A Weapon-System Life-Cycle Overview: The A-7D Experience


A Report prepared for

UNITED STATES AIR FORCE PROJECT RAND
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One reason for the considerable interest in weapon-system life-cycle cost is that it is not uncommon to find "cost growth" during the early years of operation as well as during the acquisition of a new weapon system. Experience has shown that the maintenance and repair of a relatively few components add significantly to the recurring operating cost. These same components can be responsible for an important part of the Not Operationally Ready (NOR) time of the system, directly affecting its combat capability. Thus weapon-system life-cycle analysis must consider both capability and cost. This study addresses the problem of achieving a better balance between the acquisition and operational phases of a new weapon system in terms of its combat capability and total life-cycle cost.

An earlier Rand study suggested that a strategy of austere development and incremental acquisition during the acquisition process—particularly during the test phase—might lead to earlier correction of critical problems responsible for cost growth and capability degradation. This correction should in turn reduce initial and recurring operational and maintenance costs and sufficiently increase the capability of the system to permit a net improvement in the overall capability-to-cost ratio of the system.* In order to understand this process in greater detail, Rand initiated a study with three broad objectives: (1) to determine the capability improvement and/or cost reduction that might be achieved in the operations phase if the reliability and maintainability of critical components were improved before production of the operational item, (2) to assess the cost and time implications of making those improvements during the acquisition phase, and (3) to suggest any changes that might be necessary in acquisition or test procedures. The initial phase of the project focused on the collection and analysis of test, operations, and cost

data for a representative weapon system, the A-7D attack aircraft, which was selected principally because of the availability of the necessary data.

Preliminary results of the project were briefed to numerous Air Force offices during 1973, including the Project RAND Air Force Advisory Group in November. Since then additional data have been obtained and the results have been expanded and refined. Although not yet completed, the collection and analysis of A-7D data have progressed to the point where insights have been obtained and tentative conclusions and recommendations may be formulated.* The objectives of this report are to present for Air Force assessment (1) a summary of the present methodology and initial results to date concerning our approach to weapon-system life-cycle analysis and (2) suggestions of potentially useful directions for future investigation and utilization of the results.

This project is one in a continuing series of studies at Rand, within the R&D and Acquisition Studies Program, on the acquisition and operational experience of complex weapons systems. This report should be of particular interest to the various USAF, DoD, and industry groups concerned with life-cycle analysis as it pertains to weapon-system definition, acquisition, and operation, and as it affects procedures, processes, and institutions.

In an era of constrained budgets and ever-increasing manpower and material costs, it becomes vital for the planner and manager of new system development programs to fully understand the trade-offs of resources among the development, production, and operating phases of a system in order to maximize the operational capability of a system for a given total life-cycle cost. Rand is performing several studies on this subject, of which this report is the first product.

As a life-cycle analysis of the A-7D weapon system, this report is principally focused on a comparison of test-phase results with subsequent operational experience. The objectives have been to determine when component reliability and maintenance problems were revealed, what kinds of problems showed up in the various stages of the A-7D weapon-system acquisition and deployment, and how these problems affected operational availability and operating cost. A secondary study objective is to suggest improvements in the data collection and analysis systems currently in use. Our analysis of the A-7D weapon system yielded the following findings:

- A number of major problems were uncovered early in routine flight testing (DT&E—Development Test and Evaluation) and emphasis was placed on correcting those that involved safety of flight or important areas of system performance. However, because of the compressed schedule to the start of full-scale production, there was little opportunity for correction of numerous component reliability and maintenance problems. During the subsequent operations phase, some of those problems caused major difficulties in terms of both high maintenance cost and limited operational availability.

- Avionics component reliability specifications based on bench tests appear to have little relation to the subsequent reliability of the component in an operational environment.

- Data now being routinely collected during both initial and operational test phases are being used to some extent to estimate
future operating costs of the system. These same data could be used to estimate operational availability.

Understanding of the weapon-system life-cycle process will be enhanced with the better data systems now being implemented. In particular, the Tactical Air Command MILAP System (Maintenance Information Logically Analyzed and Presented) is intended to link the operational sortie of an aircraft to the necessary maintenance actions required when the aircraft lands to prepare it for its next sortie. This could be a valuable tool in collecting the kind of data needed to estimate weapon-system capability. In addition, the Air Force Logistics Command IROS (Increase Reliability of Operational Systems) program could be the basis for bringing together several of the cost elements essential for understanding a weapon-system life-cycle cost. Rand has studied both of these systems and has identified some possible improvements. An effort is now underway to significantly improve the quality of MILAP data through a new error-edit procedure being developed jointly with TAC, and recommendations for improving IROS are being prepared. Modification of the existing cost accounting system to provide common equipment costs attributed to weapon systems also would be beneficial for an improved "actual" life-cycle cost. This item is still under study. These data systems will provide the base from which prediction techniques may be devised for application to new systems during planning and acquisition phases.

Conclusions and recommendations based on the findings are that:

- Existing data systems should be improved where necessary and utilized to obtain a better understanding of system cost and operational availability.
- More realistic specifications and procedures should be devised for avionics components, peculiar ground support equipment, and associated software prior to IOT&E.
- Many of the components that cause important support cost and operational availability problems were detected early enough in the test phase to consider corrective action before
committing the system to full-scale production. Such actions would undoubtedly delay the apparent IOC (Initial Operational Capability) date. However, new systems frequently encounter a two- or three-year shakedown and debugging period after IOC in order to bring the operational availability rate up to an acceptable level. It seems likely that a somewhat extended development and test phase, during which some of the component problems could be corrected prior to high-volume production, would result in a truly operational force at a date no later than the present procedure and with a considerably improved operational availability relative to its support cost.

Appropriate structuring of the test program should be considered during early planning and definition so that sufficient time and effort is allowed for testing and evaluation to correct major problems uncovered in early DT&E. Also, the opportunity should be provided during an appropriate Initial Operational Test and Evaluation (IOT&E) to reveal any additional major problem areas, such as those revealed after an accumulation of lead-the-fleet test hours.

Future study will focus on developing an improved methodology for utilizing test data on component reliability and performance to assess subsequent combat capability and support costs for a new weapon system. Attention will be focused on how the methodology and results derived from this study may be applied to new systems.
ACKNOWLEDGMENTS

We wish to acknowledge the considerable assistance and contributions of Air Force personnel, officers, airmen, and civilians, too numerous to list by individual, from various organizations throughout Headquarters Air Force, AFSC, AFLC, and TAC, without whose help this study could not have achieved its present form.

