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THE IMPACT OF RELIABILITY ON CAPABILITY AND COST IN A COMBAT ENVIRONMENT: AN INITIAL ASSESSMENT

Karen W. Tyson
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July 1988

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This paper discusses a methodology for assessing the cost and performance trade-offs between equipment reliability and logistic support under combat conditions. Using F-15C data and the Dyna-Metric model, the sortie generation capability of a squadron was evaluated under varying levels of reliability and varying combat conditions, including battle damage.

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PREFACE

This report was prepared by the Institute for Defense Analyses (IDA) for the Weapons Support Improvement Group in the Office of the Assistant Secretary of Defense (Production and Logistics), under Contract Number MDA903-84-C-0031, Task T-B6-425, "Weapon Reliability and Logistic Support Costs in a Combat Environment."

The purpose of the study is to develop and test a methodology for assessing the cost and performance trade-offs between equipment reliability and logistics support under combat conditions and to determine how reliability influences sortie generation capability and costs. This paper documents the first year of the study work.

This paper was reviewed by Dr. Jeffrey Grotte and Mr. Paul Goree.

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I. INTRODUCTION

The purpose of this study is to develop and test a methodology for assessing the cost and performance trade-offs between equipment reliability and logistic support under combat conditions, to determine whether reliability influences sortie generation and costs and, if so, to what extent.

Improvements in the reliability of equipment have two important benefits, in theory:

- Costs are lowered. A given peacetime or wartime flying program could be completed at a lower cost for spare parts, manpower, support equipment, etc.
- Sortie generation capability is higher. For a given set of support conditions, more missions can be flown. This would be particularly true for non-standard logistic support.

Support cost analysis should be used to examine the cost of alternative ways of achieving specified levels of combat effectiveness. Thus, there is a need for tools to evaluate the value of improved reliability in a wartime context. As with other aspects of system design, desired reliability should be determined through explicit consideration of the environment in which the system is meant to be used. This implies not only using methods designed to reflect the combat environment as closely as possible but also applying the methods to data developed in as combat-like a setting as possible. These methods must be used to assess the reliability of new systems for which it is easier to alter reliability. Our goal is to develop a method for evaluating these issues which can also be used for prospective systems.

The following four-step procedure was undertaken to fulfill our objectives:

- Develop or adapt a model that can relate the reliability and cost of the components of a weapon system to the performance of the system in a combat environment and to the cost of achieving that level of performance.
- Demonstrate the methodology with an existing system. (The F-15 was selected for this purpose.)
- Develop techniques to analyze the value of alternative levels of reliability for weapon systems that are in early stages of the acquisition process.

- Apply these techniques to a prospective system. The Air Force's next generation fighter, the Advanced Tactical Fighter (ATF) is planned for this role. This phase of the analysis has just begun.

Some aspects of combat operations were not considered in our analysis of sortie generation capability. These include the availability of personnel to perform repair work and the effect of airfield damage. Estimates of the cost of personnel under different reliability assumptions will eventually be included in our analysis, but spare parts and repair capability are the only resources that have been considered in determining the availability of aircraft. These factors seem most closely related to the reliability of equipment.

A. MODEL SELECTION

Since many models have been developed that can link reliability to the sortie generation capability of a squadro . of aircraft, developing a model was not necessary. Two kinds of simulation models were considered, Monte Carlo models such as the Logistics Composite Module (LCOM), Simulation Package for the Evaluation by Computer Technique of Readiness, Utilization, and Maintenance Model (SPECTRUM), and Comprehensive Aircraft Support Effectiveness Evaluation Model (CASEE), and analytic simulators such as Dynamic Multi-Echelon for Recoverable Item Control (Dyna-METRIC), Availability Centered Inventory Model (ACIM) and Multi-Item, Multi-Echelon (MIME)

We evaluated these models on the basis of their ease of use and their ability to adequately capture the following critical aspects of wartime operations:

- Ability to accommodate a varying sortie rate over the period of the conflict
- Ability to simulate an austere operating environment, in which only limited repairs can be done during a portion of the period being studied
- Ability to simulate vulnerable logistic support, when the delivery of additional spare parts is interrupted
- Ability to capture the effects of battle damage.

The first three characteristics are important to examine because analysis that includes them is likely to demonstrate the value of reliability. If particularly challenging sortie rates are to be accomplished at critical junctures in the war, and if repairs are inhibited by the lack of equipment or spare parts, improved reliability could significantly affect sortie generation capability. If, however, most inoperative aircraft are not mission capable because they have been damaged by enemy fire, improved reliability is unlikely to affect sortie generation capability. Battle damaged aircraft are likely to be inoperable, regardless of the reliability factor.

To adequately analyze the net value of improved reliability in a battlefield context, all of these considerations must be examined.

Monte Carlo models were eliminated from consideration because of their complexity and because of the increased computer time and multiple runs required to obtain results. Of the analytic simulators, Dyna-METRIC accommodated variations in the operating tempo to the greatest extent. Therefore, Dyna-METRIC was selected as our analytic tool; its workings are discussed in more detail in the next chapter.

B. DEMONSTRATING THE METHODOLOGY WITH AN EXISTING SYSTEM

Our purpose was to demonstrate that a methodology based on the use of Dyna-METRIC could be used to assess the value of higher reliability under wartime conditions. To do this, we carried out the following sequence of steps:

- Data reflecting the reliability and cost of the components of the F-15 were gathered and Dyna-METRIC was adapted to analyze these data was developed.
- A wartime flying scenario was obtained.
- Dyna-METRIC was used to generate war reserve spares kits (WRSKs) for a deployed F-15 squadron. Kits were developed for three levels of reliability: the historical level, a level reflecting failure rates 50 percent less than of the historical level (a doubling of reliability), and a level reflecting failure rates 50 percent greater than of the historical level. In developing the WRSK, Dyna-METRIC was focused on buying parts that achieve specified levels of aircraft availability under a specified scenario, as inexpensively as possible.
- The effect of reliability on the cost of WRSK kits was calculated. These costs were calculated using the same methodology used by the Air Force to develop spares packages.
- For all three levels of reliability, baseline sortie generation profiles were developed for 30 days of simulated operations under standard assumptions about logistic support (resupply times and maintenance capability). These profiles were compared with the levels of sortie generation called for by the scenario. Following Air Force practice, in the baseline case, simple repairs were begun on the 5th day of operations, more complex repairs were delayed to the 30th day (and thus did not affect our calculations). Standard Air Force assumptions for the resupply times for individual parts were used. No battle

damage or attrition was assumed. All of our analyses (both the baseline and excursions from it) permitted cannibalization and incorporated a delay for the performance of corrective maintenance.

- The core of our analysis involved modifying the baseline assumptions in ways that incorporated more of the characteristics of combat and developing sortie generation curves that reflected the new assumptions. The onset of simple repairs (remove and replace) was delayed. Transportation was interrupted, increasing the resupply time for parts. A one-percent attrition rate was incorporated and a level of battle damage reflecting Vietnam experience was introduced into the analysis. These departures from the baseline were examined both singly and collectively for all three levels of reliability.
- The sortie profiles developed under the more combat-like assumptions were compared with those developed under the baseline to draw inferences about whether reliability is likely to be more important in a combat environment than in a more benign environment.

C. ANALYZING RELIABILITY EARLY IN THE ACQUISITION PROCESS

Learning more about the value of improved reliability for existing weapon systems could help guide reliability improvement programs. Determining the value of reliability for systems in early stages of the design process would be more beneficial since improvements are least expensive and least disruptive to the design process. The analytic procedure outlined in the preceding section must be modified to permit analysis of systems that do not yet have firm designs and detailed data on the cost and failure rates of their components are not yet available.

To develop and test such modifications, we are beginning to analyze the F-15 as if it were in an early stage of system development and proceeding as if we have only the aggregate information on F-15 reliability and the cost of its components that is typically available at such a stage. In addition to the assuming average failure rate and cost of the components of the system, we are assuming the availability of specific information on a small number of critical parts. We are attempting to develop a set of disaggregation rules that (when applied to the aggregated F-15 data) would yield a good approximation of the results achieved from using actual disaggregated data for the F-15. Simulating disaggregate data with aggregate data involves making alternative assumptions about the relationship between the cost and the failure rate of components.

As this work proceeds, we will continue our efforts to acquire preliminary data for the ATF and to understand the design philosophy being used for that aircraft. Because of the extensive redundancies being contemplated for the ATF, the approach used to analyze the value of reliability in the F-15 is expected to be modified for use with the ATF.

D. ORGANIZATION

The study, Weapon Reliability and Logistic Support Costs in a Combat Environment, has three phases. This report covers the bulk of the first two phases of work, from the acquisition of the model to tests of methods for incorporating more realistic combat conditions in an existing system. The final phase of the project will include analysis of a prospective system.

Chapter II describes the model and the data used. Chapter III gives several examples of our analysis of various combat conditions for the F-15. Chapter IV discusses the implications of these results and future plans. Appendix A contains a more detailed description of the Dyna-METRIC model, Appendix B details the Coronet Warrior Exercise, and Appendix C describes the implementation of the Dyna-METRIC model on the IDA VAX computer systems. Appendix D lists the F-15 line replaceable units (LRUs) used in the analysis.

II. MODEL AND DATA

A. THE DYNA-METRIC MODEL

The Dyna-METRIC model is used to develop inventory requirements to meet specified levels of supply readiness (at minimal cost) and evaluate the readiness and sortie generation capability of aircraft in terms of logistic support (supply and maintenance) and operational considerations (such as flight scenarios and attrition rates).

Dyna-METRIC was selected for use in this study for the following reasons:

- It is capable of assessing the following factors of readiness and sortie generation capability in an integrated fashion:
  - Reliability of aircraft components
  - Dynamic (fluctuating) flight hour programs
  - Dynamic logistic support availability (resupply cut-off and delayed intermediate-level maintenance support)
  - Aircraft attrition.
- It is flexible in terms of data requirements, making it suitable for use throughout the entire acquisition process. Dyna-METRIC can assess baseline reliability and maintainability, aircraft configurations and generic logistics support, and force deployment strategies. As improved data on aircraft configuration, component reliability, component cost, maintainability, and logistic support structures become available, data bases can be easily modified for use in the model. While data quality improves, the evaluation technique remains constant. This improves the accuracy of model estimates of, for example, readiness, and maintains consistency so that changes in results can always be attributed to data input rather than the peculiarities of models.
- It has become accepted by a large section of the Air Force community as a tool for evaluating logistic support in terms of capability.
- It is used by the Air Force Logistics Command (AFLC) to determine inventory requirements (such as WRSKs) to meet readiness objectives.
- It is relatively easy to use. Data elements are transparent to decision makers, and model execution is relatively inexpensive and rapid.

1. Limitations of the Model

Dyna-METRIC, like any model of this type, provides assessments of performance on the basis of assumptions made about the general operations of supply, maintenance, and sortie generation built into the model and the relevant data fed into the model. These models do have some limitations. They cannot, for example, take into account the ingenuity of supply and maintenance officers, all of the unobserved or unexpected conditions resulting from wartime operations, or the perturbations in failure rates and repair times (from expected values) that can result during any operation. While Dyna-METRIC does not model every nuance of aviation support and operations it does model aircraft operations and supply and maintenance with sufficient accuracy and detail to allow managers to make effective decisions about support and design requirements for aircraft. The following discussion describes the basic characteristics of Dyna-METRIC and how the model was used in this study to evaluate alternative aircraft reliability levels and support concepts; however, the model is more flexible than indicated here. When appropriate we indicate additional features developed by the study team for this analysis. Refer to Appendix A and Reference 3 for a more complete description of the model. Model validation and the Coronet Warrior exercise, described in Appendix B, indicated a close relationship between Dyna-METRIC model results and actual exercise experiences.

2. Data Required to Use Dyna-METRIC

Dyna-METRIC attempts to estimate the effect of logistic support on a planned operating scenario. In this study, we analyzed operations at one base and for one Type-Model-Series (TMS) aircraft. Assuming a specified level of rear-echelon support, Dyna-METRIC is capable of simultaneously analyzing multiple site operations in a multi-echelon support network. The user must supply the following input to the model to define the planned platform operating scenario:

- Force levels (number of aircraft)
- Flying hour program
  - number of sorties per day
    - -- peacetime rate
    - -- number per day for each day of wartime portion of the scenario
  - flight hours per sortie
- Attrition rates (separate rates can be specified for each day of the wartime portion of the scenario).

To analyze operations in terms of logistic support, each aircraft must be described in terms of its components (Line Replaceable Units (LRUs)) and, if possible, the lower identured components of the LRUs (Shop Replaceable Units (SRUs) and sub SRUs). Analysis conducted in this study focused on LRUs. The model uses the following LRU factors to analyze the effectiveness of a logistic support system:[1]

- Aircraft configuration (a complete list of LRUs on the aircraft)
- Removal rate for each component (per flight hour or per sortie)
- Quantity of each LRU per aircraft
- Level of repair for each component (an indication of whether component can be repaired on site or must be repaired at higher echelons of support (such as depots)
- Not-Repairable-This-Site (NRTS) rate for each LRU. This is the percentage of removals that must be condemned or sent to higher repair echelons because, for example, the site does not have complete repair capabilities.
- Turn Around Time[2] (TAT) for each LRU. This is the time it takes maintenance to return a failed part to a ready-for-issue state and should not be confused with the time it takes to remove a failed part from an aircraft and replace it with a working part.
- Resupply time for each LRU. This is the time it takes rear-echelon support to meet requirements for parts that fail and cannot be repaired on site.

In addition to these factors, which Dyna-METRIC has been programmed to treat, the model was adjusted to analyze the effects of battle damage. We first describe the model's use of reliability and maintability data; how the model is used to analyze battle damage is discussed in the next section. To employ the battle damage analysis option, the user must supply the battle damage rate -- the number of battle damage incidents per sortie.[3]

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1 If lower indentured parts are analyzed, similar factors must be supplied for the SRUs and sub SRUs.

2 When analyzing rear-echelon support, these factors must be supplied for repair done at these sites.

3 Current IDA programming of this feature assumes battle damage rates are constant during the wartime scenario, but with additional computer time and analyst intervention, the model can evaluate variations in the battle damage rate.

3. Adaptation of the Model for Maintenance Delay and Battle Damage

An important factor not programmed into Dyna-METRIC is organizational maintenance. The model was not designed to consider aircraft repair delays caused by maintenance on aircraft. It does consider repair delay caused by supply support but disregards the time it takes to remove and replace a part when a replacement spare part is available. IDA has developed a technique to incorporate organizational maintenance into the model. To do this, the Mean Time to Repair (MTTR) for each LRU must be specified. This is the time it takes organizational maintenance to remove a failed part, acquire a replacement from supply (assuming a replacement is in stock), and install the ready-for-issue part on the aircraft.

IDA modifications of Dyna-METRIC to include battle damage and organizational-level repair time analyses are done through Dyna-METRIC's modeling of LRUs.

Aircraft downtime due to organizational-level repair is modeled by constructing a pseudo LRU for each LRU in the data base. Each pseudo LRU has the same failure rate and quantity per aircraft as its associated LRU. However, the NRTS rate for the pseudo LRU is always 0, and its TAT is the MTTR of the associated LRU's. The objective is to have the pseudo LRU fail whenever the corresponding LRU fails. By assuming the pseudo LRU stock level to be zero, Dyna-METRIC delays repair of the LRU on the aircraft (through the pseudo LRU) by MTTR. Delays in repair due to supply (awaiting parts time) are modeled explicitly by Dyna-METRIC using data supplied for the LRU.[4]

Delays in aircraft repair due to battle damage are modeled in a similar manner. Currently, functional areas of the aircraft are designated as battle damage LRUs. Failure rates (battle damage rates) are specified for each area. An MTTR is specified and used with battle damage LRUs to have the model simulate repair and associated down time due to battle damage repair.[5]

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4 Because the model assumes parts fail independently, this technique only approximates delays due to organizational maintenance, since it does not guarantee that MTTR is added in total to awaiting parts time in the removal and replacement of a failed LRU.

