ICAS-88-2.11.3

A Reliability and Maintainability Prediction Method for Aircraft Conceptual Design

by

V C SERGHIDES AND J P FIELDING

College of Aeronautics
Cranfield Institute of Technology
Cranfield, Bedford, MK43 0AL, UK

ABSTRACT

Increasing emphasis is being placed on the R & M of every new aircraft. This is particularly pronounced for combat and commercial aircraft. Stringent in-service R & M targets are included in their design specifications. It is generally accepted that attainment of the set targets is only possible by a rigorous design effort during the earliest stages of a new aircraft project.

This is because each design has an inherent maximum limit of reliability. The design, development and production phases must ensure the attainment of this valve. Any improvements beyond the limit are only possible by re-design, which is usually very expensive.

Many methods are available to predict R & M,once the design has reached the detailed stage, but this may be too late. Many design decisions will have been taken which may "lock" the design into a configuration which has a lower inherent reliability and maintainability then required.

Methods for predictions and allocating targets for systems and sub-systems at the earlier conceptual design stage are limited. There is thus a need for a technically valid and effective quantitative R & M prediction methodology for the conceptual aircraft design process, capable of projecting realistic estimates for every main aircraft system, from which acceptable targets could be derived.

This paper presents a methodology, which was developed at the College of Aeronautics, to alleviate the existing problems. It can be used in harmony with other fundamental conceptual design methods and it is based on a number of statistically derived empirical equations, which predict the R & M of each main aircraft system, from one or two aircraft design parameters per system. These parameters are both technically and statistically related to the system concerned, and directly available at the conceptual stage. Each equation is individually adjusted for advances in the system-related technology by a statistically derived factor.

Repeated application of the methodology for several combat aircraft and jet airliners, showed a very high predictive ability, technical validity and wide applicability. Examples are show in the paper together with their use in on Operations Simulation model for close air support aircraft.

1. INTRODUCTION

Stringent reliability and maintainability targets are included in modern aircraft specifications, the attainment of which is only possible by good design.

Figure 1 shows a useful illustration of how R & M performance might vary during the design, development and production phases of a project.(1) Each design has a maximum inherent level of R & M, which will not be exceeded in the process shown, except by significant, usually expensive, re-design. Initiation of a rigorous effort is therefore required in the earliest stages of a new aircraft programme to incorporate all the desirable design features and assure attainment of the set targets. A valid quantitative reliability and maintainability prediction methodology is therefore essential.

Two distinct methods are required. The first is an empirical, statistical technique for use during the conceptual design process, when little is known of design details. This method would be used to predict system and overall reliability targets, for use in subsequent analysis, and is the main part of this paper.

The design, operation and maintenance of combat aircraft is vastly different from those of civil transport aircraft. It was decided that the best approach would be to develop two separate, but similar methods for each class. The methodologies described by Serghides(2) are summarised in Fig 2 and subsequent paragraphs.

The second requirement is for a tool which will model aircraft reliability and maintainability at a later design stage. This should be used to periodically predict the achieved performance levels during the design process and determine how these compare with targets. This work will not be described here, but is shown in several Cranfield publications:-

Fielding and Meng(3) give an example of the reliability modelling for flying controls of a military aircraft. Serghides and Fielding(4) show a similar example of reliability modelling a training aircraft oxygen system. Serghides and Fielding(5) show the maintainability modelling for a military aircraft. Fielding and Hussein(6) describe the reliability modelling of systems on a civil transport aircraft. Additional work has been performed by Burleigh and Fielding(7) to produce an operations simulation model for combat aircraft, incorporating R & M inputs, together with predictions of attrition. Some initial work has been carried out in reliability modelling of a Space Launcher Vehicle by Mantzavinatos(8).

2. RELIABILITY PREDICTION METHODOLOGY FOR USE IN CONCEPTUAL DESIGN

The civil aircraft dispatch reliability method of Fielding(9) was computerised, but will not be described here. The method shown is for combat aircraft.

Defect Data Collection

The availability of published confirmed defect rate data for combat aircraft is very limited, as these are usually restricted for reasons of National Security. The development of accurate prediction equations however, demands the use of valid operational data, collected from a large aircraft inventory over a long period of time. The inclusion in the sample of a large number of aircraft types is also highly desirable because it offers a wider range of aircraft design parameters for correlation with mature aircraft defect rate data.

The selection of the aircraft sample for this study was therefore largely governed by the availability of data and the above mentioned considerations. It includes a total of nine jet combat aircraft types of various different roles. The following aircraft were finally selected: A bomber (B1), two fighters (F1 and F2), two attack aircraft (A1 and A2), two advanced trainers (ATR1 and ATR2), which are also used in the light attack role, the reconnaissance version of the Crusader, the RF-8G and the A-7E Corsair. Ref 10 was used to obtain data for the latter two aircraft, whilst the former aircraft are not identified, for security reasons.

All US data, for each aircraft system, are tabulated according to the Work Unit Code (WUC) classification system. This is significantly different from the classification system used by the other air force. It was therefore essential to establish compatibility of the data before mixing them together for statistical analysis. This was achieved by devising an acceptable method of conversion of one system to the other. The complete aircraft was divided into several subsystems which were allocated to eight main system groups. The first of these groups includes all the aircraft mechanical systems. The author decided that it would be most appropriate for aircraft design work to divide the mechanical systems group into seven main systems and to exclude completely the last group for the reconnaissance systems which comprises special mission equipment, not available on every aircraft.