At Rand we wish to thank Janet Ives for the formulation of several of the original computer programs, D. W. McIver for assistance with initial IROS data, and D. C. Gogerty, A. J. Harman, E. D. Harris, R. M. Paulson, and H. L. Shulman for discussions and clarification of data and ideas.
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I. INTRODUCTION

Policy changes within the Department of Defense in the last few years have affected the acquisition of major systems, program management, and testing and evaluation. * Organizational changes have been made in an attempt to clarify the Research, Development, Test and Evaluation (RDT&E) and life-cycle cost issues (e.g., the new Air Force Test and Evaluation Center (AFTEC) organization and the DCS for Acquisition and Logistics at AFLC headquarters). To provide perspective to this present environment, this report discusses a weapon-system life-cycle analysis for the A-7D program, with two purposes in mind: to present the methodology and initial results to date of one approach to weapon-system life-cycle analysis, and to indicate a potentially useful direction for future investigation and utilization of the results.

The problem is that experience with new weapon systems has frequently shown that expectations generated during the conceptual and definition phases are not fulfilled when the system becomes operational. Costs are usually greater than planned; the system frequently performs less well than promised; schedules are not always achieved; reliability goals are rarely attained; and support requirements are invariably higher than anticipated. This study will examine some aspects of these factors with regard to the A-7D weapon system, chosen as our initial example because of the availability of sufficient test, operational, and cost data.

The overall objective of this study is the reduction of total life-cycle cost for a given force capability. † It is emphasized throughout this study that weapon-system life-cycle analysis must be concerned not only with life-cycle costs but also with the capability of the weapon system. What are you getting for the price you are paying?

Capability comprises a number of areas: availability of the force, particularly in terms of a capability level achieved at some date (i.e.,

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*See, for example, DoD Directive 5000.1, the AFR 800 series, and AFR 80-14.
† The study results and recommendations could of course also be used to increase force capability for a given cost.
an Initial Operational Capability (IOC) date; the availability of individual aircraft to conduct combat missions; the sortie success of that aircraft in the conduct of its missions; and the mission effectiveness in terms of the design criteria of interest (in the case of a close-air-support mission, for example, payload capacity, radius, loiter time, maneuverability, delivery accuracy, and survivability). This study has been concerned primarily with the first two measures of capability: IOC date and sortie availability.

This study also examines the various elements contributing to the life-cycle cost of a system and the potential of trading off among these cost elements: RDT&E, procurement, and operations and support. The procedure for this initial study was to examine a past program with particular emphasis on comparing the maintenance and reliability problems determined during the test phase with those later experienced in operational use. When were problems first revealed? Did problems that showed up during testing continue to show up during operational use? Could problems that showed up in operational use but not in testing have been revealed during testing if testing had been conducted differently? What are the impacts of these problems with respect to the cost for the weapon system?

In Sec. II we present an overview of the A-7D at the weapon-system level of aggregation. In Sec. III, analyses of the data of the various test phases and selected operational experience are compared to show how certain of the components affected the weapon system life cycle at different times in the cycle. Section IV contains a suggested alternative acquisition and test strategy, based on the findings discussed in Secs. II and III. Section V presents conclusions and recommendations based on our analysis to date. The data collection effort required to support the study is described in the Appendix.
II. THE A-7D WEAPON SYSTEM

In this section we review the A-7D program, chosen as the representative weapon system in this study because of the availability of cost and operational data from both test and operational phases. We also present an overall measure of system performance (the combat-ready rate) for different time periods, and provide a measure of the weapon system's total life-cycle cost.

A-7D PROGRAM

The history of the A-7D program is outlined in Fig. 1. The various A-7D testing and operational periods are shown, together with the deliveries of preproduction and production aircraft into the fleet.

START

CAT I  ▼
CAT II  ▼
CAT III Ph 1a  ▼
  Ph 1b  ▼
  Ph 2a  ▼
OPERATIONAL  ▼
DELIVERIES

Preproduction  2 1 2 1 4 2 6 3 5
Production      2 20 26 17 37 27 27 28 29 26 25 27 25 18
Cumulative  5 18 74 182 290 387

| 1 2 3 4 | 1 2 3 4 | 1 2 3 4 | 1 2 3 4 | 1 2 3 4 | 1 2 3 4 | 1 2 3 4 | 1 2 3 4 |

Fig. 1 — Outline of the A-7D program
The A-7D program started with a letter contract in April 1966. It was originally intended to be a relatively straightforward procurement of a slightly modified version of the existing Navy A-7A. However, between the letter contract and the first flight of the aircraft two years later, there were four major design changes introduced into the weapon system: (1) a new engine, (2) a new gun, (3) a new avionics suite, and (4) the addition of survivability features. The unit price of the aircraft doubled, but it was expected that the effectiveness in terms of payload capacity, radius, loiter time, firepower, delivery accuracy, and survivability would more than double if the performance expected from these new components were indeed realized.

In retrospect, the program was not a simple, straightforward, off-the-shelf procurement. However, funding for development remained minimal and a total of less than $60 million was spent for: (1) redesign of the A-7A to an Air Force configuration, (2) qualification of the TF-41 engine, and (3) all other related RDT&E. No RDT&E money was allocated by the SPO to manufacturers for any of the avionics and related peculiar ground support equipment, which was considered to be contractor-furnished equipment (CFE) needing only minor modifications and integration.* However, reliability and maintainability problems arose during operational service as a result of this modified equipment and it turned out that extensive further modifications were necessary.

Several aspects of the testing activity are of particular interest. First, no aircraft flew in more than one of the test periods, and no aircraft flew more than 300 hours. During Cat III Phase 2a (the Operational Test and Evaluation (OT&E) test leading to IOC in March 1971), only one of the aircraft flew more than 100 hours. Therefore, throughout the test program very little flying time was accumulated on any particular airframe. This minimal amount of flight testing failed to uncover a number of problems which showed up later in operational experience.

