Metrics, Key Performance Indicators, and Modeling of Long Range Aircraft Availability and Readiness

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ABSTRACT

There are numerous parameters that influence the availability of long range aircraft. In order to develop models evaluating aircraft availability, an understanding of these parameters, along with the corresponding metrics, is required. An analysis of historical data for a modern long range transport aircraft shows that unscheduled organizational-level maintenance and depot maintenance are the largest contributors to downtime. A similar analysis of a legacy long range strike aircraft shows that unscheduled unit-level maintenance is a driver, but also shows that supply delays are a significant contributor to aircraft downtime. Boeing's System Health Operational Assessment Model (SHOAM) is described, along with the results of a case study that identifies maintenance infrastructure as the key drivers for long range aircraft availability.

1.0 INTRODUCTION

"Availability is a measure of the degree to which an item is in an operable state and can be committed at the start of a mission when the mission is called for at an unknown (random) point in time."[1] There are numerous parameters that influence the availability of long range aircraft. These parameters, which can be categorized into those associated with aircraft design, maintenance infrastructure, and operations, are defined along with their associated metrics. An analysis of historical data is provided to gain insight into availability drivers. Finally, a Boeing developed model that can be used to determine the sensitivity of availability to various parameters is described along with the results of a case study that identifies the key parameters for long range aircraft availability.

2.0 PARAMETERS AND METRICS

In simplest terms, availability is calculated by dividing system up time by total time. However, as seen in Figure 1, there are many components of system downtime that affect availability. Each of these components has a set of associated parameters and metrics that must be understood in order to calculate aircraft availability. These parameters can be categorized into those associated with aircraft design, maintenance infrastructure, and operations.

$$Availability = \frac{Up\ Time}{Total\ Time} \quad or \quad \frac{Total\ Time - Down\ Time}{Total\ Time}$$

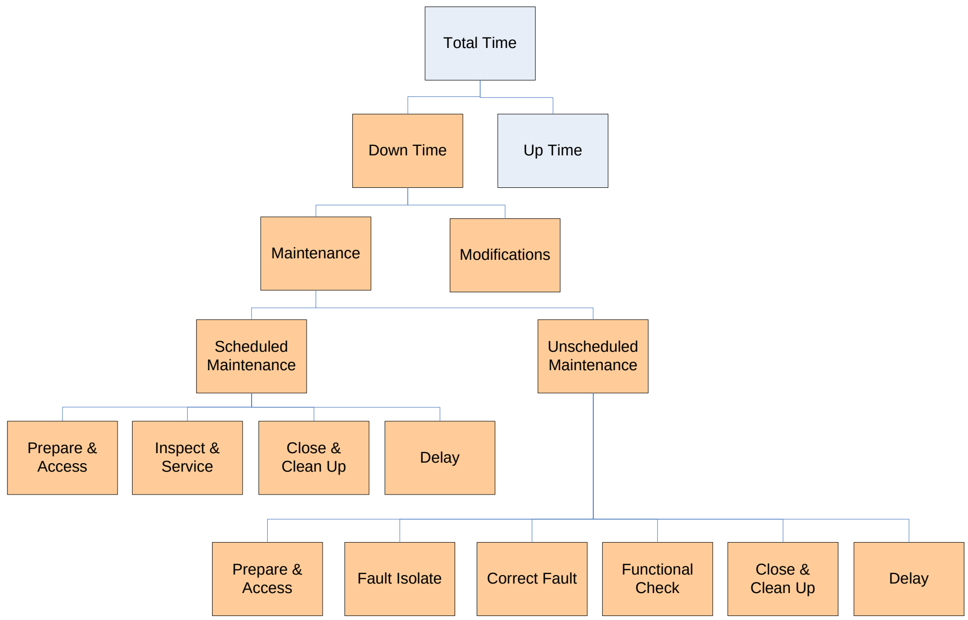

Figure 1: Breakdown of Aircraft Time.

2.1 Design

The design of the aircraft plays a significant role in its operational availability. In the area of unscheduled maintenance, design factors include the inherent reliability of the aircraft which is influenced by the system's complexity and technology. The primary metric for measuring the inherent reliability of a component or system is Mean Time Between Failure (MTBF). The design's diagnostic capability, including the ability to accurately detect failures and isolate them, also has a major influence on availability. The number of Can Not Duplicates (CND), discrepancies that maintainers can not detect during fault isolation, and Re-Test OKs (RTOK), on-equipment component malfunctions that can not be duplicated during off-equipment testing, are key metrics of its ability to accurately detect and isolate faults. Increased CND and RTOK rates lower the effective MTBF of the system below that of the design's inherent reliability, resulting in reduced aircraft availability. An aircraft's scheduled maintenance requirements also have a major influence on availability. Scheduled maintenance, or preventive downtime, can be measured as a combination of the Mean Time Between Preventive Maintenance (MTBPM), the interval between scheduled maintenance, and Mean Preventive Maintenance Time (M_{pt}), the time required to complete the scheduled maintenance. Finally, the amount of maintainer accessibility in a design contributes to the amount of downtime for both scheduled and unscheduled maintenance. The maintainability of a system can be measured through the Mean Time To Repair (MTTR) metric.

