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A DISCUSSION PAPER
REGARDING THE AVAILABILITY CONCEPT
IN AIRCRAFT APPLICATIONS

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A Discussion Paper Regarding
the Availability Concept
in Aircraft Applications

CONTENT

- 0 INTRODUCTION
- 1 AVAILABILITY AND RELATED CONCEPTS
 - 1.1 Definitions
 - 1.2 The relation between Operational Availability and Operational Readiness
 - 1.3 The relation between Operational Availability and Dispatch Reliability
- 2 THE ROLE OF AVAILABILITY IN SYSTEM EFFECTIVENESS
- 3 THE PATTERN OF DEMAND FOR SYSTEM OPERATION - A FACTOR OF CRITICAL IMPORTANCE
- 4 AVAILABILITY AND MISSION RELIABILITY
 - 4.1 Operating conditions
 - 4.2 Mission Adapted Operational Availability
 - 4.3 How mission reliable is an available aircraft?
 - 4.4 The significance of Preventive Maintenance and Test
- 5 AVAILABILITY, UTILIZATION AND RESOURCE - DEPENDENCE
 - 5.1 Aircraft utilization affects downtime
 - 5.2 Availability and its resource dependence
 - 5.3 Availability - dependence on number of aircraft
 - 5.4 Number of aircraft unavailable for different reasons
- 6 LIFE CYCLE COST IMPLICATIONS
- 7 THE ROLE OF AVAILABILITY IN SYSTEM DESIGN
- 8 THE ROLE OF AVAILABILITY IN SYSTEM OPTIMIZATION
 - 8.1 Sparing to availability
 - 8.2 Resourcing to system - effectiveness
 - 8.3 Designing to system - effectiveness
 - 8.4 Optimized Availability
- 9 REFERENCES
- APPENDIX 1

0 INTRODUCTION

This paper was written in order to stimulate a discussion of the Availability concept, with the final objective of making it more useful in our efforts to create cost-effective systems.

Basic definitions of availability seen in literature, are very often given the following (or quite similar) form (ref 1) "the probability that at any point in time the system is either operating satisfactorily or ready to be placed in operation on demand when used under stated conditions". As is pointed out in ref 2 this "...concept of availability was originally developed for repairable systems that are required to operate continuously, i.e. round the clock, and are at any random point in time either operating or are "down" because of failure and are being worked upon so as to restore their operation in minimum time. In this original concept a system is considered to be in only two possible states, operating or in repair".

Such definitions of availability lead to the well known "inherent availability" formula $A = \text{MTBF} / (\text{MTBF} + \text{MTTR})$ where MTBF is the mean time between failures and MTTR the mean time to repair.

The original success of this concept apparently lies in the fact that it relates in a simple manner the two complex design features reliability and maintainability. However, one has to be careful - let us again turn to ref 2: "Thus the availability A does not depend on the actual values of the MTBF or MTTR but only on their ratio. A system with an MTBF of say 4 hr and an MTTR of 1 hr will have the same steady state availability of 80 % as a system with a MTBF of 100 hr and an MTTR of 25 hr.

But from a mission accomplishment viewpoint it may make all the difference whether the system has an MTBF of 100 hr or 4 hr!"

Consequently, an availability requirement should in general be accompanied with a dependability requirement. This aspect is covered in section 2.

In addition it is well known that availability in the above described form is of very limited applicational value for systems of any reasonable complexity which must be capable of alternate modes of operation and operation in different environments of varying demands (see again ref 1).

So therefore a number of questions naturally comes into ones mind which need to be answered in order to make the availability concept useful in our efforts to develop cost effective systems. Some of them are listed below and then in the rest of the paper an attempt has been made to analyse and in some cases also propose solutions to these questions.

- 1) What are the main characteristics and differences from an availability point of view - of military aircraft operations and civil airlines operation?
- 2) How does the concept of "dispatch reliability" used by the airlines relate to the availability concept?

