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EVALUATION OF F-15E AVAILABILITY DURING OPERATIONAL TEST

Capt Letitia M. Pohl, USAF

Air Force Operational Test and Evaluation Center
Logistics Studies and Analysis Division
Kirtland AFB, NM 87117-7001

ABSTRACT

The Air Force conducted an Operational Test and Evaluation (OT&E) of the F-15E Dual Role Fighter from December 1988 to September 1989. In support of the testing, an F-15E Availability Model was developed to address the mission reliability, maintainability and availability of a 24 aircraft squadron in an operational environment. This paper defines mission reliability, maintainability and availability for the purpose of discussing model usage. It also describes why the model was developed, some of its capabilities and limitations, model verification and validation, and the results of the OT&E analysis using the model.

1 INTRODUCTION

The F-15E dual role fighter is an advanced two-place aircraft designed for superiority over enemy surface and air threats. The aircraft is capable of performing air-to-surface and air-to-air missions day or night, in and under the weather. The Air Force Operational Test and Evaluation Center (AFOTEC) conducted an operational test and evaluation (OT&E) of the F-15E, which was designed to identify operational capabilities and/or deficiencies to the Tactical Air Forces (TAF) and to influence the configuration of the production aircraft (Jacobsen 1988).

The OT&E was conducted primarily at Edwards AFB, CA, from December 1988 to September 1989, with two F-15Es that were representative of the production design. During this period the OT&E aircraft were flown and maintained by USAF pilots and maintenance technicians with operational experience with other tactical aircraft. All aircraft flight time, failure and maintenance data were collected. The test results are summarized in Jacobsen (1990).

The F-15E Availability Model was developed by HQ AFOTEC, the Logistics Studies and Analysis Division, using the Simulation Language for Alternative Modeling (SLAM II) (Pritsker 1986). The model simulates the daily operations and maintenance of an F-15E squadron in both wartime and peacetime environments. The model's primary fuction is to estimate the mission reliability, maintainability and availability for a mature squadron of 24 aircraft.

1.1 Definitions

Mission reliability is the probability a system performs its required function(s) at a specified mission time or for a mission of stated duration, given it was initially capable. The parameter used to measure mission reliability for the F-15E is break rate, which is defined as the percent of aircraft that land from a sortie with one or more mission critical subsystems inoperable. In this situation, the aircraft is considered "not mission capable", or NMC, and would require maintenance before it could fly again.
Maintainability is a measure of a system's ability to be maintained in or restored to a specified condition under stated conditions. The two parameters used to describe F-15E maintainability are fix rate and mean repair time (MRT). Fix rate is the percent of aircraft returning from a sortie with critical failure(s) which are repaired and returned to a mission capable status within a specified period of time, normally 2, 4 or 8 hours. The time period used to calculate fix rate is the time the aircraft is down due to the critical failures, and includes corrective maintenance time and any associated logistics or supply delays. MRT is the average on-equipment (generally flightline) maintenance time required to repair a system discrepancy. MRT considers active maintenance time only; it does not include associated delays.

Availability is the parameter that translates the reliability and maintainability characteristics of a system into a measure of interest to the system user. It is the probability an item is in an operable and committable state at any random time. The measure of availability for the F-15E in a wartime scenario is sortie generation rate, or the number of sorties that can be generated per aircraft per day. F-15E availability for the peacetime scenario is measured by mission capable (MC) rate, which is the percent of time an aircraft is capable of performing at least one of its assigned missions. MC rate is equal to one minus NMC rate.

The parameters discussed above are dependent on the inherent reliability and maintainability of the aircraft, and also on the manner and environment in which it is operated and maintained. For instance, availability is determined by how the aircraft is operated and the frequency of use, how often it fails, the time required to repair the aircraft, and the maintenance resources available at the time of each failure (manpower, support equipment, and spare parts). Since the interrelationships of these factors can be quite complex, simulation is a valuable tool in examining the relationships and predicting system performance in different environments.

