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R.A.P.I.D. MODEL: AN AGUSTA/WESTLAND METHODOLOGY TO DERIVE RELIABIITY TARGETS OF THE EH101 BY INTEGRATION OF APPORTIONMENT AND PREDICTION PROCESSES

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ABSTRACT

During the Product Definition of the EH101 (the new project of a long range, large capacity helicopter jointly undertaken by AGUSTA and WESTLAND) the joint R.& M. Working Group felt the necessity of a methodological rationalization of the activities carried out to derive feasible targets and which are nowadays run in a non-organic fashion.

The R.A.P.I.D. (Reliability Apportionment and Prediction: an Integrated Derivation) was so developed and adopted as a standard procedure.

The model is an integration of two techinques adopting two different types of logic:

- TOP DOWN logic for the derivation of individual reliability figures (I.R.F.) from global reliability figures (G.R.F.);
- BOTTOM UP logic for the derivation of G.R.F. from I.R.F.

The two different pairs of reliability figures are then compared and the process fed back in order to derive appropriate reliability targets.

The main result of the R.A.P.I.D. model application has been the improvement of Reliability visibility and design feed-back during all the phases of the project.

1. INTRODUCTION

A feasibility study to derive design targets must be carried out having in mind what is possible as well as what is desirable or required.
This implies a comparison between what is known (and therefore possible) and what is desirable or required but not proved to be feasible within cost constraints. Clearly before a comparison can be made, it is essential to have the two components to compare.

In the case of the reliability requirements of a helicopter the two components to be considered during the comparison process are of very different types which can be assembled into two groups:-

GROUP A GLOBAL RELIABILITY FIGURES (G.R.F.) from the aircraft reliability requirements, i.e., aircraft logistic M.T.B.F., aircraft mission reliability, aircraft safety.

GROUP B INDIVIDUAL RELIABILITY FIGURES (I.R.F.) from past experience, i.e., equipment M.T.B.F. or failure rate.

Therefore, it becomes necessary to obtain two pairs of numbers from the above groups, as follows:-

(i) COMPARABLE NUMBERS to make a comparison between G.R.F., the first taken directly from Group A and the second derived from Group B.

(ii) COMPARABLE NUMBERS to make a comparison between I.R.F., the first derived from Group A and the second taken directly from Group B.

Intuitively, the derivations introduced above are obtained from the type of logic:-

(i) TOP DOWN logic for the derivation of I.R.F. from G.R.F.

(ii) UP logic for the derivation of G.R.F. from I.R.F.

The above approach is depicted in figure 1, where the trees represent any appropriate deductive (TOP DOWN) or inductive (BOTTOM UP) technique.
The aim of this paper is to present an integration of two of these techniques and the relationship between them in order to derive appropriate reliability targets.
This integration has been formalized in the R.A.P.I.D. Model (Reliability Apportionment and Prediction: an Integrated Derivation) during the Product Definition of the EH101 (the new project of a long range large capacity helicopter jointly undertaken by AGUSTA and WESTLAND) and adopted as a standard procedure.

2. DESCRIPTION OF THE R.A.P.I.D. MODEL

The overall logic flow of the R.A.P.I.D. model is illustrated in figure 2. It can be seen from the figure that the model is split into three main processes as follows:-

(i) The Top Down Reliability Apportionment Process, which makes use of current aircraft information (i.e., requirements, datum mission, preliminary sub-system architecture etc.) and "value analysis" techniques.

(ii) The Bottom Up Reliability Predictions Process which makes use of conventional reliability prediction and modelling techniques.

(iii) The Comparison, Assignment and Feedback Process which provides the final outputs, and controls the whole model by continuous comparison, feedback and optimisation of the variables involved.