2.2 Maintenance Infrastructure

The maintenance infrastructure associated with an aircraft fleet is also a major driver in overall availability. The predominant parameter in this area is the maintenance workforce, measured by the number of maintainers available. Another significant influencer of availability is the supply chain. The ability to have spares in place in a timely manner has a large impact on the ability to fly required missions. Finally, the time required for information to flow through the maintenance infrastructure impacts administrative delay times. Spares availability and administrative time are included as part of a metric called Mean Administrative and Logistic Delay Times (MALDT).

2.3 Operations

The conditions that an aircraft operates in also play a part in its ability to consistently perform. This is especially true for long range aircraft due to the great distance which they regularly operate from established bases. The concept of operations of these platforms means that they have a greater likelihood of critical failures occurring in unsupported locations where repair capability is limited or non-existent, significantly increasing Mean Time To Repair. Returning these aircraft to service is time consuming, involving a specialized recovery team, other long range transport aircraft, and equipment dedicated to the recovery. These events are unpredictable and have a disproportionate impact on aircraft downtime. The probability of remote maintenance (P_{remote}) is the metric used to model the impact of off-station maintenance. Long range aircraft also may operate in more diverse and extreme environments, which may impact the system reliability and scheduled maintenance parameters discussed in Section 2.1.

Table 1 contains a summary of the parameters and metrics associated with system availability. The sensitivity of availability to some of these parameters is presented in Section 4.3.

Table 1: Availability Influencing Parameters and Metrics.

Category	Parameter	Metrics
Design	Inherent Reliability	MTBF
	Fault Detection & Isolation	CND RTOK
	Scheduled Maintenance	MTBPM M_{pt}
	Maintainability	MTTR
Maintenance Infrastructure	Maintenance Workforce	No. of Maintainers
	Spares Availability	MALDT
	Administration Time	
Operation	Remote Maintenance	P_{remote}

3.0 HISTORICAL DATA ANALYSIS

An analysis of historical data for long range transport and strike aircraft can provide insight into what types of maintenance contribute the most to aircraft downtime. The following sections provide such an analysis based on data from the United States Air Force's Reliability and Maintainability Information System (REMIS).

3.1 Long Range Transport Aircraft

An analysis of recent data for a modern long range transport aircraft shows that one-third of the aircraft downtime was associated with the aircraft being at the depot for inspection and refurbishment. The remainder of the downtime is associated with the aircraft being in a state such that it cannot perform any its missions and therefore is reported as Not Mission Capable (NMC). During this time the aircraft were awaiting maintenance, or Not Mission Capable Maintenance (NMCM), for three-quarters of this time, Not Mission Capable Supply (NMCS) 15% of this time, and awaiting a combination of both maintenance and supply, Not Mission Capable Both (NMCB), for the remainder of the time. Of the Not Mission Capable Maintenance time, 80% is attributed to unscheduled maintenance (NMCMU) with the rest related to scheduled maintenance (NMCMS) actions at the operational unit. Figure 2 illustrates the distribution of each category of downtime. When these categories of availability degradation are compared in Figure 3, it can be seen that unit-level unscheduled maintenance requirements are the largest driver with over 40 percent of the total aircraft downtime. Depot maintenance accounts for about a third of the downtime. The remaining downtime is distributed among unit level scheduled maintenance, awaiting supply, and awaiting both supply and maintenance.

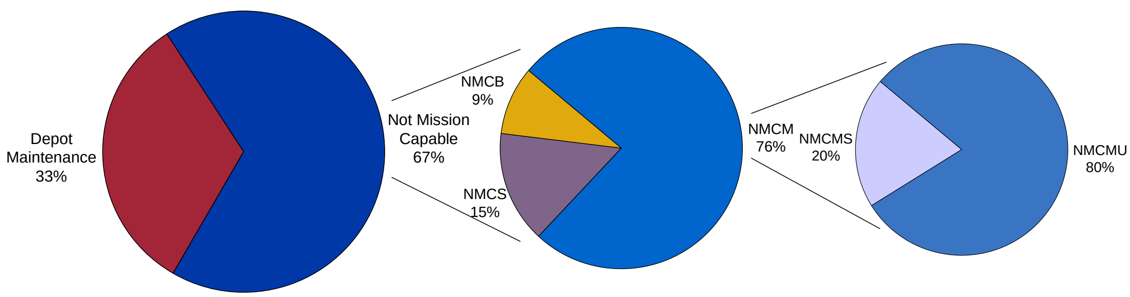

Figure 2: Long Range Transport Aircraft Downtime Distributions.

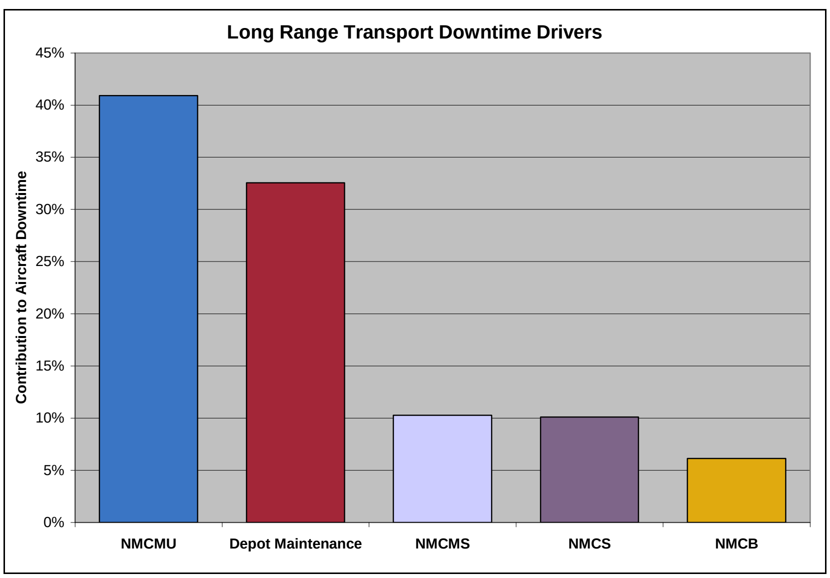

Figure 3: Long Range Transport Aircraft Downtime Drivers.