1.2 Purpose of the model

The availability model was essential to evaluating the operational requirements as they were defined. The TAF requirements for F-15E reliability, maintainability and availability were based on the performance of a mature squadron of aircraft at an operational TAF base. There were significant differences between the test environment and the intended operational environment, some of which are summarized in Table 1. Due to these differences, the availability and maintainability parameters measured directly in the test environment were not an accurate assessment of the performance of an F-15E squadron in the operational environment. The availability model provided the capability to evaluate how a squadron of aircraft would perform in the intended operational environment, based on the data gathered during OT&E. The use of simulation enhanced the evaluation capability in the following manner:

1) Allowed extrapolation of the performance of two aircraft to 24 aircraft.

2) Showed effects of actual manpower, support equipment and spare parts allocation, shared between 24 aircraft.

3) Allowed evaluation of the complete "system", including the aircraft and the support structure.

4) Enabled the analyst to make use of the much larger operational database for the aircraft components already in field use.

5) Allowed use of estimated mature subsystem reliabilities.

2 MODEL DESCRIPTION

The availability model is a network-based, discrete event model using SLAM II with extensive user-written FORTRAN subroutines. It was designed to operate on a VAX/VMS system. A detailed description of the model, including source code and input and output files can be found in Chen (1989).

The model describes the major aspects of the TAF operational environment: similar flying schedules, sortie length, maintenance priorities, manpower allocation and usage by Air Force Specialty Code (AFSC), and scheduled and unscheduled maintenance per four digit work unit code (WUC). A WUC is an alphanumeric code designating a particular aircraft component.

Figure 1 is a top-level logic flow diagram of the F-15E Availability Model. Each simulated day begins by performing preflight maintenance on the mission capable aircraft, scheduling sorties and checking whether preventive maintenance, such as phased inspections, is required. There are 24 entities which represent aircraft. They flow through a network which simulates squadron operations. When failures occur (based on the input failure rates and the flight hours accumulated) and immediate maintenance is required, the aircraft entities are routed to an orgainizational-level (flightline) maintenance network for the appropriate repair action. If the aircraft can continue to fly with existing failures, the maintenance is deferred until the end of the flying day. There are also entities that represent failed components which must go to the appropriate shop for repair. This requires an on-base or intermediate-level shop, or an off-base shop at a depot. The appropriate resources (manpower, support equipment and spare parts) must be available at either the organizational-level or intermediate-level before maintenance will begin. The depot is simply modeled by an average delay time. Throughout the simulation, the mission capable status of each aircraft is tracked, in order to estimate average aircraft availability.

Table 1: Environmental Differences

TEST ENVIRONMENT	OPERATIONAL ENVIRONMENT
2 Aircraft	Over 24 aircraft per location
Test flying schedule	Operational flying schedule
Maintenance personnel	Maintenance personnel
test team	sized for wing/squadron operations
some contractor maintenance	all Air Force personnel
Contractor supply support	Air Force supply support
Sparse support equipment	Support equipment available
Evolving system design	Mature system design

