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CASS Requirements for a Regional Maintenance Center

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13. ABSTRACT ***(Maximum 200 Words)***
The Consolidated Automated Support System (CASS) is a computerized Automatic Test Equipment (ATE) systems that is currently being fielded by the Department of the Navy. Over the next several years, CASS will replace existing ATE systems and help the Navy standardize test and training procedures. The Director of the Navy's Air Warfare Division (N88) and the Support Equipment Program Office (PMA-260) asked CNA to review the Navy s current plans for CASS implementation within the fleet. These plans call for the phase integration of CASS into both Navy and Marine Corps maintenance facilities. This paper examines CASS requirements for supporting avionics components at shore-based Regional Maintenance Centers (RMCs). Specifically, our sponsor wanted to know: how many CASS stations do RMCs need; and how many of each type of CASS stations do they need? We address these questions by examining the planned RMC support for (only) F/A-18 and F-14 aircraft at Oceana

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Contents

Summary

Background: What is CASS?

The Consolidated Automated Support System (CASS) is a computerized automatic test equipment (ATE) system that is currently being fielded by the Department of the Navy. Over the next several years, CASS will replace many existing ATE systems and help the Navy standardize test and training procedures.

There are four CASS configurations. Table 1 lists the purpose and average unit cost of each.

Table 1. CASS configurations and their costs

CASS configuration	Purpose	Average unit cost[a] ($M)
Hybrid	General-purpose component tester	1.0
RF	General-purpose plus radio-frequency component tester	1.5
EO	General-purpose plus electro-optical component tester	4.5
CNI	General-purpose plus communication, navigation, and identification component tester	1.7

a. Hardware costs for 1997 scheduled CASS purchases (in FY 1995 dollars). Data from PMA-260 as of July 1995.

The RF and EO configurations are Hybrid stations with additional test instruments that repair RF and EO components, respectively. The CNI configuration is an RF station with additional instruments that repair CNI components.

Purpose of this and previous studies

The Director of the Navy's Air Warfare Division (N88) and the Support Equipment Program Office (PMA-260) asked CNA to review the Navy's current plans for CASS implementation within the fleet.[1] These plans call for the phased integration of CASS into both Navy and Marine Corps maintenance facilities.

In previous analyses, we examined CASS requirements for carrier Aircraft Intermediate Maintenance Departments (AIMDs) and Marine Aviation Logistics Squadrons (MALS). Table 2 lists the scope of these previous studies.

Table 2. Previous CNA analyses of CASS requirements

Analysis	Weapon systems studied	Deployment scenario	Maintenance facility
CNA CRM 94-187 [1]	Existing	Peacetime	Carrier AIMD
CNA CRM 95-148 [2]	Existing and emerging	Peacetime	Carrier AIMD
CNA CRM 95-191 [3]	Existing and emerging	Wartime	Carrier AIMD
CNA CRM 95-92 [4]	Existing	Wartime	MALS

This paper examines CASS requirements for supporting *avionics components* at shore-based Regional Maintenance Centers (RMCs).[2] Specifically, our sponsors wanted to know:

- How many total CASS stations do RMCs need?
- How many of each type of CASS station do they need?

We have addressed these questions by examining the planned RMC support for (only) F/A–18 and F–14 aircraft at Oceana. If time

1. The primary planning tool for CASS implementation is the CASS Implementation Plan, or CIP. The CIP is revised periodically and published jointly by the Naval Air Systems Command and the Naval Air Warfare Center (Lakehurst).
2. CNA is currently analyzing the cost-effectiveness of using CASS to support shipboard electronic systems in a separate study.

permits, we hope to examine RMC support at North Island later in the study.

Approach and assumptions

We have approached these questions by simulating CASS in an operational setting. The Aviation Logistics Model (ALM) simulates carrier operations by replaying historical flight, maintenance, and supply actions. By substituting CASS for the carrier's current ATE capabilities, ALM can simulate use of CASS under operational conditions.

For this study, we simulated CASS support for F/A–18 and F–14 aircraft—flying at peacetime rates—at the Oceana RMC in the year 2000. By 2000, the AIMD at Miramar will be closed, and shore-based F–14 support will be single-sited at Oceana. Navy F/A–18 support, though, will still be split between the east and west coasts (at Lemoore and Oceana). Based on these assumptions, we used estimates for the fleet's inventory of these aircraft in the year 2000, and what fraction of these aircraft would be supported by the RMC at Oceana. These inventories help shape the RMC's CASS requirements.

We used historical maintenance action form (MAF) information to describe much of the reliability and maintainability (R&M) data for this study. Specifically, we used all of the F/A–18 and F–14 MAF data collected at Miramar, Oceana, and Cecil Field[3] during the calendar year 1994. This amounted to more than 250,000 MAFs, and is a sufficient database from which to draw requirements conclusions.

F/A–18s and F–14s in the year 2000 will contain some "emerging systems" that were not present in the 1994 MAF data. We accounted for these requirements by augmenting the MAF data. Assistant Program Managers for Logistics (APMLs) provided most of the emerging weapon systems data we used. To estimate emerging systems data that were not well-defined—such as elapsed maintenance times—we used distributions from existing weapon systems data.

3. F/A–18s currently supported at Cecil Field will be supported by the Oceana RMC in the year 2000.

We examined assumed CASS availability levels of 80 and 90 percent. These values bound the current availability assumptions that PMA-260 uses for all fleet sites. For shore sites, PMA-260 assumes CASS availability (A_0) is 80 percent. Current fleet data—with limited workload—currently indicate CASS A_0 is about 95 percent.

Results

CASS requirements

We considered five measures of effectiveness to evaluate CASS requirements: full-mission-capable (FMC) and mission-capable (MC) rates, sortie-generation rate, cannibalization rate, and RMC turnaround time. For each of these measures, we found that—at some point—adding more CASS stations does not improve RMC performance. Table 3 summarizes our findings. It shows the least-cost number of CASS stations that achieves the maximum effectiveness levels for supporting F/A–18 and F–14 aircraft at Oceana in the year 2000.[4]

Table 3. RMC CASS bench requirements

	CASS availability	
Measure	$A_0 = 90\%$	$A_0 = 80\%$
FMC rate	29	33
MC rate	29	33
Sortie-generation rate	24	27
Cannibalization rate	31	35
Turnaround time[a]	33	36

a. This is the average turnaround time for parts that require CASS. Although additional CASS stations can yield even lower turnaround times, the addition of these stations would not lower supply costs enough to justify their purchase.

As expected, CASS requirements depend upon the availability (A_0) of the system. If CASS' reliability and maintainability allow it to be "up"

4. That is, adding additional (costly) CASS stations will not provide better RMC performance (to a 5-percent level of significance) for the measures listed in table 3.

90 percent of the time, then the RMC will need only 33 stations to support its F–14 and F/A–18 requirements. Of these 33 stations, we found the following mix is the most cost-effective: 17 RF, 14 Hybrid, 1 EO, and 1 CNI. If, however, CASS' availability is only 80 percent (as PMA-260 assumes), then 36 stations will be needed to satisfy all of the measures that we list in table 3. The most cost-effective mix of CASS with A_0 = 80 percent is: 19 RF, 15 Hybrid, 1 EO, and 1 CNI.

Comparison with current Navy plans

The Navy currently uses the Systems Synthesis Model (SSM) to help predict its CASS requirements. SSM generates *expected-value* predictions by assuming constant failure rates and maintenance times for aviation components. These failure rates and maintenance times come from the Navy's NALDA database. For RMCs, the Navy assumes CASS A_0 = 80 percent.

We compared our ALM simulation results with the Navy's current plans. Table 4 shows this comparison.

Table 4. CASS requirements versus current Navy plans (A_0 = 80%)

Type of CASS	CNA recommendation	Current Navy plans
Hybrid	15	23
RF	19	18
EO	1	1
CNI	1	1
Total stations	36	43

The Navy's current plan calls for installation of 43 CASS stations at the RMC. ALM's prediction, based on actual failure rate and maintenance time data, is only 36 stations. This difference—seven stations—is composed of an overestimate of eight Hybrid stations and an underestimate of one RF station.

There are several reasons for this difference in predictions. First, the Navy is assuming higher optempo rates. We studied historical utilization rates of shore-based aircraft and found that the Navy's optempo predictions should be lowered.

The Navy also uses a different reliability and maintenance database. We have used actual failure rate and maintenance time data. We believe that our database—taken directly from a recent year's worth of MAF data—supports a more credible prediction for CASS requirements.

Last, the Navy's current CASS prediction was developed using dated estimates of aircraft quantities. We have updated these estimates—and found that fewer CASS stations are needed to support these estimates.

Impact

Reducing the RMC's requirements from 43 to 36 stations will save the Navy approximately $11 million in 20-year life-cycle costs. These savings come from reductions in CASS hardware, spare parts, installation, and manpower costs. We detail the calculation of these savings later in this paper.

Simulating CASS requirements

In this section, we describe some of our assumptions and results from simulating the CASS requirements for a Regional Maintenance Center. We will first discuss, in theory, how CASS will support RMC operations. Then we will present some key assumptions we made regarding the composition and optempo for the aircraft that the RMC will support. We will also list the ATE that CASS will initially replace at the RMC—this helps define the "workload" for CASS. And last, we will present our simulation results.

CASS support at an RMC

CASS supports an RMC by helping technicians to repair failed components. Too few CASS stations at an RMC can lead to maintenance delays, higher turnaround times, more cannibalizations, and lower aircraft readiness. Too many CASS stations may keep turnaround times low, but these come at additional cost and take up space. Implementation of CASS at an RMC is ultimately a question of cost-effectiveness: How many CASS stations are enough? In appendix A, we discuss how we addressed this question using CNA's Aviation Logistics Model (ALM). In appendix B, we present a mathematical description of the problem.

Simulation issues

To simulate CASS support at an RMC, we must model both the reliability and maintenance of the aircraft that will be supported there. We did this, in part, by using historical maintenance action form data for existing weapon systems. Specifically, we used aircraft component *failure rates* and *maintenance times* from the 1994 MAF data collected at the Miramar, Cecil, and Oceana AIMDs. This amounted to a database of more than 250,000 maintenance actions. We discuss the emerging systems data we used for this study in appendix C.

Our goal is to find out how many CASS stations, and which types, the RMC needs. We will look for the point at which adding additional CASS stations no longer serves any statistically significant benefit to supporting aircraft operations.

We will use five measures of effectiveness to make our comparisons. These measures—FMC, MC, and sortie-generation rates; cannibalizations; and turnaround times—all help describe the adequacy of varying levels of CASS support.

Assumptions

Aircraft composition and flight hours

Table 5 lists the expected number and types of aircraft that the RMC at Oceana will support in the year 2000. These estimates were provided by the F–14 and F/A–18 program offices by way of PMA-260. They assume that shore F–14 maintenance support will be single-sited at the Oceana RMC, but F/A–18 maintenance will still be split between coasts (at Oceana and Lemoore). These estimates also account for aircraft that will be deployed—and supported by a carrier's AIMD rather than at the RMC.