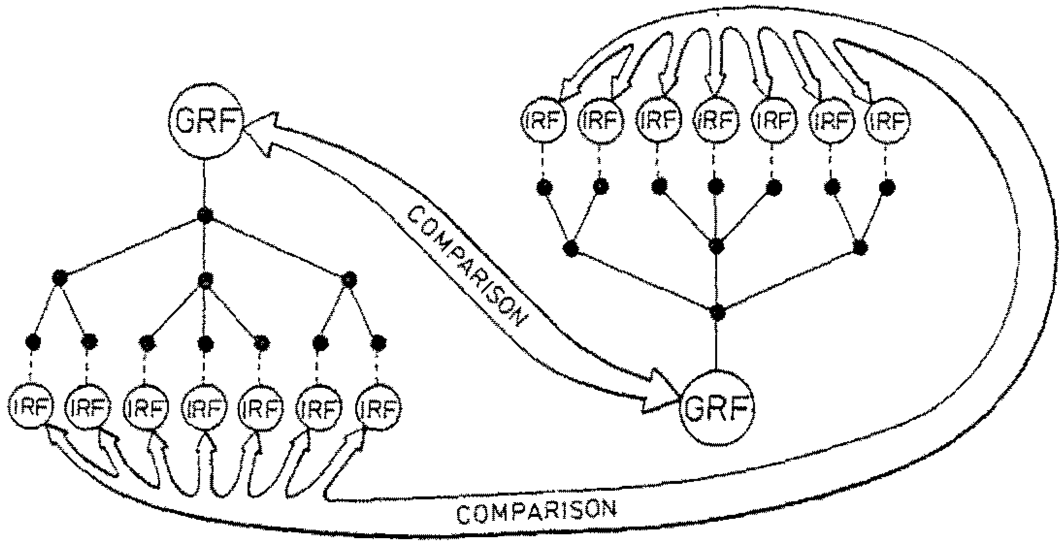
In the following paragraphs the logic flows of these three main processes are described in more detail. The general terms "system", "sub-system" and "unit" are used throughout to indicate any one of the following sets:-

(i) "aircraft", "aircraft systems" and "equipments";

(ii) "aircraft system", "equipments" and "units";

(iii) "equipment", "units" and "modules".

This convention is adopted because the same processes are repeated at all levels. The difference existing to the general flows are indicated in the text when necessary.



PICTORAL REPRESENTATION OF THE TOPDOWN - BOTTOM UP APPROACH

FIGURE 1

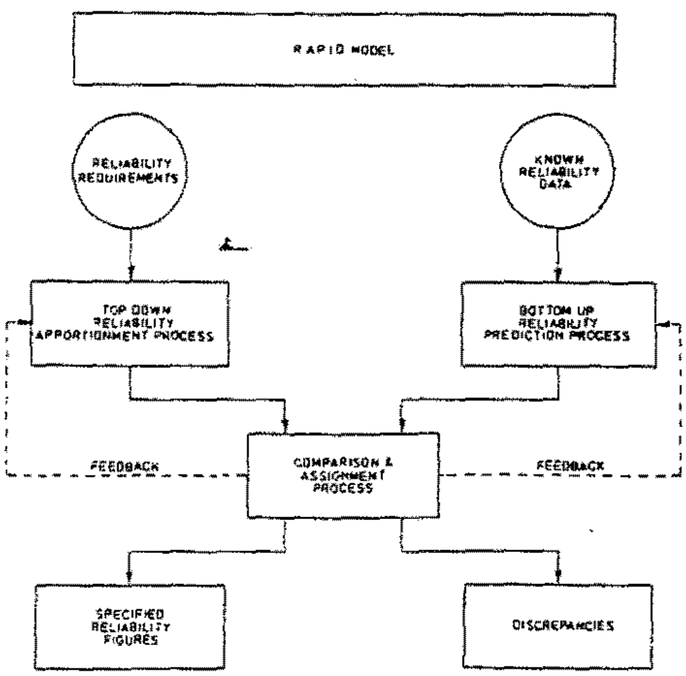


FIGURE 2

2.1 TOP DOWN RELIABILITY APPORTIONMENT PROCESS

The logic flow of the apportionment process is illustrated in figure 3. The explanation of each block is given below:-

Block 1 Primary Inputs

Beside the reliability requirements (system logistic M.T.B.F., system mission reliability and system safety requirements), data concerning both system architecture and mission profile (*), provide inputs to the process.