3.2 Long Range Strike Aircraft

A similar analysis was conducted for a legacy strike aircraft, as shown in Figure 4. The data, representing one year of operation, show that the fleet had a very low amount of downtime associated with Depot Maintenance. However, it is assumed that the small amount of Depot Maintenance is a function of the fleet's maintenance schedule during the time period analyzed, not the actual maintenance requirements of the aircraft. An analysis of a different or larger time period would most likely yield a percentage of Depot Maintenance similar to that seen in the transport aircraft analysis. Of the remaining Not Mission Capable time, approximately three-fifths were associated with maintenance alone, while the remaining time was split equally between supply and combined maintenance and supply delays. The Not Mission Capable Maintenance time was distributed in a similar manner as the transport aircraft, with about three-quarters associated with unscheduled maintenance. A comparison of all the downtime categories in Figure 5 shows that unscheduled maintenance is the largest factor with supply. Scheduled maintenance factors also provide significant contributions. The higher percentage of downtime connected with supply for the strike aircraft, compared to the transport aircraft, can most likely be contributed to the age of fleet and the associated diminishing manufacturing resource issues, not the strike mission itself.

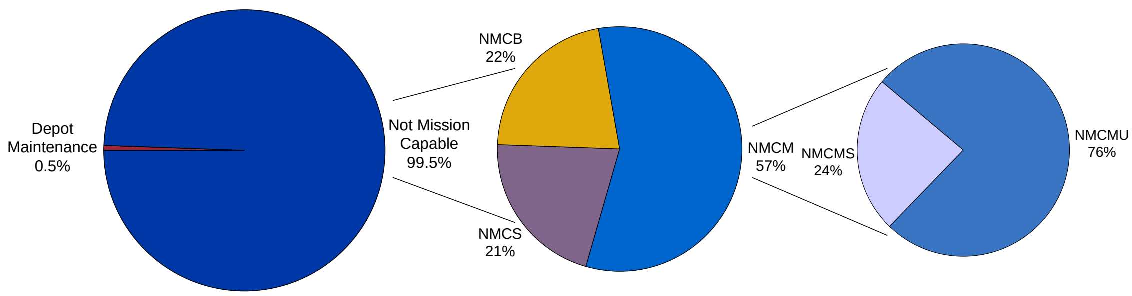

Figure 4: Long Range Strike Aircraft Downtime Distributions.

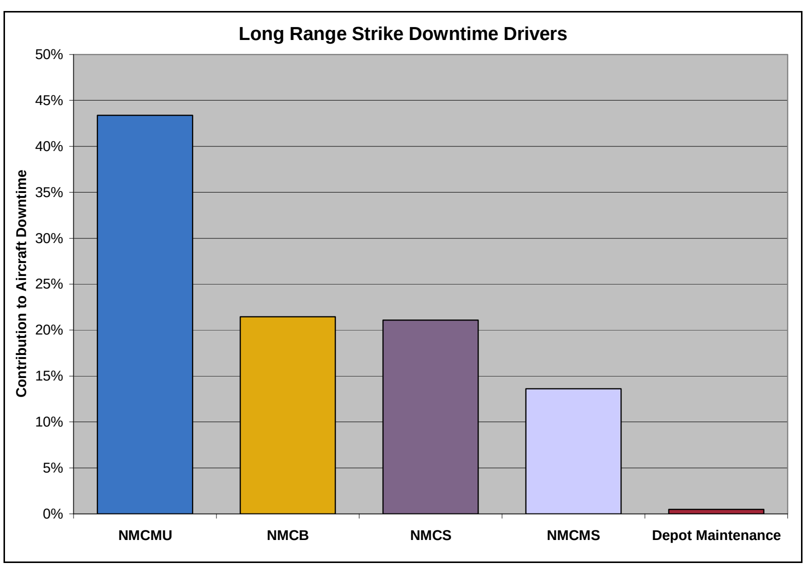

Figure 5: Long Range Strike Aircraft Downtime Drivers.

4.0 BOEING MODEL AND SENSITIVITY CASE STUDY

With an understanding of the historical drivers of long range aircraft downtime, the parameters affecting these drivers can be modelled to analyze the system's sensitivity to these parameters. The Boeing Company has developed the System Health Operational Analysis Model (SHOAM), a stochastic discrete event simulation tool, to analyze system sensitivities and predict performance for various health management solutions.