A further 6 system groups were added to these to give the 13 shown in table 1.

The WUC system divides the complete aircraft into 32 systems. During the conversion, these were carefully allocated to the 13 systems.

Initial Analysis

Engineering judgment was used to determine the likely range of aircraft parameters which would affect reliability. These parameters had to be ones which would be available at the earliest stage of conceptual design. The final list parameters was:-

Design Parameter	Notation	Units
1. Altitude (maximum)	H_{max}	m
2. Gross Wing Area	A_w	m²
3. Crew (number)	N_c	-
4. Internal Fuel Capacity	F_c	lts
5. Mach Number	M	-
6. Engines (number)	N_e	-
7. Total Thrust (Maximum)	T_t	KN
8. Hardpoints (number)	N_h	-
9. Guns (Number)	N_g	-
10. Payload (maximum)	W_p	Kg
11. Maximum Take-Off Weight	MTOW	Kg
12. Empty Weight	W_e	Kg
13. Combat Radius	R_c	Km

Two correlation analyses were carried out, initially, to investigate the existing correlation between the defect rate data of each aircraft with each one of the design parameters. In the first analysis a linear variation was assumed between defect rates and each design parameter. In the second analysis the variation was assumed to be exponential. A total of 338 correlations were investigated during these first two analyses. This was made possible by a special computer program developed by the author for this purpose. The program calculates the correlation coefficient, the standard error of estimate and the rank for each one of the 169 combinations of defect rates and design parameters.

A multicollinearity analysis was then carried out by a computer program which correlated the design parameters, above, with each other and calculated the correlation coefficients and standard errors of estimate. This is basically a linear correlation analysis, aiming to determine which of the aircraft design parameters may be expressed mathematically as an approximate linear function of ther design parameters. When a strong correlation exists between parameters, then these are considered as statistically equivalent and the use of both parameters in the same equation is mathematically redundant, as both would make approximately the same contribution to the predictive ability of an equation.

The following parameters exhibited high correlation:

Correlated Parameters	Correlation Coefficient
A_w with F_c	0.9957
A_w with MTOW	0.9896
A_w with W_e	0.9799
F_c with MTOW	0.9916
F_c with W_e	0.9874
MTOW with W_e	0.9967

This analysis therefore suggested that several design parameters were redundant and that they could be omitted to improve computational efficiency.

Selection of Final Design Parameters

The object was to identify which of the thirteen design parameters were both statistically and technically associated with each different aircraft system. The whole process was based on the following important criteria:

(i) The selection of a maximum of two parameters, on an engineering judgment basis. The one, should indicate the size of the system concerned and the other should be relevant to factors affecting the system reliability.

(ii) The selection of those parameters with the highest possible correlation coefficients and lowest standard errors of estimate. This may be based on the results of a linear or exponential variation depending which one offers the best fit.

(iii) The results of the multicollinearity analysis should be observed.

Table 1 shows the parameters that were selected, on the above basis. An example of the engineering choice of parameters is that of Flying Controls:-

COMPLEXITY - Crew (number) - This reflects the increased complexity which is introduced in aircraft with dual flying controls. N_c is therefore a system complexity indicator.

SIZE - Gross Wing Area - The size and number of flying control surfaces is usually proportional to the wing area, therefore A_w may be regarded as a size factor.

Computer-generated scatter diagrams were produced for each system and each parameter. Fig 3 shows a typical diagram for the Flying Controls.

The Prediction Equations

It was decided to use the above parameters in equations for each system of the form:

$$Y = b_o + b_1 X1 + b_2 X2$$

where

Y = system defect rate

$X1, X2$ = the first and second best-correlated design parameters for the particular system.

b_o, b_1, b_2 = constants

The values of X1 and XZ are those shown in table 1 and the constants were obtained from a multiple regression analysis. The final rates for all systems were summed to give the scatter diagram shown as figure 4, for the whole aircraft, after applying technology/improvement factors for each system (see below).

Technology/Improvement Factors

The degree of technology improvement incorporated in an aircraft obviously depends on the existing state of the art at the time at which the aircraft was designed. However, the degree of improvement is not the same for all aircraft systems. Considerable advances have been made in the design of some systems with significant improvements in reliability while in some others the progress made was relatively small. Some improvements also accrue from operating crew learning and reliability improvement modifications. A computer program was written which evaluated all the basic prediction equations and compared the predicted system defect rates with the actual system defect rates for each aircraft in the sample. The program used linear correlation analysis and gave the Technology/Improvement Factors (TIF) for each system as:-

$$TIF = a_o + a_1 Y_r \quad .... (2)$$

Where a_o and a_1 are constants derived for each system and Y_r is the time in years between 1952 and first flight date for the aircraft being analysed.
It must be said, however, that the correlation coefficients for the TIFs are generally not as good as those for the basic equations. This is due to limited data, and should be improved in the future. The overall accuracy, however, is good, as shown later.