Block 2 Secondary Inputs

Starting from the datum mission and system architecture (primary performance inputs), a set of parameters and tools that bound the problem are derived as follows:-

(i) Duty Cycles - to take into account the different utilisation of each sub-system throughout the mission.

(ii) Operational Reliability Configuration - to take into account both the functional and reliability inter-relationship between the sub-systems involved in each phase of the mission.

(iii) Importance Factors - to take into account the criticality of each sub-system throughout the mission.

(iv) Complexity Factors - to take into account the hardware content of each sub-system relative to that of the system.

(*) In this context, by the expression mission profile is intended to indicate a composite reference mission that includes all possible eventualities without overlap between them. This may, of course, not necessarily be a realistic mission.

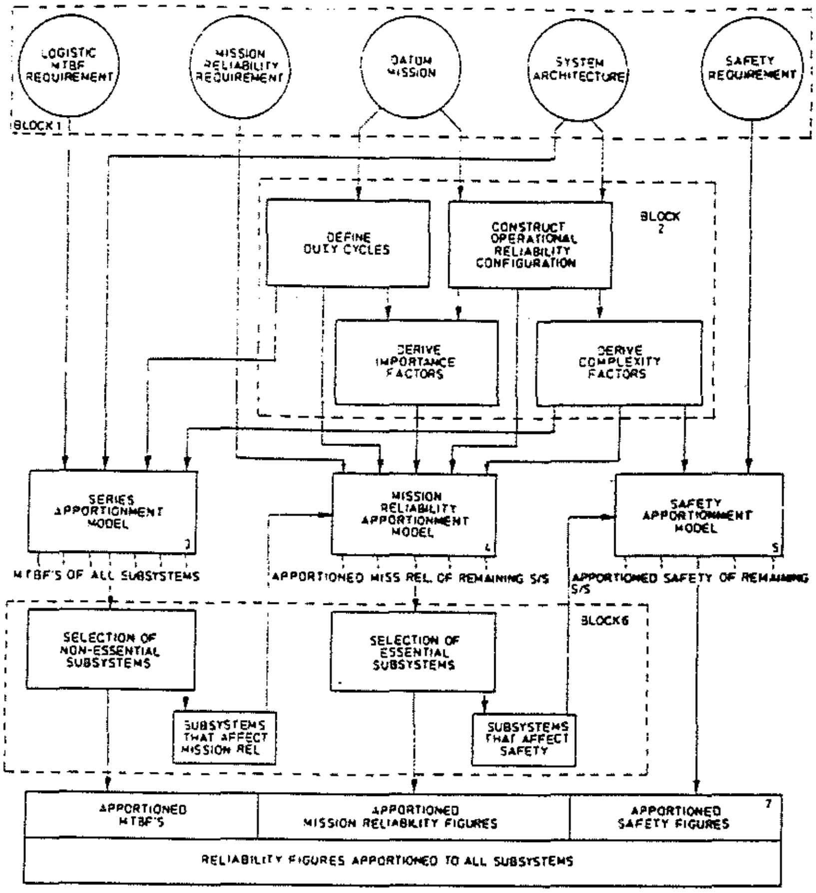


FIGURE 3

FUNCTION No

FUNCTION No	1	2	3	4	5	6	7	8	9	10
1	X									
2		X								
3			X							
4				X						
5					X					
6						X				
7							X			
8								X		
9									X	
10										X

FIGURE 4

DATE ____________________

COMPILED BY______________

DEPARTMENT______________

SIGNATURE _______________

The informations required to proceed with the construction of the operational reliability configuration are datum mission and system architecture.

The construction is performed by the following steps:-

1. Divide the mission into phases.
2. Define basic sub-systems (functions) which are required to perform the datum mission.
3. Select from the above sub-systems two groups:-
   (i) ESSENTIAL - for mission reliability modelling purposes.
   (ii) CRITICAL - for safety modelling purposes.
4. Define which sub-systems are required for each phase.
5. Relate units to each sub-system.
6. Construct reliability block diagram for each sub-system.
7. Construct reliability block diagram for each phase.
8. Define all limiting assumptions made in the construction of the model.

