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September 1987

Final Task Report

**SIMULATION AND EXPERIMENTS TO DETERMINE
COMMUNICATIONS IMPACT ON PERFORMANCE
MEASURES IN LOGISTICS**

**TASK 2--COMMUNICATION PERFORMANCE/
EXTERNAL AIRCRAFT FUEL TANK
AVAILABILITY TRADEOFFS**

Contract No. N66001-84-D-077, D.O. 0025
Report Period: 23 September 1986 to 4 April 1987

By: RICHARD H. MONAHAN MARY ANN R. HACKWORTH

Prepared for:

NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

and

DAVID W. TAYLOR NAVAL SHIP
RESEARCH AND DEVELOPMENT CENTER
BETHESDA, MARYLAND 20884

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Systems Development Division

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PREFACE

This report documents the results of research conducted for the Naval Ocean Systems Command (NOSC), San Diego, California, and the David W. Taylor Naval Ship Research and Development Center (DTNSRDC), Bethesda, Maryland. The technical monitor for NOSC is G. L. Allgaier, Code 444. The research is in response to DTNSRDC under the direction of M. J. Zubkoff, Code 1870. The research was performed under Contract N66001-84-D-077, D.O. 0025.

The SRI program manager for the overall contract was F. F. Kuo of the Computer and Information Sciences Division (CISD). D. L. Nielson is Vice President of CISD. R. H. Monahan of the Systems Development Division (SDD) was the project manager for this delivery order. J. P. McHenry is Vice President of SDD.

The research on Task 2, the subject of this report, was performed in both SDD and the Advanced Technology Division (ATD). W. F. Greenman is Vice President of ATD. R. H. Monahan of SDD was the task leader and M. A. Hackworth of the Transportation and Control Program of ATD provided model design and programming support.



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I INTRODUCTION

A. Objective

The objective of this delivery order was to establish an estimate of the impact of communications on (1) performance measures relating to the logistical aspects of theater-level war games and fleet exercises, and (2) the physical distribution of critical components to support C₂ operations during sustained periods of naval combat operations. The research was conducted in accordance with the following three task statements:

Task 1: Communications Impact on Performance Measures in Logistics:

The contractor shall define a set of logistics performance measures to model the effectiveness of logistics systems and procedures within the context of joint theater-level war games and fleet exercises. The relationship between these performance measures and communications effectiveness shall be established.

Task 2. Communication Performance/External Aircraft Fuel Tank Availability Tradeoffs:

The contractor shall perform the required modifications to the physical distribution system computer simulation model FTANKS to provide for the assembly, recovery, and reuse of disposable external aircraft fuel tanks during combat operations.

Task 3. Portable Aircraft Fuel Tank Assembly System Feasibility Experiments for Simulation and Model Validation:

The contractor shall provide a design of a portable fuel tank automated assembly system for demonstrating the feasibility of use of such an assembly system within an aircraft carrier battle group for assembly of nestable, disposable external aircraft fuel tanks during combat. (JF)

operations. The developmental fuel tank assembly system will be housed within a 20x8x8-ft portable container that is transportable between the aircraft carrier and one of its support ships.

The results of the research performed under Task 2 are presented in this report.

B. Background

The science of logistics is a technical integration of many supportive disciplines such as acquisition and supply, replenishment, reliability and maintainability, and advanced basing. The David W. Taylor Naval Ship Research and Development Center (DTNSRDC) logistics technology program involves the analysis of support requirements associated with air vehicle technology and the logistics effects of Fleet operational performance. To that end, air logistics technology support is required in the conduct of Fleet performance simulation exercises to determine logistics requirements of air vehicles.

A need for exploratory development research has arisen concerning the adequacy of aircraft fuel tanks in the fleet, tank storage locations, methods for tank distribution, system responsiveness to need, and alternatives for acquiring such tanks. Failure to have adequate responsive access to such fuel tanks will have a deleterious effect on operational readiness of Fleet aircraft and, consequently, on carrier battle group readiness.