(For example the 1983 airline industry standard glossary WATOG (ref 3), does not even mention the availability concept).
- 3) Availability is normally not a purpose in itself - it has to be incorporated into some kind of "system effectiveness". Which are the most common measures of system effectiveness and what is the role of availability in them?
- 4) The demand for system operations may be limited to certain periods in time. The demands may e.g. occur on either an unscheduled random basis or be well planned long in before.
Availability will thus depend on the demand pattern governing the system operations. How can this dependency be treated explicitly?
- 5) What is the relation between "operational readiness" and "operational availability"?
- 6) The aircraft utilization, that is the no of flying hours produced by a single aircraft per day, will of course have a heavy impact on the aircraft availability - how does it explicitly influence the availability?
- 7) The reason for an aircraft being unavailable is always interesting when choosing the best action to improve the availability.

Is it possible to define availability in such a way that different types of unavailability become visible?
- 8) Lack of maintenance resources e.g. spares causes aircraft logistic downtime and is therefore of primary importance for availability.
Are there any explicit ways to take into account the influence of the resources acquired or recommended on availability?
- 9) Availability can be increased both by investing in more aircraft and in more maintenance resources.
This indicates that within a given budget it should be possible to find a balanced cost-effective mix of aircraft and resources.
In what way is availability dependent on the number of aircraft acquired or recommended?

1 AVAILABILITY AND RELATED CONCEPTS

1.1 Definitions

Let us start with a citation from ref 11, giving the basic well established definitions of availability:

"A. Availability (A). Availability may be expressed in four ways:

- 1 Operational Availability (A_o) is the probability that a system or equipment, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon. It is expressed as

$$A_o = \frac{MTBM}{MTBM + MDT}$$

where

MTBM= mean-time-between-maintenance.

and

MDT= mean maintenance downtime.

MTBM reflects the frequency of maintenance which in turn is a significant factor in determining logistic support requirements. MDT includes active maintenance time, logistics supply time, and administrative delay time.

- 2 Achieved Availability (A_a) is the probability that a system or equipment, when used under stated conditions in an ideal support environment (i.e., available tools, spares, manpower, etc) will operate satisfactorily at any point in time. It excludes logistics supply time and administrative delay time. Achieved availability (A_a) is more directly relatable to the early design process (as a means of measuring equipment reliability and maintainability characteristics) and is expressed as

$$A_a = \frac{MTBM}{MTBM + M}$$

where

M = mean active maintenance time. This includes corrective (unscheduled) and preventive (scheduled) maintenance times.

- 3 Inherent Availability (A_i) is the probability that a system or equipment, when used under stated conditions in an ideal support environment (i.e., available tools, spares, manpower, etc) will operate satisfactorily at any point in time. It excludes preventive maintenance actions, logistics supply time, and administrative downtime and is expressed as

$$A_i = \frac{MTBF}{MTBF + Mct}$$

where

MTBF = mean-time- between-failures

and

Mct = mean corrective maintenance time.

- 4 Availability is a measure of the degree to which an items is in the operable and committable state at the start of the mission, when the mission is called for at an unknown (random) point in time."

In this paper the above definitions are discussed, compared and interpreted with respect to their specific meaning and use in aircraft applications.

As a result of this analysis a new availability measure, called Mission Adapted Operational Availability, is defined. It is recommended as the best definition to use, both for design and development and life cycle cost work.

Furthermore, in the interpretation of the basic definition of Operational Availability, the downtimes due to mission specific preflighting, are recommended to be excluded. The list of availability definitions is therefore expanded with:

- 5 Mission Adapted Operational Availability (A_{oa}) is the probability that a system is not only Operationally Available, but also specifically preflighted for it's intended mission:

$$A_{oa} = A_o - u \cdot TPMS$$

where

A_o is the Operational Availability

u is the average aircraft utilization

TPMS is the average Time for Mission Specific Preflighting

From an applicational point of view it might be useful to add the so called "ready-rate" definition which in all essential is a measure of operational availability.

$$RR = N/N_o = 1 - \frac{NMC}{N_o}$$

where

RR = ready rate

N = average no of operationally ready aircraft at a base

N_o = the no of aircraft assigned to the base

NMC = average no of non mission capable aircraft

Considering ready rate RR as equivalent with operational availability i.e.