Steps 2 to 5 are performed in collaboration with the Design Department and flight personnel using an appropriate consensus method.
A possible format for the reliability block diagram is given in column 5 of table 1.

The sub-system importance factor is defined as the probability that the system will fail to accomplish its mission if the sub-sytem fails while all others are satisfactory.
Because a finite value for this probability is not known, it is necessary to make an estimate based on the behaviour of the system and its sub-systems.
In order to avoid a single point estimate it is essential to use a method which minimises the subjectivity. This is achieved using VALUE ANALYSIS techniques.

The approach used in the model is illustrated by the following steps:-

1. Compile a comparison matrix as illustrated in figure 4 with sub-systems (functions) listed in both rows and columns.

2. Formulate the appropriate question (consistent with the definition) to compare each function with each other. This is the most important step of the procedure because the credibility of the results depends upon how the question is formulated.

3. By asking the above question to a consistent number of suitably experienced people fill each square of the matrix with one of two mutually exclusive responses.

4. Compute from all the completed matrices a score for each function.

5. List the functions in order of score.

6. Delineate between critical and essential functions, and essential and non-essential functions.

7. Construct the importance factor assignment diagram as illustrated in figure 5.

8. Assign an importance factor to each function from the diagram.

Block 3 Series Apportionment Model

A first apportionment concerning the system logistic M.T.B.F. requirement is performed to sub-system level as defined in the system architecture, and weighted according to complexity factors and duty cycles.
It is performed using the AGREE allocation model:-

$$\hat{\lambda}_j = \lambda \frac{C_j}{r_j}$$

where

$\hat{\lambda}_j$ is the apportioned failure rate of the j^{th} sub-system.

λ is the system failure rate requirement.

C_j is the sub-system complexity factor.

r_j is the sub-system duty cycle.

Block 4 Mission Reliability Apportionment Model

A second apportionment, concerning the system mission reliability requirement, is performed considering the sub-systems (with their redundancies) that affect the mission reliability and safety. This different apportionment is necessary because the most significant figure in this case is the probability of successfully completing the mission without a mission failure.
It is carried out in two different ways depending upon the level of apportionment:-

(i). At the lowest level using the mission reliability apportionment model derived from the operational reliability configuration.

(ii) At all other levels using the AGREE allocation model:-

$$\hat{R}(t_j) = \frac{1 - [R(T)]^{C_j}}{E_j}$$

where

$\hat{R}(t_j)$ is the apportioned reliability of the j^{th} sub-system over t_j operating hours (*).

$R(T)$ is the system mission reliability requirement over time T.

C_j is the complexity factor of the j^{th} sub-system.

E_j is the importance factor of the j^{th} sub-system.

T is the overall length of the mission.

t_j is the operation time of the j^{th} sub-system.

(*) This figure, which is a function of duty cycles, must be corrected to an equivalent figure reflecting the total mission time by using Bayesian Techniques.

Block 5 Safety Reliability Apportionment Model

A third apportionment concerning the system safety requirement is performed in the same way as the mission reliability apportionment, but taking into account only those sub-systems that affect safety. This further apportionment is necessary because the most significant figure in this case is probability of successfully completing the mission without a critical failure.

Block 6 Selection of Appropriate Reliability Figures

The appropriate reliability figures are selected and assigned in the following priority:-

(i) Apportioned logistic M.T.B.F. to those sub-systems that only affect the logistic M.T.B.F. requirement.

(ii) Apportioned mission reliability only to those sub-systems that affect the mission reliability requirement, but not safety.

(iii) Apportioned safety only to those sub-systems that affect the safety requirement.

This block is not applicable to the apportionment of the aircraft reliability requirements to aircraft sub-systems (i.e., avionics, power plant etc.), as each of these must have a requirement for all three apportionment figures associated with it.

Block 7 Outputs

Appropriate apportioned reliability figures for all sub-systems are obtained.

2.2 BOTTOM UP RELIABILITY PREDICTION PROCESS

The logic flow of the prediction process is illustrated in figure 6. The explanation of each block is given below:-

Block 1 Inputs

Beside unit failure rates, based on past experience or taken from technical literature, data concerning both system architecture and mission profile provide inputs to the process.

