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CREW COMPOSITION STUDY FOR AN ADVANCED TANKER/CARGO AIRCRAFT (A--ETC(U)
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CREW COMPOSITION STUDY FOR AN ADVANCED TANKER/CARGO AIRCRAFT (ATCA)

*CREW EQUIPMENT AND HUMAN FACTORS DIVISION
DIRECTORATE OF EQUIPMENT ENGINEERING*

OCTOBER 1976

TECHNICAL REPORT ASD-TR-76-20

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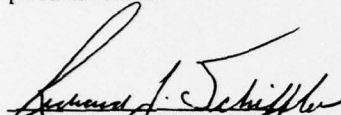
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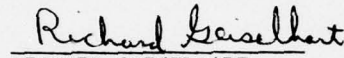
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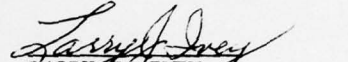
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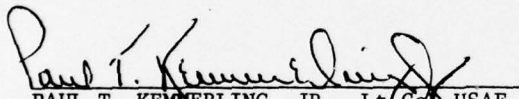
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→ Operator) was the most advantageous and could handle most tasks below
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FOREWORD

This report was prepared in the Crew Equipment and Human Factors Division (ENEC), Directorate of Equipment Engineering, Deputy for Engineering, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. The work was performed under Project Number ASDD0008.

This report covers work performed when the ATCA was still required to perform in the Emergency War Order (EWO) environment. It does not consider the revised operational requirements, programming, and basic commercial configuration which have been under consideration since July 1975.

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ABSTRACT

To determine the minimum crew complement required for an Advanced Tanker/Cargo Aircraft a series of contractor and AF task analyses were reviewed and evaluated. Coupled with these analyses were a series of flight tests which verified some of the task times and procedures required for Advanced Tanker/Cargo Aircraft. It was concluded that a three man crew (P, CP, Boom Operator) had crew work overloads during several flight segments and this crew size would be unacceptable in a Emergency War Order (EWO) environment. A four man crew (P, CP, N/FE and Boom Operator) was the most advantageous and could handle most tasks below a 100% task loading.

TABLE OF CONTENTS

| SECTION | | PAGE |
|---------|---|------|
| I | INTRODUCTION | 1 |
| II | METHODOLOGY | 4 |
| III | RESULTS | 5 |
| | 1. DC-10 Douglas Crew Workload Study | 5 |
| | 2. ENECC Task Analysis Based on KC-135 Data | 8 |
| | 3. Boeing 747 Task/Training Analysis | 14 |
| IV | CONSOLIDATED ANALYSIS | 16 |
| V | DISCUSSION | 26 |
| VI | CONCLUSIONS | 29 |
| | APPENDIX - PRELIMINARY KC-135 TASK ANALYSIS | 30 |

LIST OF ILLUSTRATIONS

| FIGURE | | PAGE |
|--------|---|------|
| 1 | AIR REFUELING TRAINING MISSION PROFILE | 10 |
| 1a | AIR REFUELING TRAINING MISSION PROFILE | 11 |
| 2 | CREW WORKLOADING DURING RENDEZVOUS | 17 |
| 3 | CREW WORKLOADING DURING MISSION CHANGE RENDEZVOUS | 20 |
| 4 | CREW WORKLOADING DURING AIR REFUELING | 23 |
| 5 | CREW WORKLOADING DURING INS CALIBRATION | 25 |

LIST OF TABLES

| TABLE | | PAGE |
|-------|---|------|
| 1 | PERCENT WORKLOAD FOR RENDEZVOUS PORTION OF KC-135 REFUELING MISSION | 13 |
| 2 | LIST OF EMERGENCY OR UNUSUAL OPERATIONS THAT MIGHT OCCUR ON AN AERIAL REFUELING MISSION | 18 |
| 3 | BREAKDOWN OF NAVIGATORS TASK DURING RENDEZVOUS AND MISSION CHANGE DURING RENDEZVOUS | 22 |

SECTION I

INTRODUCTION

The requirement for an Advanced Tanker Cargo Aircraft (ATCA) capable of refueling the C-5 and other aircraft was imposed in an austere economic environment with guidance to procure such a system at the lowest possible acquisition and life cycle costs. At the same time the Federal Aviation Administration (FAA) requirement for more precise navigation over water was imposed for the 1980 time frame. These events made it attractive to the Air Force to procure an off-the-self system that carried more sophisticated navigational equipment such as an inertial navigation system (INS). The DC-10 and 747 commercial aircraft appear to be likely candidates.