Table 5. Aircraft supported by the RMC in the year 2000

Aircraft type-model-series	Quantity	Peacetime utilization (hrs/mo/aircraft)
F–14A	97	22.5
F–14B	62	22.5
F–14D	35	27.0
F/A–18C[a]	182	32.0
F/A–18E	14	33.8
Total	390	

a. 92 F/A–18Cs were assumed to be equipped with the APG-73 radar; 90 were equipped with the APG-65 radar.

Table 5 also lists the expected peacetime optempo for each type-model-series aircraft. We determined these utilization rates by adjusting the peacetime utilization rates specified in each aircraft's WSPD by a factor to account for deployed aircraft—ones not supported by the RMC. Appendix D provides further details about the aircraft quantities and optempos that we used.

Note that table 5 includes both current naval aircraft and one aircraft still under development (the F/A–18E). The F/A–18E will include emerging systems that are not in the fleet today. Consequently, we had to treat these emerging systems differently. Appendix C describes how we incorporated emerging systems data into our analysis.

We simulated these aircraft flying at these peacetime rates for 4 months. We chose a period of 4 months to ensure that the RMC would achieve "steady state" operations. If too few aircraft were available to meet a given day's air plan, ALM would simulate that some sorties were missed. The model, however, allows these missed sorties to be made up if additional aircraft later become available. This assumption allows us to try to maintain the same total workload on the RMC over the course of the simulation.

Model calibration

Because the WSPD-based optempo rates we used were roughly twice as high as historical 1994 rates, we had to calibrate the raw organizational-level turnaround times to achieve historical NMCM (non-mission capable due to maintenance) rates. This calibration allowed us to more accurately capture how varying quantities of CASS affect aircraft readiness.

Sparing policy

We calculated a new SHORECAL (shore consolidated allowance list) for these aircraft to reflect the group's composition. We used the same method that the Aviation Supply Office (NAVICP–Philadelphia) uses to determine allowances—readiness-based sparing for weapon-replaceable assemblies, and demand-based sparing for shop-replaceable assemblies.

Test bench, software, and manning availability

We determined the automatic test equipment (ATE) that CASS will replace by the year 2000. We counted six types of benches that support F–14 and F/A–18 aircraft that CASS will replace by 2000:

- AWM-23 LFTS
- AWM-23 RFTS
- APM-446
- USM-247
- USM-470v(1)
- USM-470v(2).

We assumed that all the test program sets (TPSs) to support this ATE "offload" are complete by the year 2000 as well.

We also assumed the RMC operates as a "seamless" facility. TPSs are fully transportable from one work center to another, and each CASS station is equally available to any work center that needs it.

Manpower and ATE availability (A_0) are important factors that determine RMC throughput. In past analyses [1 through 4], we found that an assumption of availability between 80 and 90 percent for existing ATE yields modeling results similar to defaulting maintenance times from historical data. Consequently, we examined availability levels of 80 and 90 percent in this paper. (PMA-260 assumes CASS' availability for shore sites will be 80 percent).

Furthermore, we always included at least one RF, one EO, and one CNI CASS station in the alternatives we examined. Our previous analyses [1, 2] support the cost-effectiveness of placing at least one of each of these configurations at maintenance facilities (where there is measurable RF, EO, or CNI demand).

Modeled parts

We used ALM to model supply and maintenance actions for all weapon-replaceable and shop-replaceable assemblies that CASS repairs. We simulated supply and maintenance actions on all remaining parts by using historical times from maintenance action forms.

Monte Carlo iterations and statistical significance

As we explain in detail in appendices A and C, we used ALM as a stochastic model for this analysis. Due to time and computer resource constraints, we were limited in the number of iterations we could produce for each set of CASS alternatives. We settled on five iterations per CASS alternative. This number allowed us to produce meaningful, statistically significant results, but it is less than the number of iterations typically desired for normal parametric distributions [5].

We performed a statistical test on each pair of CASS alternatives that we examined. This test was designed to determine whether we could reject the hypothesis that the two sets of results were indistinguishable. If we could reject the hypothesis, we could state (with 95-percent certainty) that one alternative was better than the other. Otherwise, we accepted the hypothesis that the differences in the results were not significant. We provide more detail on the statistical test we employed in appendix E.

Results

Matrix of test alternatives

Table 6 indicates the matrix of CASS alternatives that we examined. Because each alternative required 8 hours or more to test, we had to be selective in choosing which alternatives to examine.

We examined the solution space near the expected-value solutions,[5] and tested the outlying sensitivity of our measures (FMC and MC rates, etc.). Every alternative we examined

5. For A_0 = 90 percent, the integer expected-value solution is 22 Hybrid, 11 RF, 1 CNI, and 1 EO CASS station. For A_0 = 80 percent, the integer expected-value solution is 24 Hybrid, 13 RF, 1 CNI, and 1 EO CASS station.

Table 6. CASS alternatives examined[a]

RF stations	Total number of CASS stations 23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
11													90[b]								
12	90	90	90	90	90	90	90	90					90								
13										90	90	90	90				80[c]				
14				80	80	80	80	B	B	B	B	B	B	B	90		80				
15										90	90	90	90	B	B	80	80				
16										90	90	B	B	80	80	80	80				
17										90	90	90	B	80	80	80	80				
18										90	90	90	B	B	B	B	B	90	90	90	B[d]
19													80	80	80	80	80				
20													80	80	80	80	80				
21													80	80	80	80	80	80	80	80	80
22													80			80	80				

a. 90 = examined for A_0 = 90%; 80 = examined for A_0 = 80%; B = examined for both A_0 = 80, 90%.
b. This is the expected-value solution for A_0 = 90%.
c. This is the expected-value solution for A_0 = 80%.
d. This is the Navy's current plan.

contained exactly one EO and one CNI station.[6] The remaining stations were divided between RF and Hybrid stations.

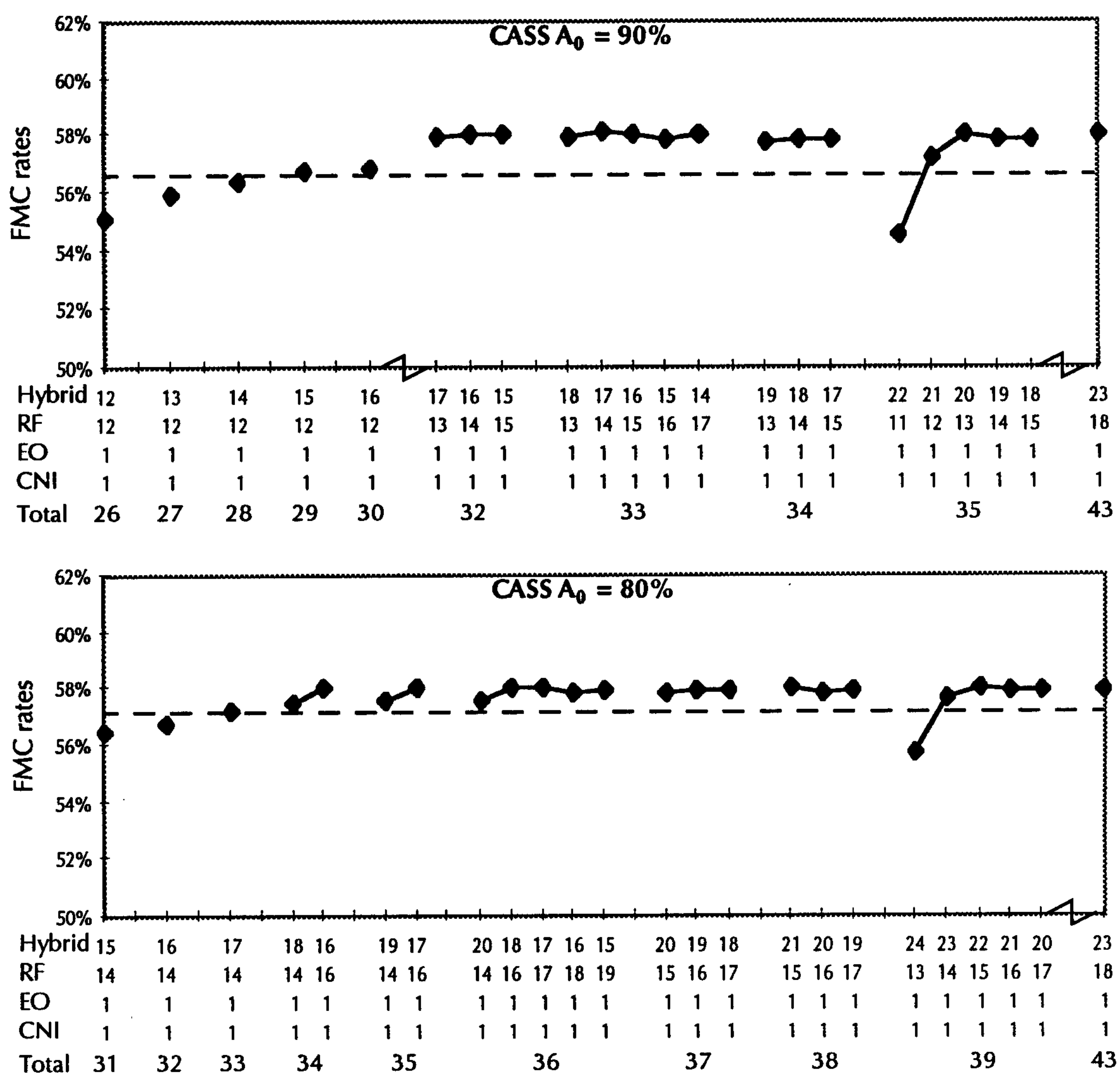
CASS requirements

FMC rates

Figure 1 shows how the FMC readiness rates vary with numbers and types of CASS stations, as well as CASS availability levels. The top half of the figure shows our results for when CASS A_0 is 90 percent; the bottom half shows A_0 = 80 percent results. In each chart, the x-axis refers to the "mix" (quantities and types) of CASS stations, whereas the y-axis measures combined F–14 and F/A–18 average FMC rates that result from each of these mixes.[7]

6. Due to the small EO- and CNI-specific workload, we only explored solutions with one EO and one CNI station.
7. All averages were taken over five simulation iterations.

Figure 1. FMC results



For each chart, the dashed line represents a boundary of statistical significance. That is, results that are above this line are statistically equivalent—and superior to all results below this line. We will use this same format for presenting all our results.

CASS A_0 = 90 percent. For example, let's first consider the top plot where CASS A_0 = 90 percent. Here we show FMC results for three different sets of alternatives that comprise 32 total CASS stations (1 EO and 1 CNI plus either 17 Hybrid and 13 RF, 16 Hybrid and 14 RF, or 15 Hybrid and 15 RF). Similarly, we show results for other sets of CASS alternatives that total 26 through 43 stations.