3. MAINTAINABILITY PREDICTION METHODOLOGY FOR USE IN CONCEPTUAL DESIGN

Method for Combat Aircraft

The maintainability prediction method for military aircraft was developed in a similar manner to that for reliability in para 2, above. The measure of maintainability was taken to be direct maintenance manhours per flying hour. The method involved isolation of 12 system parameters applicable to maintenance. Regression analysis, collinearity and technology/improvement factors were again derived. The results shown fully in Serghides and Fielding, (11) but fig 5 shows the accuracy of predictions for complete aircraft and has a correlation coefficient of 0.82.

Method for Civil Transport Aircraft

Data. The object of the aircraft sample selection procedure was to select a sample, comprising a number of different jet airliner types or even different models of the same type, for which mature maintainability data were available from airline service experience.

The finally selected sample, consisted of seventeen Western jets, passenger aircraft ranging from 707 to A300 and 747. No cargo or turboprop aircraft were included in this study.

The original data came from a number of airlines which will remain unidentified for confidentiality reasons and also from a number of airframe manufacturers who provided estimates, based on the feedback received from customer airlines, over the years.

The maintainability data used in this study are for the airframe systems only. No information was available on APUs or powerplants, largely because these items are not standard on each aircraft, but differ according to individual customer choice.

The maintainability data are reported either in terms of man-hours per flying hour (MH/FH) or man-hours per flight cycle (MH/FC) for each aircraft system, according to the ATA 100 scheme. It was decided that it would be more appropriate for this study, to express all data in terms of MH/FH. Therefore all MH/FC data were converted to MH/FH, by considering the average flight cycle duration which was reported together with each set of data. Also, some other data which were expressed in MH per block were converted to MH/FH.

Selection of Final Design Parameters

The selection was done in a similar manner to that for military aircraft reliability so will not be repeated. It included regression analysis of the airframe data, collinearity and technology/improvement factor derivation. The chosen system parameters are shown in table 2, along with their accuracy. The abbreviations are:-

1.	Wing Span	h
2.	Overall length	l_o
3.	Overall height	h_o
4.	Tailplane span	b_1
5.	Wheel track	w_1
6.	Wheel base	w_b
7.	Cabin length	l_c
8.	Cabin width	w_c
9.	Cabin height	h_c
10.	Freight-hold volume	V_{fr}
11.	Gross wing area	A_w
12.	Empty operating weight	W_e
13.	Payload	W_p
14.	Maximum take-off weight	MTOW
15.	Landing weight	W_L
16.	Maximum cruise speed	V_{er}
17.	Cruise altitude	H_{er}
18.	Range(with maximum fuel)	R_a
19.	Total thrust	T_t
20.	Engines (number)	N_e
21.	Passengers(Maximum number)	N_p
22.	Total fuel capacity	F_c
23.	Approximate cabin volume	$l_c x w_c x h_c$
24.	Cruise mach number	M_{cr}

The final maintainability equations were obtained by simply multiplying the basic maintainability prediction equations with their corresponding TIFs. For example, for the Equipment/Furnishings,

$$MH/FH = (-1.3934 + 0.6634 \times 10^{-4} \times R_a + 0.2085 \times 10^{-2} \times N_p) \times (1.2620 - 0.1988 \times 10^{-1} \times Y_r) \quad ....(3)$$

Where Y_r is the time in years between 1959 and the date of the aircraft model first flight:

Figure 6 shows the accuracy of the method for the types of aircraft used in the data sources.

4. VALIDATION

Combat Aircraft

Three classified aircraft were used for the validation of the R & M prediction methodology for combat aircraft. The ATR2, F2 and A3. The R & M data for the ATR2 are more recent than those used in the sample for the same type of aircraft. The recent data are mature and therefore more suitable for this purpose. The F2 is the latest version of the type used in the sample and the corresponding R & M data are again recent. No version of the A3 was previously included in the aircraft sample. Results were:-

Aircraft Type	% Error (DR)	% Error (MNHR)
ATR2	3.3	13.0
F2	-1.8	-29.2
A3	-17.5	-18.8

The ATR2 gives the best overall results because it has now reached maturity. The F2 however, has ageing problems which adversely affect its DMHR and hence the prediction error.

The A3 was a new aircraft which, at the time of the validation data, had not reached a mature performance level. Current levels are much closer to our predictions.

Civil Aircraft

Only the MD-80 and Boeing 757 and 767 were used for validation, as no other independent data were available. Our method does not predict the maintainability of engines and APU, but information was available for an estimate of these to be made for the MD-80. This was added to the airframe prediction for this aircraft and gave a prediction error of -10.9% for maintenance hours per flying hour and -13.1% for dispatch reliability.

British Operators of the Boeing 757 and 767 gave current figures for the dispatch reliability, but were unable to supply suitable maintenance figures. The results were:-

	Actual	Predicted
Boeing 757	98.5	98.09
Boeing 767	98.41	98.39

The figures are not totally consistent because the prediction method assumed delays to be classified as greater than 15 min. whilst the airlines use a criteria of 3 and 5 min. The distribution of delay times, however, shows that this error is usually very small.

5. EXAMPLE OF THE USE OF THE METHOD

The subject of the 1987/8 student design project was the S-87 close air support aircraft shown in Fig 7.