There are some obvious differences between these aircraft and the present KC-135 tanker, aside from the size and cargo capacity. In addition to a pilot and copilot the KC-135 has a navigator and boom operator; while the commercial aircraft under consideration have a crew composition of a pilot and copilot, and a flight engineer who is also a pilot. The differences in crew composition are related to the missions of the respective aircraft. On the KC-135 the requirement for the boom operator obviously is tied to the refueling function. The pilot and copilot perform similar functions in both the commercial and military aircraft; however, the navigation duties are largely assumed by the copilot in the commercial aircraft after the flight engineer accomplishes the initial setup of the INS. In addition to the INS setup the flight engineer primarily monitors the various subsystems, e.g., electrical, air handling units, hydraulics, propulsion, and fuel subsystems. The flight engineer's

function on the KC-135 is shared by the copilot and boom operator. There are other functions related to refueling not required on the commercial aircraft that are assumed by the navigator on the KC-135.

If the Air Force is to use a commercial aircraft as an Advanced tanker there will be a function reallocation required to accommodate differences in mission, crew composition, training, and aircraft configuration. Of primary interest in the reallocation of functions is of course the possibility of the navigation function being assumed by the copilot as it is in the commercial aircraft. This would result in considerable reduction in life cycle costs providing that the mission capability remains the same. However, the responsibilities of the navigator are quite extensive; they include not only mission planning and navigation duties per se, but communications during rendezvous and cell formation (several KC-135 tankers refueling several receivers). The KC-135 navigators also have coding and decoding and safe passage procedures during the emergency war order (EWO) mission. Thus, the installation of an INS reduces the overall workload in only the navigation area with the other functions essentially remaining unchanged. Therefore, if we are to eliminate the navigator's position all of his other functions must be assumed.

The purpose of this overall analysis is to determine the minimum crew composition required to accomplish the ATCA mission with minimum change to the crew station of an off-the-shelf commercial aircraft. In order to accomplish this a three phase program was pursued consisting of the following:

1. A task analysis of current air refueling operations in KC-135's to define peak crew workloads, equipment configurations, and crew procedures. A second step in this analysis was the extrapolation of this of this data to an ATCA configured aircraft.

2. In the second phase several mockups of the two principal crew stations were configured in a C-135 simulator shell.

3. In the third phase the Human Factors Branch (ENECC) of the Aeronautical Systems Division, WPAFB, will participate in a flight test called GIANT CHANGE with the Strategic Air Command (SAC). A palletized INS and a minimum crew composition of pilot, copilot, and boom operator will be used. The current report discusses the first phase of the ENECC trade study: the task analysis of KC-135 crew duties, extrapolation to ATCA configured aircraft and refueling flights on KC-135 aircraft. One major goal of this study was to examine in detail the crew duties of the navigator. The increased sophistication of navigation equipment and the current practice of not using navigators on large commercial aircraft have led to a reevaluation of the need for a navigator on a military aircraft. The navigator's responsibilities on current KC-135 air refueling operations and in advanced tanker operations were therefore analyzed in greater detail than duties of other members.

METHODOLOGY

Several sources of data were used to analyze workloads (Phase I) that would be encountered in an air refueling mission using the ATCA.

ENECC completed a task analysis describing the activities of KC-135 Pilot, co-pilot, navigator and boomer in an air refueling mission. The analysis identified and organized in a systematic way the sequential and the interactive activities performed by the flight crew in all phases of flight. The major emphasis in performing a task analysis in the KC-135 aircraft was to identify overall and peak crew loadings. The resulting data were then used to optimally mix man and machine in future modifications to the KC-135 and possible modifications for advanced refueling operations (single or multipoint refueling) on advanced tanker aircraft. A second data source for determining crew workload was a trade study conducted by Douglas on the DC-10. The third data source was a Boeing Task Analysis based on a London/New York commercial flight.