We see that for A_0 = 90 percent, FMC rates do not significantly decline until there are fewer than 29 CASS stations (or fewer than 12 RF ones). Although FMC results with 32 stations (and at least 13 RF ones) appear to be better than results with just 30 stations (and 12 RF), these differences were not at a statistically significant level. *However, the Navy's current plan of using 43 stations (with 18 RF stations), is clearly more than what is needed to solely meet full-mission-capable readiness rates under these assumptions.*

CASS A_0 = 80 percent. The bottom half of figure 1 shows our results for an assumption of 80 percent CASS availability. We found that at least 33 stations are needed to maximize FMC rates. Of these 33 stations, at least 14 must be RF ones. Again, the Navy's current plan of installing 43 stations (with 18 RF ones) is clearly more than what is needed to solely maintain FMC rates—even if CASS A_0 is only 80 percent.

MC rates

Figure 2 shows the MC rate results. These results were very similar to the FMC results (but a few readiness points higher).

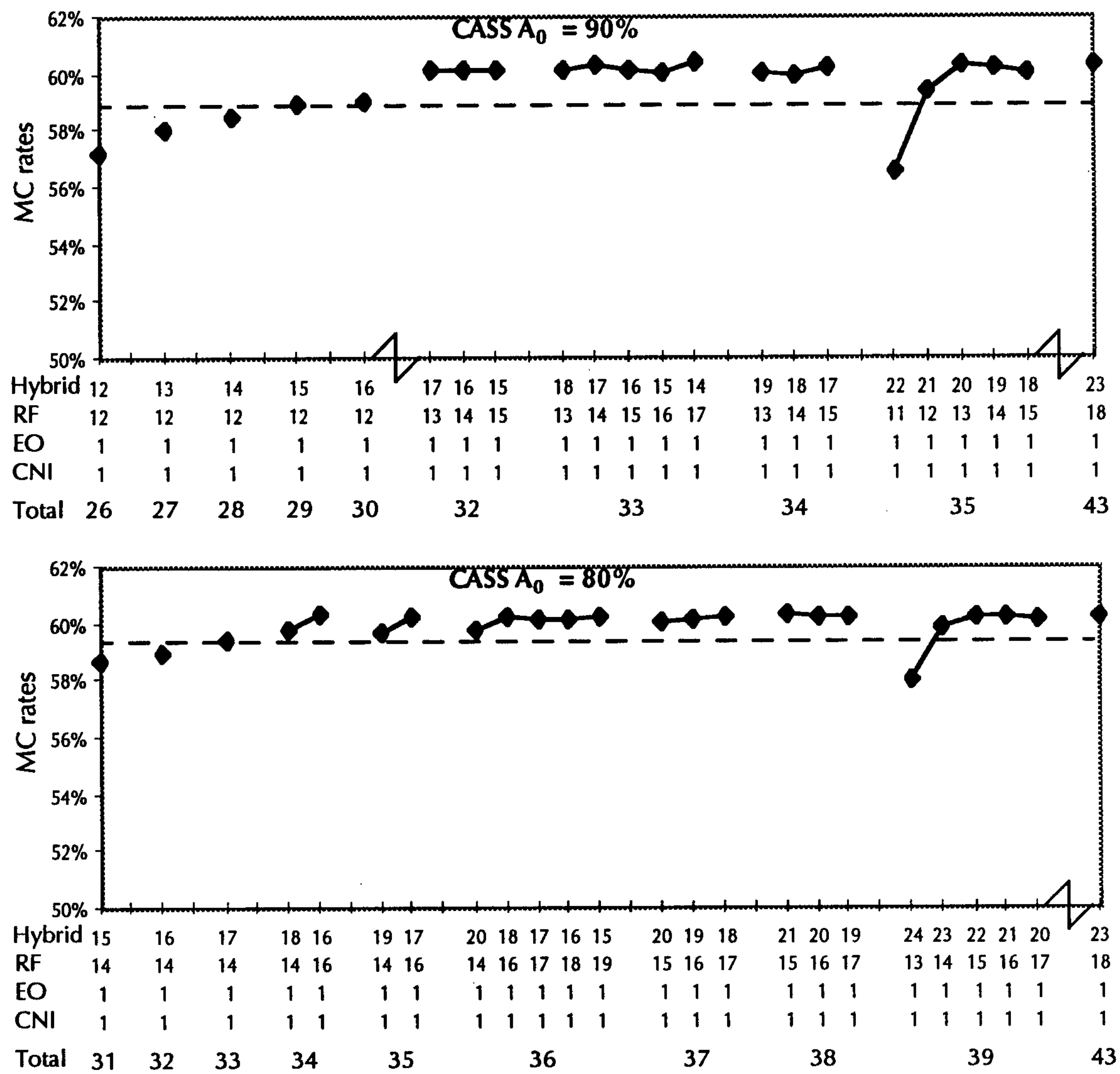
CASS A_0 = 90 percent. For A_0 = 90 percent, the highest MC rates are only achieved when there are at least 29 CASS stations. Of these 29 stations, at least 12 must be RF-configured.

CASS A_0 = 80 percent. For A_0 = 80 percent, and similar to our FMC results, we found the MC rate does not significantly decline until there are fewer than 33 stations. Of these 33 stations, at least 14 must be RF ones. Again, the Navy's current plan of installing 43 stations is excessive.

Sortie rates

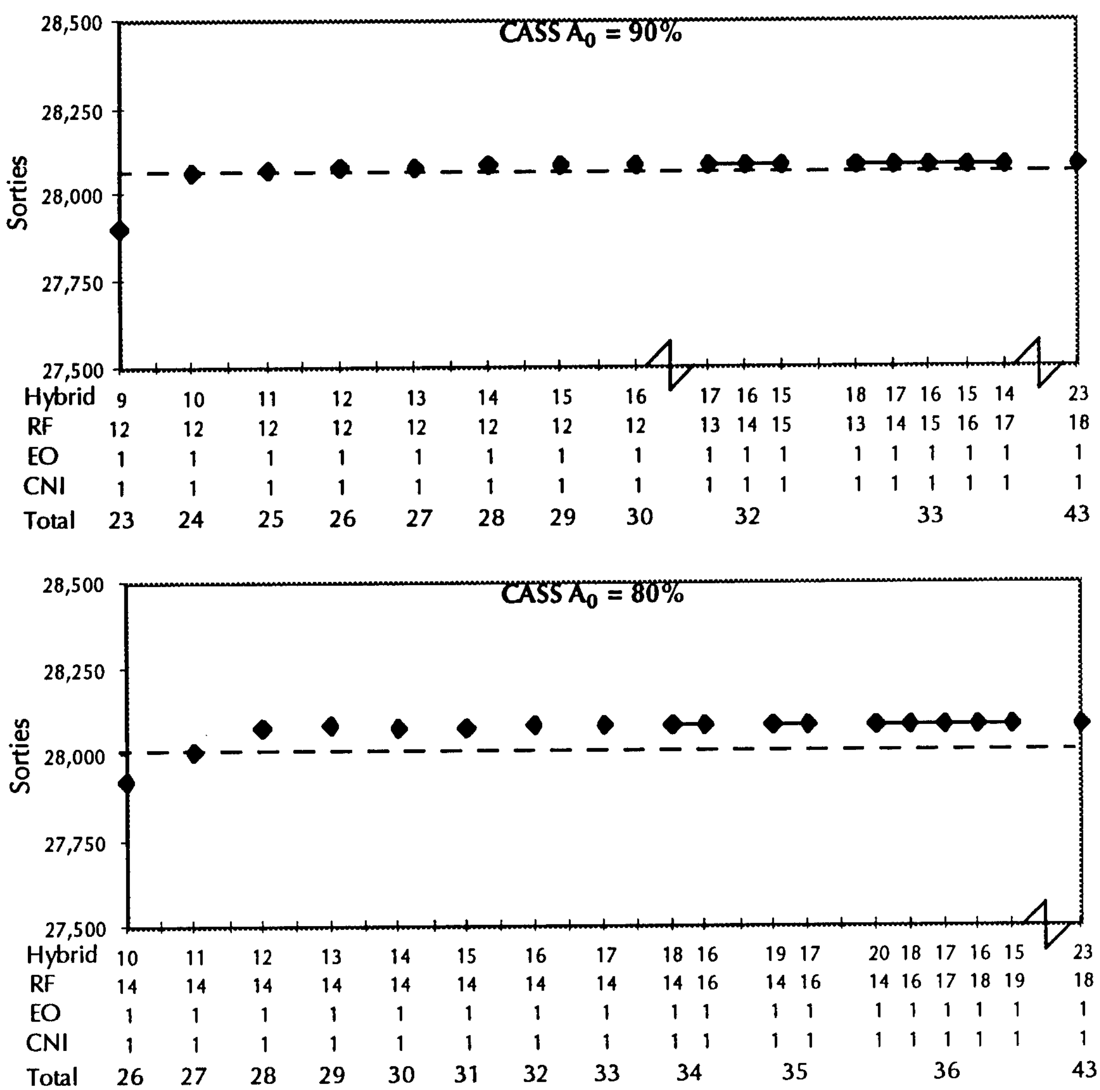
Figure 3 shows our sortie rate results. We simulated a scenario in which the 390 F-14 and F/A-18 aircraft attempt to fly 28,081 sorties over a 120-day period. This schedule equates to about 18 flights per aircraft per month—which is consistent with peacetime ashore planning factors.

Figure 2. MC results



CASS A_0 = 90 percent. We found the RMC would need at least 24 stations to achieve the statistically highest levels of sortie-generation potential. (That is, sortie differences with 24 or more CASS stations were not statistically significant). We also found the RMC could not consistently support the full air plan until it had at least 30 stations; even with 29 stations, a few sorties were missed.