Another item to note in the context of the testing activities is that the production delivery schedule was accelerated from about one

*Additional non-recurring production and component-improvement money was allocated for avionics configuration changes to fix problems revealed by testing and operational use.
or two per month to seven or eight per month when Cat II and III testing was still going on. In fact, the decision to accelerate production was made before Cat II testing even started—a production acceleration decision potentially justifiable on the basis of Vietnam requirements.*

The shaded areas in Fig. 1 represent the data obtained for this study; they cover much of Cat II testing, all three phases of Cat III testing, and two years of operational experience. Data on the first year of Cat II have been analyzed, all of the Cat III data, and one year of operational data (extending from one-and-a-half to two-and-a-half years after IOC). †

Each one of these test periods had a specific set of test objectives. Category I was the contractor's development phase. Category II was primarily intended for engineering and systems-oriented testing aimed at safety of flight, performance, and systems checkout. The chief concern of this test phase was for system and component performance and system and individual component reliability and maintainability, with only a secondary concern for the user-oriented combat mission that the airplane was intended to fly (although some combat-oriented missions were flown). For instance, during the A-7D testing in Cat II, the gun was fired only in one out of ten sorties, and only once out of four or five sorties was the armament subsystem used.

Category III testing was more combat-oriented, as evidenced by the reliability and maintainability problems discovered for the armament subsystems. Phase 1a of Cat III was a good representation of what would now be considered an Initial Operational Test and Evaluation (IOT&E) as defined in APR 80-14—four preproduction airplanes were exercised at Luke Air Force Base by a TAC test team. Phase 1b turned out to be a period of transition from a test team to a wing-organizational structure, and the data indicate a period of considerable turmoil; it will not be considered further in the present analysis. Phase 2a appears to be representative of an OT&E period.

* Although the Vietnam War was in progress at the time the production decision was made, the A-7D was not used in significant numbers before the war was ended.
† The data collection for this study is discussed in the Appendix.
Section III will focus primarily on comparing subsystem performance from the Cat III Phase 1a (IOT&E) and the Cat III Phase 2a (O&G) periods with some operational results about two years after IOC. A more complete historical tracking of the overall weapon system's operational capability is considered next.

**COMBAT-READY HISTORY**

The combat-ready history for the early operational period of the A-7D is presented in Fig. 2. The possessed hours during which the aircraft is not considered to be combat ready include periods during which the aircraft is: (1) in unscheduled maintenance (UM), (2) not operationally ready due to supply (NORS) and is either grounded (NORS-G) or flyable (NORS-F), and (3) not operationally ready due to maintenance (NORM-G or NORM-F).

The initial wing of A-7D aircraft had an IOC date of March 1971. It can be seen in Fig. 2 that during the first year of operational service, the combat-ready rate met the 71 percent level in only two months at Myrtle Beach Air Force Base. The fleet was grounded in April 1972 due to an engine problem (the Air Force suffered a reduction in capability during this month); the grounding was lifted in May 1972. The wing achieved a 71 percent combat-ready rate in September 1972 at the time it was preparing to go overseas. At that time it had top priority on supply parts and skilled maintenance personnel.

The residual wing element left at Myrtle Beach Air Force Base sustained reduced capability after the deployment to Thailand, of which two months are shown in Fig. 2(a). This may be attributed to the fact that the bulk of the highly skilled personnel and the best aircraft were deployed to the combat area. The contingent that arrived at Korat Air Force Base in Thailand achieved very close to the 71 percent ready

*The NORM categories do not appear in Fig. 2 because in the analysis of the data used to construct this figure no aircraft were found to be categorized as NORM-G or NORM-F.

†TAC requires each wing to maintain an operational ready rate of 71 percent. We feel that combat readiness is a more meaningful measure of weapon-system capability since an aircraft can be considered operationally ready even if certain subsystems place it in the NORS-F or NORM-F category.
Fig. 2 — Combat-ready history

Source: AF 65-110 operational data system
rate, as shown in Fig. 2(b). The other wing operational during this period, which was stationed at Davis-Monthan Air Force Base, experienced a low operational readiness rate, as shown in Fig. 2(c). The wing about to become operational at England Air Force Base in the Spring of 1973 is also below the 71 percent combat-ready rate.

A question raised by Fig. 2 is: What was the value of the March 1971 IOC date in terms of force capability if it took one-and-a-half years after the A-7D IOC for the first wing to attain a combat-ready condition, and then only at the expense of the remaining wing or wings suffering a considerable degradation in capability? The cause of this delay and the reason for the degradation of the remaining wing's capability can in part be identified by considering the impact of subsystem performance upon downtime, as is undertaken in Sec. III of this report.

A-7D LIFE-CYCLE COST

A measure of a weapon system's "total cost" is the present value of all previous and forthcoming expenditures directly related to the RDT&E, procurement, and ownership (i.e., operation) of the system. Such a "total cost" is referred to as a life-cycle cost. At the time that a life-cycle cost is calculated, forthcoming expenditures can only be estimated, whereas expenditures to date should be measurable with a fair degree of accuracy. In theory, the life-cycle cost measure is very attractive for indicating the magnitude of the potential trade-offs of resources among the development, production, and operating phases of a system in order to optimize capability and cost characteristics. To test this theory we applied this measure to the A-7D.

Figure 3 presents an FY 1973 calculated projection of life-cycle cost for the A-7D in terms of FY 1973 dollars. Since the aircraft was still in production during FY 1973, the life-cycle cost is stated in terms of a per aircraft cost rather than a fleet cost. The acquisition cost is based upon the total planned buy (411 aircraft) as of FY 1973. The estimated costs of ownership are based upon the assumption that the

* A detailed analysis can be found in M. R. Fiorello, Estimating Life-Cycle Costs: A Case Study of the A-7D (to be published).
FY 1973 observed average per unit operating cost is representative of the ownership costs for the duration of the aircraft's useful life, which is assumed to be 15 years.

The present value for the average acquisition cost per unit (in constant FY 1973 dollars) was calculated by applying a long-term discount rate of 5 percent after adjusting the RDT&E and procurement expenditures for inflation. The present value for the average cost of ownership per unit (also in constant FY 1973 dollars) was computed on the basis of a 15-year operating period at the FY 1973 average cost of ownership and discounted at a rate of 5 percent.