Previous research has indicated that the development of disposable, nestable aircraft external fuel tanks with automatic assembly aboard ship is feasible.* A preliminary cost-benefit analysis of several design concepts for nestable fuel tanks indicated that the effectiveness of task group air combat operations can be significantly increased with

* Andeen, G. et al., "Physical Distribution System for Aircraft External Fuel Tanks - Candidate System Design Evaluations," SRI Project 1076, DTNSRDC Report No. CMLD-CR-58-86 (November 1986).

the availability of nestable fuel tanks. In that analysis, fuel tanks were assumed to be completely disposable. That is, all external fuel tanks would be ejected by an aircraft during a mission. Subsequent to that analysis, DTNSRDC requested that this simplifying assumption be relaxed by assuming that aircraft may return to the carrier with empty fuel tanks when there is no need to eject them during a mission. Thus, the primary objective of Task 2, as indicated by the statement for Task 3 in the previous subsection, was to revise the physical distribution system computer simulation model FTANKS to provide for carrier recovery of aircraft with empty fuel tanks.

The original version of the model only allowed one replication to be run for a given scenario. However, the model should be allowed to generate outputs that are based on the averaged results of several replications, since this model is essentially a Monte Carlo type. Thus, another required modification was to expand the model to allow for multiple replications of the same scenario.

Descriptions of the model modifications are the focus of this report.

II ORIGINAL PHYSICAL DISTRIBUTION SIMULATION MODEL (FTANKS)

The physical distribution simulation model FTANKS is described in detail in the previously cited report.* This computer model is an event-sequenced Monte Carlo simulation that examines the effectiveness of carrier-borne aircraft in conducting a variety of missions under changing conditions of external fuel tank availability. The original version of the model assumes that the external fuel tanks are completely disposable, that is, all external fuel tanks are ejected by an aircraft during a mission.†

The underlying scenario for the model assumes that a carrier task group is deployed offshore in support of possible contingency operations onshore. The carrier aircraft are required to fly various support missions when hostilities break out. Mission requests are randomly generated as to both time and type. The mission requirements vary according to the number and type of aircraft, the number of external fuel tanks per aircraft, and the average mission flight time. Available aircraft are assigned to fly missions as they are requested, if there is a sufficient supply of external fuel tanks. Mission requests, when not immediately filled, remain active for a specified period and can be filled when aircraft and/or fuel tanks become available. If a mission request is not filled within the designated period, that request is designated as an "aborted mission" and is deleted from the mission request queue.

The supply of external fuel tanks is simulated according to the physical distribution system assumed for a particular simulation run. The physical system options available for analysis are indicated in Figure 1. These system options assume an initial stock point (supply

* Ibid pp. 119-216.

† One of the model modifications described in Section III allows aircraft to return with fuel tanks in accordance with an input-specified probability factor.