4.1 Stochastic, Discrete Event Simulation Defined

Discrete Event Simulation is defined as one in which the state variables change only at a discrete set of points in time [4]. For example, in a fleet availability model the state variables would include availability and fleet population. As vehicles come into the fleet, or come out of maintenance, the state variables of availability and/or fleet population change. These events can be counted, and therefore, are discrete events. A stochastic simulation is defined as one that uses some random inputs in the form of a probability density function to randomize events during the model run. For example, vehicle repair times are not fixed. They are randomized in that there is an identifiable trend (typically available from a maintenance information system) that corresponds to a repair time distribution. Applying randomness to the appropriate inputs (rarely would all inputs be stochastic), adds realism, and often, significant additional insight to the dynamic operation of the system.

4.2 SHOAM Overview

Boeing's SHOAM tool can be used to analyze and demonstrate the operational impacts of technology and process improvements on new and legacy platforms. SHOAM provides a method to model the complex interaction of the relevant parameters to not only gain insight into what drives aircraft availability, but also to measure the estimated impact of proposed changes on availability. SHOAM breaks system operations into five functional areas: Mission Operations, Fleet Management, Command and Control, Maintenance Operations, and Original Equipment Manufacturer (OEM). Each of these areas has unique performance metrics and operational tasks. The model can incorporate multiple operational scenarios including sustained peacetime or surge contingency operations. The model creates systems with specific reliability characteristics, ages those systems by running them through realistic scenarios allowing failures to occur, and performing the required maintenance. Basic reliability, maintainability, and operational scenarios are inputs. Results from the SHOAM model include aircraft and fleet operational availability and reliability metrics. Since its development, SHOAM has been used to analyze the impact of various solutions on several long range aircraft. Figure 6 is a screen shot of the "Command & Control" animation area of the model providing overall status during the run.

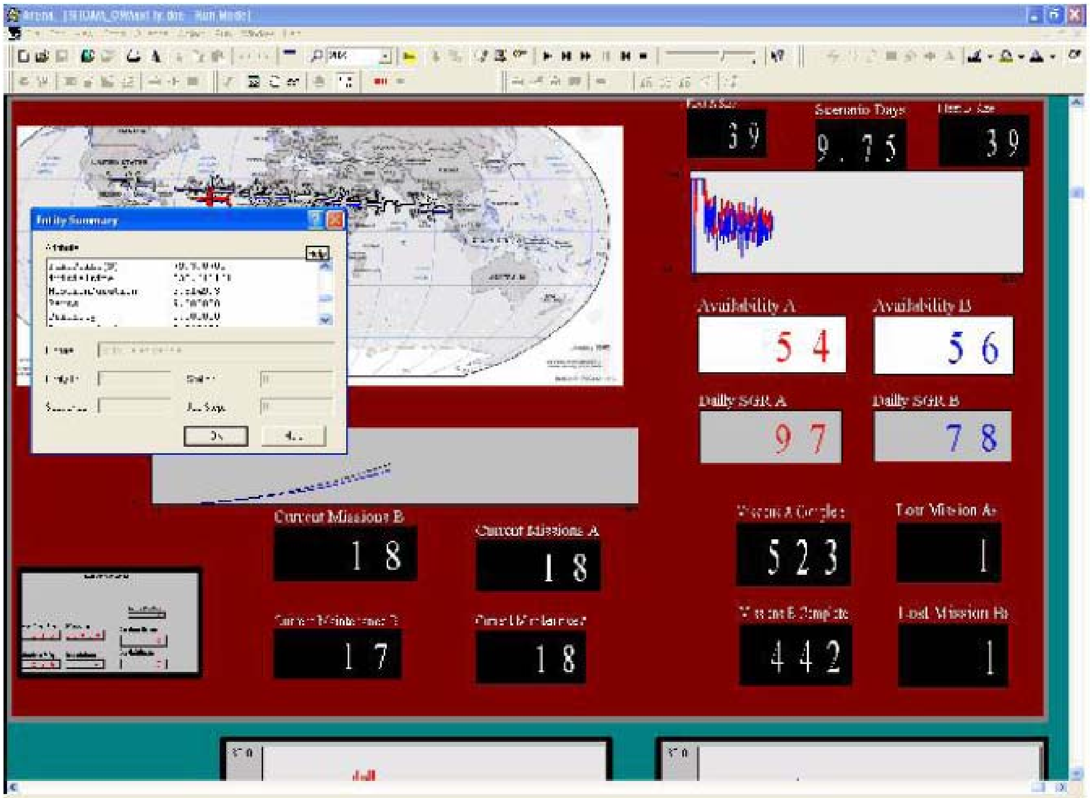

Figure 6: SHOAM Screen Shot.

4.3 Sensitivity Case Study

The sensitivity of aircraft and fleet availability to applicable parameters can also be estimated using the SHOAM tool. To illustrate the sensitivities that can be outlined in a simulation, one year's worth of recent operational and maintenance data was collected for a United States Air Force long range strike aircraft. This data serves as a baseline for the case study to illustrate the sensitivities of design, maintenance infrastructure, and operations parameters for a long range strike aircraft.

4.3.1 Inherent Reliability

The inherent reliability of an aircraft is influenced by the system's complexity and technology and is primarily measured by the system's Mean Time between Failure (MTBF). Figure 7 illustrates the sensitivity of availability to the top three system drivers of inherent reliability for the long range strike aircraft: avionics, propulsion, and environmental control. The chart illustrates the impact of improvement in system reliability on availability. For example, a 20 percent improvement in avionics, structures, and propulsion inherent reliability results in more than a 3 percent improvement in operational availability.