Block 2 Definition of Reliability Configuration

Starting with the datum mission and system architecture, the different phases of the mission are defined and the sub-system utilisation during each mission phase established.
The system operational reliability configuration for each mission phase is now constructed taking into account both functional and reliability inter-relationships between sub-systems (Table 1).

Block 3 Series Model

A simple series model is used to predict the system logistic M.T.B.F. starting with unit failure rates (λ_i):-

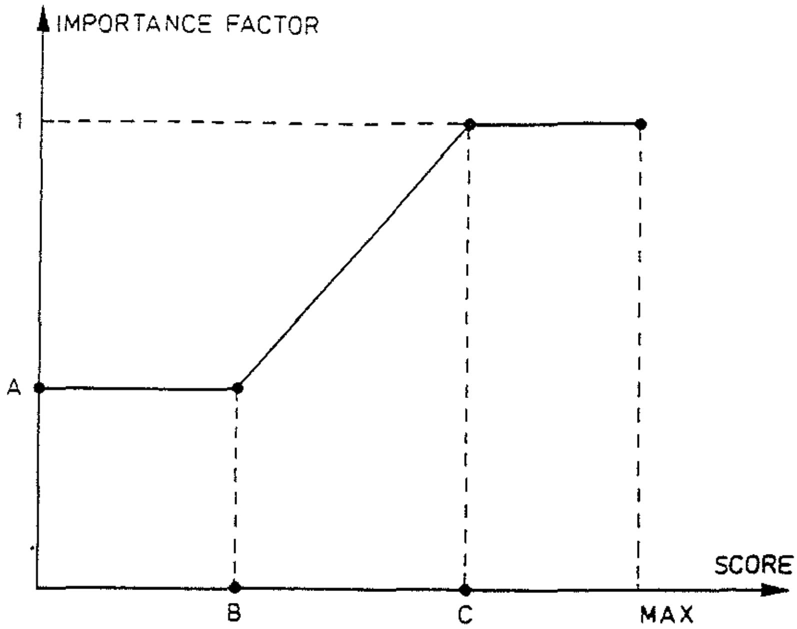
$$\text{M.T.B.F.}_{\text{System}} = \frac{1}{\sum_{i=1}^{n} \lambda_i}$$

where n is the number of subsystems.

Block 4 Mission Reliability Model

Starting from the reliability configuration of each phase and the unit failure rates, the system mission reliability is predicted using the model:-

$$R_H(T) = \prod_{i=1}^{n} R_{PHi}(t_i) = \prod_{i=1}^{n} \left[\prod_{j=1}^{k_i} R_j(t_i) \right]$$



A: MINIMUM ESTIMATED IMPORTANCE FACTOR TO BE ASSIGNED TO NON CRITICAL FUNCTIONS.