$RR = A_o$ yields

$$NMC = N_o \cdot (1 - A_o)$$

which is useful in many contexts.

1.2 The relation between Operational Availability and Operational Readiness

The difference between Operational Availability and Operational Readiness is illustrated in figur 1.2. It is assumed that an aircraft, at any point in time can be found in (at least) one of the states listed in the figure. For each aircraft state and for each availability measure it is indicated by "yes" or "no", whether that state is considered to be an up-state or not.

It can be seen from the figure that an aircraft, in order to be Operationally Available, as a minimum need to be pre-/postflight serviced while not yet being assigned to a mission.

To be Mission Adapted Operationally Available, an aircraft as a minimum has to be not only Operationally Available but also specifically preflighted for it's intended mission.

To be Operationally Ready, however an aircraft as a minimum has to be not only Mission Adapted Operationally available, but also moved into it's take-off position and provided with all the necessary operational resources, including crew.

The three main parties interested in an aircraft system, i.e. the manufacturer, the acquisitioner and the operator, put different interests in the five measures:

Aircraft state:

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The manufacturer naturally will place emphasis in the R&M driven measures A_i , A_a and A_{oa} , even if he also recognizes the impact of Supportability and Logistic Support Effectiveness (S). On the other hand, the operator will be very sensitive to the base operational resources, preflighting and reconfiguration activities, transportations etc. These aspects tend to make him choose the OR, A_{oa} and the A_o measures in his op. requirements analysis and specifications. The operator has a tendency to consider high R&M-performance as a matter of course.

Finally the acquisitioner will be responsible of compromising the operators and the manufacturers interest, taking the budget constraints imposed on the system, into account. He will therefore be forced to consider both the A_a , A_o and the A_{oa} and sometimes all five measures.

Based on the notation of the aircraft states given in fig. 1.2, and the technique described in Appendix 1 the following expressions can be used to calculate the five measures (note that all the times addressed are expressed in hours per flight hour):

$$A_i = 1 - u \cdot \text{TAMC}$$

where

u is the average utilization expressed in flight-hours per duty-hour and aircraft

TAMC and all other time variables are explained in fig 1.2

$$A_a = 1 - u \cdot (\text{TAMC} + \text{TAMP})$$

$$A_o = 1 - u \cdot (\text{TAMC} + \text{TAMP} + \text{TWLRS} + \text{TWAL} + \text{TTRL} + \text{TPPG})$$

$$A_{oa} = 1 - u \cdot (\text{TAMC} + \text{TAMP} + \text{TWLRS} + \text{TWAL} + \text{TTRL} + \text{TPPG} + \text{TPMS})$$

and finally the

$$\text{OR} = A_o - u \cdot (\text{TTRT} + \text{TMNA} + \text{TPMS} + \text{TWORS})$$

The relations between the four measures are (starting with $A_i = 1 - u \cdot \text{TAMC}$):

$$A_a = A_i - u \cdot \text{TAMP}$$

$$A_o = A_a - u \cdot (\text{TWLRS} + \text{TWAL} + \text{TTRL} + \text{TPPG})$$

$$A_{oa} = A_o - u \cdot \text{TPMS}$$

$$\text{OR} = A_{oa} - u \cdot (\text{TTRT} + \text{TMNA} + \text{TPMS} + \text{TWORS})$$

It also holds that

$$0 \leq u \leq \text{OR} \leq A_{oa} \leq A_o \leq A_a \leq A_i \leq 1$$