Figure 3. Sortie results

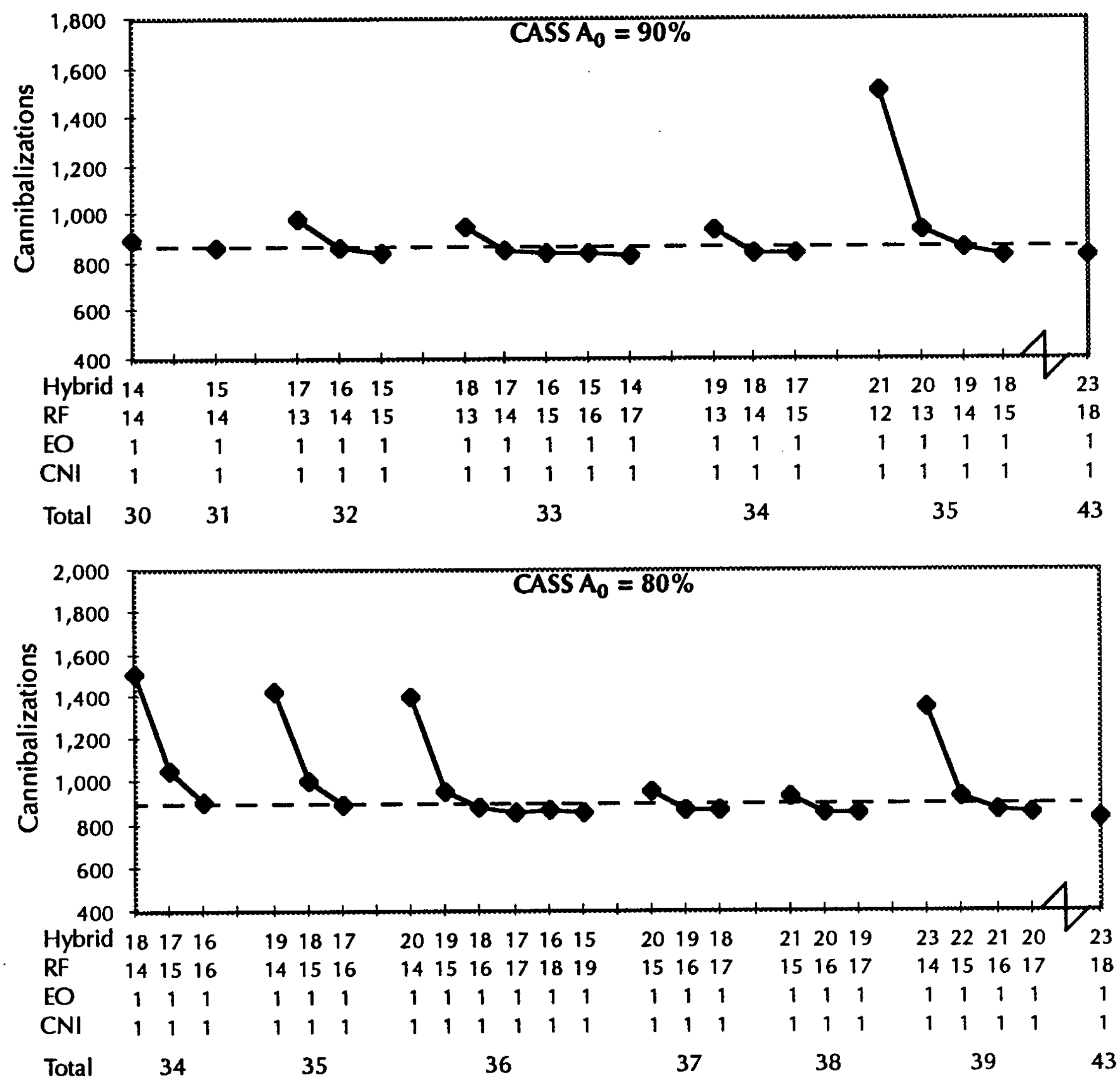


CASS A_0 = 80 percent. With CASS availability only 80 percent, the RMC will need at least 27 CASS stations to achieve the statistically highest levels of sortie-generation potential. We also found the RMC could not consistently support the full air plan until it had at least 32 stations. That is, with fewer than 32 stations a few sorties were missed.

Cannibalization

Figure 4 shows our results for tracking cannibalization actions. We should note that the level of cannibalization was generally low; in our scenario, 1,000 cannibalization actions represent only about 2.3 cannibalizations per 100 flight hours.

Figure 4. Cannibalization results



CASS A_0 = 90 percent. We found that 31 stations (with at least 14 RF ones) are needed to reach the lowest cannibalization levels. We found that as either the total number of CASS stations or just the number of RF stations becomes inadequate, cannibalization actions become much more frequent.

Indeed, although we don't show this in figure 4, the reason only 24 stations are needed to maintain sortie-generation potential (with CASS A_0 = 90 percent) is that cannibalization is being used as a substitute for adequate maintenance resources. The number of cannibalization actions with only 24 CASS stations (12 RF) is almost 3,700 (roughly 8.6 per 100 flight-hours).

CASS A_0 = 80 percent. The lower half of figure 4 shows our results for when CASS A_0 is only 80 percent. In this case, we found the RMC will need at least 35 stations—with 16 RF—in order to minimize cannibalization actions. Cannibalizations rise dramatically when fewer than 15 RF stations are available.

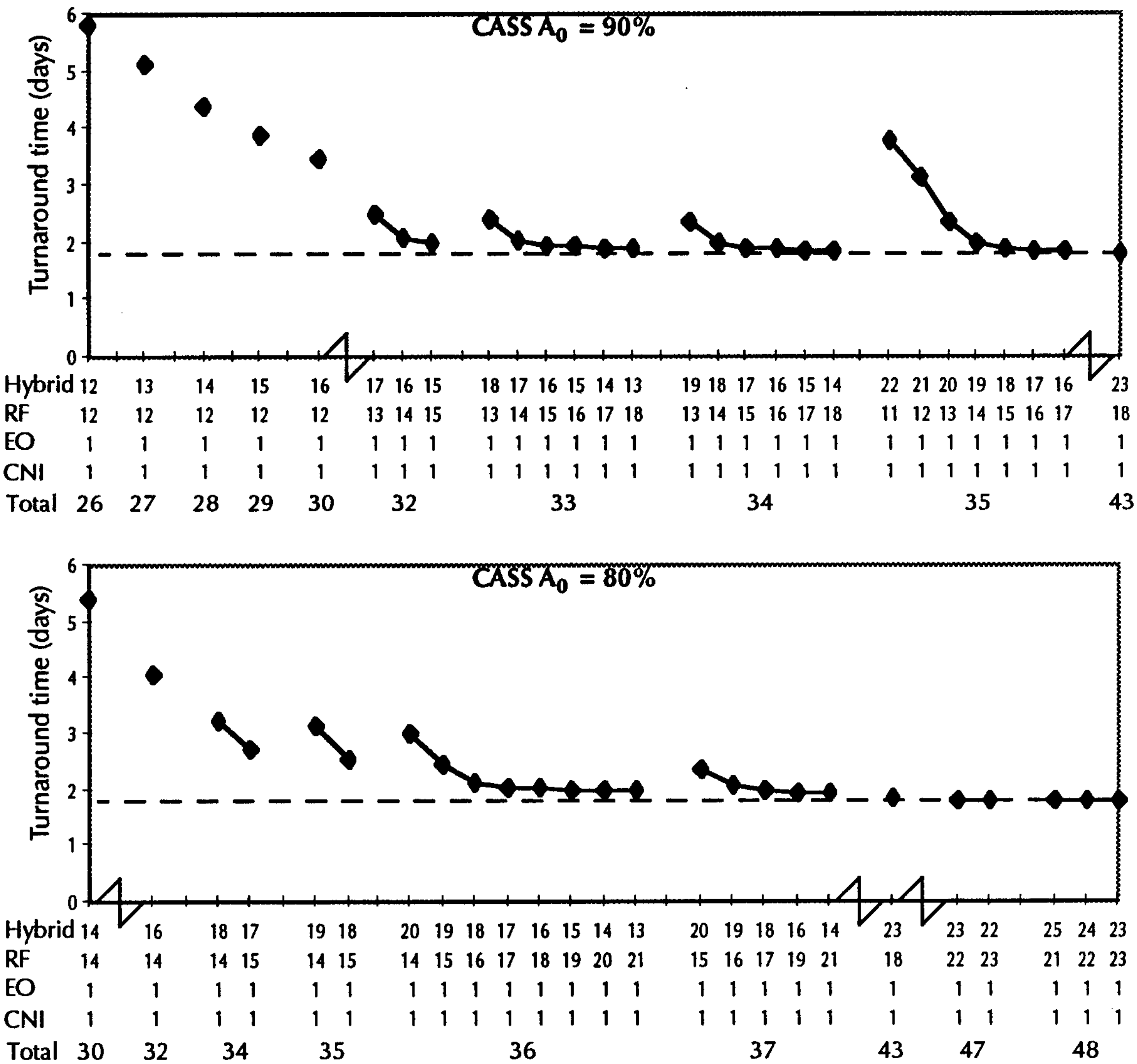
AIMD turnaround time (TAT)

Figure 5 shows our results for RMC turnaround times as a function of the quantity and types of CASS stations. These TAT values represent the average TAT for all CASS-repairable actions *that were completed* before the end of the simulation (day 120). Both charts show that turnaround times for parts that CASS repairs continue to decline as more and more CASS stations are added.

CASS A_0 = 90 percent. Turnaround times with the Navy's plan of 43 CASS stations were less than half of what they were using the expected-value solution (22 Hybrid, 11 RF, 1 EO, and 1 CNI station). In fact, despite the apparent closeness of the results, every potential solution set of CASS stations in this figure had statistically longer turnaround times than the Navy's current plan. We also found that the TAT penalty for having too few CASS stations accelerates if fewer than 32 stations are available.

CASS A_0 = 80 percent. With CASS availability only 80 percent, we found that to minimize turnaround times the RMC would need 48 CASS

Figure 5. Turnaround time results



stations. Clearly, however almost identical turnaround times can be achieved with far fewer stations.

Is minimizing turnaround time a cost-effective strategy? Shorter turnaround times can lead to less costly SHORECALs. Do these potential supply savings justify the added cost for more maintenance resources?

The next section addresses this question by examining the life-cycle costs of adding CASS stations to reduce turnaround times.

Life-cycle costs of adding extra CASS benches

RMC turnaround time has a direct effect on how SHORECALs are built. The Navy's Inventory Control Point uses historical turnaround times to determine SHORECAL sparing quantities. When turnaround times increase, so too do SHORECAL quantities in order to maintain readiness rates.

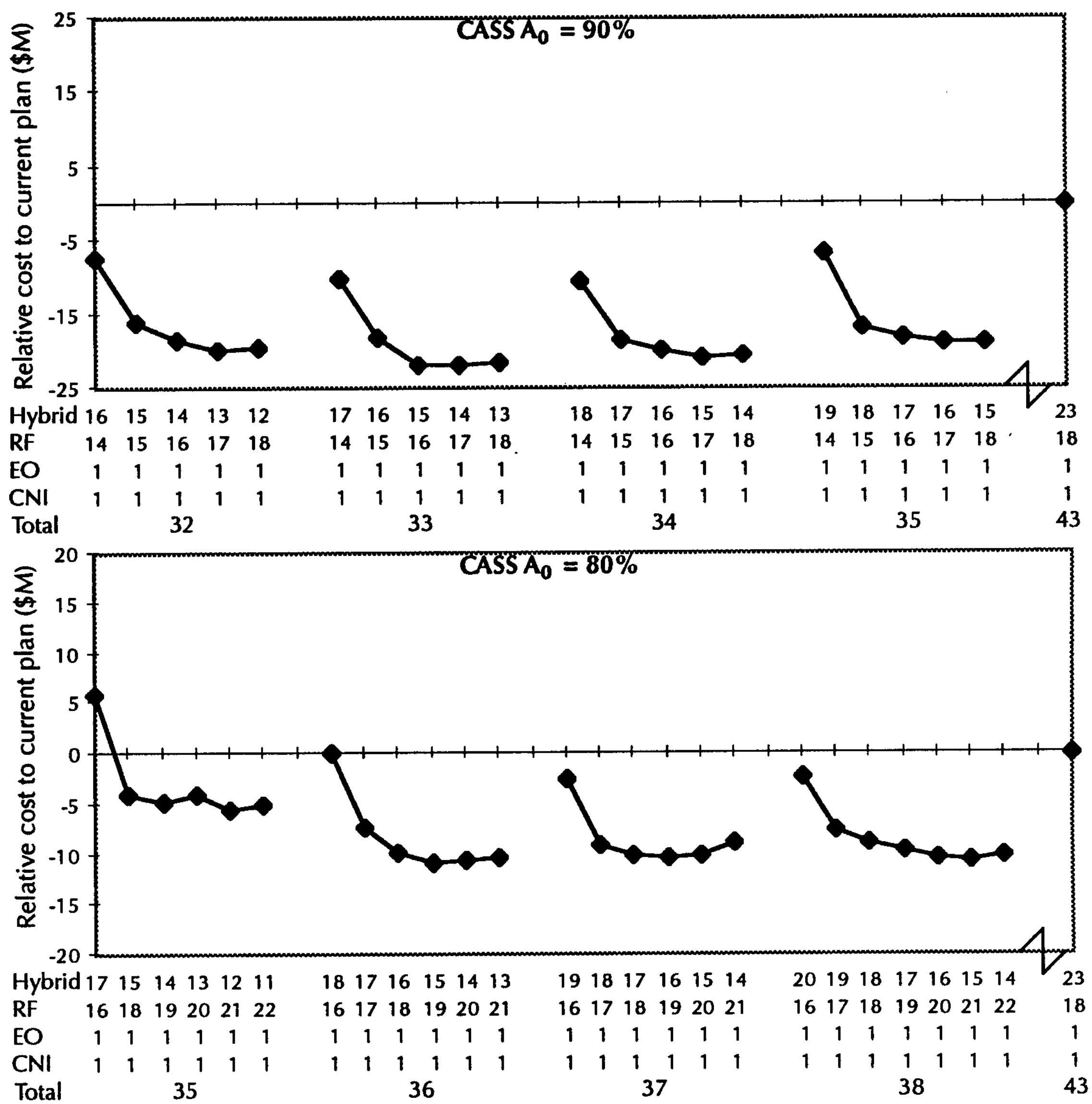
To a point, our ALM results suggest that an increase in CASS stations will decrease turnaround times for CASS-repairable components. But do these reduced turnaround times lead to lower SHORECAL quantities?—Low enough for additional CASS stations to "pay for themselves?"