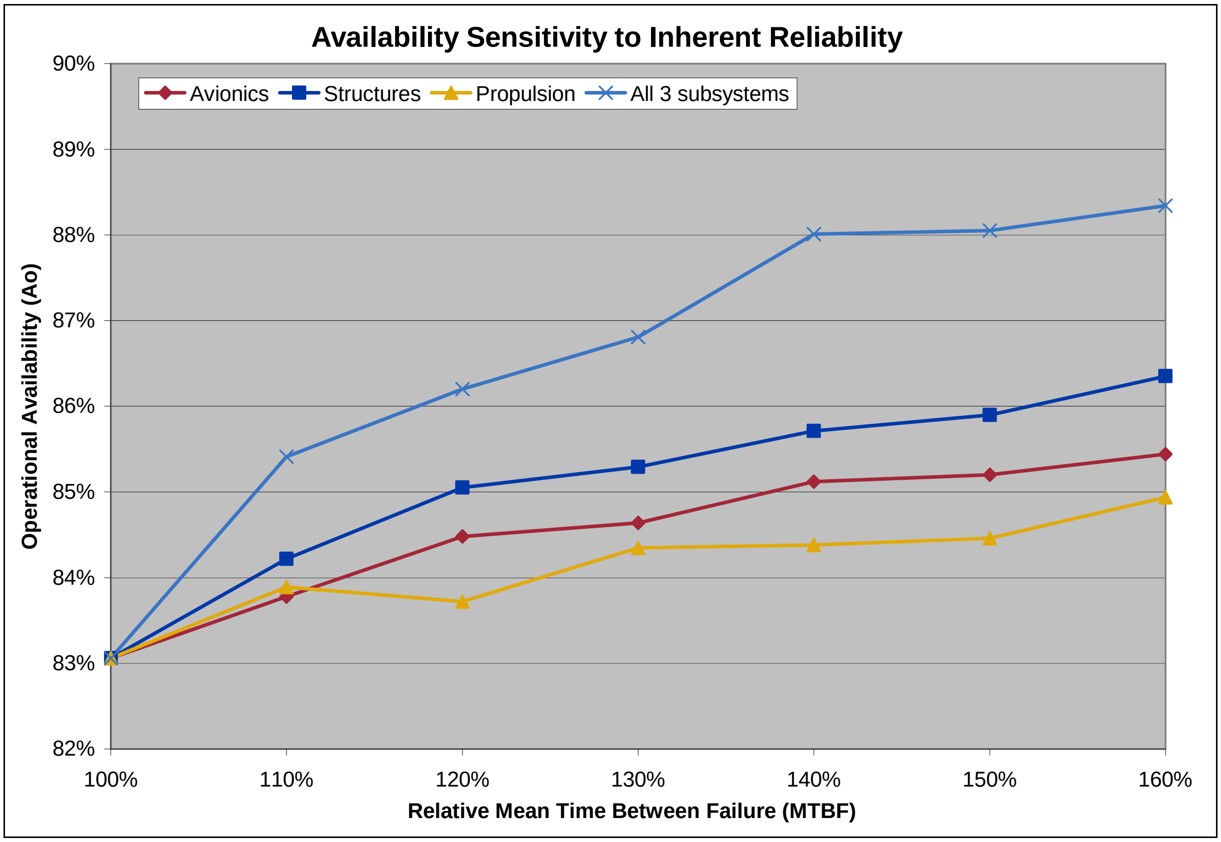

Figure 7: Sensitivity of Availability to Inherent Reliability.

4.3.2 Maintainability

Just as inherent reliability can impact operational performance, maintainability metrics can also have a large impact. These metrics can include Mean Time to Repair (MTTR), Mean Time to Fault Isolate, Mean Administrative Logistics Delay Time (MALDT), and wait times. Maintainability issues can be addressed in a fielded system, whereas inherent reliability is typically a design function and subject to engineering improvements only in extreme cases of substandard performance. Maintainability can be improved by increasing maintenance resources such as manpower, spares, and repair locations and by improving the maintenance concept and maintenance decisions. Unlike design and production efforts to improve inherent reliability, each of these comes at a significant annual recurring cost. These sensitivities and process changes can be evaluated by the use of the SHOAM tool. Figure 8 shows the sensitivity of the long range strike aircraft's availability to the Mean Time to Repair (MTTR) metric.