The whole design process started with the conceptual design of the aircraft, by members of staff, in the summer of 1987. This work was summarised in Ref 12 which was given to the 28 students in October of that year. Each student was given responsibility for the detail design, stressing and fatigue analysis of components such as forward fuselage, outer wing, tail etc. Some students designed mechanical systems such as fuel, flying controls, engine installations etc.

The large numbers of student meant that we were able to give students responsibility for design of the weapon system, avionics installation, reliability, maintainability, survivability, aero-electricity and performance. The Cranfield group project is unique in the level of staff preparation, allowing more detailed work by students then in group projects elsewhere.

The project was managed to a demanding 8 month programme by means of weekly project meetings, where students reported progress, received advice and instructions for subsequent work. The most important function of these meetings was that of a forum where design conflicts were resolved.

The programme ended in May, 1988 with the submission of large project theses which contained descriptions of the designed components, supporting analysis, drawings, CAD plots, Finite Element results, FMECA results, etc. Some 200 engineering drawings and 5000 pages of text were produced.

The design for R & M and surviveability was carried out by all the students, but overall responsibility for achievement of targets was given to the students specialising in these fields. M & R targets were given for the aircraft by use of the methods outlined in this paper, in terms of confirmed defects per 1000 hours and direct maintenance manhours per 1000 flying hours. R & M modelling was performed for each system and vulnerability analysis carried-out for the entire aircraft. This information was fed into the operation simulation model of ref 7. This model was used to keep count of the number of attack sorties flown and the number of aircraft ready to fly additional sorties.

Operation Simulation data being already available for the Fairchild A-10, the aim of this work was to obtain similar information about the S-87 CAS operations, so that the performance of the two aircraft could be compared, (under similar conditions).

For the purposes of this comparison, the operations of an initial fleet of 24 aircraft, of each kind, were observed over a conflict period of 10 days, to establish the total number of sorties generated by each fleet, and to find the respective numbers of aircraft available at the end.

Assuming a 12-hour flying day, a 24-hour maintenance day, and given average sortie times for the S-87, together with turn round times a maximum of 12 sorties per day was calculated. The Fairchild A-10 being slower than the S-87, would only generate 9 sorties a day, for the same combat radius.

The model output can be provided in several forms but the most convenient was found to be a table giving the "end of day" values of serviceability and cumulative sortie generation, with additional output of the number of aircraft that would be available for use on the day after the deployment is terminated or end of battle (Fig 8). Vulnerability calculations gave a 5% and 3% attrition for the A-10 and S-87, maximum respectively.

Given the respective A-10 and S-87 payloads of 7.26 T and 4.22 T, the number of sorties viz 426 and 736, and assuming that maximum payload was dropped on each sortie, one can easily calculate the total payload delivered as 3093 and 3106 T, respectively.

More of the S-87 aircraft survive to the end of the 10 day period. Furthermore, although on day one there is not a very substantial difference between the two fleets, it grows progressively larger in favour of the S-87, because of its higher survival rate. Thus the longer the conflict, the more significantly this factor will come into play, and greater the payload delivery of the S-87 will be. The greater number of sorties also increases the possible number of targets that may be attacked.

Two other factors in favour of the S-87 are that its superior field performance allows closer basing to the battle area and improved avionics allows more operations at night, or in bad weather. These factors are not allowed for in the results shown.

6. DISCUSSION

The development of the R & M prediction equations for Combat Aircraft and Jet Airliners represents an enormous analysis.

A large number of computer programs were developed specifically for this analysis. An equally large number of associated input data files were also created. A total of 2500 correlations were performed between the R & M data and design parameters.

All the aircraft used in the development of equations were mature. This is important because these aircraft exhibit constant R & M rates which can be used with confidence during the analysis. The R & M targets set in a modern aircraft specification refer to the mature rates and therefore the developed equations are intended for the prediction of these constant rates. The number of aircraft types used in the development of each set of equations was sufficient in all cases, but it was always limited by the availability of suitable data.

The aircraft design parameters which were finally selected for use in the equations are both technically and statistically related to the R & M of the systems concerned. It was discovered in several cases that the best design parameters were not always the directly obvious ones. This led to a better understanding of the factors which influence the R & M of each aircraft system.

The developed R & M prediction methodology is applicable to a wide spectrum of aircraft, defined by the types of aircraft which were included in the sample during the development of the prediction equations. Therefore, the methodology is specifically suitable for bombers, fighters, attack aircraft and advanced trainers. Only basic trainers and cargo aircraft are excluded from this spectrum. The civil method is only suitable for turbojet or turbo-fan powered aircraft. Propeller driven aircraft would need to have a similar method derived from suitable data.

The use of R & M prediction and modelling in the operation simulation model gives a very good guide to the effectiveness of combat aircraft. Such programs are also useful teaching tools to show the relevant importance of the major aircraft parameters.

7. CONCLUSION

The predictive ability of the final prediction equations is generally high. Application of the equations to aircraft in the sample yielded predictions which are strongly correlated with the actual R & M rates. Application of the equations to other aircraft for validation purposes yielded good results, particularly for the reliability of combat aircraft.

The selected design parameters are all directly available at the conceptual design stage. All the predictive equations project realistic estimates of mature R & M rates and they are therefore suitable for R & M targets allocation at aircraft and system levels, during the conceptual aircraft design process.