SECTION III

RESULTS

DC-10 DOUGLAS CREW WORKLOAD TRADE STUDY

Douglas conducted a trade study of DC-10/ATCA crew consolidation which involved the analysis of a three-man crew (pilot, copilot/navigator and flight engineer/boomer) and a four-man crew (pilot, copilot, navigator/flight engineer and boomer). In this study they postulated an air vehicle that was equipped with communications, navigation, and rendezvous equipment which would be common to an ATCA configured aircraft system. A complete listing of the equipment is shown in Table 1. A major objective of this effort was to quantify the crew workload during different phases of the mission. Among the factors examined were definition of tasks, task times, and task assignments. A workload analysis as a function of aircraft and aircrew configuration was also included.

To quantify workloads Douglas computed average workload as: ratio of time required to complete a task to the time available for that particular segment. This procedure yields the following formula:

$$\text{Percentage Crew Workload} = \frac{\text{time required}}{\text{time available}} \times 100$$

This formula gives the average time/unit to accomplish a task. For example, a 77% crew workloading would mean that for 77 minutes out of a 100 minute mission segment an operator would be busy accomplishing some required task or tasks. The time available is determined by the mission, aircraft performance, operational environment, or some combination thereof.

Navigation AidsCommunications EquipmentRendezvous Equipment

| | | |
|---------------------------|----------------------|--------------------------|
| Dual INS | HF Transceiver | TACAN Beacon Transponder |
| (2 nm/hr error) | VHF Transceiver | IFF Interrogator |
| Weather/mapping radar | UHF Transceiver-Dual | Transponder |
| VOR (dual) | | |
| TACAN | | |
| ILS-Dual | | |
| UHF ADF | | |
| IFF/SIF | | |
| Autopilot Flight Director | | |

TABLE 1 AVIONICS POSTULATED FOR ATCA (DOUGLAS REPORT)

The time required is dependent on the crew configuration, operational procedures, task time, or some combination thereof. If the time required is greater than the time available then one would obtain a percentage greater than 100. This would indicate an overload situation on the operator or crew member. In this type of situation, the operator must work faster to accomplish all the tasks required, or if that is not possible then some tasks would be omitted. A third alternative could be that the tasks would be completed, but take a longer time than allowed. In the first case, you would have a stressful situation; in the second case you would encounter a degradation in performance; and in the third case you would have a failure to meet some required schedule of events. Any one or combination of events could occur in an overload situation. This problem will be addressed in more detail in the discussion section.

The Douglas workload analysis model was applied to a composite mission scenario which incorporated three rendezvous patterns:

- (1) Rendezvous with ATCA as a receiver
- (2) Rendezvous with B-52's as receivers
- (3) Rendezvous with F-106's as receivers

Included in this refueling mission scenario were modifications to the flight plan to avoid weather or danger areas.

Based on the above mission scenario the following conclusions were drawn concerning crew composition and workload:

- (1) Both three-man and four-man mission crew configurations are physically practicable for the DC-10 ATCA.

(2) Navigation duties can be performed satisfactorily by either a combined copilot (pilot)/navigator or a combined navigator/flight engineer.

(3) Refueling operations can be performed satisfactorily by either a combined boom operator/flight engineer or a separate boom operator.

(4) Refueling missions can be performed satisfactorily by either a three-man or four-man mission crew within acceptable workloads.

The conclusions that a three-man crew could operate the system successfully, based on computer workloading, seems warranted and correct. However, the conclusions are warranted only under conditions of minimal change, and no emergencies, which severely limits the applicability of these results to an operational environment.

The two mission changes programmed to avoid weather and danger areas occurred during air refueling segments. This would be a segment in which the navigator's tasks would be lower and the increased navigation workloading would not have as large an impact on mission success as it might during the rendezvous segment (a period of high navigator workloading). In fact, one of the recommendations Douglas made in their report was that additional trade studies should be performed to include the effects of emergency/contingency conditions. Such an analysis was conducted by ENECC and is described later in this report.