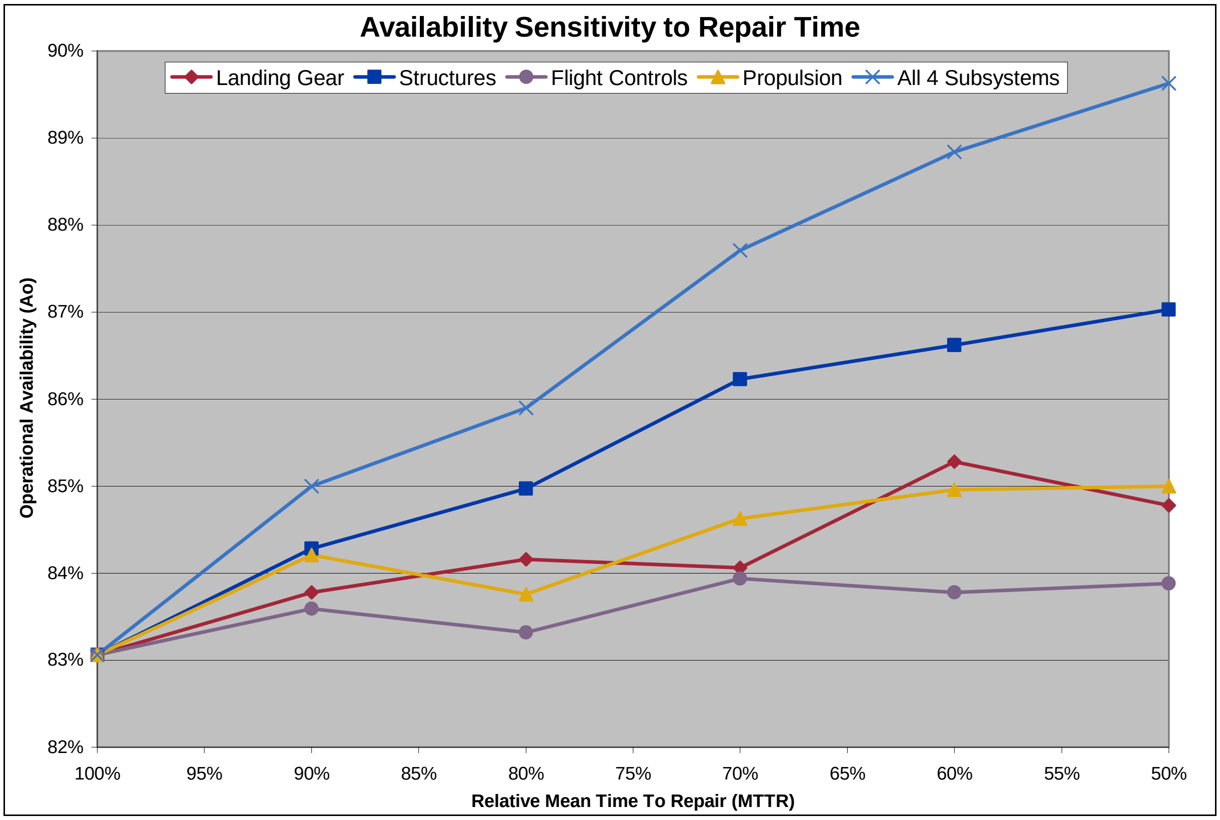

Figure 8: Sensitivity of Availability to Maintainability.

4.3.3 Manpower

On any large aircraft fleet, manning requirements are the single largest Operations and Support (O&S) cost element. There is an identifiable relationship between operational Availability (or Mission Capability) and man power utilization rate. Utilization can be defined as:

$$Utilization = \frac{Ma\,\mathrm{int}\,enanceManHrs}{Scheduled\,ManHours}$$

Utilization can fluctuate greatly since the maintenance manhours are a function of operational tempo which can vary greatly over time in military aircraft fleets. The manpower must be established based on operational performance requirements of the worst case scenario, i.e. the high tempo operations associated with deployed units and joint military operations.

As shown in Figure 9, an analysis of the sensitivity of operational availability to maintenance manning was conducted on the data for long range strike aircraft. The analysis quantified the trade-off between maintenance manpower and availability for the existing design. The analysis identified the "knee in the curve" where there are diminishing marginal returns in the form of availability for adding manpower. This information enables logistics planners to make design and logistics decisions well in advance of fielding a system.