With the foregoing assumptions as a basis, Fig. 3 shows that the cost of ownership is approximately 30 percent higher than the acquisition cost. However, if the analysis is repeated with a 10 percent long-term discount rate, the acquisition cost is approximately 36 percent higher than the ownership cost. Thus for long-term discount rates in the range of 5 to 10 percent the average per unit costs of ownership would be comparable to the average per unit costs of acquisition for
the A-7D. (However, note that the A-7D program is unusual in that the total RDT&E cost amounted to only 5 percent of the acquisition cost, based upon a total buy of 411 aircraft.)

Several of the costs of ownership are not very sensitive to the reliability and maintainability of the weapon system (e.g., training (TNG), petroleum, oils, and lubricants (POL), and base operating support (BOS)). However, the largest portion—the remaining 79 percent of the ownership costs (e.g., operation and maintenance (O&M), depot, and investment)—are very sensitive to weapon-system reliability and maintainability as well as manning, support, and deployment decisions. The base-level O&M costs alone account for nearly 50 percent of the ownership costs. One of the elements of the O&M cost which is particularly sensitive to the weapon system's reliability and maintainability is the labor cost for unscheduled maintenance at the base.

In order to understand the contributors to low combat-ready levels and high ownership costs, it is necessary to delve into the detailed information on component and subsystem reliability. It is to these subjects that we now turn.
III. ANALYSIS OF THE A-7D LIFE CYCLE

To support the analysis of component and subsystem reliability on combat-ready rates and ownership costs, an extensive data collection effort was mounted. As the initial analysis progressed, we employed a number of measures for analyzing this growing set of data. In the following subsection, we use these measures to provide illustrations of the underlying components which impact on both capability and cost.

A TRADITIONAL MEASURE FOR RELIABILITY AND LIFE-CYCLE COST

Certain logistics indicators are frequently used as measures of system reliability and as a basis for estimating maintenance costs. When attempting to quantify the support cost component of life-cycle cost of a new weapon system, one measure widely used today is mean time between failure (MTBF).* An attempt was made to look at a historical trace of MTBF data for certain selected bomb navigation system components for the A-7D.† The five components presented in Fig. 4 are: the forward-looking radar (FLR, WUC 73A00); the inertial measurement set (IMS, WUC 73F00); the air data computer (ADC, WUC 73C00); the doppler radar set (DRS, WUC 73D00); and the heads-up display (HUD, WUC 73E00). The figure shows the manufacturer's contracted specification; the prime contractor's (Ling-Temco-Vought) prediction (as of June 1970 when Phase

* The only "failures" counted here are those caused by a true defect (not a maintenance action for which "no defect" is identified), and the only time counted is flying time. It should be noted that the actual operating hours for avionics components tend to be about double the flying hours, and the manufacturers believe that operating hours are a more realistic yardstick. The MTBF specification that an avionics component must meet is based on operating hours in the manufacturer's plant.


‡ Work Unit Codes are used to designate maintenance activity on specified components.
Fig. 4 — Reliability comparison for selected components of the A-7D bomb navigation system.

Source: Contractor, SPO, and MDC 66-1 data.

la of Cat III was completed) of how well that component would operate in the weapon system’s operational environment; Cat II test results as of August 1970; Cat III test results as of June 1970; and selected operational results at the end of calendar year 1971, the third quarter of 1972 at Myrtle Beach Air Force Base, and the first half of 1973 at England Air Force Base.

MTBF is a measure of interest to logisticians who are concerned with providing enough spare parts to fix defective equipment operating in the field environment. However, MTBF is not a perfect measure of item reliability or the frequency of maintenance action. Component failure reports are not always consistent. Additionally, the test and operational values in Fig. 4 would be even lower if the mean time between maintenance actions (MTBMA)* was used. The MTBMA measure is of

*MTBMA includes all on- and off-equipment and defect and no-defect maintenance actions charged against a particular work unit code.
interest to manpower planners who are concerned with providing enough manpower for all of the writeups and defects which must be taken care of if operational readiness is to be achieved and maintained.

It can be seen from Fig. 4 that the Mil Spec standard and the prediction of the prime contractor considerably exceeded actual results in the field during operational experience. It appears that the results obtained from flight testing give a fairly good indication of what could be expected in operational use.* It is also evident from the data that the situation is not improving with operational experience, which is contrary to the assumption prevalent today that things will "mature" with use in the field. Item reliability will not improve unless specific steps are taken to fix problems encountered during testing. The trend of deteriorated reliability of individual components is by no means the whole story; weapon systems can function successfully with some degree of low reliability for noncritical components. We are concerned when such reliability problems cause the airplane to be grounded, to fly in a degraded condition, or to be unavailable for the full combat mission for which it was procured. Of special interest is the degree to which a small number of components contribute to lower than expected capability and/or higher than expected cost.

DOWNTIME HISTORY

Thus, a more adequate measure of overall system performance than individual component MTBF is the combat-ready rate. This measure does not, however, show the relative impact of subsystem reliability and maintainability on overall performance. One way to determine these relative impacts is to look at the aircraft downtime attributable to

*The MTBF values shown in Fig. 4 indicate that operational experience for these components is less than 5 percent of the contractual Mil Spec MTBF. Moreover, operational experience could not be reliably predicted by such an adjustment to the Mil Spec. On the other hand, Cat III (Phase 1a) test information yields the following predictive equation of the operational experience just prior to the deployment from Myrtle Beach AFB in 1972:

\[
\text{MTBF}_{\text{Op72}} = -1.24 + .89 \text{MTBF}_{\text{Test}} \quad R^2 = .81
\]

The MTBF_{\text{Test}} coefficient has a t-statistic of 3.6, which indicates the coefficient is significant at the 5 percent level. Thus, in preparation for combat deployment, Myrtle Beach AFB was able to attain about 90 percent of the MTBF level indicated in IOT&E.
each subsystem.* By considering both the combat-ready rate (see prior discussion in Sec. II) and the downtime by subsystem, we have two measures for considering both the overall system capability and the impact on it of subsystem performance.

Downtime is defined to include the time that the aircraft is on the ground (because it is not operationally ready due to maintenance (NORM-G) or supply (NORS-G)) and, in addition, the time that the system is suffering some degradation in mission capability even though the aircraft is allowed to fly (NORM-F and NORS-F). After removing these times from the total aircraft availability, we have a measure of combat-ready time (Fig. 2). We have used this time measure to represent what capability the Air Force is getting (in terms of availability).