5 Plans have been made to analyze battle damage by component. This requires tbat LRU failure rates MTTRs, TATs, and NRTS rates be adjusted to reflect battle damage. Development of such factors is currently underway, but estimates are not available at this time.

4. Logistic Support Variations

An operational scenario is also specified for logistic support. In particular, the following input variables specify this scenario:

- Times and durations of cut-offs in resupply
- Delays in establishing repair capability for components.

Although resupply delays are applied to all demands for replenishment of components from rear-echelon support, maintenance capability delays can be specified for each LRU (and SRU if appropriate). This feature is important since developing total repair capability at advanced bases is incremental over time. Moreover, it permits battle damage repair and organizational-level repair analysis using the techniques described in the preceding section.

5. What Dyna-METRIC Does

When supplied with LRU inventory levels, Dyna-METRIC simulates flight operations and resulting supply and maintenance responses[6]. Unavailability of repair parts is represented by the model as "holes" in aircraft (down aircraft). The Dyna-METRIC provision to allow component cannibalization is used for all LRUs. (Holes are consolidated). Cannibalization is not allowed for organizational-level maintenance parts (pseudo LRUs) and battle damage parts, since the requirements for repairs on an aircraft cannot be transferred from one aircraft to another.

Dyna-METRIC can then estimate the percentage of aircraft available at any point in the scenario. Using this information with the specified maximum number of sorties per aircraft per day, the model estimates the number of planned sorties that can be accomplished at each point in the scenario.

Note that when Dyna-METRIC is used to evaluate logistic support in meeting a planned scenario, inventory level specifications must be made for each aircraft component in this analysis.

For this study, Dyna-METRIC was also used to determine inventory requirements. Dyna-METRIC has an optimization routine that uses its evaluation methodology to select an inventory that will meet a readiness objective at minimal inventory cost. Any inventory

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6 Dyna-METRIC is not a Monte-Carlo simulation (such as LCOM) but an analytic simulator.

developed by Dyna-METRIC for use in this study was constructed using the same parameters that would typically be used by AFLC in inventory requirements development.

B. DATA

A specific configuration of the F-15 had to be chosen for the study. We chose the F-15C configured for Pacific Air Force (PACAF) operations. This section describes The F-15C data used to illustrate the use of Dyna-METRIC in analyzing aircraft reliability. They are presented in terms of the Dyna-METRIC input variables listed in the preceding section.

1. Operating Scenario

All analysis presented in this paper is centered on supporting 24 forward-deployed F-15 aircraft during a 30-day wartime scenario with the flying schedule contained in Table II-1.

Table II-1. Wartime Flying Scenario Used in the Analysis

Day of Scenario	Planned Sorties Per Aircraft Per Day	Flight Hours Per Sortie	Total Planned Flight Hours Per Day
1-3	3.13	2	150.2
4-6	3.09	2	148.3
7-19	1.00	2	48.0
20-30	.98	2	47.0

Attrition rates (when used) were assumed to be 2 per 100 sorties for days 1 through 6 of the scenario and 1 per 100 sorties for days 7 through 30.

Battle damage rates (when used) were assumed, throughout the scenario, to be 10 per 100 sorties. (Dyna-METRIC can analyze dynamic battle damage rates. However, user intervention at appropriate points in the simulated scenario and additional computer time would be required.)

Recall that in this analysis battle damage was modeled from a maintenance delay point of view, and the effect of the unavailability of repair material was not modeled. In particular, battle damage repair was modeled for eight areas of the aircraft. Two types of battle damage were considered, damage from small arms fire and damage from high explosives. The probabilities of battle damage in each functional area (given a battle damage incident) assuming small arms or high explosive damage are listed in Table II-2.

All figures were based on combat damage to U.S. Air Force fighter aircraft involved in the Southeast Asia conflict (reported in Reference 1).

Table II-2. Probability of Battle Damage by Type of Threat and Functional Area

F-15 Functional Area	Probability of Battle Damage Given	
	Small Arms	High Explosive
Structure	.933	.927
Flight Controls	.126	.182
Propulsion	.163	.225
Fuel	.153	.309
Power	.047	.309
Avionics	.140	.091
Crew Station	.042	.073
Armament	.032	.055

Mean repair times for individual battle damage repair were also taken from data contained in Reference 1 and are shown in Table II-3.

Table II-3. Mean Battle Damage Repair Times by Type of Threat and Functional Area

F-15 Functional Area	MeanRepairTimes(hours)	
	Small Arms	High Explosive
Structure	8.4	21.3
Flight Controls	30.6	27.7
Propulsion	17.8	157.3
Fuel	5.0	5.0
Power	35.0	652.2
Crew Station	20.0	51.9
Armament	5.0	5.0

The data in Tables II-2 and II-3 were used in the analysis to describe requirements based on the assumed number of battle damage incidents (10 per 100 sorties) and an assumed split between small arms and high explosive battle damage. For the analysis, we assumed a 50-50 split, but the model can easily examine any desired split of battle damage between small arms and high explosive threats.

2. Logistic Support Scenario

Although the operating scenario was kept constant in all of the analyses presented in this study, the logistic support scenario described in the following paragraphs was used as a baseline. Elements such as resupply times and intermediate-level maintenance capability were varied to test the sensitivity of results to these logistic parameters.

The following were the baseline parameters for logistic elements:

- No resupply from rear-echelon support points occurred during the 30-day scenario. Spare part inventories were designed to support 30 days of operations and were assumed to be on hand at the beginning of the scenario.
- Intermediate-level component repair capability varied among aircraft components
  - Repair of Remove, Repair, and Replace (RRR) F-15 components (as designated by AFLC) could begin any time after day 4 of the scenario.
  - Repair of Remove and Repair (RR) F-15 components (as designated by AFLC) could not be accomplished during the first 30 days.

Component repair capability varies because of requirements for support equipment and personnel. The designation of RR and RRR components is made on the basis of failure rates, mission criticality, and the amount of equipment needed to perform repair. The capability to perform organizational-level maintenance and to do battle damage repair was assumed to commence on day 1 of the scenario. Time to repair failed components at the organizational level (assuming repair parts are available), that is, MTTR, was assumed to be 2 hours for each LRU.

3. Component Reliability and Maintainability (R&M) Data

Baseline reliability and maintainability (R&M) data specifying LRUs of the F-15, LRU failure and NRTS rates and LRU intermediate-level maintenance repair times (TATs) were developed for Pacific Air Force (PACAF) WRSK components. Results of the analyses are based on the 387 LRUs of this data base, as established by AFLC for spares requirements determination. A complete list of these components and associated R&M parameters is contained in Appendix D.

Analyses of alternative aircraft reliability levels were carried out by scaling failure rate parameters of the R&M data base. For example, to analyze the effect of a doubling of reliability, the failure rate of each LRU in the data base was multiplied by 0.5.

Note that any evaluation of F-15 performance required a specification of the WRSKs. These specifications were developed using the appropriate parameters via the

Dyna-METRIC inventory selection routine. The analysis of the sortie generation capability of aircraft with double the baseline level of reliability was based on a WRSK developed on the basis of this higher reliability, which mirrors current AFLC practice.

III. DEMONSTRATIONS OF METHOD

This chapter contains the results of computer runs using F-15 data and the Dyna-METRIC model to demonstrate how changes in system reliability affect spares costs and sortie generation. We made the following baseline assumptions:

- Sortie program with surge in first six days (see Table II-1 for details)
- RRR repair beginning on day 5; no RR repair during the scenario.

Our process of analysis was:

- Buy spares to achieve this baseline scenario, at three levels of reliability.
- Analyze the cost of these spares.
- Vary the assumptions about attrition, battle damage, and other characteristics. In each case, begin with sufficient spares to achieve the flying program, under baseline conditions, at each level of reliability. Determine how well the squadron does with these spares packages in each excursion.
- Evaluate the percentage of sorties achieved and the total sorties achieved in each excursion.

In each case, increased reliability allows the squadron to achieve more sorties. This is always true during the initial surge period, a crucial time of the conflict, and usually true even during the last 24 days of the scenario when only one sortie per aircraft per day is required. Diminished reliability decreases the percentage of the flying program achieved.

In addition to this analysis, we did some preliminary investigations on how such evaluations might be performed on systems with incomplete data. We are beginning to analyze the F-15 as if it were in the early stages of system development. This involves using aggregated F-15 data to see whether we can obtain a good approximation of the results obtained from actual data.

A. ASSESSING THE COST OF SPARING UNDER DIFFERENT RELIABILITY LEVELS

The first step in the analysis was to determine the spare parts packages required to achieve the flying program under the baseline assumptions and the three reliability levels.

As expected, the costs of the spare parts packages are substantially different under the three different reliability assumptions:

Level of Reliability	Cost
Normal (AFLC failure rates)	$78,791
High (50 percent less than normal failure rate)	$32,389
Low (50 percent greater than normal failure rate)	$107,133

These results indicate that one of the benefits of increased reliability is that it lowers the cost of a given flying program under given conditions. Note that throughout the analysis described in the following section, we begin with spares packages that allow the flying program to be achieved under baseline conditions, reflecting Air Force practice. We have not tried to run each variation with equal spare parts packages independent of failure rates.

B. ASSESSING THE EFFECT OF RELIABILITY ON SORTIE GENERATION CAPABILITY UNDER DIFFERING CONDITIONS

Figure III-1 shows the sortie program for the analysis--a 30-day scenario with a surge in the first six days. We evaluated the ability of the squadron to fly the sortie program under the following sets of conditions:

- Organizational-level maintenance delay of two hours for each failure, an approximation of the time required to diagnose the problem, find the part, and fix the problem. (See Figure III-2.)
- Attrition of two percent per sortie during the surge and one percent thereafter, along with maintenance delay. (See Figure III-3.)
- Battle damage of ten percent per sortie, along with maintenance delay. This represents a preliminary analysis of the effects of battle damage; we are just beginning to explore the potential of this analysis. As a starting point, we assumed a ten-percent battle damage rate per sortie throughout the scenario. (Planning factors indicate that battle damage generally runs four to five times higher than attrition.) Since we assumed this rate throughout the scenario, it is a severe test of our concern that battle damage may "snow" the value of reliability. This analysis also included a two-hour maintenance delay. (See Figure III-4.)
- Battle damage, attrition, and maintenance delay together. (See Figure III-5)

- Delayed repair, no RRR repair capability until day 10 (rather than day 5 in the baseline), combined with attrition, battle damage, and maintenance delay. (See Figure III-6.)

Figures III-1 through III-6 and Table III-1 summarize the results. The figures show the percent of planned sorties achieved on each day, at each level of reliability. The table shows the cumulative number of sorties achieved by day 7 and by day 30.

Organizational-level maintenance delay affects sortie generation during the initial six-day surge, as seen in Figures III-3 and III-4. While nearly all sorties are achieved in the high-reliability case, less than 67 percent of the sorties during the surge in the normal-reliability case and approximately 42 percent of the sorties in the low-reliability case are achieved. After the first six days, all sorties are achieved in all cases.

Thus, the level of reliability does affect a squadron's ability to fly when the model is adjusted to reflect reasonable repair times each time a part fails. Our model indicates that even without combat-like conditions, reliability affects sortie generation. This fact is not identified in the Air Force's provisioning analysis, which incorporates no repair time.

Adding attrition to the maintenance delay excursion has a dramatic effect on sortie generation during the initial six-day surge. During the surge, the percent of sorties achieved falls to 49 by the end of day 6 in the normal-reliability case, 69 percent in the high-reliability case, and 33 percent in the low-reliability case. There are no differences by reliability level in performance during the last 24 days.

Battle damage substantially degraded mission capability at all reliability levels, but the reliability level still affected sortie generation capability during the surge period. After the surge, there were essentially no differences by reliability level.

The hypothesis that the existence of battle damage makes reliability less valuable does not seem to be borne out for the levels of battle damage and reliability we examined. Because some aircraft will suffer battle damage, having other failure-free aircraft is especially important.

When battle damage, attrition, and maintenance delay are combined, overall performance deteriorated considerably from the preceding cases. However, reliability did have a substantial effect during the surge period. By the end of the day six, only 20 percent of sorties could be flown in the normal-reliability cases and only 14 percent in the low-reliability cases. In the high-reliability case, however, 30 percent of the sorties were flown. After the surge, reliability made less of a difference in sortie generation.