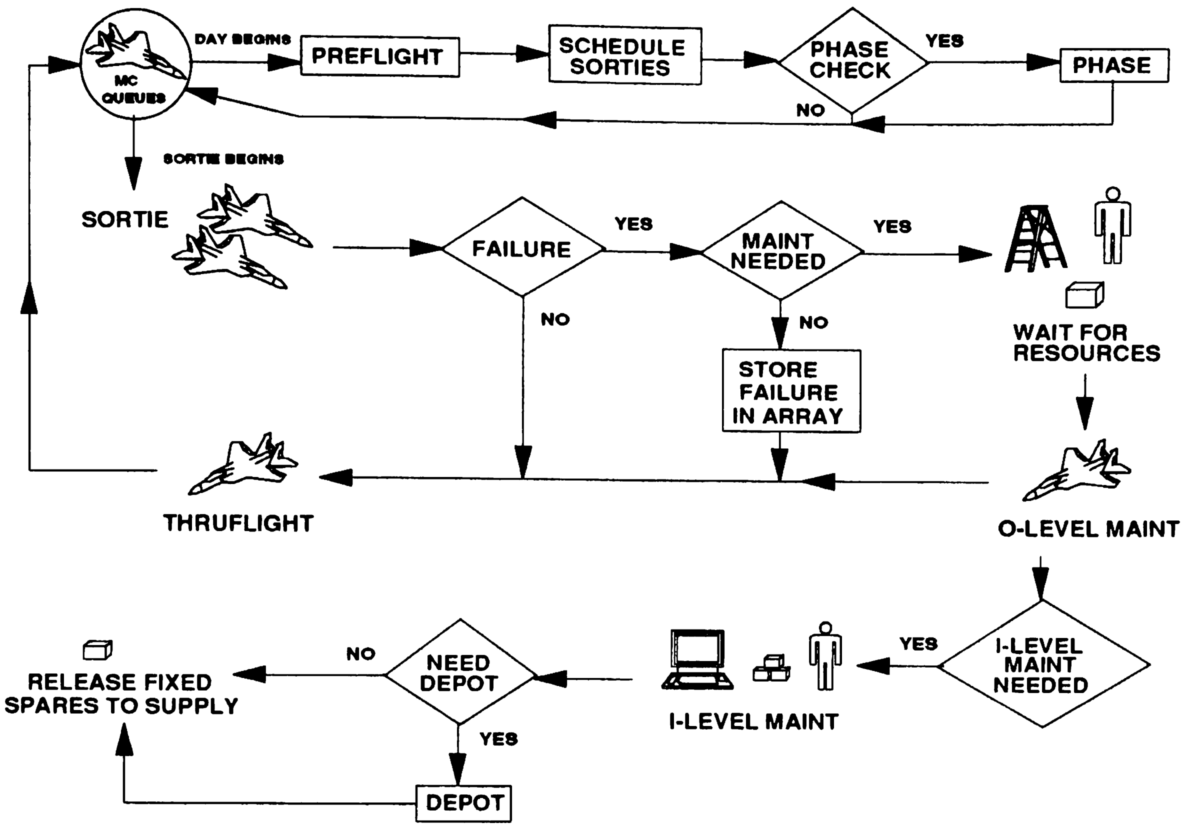

Figure 1: F-15E Availability Model Flow Diagram

2.1 Input Variables

The primary inputs to the model are reliability data and repair data, by aircraft subsystem. The reliabilities are modeled by the exponential distribution. The inputs are mean times between corrective maintenance (MTBMs) in terms of flight hours, and probabilities of critical failure. Corrective maintenance, as opposed to scheduled or preventive maintenance, is the repair action required to resolve an aircraft discrepancy or failure. The model also requires repair data for each subsystem, which include probabilities of a particular type of maintenance (e.g., remove and replace a part, repair in place), and for each of these maintenance types, repair times and the type and number of manpower and support equipment required. The maintenance task times are modeled by either the lognormal or triangular distribution.

The reliability and repair data used for the OT&E evaluation came from two sources: F-15E OT&E data, and data from an operational squadron of F-15Cs. The operational data, which were based on over ten thousand flying hours, were used for the aircraft components common to other types of F-15s in the inventory. Test data, with reliabilities projected to maturity, were used for the F-15E unique subsystems.

2.2 Model Assumptions

The following parameters and assumptions made in the model are common to both the peacetime and wartime scenarios. There are 24 aircraft modeled. There are three primary missions of the F-15E: air-to-air, air-to-ground, and dual role (both air-to-air and air-to-ground). The aircraft fly singly and in two ship formations. The squadron has only F-15Es, with the projected maintenance manpower allocations. The availability of aircrews is assumed to be 100 percent.

The peacetime scenario consists of a one year simulation, with a 30 day warmup period. The scheduled sortie rate averages 1.05 sorties per aircraft per day. There are three 8 hour maintenance shifts, five days per week. The first shift of the day is a servicing shift with a minimum number of personnel. The spare parts levels include the peacetime operating stock (POS) and the wartime readiness spares kit (WRSK).