The integration of R & M predictions into an Operations Simulation Model gave a good idea of operational effectiveness at a very early stage in the design process. Similar methodologies should be developed for classes of aircraft other than those currently covered.

8. REFERENCES

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NO.	AIRCRAFT SYSTEM	TYPE OF VARIATION	1st DESIGN PARAMETER			2nd DESIGN PARAMETER		
			SYMBOL	COR.COEFF.	STD.ERROR	SYMBOL	COR.COEFF.	STD.ERROR
1.	Air Conditioning	Lin.	N_e	0.7469	7.0468	W_e	0.7043	7.5229
2.	Flying/Operational Controls	Lin.	N_c	0.7494	11.3826	A_w	0.6086	13.6406
3.	Fuel System (Airframe)	Exp.	N_e	0.6859	0.5150	T_t	0.6101	0.5608
4.	Hydraulic Power & Pneumatics	Exp.	N_e	0.5931	0.4434	T_t	0.5726	0.4515
5.	Alighting/Arrestor Gear	Lin.	W_p	-0.5528	75.3194	-	-	-
6.	Oxygen	Exp.	H_{max}	0.4374	0.2876	N_c	0.4129	0.2913
7.	Misc. Utilities (Mechanical)	Lin.	M	0.6121	12.8701	-	-	-
8.	Structure Systems	Lin.	N_e	0.8926	54.5932	W_e	0.8312	67.3146
9.	Propulsion Systems	Exp.	T_t	0.6345	0.3830	N_e	0.5967	0.3976
10.	Armament Systems	Lin.	N_h	0.7420	93.3592	M	0.6626	104.3043
11.	Tactical Avionic Systems	Lin.	MTOW	0.7344	67.5198	R_c	0.5297	84.3807
12.	Navigation & Comms. Systems	Lin.	T_t	0.8558	24.5224	R_c	0.7270	32.5437
13.	Electrical & Instrument Systems	Lin.	H_{max}	0.6263	78.1947	M	0.4171	91.1596

TABLE 1 - SYSTEMS AND DESIGN PARAMETERS - COMBAT AIRCRAFT RELIABILITY

ATA CHAPTER	AIRFRAME SYSTEM	TYPE OF VARIATION	1st DESIGN PARAMETER			2nd DESIGN PARAMETER		
			SYMBOL	COR.COEFF.	STD.ERROR	SYMBOL	COR.COEFF.	STD.ERROR
21	Air Conditioning	Lin.	MTOW	0.6197	0.1048	l_o	0.6188	0.1049
22	Auto-Flight	Lin.	R_a	-0.4450	0.5097	MTOW	-0.3256	0.5381
23	Communications	Lin.	N_p	0.8577	0.0754	h_o	0.7782	0.0921
24	Electrical Power	Lin.	w_c	0.6906	0.1322	T_t	0.6123	0.1446
25	Equipment/Furnishings	Exp.	R_a	0.6379	0.4871	N_p	0.6278	0.4924
26	Fire Protection	Lin.	W_p	0.7810	0.0126	T_t	0.6795	0.0148
27	Flight Controls	Exp.	V_{cr}	0.4275	0.9308	$l_c x w_c x h_c$	0.2163	1.0052
28	Fuel	Exp.	R_a	0.5608	0.6018	b	0.4759	0.6392
29	Hydraulic Power	Lin.	$l_c x w_c x h_c$	0.7411	0.0537	W_p	0.7317	0.0545
30	Ice & Rain Protection	Exp.	w_c	0.5518	0.6990	W_e	0.3978	0.7690
31	Instruments	Lin.	H_{cr}	-0.2388	0.0242	V_{cr}	0.1369	0.0246
32	Landing Gear	Exp.	W_p	-0.3487	0.4289	-	-	-
33	Lights	Exp.	R_a	0.5617	0.8024	h_o	0.5520	0.8086
34	Navigation	Lin.	MTOW	0.8661	0.1004	h_o	0.7962	0.1215
35	Oxygen	Exp.	h_c	0.4742	0.8688	l_o	0.3743	0.9151
36	Pneumatics	Lin.	H_{cr}	0.4081	0.0578	N_p	0.3396	0.0596
37	Water/Waste	Exp.	w_c	0.5553	0.5818	W_e	0.4987	0.6064
51-7	Structure	Lin.	w_t	0.7965	0.4833	W_e	0.7874	0.4927