To answer this question, we examined the life-cycle costs associated with adding extra CASS benches. There are four types of costs we need to consider: CASS hardware (including spares), CASS manpower, CASS installation, and SHORECAL costs. We compared the CASS-related costs of adding extra stations to the potential savings in SHORECAL costs (from shorter turnaround times) to find the least-cost solution. We show this comparison in figure 6 for CASS availabilities of 80 and 90 percent. *For each chart, we have plotted the total 20-year life-cycle cost differential between the Navy's current plan (23 Hybrid, 18 RF, 1 EO, 1 CNI) and other sets of CASS alternatives.* That is, we have plotted costs relative to the Navy's current plan.

CASS A_0 = 90 percent. With an aggressive assumption of CASS availability of 90 percent, we found the least-cost solution is 33 stations (14 Hybrid, 17 RF, 1 EO, 1 CNI). *This solution offers potential savings of almost $22 million compared with the Navy's current plans.* As figure 6 shows, other solutions with either 33 or 34 CASS (of which 16 to 18 are RF stations) are almost as cost-effective. Solutions with less than 15 RF stations are considerably less cost-effective.

CASS A_0 = 80 percent. With a more conservative assumption of CASS availability of only 80 percent, the RMC needs more CASS stations than if A_0 were 90 percent. We found the least-cost solution in this

Figure 6. Life-cycle cost comparison of adding CASS stations



case is 36 stations (15 Hybrid, 19 RF, 1 EO, 1 CNI). *This solution still offers potential savings of almost $11 million compared with the Navy's current plans.* Other solutions with 36 to 38 CASS (of which 18 to 21 are RF stations) are almost as cost-effective. Solutions with less than 36 stations, or less than 17 RF are considerably less cost-effective.

Recommendation

A recommendation for the number and types of CASS stations required to support the Oceana RMC in the year 2000 depends on several assumptions—CASS availability, aircraft quantities and optempo, maintenance times and scheduling, etc.

Although we have shown results for two CASS availability levels (80 and 90 percent), we believe the better choice for estimating RMC CASS requirements is to assume A_0 will be about 80 percent. This is PMA-260's current assumption, and it reflects the knowledge of how operations ashore differ from those afloat.

With CASS A_0 = 80 percent, we found that a modest number of CASS stations—33—can achieve maximum readiness rates and sortie-generation potential. Yet, with only 33 stations, cannibalizations and turnaround times grow significantly. These undesired effects do not initially reduce readiness, but they indicate that the RMC—with no slack—is being pushed to the limit to keep up with demand. Longer turnaround times can ultimately force the Navy to incur additional, substantial supply-related costs.

We recommend the Navy install 36 CASS stations to cover the RMC ATE offload before the year 2000. Nineteen of these should be RF stations; 15 should be Hybrid stations; one should be an EO station; and one should be a CNI station. We found that this solution provides the most cost-effective support for the fleet.

Installation of only 36 stations, instead of the 43 that are currently planned, should save the Navy at least $11 million in 20-year life-cycle costs.

Appendix A: Modeling CASS support with the Aviation Logistics Model

ALM: An overview

The Aviation Logistics Model (ALM) is a digital simulation that can replay aviation flight, maintenance, and supply activities. Unlike most models, ALM uses mostly historical data to simulate these operations. These historical data allow ALM to predict how well the logistics support system maintains aircraft readiness and supports flight operations.[8]

ALM has two primary modes of application:

- ALM can recreate a historical scenario (e.g., replaying a carrier deployment)
- ALM can model a user-defined scenario (e.g., simulating different aircraft mixes and/or optempos).

This study used ALM in the latter mode. We studied CASS requirements for an RMC that is supporting peacetime F–14 and F/A–18 operations. Even in this ALM mode, however, the model still relies heavily on using historically-recorded maintenance and supply data.

The user-defined scenario mode requires running ALM as a Monte Carlo model. For every sortie that is flown, ALM *randomly* selects a historical sortie from a pool of potential candidates. (For this study, the pool of potential candidates was every 1994 sortie that was flown by aircraft being supported by the Miramar, Cecil Field, and Oceana AIMDs.) Selection from this pool is made with replacement. The Monte Carlo

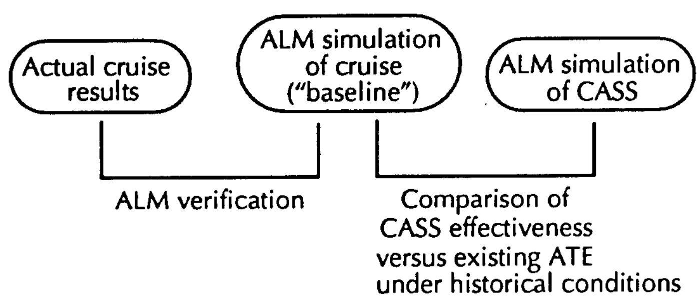
8. For a more detailed discussion of the underlying logic in ALM, consult CNA Research Contribution 576, *Aviation Logistics Model*, by John D. Parsons and S. Craig Goodwyn, January 1988.

process ensures that ALM will faithfully sample from the full set of historical data.

Each historical sortie has a "string" of maintenance and supply actions attached to it. ALM models these actions using data directly off the historical MAF forms.

An important step before simulating CASS is for ALM to first mimic the actual experience of the carrier's operations (figure 7). This simulation, which we call the "baseline case," verifies that ALM's readiness rates and other predictions are in line with historical results.[9]

Figure 7. Relationship between historical results and modeling of CASS



Perhaps ALM's greatest strength is its ability to conduct sensitivity or "what-if" analyses. For this study, we varied the quantities and types of CASS stations available in the RMC. This allowed us to predict how CASS-related changes in maintenance capability would affect the ability of the RMC to sustain F–14 and F/A–18 operations.

9. Reference [1] demonstrated close agreement between ALM's baseline and historical peacetime readiness predictions.

ALM data

ALM is not an expected-value model. Instead, ALM relies upon actual, historical data for most of its simulation. These data come from three main sources:

- Flight activity records
- Supply (AVCAL) data
- Maintenance action forms.

Flight activity records

ALM uses historical flight records from flight operations. For this study, we pooled historical F–14 and F/A–18 flight records and allowed ALM to pull one such record at random (for a given T/M/S aircraft) for each scheduled sortie. When enough aircraft remain mission capable, ALM will "fly" all of the day's scheduled sorties. If the airwing cannot meet these sortie requirements (due to low readiness), ALM captures this as well.

AVCAL data

ALM requires that the user specify on-hand supply quantities. Our previous analyses of historical peacetime carrier deployments have used the corresponding historical carrier AVCAL. For this study, however, we simulated a different, shore-based aircraft mix and optempo. Consequently, we had to recalculate sparing levels to be consistent with these assumptions. We used ASO's readiness-based sparing (RBS) rules to calculate this SHORECAL.

Maintenance action forms

ALM relies on the maintenance action forms (MAFs) that are filled out whenever a maintenance action is performed. These MAFs tell ALM exactly what part numbers failed, when they failed, and the specific maintenance actions that ensued.

MAFs include important information about the history of repairs. The time a failed component is awaiting maintenance (AWM), awaiting a replacement part (AWP), or actually in-work (elapsed maintenance time (EMT)) all contribute to the total time required for the maintenance facility to turn that component around.[10] These times are also important for ALM, and how ALM simulates the RMC's operations.

We thoroughly "scrub" the MAF data to correct errors in part number entries. We trace most of these errors through other MAF data, such as work centers or work unit codes. If we did not correlate the vast majority of MAF part numbers to stocking levels and test bench requirements, MAF data would not support meaningful modeling of the ILS network.

Modeling the logistics support network

AWP, AWM, and EMT times

ALM has two modes for modeling these supply and maintenance times. The first is a default mode. The default mode replays both organizational-level (O-level) and intermediate-level (I-level) times directly from MAF forms. We call this "defaulting" supply and maintenance times for parts. *For this study, we defaulted AWP, AWM, and EMT times for parts that CASS does not repair.*

The other ALM mode dynamically tracks the availability of supply and maintenance resources. We call this "modeling" supply and maintenance times for parts. When modeled, AWM times depend on current workload, repair priority, and the availability of manning and test equipment. A reduction in the quantity of CASS stations can easily produce longer I-level AWM times than those from the default case, whereas an adequate amount of men and ATE can lead to shorter AWM times. Similarly, ALM derives modeled AWP times by continuously tracking the ready-for-issue stock of parts in supply.

We assumed that EMT times for components transitioning to CASS were identical to their EMT times on existing test benches.

Modeling emerging systems. Clearly, MAF data do not exist for the vast majority of the emerging systems. Therefore, we had to make assumptions about their EMT times and their subcomponents' AWP times.

10. Note AIMD turnaround time = AWM + AWP + EMT.

We used data from existing systems to help fill in gaps in our database for these systems. We cover these assumptions in detail in appendix C.

ALM: applications and limitations

How should ALM be used? What are its limitations?

ALM is a simulation that relies on historical data to replay past events. Yet, some events within the ILS are not easily captured.