The wartime simulation period is 30 days, divided into a 7 day surge period and 23 day sustained period. Sustained operations involve high sortie rates, and surge operations require even higher sortie rates. There is no simulation warmup period, because the goal is to estimate sortie generation capability for the first 30 days of war, not steady state conditions. There are two 12 hour maintenance shifts, seven days per week. The spares come from the WRSK.

2.3 Model Limitations

The model does not consider perturbations in the daily operation of a TAF squadron, such as weather, deployments, working on the weekend during peacetime, and no-flying days. Every day is an average day.

All maintenance is performed on each aircraft in parallel. The model includes cannibalization (removing a part from one aircraft to use on another aircraft in the absence of a spare part). However, the deterioration of part reliability due to the additional maintenance actions is not modeled.

Only major avionics test stations and some munitions loading equipment are modeled as support equipment. All other support or test equipment such as air conditioners, power carts, tools, ladders, jacks, etc., are assumed to be available.

The availability model does not consider battle damage or attrition, since the operational requirements being addressed are independent of those two factors.

3 VERIFICATION AND VALIDATION

The availability model underwent a detailed in-house review by a committee of logistics analysts. The purpose of the committee was to assist with verification and validation of the F-15E Availability Model for use during OT&E and to approve the model for release to other Air Force agencies.

The verification process ensured that the model code executed as intended. This was accomplished by using inherent SLAM II capabilities for error checking, and user-written error detection code. Sensitivity analyses were done to ensure the model response to input changes was appropriate.

The validation effort attempted to establish desired accuracy or correspondence between the model and the real world. An important step in the validation process was to compare model performance to a similar system currently in Air Force use. In this case, the comparable system was a squadron of late model F-15Cs, which are primarily air-to-air fighters. There was considerable analyst interface with the operational unit being modeled, in order to accurately capture any differences in operational and maintenance concepts between the two aircraft types, and the correct resource levels for that unit. Six months of the unit's failure and repair data were used as input. The operational statistics for MC rate, break rate, fix rate and MRT, as calculated by the F-15C unit, were compared to the model estimates for a six month simulation. The results are shown in Table 2.

The model estimates were within 5 percent of the actual statistics in all cases except fix rate. Fix rate measures how effectively a unit can manage its resources, and can vary from unit to unit. The model estimate was higher than field results for two possible reasons. First, the model efficiently allocates resources to a repair based simply on the repair action and the available resources. Secondly, there are simplifying assumptions in the area of resources that could affect fix rate: no personnel absences due to illness, leave, or training; most of the support equipment is assumed to be 100 percent available; and the support equipment that is modeled has perfect reliability. Because there was limited data to support any assumptions in these areas, the model was not modified. The model estimates of fix rate can therefore be considered somewhat optimistic.

Table 2: Model Validation Using Operational Data

	Operational Data	Model Estimate
MC Rate	89.3%	88.3%
Break Rate	9.7%	10.2%
Fix Rate (< 8 hrs)	82.3%	90.9%
MRT	1.8 hrs	1.9 hrs

Following the comparison exercise, the model logic and assumptions for the F-15E simulation was thoroughly reviewed by the model committee, OT&E test team, and personnel from the using command, Tactical Air Command (TAC). Minor model changes were made to reflect the expert opinions received, and the model was accredited for use in OT&E by AFOTEC and HQ TAC.

The verification and validation effort was accomplished in order to use the model to evaluate the F-15E in OT&E. Before using this model in future studies, the validation process should be taken a step further, by comparing model inputs and performance to data from actual operational F-15E units.

4 ANALYSIS RESULTS

4.1 Test Data Summary

The OT&E data were collected on two F-15Es over almost twelve months of flying. During the course of OT&E, the test team flew 310 sorties and accumulated 510.8 flight hours. There were 585 corrective maintenance events (failures) recorded during this time period, of which 411 were of the new subsystems, or those unique to the F-15E. The remaining failures occured on subsystems common to the F-15C, and therefore were not used as model input.

4.2 Model Inputs

The aircraft is modeled as 309 subsystems. As noted in Section 2.1, the model requires reliability and repair data as input for each of these subsystems. The MTBMs for F-15 components already fielded, such as the airframe, engines and landing gear, were obtained from the operational data used during model validation and were considered mature.