TABLE 2 - SYSTEMS AND DESIGN PARAMETERS - CIVIL MAINTAINABILITY

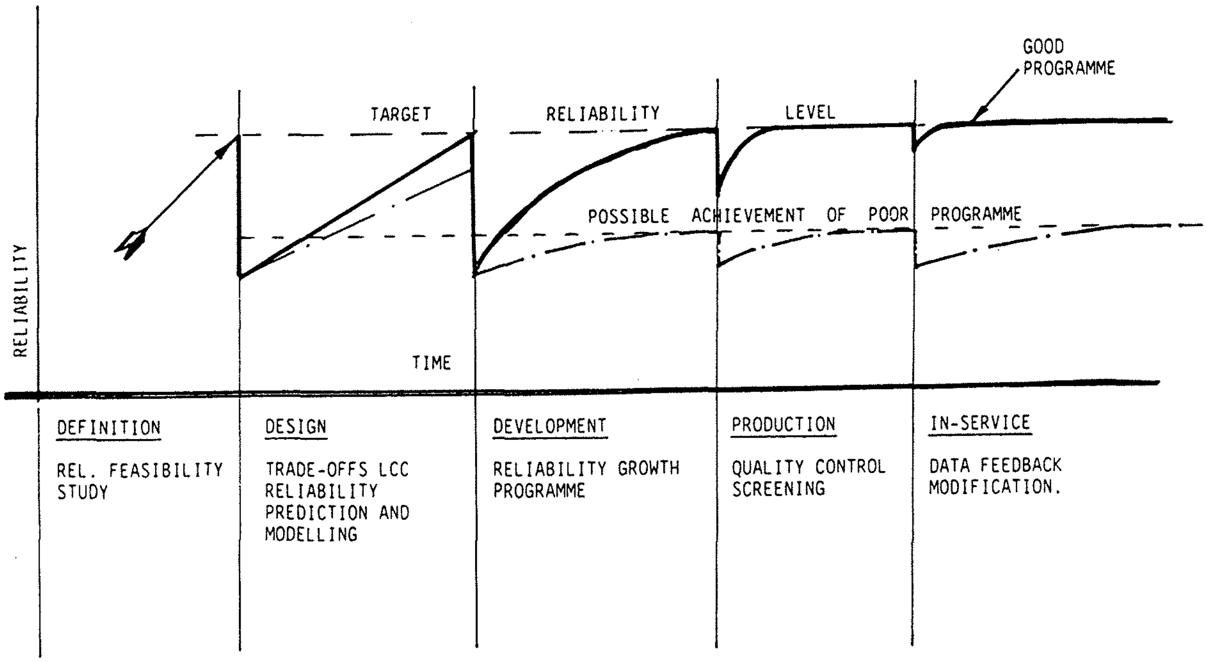

FIG. 1 RELIABILITY ACTIVITIES DURING PRINCIPAL PROJECT PHASES

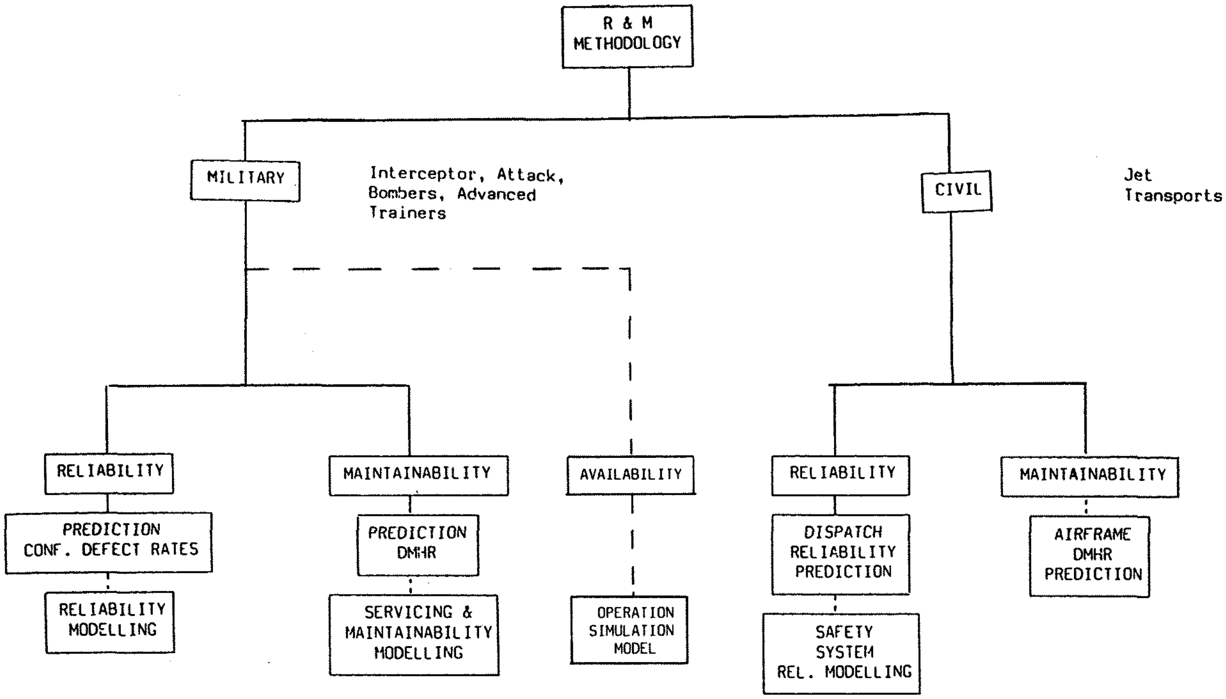

FIG 2 OVERALL RELIABILITY AND MAINTAINABILITY METHODOLOGY