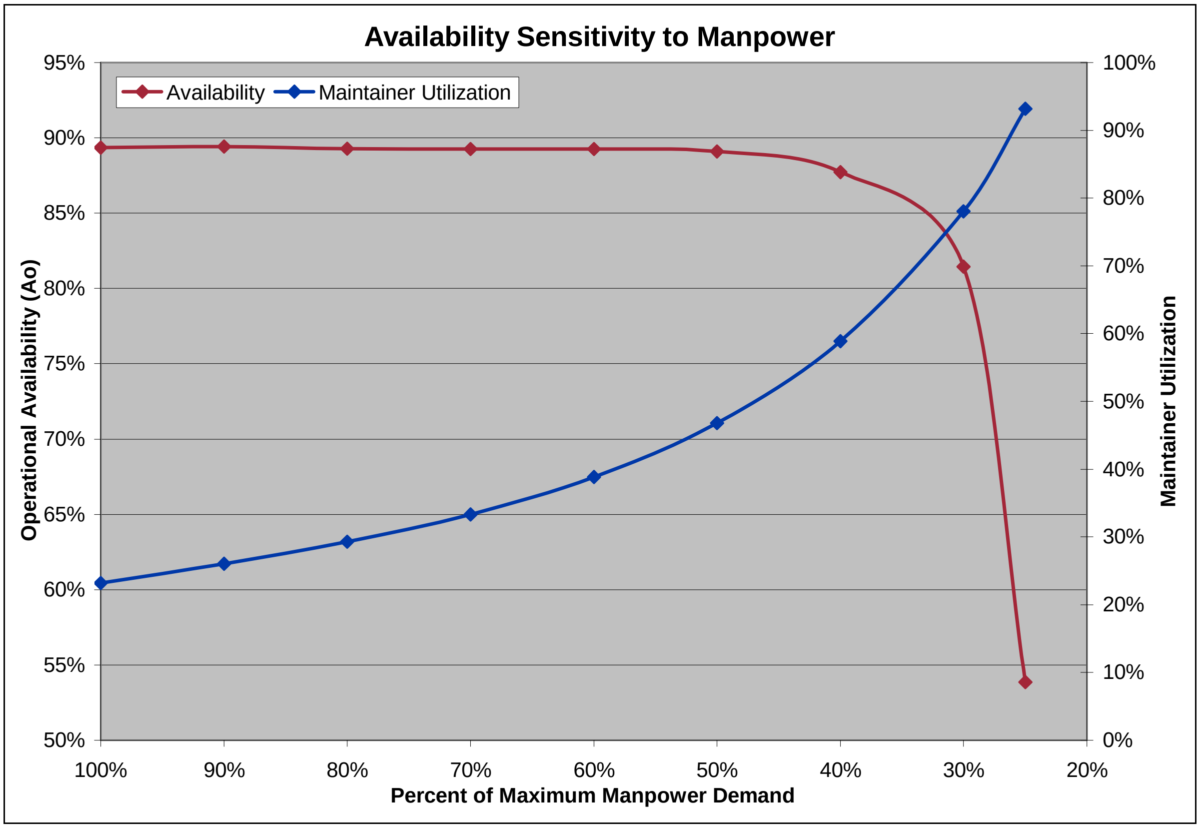

Figure 9: Sensitivity of Availability to Manpower.

4.3.4 Spares Provisioning

The purchase, distribution, repair, and management of spares are major drivers in performance and cost. This element is the subject of vigorous scrutiny during the design phase and, especially, during production and support phases of a program. Ideally, whenever a failure has occurred and a replacement is required, a spare will be available, and with a minimum of extra spare parts or excess provisioning. In order for this to occur, reliability predictions would have to be nearly perfect, usage of the system would have to be exactly as planned, failures would occur where maintenance capability and spare parts are available, and maintainers would never induce excess maintenance from errors or cause a failure while performing other maintenance. Obviously, this is unrealistic. However, planners can use SHOAM to identify operational and logistics issues during the design phase and model the system in a simulated environment to better understand the system and identify an appropriate provisioning level in various locations. Figure 10 illustrates the sensitivity of availability to spares availability.

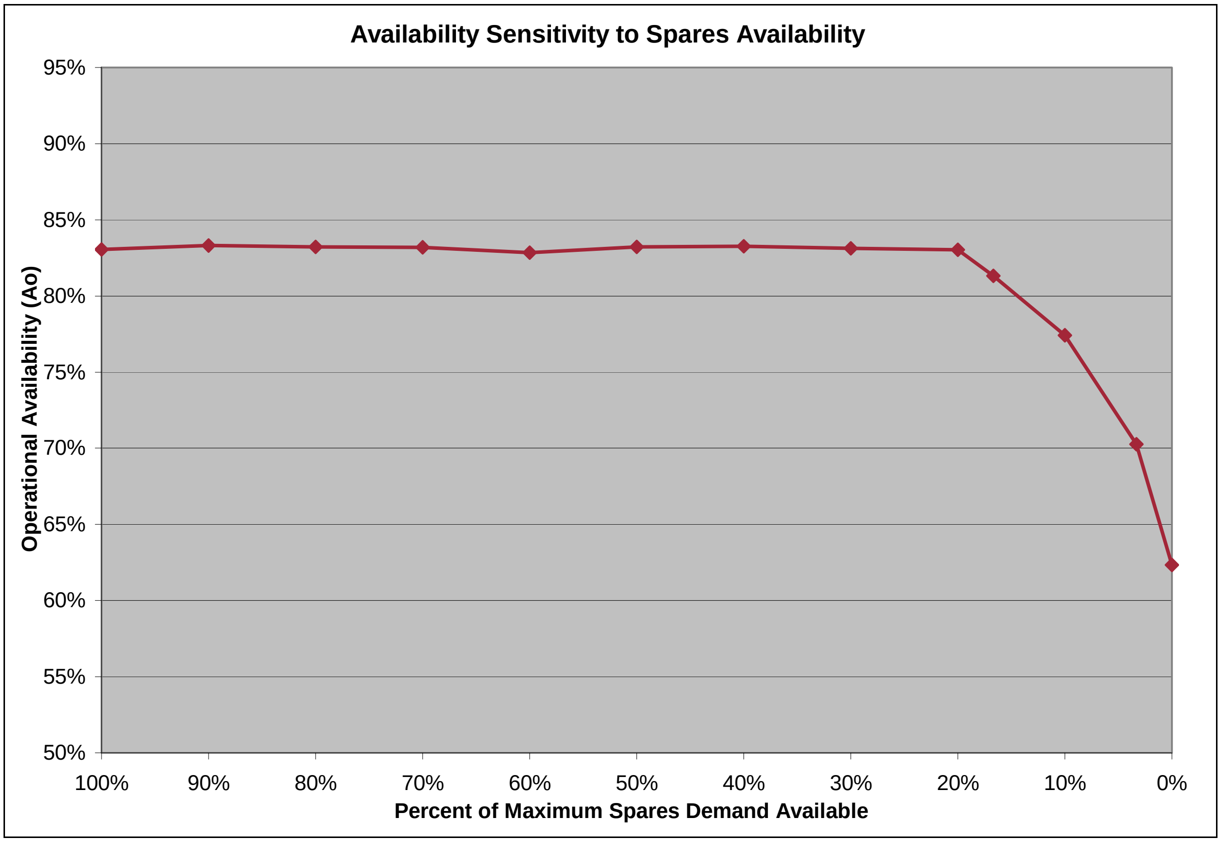

Figure 10: Sensitivity of Availability to Spares Availability.