When should maintenance personnel cannibalize aircraft? ALM assumes that cannibalizations only occur when a failed part reduces the readiness status of an aircraft *and* there are no more spare parts in supply. Yet, sometimes maintenance personnel cannibalize aircraft even when spares are available. Clearly, ALM cannot replicate every decision made aboard a carrier.

The best use of ALM is for conducting relative comparisons of modeled results. These comparisons allow users to isolate cause and effect relationships. Absolute comparisons—between ALM results and actual experience—are more difficult.

For example, ALM and carrier airwings calculate readiness rates differently. ALM's calculations use MAF data.[11] Airwings track day-to-day readiness by tabulating Aircraft Material Readiness Reports (AMRRs). These reports are more subjective than MAF data; they are the airwing's *estimate* of how many aircraft can be made ready on a given day. It is not surprising that ALM's readiness predictions often vary from AMRR rates.

Measures of effectiveness

ALM can track many different measures of effectiveness. We selected five—FMC and MC readiness rates, sorties, cannibalizations, and

11. The MAFs do this by reporting equipment operational capability codes. ALM uses these codes, together with the Navy's Mission Essential Subsystem Matrix and Subsystem Capability and Impact Reporting formula, to calculate readiness rates.

turnaround times—to track how the quantity and types of CASS stations in the RMC affect the ability of the ILS to support airwing operations.

Readiness rates

The best measures of aircraft readiness are readiness statistics themselves. ALM predicts FMC, MC, and NMC rates at both the aircraft and squadron levels of aggregation.

Readiness rates alone, however, can be deceiving. For example, cannibalization can inflate readiness rates, yet have other undesired consequences. We need to examine other measures as well.

Sorties

We also need to look at sortie completions, both over extended periods and on a daily basis. Shortages of CASS stations can cause RMC TATs to be high, repair backlog to grow, and aircraft to miss sorties. Even with acceptable readiness levels over extended periods, some sorties can still be missed during short periods of intense operations.

Cannibalizations

In the short-term, aircraft are cannibalized to maintain readiness and meet sortie demands. We need to track cannibalizations to ensure that they are not a placebo for low RMC throughput.

Turnaround times

TATs allow us to track how well CASS is supporting the RMC's workload. We should expect that too few CASS stations will lead to longer TATs, whereas adding excess CASS stations will have little effect on TAT.

Appendix B: Mathematical description of the problem

In this appendix, we briefly outline the mathematical problem we resolved in this paper. We can formulate this problem as a nonlinear integer program with integer variables N_H (number of Hybrid stations), N_{RF} (number of RF stations), N_{EO} (number of EO stations), and N_{CNI} (number of CNI stations):

Minimize cost = f (N_H, N_{RF}, N_{EO}, N_{CNI})

subject to:

Readiness (N_H, N_{RF}, N_{EO}, N_{CNI}) > = Readiness (all other CASS alternatives)

Sortie generation (N_H, N_{RF}, N_{EO}, N_{CNI}) > = Sortie generation (all other CASS alternatives)

RMC TAT(N_H, N_{RF}, N_{EO}, N_{CNI}) < = RMC TAT (all other CASS alternatives)

Cannibalizations (N_H, N_{RF}, N_{EO}, N_{CNI}) < = Cannibalizations (all other CASS alternatives)

The objective—to minimize cost—depends on how many of each type of CASS station the RMC needs. We have introduced constraints for readiness, sortie generation, cannibalization rate, and turnaround time that ensure the optimal solution will not be any worse than other potential solutions with regard to these measures. These constraints are nonlinear with regard to N_H, N_{RF}, N_{EO}, N_{CNI} and are not independent. In fact, because of the complexity of modeling these constraints, this integer program cannot be solved with typical closed-form solution techniques. Instead, we used the branch-and-bound technique to intelligently probe the potential solution space for $\{N_H, N_{RF}, N_{EO}, N_{CNI}\}$.

Appendix C: Emerging systems

In this appendix, we present the emerging systems data we used, and the additional assumptions we made to model these systems with ALM.

Emerging systems data

Table 7 (at the end of this appendix) lists the emerging systems data that we used for this study. Units under test (UUTs) for each system are arranged to indicate the indenture structure for that system. In the sections that follow, we discuss the data in this table, and other data that we used to model supply and maintenance of each of these UUTs.

List of UUTs

To create the list of emerging systems UUTs, we began with a candidate list compiled by the Naval Air Warfare Center–Lakehurst. We then visited all of the respective program offices to verify whether each of these UUTs was still a candidate for CASS. If there were no plans to fund test program set development for a UUT, that UUT was excluded from our list.

Mean time between unscheduled maintenance action (MTBUMA)

We consulted a variety of sources when determining the MTBUMA for each UUT. We obtained much of our data through Assistant Program Managers for Logistics (APMLs). Other MTBUMA data were provided by the Naval Surface Warfare Center–Crane, and the Aviation Supply Office. For a handful of systems, we used Naval Sea Logistics Center data for similar systems on other aircraft. We also retained a little of the original NAWC–Lakehurst data for UUTs where we could find no better estimates. It took almost 6 months to fully collect and review these data.

ALM uses these MTBUMA values to generate component failures during the simulation.[12] Specifically, ALM assumes a binomial failure distribution based upon these MTBUMA values and the total flight hours for each type/model/series aircraft during the cruise. Shop-replaceable assembly (SRA) failures are modeled conditionally; they can only fail if the parent weapon-replaceable assembly (WRA) fails.

ATE requirements

In general, we accepted the CASS configuration assignments that NAWC–Lakehurst prescribed for each UUT. For a few UUTs, however, APMLs had better information on CASS configuration assignments.

As table 7 shows, we list a few UUTs that need ATE other than CASS. These UUTs appear in this table to fully specify the indenture structure of all emerging systems UUTs.

Replacement part numbers

Some of the emerging systems listed in table 7 will replace existing systems already found on carrier aircraft. To accurately model the CASS workload, we needed to delete these replaced parts from our simulation database. That is, we needed to ensure that we did not "double count" any systems.

Elapsed maintenance times (EMTs)

Virtually no information on expected elapsed maintenance times was available for these new emerging systems. Yet the ALM model needs this important input parameter to determine CASS workload requirements. As a substitute, we used EMT distributions from existing weapon systems to approximate these values for emerging systems.

12. For emerging systems only. For existing systems, failures are read directly from the existing MAF data.

Awaiting parts times

Just as EMT data were not available for most of the emerging systems, I-level AWP times (for subcomponents of these systems) were not either.[13] These AWP times represent the amount of time an emerging system's UUT waits for some subcomponent to become available. We drew upon existing systems' data to fill in this deficiency too.

Table 7. Emerging systems data

Program	Aircraft	Indenture	Part number	ATE	Replacement part number	MTBUMA (hours)
AN/ALQ–126B RF	F–14, F/A–18	WRA	5921489G2	NEWTS		168
AN/ALQ–126B RF	F–14, F/A–18	SRA	5969941G1	RF		10,000
AN/ALQ–126B RF	F–14, F/A–18	SRA	5969942G1	RF		7,692
AN/ALQ–126B RF	F–14, F/A–18	SRA	5969943G1	RF		7,692
AN/ALQ–126B RF	F–14, F/A–18	SRA	5969944G1	RF		769
AN/ALQ–126B RF	F–14, F/A–18	SRA	5969945G1	RF		833
F–14 A/B Upgrade	F–14B	WRA	91K000001	HYB	3071000002	801
F–14 A/B Upgrade	F–14B	WRA	1322060702	HYB	481451168	948
F–14 A/B Upgrade	F–14B	WRA	91L1400002	HYB	6632932008	1,069
F–14 A/B Upgrade	F–14B	WRA	A55A90873	HYB	481580170	200
F–14 CSDC	F–14D	WRA	8710000521	HYB		2,400
F–14 PMDIG	F–14D	WRA	91L1000002	HYB		985
F–14 PTID	F–14D	WRA	414000	HYB		670
AN/ALE–50	F/A–18	WRA	3410AS1001	HYB		394
AN/ALE–50	F/A–18	SRA	3410AS10001	HYB		1,007
F–14B/D	F–14B/D	WRA	A55A90031	HYB	A51A91751	2,450
F–14B/D	F–14B/D	SRA	290275303	HYB		509
F–14B/D	F–14B/D	WRA	A51A92165	HYB		2,400
F–14B/D	F–14B/D	SRA	7220939004	HYB		1,900
F–14B/D	F–14B/D	SRA	7220941003	HYB		1,702
F–14B/D	F–14B/D	SRA	7221025005	HYB		1,100
F–14B/D	F–14B/D	SRA	7221641003	HYB		2,600
F–14B/D	F–14B/D	SRA	7221643003	HYB		2,600
AN/ALR–67(V)3/4	F–14, F/A–18	WRA	1874AS7000100	HYB	3105217003	407
AN/ALR–67(V)3/4	F–14, F/A–18	SRA	1874AS7010	HYB		7,670

13. O-level AWP times are modeled dynamically in ALM, as are I-level AWP times for parts that ALM tracks stocking levels on.

Table 7. Emerging systems data

Program	Aircraft	Inden-ture	Part number	ATE	Replacement part number	MTBUMA (hours)
AN/ALR-67(V)3/4	F-14, F/A-18	SRA	1874AS7400	HYB		513
AN/ALR-67(V)3/4	F-14, F/A-18	SRA	1874AS7030	HYB		7,389
AN/ALR-67(V)3/4	F-14, F/A-18	SRA	1874AS7056	HYB		4,134
AN/ALR-67(V)3/4	F-14, F/A-18	WRA	1874AS5000100	RF	3105383902	590
AN/ALR-67(V)3/4	F-14, F/A-18	SRA	1874AS5205	HYB		6,761
AN/ALR-67(V)3/4	F-14, F/A-18	SRA	1874AS5310	RF		787
AN/ALR-67(V)3/4	F-14, F/A-18	SRA	1874AS5100	RF		16,877
AN/ALR-67(V)3/4	F-14, F/A-18	WRA	1874AS6000100	RF	3105216403	585
AN/ALR-67(V)3/4	F-14, F/A-18	SRA	1874AS6600	RF		2,098
AN/ALR-67(V)3/4	F-14, F/A-18	SRA	1874AS6500	RF		1,166
AN/ALR-67(V)3/4	F-14, F/A-18	SRA	1874AS6700	RF		4,590
AN/ALE-47	F/A-18	WRA	1792500002	HYB		5,230
AN/ALE-47	F/A-18	SRA	1774170001	HYB		64,820
AN/ALE-47	F/A-18	SRA	1774230002	HYB		22,089
AN/ALE-47	F/A-18	WRA	1797300004	HYB	3100100000000	3,239
AN/ALE-47	F/A-18	SRA	1742600007	HYB		11,892
AN/ALE-47	F/A-18	SRA	1742650003	HYB		9,969
AN/ALE-47	F/A-18	SRA	1742550004	HYB		36,940
AN/ALE-47	F/A-18	SRA	1797350005	HYB		11,606
AN/ALE-47	F/A-18	SRA	1760790004	HYB		83,249
AN/ALE-47	F/A-18	SRA	1743270001	HYB		57,571
AN/APG-73	F/A-18	WRA	3525046110	HYB	3525022150	179
AN/APG-73	F/A-18	SRA	356211910	HYB	3525041150	1,143
AN/APG-73	F/A-18	SRA	356212015	HYB		2,439
AN/APG-73	F/A-18	SRA	356212220	HYB		5,000
AN/APG-73	F/A-18	SRA	3579669	HYB		4,348
AN/APG-73	F/A-18	SRA	5042140	HYB		506
AN/APG-73	F/A-18	SRA	50423505	HYB		6,924
AN/APG-73	F/A-18	SRA	50423605	HYB		2,439
AN/APG-73	F/A-18	SRA	50952105	HYB		4,348
AN/APG-73	F/A-18	SRA	5095220	HYB		6,667
AN/APG-73	F/A-18	SRA	5097430	HYB		5,556
AN/APG-73	F/A-18	SRA	5097530	HYB		4,348
AN/APG-73	F/A-18	SRA	5097540	HYB		4,168
AN/APG-73	F/A-18	SRA	5105340	HYB		1,754
AN/APG-73	F/A-18	WRA	3525026110	RF		133
AN/APG-73	F/A-18	SRA	508601010	HYB		2,168
AN/APG-73	F/A-18	SRA	50915905	HYB		2,273