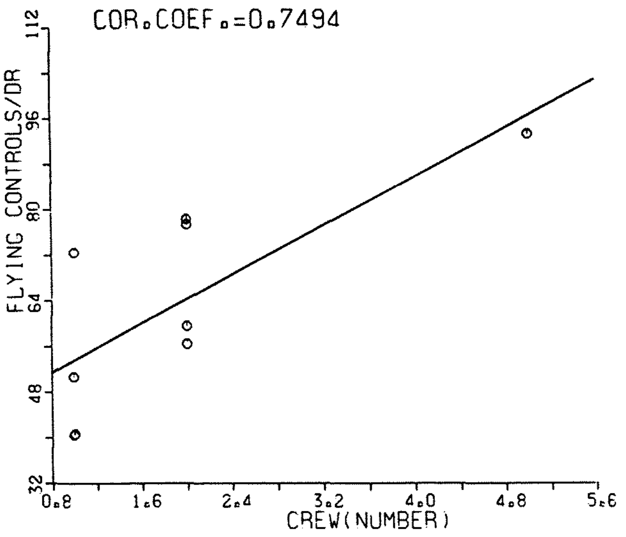

FIG 3. SCATTER DIAGRAM COMBAT AIRCRAFT-
FLYING CONTROLS RELIABILITY

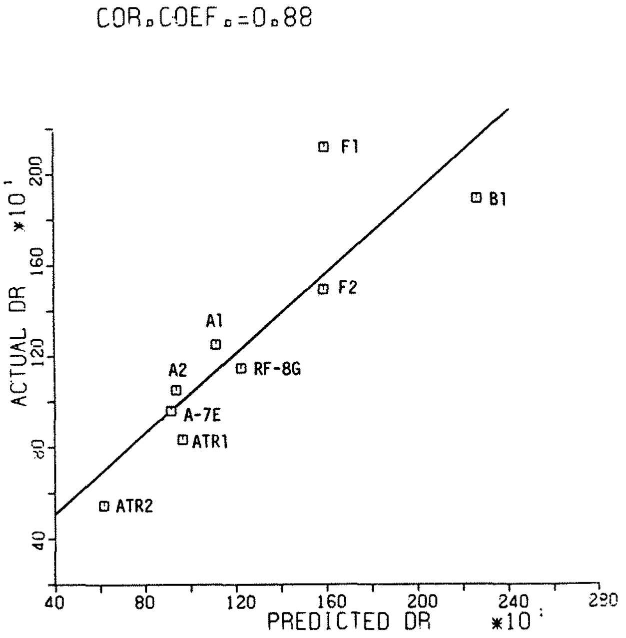

FIG 4. COMBAT AIRCRAFT OVERALL RELIABILITY

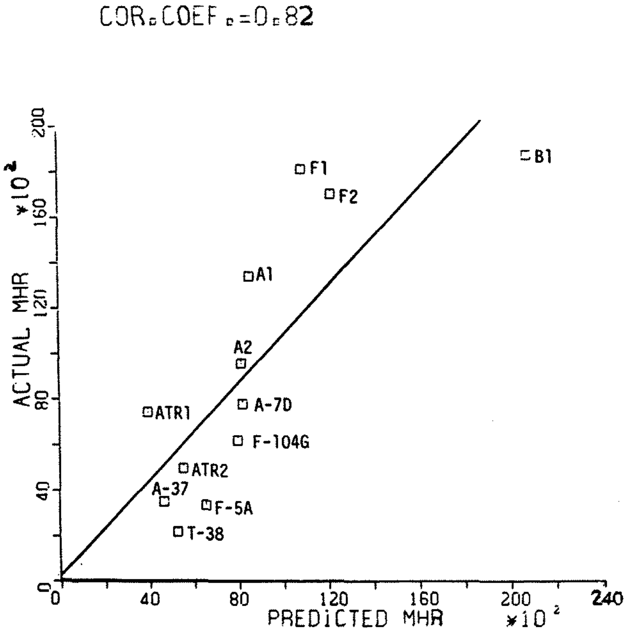

FIG 5. COMBAT AIRCRAFT OVERALL MAINTAINABILITY