B: MAXIMUM SCORE ACQUIRED BY A NON ESSENTIAL FUNCTION

C: MINIMUM SCORE ACQUIRED BY A CRITICAL FUNCTION

FIGURE 5

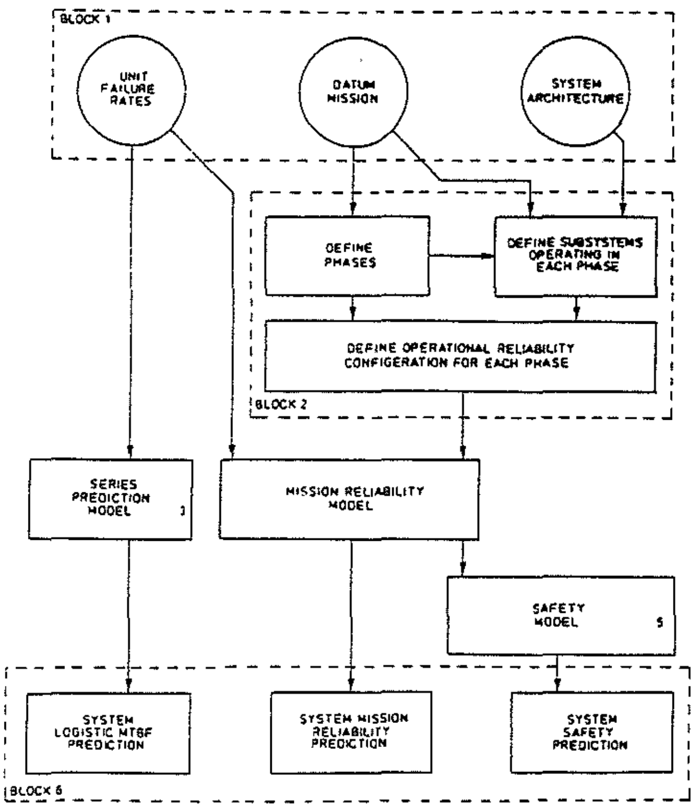


FIGURE 6

where

$R_M(T)$ is the probability of the system successfully completing a mission of T hours without a mission failure.

$R_{PM_i}(t_i)$ is the probability of successfully completing a mission up to the end of the i-th phase without a mission failure.

$R_j(t_i)$ is the reliability of j-th syb-system over ti hours.

T is the length of the misssion.

t_i is the elapsed time up to the end of the i-th phase.

n is the number of mission phases.

K_i is the number of sub-systems involved in i-th phase.

Block 5 Safety Model

The system safety is predicted in the same way as the mission reliability, but taking into account only those sub-systems which affect safety (i.e., those which are designated critical), using the modified model:-

$$S(T) = \prod_{j=1}^{k} R_j(T)$$

where

$S(T)$ is the probability of the system successfully completing a mission of T hours without a critical mission failure.

$R_j(T)$ is the probability of the j-th sub-system successfully completing a mission of T hours without a critical failure.

k is the number of critical sub-systems.

Block 6 Outputs

The predicted logistic M.T.B.F., mission reliability and safety is obtained for the system.

2.3 COMPARISON AND ASSIGNMENT PROCESS

The logic flow of the comparison process is illustrated in figure 7. The explanation of each block is given below:-

(1) No.	(2) SUBSYSTEMS (FUNCTIONS)	(3) UNITS	(4) CRITICALITY NOT ESS.	ESS.	CRIT.	(5) MISSION (... HOURS) PHASE # 1 (... Hr)	PHASE # 2 (... Hr)	PHASE # 3 (... Hr)	(6) FAILURE RATE (F/10[6] Hr)	(7) SUBSYSTEM RELIABILITY PHASE # 1 t = ... HOURS	PHASE # 2 t = ... Hr	PHASE # 3 t = ... Hr	(8) PREDICTION (RF's
1	SUBSYSTEM 1	UNIT # 11	•										
2	SUBSYSTEM 2	UNIT # 21	•										
		UNIT # 22	•										
		UNIT # 23	•										
3	SUBSYSTEM 3	UNIT # 31		•									
		UNIT # 32		•									
4	SUBSYSTEM 4	UNIT # 41		•									
		UNIT # 42		•									
N	SUBSYSTEM N	UNIT # 1			•								
		UNIT # 2			•								
		UNIT # 3			•								
								TOTAL					