Table 7. Emerging systems data

Program	Aircraft	Inden-ture	Part number	ATE	Replacement part number	MTBUMA (hours)
AN/APG-73	F/A-18	SRA	503996010	RF		765
AN/APG-73	F/A-18	SRA	5097660	RF		1,191
AN/APG-73	F/A-18	SRA	5097670	HYB		2,857
AN/APG-73	F/A-18	SRA	5097750	HYB		1,408
AN/APG-73	F/A-18	SRA	5099680	RF		2,560
AN/APG-73	F/A-18	SRA	5099710	RF		2,742
AN/APG-73	F/A-18	SRA	5099770	RF		2,194
AN/APG-73	F/A-18	SRA	5099870	RF		3,142
AN/APG-73	F/A-18	SRA	5099910	RF		3,118
AN/APG-73	F/A-18	WRA	3525683111	RF		562
AN/APG-73	F/A-18	SRA	5102380	HYB		2,872
AN/APG-73	F/A-18	SRA	5102400	HYB		2,463
AN/APG-73	F/A-18	SRA	5102420	HYB		2,317
AN/APG-73	F/A-18	SRA	5102440	HYB		2,081
AN/APG-73	F/A-18	WRA	3525078110	HYB		33,000
F/A-18 E/F	F/A-18E	WRA	1680009	HYB		600
F/A-18 E/F	F/A-18E	WRA	1686009	HYB		2,447
F/A-18 E/F	F/A-18E	WRA	MT931072491	HYB		3,372
F/A-18 E/F	F/A-18E	WRA	2100011	HYB		2,826
F/A-18 E/F	F/A-18E	WRA	43107001	HYB		8,936
F/A-18 E/F	F/A-18E	WRA	8142372	HYB		410
F/A-18 E/F	F/A-18E	WRA	90154001	HYB		12,297
F/A-18 E/F	F/A-18E	WRA	EF1	HYB		58,823
F/A-18 E/F	F/A-18E	WRA	GE18001	HYB		2,524
F/A-18 SMS	F/A-18	WRA	CP---/AYQ	HYB		3,088
F/A-18 SMS	F/A-18	SRA	8064101	HYB		45,744
F/A-18 SMS	F/A-18	SRA	8064102	HYB		63,052
F/A-18 SMS	F/A-18	SRA	806403	HYB		84,940
F/A-18 SMS	F/A-18	SRA	8064104	HYB		30,008
F/A-18 SMS	F/A-18	SRA	8064105	HYB		10,000
F/A-18 SMS	F/A-18	SRA	8064106	HYB		45,054
F/A-18 SMS	F/A-18	SRA	8064107	HYB		41,011
F/A-18 SMS	F/A-18	SRA	8064108	HYB		46,647
F/A-18 SMS	F/A-18	SRA	8064109	HYB		77,943
F/A-18 SMS	F/A-18	SRA	8064110	HYB		54,351
F/A-18 SMS	F/A-18	SRA	8064111	HYB		10,846
F/A-18 FLIR	F/A-18	WRA	R2493/AAS42	NIATS		4,536
F/A-18 FLIR	F/A-18	SRA	2606251	EO		13,500

Table 7. Emerging systems data

Program	Aircraft	Indenture	Part number	ATE	Replacement part number	MTBUMA (hours)
F/A–18 FLIR	F/A–18	SRA	2606261	EO		13,500
F/A–18 FLIR	F/A–18	SRA	2606271	EO		13,500
F/A–18 FLIR	F/A–18	SRA	31195891	EO		13,500
F/A–18 FLIR	F/A–18	SRA	31195951	EO		13,500
F/A–18 FLIR	F/A–18	SRA	31195991	EO		13,500
F/A–18 FLIR	F/A–18	SRA	31196041	EO		13,500
F/A–18 FLIR	F/A–18	SRA	31196091	EO		13,500
F/A–18 FLIR	F/A–18	SRA	31196161	EO		13,500
F/A–18 FLIR	F/A–18	SRA	31196191	EO		13,500
AN/ALE–50	F/A–18E	WRA	3410AS1001	HYB		394
AN/ALE–50	F/A–18E	SRA	3410AS10001	HYB		1,007
JTIDS URC107 (V)	F–14D	WRA	6227961031	CNI	80100001831	949
JTIDS URC107 (V)	F–14D	WRA	P310A01230	HYB		399
F–14D SMS	F–14D	WRA	A55A900229	HYB	A51A913715	1,500
F–14D SMS	F–14D	SRA	7955722001	HYB		13,452
F–14D SMS	F–14D	SRA	7955723002	HYB		7,751
F–14D SMS	F–14D	SRA	7955724102	HYB		55,632
F–14D SMS	F–14D	SRA	7955725101	HYB		48,962
F–14D SMS	F–14D	SRA	7955732102	HYB		46,017
F–14D SMS	F–14D	SRA	7103792001	HYB		1,052
F–14D SMS	F–14D	WRA	A55A900217	HYB		1,600
F–14D SMS	F–14D	SRA	7955750001	HYB		45,239
F–14D SMS	F–14D	SRA	7959667003	HYB		93,512
F–14D SMS	F–14D	SRA	7959698500	HYB		28,641
F–14D SMS	F–14D	SRA	7959664600	HYB		28,890
F–14D SMS	F–14D	SRA	7959665600	HYB		16,967
F–14D SMS	F–14D	SRA	7955749201	HYB		14,683
F–14D SMS	F–14D	SRA	7958601600	HYB		4,051
F–14D SMS	F–14D	SRA	7959651600	HYB		7,950
F–14D SMS	F–14D	SRA	7959659002	HYB		1,250
F–14D SMS	F–14D	SRA	7959661205	HYB		32,950
F–14D SMS	F–14D	SRA	7959686702	HYB		8,017
F–14D SMS	F–14D	SRA	7959696600	HYB		20,018
F–14D SMS	F–14D	SRA	7959699600	HYB		20,868
F–14D SMS	F–14D	WRA	A55A900215	HYB	A51A913771	1,400
F–14D SMS	F–14D	SRA	7955740102	HYB		21,846
F–14D SMS	F–14D	SRA	7955741101	HYB		47,907
F–14D SMS	F–14D	SRA	7955742101	HYB		66,262

Table 7. Emerging systems data

Program	Aircraft	Indenture	Part number	ATE	Replacement part number	MTBUMA (hours)
F–14D SMS	F–14D	SRA	7955743101	HYB		65,150
F–14D SMS	F–14D	SRA	7955747101	HYB		31,958
F–14D SMS	F–14D	SRA	7103792001	HYB		900
F–14D SMS	F–14D	WRA	A55A90027	HYB		1,800
F–14D SMS	F–14D	SRA	7955814102	HYB		32,755
F–14D SMS	F–14D	WRA	A55A900221	HYB		9,312
F–14D SMS	F–14D	SRA	7955700102	HYB		9,313
F–14D SMS	F–14D	SRA	7955702102	HYB		9,312
F–14D SMS	F–14D	SRA	7977705102	HYB		8,740
F–14D SMS	F–14D	SRA	7955706102	HYB		3,800
F–14D SMS	F–14D	SRA	7955707003	HYB		2,600
F–14D SMS	F–14D	WRA	A55A900225	HYB	3071000002	985
F–14D SMS	F–14D	SRA	7955847202	HYB		16,961
F–14 IRSTS	F–14D	WRA	7331800G1	EO		360
F–14 IRSTS	F–14D	SRA	149D4571G1	HYB		1,920
F–14 IRSTS	F–14D	SRA	149D4573G1	HYB		1,562
F–14 IRSTS	F–14D	SRA	7331802G2	HYB		1,600
F–14 IRSTS	F–14D	SSRA	149D4577G1	HYB		2,340
F–14 IRSTS	F–14D	SSRA	174D3185G2	HYB		2,500
F–14 IRSTS	F–14D	WRA	7331805G1	HYB		421
F–14 IRSTS	F–14D	SRA	174D1221G1	HYB		2,100
F–14 IRSTS	F–14D	SRA	174D1846G1	HYB		2,560
F–14 IRSTS	F–14D	SRA	174D5000G1	HYB		3,170
F–14 IRSTS	F–14D	SRA	174D5003G1	HYB		3,110
F–14 IRSTS	F–14D	SRA	174D5006G1	HYB		455
F–14 IRSTS	F–14D	SRA	174D5009G1	HYB		2,486
F–14 IRSTS	F–14D	SRA	174D5012G1	HYB		3,100
F–14 IRSTS	F–14D	SRA	174D5015G1	HYB		1,942
F–14 IRSTS	F–14D	SRA	174D5018G1	HYB		6,170
F–14 IRSTS	F–14D	SRA	174D5021G1	HYB		4,110
F–14 IRSTS	F–14D	SRA	174D5024G1	HYB		6,370
F–14 IRSTS	F–14D	SRA	174D5027G1	HYB		10,000
F–14 IRSTS	F–14D	SRA	174D5030G1	HYB		9,813
F–14 IRSTS	F–14D	SRA	174D5033G1	HYB		7,616
F–14 IRSTS	F–14D	SRA	174D5036G1	HYB		8,715
F–14 IRSTS	F–14D	SRA	174D5321G1	HYB		10,000
APG–71	F–14D	WRA	481044	RDCM	2538956	262
APG–71	F–14D	SRA	3562190	HYB	481004150	785