The downtime attributed to specific components by work unit code during testing and operational experience is portrayed in Fig. 5. We

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<th>CAT III</th>
<th>OPERATIONAL</th>
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<td>PH 2A</td>
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<tr>
<td>HUD</td>
<td>73 E 00</td>
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<tr>
<td>Fuel Ind.</td>
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DOWNTIME AS A PERCENTAGE OF POSSESSED HOURS

<p>| | | | | | |</p>
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<td>32.0</td>
<td>31.0</td>
<td>44.6</td>
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<tr>
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<td>45.5</td>
<td>24.0</td>
<td>21.5</td>
<td>34.0</td>
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</table>

Fig. 5—A-7D subsystems ranked by downtime

Source: MDC 66-1 and AF 65/130 data.

* The total downtime of all systems is used to determine the combat-ready rate.
indicate the ordinal ranking from 1 to 10 for the top ten contributors to downtime for the A-7D weapon system. The components causing the downtime are listed at the three-digit WUC level, of which there are 128 for the aircraft. Figure 5 displays the test results from the IOT&E (Cat III, Phase 1a) and OT&E (Cat III, Phase 2a); operational results from Myrtle Beach Air Force Base (July, August, and September 1972); combat data from Korat Air Force Base (November and December 1972); and data from England Air Force Base (March, April, and May 1973) during preparations to achieve their IOC, six months after the Myrtle Beach unit was deployed to Korat and two years after that unit had achieved IOC.

Avionics problems that showed up in testing continued to show up in operational use. The engine and airframe components show different patterns in that some problems were not discovered until after testing. In fact, there appear to be three classes of problems in weapon systems: (1) those that are quickly evident in flight testing such as stability and control, inlet-engine matching, or a black box not working; (2) those associated with a longer time period, such as wear, endurance, cycling, and fatigue (airframes and engines tend to be in this class), which testing could uncover given sufficient test time (such as through lead-the-fleet testing on a few designated aircraft); and (3) those associated with high-volume production, such as quality control or tolerance stackup, in which flight testing cannot be of assistance.

It may also be seen from Fig. 5 that a few components contributed a major share of the downtime of all the subsystems. The top ten (of the 128 WUCs) contributed two-thirds to three-fourths of total downtime. There is a considerable improvement on total downtime at Myrtle Beach (before overseas deployment) and at Korat following the October 1972 deployment of the Myrtle Beach contingent (Fig. 2). The operational capability obtained at Korat was close to the combat-ready rate of 71 percent. However, it should be noted that during this period this particular wing had top priority on supply parts and maintenance personnel—first at Myrtle Beach because it was preparing to go overseas, and then at Korat in the combat environment. On the other hand, the other wing active in CONUS during this time period, at Davis-Monthan Air Force Base, suffered quite drastically; their combat-ready rate went to about 50 percent (see also Fig. 2). Figure 5 also
shows the subsystem downtimes of the wing at England Air Force Base when preparing to achieve operational status some six months after the Korat deployment. The wing at England Air Force Base experienced problems in the supply of parts and skilled maintenance personnel which undoubtedly contributed to their achieving a combat-ready rate of approximately 50 to 60 percent.

In sum, it was one-and-a-half years after IOC before the first wing sustained a combat-ready rate of 71 percent. In order to achieve this, the wing that was in CONUS and a wing preparing for IOC suffered from lack of supply parts and skilled personnel.

The foregoing combat-oriented observations could not have been made using the MTBF measure; however, these observations do not directly shed light on the contributors to high weapon-system support cost.

**UNSCHEDULED MAINTENANCE MANHOUR HISTORY**

The downtime rank comparison (Fig. 5) provides some limited insight into the probable maintenance support costs. One might expect that the top ten downtime subsystems would also rank high in terms of unscheduled maintenance manhour costs and logistics support costs. These issues will be explored in this and the following subsection.

The subsystems ranked by unscheduled maintenance manhours for the A-7D during the selected test and operational periods are shown in Fig. 6. Again the Cat III results are compared to operational data and again the same pattern emerges; that is, problems that show up in early testing continue to show up throughout operational use, particularly in the avionics area. Note also that 10 out of 128 three-digit WUCs consume half of the unscheduled maintenance time; over all phases of testing and operational experience less than 20 components were involved.

Problems with armament differ from the persistence of some avionics problems. In this program, armament (launchers, racks, and the gun installation) was to consist of off-the-shelf items. However, installation of even an off-the-shelf item represents a unique design to the airframe, which can entail installation problems. The launchers and racks are very high maintenance time consumers (Fig. 6) but not weapon
system downtime contributors (Fig. 5). This is because they are easy to remove and install on the aircraft. Most of the maintenance effort for this equipment is performed in the shop (off-equipment).

A problem of hung bombs was initially felt to be a hardware switching and wiring problem and much of the maintenance effort was preventative in nature (e.g., checking, cleaning, etc.). When the Navy checked out an "operational" software package (for the A-7E, which contains the same avionics suite as the A-7D) at the Naval Weapons Center using a software simulation facility and flight testing, they were able to trace the problem to a software programming error. In short, there is a clear need for an improved software checkout procedure during testing. The procedure should include software associated with the complex ground-support equipment used to check out the flight hardware, as well.
We observed from the data that the unscheduled maintenance on the A-7D accounts for about 25 to 35 percent of total maintenance. Also of interest is that 15 to 25 percent of the unscheduled maintenance is "no-defect"; that is, there is a writeup after flight, a part is removed, checked, found operational, and reinstalled on the airplane. Thus, some 5 to 10 percent of all the maintenance manhours on the A-7D can be attributed to no-defect maintenance, a large portion of which is related to software associated with avionics flight hardware.

Aerospace Ground Equipment (AGE) maintenance must be added to this total. Based on a sample analysis, we estimate that at least an additional 10 percent of manhours is for AGE maintenance. The avionics AGE is as complex as the flight hardware, and it also uses software. Thus, in any new weapon system where highly sophisticated, highly integrated avionics systems are to be utilized, attention must be paid during testing not only to flight hardware but also to flight software and to ground-support equipment hardware and software.