ENECC TASK ANALYSIS BASED ON KC-135 DATA

The task analysis performed by ENECC using the KC-135A mission as a baseline was accomplished in an evolutionary manner. The first step was an appraisal of an existing training task analysis performed by the

Logicon Corporation (Reference 2). This analysis contained much useful information but since its objective was to provide for an instructional system development (ISD), effort it did not provide a time line base to overlay on the crew tasks. This is mandatory for assessing crew task loading. These data, coupled with an analysis of two SAC training films of an air refueling scenario, resulted in a preliminary task analysis contained in the appendix of this report. This preliminary task analysis was then finalized and verified during four air refueling missions flown with the 17th Bomb Wing, located at the time at Wright-Patterson AFB. These four missions were as follows: two B-52 refuelings (SAC mission), one multiple refueling of three F-4 aircraft (TAC mission), and one night drogue refueling of three F-100's (ANG mission). These missions were analyzed from flight planning throughout the mission and continued through debriefing. A pictogram of major events in these Wright-Patterson AFB refueling missions are depicted in Figures 1 and 1a.

Following takeoff and climb-out the tanker proceeds to Falmouth which is the initial navigational check point. As the flight continues towards the air refueling contact point the copilot makes initial radio contact with the receiver at the air refueling initial point (ARIP). This initial contact occurs 15 - 20 minutes prior to the tanker reaching the air refueling contact point (ARCP). The navigator maintains radio contact with the receiver until the receiver and tanker are three miles apart. At that time either the pilot or the copilot handles the communications with the receiver while the tanker is proceeding down the refueling track. As the tanker and receiver approaches the ARCP, the tanker pilot maintains communications as required until the receiver calls 1/2 mile behind the tanker. At that time the boomer assumes tanker communication