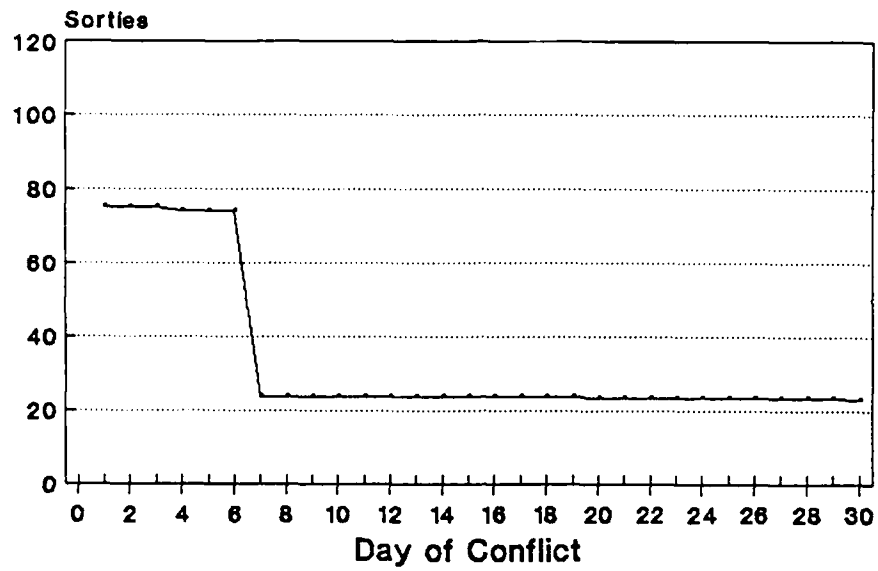

Figure III-1. Assumed Sortie Program for F-15C PACAF, 24-Aircraft Squadron

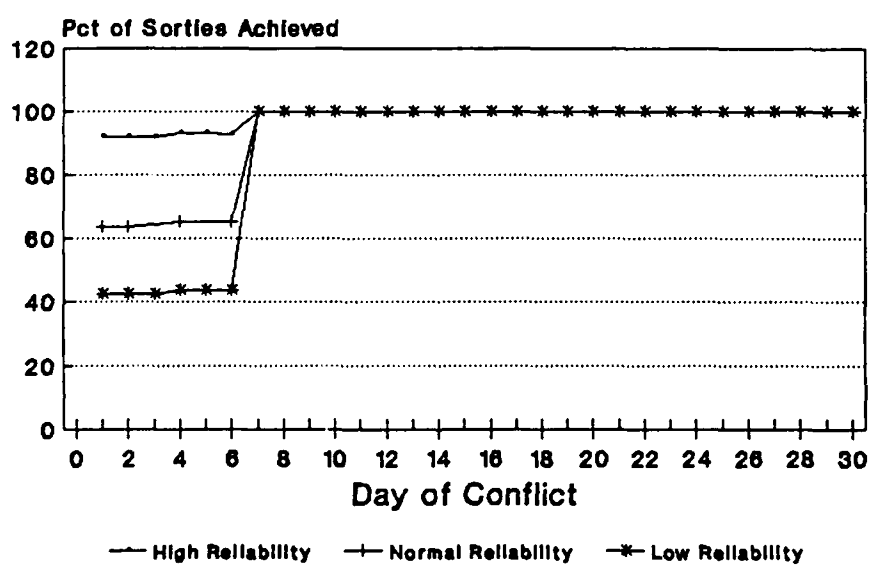

Figure III-2 Percent of Sorties Achieved with Maintenance Delay

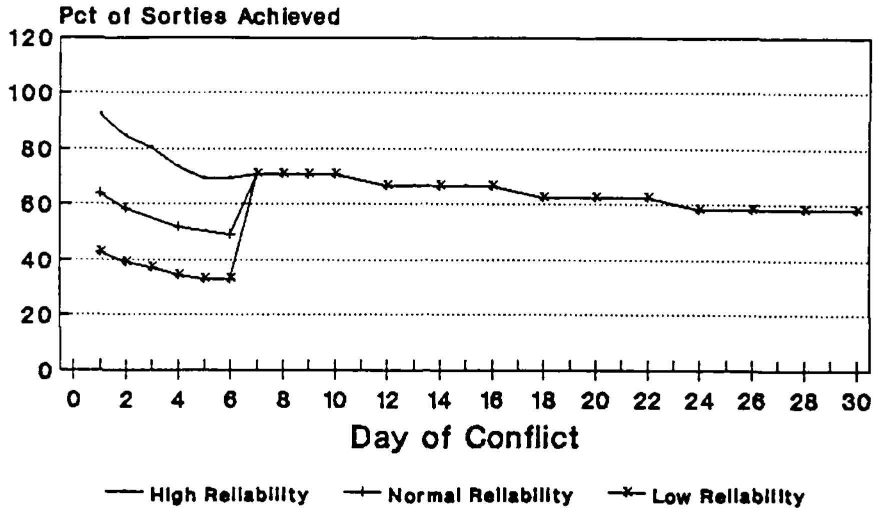

Figure III-3. Percent of Sorties Achieved with Attrition and Maintenance Delay

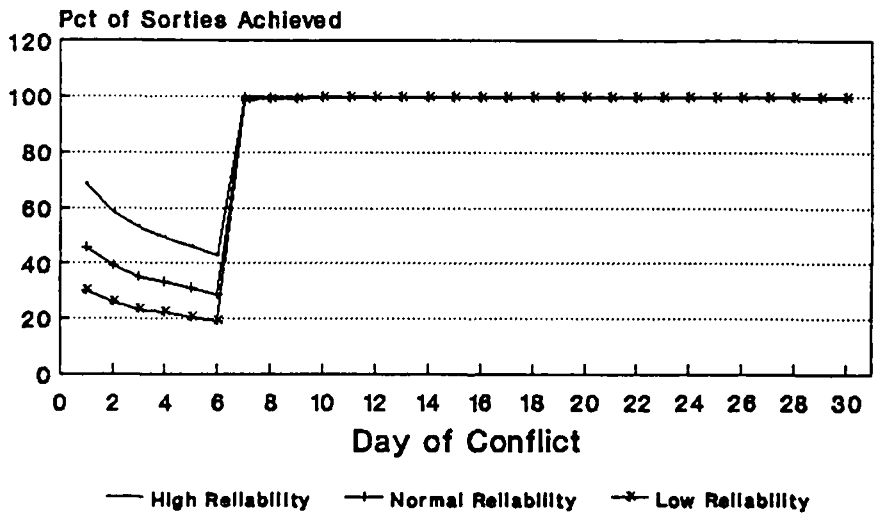

Figure III-4. Percent of Sorties Achieved with Battle Damage and Maintenance Delay

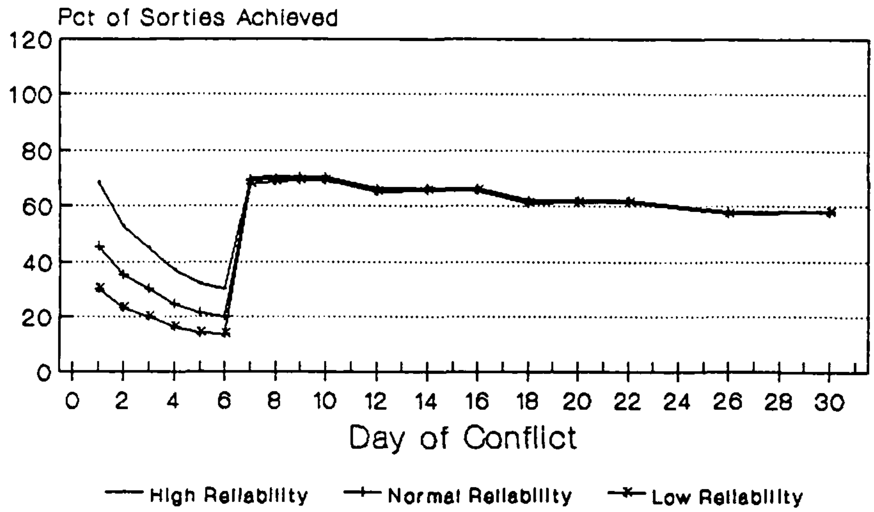

Figure III-5. Percent of Sorties Achieved with Attrition, Battle Damage, and Maintenance Delay

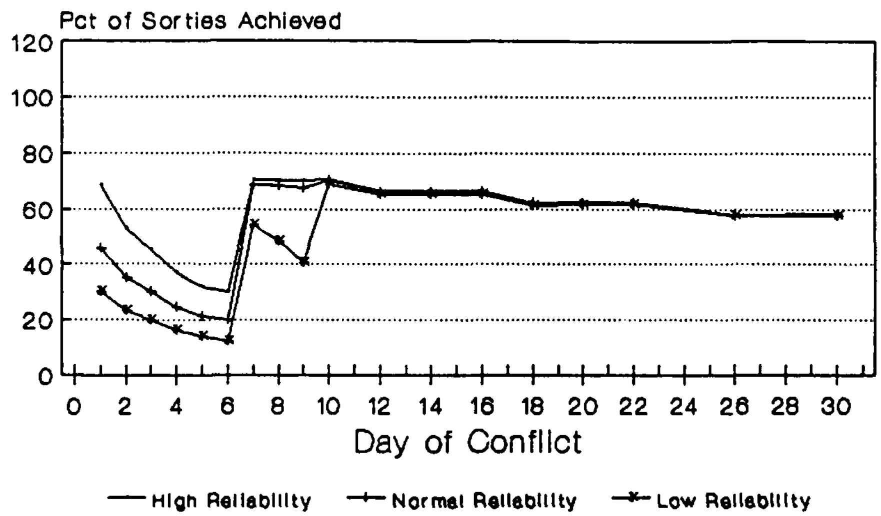

Figure III-6. Percent of Sorties Achieved in Delayed Repair Case with Attrition, Battle Damage and Maintenance Delay

Table III-1. Sorties Flown Under Different Conditions and Varying Levels of Reliability

	Number of Sorties Flown	
Sortie Condition	First 7 Days	Entire 30 Days
Baseline		
High	471.8	1018.2
Normal	471.8	1018.2
Low	470.5	1017.0
Maintenance Delay		
High	438.8	985.3
Normal	313.3	859.8
Low	216.8	763.2
Attrition		
High	366.8	713.8
Normal	261.8	608.8
Low	180.2	527.2
Battle Damage		
High	261.8	808.2
Normal	182.6	728.7
Low	129.4	673.9
Attrition and Battle Damage		
High	215.5	562.5
Normal	149.2	494.4
Low	104.5	445.8
RRR Day 10		
High	215.4	562.4
Normal	148.9	493.3
Low	100.3	429.6

Delayed repair (RRR on day 10) had only a relatively small effect compared to RRR on day 5, within reliability levels.

C PRELIMINARY ASSESSMENT OF THE CASE OF INCOMPLETE DATA

As a first step in using the model to analyze reliability in new systems, we are beginning to analyze the F-15 as if it were a system in the early stages of development. If our use of incomplete data reasonably approximates results obtained when actual, complete data is used, this will indicate that the method can be used for new systems.

The idea behind the method is to use the distribution of costs and failure rates of the LRUs in an existing system (in our case, the F-15) to specify the distribution of LRUs in a new system,when the new system's distribution is not yet known. If there are planning factors such as overall mean costs and failure rates available for the new system, these can be factored into the analysis.

We took the actual F-15 data and aggregated it to a level similar to that which might be available for a new system. Using a method described in Reference 2, we divided the actual F-15 LRUs into an 8-by-8 matrix based on the distribution of cost and failure rate. LRUs with low costs and low failure rates appeared in the top left of the matrix; LRUs with high costs and high failure rates appeared in the bottom right of the matrix. We then assigned LRUs in each of the 64 cells the mean cost and failure rate in the cell. Quantity per aircraft was always assumed to be one. Thus, we had a "false" data set of 387 LRUs with assigned costs and failure rates. We refer to this as the general knowledge scenario. We tested another false data set, referred to as the 14-LRU scenario, in which we assumed that we knew the actual data for the 14 LRUs with the highest costs and failure rates, while the rest of the LRUs had assigned data as before.

Table III-2 presents preliminary results of the first tests of the method. Rankings of costs by reliability level were the same in all cases--the low-reliability case had the highest costs and the high-reliability case the lowest. However, magnitudes differed. In the normal-reliability case, knowledge of only 14 LRUs led to cost estimates 11.5 percent higher. General knowledge of the cost distribution led to cost estimates 27 percent higher. The spread between high and low reliability also reflected some differences in cases of incomplete knowledge.

Table III-2. Costs of Spare Parts Packages (Thousands of Dollars) with Incomplete Data, by Reliability Level

Reliability Level	Level of Data Knowledge		
	Complete	14-LRUs	General
High	$32389	$43198	$50911
Normal	78791	87883	100070
Low	107133	129403	145859
	Ratio to Complete Knowledge Rate of Cost (Complete Knowledge Cost = 1)		
High	1	1.334	1.572
Normal	1	1.115	1.270
Low	1	1.208	1.361
Ratio of Cost (Normal Reliability Cost = 1)			
High	0.411	0.492	0.509
Normal	1	1	1
Low	1.360	1.472	1.458

We have completed only preliminary analysis in this area. In the future, we will analyze the effect of incomplete data knowledge on sortie generation and mission capable rates.

IV. IMPLICATIONS OF INITIAL RESULTS AND FUTURE PLANS

A. INITIAL CONCLUSIONS

The results of our analysis indicate the following:

- The method we have chosen for assessing the value of reliability produces credible results for an existing system.
- The methods of incorporating maintenance delay and battle damage repair into Dyna-METRIC also seem to produce credible results for an existing system.
- Even with a relatively high assumed rate of battle damage, greater reliability does have a positive value in the surge portion of the scenario.
- As long as WRSKs are bought using a methodology that does not account for the time needed to replace parts, higher reliability makes a significant difference in the ability to meet early surge flying requirements. This is true whether or not the logistic system is stressed by attrition, battle damage, and lack of repair capability.
- When circumstances are particularly trying, higher reliability allows substantially more sorties to be flown even after the surge portion of the scenario has passed. To this extent, reliability seems more beneficial under combat-like conditions than in more benign circumstances.

B. REFINING THE METHOD TO INCLUDE BATTLE DAMAGE

While the method used to evaluate battle damage seems to produce credible results, improved estimates are needed.

The estimates of time to repair and the distribution of damage by system used in the current analysis are not F-15 specific but were based on data from the Vietnam war. The F-4 is the most prevalent aircraft in the data. The battle damage rate per sortie is based on commonly used planning factors that suggest that battle damage occurs at four or five times the rate of attrition. Better data inputs would yield better estimates.

C. ASSESSING NEW SYSTEMS

The preliminary results of this analysis suggest that using incomplete data to assess the value of reliability in new systems is feasible. These methods do not provide exact magnitudes but appear to be useful for sensitivity analyses.

The unique architecture of the ATF presents some problems for analysis; aspects such as redundancy and the flying program will be difficult to analyze. Later in the study, we will strive to integrate as much data as can be obtained on the new system.

D. FUTURE PLANS

The conclusions presented in of this paper are preliminary. While we have demonstrated the practicality of this method of assessing the value of reliability in a combat-like environment, to fully realize the potential of this method, additional research is needed.

We will strive to develop estimates of the value of reliability for the next-generation tactical fighter. However, the quality of these estimates will depend on the quality of the data inputs obtained from the Air Force.

Other potential future work is identifying how changing the reliability of particular parts will affect combat sorties. This information could be useful in analyzing the value of component improvement programs.

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[2] Ince, John F., Evanovich, Peter, *Timely Analysis of the Readiness of New Systems*, Report No. CRM 86-119, Center for Naval Analyses, June 1986.

[3] Isaacson, K., Boren, P., Tsai, C., and Pyles, R. *Dyna-METRIC Version 4: Modeling Worldwide Logistic Support of Aircraft Components*, Report No. R-3389-AF, The RAND Corporation, May 1985.

[4] U. S. Air Force Logistics Command, *Coronet Warrior Exercise*, Briefing presented at LOGCAS-88, Logistics Capability Assessment Symposium, Colorado Springs, April 1988.

APPENDIX A

THE DYNA-METRIC MODEL--CAPABILITIES, outPUTS, AND LIMITATIONS

This section describes the Dyna-METRIC model's capabilities which include assessing system performance in a dynamic wartime scenario and assisting in identifying factors that may limit performance. Some of the model limitations are also discussed. Reference 3 provides additional detail on the model

Dyna-METRIC was selected as the model to use in studying the effect of repairable spares on warfighting capability. The model provides a representation for predicting Fully Mission Capable (FMC) status of a complete squadron of Air Force aircraft. It accepts a flying hour program for scenarios up to several months in length. Output from the model includes expected sortie generation capability along with a listing of potential problem parts for Remove, Repair, and Replace (RRR) and Remove and Repair (RR) maintenance items.

One major reason for selecting the Dyna-METRIC model for use in the IDA study is that Dyna-METRIC is currently being used by the Air Force to determine the components and repair parts to stock in War Readiness Spares Kits (WRSKs) and Base Level Self-sufficiency Spares (BLSS) to support up to 30 days of austere wartime flying. In addition, the Dyna-METRIC model is currently one of the leading models for generating reliability insights for items such as electronic warfare equipment.

The Air Force Logistics Command (AFLC) has implemented Dyna-METRIC into its Weapons System Management Information System (WSMIS) program to assess theater-level supportability of wartime operating plans. WSMIS is being expanded to assess repairable spares and engines for nearly all Air Force weapon systems. Dyna-METRIC spares assessments are closely related to the requirements process used to compute Air Force authorizations.

Dyna-METRIC computes an expected pipeline value for each part, which becomes the minimum quantity for each part. A safety level is then added through a marginal analysis routine until a specified not mission capable rate and back order goal for the squadron is achieved.

WRSK/BLSS computations assume that the failure rates for most parts are functions of flying hours. This is not the case for several classes of items such as guns, landing gear, and support equipment. For these non-optimized (NOP) items, required quantities for the kits are manually determined based on expert judgment supported by whatever demand data are available.

Air Force Logistics Assessment Exercises such as Coronet Warrior have indicated a close relationship between Dyna-METRIC model results and actual exercise experiences (see Appendix B).

A. CAPABILITIES OF DYNA-METRIC

Dyna-METRIC provides a detailed representation of the logistics system for many individual aircraft components -- particularly in the areas of component demand processes (permitting time-varying demand factors, sortie or flying-hour based demands, and onshore and offshore demand factors) and repair processes (permitting Not-Repairable-This-Station (NRTS) indicators). Different repair times at different echelons may be considered by the models, along with different repair resources and scope of repair at different echelons. In addition, the model can do depot workload and stockage computations and can compute base-level stockage with a no-cannibalization constraint. (Cannibalization is the practice of transferring a serviceable component from one aircraft to another.) Cannibalizaton is possible only when a serviceable component needed to repair one aircraft cannot be obtained from local supplies and another aircraft is already unserviceable because some other component has failed.

The primary measure of performance for the model is the calculation of the Fully Mission Capable (FMC) aircraft and sorties generated from the flightline when specific components are cannibalized. The Dyna-METRIC model provides a means of simulating one or more types of aircraft, at one or more bases located in one or more theaters of operations, for a period of time that may range from several days to several years. The model can predict the effect of the logistics support system on the bases' ability to execute their assigned flying programs.