The MTBMs demonstrated during OT&E for the new F-15E subsystems were not mature because there were design changes ongoing to improve the aircraft reliability. Historical data have shown that the reliabilities of systems continue to improve after fielding when there is an effort to correct design problems as they are found. For this reason, the reliability growth rates seen during test were tracked and projections were made using the Duane reliability growth model (MIL-HDBK-189, 1981). For further information on the reliability growth analysis and listings of the data, consult Pohl (1991).

Table 3 shows the total MTBM estimates for the mature F-15 common subsystems, and the demonstrated and mature MTBMs for the remaining aircraft systems. The data for the F-15 common systems were obtained at the subsystem level. The reliability growth analysis on the F-15E unique subsystems, with some exceptions, was done at the system-level and therefore the mature estimate had to be partitioned into individual subsystem MTBMs for the model inputs. This was done based on how many failures occurred in each subsystem during OT&E.

Table 3: F-15E Subsystem and Total MTBM

	Demonstrated MTBM	Mature MTBM
F-15 Common	-	2.1
F-15E Unique	1.1	1.8
Total F-15E	0.72	0.98

The model was baselined using repair data from the operational database. The baseline repair data for the new components were estimated from similar existing systems using the expertise of the maintainers on the OT&E test team. These estimates were updated with test data as it became available.

4.3 Peacetime Scenario Results

This section summarizes the results of the one year peacetime scenario analysis of break rate, fix rate, MRT, and MC rate. The numbers reported for OT&E were the result of multiple replications of the simulation. Table 4 presents the average model results for these parameters and the required performance.

Table 4: Peacetime Simulation Results

	Average Model Output	Requirement
Break Rate	23.2%	14%
Fix Rate		
< 2 hours	56.8%	45%
< 4 hours	85.1%	65%
< 8 hours	92.8%	80%
Mean Repair Time	1.65 hours	1.82 hours
MC Rate	89.9%	85%

The only parameter that did not meet or exceed the operational requirement was break rate. This variable was dependent on the critical failure rate and the mission duration, which was defined by the using command. The model output was examined to identify the major contributors to break rate, by subsystem. Additional model runs were made to quantify the effect of reliability improvements in these subsystems.

Model resource usage was examined to identify potential shortfalls in the planned levels. All levels were adequate to meet the availability requirements. However, the model showed particularly high usage rates for certain maintenance specialists and avionics test equipment, due to the low reliabilities of some of the avionics units.

4.4 Wartime Scenario Results

The wartime availability requirement of SGR was evaluated using the 30 day wartime simulation. The required SGR was used as an input, as the basis for scheduling sorties. The requirement was met since the simulated squadron was able to achieve the scheduled SGR.

Further analysis showed that sortie rates above the required SGR were achievable. As the input SGR was increased incrementally for each additional set of runs, the achieved rate began to lag and leveled off to a maximum achievable SGR. As a result of the increased sorties flown each day, the MC rate fell to around 50 percent. The factors limiting the maximum SGR were the availability of maintenance manpower, support equipment, and particularly spare parts. Another factor which would limit high sortie rates is aircrew availability, but for this evaluation, the number of aircrews was not constrained.

5 CONCLUSIONS

Use of the F-15E Availability Model was essential to the evaluation of F-15E mission reliability, maintainability and availability during OT&E. It provided the capability to evaluate aircraft squadron performance in an operational environment, based on the performance of two aircraft in a test environment. In the process, the adequacy of the planned maintenance concept and resources was examined. The model also allowed investigation of potential system improvements, and their impact, in the areas where the operational requirements were not met.

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AUTHOR BIOGRAPHY

Captain **LETITIA M. POHL** is an aircraft logistics analyst at the Air Force Operational Test and Evaluation Center, Kirtland AFB. She received a B.S. in Mechanical Engineering from Tulane University in 1984, and a M.S. in Systems Engineering from the Air Force Institute of Technology in 1988. She currently is planning the operational evaluation of the reliability, maintainability and availability of the Advanced Tactical Fighter.