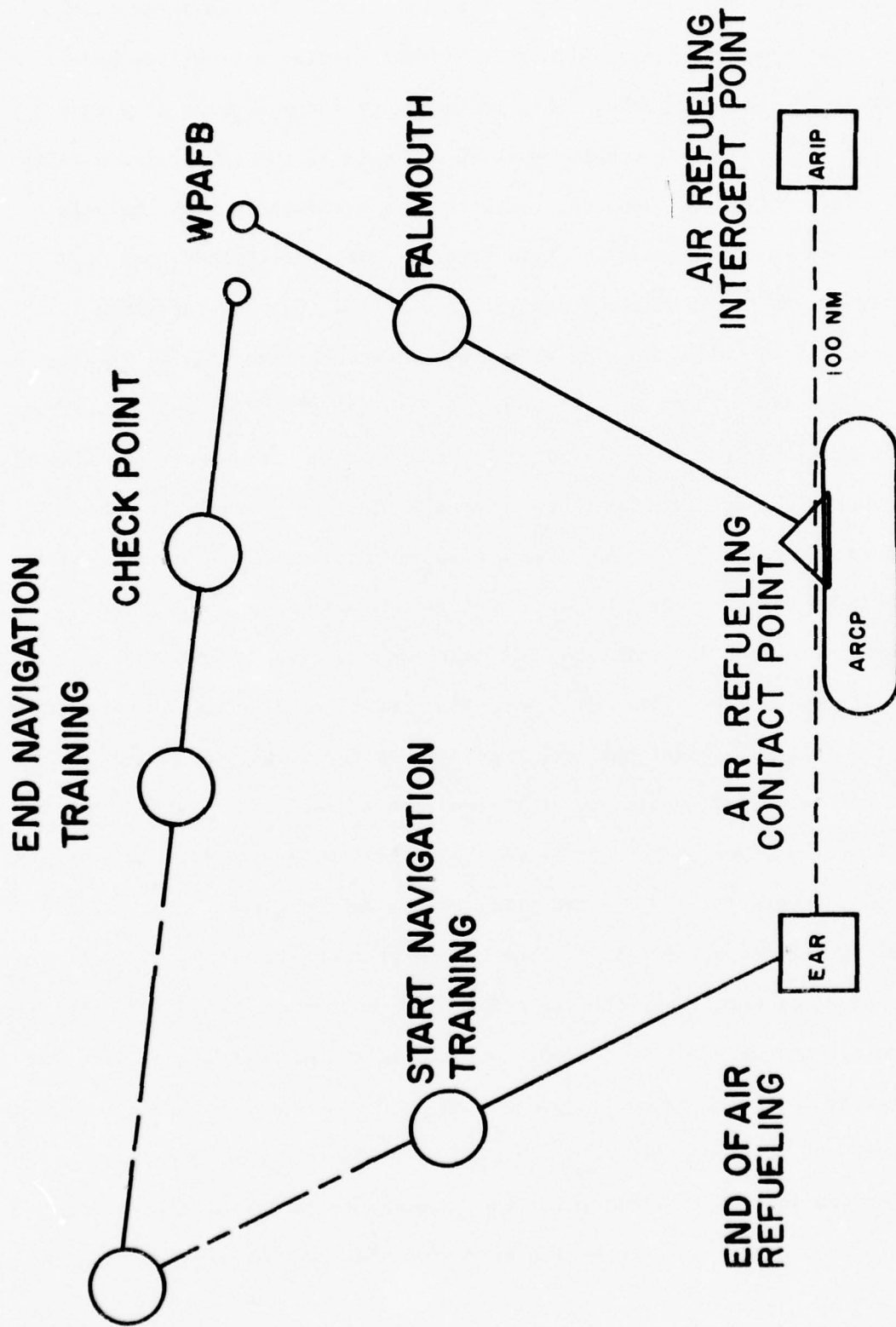


FIGURE 1-AIR REFUELING TRAINING MISSION PROFILE

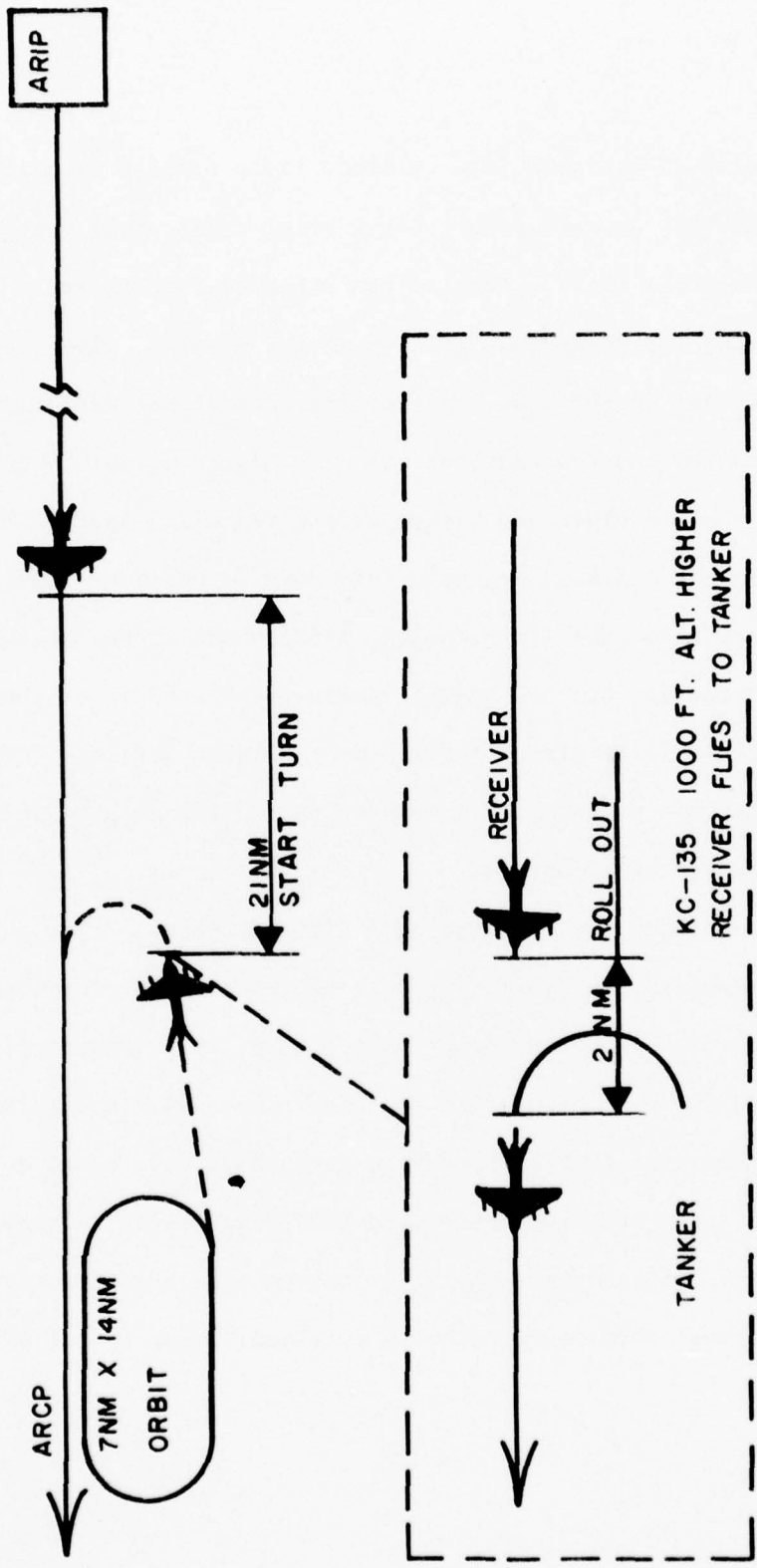
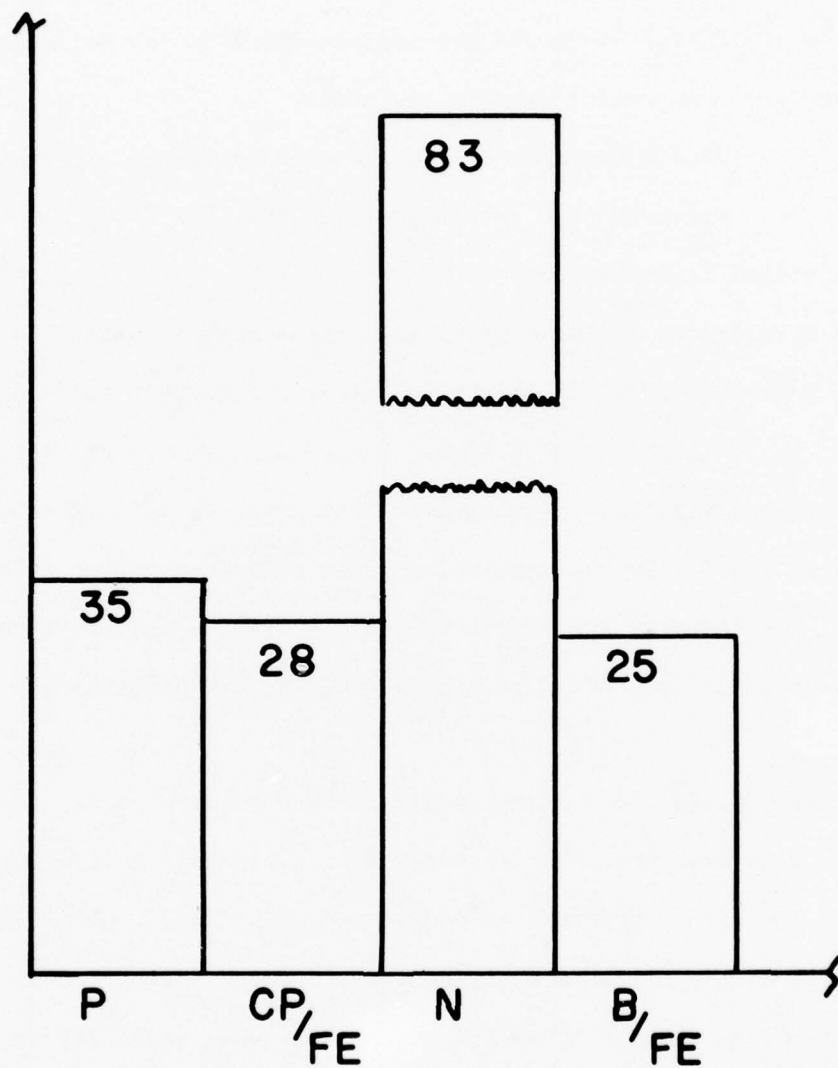


FIGURE 1a - AIR REFUELING TRAINING MISSION PROFILE

responsibilities (See Figure 1a). Minimum radio contact is maintained as the two aircraft proceed down the refueling track until reaching the end of air refueling (EAR). Most of the detailed task analysis was conducted during the rendezvous portion of the mission. The rendezvous portion is defined as the time when initial contact was established between the tanker and the receiver (15 - 20 minutes prior to ARCP) and the time when receiver and tanker were three miles apart. This rendezvous segment consumed approximately 30 - 35 minutes. The rendezvous portion of the air refueling mission was chosen because the successful completion of this segment defines the success of the overall mission. It is also a segment where higher workload for one or more of the crew members would be expected. This is particularly true of the navigator's position.