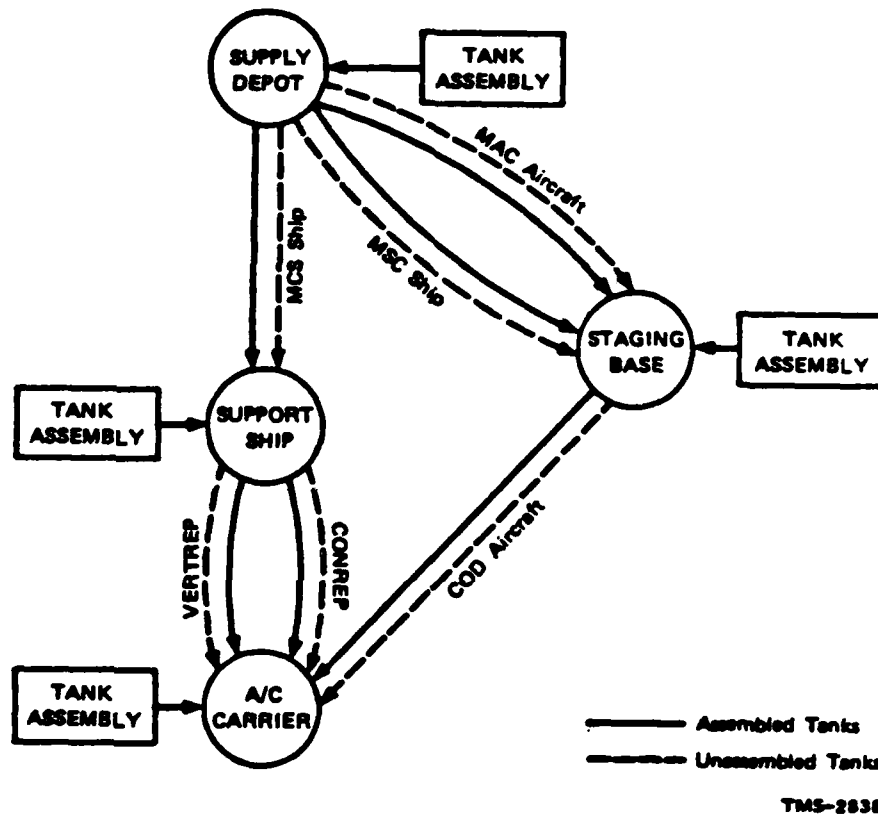


FIGURE 1 PHYSICAL DISTRIBUTION OPTIONS

depot), an intermediate supply point (staging base or support ship), and a terminal supply point (aircraft carrier). Fuel tanks may be assembled at any of the supply points, but at only one for a particular physical distribution system option. Assembly of fuel tanks is assumed to be continual and ongoing as long as there is space available for storage of assembled fuel tanks. Initial stocks of fuel tanks (assembled, unassembled, or both, depending on the point of assembly) are assumed at each supply point, with an unlimited supply at the initial stock point, a fairly large supply at the intermediate supply point, and a highly limited supply at the terminal point (because of limited storage space). *Unassembled fuel tanks are shipped to the point of assembly.* Shipping between the supply depot and staging base is conducted by Military Sealift Command (MSC) ships or Military Aircraft Command (MAC) aircraft. MSC ships are the only shipping vehicles between the supply depot and

the support ship. Shipping between the staging base and the aircraft carrier is conducted solely by Carrier-On-Board-Delivery (COD) aircraft. Transfer of fuel tanks from the support ship to the aircraft carrier is conducted either by Vertical Replenishment (VERTREP) aircraft or by Connected Replenishment (CONREP). Fuel tank resupply from the initial stock point to the intermediate supply point is done on a "push" (non-requisition) basis. "Push" resupply is estimated according to the expected demand for a short-term contingency operation. Resupply from the intermediate point to the terminal point is done on a "pull" (requisition) basis, with replenishment orders issued when the fuel tank supply drops below a prespecified order level.

The model simulates the availability of assembled fuel tanks aboard the aircraft carrier. After the breakout of hostilities at time zero, aircraft are assigned to fly missions as requests are received. Once armed, the aircraft are launched and fly out to conduct their assignments, reducing the number of aircraft available for subsequent missions and the supply of assembled fuel tanks aboard the carrier.

After a specified turnaround time, aircraft that return from missions become available to fly new missions. As the fuel tank supply diminishes, replenishment orders are issued, and resupply is initiated at the intermediate supply point. When available, replenishment aircraft are loaded to capacity and dispatched to the aircraft carrier. (During CONREP replenishment, the support ship begins steaming in the direction of the aircraft carrier unless it is tied up with an MSC replenishment ship.) Upon arrival and offloading of the replenishment aircraft, the fuel tank supplies are increased, and the replenishment aircraft return to the intermediate supply point. (During CONREP replenishments, on arrival of the support ship at the aircraft carrier, all scheduled mission flights are allowed to continue. The ships do not tie up alongside one another until the last aircraft returns from ongoing missions. New mission requests are put on hold. When the transfer of fuel tanks is completed, the support ship sails to its station and mission flights from the carrier are initiated again.) During the operations, some mission requests may

not be filled within their lifetime periods. Causes of mission delay include the unavailability of aircraft or fuel tanks or the suspension of flight operations before and during CONREP replenishments. These unfilled mission requests are identified as "aborted missions" and removed from the mission request list.

The primary effectiveness measures for comparing alternative fuel tank system designs involve the proportion of missions flown to the total number of missions requested and also the O&MN costs associated with the distribution of fuel tanks. The principal outputs of the model are related to these effectiveness measures. The model generates daily tables and a summary table denoting (1) the numbers of missions aborted according to mission type and reason for abort, and (2) the numbers of missions requested and flown, by type. The tables also display the associated proportions of missions aborted to missions requested, including reasons for abort, as well as proportions of total missions aborted and flown to total missions requested. Also, fuel tank O&MN costs are summarized and are broken down as to acquisition, assembly, and shipping costs. Other auxiliary outputs, such as investment and R&D costs, assembly man-hours used, and number of replenishments, are also available.