However, the base unscheduled maintenance and the base AGE maintenance account for only part of the O&M costs. In order to determine the total base and depot O&M costs, the DPEM and the RMS data systems (described in the Appendix) were used to derive overall weapon system costs (see Sec. II). However, these systems only track the aggregate subsystem costs. Next, we consider a separate data system which may be used to track a substantial portion of the O&M costs at the lower component levels—the level needed to identify major problem areas where product improvement would have high payoff.

**LOGISTIC SUPPORT COST**

IROS (Increase Reliability of Operational Systems), an AFLC data collection and analysis program, is a method which attempts to collect the logistic support costs (i.e., parts and labor costs at both the base and the depot) by WUC for a particular system. Figure 7 shows an example of IROS-determined costs for the A-7D for the four quarters of FY 1973. The objective of IROS is to highlight the main

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*A detailed presentation may be found in M. R. Fiorello and P. Konoske Dey, A Comparative Analysis of IROS Logistics Support Costs (to be published).*
<table>
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<tr>
<th>DESCRIPTION</th>
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<th>4TH QTR 1972 ($2.55M)</th>
<th>1ST QTR 1973 ($3.07M)</th>
<th>2ND QTR 1973 ($3.18M)</th>
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<tr>
<td></td>
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<td>RANK</td>
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<td>3.6</td>
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<td>2.7</td>
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<td>3.1</td>
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<td>2.7</td>
<td>6</td>
<td>2.4</td>
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<tr>
<td>Launch and Racks</td>
<td>75 A009</td>
<td>3</td>
<td>5.4</td>
<td>2</td>
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<td>AC/DC Pwr Supply</td>
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<td>2.9</td>
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<td>7</td>
<td>3.0</td>
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<td>9,219</td>
<td>10,992</td>
<td>11,874</td>
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*Avionics

**Airframe

Fig. 7—An example of the IROS data system product** for the A-7D

* Totals may not add up due to rounding.

** These data are presented only as an example. See text for discussion.

problem areas in each weapon system in terms of cost. Figure 7 portrays the chief high-cost items of the 128 three-digit WUCs on the A-7D. We emphasize that Fig. 7 is an example illustration only, since it appears that at the present time IROS is capturing only one-fourth to one-third of the costs it should. Also, more airframe and engine data are missing than avionics data, thus invalidating the rank and percentage data in Fig. 7.* However, we feel that if IROS were improved, it would be a valuable tool for developing a data base for detailed life-cycle cost studies.

EMERGENCY UNSATISFACTORY REPORTS AND UNSATISFACTORY REPORTS

So far we have examined some of the impacts of subsystem reliability and maintainability upon weapon-system capability and cost. One of

*For further details, see M. Fiorello and P. Konoske Dev. A Comparative Analysis of IROS Logistics Support Costs (to be published).
the dominant themes has been that problems discovered during testing frequently persist into the operational phase and result in increased costs and significant degradations in capability. The underlying reason for the persistence of problems can be illustrated with the help of Fig. 8, which presents a summary of the Emergency Unsatisfactory Reports and Unsatisfactory Reports submitted during Cat II from August 1969 to August 1970. These are writeups of problems occurring on the various systems listed during the Cat II testing; there are over 200 writeups for the A-7D. Half of these writeups were closed out by August 1970; however, half were still outstanding when high-volume production was underway and production-configuration airplanes were being delivered.

<table>
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<tr>
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<td>FUEL SYSTEM</td>
<td>46 000</td>
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<td>LANDING GEAR</td>
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<td>OTHER</td>
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<tr>
<td>TOTALS</td>
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Fig. 8—Summary of Cat II emergency unsatisfactory reports (EUR) and unsatisfactory reports (UR)

The bomb-navigation system had the most writeups, with the propulsion system second highest. Problems with these components continued to show up in later test and operational periods. In contrast, problems with armament do not show up in the list of airframe subsystems. As previously mentioned, the armament subsystem was tested less frequently; the gun was fired in one out of ten sorties and the launchers and racks were exercised in only one out of every four or five sorties. Thus, armament problems did not show up until user-oriented Cat III testing, when many more combat-range missions were flown.*

In this program, RDT&E costs were minimal. The avionics subsystem components were considered off-the-shelf and thus little funding was available to fix problems uncovered in Cat I and II testing; moreover safety-of-flight problems certainly had top priority.

The low RDT&E budget and the commencement of high-volume production while half of the Cat II unsatisfactory reports were outstanding contributed to the persistence of a number of problems which subsequently resulted in increased support costs and a significant degradation in capability (as evidenced by the low combat-ready rates for two of the three wings a year-and-a-half after IOC).

* A more detailed discussion of various test period results is found in A. Sweetland, Evaluating Aircraft Performance Capability from Testing (to be published).
IV. AN ALTERNATIVE ACQUISITION AND TEST STRATEGY

The analysis outlined in the previous section clearly demonstrates that a number of component reliability and maintenance problems that caused serious difficulties during the first few years of weapon-system operation were identified relatively early in the test phase. The obvious inference is that a more satisfactory operational performance would have ensued if more time and resources had been devoted to correcting those problems prior to full-scale production of the system. Such a procedure would of course entail some costs—principally a delay in IOC.* Do the potential benefits of an extended RDT&E—including IOT&E and OT&E phases—outweigh the IOC delay?

The present analysis suggests that in the case of the A-7D system the improvement in operational availability and reduction in operations cost could have been significant. Through reduction in unscheduled maintenance on a few critical items, the aircraft availability could have been significantly improved and the maintenance-related cost reduced. We believe that the consequent improvement in both the operational availability and costs would be large enough to warrant expenditure of significant additional effort during the test phase.

How might a program be structured in order to allow sufficient time to use test results? Shown in part (a) of Fig. 9 is the A-7D program from first flight, together with aircraft cumulative deliveries that show the slow build up at the rate of one or two per month for a period of time, and then the high-volume production of about 7 to 8 per month with an IOC in March 1971. Part (b) of the figure indicates an alternative production rate (dotted line) and test program here defined according to APR 80-14. The alternative suggested in this section includes a DT&E period of about two years, and an initial IOT&E period.