Aircraft can operate out of a base on a fly-out, fly-back sortie program (as fighter aircraft typically do) or on a fly-in, fly-out program (for example, a cargo aircraft flying a circuit). In either case, broken parts arrive with incoming planes, but, in the case of cargo aircraft, removals of failed components may be more likely at some bases than at others.

Although aircraft are usually assumed to be identical, they can be flown on different missions at different times. For example, a base might fly air-to-air missions for some initial period and subsequently fly ground attack missions.

The flying programs to be executed may vary over time. The number of aircraft can increase with the deployment of new units and decrease due to attrition or the reassignment of aircraft. The number and length of sorties may vary each day, as can the maximum single aircraft sortie rate, which limits the number of sorties that can be flown by one operational aircraft in a single day. With this flexibility, the model can accommodate almost any conceivable flying program, including the peacetime or wartime scenarios.

1. Aircraft

Aircraft are assumed to have an indentured component structure. An aircraft is composed of Line-Replaceable Units (LRUs), which are composed of Shop-Replaceable Units (SRUs), which are composed in turn of sub SRU's. (Sub SRUs include bits and pieces that are consumed during repair of the SRU and other repairable components that may be repaired either locally or at a higher echelon).

Dyna-METRIC views the entire aircraft as a collection of LRUs. Certain major aircraft components, such as engines, are generally not referred to as LRUs, but these components can be treated as LRUs in the model.

In the model, aircraft availability is a direct function of the availability of the aircraft's LRUs. SRUs affect aircraft availability only through their ability to support the repair of their parent LRUs, and sub SRUs affect aircraft availability through their support of the repair of SRUs.

A given LRU may be on an aircraft one or more times. If several of a given LRU are on a plane, they can all be classified as essential or they may be classified as wholly or partially redundant. If wholly or partially redundant, more than one unit must fail before the aircraft is rendered Not Fully Mission Capable (NFMC).

LRUs may also be classified as essential or non-essential to a particular mission that the aircraft can execute. For example, a plane with a broken radar unit might be incapable of executing an air-to-air mission but capable of ground attack.

The model also accommodates the possibility of limited differences in the components on the aircraft at a single base. This situation may occur when components are being phased in or out or when some of the aircraft are specially equipped.

2. Logistics System

Repairable components essentially move upward in a hierarchical level of repair stations. Repairable parts are removed from the aircraft at the flightline and are serviced at the base level. If not repairable there, they are transported to a Centralized Intermediate Repair Facility (CIRF) and serviced. If not repaired there, they are sent to the depot. Parts at any level can also be condemned as not repairable. Stocks of serviceable spare parts may be held at any level, and over time these serviceable spares are sent down the hierarchy to replace the repairable ones that have been sent up.

The repair capabilities of each level can be modeled in considerable detail. Repair for LRUs can be specified as unconstrained or constrained. In the unconstrained case, maintenance is assumed to begin as soon as a component arrives at a repair facility. In the constrained case, the arriving components join a queue of other components also awaiting service. Components are selected from this queue based on a priority scheme that minimizes maximum back orders rather than on a first-come, first-served basis. How long a component waits for service depends on how many aircraft are not fully mission capable relative to other components and on how heavily loaded the repair facility is.

In addition to modeling repariable items, Dyna-METRIC can handle consumables if these components are assigned condemnation rates of 100 percent.

Dyna-METRIC portrays component support processes as a network of pipelines through which components flow as they are repaired or replaced. Each pipeline segment is characterized by a delay time that arriving components must spend in the pipeline before exiting the segment. Some delay times (such as local repair times) vary from component to component; others (such as intratheater transportation times) depend on the base being assessed. There may also be times when components are frozen in their pipeline segments and do not flow. For example, the transportation segments are modeled as being frozen when a transportation cutoff is in effect.

Failed components enter the pipeline network at the bases' flightlines. Each base has a flightline support capability that removes and replaces those components, drawing serviceable spares from local supply as needed to repair aircraft. Each base may also have component repair shops that test failed components and return them to serviceable condition. For units deploying to new bases, the repair capability may be available only after some delay, while the repair facility is being deployed and set up.

Once components have been removed from an aircraft, they are repaired at a local shop or sent to other facilities for repair. If the component can be repaired locally, it is returned to local stock. If the component cannot be repaired at all, the base condemns the component and requisitions a replacement.

If the component cannot be repaired at the base, it is declared NRTS and sent to either a CIRF or a depot, and a replacement component is requisitioned. Replacement components are requisitioned from the facility to which the NRTSed component is sent; that facility will immediately send the base a serviceable spare if one is available. If none is available, one will be sent as soon as possible after all prior requisitions for the same component have been filled. Once the repairable component reaches the CIRF or the depot, it is repaired and returned to that facility's stock so that it can be issued to satisfy the next demand.

If a component is sent to a CIRF and the CIRF cannot perform the repair, the CIRF will condemn the component or send it to the depot and requisition a replacement component from the depot. If a component is sent to the depot and the depot cannot perform the repair, the depot condemns the component and orders a replacement from the supplier. (If the scenario does not permit resupply of the depot, the supplier may be cut off.) As LRUs are processed at the various facilities, failed SRUs may be discovered. The SRU repair and resupply network is essentially the same as that for LRUs, as is the repair and resupply network for sub SRUs.

3. How the Model Represents the Logistics System

The key equation in Dyna-METRIC computes each LRU's, SRU's, or sub SRU's expected pipeline contents -- the expected number of each component that will be in each segment of the pipeline network. The computation is based on the planned time-dependent aircraft flying activity or (optionally) on the achievable Partially Mission Capable (PMC) and FMC time-dependent aircraft flying activity.

The model computes the removals caused by that activity, and then, using the time-dependent availability and delays associated with transportation and repair at bases, CIRFs, and depots, and the likelihood that the component will be classified as NRTS or condemned, determines the expected contents of each pipeline segment. The segments are totaled to forecast the total pipeline size (the expected quantity on order and in local repair) as seen by each base. The expected total pipeline size is the key parameter for a probability distribution that describes the number of components in the network, as seen at each base's flightline. That is, the expected total pipeline size is used to determine the probability that there are two components, the probability that there are three components, and so on.

Dyna-METRIC combines each component's dynamic demand and repair process time to estimate the expected pipeline quantity for each pipeline segment. The dynamic demands for pipeline segments after the base repair pipeline segment are derived from the dynamic departures from the preceding pipeline segment. For example, the LRUs entering the base-to-CIRF pipeline are the NRTS rate times the departures from the base repair pipeline segment.

The model computes expected pipeline quantities for each LRU's, SRU's, and sub SRU's repair pipeline segments (at base, CIRF, and depot) and transportation segments between these locations. SRUs awaiting parts at each location are computed for the number of sub SRUs in stock and under repair, and LRUs awaiting parts are computed from SRUs in stock, in repair, and awaiting parts.

Back orders at depots and CIRFs are computed from quantities in stock, in repair, awaiting parts, and on order. Those back orders are allocated to bases under a first-come, first-served rule. The expected base pipeline for LRUs, SRUs, and sub SRUs then consists of items in local repair and on order from higher echelons (in transit and back ordered).

B. OUTPUTS OF THE MODEL

Given descriptions of the scenario, the aircraft, and the logistics system, Dyna-METRIC provides various measures of performance. Besides traditional component-oriented logistics statistics, such as back orders, Dyna-METRIC provides higher combat capability-oriented measures related to the force's ability to generate sorties. The combat measures include aircraft availability and daily sortie generation capability. For each operating location, the model reports the expected number of available aircraft at any specified time and at any specified confidence level. For example, Dyna-METRIC might report that on day five of a scenario a given base could expect, on average, 16 available aircraft but that only 13 aircraft will be available with 95 percent confidence.

Dyna-METRIC also estimates the expected number of sorties a base can generate on any specified day. The model assumes that a base never overflies the program specified in the scenario (though the base may fail to achieve its program due to a shortage of available aircraft), so the predicted sortie generation capability will be less than or equal to the scenario's flying program. Thus the model's daily sortie estimates reflect both requested sorties and available aircraft.

Higher order performance measures are quite sensitive to whether or not LRUs can be cannibalized from one aircraft to repair another. Aircraft availability and sortie generation are typically much higher under a full cannibalization policy than under one of no cannibalization. The model allows the user to label each LRU as cannibalizable or not cannibalizable and then computes aircraft availability and sortie generation first using this data, then assuming a policy of full cannibalization. A policy that permits no cannibalization can be modeled by marking all components not cannibalizable.

From the expected base pipeline value, the model derives the probability that a given number of components are in repair or on order at each base. Using these total pipeline probability distributions for each component and the component's available stock at each base, the model next forecasts how the LRUs in repair and on order would (probabilistically) generate back orders (or aircraft "holes") for each component at a given time. It then distributes those holes across aircraft for two alternative cannibalization policies. For full cannibalization, Dyna-METRIC assumes that all component holes at each base are instantly consolidated on the fewest possible aircraft, thus making as many FMC aircraft as possible.

For partial cannibalization, holes of LRUs flagged as not cannibalizable are assumed to occur randomly across the aircraft at each base. Holes of cannibalizable LRUs are then consolidated onto aircraft already down for noncannibalizable LRUs. Leftover holes are consolidated onto as few of the remaining aircraft as possible. In each case, the model derives a full probability distribution for the number of degraded aircraft from which the fields in the capability assessment report are directly obtained. In particular, the expected number of NFMC aircraft and the expected number of FMC sorties are computed and reported for both cannibalization policies.

Dyna-METRIC generates a report that identifies the LRUs that are most likely to be a problem for at least one base and sorts them by the number of aircraft they are likely to ground. This report is especially helpful when the projected performance is unsatisfactory. For these LRUs, the model reports

- How many aircraft they will probably ground
- How many aircraft they would ground if the base-level spares were most effectively redistributed

- Where in the logistics system the LRUs are tied up (such as queued for repair at the CIRF, in transit from the depot, or awaiting serviceable SRUs at a base)
- Which SRUs (and sub SRUs) are tied up and where, if they limit LRU availability.

Two requirements computations are incorporated in the model. The stockage algorithm optionally computes stock with simple, single component fill rate goals, or with full-or-no-cannibalization FMC aircraft goals. The depot workload requirement computes the maximum and minimum workload necessary for a depot surge to meet its expected requisition levels for each component.

The pipeline probability distributions are used to compute stockage requirements. In this mode, Dyna-METRIC recommends additional LRU, SRU and sub SRU stock to achieve an FMC goal at the lowest cost. Two general strategies are employed: buying spares to ensure that each component will individually achieve a target FMC goal (disregarding other components) or buying spares so that all LRUs jointly achieve the FMC goal. Note that the first strategy does not achieve the goal of the second. Suppose that there are two LRUs, and each has a .1 probability of causing too many NFMC aircraft, so there is sufficient stock of each under the first strategy. But the probability that at least one of the two components will cause many NFMC aircraft is .19, so additional stock must be purchased to achieve the more ultimate aircraft-oriented goal under the second strategy.

If the user's objective is only to ensure that each LRU does not violate the NFMC goal with the stated confidence level, the model uses the LRU's individual pipeline probability distributions and increases each LRU's stock level until the stated confidence level is achieved for that component alone. If the objective is to ensure that all of the LRUs jointly achieve either a certain confidence level less than the stated percent NFMC, with full cannibalization, or expected NFMC less than a target NFMC percent with no cannibalization, the model first makes sure that each LRU achieves the goal individually, then it "buys" more LRUs across the full range of LRUs to achieve the overall goal. In either case, the model employs a marginal analysis technique. It first determines how much closer to the goal the user would be with an additional unit of LRU 1, or of LRU 2, or of LRU 3, and so on. It then adds an additional unit of the LRU with the best benefit/cost ratio and continues to add LRUs in this manner until the goal is attained.

A final Dyna-METRIC option is computing the maximum possible wartime depot repair workload (the expected daily arrivals for depot repair), the minimum required wartime depot workload (the minimum number of LRUs that must be inducted on each day into depot repair to satisfy expected depot requisitions), and the amount of LRU stock needed at the depot to offset repair and retrograde transportation delays under dynamic wartime conditions.

C. LIMITATIONS

Dyna-METRIC has several limitations that arise from the model's mathematical assumptions, approximations, and program implementation constraints. Generally, the mathematical assumptions exist because of the current state of the art in the modeling of inventory systems. Overcoming these limitations will require new mathematical breakthroughs. Using mathematical approximations reflects design choices--mathematical rigor required excessive computer time.

Dyna-METRIC's eight most frequently noted limitations are tied to mathematical assumptions, approximation, or implementation constraints:

- **Unconstrained repair may overestimate or underestimate performance.** In the model's simplest uses where constrained repair is not modeled, the mathematics underlying the model make two key assumptions about demands, transportation, and repair processes. First, demands arrive randomly according to one of two well-known arrival probability distributions (Poisson or negative binominal), and second, repair and transportation times have known probability distributions that are independent of the demand history. Neither of these assumptions is likely to be exactly true. Thus, these two assumptions may cause the model to underestimate or overestimate the logistics system performance if repair resources are not explicitly modeled. If one can judge that the demand and repair processes do not deviate radically from these assumptions, the model should be relatively accurate.
- **Lateral resupply is not modeled explicitly.** The assumption that demands, repair, and resupply functions are independent also prevents the model from directly assessing the effects of lateral supply across bases. Essentially, lateral supply would have the same effect as expedited resupply from a higher echelon. Because the effective resupply time would depend on the history of prior demands, repairs, and resupplied items, lateral resupply violates the model's underlying mathematical assumptions. An approximate workaround exists for this situation, however. If CIRFs are not being used for any other purpose in an analysis, one can model several related bases as being supported by a CIRF. Some of the theater's stock can then be relocated to the CIRF to be requisitioned and shared across all the bases to simulate lateral resupply.

- **The model assumes that aircraft deployed at each base are nearly identical.** It does allow for some fraction of the base's aircraft to have additional LRUs, but it assumes that aircraft can be described as subsets of other aircraft. The assumption is critical to the computation of both the full cannibalization and the partial cannibalization of FMC aircraft. Again, a workaround exists if the CIRF feature is not being used in the analysis. One can represent each real base with multiple aircraft types as several bases with a common CIRF containing the base's stocks for all the aircraft. By setting the base-to-CIRF and CIRF-to-base transportation times to zero, one can assess how both unique and common components' support affects the capabilities of multiple aircraft types.
- **The constrained repair computations are only approximate.** The model uses a deterministic, expected value computation to compute the expected pipelines for constrained, priority repair, so it only approximates real world repair processes. Further, it applies the resulting component pipeline distributions as though they were independent. Thus, the constrained repair computations only approximate likely logistics system performance, particularly when using the model to assess peacetime queueing. Scenario idiosyncrasies may cause some components' back orders to grow until they nearly match the worst component. Then, the model would not consider the correlations induced by priority repair, and it would provide an overly pessimistic assessment of performance. In such a case, one can use the model's problem LRUs report to detect an overly pessimistic assessment. If two or more LRUs that share a repair resource rank near each other in their NFMC impact, the assessment may be somewhat pessimistic.
- **Ordering policies for economic order quanitities and consumables are not modeled.** Some spare parts are so small or inexpensive that they are ordered in economic order quantities greater than one at a time (to avoid the trouble and cost of excess paperwork and handling). The model's mathematics precisely apply to only those cases where the order quantity is one. The mathematics are only approximately accurate for larger order quantity policies. As the order quantity increases, the pipeline variability would also effectively increase. One can work around this approximately by increasing the demand variance-to-mean ratio proportional to the square root of the order quantity. The pipeline variability will then reflect the expected variability due to the order quantity.
- **Expected back orders and awaiting parts quantities approximate additive pipelines.** For computational efficiency, the model does not compute the joint probabilistic effects of back orders and awaiting parts quantities with related pipelines. Instead, the expected values of these quantities are added to the appropriate pipelines as though they were also

Poisson or negative binomial distributions, which is not strictly correct. To treat this rigorously, the model must convolve the related probability distributions -- a task that would greatly increase computer time. However, tests of the approximation show that only modest errors are introduced in the computations of total base component breakdowns or NFMC aircraft when the expected back orders or awaiting parts quantities are small (less then 1). When these quantities increase, the errors appear to decrease.