III MODEL MODIFICATIONS

Two major modifications were added to the FTANKS simulation model under this delivery order: (1) the ability to run a number of replications of a given scenario and (2) the possibility for aircraft to return from missions with empty fuel tanks. These modifications are described in the following two sections. These descriptions assume that the reader is familiar with the model description presented in the previous report.*

A. Multiple Number of Replications

The original version of FTANKS did not allow multiple replications of a given scenario. Thus, if the user wanted to run a number of replications for a given scenario (allowing alternate scheduling of missions, as well as the random damage inflicted on fuel tanks during shipping and handling), he would have to run the model a number of times with different random number seeds and then compute average outputs off-line. During the initial model development, missions were to be scheduled on a fixed periodic basis, so the use of one replication per scenario did not appear to cause any problems. However, it was decided later, well into the model development, to allow random mission scheduling. By then, it was too late to revise the model to allow multiple replications within the project time constraint. Also, allowing random returns of mission aircraft with empty fuel tanks increases the stochastic nature of the model, increasing the desirability of multiple replications. So, the inclusion of this modification in the model was a requirement of the present delivery order.

The inclusion of this replication capability in the computer model resulted in the addition of two new subroutines (REINIT and CALCAV), as

* Ibid.

well as modifications of the main program module, FTANKS, and of several other subroutines (GENMR, INITRG, RIDATA, WRTCST, and WRTOUT). The first new subroutine, REINIT, reinitializes several variables in common blocks that should be the same at the beginning of each replication: fuel tank inventories at the various supply points, scheduled arrival of next supply vehicle at the intermediate supply point, and so on.

The other new subroutine, CALCAV, calculates the summary statistics of the major program outputs: the averages of the program outputs over all the replications.

Program FTANKS, the program control module, has been modified to allow the program to loop through NREPLIC replications of the same scenario. FTANKS call the various subroutines, as before, to generate the replication outputs and also calls the new subroutines, REINIT and CALCAV, to perform their functions at the proper times during the simulation.

Subroutine GENMR, the mission request generator, has been modified so that the seed value of the random number generator available at the end of the missions for one replication becomes the initial seed value for generating the missions on the next replication. This modification is required so that, when comparing alternative distribution systems for a given scenario, the scheduled missions for all the replications will be the same for each computer run representing a different distribution system. Because the random numbers generated during a replication will not be the same for different distribution systems, the value of the seed after the first replication for one distribution system will differ from that value for another distribution system. In this case, the initiating seed for scheduling missions for the second replication for one distribution system would differ from the initiating seed for another distribution system. Thus, missions would be scheduled differently for the respective second and all subsequent replications. The new GENMR modification prevents this problem.

Subroutine INITRG, which initializes several registers and counters at the beginning of a simulation run, had to be expanded. In its new

form, INITRG initializes a number of additional counters to zero. Although all program variables are set to zero at the beginning of the simulation, the additional counters need to be set again to zero after each replication. The modifications to INITRG accomplish this function.

Subroutine RIDATA, which reads in the program inputs, had to be modified to read in the values of two new input parameters: NREPLIC, the number of replications to run for a given simulation and REPORT, which identifies the type of output tables desired for a given run (D = all tables, R = replication and summary tables, and S = summary tables only).

Subroutine WRTCST, which writes out the cost and man-hour expenditure results, had to be modified to generate both the required output results for each replication and the averaged summary results from all replications. Because of format requirements, the modification also included converting real-valued output to integer-valued output.

Subroutine WRTOU, which writes out the program output tables of the mission results, had to be modified to print out tables for each replication, as well as for the average summary results. In the previous version of the model, the user had the choice of either printing out the battle results daily and the total results over the duration of the battle, or else just printing out the total battle results. In the modified version, the user may print out (1) all of the results (daily results for each replication, summary battle results for each replication, and summary battle results over all the replications), (2) the summary battle results by replication as well as the results over all the replications, or (3) just the summary battle results over all the replications. The input parameter REPORT specifies the output requirements (D = all tables, R = replication and summary tables, S = summary tables only).