*It is recognized that higher unit prices may prevail for the few early production aircraft. It is also recognized that it will cost more to correct problems in a large operational fleet than prior to production. The argument that it will cost more later due to inflation ignores the concept of the present value of future expenditures (by the use of discounting); see also discussion of life-cycle cost in Sec. II.
Fig. 9 — Alternative approaches to test program structure
starting one-and-a-half years after first flight and proceeding for a year before the high-volume production go-ahead decision (DSARC III) is made. At this point, the DSARC III decision could be made on the basis of considerable test information. A period of 18 months is allowed after production go-ahead to achieve high-volume production, followed by delivery of a squadron of production-configured airplanes to the operating command and a six-month OT&E leading to IOC.

The date of initial operational capability for the alternative strategy is shown in a different type face (IOC) because it should represent a significantly different level of operational capability than that available at IOC in the actual A-7D program. It should be remembered that in the comparison between Cat III testing and operational experience for the A-7D, the time difference between IOC and an approach to the true combat operational capability was 18 months. Thus, it seems possible that even after allowing an expanded time period to achieve a comprehensive IOT&E, the alternative strategy might take no longer in terms of the time to achieve a level of capability for the force. The continuing low level of production during the test program would support a skilled cadre of engineering and production personnel necessary for the full production program. A go-stop-go approach for engineering and manufacturing is not advocated.

The commencement of IOT&E was selected on the basis of passing a 150-hour man-rated Model Qualification Test (MQT) for the propulsion system, since this test period would be conducted by the using command personnel. The DT&E program start (first flight) could be achieved with a 50-hour engine Preliminary Flight Rating Test (PFRT). One-and-a-half years are allowed to achieve MQT from PFRT status for a new engine program. Thus, IOT&E starts one-and-a-half years after start of DT&E. A recent study by the Air Force Scientific Advisory Board concerning future aircraft turbine engine development programs recommended a one-year period after MQT for engine-airframe flight testing to explore the flight envelope and insure compatibility of the engine-airframe combination.

This recommendation would coincide with the one-year IOT&E test program outlined here. The additional time could also be used to improve the Time Between Overhaul (TBO) of the engine, thus allowing a reduction in the number of spare engines that would have to be ordered to support the fleet once high-volume production is initiated.

It is, of course, not possible to prove that the suggested benefits would have been achieved if the alternative strategy outlined here had been followed for the A-7D. Wise and accurate decisions are always easier to make in hindsight than in the midst of a complex and dynamic acquisition and test program. However, it seems quite clear that the potential for important improvements does exist if the appropriate information can be made available to the program manager in a timely manner. To accomplish this objective, a new procedure is needed for the utilization of test results to aid the program manager in identifying priority problem areas and resolving when to commit the system to quantity production.

A conceptual outline of such a procedure is shown in Fig. 10. As shown in part (a) of the figure, force capability and cost have in the past been determined by the postulated force and operating concepts, the aircraft characteristics predicted in paper studies provided by the contractors, and some measure of total cost as predicted by cost estimation models. Test results have only entered into consideration after the fact in the form of decisions to modify those components which absolutely had to be fixed in order for the system to be introduced into the force. Part (b) of the figure illustrates the concept of bringing test results into use directly in predicting force capability and cost through some combination of simulation and cost modeling based on the test results. Then if the force capability and costs predicted on the basis of the test results are not acceptable, those components which are most seriously degrading capability can be determined and a feedback loop instituted to bring system modification under deliberate consideration. If necessary, high-volume production can be delayed until the troublesome components are brought up to an acceptable level.

This analysis tool would provide the decisionmaker with (1) additional information on his predicted force capability based on actual
Fig. 10 — Force capability/cost prediction procedure
test data rather than on paper studies, (2) identification of troublesome components, and (3) isolation of those improvements that might be expected to yield significant enhancement in force capability if components could be improved.*

Figure 11 shows in detail the force capability and cost methodology required to predict a combat-oriented sortie rate and its associated cost. This particular figure, which was drawn seven years ago, illustrates the methodology that we employed in the Sortie Rate Analysis Study at Headquarters USAF in 1967.† We used the Rand-developed SAMSOM simulation model with Rand/USAF cost models. The input data at that time was operational combat experience from Southeast Asia. It seems clear that the input data could be drawn just as well from the early IOT&E test data collected on a new system, and the same methodology applied with respect to operations, maintenance, manpower, and supply in order to estimate capability and cost on the basis of actual test data.

*The technological level of a given component may be an indicator of the improvement available for some resource expenditure. This avenue is being explored. For example, see R. Shishko, Technological Change Through Product Improvement in Aircraft Turbine Engines, R-1061-PR, The Rand Corporation, May 1973. Section IV presents an example of a model which attempts to determine how much it is likely to cost for a given improvement in aircraft turbine engines. See also J. R. Nelson and F. S. Timson, Relating Technology to Acquisition Costs: Aircraft Turbine Engines, R-1288-PR, The Rand Corporation, March 1974, for a discussion and analysis of development and component improvement models.

†Sortie Rate Analysis (U), Headquarters USAF, DCS/Plans and Operations, January 2, 1968 (Secret).
Fig. 11 — Force capability/cost methodology
V. CONCLUSIONS AND RECOMMENDATIONS

The analysis of reliability and maintenance data throughout the test and early operational phases of the A-7D weapon system yields the following general conclusions and recommendations:

Current test methods and procedures identify many component reliability and maintenance problems relatively early in the test program, but there is little emphasis on early correction of those not affecting safety of flight.

It appears that routine flight testing is effective in yielding early and reliable information on at least some of the component failure rates and maintenance problems that carry forward to cause difficulties in the subsequent operational phase. However, since the early portions of a normal test program are focused on safety of flight and verification of system performance levels, component reliability data are seldom used to identify major maintenance problems or corrective action taken unless those problems interfere with the principal test objectives.

Additional reliability and maintenance problems could be identified during early test through a comprehensive IOT&E.

A large fraction of the maintenance problems that affected the A-7D weapon system during the first few years of its operational phase were related to mission-oriented components (e.g., radar, inertial measurement system, gun launchers and racks). Such components are not normally exercised extensively in a combat-mission-oriented environment during DT&E, and thus the severity of maintenance problems might not be recognized until an IOT&E or OT&E test phase.

It is recommended that consideration be given during the definition phase of any new weapon system to a comprehensive IOT&E. This would be a combat-oriented test period with user pilots and maintenance personnel. It would include lead-the-fleet testing specifically geared
to reveal the envelope of capability and costs, so that deliberate decisions and corrective actions can be taken early, on the basis of information obtained from testing before high-volume production is initiated. A methodology needs to be developed whereby such test data could be used to estimate a new weapon system's potential capability and cost.