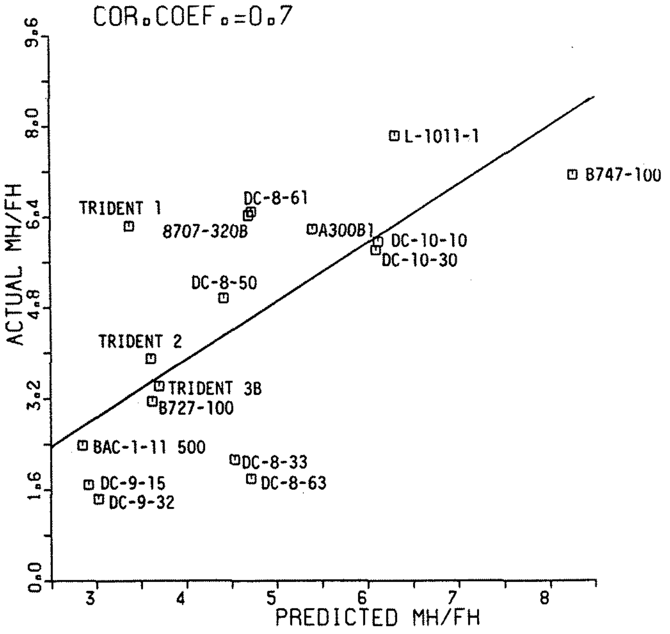

FIG. 6. TRANSPORT AIRCRAFT AIRFRAME MAINTAINABILITY

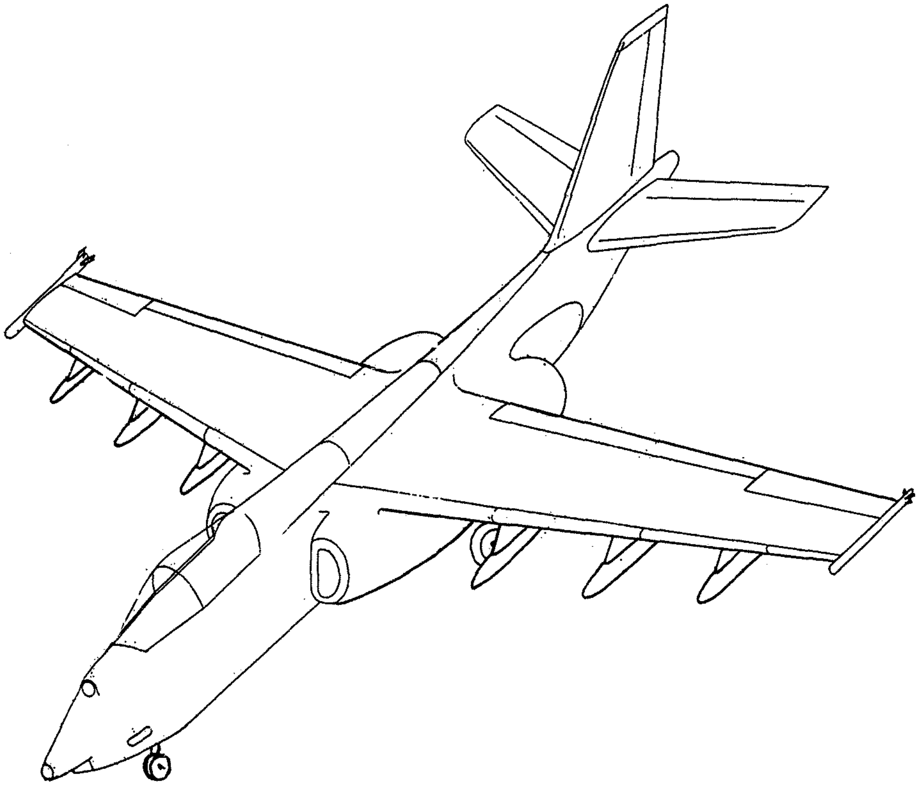

FIG 7. S-87 CLOSE AIR SUPPORT PROJECT

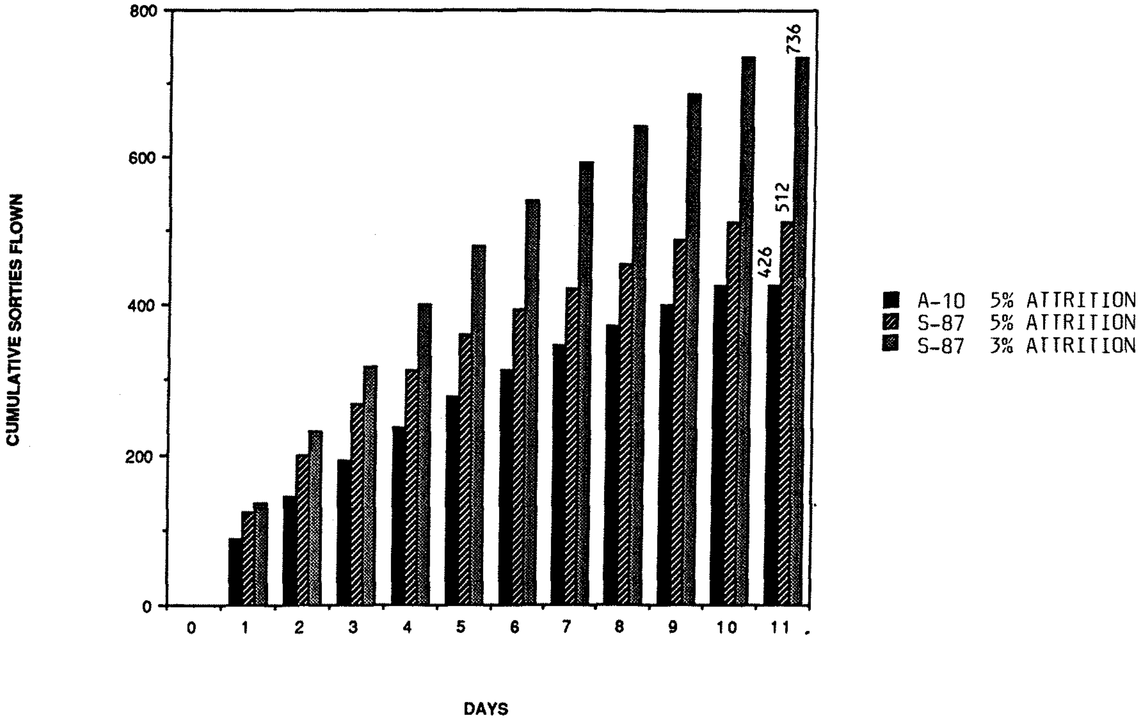

FIG 8. RESULTS OF OPERATION SIMULATION MODEL RUNS
(INITIAL FLEET OF 24 AIRCRAFT)