A computer run was made to illustrate the results from a number of replications of a given scenario. The input values in this scenario were chosen from those used in generating the results presented in the previous report. The EASTMED task group deployment and the three-piece welded fuel tank assembly system were assumed. The assumed physical distribution system provided shipment of unassembled fuel tanks from

CONUS to the support ship by MSC ships, and on to the aircraft carrier by VERTREP helicopters. Fuel tank assembly was conducted aboard the aircraft carrier. The assumed mission demand rate was one per hour. The primary program outputs for each of 10 battle replications are presented in Table 1, with the mean values over all of these replications. The Percent Missions Flown outputs vary from 47.3 to 56.4, with a mean value of 52.6, a variation from -10.1 to 7.2% of the mean. The Operations and Maintenance, Navy (O&MN) Cost outputs vary from \$1.106 to \$1.127M with a mean value of \$1.116M, a variation of -0.9 to 1.0%. The Effective Assembly Man-Hours Used vary from 430 to 438 with a mean value of 435, a variation of -1.1 to 0.7%. These results indicate that there are significant variations in the Percent Missions Flown outputs, but the variations for the other two outputs are not very significant. However, Percent Missions Flown is a very critical variable for tradeoff analyses. So, the capability for multiple replications of the battle scenario will provide useful results for these types of analyses.

Table 1
MULTIPLE REPLICATION RESULTS

Replication Number	Percent Missions Flown	O&MN Cost (\$M)	Effective Assembly Man-Hours Used
1	56.4	1.127	438
2	52.3	1.106	430
3	49.1	1.110	431
4	55.5	1.114	434
5	54.2	1.110	434
6	47.3	1.110	433
7	54.3	1.126	438
8	52.6	1.123	437
9	54.8	1.122	436
10	50.8	1.111	432
Mean	52.6	1.116	435

B. Aircraft Returning with Fuel Tanks

In the original version of FTANKS, it was assumed that each aircraft ejected all of its fuel tanks during a mission. For this delivery order, one requirement was to relax this simplifying assumption by allowing aircraft, with an input-specified probability, to return to the aircraft carrier from a mission with empty fuel tanks, which would then be returned to the carrier's assembled fuel tank inventory.

The inclusion of this capability in the computer model resulted in the addition of one new subroutine (DROPTANKS) and the modification of four subroutines (ACACCD, PRMIP, RIDATA, and MASSGN). The new subroutine DROPTANKS stochastically determines whether or not aircraft in a raid group return with fuel tanks. When the program processes an Aircraft-Return-to-Carrier event by calling subroutine PRMIP, subroutine DROPTANKS is called and, for each aircraft in the returning group, a random number R between zero and one is generated. This random number is compared to the probability that an aircraft returns from a mission with fuel tanks (no drop), PRETT. If $R < \text{PRETT}$, the aircraft has returned with fuel tanks, and number of returning fuel tanks NRETURN for this raid group is increased by MFTREQ(MI,L), the number of fuel tanks required per aircraft of type L for a mission of type MI. If $R > \text{PRETT}$, the aircraft has ejected its fuel tanks during the mission. In this case, the number of dropped tanks NDROPPED for this raid group is incremented by MFTREQ(MI,L). Initially, on each call to DROPTANKS, NRETURN and NDROPPED are each set to zero. After each aircraft in a raid group has been checked for returning fuel tanks, control is returned to subroutine PRMIP for further processing, with the resulting values of NRETURN and NDROPPED.

Subroutine ACACCD, which processes the departure of mission-flying aircraft from the carrier, had to be slightly modified when scheduling a Mission-In-Process event. In the previous version of the model, there was no need to identify the type of mission flown for each entry in the Mission-In-Process (MIP) register. However, in the new version, this identification is required, so the dimensions of the MIP entries had to be increased from (3,NMIP) to (4,NMIP), where NMIP is the number of

missions in progress at any given time. The value represented by MIP(4,J) is the type of mission associated with the Jth mission in progress. In this subroutine, the values of MIP(I,J) for each new mission are entered in the MIP register, so the subroutine had to be modified to transfer the value of MIP(4,J) to the MIP register.