- **Flightline and operational constraints are not explicitly modeled.** Operational constraints and flightline resources affect the sortie rates that can be achieved with an FMC aircraft. These factors are beyond the scope of the Dyna-METRIC model, so they do not appear explicitly. Nevertheless, their effects can be estimated in other models or analyses and incorporated in the Dyna-METRIC model sortie rate parameter.
- **The limitations of computers, such as word size representation, may affect the model's precision and accuracy.** Unlike the mathematics that the the computerized model is based on, the model itself cannot always carry out its computations with infinite precision. Computer and programming language manuals generally provide maximum and minimum quantities that can be represented. A program such as Dyna-METRIC computes extremely small probabilities and sums them in various ways. Often, a computed probability will be smaller than what can be represented by the programming technique used. Summing these small numbers, or almost zeroes, leads to cumulative errors called numeric instabilities, which may affect the model's results. Dyna-METRIC partially compensates for this effect when possible by using logarithms, which permit the model to represent much smaller numbers. In general, Dyna-METRIC encounters numerical instabilities only in rare cases when the expected pipeline sizes grow extremely large, beyond several thousand units. Such an instability will result in an extraordinary value for the number of NFMC aircraft -- nearly all aircraft will be NFMC. When such a situation occurs, the problem LRUs report will indicate that one or more LRUs (or SRUs) have very large pipelines. Removing the offending component from the analysis will usually correct the problem. Such components are usually analyzed, more appropriately, outside of the rigorous confines of a model like Dyna-METRIC.

Most of these limitations do not affect the current analysis. Despite any known limitations, Dyna-METRIC is a useful model for the type of analysis IDA is performing. The model allows analysis of a variety of operating tempos and logistic support scenarios at a reasonable level of detail and reasonable computer cost.

APPENDIX B

MODEL VALIDATION--THE CORONET WARRIOR EXERCISE

One of the most difficult tasks in research analysis is trying to determine whether a model that has been used is valid. While much has been written about the problem, no truly satisfactory solutions have been proposed, and many writers take refuge in philosophical abstraction or statistical mathematics. The following sections describe a more common sense approach to a validation process for Dyna-METRIC.

A. GUIDELINES FOR MODEL ASSESSMENT

Model validity is often confused with truth and attempts that are made to prove that some model results are true. Model assessment is quite different; it is the process by which we establish sufficient confidence in the Dyna-METRIC model to use it for the intended purpose.

The only absolute test of a model's validity that is theoretically possible is to observe and record events from an actual system in an actual environment at a suitable time. However, this test is very difficult in practice; true validation of a model that simulates wartime activity is nearly impossible. For this reason, validation should be used as a confidence-boosting exercise. Because models are built for a distinct purpose, model assessment should be used to determine whether the model meets its intended purpose. Models cannot be classified as absolutely valid or completely invalid, except in relation to a particular purpose, and a model that serves for one purpose may be misleading if used for another.

The following questions are suggested guidelines for model assessment:

- Are the system boundaries properly considered in terms of intended use? If the model does not include the parts of the system that can be changed to influence operational behavior, it is virtually useless and therefore invalid. For example, a model might present an excellent treatment of air-to-air munitions effectiveness after launch but ignore potential problems in transporting the aircraft with the munitions to the combat area.

- Do any gross model errors exist? For example, a model that produces negative results when positive results are obviously appropriate is not particularly valid because its results are conceptually impossible or are beyond all system logic. Errors of this type may be due to simple mistakes. Alternatively, they may arise from failure to model constraints properly or to represent decision functions realistically or from dimensional errors. Model validation is not simply a statistical exercise in curve fitting but primarily a matter of judgment, even when statistical procedures are employed.
- Does the model structure sufficiently correspond with the system being studied? The analysts must be confident in using the model, and managers must be confident in making decisions based on insights gained from using the model. The model should accurately represent the system. A check must be made to ensure that the proper variables have been correctly interconnected and the decision functions in the model reasonably reflect those actually used, which is very difficult to do. Data are rarely available to verify that the modeled decision function reflects what was done in the past. Even when these data are available, they can only be used to reject an obviously incorrect formulation. In practice, a sound approach is to conduct a simulation session with managers or decision-makers. They should be asked what they would do under various sets of circumstances; the model should then be made to function similarly, for the same reasons.
- Are the parameter values correct? (This is, in many ways, a minor question.) The dynamics of a system are usually not greatly affected by most of the parameters, providing they are within a fairly broad range. However, some of the parameters will be more critical, and changing their values may change the behavior mode of the system.
- Does the model reproduce the system behavior? To answer this question, time series from the system must be compared to series for the same variable from the model, and the model fails if its values do not sufficiently agree with the actual history. This classical approach is often allied to sophisticated statistical procedures but some serious difficulties may occur in application.

In practice, total validation is rarely possible, as the data are usually not available. Even when data can be found, they relate only to the system states and rarely to the policies by which these states are controlled. Comparing model output to actual data is meaningless unless one also knows that the policies were identical and were consistently applied. It seems too restrictive to reject a model because one or two of its outputs do not match an uncertain past data history.

Unfortunately, most of the statistical tests for the agreement between two time series (the model's and the actual data) require about 30 data points. Even with monthly data it is unlikely that one could find a representative 2 1/2-year period during which no system changes occurred and from which actual data is available. For a quarterly model, finding or collecting the required amount of data is virtually impossible.

Generally, the best method for building confidence in a model is ensuring that the model has been carefully designed in conjunction with management.

B. AIR FORCE LOGISTICS ASSESSMENT EXERCISE CORONET WARRIOR

The Dyna-METRIC model used in the IDA study has been validated through Air Force Logistics assessment exercises, such as Coronet Warrior which have indicated a close relationship between Dyna-METRIC model results and actual exercise experiences[1].

The Coronet Warrior exercise was specifically designed to evaluate Dyna-METRIC's ability to predict Fully Mission Capable (FMC) aircraft, sorties, and potential problem parts in a Remove, Repair, Replace (RRR) maintenance scenario. The purpose of the exercise was to evaluate the logic and implementations of the standard Air Force spares methodology, particularly the ability of Dyna-METRIC to predict unit capability.

For the exercise, the 94th Tactical Fighter Squadron (TFS) at Langley Air Force Base isolated its F-15C squadron at home station with only the aircraft, personnel, and equipment that would be deployed in a wartime contingency. No resupply was allowed, and the unit used its actual on-hand War Reserve Spares Kits (WRSK) assets with one exception--the on-hand quantities of a handful of items were reduced to a level that supported a Dyna-METRIC prediction of a C-2 sortie flying level, as defined by the Air Force Logistics Command (AFLC). This represented a 71 percent fill of WRSK assets. The unit operated for 30 consecutive days working 12-hour shifts.

Data were collected on nearly all aspects of the exercise to support a wide range of follow-on analysis. Of primary concern was the comparison of predicted and actual performance and the reasons for any deviations, with the intent of correcting any model, data, or unit procedural deficiencies identified.

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1 Based on information presentated at LOGCAS-88, a USAF sponsored Logistics Capability Assessment Symposium, April 1988, at the US Air Force Acedemy, Colorado Springs, Colorado.

Dyna-METRIC predicted that the unit would fly only 91 percent of its tasked sorties (C-2 level), losing sorties toward the end of the surge period and the end of the exercise and would be capable of flying only 15 sorties on the last day. The unit actually flew 98 percent of the tasked sorties, losing a few sorties on various days throughout the exercise.

The differences between actual and predicted performance were more dramatic with respect to the FMC aircraft. A fully authorized WRSK is supposed to support 18 of 24 aircraft on day 30. With the 71 percent filled WRSK, Dyna-METRIC predicted the unit would only have 4 FMC aircraft at the end of 30 days. Note that the WRSK was adjusted to provide a C-2 sortie level, which was achievable with the predicted FMC aircraft level, because each aircraft is capable of flying an average of 3.5 sorties per day.

The unit actually had 17 FMC aircraft left and flew 98 percent of tasked sorties versus the 91 percent predicted. The actual FMC aircraft levels should have been sufficient to support 100 percent of tasked sorties; however, the 2 percent of sorties lost were due to factors not considered by the model. An analysis of the model and current data sources revealed sound model logic (except for some types of repair) and some key data problems.

Predicted and actual performance differed for several reasons. The main reason was that the ten predicted major problem parts did not fail at the anticipated rate. All of these items were non-optimized or electronic warfare components whose demand rates are difficult to predict. Many parts failed less than predicted, but a few failed at much higher rates than expected and would have jeopardized the outcome of the exercise if intermediate-level maintenance were not available for these items. A small portion of the differences between predicted and the actual results was caused by the repair logic of the model, which did not account for priority repair actions and assumes no constraints on test equipment and personnel.

The repair area of the model does need some improvements. In general, the high-failure-rate parts were repaired faster and more successfully than the model predicted. The repair logic in Dyna-METRIC does not adequately represent limited availability of test equipment nor priority repair actions.

From the Coronet Warrior exercise, many valuable lessons were learned about Dyna-METRIC, WRSK configuration and makeup, consumable equipment reliability, the value of repair capability, and maintenance management at a wartime tempo. Much of this information can be applied to improve logistics supportability planning for new weapons systems such as the ATF.

C. OTHER VALIDATION EXERCISES

Other validation exercises include F-4s at Leading Edge I and F-16s at Leading Edge II. These exercises indicated that Dyna-METRIC reasonably predicts general levels of sortie capability and identifies key problem items. However, both of the Leading Edge tests were limited in scope (lasting only 6 to 7 days with no repair capability), which somewhat limited the evaluation.

In the Leading Edge exercises, the evaluation of Dyna-METRIC was conducted on a non-interference basis and was not a significant portion of the exercise. In contrast, the primary purpose of Coronet Warrior was to evaluate the Dyna-METRIC model; therefore, data collection and unit procedures were established to support the evaluation.

D. CONCLUSIONS

Dyna-METRIC modeling techniques, when used with reasoned inputs, will produce appropriate WRSK requirements. The repair logic in the model needs some improvement in the areas of equipment constraints and priority repair.

Variability of demand for parts is a reality that complicates any forecasting attempts. The value of intermediate maintenance to compensate for such variability has been clearly demonstrated.

The exercise method of assessing a model identifies the problems associated with data availability. Despite the dramatic improvement in modeling assessment, many areas required improved methods for measuring the effect of logistics resource shortfalls on sortie generation capability.

APPENDIX C

APPLICATION OF THE DYNA-METRIC MODEL ON THE VAX COMPUTER SYSTEM AT THE INSTITUTE FOR DEFENSE ANALYSES

The source code, executable code, and data for the Dyna-METRIC model is maintained on a Digital Equipment Corporation VAX computer located in the main Insitute for Defense Analyses (IDA) building. Arrangement and set-up procedures have been developed to assist in providing model results for a variety of issues.

The Dyna-METRIC model source code used at IDA is RAND Version 4.4. RAND maintained the model on an IBM computer and the model was converted at IDA for use on the VAX. The data set that has been used for the analyses of this report is an F-15 data set used by the Air Force Logistics Command at Wright-Patterson Air Force Base to develop WRSK kits.

The data and the code are maintained on a project disk pack called METRICIV. This project pack is usually mounted on the DRA1: drive on the VAX 8600. The directory structure is arranged to have the Dyna-METRIC subdirectory under [GMCBRYDE]. Thus the basic default directory is DRA1:[GMCBRYDE. DYNAMETRIC].

Under the DYNAMETRIC subdirectory are a number of other subdirectories, such as the one containing the source code and executable code [.SRUDEV]. In this sub-directory, all changes to check out the model for SRU capabilities were completed. The version of the model currently in use is still set up to make SRU runs, although the model is used mainly for LRU evaluations at this time.

Other subdirectories under DYNAMETRIC are usually maintained by the month of the year when the evaluation runs were active, such as March, April, May, June, and by the aircraft of interest. The JUNEF-15 subdirectory will be used as an example. Under the subdirectory of JUNEF-15 a series of subdirectories are maintained, such as 100REL.DIR for the series of runs dealing with the normal failure runs. Other directories include the 150REL.DIR, for the series of runs dealing with failures that are 1.5 times the normal failure rates, and another directory, 050REL.DIR, for the series of runs dealing with failures that are 0.5 times the normal failure rates.

Under the subdirectory structure of 100REL.DIR, for example, a series of additional subdirectories contain the results for the analyses of air-battle-damage-repair (the ABDR.DIR); the analyses of attrition (ATTR.DIR); the analyses of RRR (RRR.DIR); the analyses of transportation (TRAN.DIR); the analyses of the effects of a 2-hour delay for repairing and replacing failed LRU components (2HR-DELAY.DIR). The analyses and evaluation of buying LRU stocks is maintained in sub-directory .BUY-EVAL.DIR.

After the needs for a particular computer run are understood, a decision can be made to fit it into one of the existing subdirectories or to create another new subdirectory that better suits the desired evaluation. If a new subdirectory is needed, it is created using normal VAX VMS commands. Then, by moving to this subdirectory and selecting a data file that most closely fits the new evaluation, a copy of the data file is made in the working subdirectory. The command file that most closely fits the evaluation needs is also copied. Figure 1 is an illustrative example of a command file often used in the current set of Dyna-METRIC evaluation runs.

After the desired changes to the data file are made and the data file is stored with a name that has some relation to the evaluation, a copy of the command file is brought into the editor and a series of substitutions are made for the XXXXX parts of the command file, with the name of the new evaluation data file. This modified command file is stored with a name related to the current evaluation. This command file may be submitted to the BATCH queue of the computer. When the run is completed, two files will be available containing the output information needed by the evaluation analyst. One is a complete set of input data, the ECHO print from Dyna-METRIC run, and the REPORT and PIPE results of the run. Another shorter output may be obtained to show only the specific output results desired.

APPENDIX D

LISTING OF F-15C PACAF LRUS USED IN THE ANALYSIS

This table is a listing of component-related data from the input data set. Column 1 lists the component part name; column 2 identifies the type of component along with the assigned input number. L indicates an LRU component, S indicates an SRU component, and SS indicates a sub SRU component. Column 3 specifies whether CIRF repair facilities are available for that component. Column 4 specifies when to decide to NRTS or condemn the part, either before or after testing. Column 5 is the cost of buying an additional unit of stock of the component. Column 6 specifies the onshore and offshore bases' peacetime demand rate per flying hour. Column 7 specifies the level of repair, BASE, CIRF or DEPOT. Column 8 specifies the peacetime and wartime resupply times, in days of the expected time for the highest echelon that repairs the component to procure a replacement during either peacetime or wartime.