TABLE 1

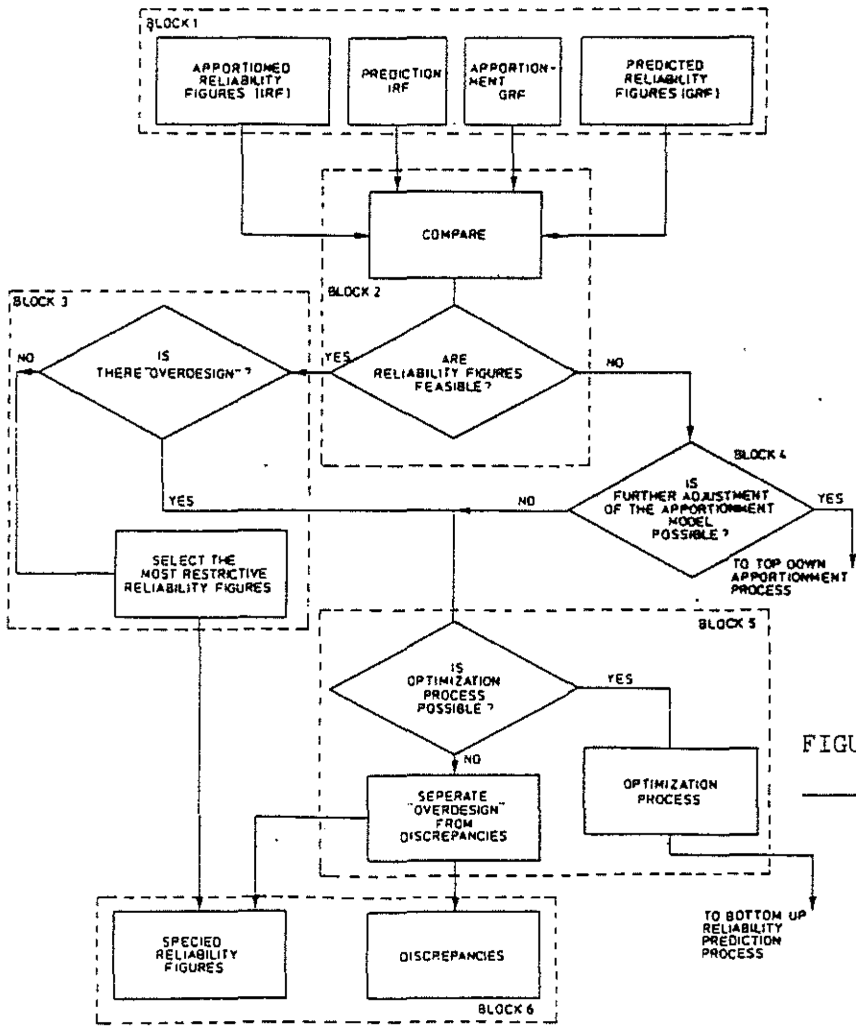


FIGURE 7

Block 1 Inputs

The inputs and outputs (I.R.F. and G.R.F.) of the two previously described processes provide the inputs to the comparison and assignement process.

Block 2 Comparison

From a critical assessment of the two comparable figures obtained from the TOP DOWN and BOTTOM UP processes a decision as to the feasibility of the reliability requirements is made.

Block 3 Selection

Depending upon a "feasible" decision and there being "no overdesign", the most restrictive between the APPORTIONED and PREDICTED reliability figure is selected and assigned to each sub-system.

Block 4 Top Down Feedback

Depending upon a "not feasible" decision a feedback process on the apportionment model is carried out until "saturation" of the model is reached.

Block 5 Bottom Up Feedback

Depending upon the "saturation" of the apportionment model or the identification of "overdesign" and subject to data on other system constraints (i.e., weight, cost etc.) being available, an optimisation of the system configuraiton is carried out and then fed back to the prediction model.

Block 6 Outputs

Appropriate reliability figures for reliability specification purposes, or any discrepancies which require further agreement are obtained. By the word "appropriate" is meant any figure either directly evolving from the model or in any other suitable for (i.e., M.T.B.F., failure rate or probability).

3. CONCLUSIONS

Making a decision presents a very difficult problem when a number of incomparable parameters are involved because of the potentially wide range of possibilities.
On one extreme is a completely subjective decision which is very easily made, but the result is completely dependent upon the quality and experience of the "decision maker".
On the other extreme is a completely objective decision which is very difficult to make, but the result does not depend upon a particular "decision maker".
Therefore, in order to be realistic but at the same time not stray too far from the optimum it is necessary to strike a balance between the two extremes and to find tools which as far as possible make use of the good points of both, i.e., the speed and relatively small data requirement of the first and the high reproducibility and confidence in the results of the second.

The method described in this paper acknowledges the above considerations by using a coherent structure containing:-

(i) Objective mathematical models.

(ii) Tools which minimise the subjectivity of inputs based on personal judgement.

A further benefit of this model is that by the integration of two very different logical processes, a higher degree of confidence can be placed in the result.
Finally the main result of the R.A.P.I.D. model application to the EH101 programme has been the improvement of reliability visibility and design feedback during all the phases of the project.