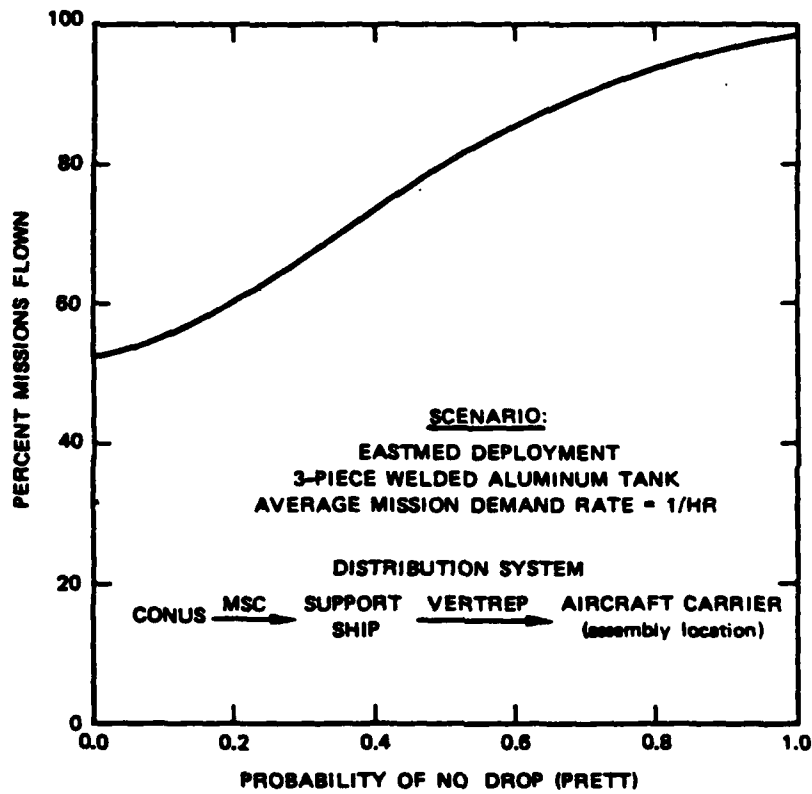
Subroutine PRMIP, which processes the Mission-In-Process (aircraft returning to carrier) events, had to be modified to account for the possible return of fuel tanks with aircraft. The subroutine's first function is to delete the mission being processed from the MIP register. This required a slight modification to account for the added dimension of the value of MIP(I,J) as discussed in the previous paragraph. After completing its first function, the subroutine must determine the number of fuel tanks, NRETURN, that are being returned by aircraft completing the mission and also the number of fuel tanks expended during the mission NDROPPED. These calculations are accomplished by calling Subroutine DROPTANKS (discussed above). Once these values are determined, then the aircraft carrier's inventory of assembled fuel tanks, FTAACC, is increased by NRETURN fuel tanks, and the cumulative number of fuel tanks expended during the battle, FTUSED, is increased by NDROPPED. Next, as in the previous version of the model, the subroutine makes the returning aircraft available to fly new missions and calls Subroutine PRHOLD to process any missions that were on hold because of unavailable aircraft. At this point, a new function is to call Subroutine PRHOLD again, but this time to process any missions that were on hold because of unavailable fuel tanks. On return from PRHOLD, the processing for this subroutine is completed, and control returns to the subroutine FTANKS.

Subroutine RIDATA, which reads in the program inputs, had to be modified to read in the value of PRETT, the probability that an aircraft returns from a mission with fuel tanks.

Subroutine MASSGN, which assigns aircraft to a mission or moves the mission request to the Mission-On-Hold register, had to be modified by eliminating one function. That function, accumulating the number of fuel tanks expended in missions, is now performed by subroutine PRMIP.

This function was previously performed in Subroutine MASSGN, since all fuel tanks aboard aircraft assigned to missions were assumed to be ejected (and, hence, expended), which is not the case in the new version of the model.

A computer run was made to illustrate the effect on battle outcomes of varying the value of PRETT, the probability of aircraft returning from a mission with empty fuel tanks or, equivalently, the probability of no drop. The EASTMED deployment and the three-piece welded aluminum tank were assumed. The physical distribution system assumed that unassembled fuel tanks were shipped from CONUS to the support ship by MSC ships and transferred to the carrier by VERTREP helicopters. Fuel tank assembly was performed aboard the aircraft carrier. Figure 2 illustrates the average values of Percent Missions Flown as a function of PRETT. As would be expected, mission effectiveness increases as the probability of aircraft returning with fuel tanks increases, because there is less demand on the inventory of assembled fuel tanks aboard the carrier. Although not shown on the figure, the O&MN Cost and Effective Man-Hours Used values decrease, as expected, as PRETT increases. The O&MN Cost drops from \$1.16M for $PRET = 0.0$ to \$0.576M for $PRETT = 0.8$, and the Effective Man-Hours Used drops from 435 to 225 for the respective values of PRETT. These latter results are due to the lower demand for acquisition and assembly of fuel tanks as more and more aircraft return with empty tanks.



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FIGURE 2 PERCENT MISSIONS FLOWN AS A FUNCTION OF PROBABILITY OF NO DROP