Table D-1. F-15C Pacific Air Force Line Replaceable Units Used in the Analysis

PART NAME	NUMBER	CAN TEST AT CIRF?	NRTS OR CONDEMN	COST	DEMANDS PER FLYING HOUR ONSHORE	DEMANDS PER FLYING HOUR OFFSHORE	LEVEL OF REPAIR	RESUPPLY (DAYS) PEACE	RESUPPLY (DAYS) WAR
1005000566753	L 1	NO	AFTER TEST	29940.	0.00060	0.00060	BASE	16.0	30.0
1270010405948	L 2	NO	AFTER TEST	50369.	0.00820	0.00820	BASE	14.0	30.0
1270010469884	L 3	NO	AFTER TEST	64321.	0.00680	0.00680	BASE	14.0	30.0
1270010635567	L 4	NO	AFTER TEST	124585.	0.00730	0.00730	BASE	14.0	30.0
1270011838987	L 5	NO	AFTER TEST	77474.	0.01050	0.01050	BASE	14.0	30.0
1280010423952	L 6	NO	AFTER TEST	37610.	0.01120	0.01120	BASE	14.0	30.0
1560010037178FX	L 7	NO	AFTER TEST	78621.	0.00110	0.00110	BASE	25.0	30.0
1650003337185	L 8	NO	AFTER TEST	3340.	0.00140	0.00140	BASE	11.0	30.0
1650010503491	L 9	NO	AFTER TEST	42364.	0.00070	0.00070	BASE	14.0	30.0
1650010653500FS	L 10	NO	AFTER TEST	3654.	0.00080	0.00080	BASE	14.0	30.0
1680010325251	L 11	NO	AFTER TEST	19667.	0.00150	0.00150	BASE	14.0	30.0
1680010473179FX	L 12	NO	AFTER TEST	17360.	0.00170	0.00170	BASE	14.0	30.0
5821001387991	L 13	NO	AFTER TEST	4729.	0.00590	0.00590	BASE	16.0	30.0
5821011365467	L 14	NO	AFTER TEST	5741.	0.00420	0.00420	BASE	16.0	30.0
5821011369512	L 15	NO	AFTER TEST	5044.	0.00590	0.00590	BASE	16.0	30.0
5826002625018	L 16	NO	AFTER TEST	9318.	0.00070	0.00070	BASE	8.0	30.0
5826010121938	L 17	NO	AFTER TEST	1865.	0.00520	0.00520	BASE	19.0	30.0
5826010211744	L 18	NO	AFTER TEST	8240.	0.00140	0.00140	BASE	14.0	30.0
5836010512886CX	L 19	NO	AFTER TEST	2586.	0.04050	0.04050	BASE	16.0	30.0
5841010032850	L 20	NO	AFTER TEST	67308.	0.00500	0.00500	BASE	14.0	30.0
5841010486312	L 21	NO	AFTER TEST	102078.	0.00640	0.00640	BASE	14.0	30.0
5841010588862	L 22	NO	AFTER TEST	12465.	0.00050	0.00050	BASE	14.0	30.0
5841010603721	L 23	NO	AFTER TEST	277457.	0.00750	0.00750	BASE	14.0	30.0
5841010630855	L 24	NO	AFTER TEST	340306.	0.01040	0.01040	BASE	14.0	30.0
5841011007363	L 25	NO	AFTER TEST	397056.	0.01430	0.01430	BASE	14.0	30.0
5841011234126	L 26	NO	AFTER TEST	151639.	0.00430	0.00430	BASE	14.0	30.0
5841011331822	L 27	NO	AFTER TEST	394321.	0.00760	0.00760	BASE	14.0	30.0
5841011356194	L 28	NO	AFTER TEST	239604.	0.01120	0.01120	BASE	14.0	30.0
5841011582818	L 29	NO	AFTER TEST	403587.	0.00620	0.00620	BASE	14.0	30.0
5865004775704EW	L 30	NO	AFTER TEST	2122.	0.00090	0.00090	BASE	17.0	30.0
5865010131798EW	L 31	NO	AFTER TEST	1632.	0.00010	0.00010	BASE	16.0	30.0
5865010456276EW	L 32	NO	AFTER TEST	93682.	0.03630	0.03630	BASE	19.0	30.0
5865010548810EW	L 33	NO	AFTER TEST	32349.	0.00580	0.00580	BASE	20.0	30.0
5865010668075EW	L 34	NO	AFTER TEST	91545.	0.03900	0.03900	BASE	11.0	30.0
5865010891745EW	L 35	NO	AFTER TEST	22566.	0.00200	0.00200	BASE	14.0	30.0
5865010891808EW	L 36	NO	AFTER TEST	77072.	0.00790	0.00790	BASE	13.0	30.0
5865011003768EW	L 37	NO	AFTER TEST	59193.	0.01820	0.01820	BASE	12.0	30.0
5865011003769EW	L 38	NO	AFTER TEST	7061.	0.00070	0.00070	BASE	21.0	30.0
5865011003770EW	L 39	NO	AFTER TEST	80985.	0.02550	0.02550	BASE	13.0	30.0
5865011003771EW	L 40	NO	AFTER TEST	7036.	0.00200	0.00200	BASE	30.0	30.0
5865011003830EW	L 41	NO	AFTER TEST	18725.	0.00080	0.00080	BASE	9.0	30.0
5865011142469EW	L 42	NO	AFTER TEST	16053.	0.00140	0.00140	BASE	14.0	30.0
5865011360443EW	L 43	NO	AFTER TEST	43247.	0.04970	0.04970	BASE	11.0	30.0
5865011449320EW	L 44	NO	AFTER TEST	160776.	0.01110	0.01110	BASE	10.0	30.0
5865012112335EW	L 45	NO	AFTER TEST	43247.	0.04470	0.04470	BASE	14.0	30.0
5895003278781	L 46	NO	AFTER TEST	2814.	0.00210	0.00210	BASE	11.0	30.0
5895003409619	L 47	NO	AFTER TEST	4198.	0.00110	0.00110	BASE	14.0	30.0
5895010162209	L 48	NO	AFTER TEST	38700.	0.00420	0.00420	BASE	14.0	30.0
5895010963727	L 49	NO	AFTER TEST	24025.	0.00200	0.00200	BASE	17.0	30.0
5895011126380	L 50	NO	AFTER TEST	19570.	0.01370	0.01370	BASE	16.0	30.0
5895011349225	L 51	NO	AFTER TEST	26780.	0.00800	0.00800	BASE	14.0	30.0
6110005390411	L 52	NO	AFTER TEST	3193.	0.00030	0.00030	BASE	14.0	30.0
6110010498639	L 53	NO	AFTER TEST	4817.	0.00140	0.00140	BASE	14.0	30.0
6605010848224	L 54	NO	AFTER TEST	22145.	0.00530	0.00530	BASE	14.0	30.0
6605010940775	L 55	NO	AFTER TEST	22544.	0.00740	0.00740	BASE	14.0	30.0

Table D-1. F-15C Pacific Air Force Line Replaceable Units Used in the Analysis (Continued)

6605010954208	L	56	NO	AFTER TEST	139222.	0.02040	0.02040	BASE	14.0	30.0
6610001226625	L	57	NO	AFTER TEST	19972.	0.00440	0.00440	BASE	14.0	30.0
6610001491134	L	58	NO	AFTER TEST	32459.	0.00890	0.00890	BASE	13.0	30.0
6610010903390	L	59	NO	AFTER TEST	22660.	0.00330	0.00330	BASE	10.0	30.0
6610011694770	L	60	NO	AFTER TEST	23936.	0.00400	0.00400	BASE	14.0	30.0
1005001886968	L	61	NO	AFTER TEST	2175.	0.01400	0.01400	BASE	14.0	30.0
1005001886969	L	62	NO	AFTER TEST	2908.	0.00550	0.00550	BASE	14.0	30.0
1005002790528	L	63	NO	AFTER TEST	3529.	0.02120	0.02120	BASE	14.0	30.0
1005010429740	L	64	NO	AFTER TEST	44487.	0.00410	0.00410	BASE	14.0	30.0
1005010932225	L	65	NO	AFTER TEST	5012.	0.00500	0.00500	BASE	14.0	30.0
1005011055476	L	66	NO	AFTER TEST	10475.	0.00220	0.00220	BASE	14.0	30.0
1095001664286	L	67	NO	AFTER TEST	2888.	0.00050	0.00050	BASE	16.0	30.0
1280010315802	L	68	NO	AFTER TEST	638.	0.00030	0.00030	BASE	11.0	30.0
1280010524811	L	69	NO	AFTER TEST	2018.	0.00100	0.00100	BASE	14.0	30.0
1280010542853	L	70	NO	AFTER TEST	481.	0.00040	0.00040	BASE	16.0	30.0
1280010542856	L	71	NO	AFTER TEST	495.	0.00030	0.00030	BASE	15.0	30.0
1280011354647	L	72	NO	AFTER TEST	29648.	0.01060	0.01060	BASE	14.0	30.0
1440010595257BL	L	73	NO	AFTER TEST	37521.	0.00080	0.00080	BASE	14.0	30.0
1440010891384AB	L	74	NO	AFTER TEST	1514.	0.00200	0.00200	BASE	14.0	30.0
1560005186889FX	L	75	NO	AFTER TEST	20148.	0.00060	0.00060	BASE	14.0	30.0
1560005235267FX	L	76	NO	AFTER TEST	24334.	0.00060	0.00060	BASE	14.0	30.0
1560010145787FX	L	77	NO	AFTER TEST	25576.	0.00140	0.00140	BASE	14.0	30.0
1560010564844FX	L	78	NO	AFTER TEST	52188.	0.00050	0.00050	BASE	14.0	30.0
1560010753550FX	L	79	NO	AFTER TEST	2961.	0.00060	0.00060	BASE	13.0	30.0
1560011426673FX	L	80	NO	AFTER TEST	17999.	0.00030	0.00030	BASE	14.0	30.0
1560011825949FX	L	81	NO	AFTER TEST	16424.	0.00050	0.00050	BASE	14.0	30.0
1620002671046	L	82	NO	AFTER TEST	15413.	0.00060	0.00060	BASE	9.0	30.0
1620010362895	L	83	NO	AFTER TEST	3885.	0.00030	0.00030	BASE	14.0	30.0
1620010627002	L	84	NO	AFTER TEST	48153.	0.00060	0.00060	BASE	14.0	30.0
1620011670999	L	85	NO	AFTER TEST	69525.	0.00060	0.00060	BASE	14.0	30.0
1620011671000	L	86	NO	AFTER TEST	69525.	0.00060	0.00060	BASE	14.0	30.0
1630003934771	L	87	NO	AFTER TEST	5944.	0.00060	0.00060	BASE	20.0	30.0
1630010182004	L	88	NO	AFTER TEST	4223.	0.00140	0.00140	BASE	16.0	30.0
1630010585912	L	89	NO	AFTER TEST	6064.	0.01080	0.01080	BASE	14.0	30.0
1630010597069	L	90	NO	AFTER TEST	15238.	0.00250	0.00250	BASE	14.0	30.0
1630010645005	L	91	NO	AFTER TEST	891.	0.00070	0.00070	BASE	17.0	30.0
1630010716112	L	92	NO	AFTER TEST	1810.	0.00890	0.00890	BASE	14.0	30.0
1650002886044	L	93	NO	AFTER TEST	7916.	0.00090	0.00090	BASE	14.0	30.0
1650002952369	L	94	NO	AFTER TEST	8673.	0.00140	0.00140	BASE	14.0	30.0
1650003035851	L	95	NO	AFTER TEST	1782.	0.00030	0.00030	BASE	15.0	30.0
1650003550211	L	96	NO	AFTER TEST	7486.	0.00110	0.00110	BASE	9.0	30.0
1650003550213	L	97	NO	AFTER TEST	19915.	0.00040	0.00040	BASE	15.0	30.0
1650003715854	L	98	NO	AFTER TEST	1545.	0.00060	0.00060	BASE	12.0	30.0
1650004330145	L	99	NO	AFTER TEST	5886.	0.00060	0.00060	BASE	13.0	30.0
1650005168603	L	100	NO	AFTER TEST	2912.	0.00020	0.00020	BASE	12.0	30.0
1650005316029	L	101	NO	AFTER TEST	10974.	0.00170	0.00170	BASE	10.0	30.0
1650005405573	L	102	NO	AFTER TEST	352.	0.00000	0.00000	BASE	23.0	30.0
1650010045794	L	103	NO	AFTER TEST	5013.	0.00030	0.00030	BASE	12.0	30.0
1650010181073	L	104	NO	AFTER TEST	4973.	0.00020	0.00020	BASE	21.0	30.0
1650010189089	L	105	NO	AFTER TEST	13907.	0.00160	0.00160	BASE	14.0	30.0
1650010206212	L	106	NO	AFTER TEST	9600.	0.00090	0.00090	BASE	9.0	30.0
1650010208093	L	107	NO	AFTER TEST	5156.	0.00050	0.00050	BASE	9.0	30.0
1650010297620	L	108	NO	AFTER TEST	3477.	0.00030	0.00030	BASE	13.0	30.0
1650010350799	L	109	NO	AFTER TEST	4024.	0.00090	0.00090	BASE	15.0	30.0
1650010505228	L	110	NO	AFTER TEST	5248.	0.00090	0.00090	BASE	12.0	30.0
1650010520916	L	111	NO	AFTER TEST	12921.	0.00070	0.00070	BASE	16.0	30.0
1650010657768	L	112	NO	AFTER TEST	24875.	0.00210	0.00210	BASE	13.0	30.0
1650010912313	L	113	NO	AFTER TEST	11372.	0.00080	0.00080	BASE	14.0	30.0
1650010964603	L	114	NO	AFTER TEST	38831.	0.00190	0.00190	BASE	14.0	30.0
1650011055523	L	115	NO	AFTER TEST	39564.	0.00220	0.00220	BASE	14.0	30.0

Table D-1. F-15C Pacific Air Force Line Replaceable Units Used in the Analysis (Continued)