Table 7. Emerging systems data

Program	Aircraft	Indenture	Part number	ATE	Replacement part number	MTBUMA (hours)
APG-71	F-14D	SRA	50100305	HYB	481024150	600
APG-71	F-14D	SRA	5042140	HYB	481033150	600
APG-71	F-14D	SRA	5042310	HYB	481034150	1,100
APG-71	F-14D	SRA	50423201	HYB	481044150	980
APG-71	F-14D	SRA	50423305	HYB	481084150	1,100
APG-71	F-14D	SRA	504235010	HYB	481551160	1,100
APG-71	F-14D	SRA	50423605	HYB	48155160	1,800
APG-71	F-14D	SRA	50423705	HYB	A55A90473	10,000
APG-71	F-14D	SRA	504325025	HYB	A55A90483	1,800
APG-71	F-14D	SRA	50568301	HYB	A55A90503	10,000
APG-71	F-14D	SRA	50614905	RF	A55A90513	850
APG-71	F-14D	SRA	5061527	RF	A55A90523	778
APG-71	F-14D	SRA	50616005	RF	A55A90583	1,000
APG-71	F-14D	SRA	506190010	HYB	A55A90723	1,000
APG-71	F-14D	SRA	50620105	RF		870
APG-71	F-14D	SRA	50620405	RF		900
APG-71	F-14D	SRA	506206015	RF		1,200
APG-71	F-14D	SRA	5062160	RF		1,800
APG-71	F-14D	SRA	50623005	RF		441
APG-71	F-14D	WRA	481034	RDCM		141
APG-71	F-14D	SRA	506542045	HYB		900
APG-71	F-14D	SRA	5065480	HYB		900
APG-71	F-14D	WRA	481551	RDCM		113
APG-71	F-14D	SRA	5085050	HYB		1,800
APG-71	F-14D	WRA	481033	RDCM		126
APG-71	F-14D	SRA	623720015	HYB		1,800
APG-71	F-14D	SRA	6237230	HYB		2,500
APG-71	F-14D	SRA	6237240	HYB		715
F-14D	F-14D	WRA	A51A92163	HYB		352
F-14D	F-14D	WRA	A55A90077	HYB		1,970
F-14D	F-14D	WRA	A55A90455	HYB		1,800
F-14D	F-14D	WRA	A55A90457	HYB		1,100
F-14D	F-14D	WRA	A55A91037	HYB		2,400
F-14D	F-14D	WRA	A55J730001	HYB		10,000
F-14D	F-14D	WRA	A55J740001	HYB		2,400

Appendix D: Aircraft quantities and optempos

In this appendix, we describe how we determined the aircraft quantities and optempos that we used in this study.

Aircraft quantities

F–14s

Airwings

East and west coast F–14 support will be single-sited at the RMC in Oceana. The RMC will support airwing F–14s, RAG F–14s, and other assorted F–14s stationed at warfare centers and other commands throughout CONUS.

We assumed that in the year 2000 there would be 10 airwings, and each would contain one squadron of 14 F–14s. At any given time, one of these airwings would be forward deployed, four would be deployed from the west and east coasts (two per coast), and five would be supported in CONUS by the RMC at Oceana.

The forward deployed squadron would be an F–14A squadron. The F–14 program office provided data which indicated that the remaining nine airwings would contain four F–14A squadrons, three F–14B squadrons, and two F–14D squadrons. In other words, of these nine airwings that were not forward deployed, 44 percent are F–14As, 33 percent are F–14Bs, and 22 percent are F–14Ds. We used this percentage breakdown and applied it to the five airwings that would be in CONUS (not deployed) and supported by the RMC. With these percentages, we estimated that of the 70 F–14s supported by the RMC, 31 would be F–14As, 23 would be F–14Bs, and 16 would be F–14Ds.

RAG

The F–14 program office estimated that there would be 58 aircraft in the F–14 RAG squadron. This included 39 F–14As, 12 F–14Bs, and 7 F–14Ds.

Other F–14s

The F–14 program office indicated that there would be about 47 F–14Ds in the fleet inventory in 2000. We have already determined that there would be two 14-plane F-14D squadrons in airwings, and 7 F–14Ds in the RAG. This leaves 12 additional F–14Ds for the RMC to support.

The F–14 program office indicated that there would be about 81 F–14Bs in the fleet inventory in 2000. We have already determined that there would be three 14-plane F-14B squadrons in airwings, and 12 F–14Bs in the RAG. This leaves 27 additional F–14Bs for the RMC to support.

The F–14 program office indicated that there would be about 66 F–14s total in the cats and dogs category. This leaves 27 additional F–14As for the RMC to support.

Total F–14s

This gives a total of 97 F–14As, 62 F–14Bs, and 35 F–14Ds.

F/A-18s

Airwings

Unlike the F–14s, Navy F/A–18 support will be split between coasts at Oceana and Lemoore. We assumed that in the year 2000 the 10 airwings would be evenly split between coasts, and each airwing would contain three 12-plane squadrons. That is, the RMC at Oceana would support 15 F/A–18 squadrons from airwings, less support provided by the Marine Corps.

The F/A–18 program office indicated that of these 15 squadrons, 2 would be F/A–18E squadrons and the remaining 13 would be F/A–18C squadrons. Thus, roughly 13 percent of the deployable aircraft would be F/A–18Es. Because two airwings from the east coast would be deployed at any time, this leaves three airwings (108 aircraft) as supported by the RMC. And if 13 percent of these are F/A–18E aircraft, then this means that the airwings contribute 94 F/A–18Cs and 14 F/A–18Es to the RMC workload before accounting for Marine F/A–18s.

Two of the F/A-18C squadrons will be Marine Corps ones supported by Beaufort. This leaves 70 F/A–18Cs. And, lastly, the Marines will provide one deployed squadron (per coast) 6 months a year—meaning that there are six more Navy F/A–18Cs for the RMC to support. Bottom line: The airwings provide 76 F/A–18Cs and 14 F/A–18Es for the RMC to support.

RAG

The F/A–18 program office indicated that the RAG would contain 45 F/A–18Cs.

Other F/A–18s

There are 61 remaining F/A–18Cs to be supported by the RMC.

Total F/A–18s

This gives a total of 182 F/A–18Cs and 14 F/A–18Es to be supported at Oceana.

APG–65 versus APG–73

The F/A–18 program office indicated that a total of 226 F/A–18Cs will have APG–73 in the year 2000. We assumed that these radars would be evenly split between coasts; this leaves 133 APG–73 radars for east coast F/A–18s. There are 262 F/A–18Cs on the east coast (13 airwings with 12 aircraft each, plus 45 RAG aircraft and 61 cats and dogs). Thus, 51 percent of all east coast F/A–18Cs will have APG–73. So, of the 182 F/A–18s supported by the RMC, 92 will have APG–73, and the remainder (90) will have the APG–65 radar.

Aircraft utilization rates

Each aircraft's Wartime Systems Planning Document (WSPD) provides guidelines for expected peacetime aircraft utilization rates (flying hours per aircraft per month). These rates, however, are fleet-wide estimates that include both deployed and nondeployed aircraft.

We analyzed historical F–14 and F/A–18 utilization rates from 1990 through 1994 for both deployed and nondeployed aircraft. We found that deployed aircraft—both F–14s and F/A–18s—consistently had higher utilization than nondeployed aircraft. Consequently, we believe that the peacetime WSPD utilization rates overestimate nondeployed aircraft optempos.

Specifically, we found that nondeployed F–14 aircraft utilization rates were only about 90 percent of the entire fleet-wide average. Nondeployed F/A–18 utilization rates were about 94 percent of the fleet-wide average. Consequently, we adjusted the WSPD projections by these factors to better project shore aircraft utilization rates. Table 8 shows the resulting utilization rates we employed in this study.

Table 8. Aircraft utilization rates

Aircraft	Adjustment factor	Peacetime WSPD utilization rate	Adjusted utilization rate
F–14A	0.90	25	22.5
F–14B	0.90	25	22.5
F–14D	0.90	30	27.0
F/A–18C	0.94	34	32.0
F/A–18E	0.94	36	33.8

Appendix E: Test of statistical certainty

Overview of hypothesis testing

In this appendix, we describe the statistical certainty test we used to determine whether one set of modeling results was "better" than another.

Specifically, we examine the null hypothesis:

H_0: CASS results $_1$ = CASS results$_2$.

The alternative hypothesis is

H_1: CASS results$_1$ $\neq$ CASS results$_2$.

For each pair of CASS results, we test to see whether the data support rejecting the null hypothesis at the 5-percent significance level (95-percent confidence level). If they do, then we conclude that one set of CASS results is "better" than the other with regard to the measure we are testing. If the data do not suggest rejecting H_0, then we provisionally accept it subject to the limitations of our statistical test.[14]

ALM's use of a random number seed

Each simulation run uses a random number seed. This seed determines which parts fail and how long they take to repair.

When ALM attempts to "fly" a sortie according to the flight schedule in our scenario, ALM uses this random number seed to decide which

14. Testing at the 5-percent significance level inherently yields a 5-percent chance of rejecting the null hypothesis even when it is true. This is called a *type I error.*

historic sorties it will mimic. That is, ALM randomly selects historic sorties and pulls up their maintenance records.

ALM also uses the random number seed to determine whether emerging systems fail during a given sortie.

Example calculation

Consider the following example. We wish to test whether the cannibalization results for the CASS alternative of {19 Hybrid, 13 RF, 1 EO, 1 CNI} are at least as good as the results for the alternative of {18 Hybrid, 14 RF, 1 EO, 1 CNI}. Table 9 shows the cannibalization results we obtained for each of these simulations.

Table 9. Cannibalization results for two CASS alternatives

	Cannibalizations	
Iteration	{19 Hybrid, 13 RF, 1 EO, 1 CNI}	{18 Hybrid, 14 RF, 1 EO, 1 CNI}
1	897	845
2	922	845
3	900	812
4	1,028	794
5	949	900
Average	939	839

These data indicate that, on average, the alternative with {19 Hybrid, 13 RF, 1 EO, 1 CNI} CASS stations resulted in 100 (over 10 percent) more cannibalizations than the alternative with {18 Hybrid, 14 RF, 1 EO, 1 CNI} CASS stations. But is this a statistically significant difference?

The test for significance

The test for statistical significance uses a "pooled estimate of the standard deviation" from the two samples [5]. This pooled estimate is denoted s, and equals

$$s = \sqrt{\frac{\sum (X-\bar{X})^2 + \sum (Y-\bar{Y})^2}{n_X + n_Y - 2}} ,$$

where X and Y represent the two distinct sets of CASS iterations; $\bar{X}$ and $\bar{Y}$ are their averages; and n_X and n_Y are the number of iterations for each set. Using the data from table 9, $s = 47.6$.

We next calculate t, which satisfies a Student's t-distribution with 8 $(n_X + n_Y - 2)$ degrees of freedom. The equation for t is

$$t = \frac{(\bar{X} - \bar{Y})}{\sqrt{\left(\frac{s^2}{n_X} + \frac{s^2}{n_Y}\right)}} \quad .$$

For the data in table 9, $t = 3.32$.

We then consult Student's t-distribution. We need to find out if the probability of t being at least 3.32 is less than 5 percent—assuming that the true average cannibalizations for each alternative are the same. We find that the probability of t being at least 3.32 is less than 5 percent ($t_{critical} = 2.31$). Consequently, we reject the H_0, and conclude that the number of cannibalizations for the alternative with {19 Hybrid, 13 RF, 1 EO, 1 CNI} CASS stations is significantly worse (higher) than for the alternative with {18 Hybrid, 14 RF, 1 EO, 1 CNI} CASS stations.

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