4.3.5 Remote Operations

Long Range aircraft, particularly long range cargo aircraft, are more likely to have operations out of remote or unsupported airfields. If there is a critical maintenance issue that needs to be addressed, a disproportionate amount of resources are required to recover the aircraft and execute the maintenance than is required when operating from a supported airfield. This is another, and somewhat unique, sensitivity that can be identified with the SHOAM tool. Figure 11 is an example of the sensitivity of availability to the percentage of time the aircraft operates from an unsupported location based on the long range strike aircraft data. Various health management technologies and processes can alleviate the impact of stranding vehicles in remote locations and would be illustrated by comparing multiple design solutions on the same chart.

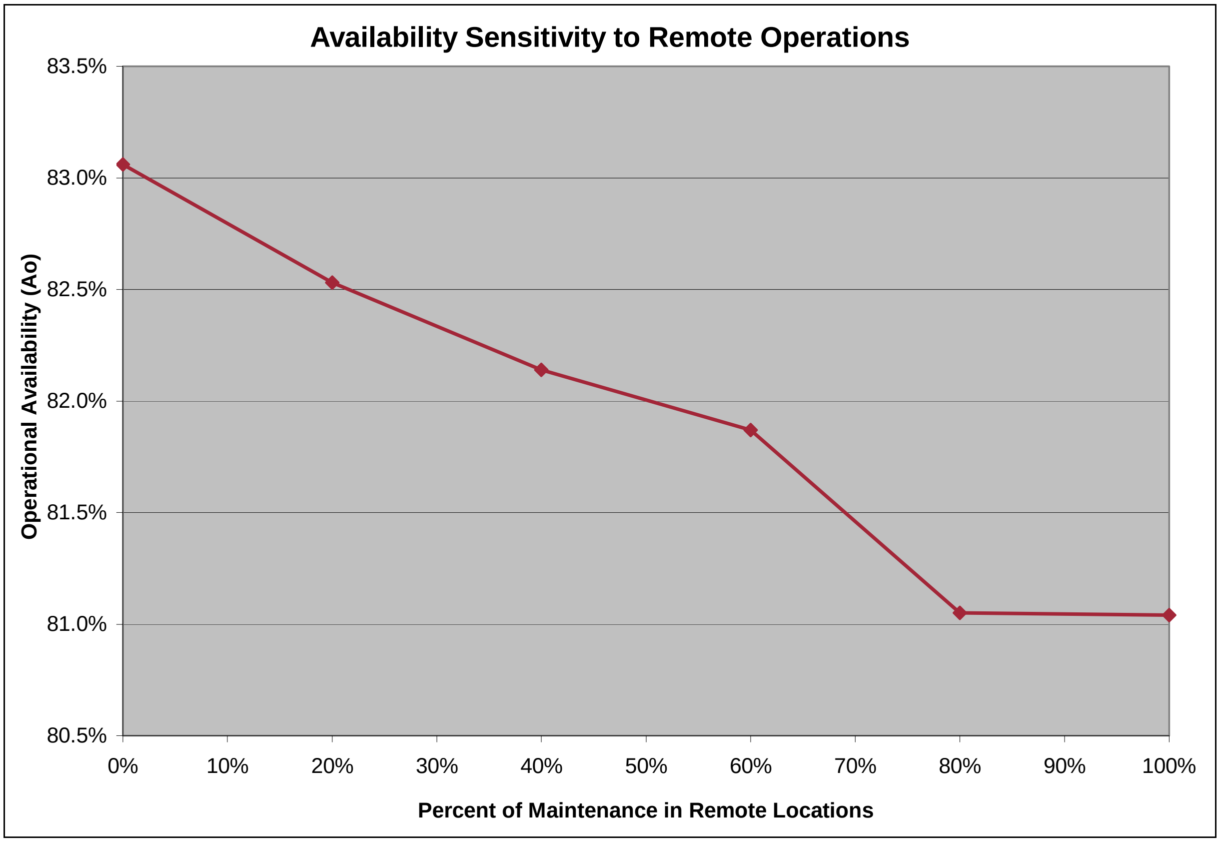

Figure 11: Sensitivity of Availability to Remote Operations.

5.0 CONCLUSION

An aircraft's design, maintenance infrastructure, and operational environment provide many factors that affect its operational availability. The analysis of historical data shows that unscheduled organizational-level maintenance, depot maintenance, and supply delays are drivers for long range aircraft downtimes. In addition, relevant metrics were modelled using discrete event simulation to provide insight into where technical and/or process improvements should be focused. The results of this modelling identify maintenance infrastructure parameters, such as manpower and spares provisioning, as the key drivers for long range aircraft availability.

6.0 REFERENCES

[1] United States Department of Defense Guide for Achieving Reliability, Availability, and Maintainability, August 3, 2005.

[2] United States Air Force, Determining Mission Capability and Supportability Requirements, AFI 10-602, 18 March 2005.

[3] Frohne, Philip T, Quantitative Measures of Logistics, Boeing Edition, 2003.

[4] Banks, Carson Nelson, Nicole; Discrete-Event System Simulation, 3rd Edition, 2001.