1650011215786	L 116	NO	AFTER TEST	10193.	0.00060	0.00060	BASE	8.0	30.0
1650011216981	L 117	NO	AFTER TEST	7246.	0.00060	0.00060	BASE	14.0	30.0
1650011226948	L 118	NO	AFTER TEST	14706.	0.00040	0.00040	BASE	13.0	30.0
1650011537932	L 119	NO	AFTER TEST	5026.	0.00040	0.00040	BASE	14.0	30.0
1650011739697	L 120	NO	AFTER TEST	158593.	0.00140	0.00140	BASE	14.0	30.0
1660001239568	L 121	NO	AFTER TEST	946.	0.00010	0.00010	BASE	21.0	30.0
1660001239583	L 122	NO	AFTER TEST	893.	0.00010	0.00010	BASE	13.0	30.0
1660001239587	L 123	NO	AFTER TEST	1752.	0.00060	0.00060	BASE	14.0	30.0
1660002381362BO	L 124	NO	AFTER TEST	2265.	0.00090	0.00090	BASE	12.0	30.0
1660002738669	L 125	NO	AFTER TEST	14214.	0.00240	0.00240	BASE	14.0	30.0
1660002876868	L 126	NO	AFTER TEST	1501.	0.00170	0.00170	BASE	11.0	30.0
1660002885532	L 127	NO	AFTER TEST	1074.	0.00010	0.00010	BASE	13.0	30.0
1660002929104	L 128	NO	AFTER TEST	2511.	0.00050	0.00050	BASE	12.0	30.0
1660003277052	L 129	NO	AFTER TEST	5651.	0.00140	0.00140	BASE	14.0	30.0
1660003679453	L 130	NO	AFTER TEST	839.	0.00020	0.00020	BASE	13.0	30.0
1660005678852BO	L 131	NO	AFTER TEST	1952.	0.00480	0.00480	BASE	13.0	30.0
1660007980235	L 132	NO	AFTER TEST	634.	0.00010	0.00010	BASE	19.0	30.0
1660010040798	L 133	NO	AFTER TEST	6529.	0.00050	0.00050	BASE	11.0	30.0
1660010155017	L 134	NO	AFTER TEST	2965.	0.00230	0.00230	BASE	14.0	30.0
1660010214822	L 135	NO	AFTER TEST	4668.	0.00170	0.00170	BASE	14.0	30.0
1660010215625	L 136	NO	AFTER TEST	2118.	0.00200	0.00200	BASE	12.0	30.0
1660010359636TP	L 137	NO	AFTER TEST	17747.	0.00240	0.00240	BASE	14.0	30.0
1660010619097	L 138	NO	AFTER TEST	1105.	0.00050	0.00050	BASE	14.0	30.0
1660010631213	L 139	NO	AFTER TEST	24703.	0.00070	0.00070	BASE	14.0	30.0
1660010808229	L 140	NO	AFTER TEST	10375.	0.00280	0.00280	BASE	14.0	30.0
1660011374105	L 141	NO	AFTER TEST	15285.	0.00110	0.00110	BASE	14.0	30.0
1680001238168	L 142	NO	AFTER TEST	4893.	0.00050	0.00050	BASE	14.0	30.0
1680001323272	L 143	NO	AFTER TEST	9570.	0.00020	0.00020	BASE	14.0	30.0
1680002988837	L 144	NO	AFTER TEST	7234.	0.00020	0.00020	BASE	14.0	30.0
1680003141930	L 145	NO	AFTER TEST	1259.	0.00140	0.00140	BASE	14.0	30.0
1680010041244FX	L 146	NO	AFTER TEST	17659.	0.00080	0.00080	BASE	14.0	30.0
1680010485183	L 147	NO	AFTER TEST	3438.	0.00080	0.00080	BASE	14.0	30.0
1680010524890	L 148	NO	AFTER TEST	4635.	0.00010	0.00010	BASE	10.0	30.0
1680010530071LS	L 149	NO	AFTER TEST	4120.	0.00020	0.00020	BASE	11.0	30.0
1680010652355	L 150	NO	AFTER TEST	3151.	0.00030	0.00030	BASE	18.0	30.0
1680010946707	L 151	NO	AFTER TEST	3716.	0.00020	0.00020	BASE	14.0	30.0
1680011390166	L 152	NO	AFTER TEST	3614.	0.00110	0.00110	BASE	14.0	30.0
1680011625850FX	L 153	NO	AFTER TEST	21309.	0.00080	0.00080	BASE	14.0	30.0
2620010632361	L 154	NO	AFTER TEST	139.	0.02170	0.02170	BASE	32.0	30.0
2620011486221	L 155	NO	AFTER TEST	274.	0.05060	0.05060	BASE	59.0	30.0
2835003901884	L 156	NO	AFTER TEST	3472.	0.00260	0.00260	BASE	14.0	30.0
2835010207249	L 157	NO	AFTER TEST	38574.	0.00180	0.00180	BASE	14.0	30.0
2835010346948	L 158	NO	AFTER TEST	171108.	0.00360	0.00360	BASE	14.0	30.0
2835010881009	L 159	NO	AFTER TEST	33321.	0.00100	0.00100	BASE	11.0	30.0
2835010912433	L 160	NO	AFTER TEST	102205.	0.00290	0.00290	BASE	14.0	30.0
2840003275432PT	L 161	NO	AFTER TEST	6387.	0.00020	0.00020	BASE	13.0	30.0
2840005232036PT	L 162	NO	AFTER TEST	119.	0.00200	0.00200	BASE	14.0	30.0
2840005341824PT	L 163	NO	AFTER TEST	474.	0.00020	0.00020	BASE	14.0	30.0
2840010491150PT	L 164	NO	AFTER TEST	19761.	0.00240	0.00240	BASE	14.0	30.0
2840011028596PT	L 165	NO	AFTER TEST	4882.	0.00050	0.00050	BASE	14.0	30.0
2840011288348PT	L 166	NO	AFTER TEST	604.	0.00170	0.00170	BASE	8.0	30.0
2840011288349PT	L 167	NO	AFTER TEST	349.	0.00100	0.00100	BASE	14.0	30.0
2840011288437PT	L 168	NO	AFTER TEST	6191.	0.00220	0.00220	BASE	20.0	30.0
2840011291044PT	L 169	NO	AFTER TEST	437.	0.00160	0.00160	BASE	12.0	30.0
2840011433254PT	L 170	NO	AFTER TEST	443.	0.00100	0.00100	BASE	15.0	30.0
2840011471898PT	L 171	NO	AFTER TEST	3976.	0.00020	0.00020	BASE	10.0	30.0
2840011471899PT	L 172	NO	AFTER TEST	4090.	0.00050	0.00050	BASE	15.0	30.0
2840011559148PT	L 173	NO	AFTER TEST	1571.	0.00070	0.00070	BASE	14.0	30.0
2840011649087PT	L 174	NO	AFTER TEST	2577.	0.00010	0.00010	BASE	14.0	30.0
2840011802935PT	L 175	NO	AFTER TEST	350.	0.00040	0.00040	BASE	29.0	30.0

Table D-1. F-15C Pacific Air Force Line Replaceable Units Used in the Analysis (Continued)

2840011802941PT	L 176	NO	AFTER TEST	547.	0.00040	0.00040	BASE	14.0	30.0
2915003353183	L 177	NO	AFTER TEST	1092.	0.00030	0.00030	BASE	14.0	30.0
2915005370336	L 178	NO	AFTER TEST	4634.	0.00010	0.00010	BASE	20.0	30.0
2915010097932	L 179	NO	AFTER TEST	562.	0.00110	0.00110	BASE	14.0	30.0
2915010350276PT	L 180	NO	AFTER TEST	17187.	0.00190	0.00190	BASE	14.0	30.0
2915010353771PT	L 181	NO	AFTER TEST	1830.	0.00020	0.00020	BASE	10.0	30.0
2915010562716	L 182	NO	AFTER TEST	4841.	0.00040	0.00040	BASE	14.0	30.0
2915010653149	L 183	NO	AFTER TEST	1002.	0.00140	0.00140	BASE	14.0	30.0
2915010658525	L 184	NO	AFTER TEST	5223.	0.00070	0.00070	BASE	10.0	30.0
2915010659589PT	L 185	NO	AFTER TEST	25853.	0.00150	0.00150	BASE	14.0	30.0
2915010718325PT	L 186	NO	AFTER TEST	5071.	0.00020	0.00020	BASE	14.0	30.0
2915010753518PT	L 187	NO	AFTER TEST	35123.	0.00210	0.00210	BASE	13.0	30.0
2915010819055PT	L 188	NO	AFTER TEST	5371.	0.00080	0.00080	BASE	14.0	30.0
2915010970518	L 189	NO	AFTER TEST	1347.	0.00080	0.00080	BASE	31.0	30.0
2915011076177PT	L 190	NO	AFTER TEST	11064.	0.00060	0.00060	BASE	14.0	30.0
2915011160968	L 191	NO	AFTER TEST	1192.	0.00170	0.00170	BASE	14.0	30.0
2915011376551PT	L 192	NO	AFTER TEST	7195.	0.00100	0.00100	BASE	14.0	30.0
2915011620998PT	L 193	NO	AFTER TEST	35799.	0.00350	0.00350	BASE	14.0	30.0
2915011699461	L 194	NO	AFTER TEST	435.	0.00020	0.00020	BASE	14.0	30.0
2915011783445	L 195	NO	AFTER TEST	5987.	0.00090	0.00090	BASE	14.0	30.0
2915012037229PT	L 196	NO	AFTER TEST	188734.	0.00200	0.00200	BASE	14.0	30.0
2925003276212PT	L 197	NO	AFTER TEST	1110.	0.00020	0.00020	BASE	14.0	30.0
2925003276214PT	L 198	NO	AFTER TEST	1832.	0.00020	0.00020	BASE	14.0	30.0
2925003276216PT	L 199	NO	AFTER TEST	3769.	0.00040	0.00040	BASE	14.0	30.0
2925010228332PT	L 200	NO	AFTER TEST	3143.	0.00080	0.00080	BASE	11.0	30.0
2925010685284PT	L 201	NO	AFTER TEST	875.	0.00010	0.00010	BASE	24.0	30.0
2925010753343PT	L 202	NO	AFTER TEST	1963.	0.00120	0.00120	BASE	12.0	30.0
2925011802149PT	L 203	NO	AFTER TEST	8909.	0.00090	0.00090	BASE	14.0	30.0
2935010078381PT	L 204	NO	AFTER TEST	891.	0.00060	0.00060	BASE	14.0	30.0
2945011441402PT	L 205	NO	AFTER TEST	1739.	0.00010	0.00010	BASE	14.0	30.0
2995005343027PT	L 206	NO	AFTER TEST	1221.	0.00030	0.00030	BASE	25.0	30.0
2995010995028PT	L 207	NO	AFTER TEST	7727.	0.00030	0.00030	BASE	16.0	30.0
2995011498836PT	L 208	NO	AFTER TEST	1475.	0.00110	0.00110	BASE	14.0	30.0
2995011595332	L 209	NO	AFTER TEST	464.	0.00090	0.00090	BASE	14.0	30.0
2995011596742	L 210	NO	AFTER TEST	1333.	0.00320	0.00320	BASE	14.0	30.0
3110011288083PT	L 211	NO	AFTER TEST	168.	0.00190	0.00190	BASE	14.0	30.0
4320011878144PT	L 212	NO	AFTER TEST	10076.	0.00010	0.00010	BASE	14.0	30.0
4710011756154PT	L 213	NO	AFTER TEST	547.	0.00040	0.00040	BASE	14.0	30.0
4710011795109PT	L 214	NO	AFTER TEST	422.	0.00020	0.00020	BASE	12.0	30.0
4810010070536	L 215	NO	AFTER TEST	3119.	0.00150	0.00150	BASE	14.0	30.0
4810010352340PT	L 216	NO	AFTER TEST	3167.	0.00010	0.00010	BASE	14.0	30.0
4810010898900	L 217	NO	AFTER TEST	1671.	0.00020	0.00020	BASE	14.0	30.0
4810010911930	L 218	NO	AFTER TEST	1714.	0.00040	0.00040	BASE	14.0	30.0
4810010944567	L 219	NO	AFTER TEST	2107.	0.00010	0.00010	BASE	14.0	30.0
4810010944568	L 220	NO	AFTER TEST	2371.	0.00020	0.00020	BASE	14.0	30.0
4820003050289TP	L 221	NO	AFTER TEST	2844.	0.00260	0.00260	BASE	13.0	30.0
4820003133307	L 222	NO	AFTER TEST	3557.	0.00020	0.00020	BASE	14.0	30.0
4820003373985	L 223	NO	AFTER TEST	505.	0.00000	0.00000	BASE	20.0	30.0
4820010681105	L 224	NO	AFTER TEST	9574.	0.00030	0.00030	BASE	24.0	30.0
4820010955359PT	L 225	NO	AFTER TEST	7054.	0.00090	0.00090	BASE	14.0	30.0
4820011526285PT	L 226	NO	AFTER TEST	920.	0.00020	0.00020	BASE	14.0	30.0
5821010934574	L 227	NO	AFTER TEST	7482.	0.00090	0.00090	BASE	14.0	30.0
5821010934632	L 228	NO	AFTER TEST	2602.	0.00090	0.00090	BASE	14.0	30.0
5821010934635	L 229	NO	AFTER TEST	14304.	0.00410	0.00410	BASE	14.0	30.0
5821010934663	L 230	NO	AFTER TEST	1055.	0.00090	0.00090	BASE	16.0	30.0
5821010934664	L 231	NO	AFTER TEST	1248.	0.00060	0.00060	BASE	14.0	30.0
5821010939985	L 232	NO	AFTER TEST	881.	0.00030	0.00030	BASE	14.0	30.0
5821011178463	L 233	NO	AFTER TEST	2152.	0.00240	0.00240	BASE	29.0	30.0
5821011280394	L 234	NO	AFTER TEST	10500.	0.00300	0.00300	BASE	14.0	30.0
5821011498710	L 235	NO	AFTER TEST	748.	0.00030	0.00030	BASE	16.0	30.0

Table D-1. F-15C Pacific Air Force Line Replaceable Units Used in the Analysis (Continued)

5821011498809	L 236	NO	AFTER TEST	1959.	0.00190	0.00190	BASE	16.0	30.0
5826010603893	L 237	NO	AFTER TEST	6265.	0.00080	0.00080	BASE	14.0	30.0
5841010451066	L 238	NO	AFTER TEST	3817.	0.00030	0.00030	BASE	33.0	30.0
5841010510385	L 239	NO	AFTER TEST	6445.	0.00020	0.00020	BASE	14.0	30.0
5841010588861	L 240	NO	AFTER TEST	3529.	0.00010	0.00010	BASE	13.0	30.0
5841010630856	L 241	NO	AFTER TEST	108154.	0.00080	0.00080	BASE	11.0	30.0
5841010714135	L 242	NO	AFTER TEST	4600.	0.00020	0.00020	BASE	14.0	30.0
5841010808787	L 243	NO	AFTER TEST	20920.	0.00060	0.00060	BASE	16.0	30.0
5841011712635	L 244	NO	AFTER TEST	3728.	0.00070	0.00070	BASE	14.0	30.0
5841011713031	L 245	NO	AFTER TEST	3213.	0.00130	0.00130	BASE	14.0	30.0
5865000037461EW	L 246	NO	AFTER TEST	817.	0.00100	0.00100	BASE	12.0	30.0
5865000037464EW	L 247	NO	AFTER TEST	5800.	0.00390	0.00390	BASE	10.0	30.0
5865000076945EW	L 248	NO	AFTER TEST	3208.	0.00980	0.00980	BASE	23.0	30.0
5865000076949EW	L 249	NO	AFTER TEST	4627.	0.01170	0.01170	BASE	16.0	30.0
5865000076950EW	L 250	NO	AFTER TEST	1530.	0.00290	0.00290	BASE	20.0	30.0
5865000094381EW	L 251	NO	AFTER TEST	9730.	0.00290	0.00290	BASE	12.0	30.0
5865000233361EW	L 252	NO	AFTER TEST	822.	0.00290	0.00290	BASE	11.0	30.0
5865001559243EW	L 253	NO	AFTER TEST	559.	0.00130	0.00130	BASE	9.0	30.0
5865001559266EW	L 254	NO	AFTER TEST	8980.	0.00780	0.00780	BASE	9.0	30.0
5865001559489EW	L 255	NO	AFTER TEST	1830.	0.00630	0.00630	BASE	16.0	30.0
5865001559499EW	L 256	NO	AFTER TEST	890.	0.00290	0.00290	BASE	12.0	30.0
5865001627964EW	L 257	NO	AFTER TEST	4217.	0.00690	0.00690	BASE	13.0	30.0
5865001854444EW	L 258	NO	AFTER TEST	4177.	0.01270	0.01270	BASE	19.0	30.0
5865001955987EW	L 259	NO	AFTER TEST	1368.	0.00390	0.00390	BASE	16.0	30.0
5865001994210EW	L 260	NO	AFTER TEST	12929.	0.01370	0.01370	BASE	16.0	30.0
5865003073292EW	L 261	NO	AFTER TEST	433.	0.02050	0.02050	BASE	17.0	30.0
5865003151482EW	L 262	NO	AFTER TEST	2680.	0.00200	0.00200	BASE	11.0	30.0
5865003151491EW	L 263	NO	AFTER TEST	825.	0.02050	0.02050	BASE	13.0	30.0
5865003151499EW	L 264	NO	AFTER TEST	1973.	0.00780	0.00780	BASE	16.0	30.0
5865003217636EW	L 265	NO	AFTER TEST	1569.	0.00490	0.00490	BASE	11.0	30.0
5865003217650EW	L 266	NO	AFTER TEST	362.	0.00030	0.00030	BASE	11.0	30.0
5865003655459EW	L 267	NO	AFTER TEST	1843.	0.01760	0.01760	BASE	12.0	30.0
5865003713344EW	L 268	NO	AFTER TEST	7904.	0.01760	0.01760	BASE	18.0	30.0
5865004438630EW	L 269	NO	AFTER..TEST	610.	0.00030	0.00030	BASE	22.0	30.0
5865004520326EW	L 270	NO	AFTER TEST	271.	0.00350	0.00350	BASE	14.0	30.0
5865004520327EW	L 271	NO	AFTER TEST	185.	0.00200	0.00200	BASE	12.0	30.0
5865004520328EW	L 272	NO	AFTER TEST	611.	0.00140	0.00140	BASE	11.0	30.0
5865004671140EW	L 273	NO	AFTER TEST	3631.	0.00790	0.00790	BASE	14.0	30.0
5865004671191EW	L 274	NO	AFTER TEST	4177.	0.00330	0.00330	BASE	14.0	30.0
5865004723317EW	L 275	NO	AFTER TEST	822.	0.00100	0.00100	BASE	14.0	30.0
5865004764442EW	L 276	NO	AFTER TEST	6273.	0.01470	0.01470	BASE	16.0	30.0
5865004764443EW	L 277	NO	AFTER TEST	3703.	0.02440	0.02440	BASE	16.0	30.0
5865004775921EW	L 278	NO	AFTER TEST	2818.	0.00100	0.00100	BASE	12.0	30.0
5865004775923EW	L 279	NO	AFTER TEST	2366.	0.00000	0.00000	BASE	14.0	30.0
5865005562035EW	L 280	NO	AFTER TEST	331.	0.00200	0.00200	BASE	18.0	30.0
5865005562036EW	L 281	NO	AFTER TEST	531.	0.00390	0.00390	BASE	14.0	30.0
5865005562037EW	L 282	NO	AFTER TEST	161.	0.00180	0.00180	BASE	11.0	30.0
5865005562038EW	L 283	NO	AFTER TEST	1270.	0.00200	0.00200	BASE	15.0	30.0
5865005562039EW	L 284	NO	AFTER TEST	1245.	0.01170	0.01170	BASE	16.0	30.0
5865005562041EW	L 285	NO	AFTER TEST	224.	0.00100	0.00100	BASE	22.0	30.0
5865005562055EW	L 286	NO	AFTER TEST	376.	0.00390	0.00390	BASE	15.0	30.0
5865005562062EW	L 287	NO	AFTER TEST	1352.	0.00100	0.00100	BASE	17.0	30.0
5865005562103EW	L 288	NO	AFTER TEST	951.	0.00290	0.00290	BASE	8.0	30.0
5865005562104EW	L 289	NO	AFTER TEST	751.	0.00720	0.00720	BASE	16.0	30.0
5865005562114EW	L 290	NO	AFTER TEST	1293.	0.00610	0.00610	BASE	15.0	30.0
5865005562122EW	L 291	NO	AFTER TEST	203.	0.00420	0.00420	BASE	17.0	30.0
5865006035397EW	L 292	NO	AFTER TEST	560.	0.00070	0.00070	BASE	25.0	30.0
5865006035404EW	L 293	NO	AFTER TEST	980.	0.00170	0.00170	BASE	16.0	30.0
5865006035409EW	L 294	NO	AFTER TEST	3999.	0.00120	0.00120	BASE	16.0	30.0
5865006035457EW	L 295	NO	AFTER TEST	71.	0.00070	0.00070	BASE	13.0	30.0