A better approach to development and test of avionic components and related software is needed.

The reliability experience of avionic components in the A-7D clearly indicates that MTBF specifications and bench test results are not well correlated with the results obtained during flight operations. Better procedures need to be developed for specifying and predicting the reliability of such components in a true operational environment. Furthermore, since the development cost of such components is relatively small when compared with the costs incurred by unreliable operation in the field, there should be a high potential payoff to spending more time and resources on improving and demonstrating reliability during the development and test phase of a weapon system, prior to committing the components to production.

Additional effort on correcting some of the reliability and maintenance problems prior to quantity production should improve operational availability and performance of the system and reduce O&M costs, without significantly delaying achievement of true operational capability.

The unscheduled maintenance that had to be performed on a few troublesome components during the first few years of A-7D operations clearly had an important impact on both the operational availability and operations cost of the system. Since in many cases the reliability and maintenance problems were identified relatively early in the test phase, it should have been possible to take corrective action (i.e., improve the reliability) of those components prior to start of production. However, that course of action has not typically been followed in recent aircraft development projects, possibly through lack of full
appreciation of the operational cost consequences and the belief that it would unduly delay IOC. Insufficient RDT&E funds to correct problems may also be a factor. In the A-7D, the improvements in operational capability and reductions in maintenance cost would have been substantial. Furthermore, it seems plausible that many of the improvements could have been achieved without incurring a delay in the actual IOC date (i.e., the date at which a significant operational capability actually existed), although there would have been a delay in the date at which the first operational unit was equipped.

Appropriate data should be collected throughout the test and operational phases of a system lifetime, to aid in decisions made in the early phases of system development and later product improvement, as well as to provide a data base for use in future analysis and methodology development.

There are available data systems which can be better exploited to aid the analyst in understanding life-cycle trade-offs. On the capability side, for instance, the MILAP system* is expected to provide a link between operations and maintenance that relates the kind of mission that the aircraft flew to the maintenance needed on the ground to get it ready for its next mission. This relationship between the sortie type and the required support actions is an important element in understanding life-cycle capability and cost.†

It is desirable to standardize data-storage systems for the various test phases and operational use across the various commands so that time-phased system performance maintenance and reliability comparisons can be made on a compatible basis. A particular command could keep a data collection system which is particularly geared for its needs as,

* Maintenance Information Logically Analyzed and Presented. This system is currently being implemented by TAC at base level throughout the operating command.
† For a discussion of sortie type and maintenance actions, see, for example, T. S. Donaldson and A. Sweetland, The Relationship of Flight-line Maintenance Manhours to Aircraft Flying Hours, The Rand Corporation, RM-5701-PR, August 1968, and Sortie Rate Analysis (U), Headquarters USAF, DCS/Plans and Operations, January 2, 1968 (Secret).
for instance, the System Effectiveness Data System (SEDS) at the Air Force Flight Test Center. With minor modifications, the same data could be collected on different programs with a minimum of effort required to put it into a format comparable to other programs. Several cost data bases are available to obtain the RDT&E, procurement, and operating and support costs. These include Selected Acquisition Reports, IROS, the Resource Management System (RMS), and the Depot Purchased Equipment Maintenance system (DPEM). In particular, an improved IROS could be a valuable tool in bringing together certain operating and support costs and providing visibility at the component level.
Appendix

A NOTE ON DATA COLLECTION

This study initially focused on the impact of maintenance and reliability on system capability and cost. To accomplish this objective, an extensive data collection effort was required, comprising many data sources and computer programs. For the A-7D the sources were distributed among the developing (AFSC), supporting (AFLC), and using (TAC) commands, and a variety of data collection and analysis programs were investigated.

The problems with the data can be categorized as to type, quantity, and quality. The type of data depends upon the mission the airplane flies, since the mission type determines in part what kind of problems develop and how long it will take to fix those problems after the airplane lands. The quantity problem pertains to how many data are necessary to be able to make reliability and maintenance estimates with some confidence. Quality is of concern because in analyzing the data numerous keypunch, alphanumeric, and work unit code errors were found; in addition, there were many illogical sequences and incomplete data records. For instance, for a particular maintenance action with an assigned job control number (JCN), there should be a remove, fix, and replace action identified for that JCN. There were many instances of remove and fix but no replace, remove and replace but no fix, and so on. (There are some deferred fix actions, but these do not account for the volume of fix and/or replace records absent in the data.) In the course of the study, error-edit programs have been developed to identify these errors, and Rand is working directly with selected TAC bases to implement these programs for base-level data management.*

In Cat III, a data collection and analysis program entitled Maintenance, Operation Supply, AGE, and Manpower (MOSAM) was used at Nellis

*There is presently a test under way at Nellis Air Force Base to improve the error-edit routines of MILAP so that the data quality will be considerably enhanced. A report is in preparation that describes this work: A. Sweetland, A Maintenance Data Inter-Record Edit Program (to be published).
Air Force Base. This program was intended to link the mission type with the maintenance that had to be performed on that airplane after it landed. MOSAM has the potential of being a considerable improvement over the MDC 66-1/65-110 system currently in operational use at base level. Difficulties in using the current system to link up the operational mission with the maintenance action have led to an extension of the MOSAM program to a new program, MILAP (Maintenance Information Logically Analyzed and Presente... TAC is implementing MILAP at base level throughout the operating command. Within the near future programs such as these should be able to obtain the kind of operational data needed to link the operations and maintenance actions.

In addition to the base-level maintenance data, there are some resource management data concerning the costs of keeping the systems operational in the field. These data are tracked by the AFLC IROS (Increase Reliability of Operational Systems) system, the Resource Management System (RMS), and the Depot Purchased Equipment Maintenance System (DPEM). All of these data systems were used in our life-cycle cost analysis. The RMS and DPEM systems were used in the development of a life-cycle cost for the A-7D program. The IROS system was used to take a closer look (at the subsystem level) at some of the logistic support costs. Neither the RMS nor the DPEM data system contains information at the detailed subsystem level (i.e., the three-digit WUC level).

*For a more thorough evaluation of the IROS system, see also M. R. Fiorello and P. Konoske Dey, A Comparative Analysis of IROS Logistics Support Costs (to be published).