10.1017/S0001924000001251 Published online by Cambridge University Press