Table D-1. F-15C Pacific Air Force Line Replaceable Units Used in the Analysis (Continued)

5865006035458EW	L 296	NO	AFTER TEST	692.	0.00030	0.00030	BASE	18.0	30.0
5865006035460EW	L 297	NO	AFTER TEST	722.	0.00020	0.00020	BASE	32.0	30.0
5865006035461EW	L 298	NO	AFTER TEST	664.	0.00070	0.00070	BASE	19.0	30.0
5865006035462EW	L 299	NO	AFTER TEST	5031.	0.00120	0.00120	BASE	14.0	30.0
5865006035520EW	L 300	NO	AFTER TEST	714.	0.00040	0.00040	BASE	26.0	30.0
5865006035524EW	L 301	NO	AFTER TEST	3592.	0.00130	0.00130	BASE	14.0	30.0
5865007598099EW	L 302	NO	AFTER TEST	10973.	0.00240	0.00240	BASE	10.0	30.0
5865010134840EW	L 303	NO	AFTER TEST	1338.	0.00290	0.00290	BASE	16.0	30.0
5865010135205EW	L 304	NO	AFTER TEST	292.	0.00200	0.00200	BASE	10.0	30.0
5865010135206EW	L 305	NO	AFTER TEST	560.	0.00200	0.00200	BASE	15.0	30.0
5865010142724EW	L 306	NO	AFTER TEST	2554.	0.00010	0.00010	BASE	15.0	30.0
5865010346003EW	L 307	NO	AFTER TEST	1423.	0.00050	0.00050	BASE	15.0	30.0
5865010599021EW	L 308	NO	AFTER TEST	1315.	0.00030	0.00030	BASE	24.0	30.0
5865010650216EW	L 309	NO	AFTER TEST	1789.	0.00050	0.00050	BASE	8.0	30.0
5865010666206EW	L 310	NO	AFTER TEST	1396.	0.00080	0.00080	BASE	21.0	30.0
5865010668149EW	L 311	NO	AFTER TEST	1326.	0.00070	0.00070	BASE	30.0	30.0
5865010770497EW	L 312	NO	AFTER TEST	6013.	0.01560	0.01560	BASE	16.0	30.0
5865010844520EW	L 313	NO	AFTER TEST	2138.	0.00100	0.00100	BASE	22.0	30.0
5865010861000EW	L 314	NO	AFTER TEST	2138.	0.00300	0.00300	BASE	11.0	30.0
5865010861001EW	L 315	NO	AFTER TEST	3097.	0.00420	0.00420	BASE	14.0	30.0
5865010861002EW	L 316	NO	AFTER TEST	2138.	0.00070	0.00070	BASE	22.0	30.0
5865010879065EW	L 317	NO	AFTER TEST	675.	0.00020	0.00020	BASE	14.0	30.0
5865010880956EW	L 318	NO	AFTER TEST	2141.	0.00030	0.00030	BASE	13.0	30.0
5865010881019EW	L 319	NO	AFTER TEST	2647.	0.00170	0.00170	BASE	17.0	30.0
5865010881025EW	L 320	NO	AFTER TEST	12248.	0.00130	0.00130	BASE	14.0	30.0
5865010889067EW	L 321	NO	AFTER TEST	716.	0.00010	0.00010	BASE	15.0	30.0
5865010972494EW	L 322	NO	AFTER TEST	602.	0.00010	0.00010	BASE	14.0	30.0
5865010998141EW	L 323	NO	AFTER TEST	650.	0.00060	0.00060	BASE	14.0	30.0
5865010999833EW	L 324	NO	AFTER TEST	689.	0.00030	0.00030	BASE	33.0	30.0
5865011172948EW	L 325	NO	AFTER TEST	497.	0.00010	0.00010	BASE	14.0	30.0
5865011185359EW	L 326	NO	AFTER TEST	3042.	0.00030	0.00030	BASE	23.0	30.0
5865011339957EW	L 327	NO	AFTER TEST	1938.	0.00190	0.00190	BASE	14.0	30.0
5865011341091EW	L 328	NO	AFTER TEST	3152.	0.00100	0.00100	BASE	14.0	30.0
5865011549042EW	L 329	NO	AFTER TEST	2580.	0.00040	0.00040	BASE	16.0	30.0
5865011701119EW	L 330	NO	AFTER TEST	1588.	0.00010	0.00010	BASE	14.0	30.0
5865012112336EW	L 331	NO	AFTER TEST	3200.	0.00090	0.00090	BASE	14.0	30.0
5865012119086EW	L 332	NO	AFTER TEST	2000.	0.00170	0.00170	BASE	14.0	30.0
5895001151029	L 333	NO	AFTER TEST	1309.	0.00260	0.00260	BASE	16.0	30.0
5895010444987	L 334	NO	AFTER TEST	1303.	0.00070	0.00070	BASE	14.0	30.0
5895010959593	L 335	NO	AFTER TEST	4093.	0.00320	0.00320	BASE	14.0	30.0
5895011132491	L 336	NO	AFTER TEST	2630.	0.00010	0.00010	BASE	14.0	30.0
5895011184625	L 337	NO	AFTER TEST	263.	0.00090	0.00090	BASE	10.0	30.0
5945003696992	L 338	NO	AFTER TEST	1725.	0.00020	0.00020	BASE	20.0	30.0
5985010304158EW	L 339	NO	AFTER TEST	2876.	0.00050	0.00050	BASE	14.0	30.0
5985010304159EW	L 340	NO	AFTER TEST	2549.	0.00400	0.00400	BASE	14.0	30.0
5995003904515CW	L 341	NO	AFTER TEST	6397.	0.00090	0.00090	BASE	15.0	30.0
5995011310957EW	L 342	NO	AFTER TEST	4874.	0.00100	0.00100	BASE	14.0	30.0
6115004690710	L 343	NO	AFTER TEST	10374.	0.00190	0.00190	BASE	14.0	30.0
6115011213632UH	L 344	NO	AFTER TEST	19692.	0.00120	0.00120	BASE	14.0	30.0
6340003327300	L 345	NO	AFTER TEST	2972.	0.00020	0.00020	BASE	14.0	30.0
6340010772900NT	L 346	NO	AFTER TEST	3791.	0.00040	0.00040	BASE	11.0	30.0
6605003142536	L 347	NO	AFTER TEST	2013.	0.00140	0.00140	BASE	14.0	30.0
6605010423335	L 348	NO	AFTER TEST	8902.	0.00160	0.00160	BASE	14.0	30.0
6605010445026	L 349	NO	AFTER TEST	3405.	0.00050	0.00050	BASE	15.0	30.0
6605010470163	L 350	NO	AFTER TEST	1386.	0.00020	0.00020	BASE	15.0	30.0
6605010977155	L 351	NO	AFTER TEST	1276.	0.00070	0.00070	BASE	14.0	30.0
6610000000122	L 352	NO	AFTER TEST	14082.	0.00150	0.00150	BASE	12.0	30.0
6610001342251	L 353	NO	AFTER TEST	3708.	0.00030	0.00030	BASE	10.0	30.0
6610001342259	L 354	NO	AFTER TEST	1643.	0.00140	0.00140	BASE	13.0	30.0
6610001342260	L 355	NO	AFTER TEST	4307.	0.00140	0.00140	BASE	11.0	30.0

Table D-1. F-15C Pacific Air Force Line Replaceable Units Used in the Analysis (Continued)

6610001600905	L 356	NO	AFTER TEST	3745.	0.00170	0.00170	BASE	17.0	30.0
6610002963574	L 357	NO	AFTER TEST	939.	0.00050	0.00050	BASE	10.0	30.0
6610003036706	L 358	NO	AFTER TEST	2411.	0.00040	0.00040	BASE	12.0	30.0
6610003293495	L 359	NO	AFTER TEST	1214.	0.00150	0.00150	BASE	12.0	30.0
6610003616686	L 360	NO	AFTER TEST	564.	0.00070	0.00070	BASE	10.0	30.0
6610005357722	L 361	NO	AFTER TEST	2199.	0.00380	0.00380	BASE	15.0	30.0
6610010379144	L 362	NO	AFTER TEST	19047.	0.00480	0.00480	BASE	14.0	30.0
6610010424831	L 363	NO	AFTER TEST	17922.	0.00600	0.00600	BASE	14.0	30.0
6610010933356	L 364	NO	AFTER TEST	3624.	0.00070	0.00070	BASE	16.0	30.0
6610011676617	L 365	NO	AFTER TEST	11588.	0.00570	0.00570	BASE	20.0	30.0
6610011687039	L 366	NO	AFTER TEST	928.	0.00030	0.00030	BASE	14.0	30.0
6610011687042	L 367	NO	AFTER TEST	927.	0.00010	0.00010	BASE	14.0	30.0
6610011692283	L 368	NO	AFTER TEST	670.	0.00010	0.00010	BASE	14.0	30.0
6615001377514	L 369	NO	AFTER TEST	29601.	0.00170	0.00170	BASE	13.0	30.0
6615002624314	L 370	NO	AFTER TEST	13993.	0.00030	0.00030	BASE	13.0	30.0
6615003036728	L 371	NO	AFTER TEST	30605.	0.00830	0.00830	BASE	12.0	30.0
6615003036730	L 372	NO	AFTER TEST	1867.	0.00120	0.00120	BASE	16.0	30.0
6615010154794	L 373	NO	AFTER TEST	27553.	0.00280	0.00280	BASE	20.0	30.0
6615010214234	L 374	NO	AFTER TEST	5452.	0.00060	0.00060	BASE	14.0	30.0
6615010950962	L 375	NO	AFTER TEST	26189.	0.00300	0.00300	BASE	14.0	30.0
6615011497475	L 376	NO	AFTER TEST	13596.	0.00110	0.00110	BASE	14.0	30.0
6620001487306	L 377	NO	AFTER TEST	2259.	0.00110	0.00110	BASE	14.0	30.0
6620004689824	L 378	NO	AFTER TEST	3871.	0.00110	0.00110	BASE	9.0	30.0
6620010872354	L 379	NO	AFTER TEST	3361.	0.00220	0.00220	BASE	12.0	30.0
6645000763050	L 380	NO	AFTER TEST	546.	0.00180	0.00180	BASE	12.0	30.0
6680010684284	L 381	NO	AFTER TEST	662.	0.00200	0.00200	BASE	10.0	30.0
6680011033419	L 382	NO	AFTER TEST	6351.	0.00180	0.00180	BASE	19.0	30.0
6680011066215	L 383	NO	AFTER TEST	6984.	0.00150	0.00150	BASE	17.0	30.0
6680011288000PT	L 384	NO	AFTER TEST	10712.	0.00730	0.00730	BASE	14.0	30.0
6685003336763	L 385	NO	AFTER TEST	415.	0.00050	0.00050	BASE	16.0	30.0
6685010482889NT	L 386	NO	AFTER TEST	2984.	0.00140	0.00140	BASE	14.0	30.0
7021004775716	L 387	NO	AFTER TEST	49372.	0.00070	0.00070	BASE	14.0	30.0

GLOSSARY

ACIM	Availability Centered Inventory Model
AFLC	Air Force Logistics Command
BLSS	Base-level self-sufficiency spares.
CAC	Combat Analysis Capability
Cannibalization	The practice of transferring a serviceable component from one aircraft to repair another. The first aircraft must be unserviceable due to another component failure, and the needed serviceable component cannot be obtained from local supplies.
CIRF	Centralized Intermediate Repair Facility
Component impact	An approximation of the expected number of aircraft rendered not fully mission capable by shortages of a particular line-replaceable unit, computed by dividing expected number of back orders of the unit by its quantity per aircraft.
Condemnation	A decision or status indicating a component or subcomponent is irreparably damaged
Dyna-METRIC	Dynamic Multi-Echelon Technique for Recoverable Item Control
ECHO:	The error checking and data echo program, the second of the five Dyna-METRIC programs
FMC	(fully mission capable): an aircraft status indicating that the weapon system can accomplish any of its wartime missions
LCOM	Logistic Composite Module (model)
LRU	(line replaceable unit): a component typically removed from the aircraft at the flight line, rather than in a back shop
MIME	Multi-Item, Multi-Echelon (model)
MTTR	(mean time to repair): The time it takes to remove a failed part, acquire a replacement from supply, and install the part on the aircraft
MOD	The pipeline file modifier, the fourth of the five Dyna-METRIC programs

NFMC	(not fully mission capable): an aircraft status indicating that the weapon system's ability to accomplish at least one wartime mission has been degraded
NOP	non-optimized parts
NRTS	(not repairable this station): a decision or status indicating that a component cannot be repaired at a specified facility
PACAF	Pacific Air Force
PART	The data set partitioner, the first of the five Dyna-METRIC programs
PIPE	The pipeline computation, the third of the five Dyna-METRIC programs
Pipeline	A network of repair and transportation processes through which repairable and serviceable parts flow as they are removed from their higher assemblies, repaired, and requisitioned from other points of supply
Pipeline segment	A single process in the pipeline characterized by part arrivals over time, a delay time, and part departures over time
PMC	(partially mission capable): an aircraft status indicating that the weapon system can perform at least one wartime mission, though perhaps in a degraded mode
QPA	(quantity per aircraft): the number of a particular component or subcomponent physically mounted on an aircraft. (This number differs from quantity per application except for LRUs.)
REPORT	The report writer, the fifth of the five Dyna-METRIC programs
R&M	Reliability and Maintainability
RR	Remove and Repair
RRR	Remove, Repair, Replace
SRU	(shop replaceable unit): a subcomponent of an LRU, typically removed from the LRU in the shop
Sub SRU	A subcomponent of an SRU, including bits and pieces that are often consumed during repair of the SRU; sub SRU may itself be repairable
TAT	(turnaround time): the time it takes maintenance to return a failed part to a ready-for-issue state
TFS	Tactical Fighter Squadron

WRSK	War Reserve Spares Kits
WSMIS	Weapon System Management Information System

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