Figure 2 depicts crew workloading during rendezvous. The method of determining workload was similar to that employed in the workload study discussed earlier. Figure 2 shows the navigator with highest workload at 83 percent and the next highest is the pilot whose workload is 35 percent. It should be remembered this percentage work loading is based on overt task loading, i.e., directly observable behavior. It is apparent that covert behavior (unobservable mental processes) such as decision making, is also occurring; this contributes to workloading but is not objectively measured.



KC-135

TABLE I- PERCENT WORKLOAD FOR RENDEZVOUS PORTION OF KC-135 REFUELING MISSION

BOEING 747 TASK/TRAINING ANALYSIS

The Boeing Task Analysis was based on a London/New York commercial flight. The crew composition included: Captain, First Officer, Flight Engineer and Flight Attendant.

While the Boeing study did not address the ACTA Air Refueling mission it did provide some useful data in two areas:

Flight Engineer duties and task loadings

Operation and updating of the INS

a. Flight Engineer

The KC-135 does not have provisions for a Flight Engineer's Station or a flight engineer (FE). On the KC-135 aircraft the FE's functions are performed by the copilot and boomer. The C-141 aircraft FE is enlisted and has the responsibilities of monitoring the aircraft systems (electrical, hydraulics, etc.). In the commercial fleet this FE function is performed by a pilot. The tasks of the flight engineer in the 747 aircraft were analyzed in terms of which ones could be accomplished by the present crew of a KC-135.

During preflight the flight engineer is working at peak loading. His check-out of interior/exterior portions of the aircraft is similar to functions presently performed by boomer and crew chief. Checkout of the instruments on the flight deck is similar to those activities performed by KC-135 pilot and copilot. The flight engineer also tests and preloads the INS, but does not monitor the system during the remaining flight segments.

During the remaining Flight Segments (take-off, cruise, and landing) the flight engineer task loadings are light using percentage workloadings

reported in the Douglas study. There does not appear to be any unusual or difficult tasks which could not be transferred to other crew members.

b. Operation of the INS

The 747 is configured with a triple INS located in the pilot's and first officer's stations. During Preflight the flight engineer tests the initial calibration of the system and loads present position in INS-1, INS-2, INS-3. The loading of the way points for the route is performed by the first officer. Prior to reaching each way point the Captain and First Officer monitor the Horizontal Situation Indicator (HSI) and Attitude Director Indicator (ADI) for proper inbound course and Omnidirectional Range Radio Magnetic Indicator (VOR-RMI)** for proper heading. Deviations are noted and INS is updated by the First Officer if needed.

While the Boeing study does define the crew task activities during an overseas flight, no information is given as to the task time, stress points, or extrapolation to Air Refueling operations. During air refueling there would be increased demands on radio contacts, (radar monitoring if on a secure mission), and continual updating of orbit times and positions. During air refueling there will also be increased demands on fuel off-load monitoring. Multipoint refueling and weather avoidances are but two additional parameters which could add to this complexity.

** VHF Omnidirectional Range - Radio Magnetic Indicator

SECTION IV
CONSOLIDATED ANALYSIS

As stated earlier one area not investigated in the Douglas ATCA Analysis was emergency or contingency events. This consolidated analysis covers contingency conditions for: (1) emergency or unusual operations for the KC-135 based on in-flight observations, (2) the three-and four-man ATCA crew compositions analyzed by Douglas, and (3) a five-man ATCA aircraft. The five-man crew was analyzed to cover possible special missions where a flight engineer might be carried as absolute insurance of mission success on a standard configuration aircraft with a separate navigator's station.

A contingency or emergency condition on a mission might include one or more of the conditions shown in Table 2. For purposes of this study three events were selected for a more detailed analysis. These were calibration of INS, mission change, and multiple refueling. Of the three selected, the mission change during rendezvous was most extensively analyzed because the successful completion of this segment defines the success of the overall mission. It is also a segment where high workload for one or more of the crew members would be expected. Finally, a mission change event was chosen because it has a high probability of occurring.

Figure 2 shows the workload likely to be encountered during rendezvous for the various crew compositions. The three-and four-man ATCA task loading is based on the Douglas analysis while the five-man task loading was computed by ENECC based on an ATCA configuration. The KC-135 task loading was based on empirical data gathered during various training flights. These data indicate the crew workload is similar in both the four-man ATCA

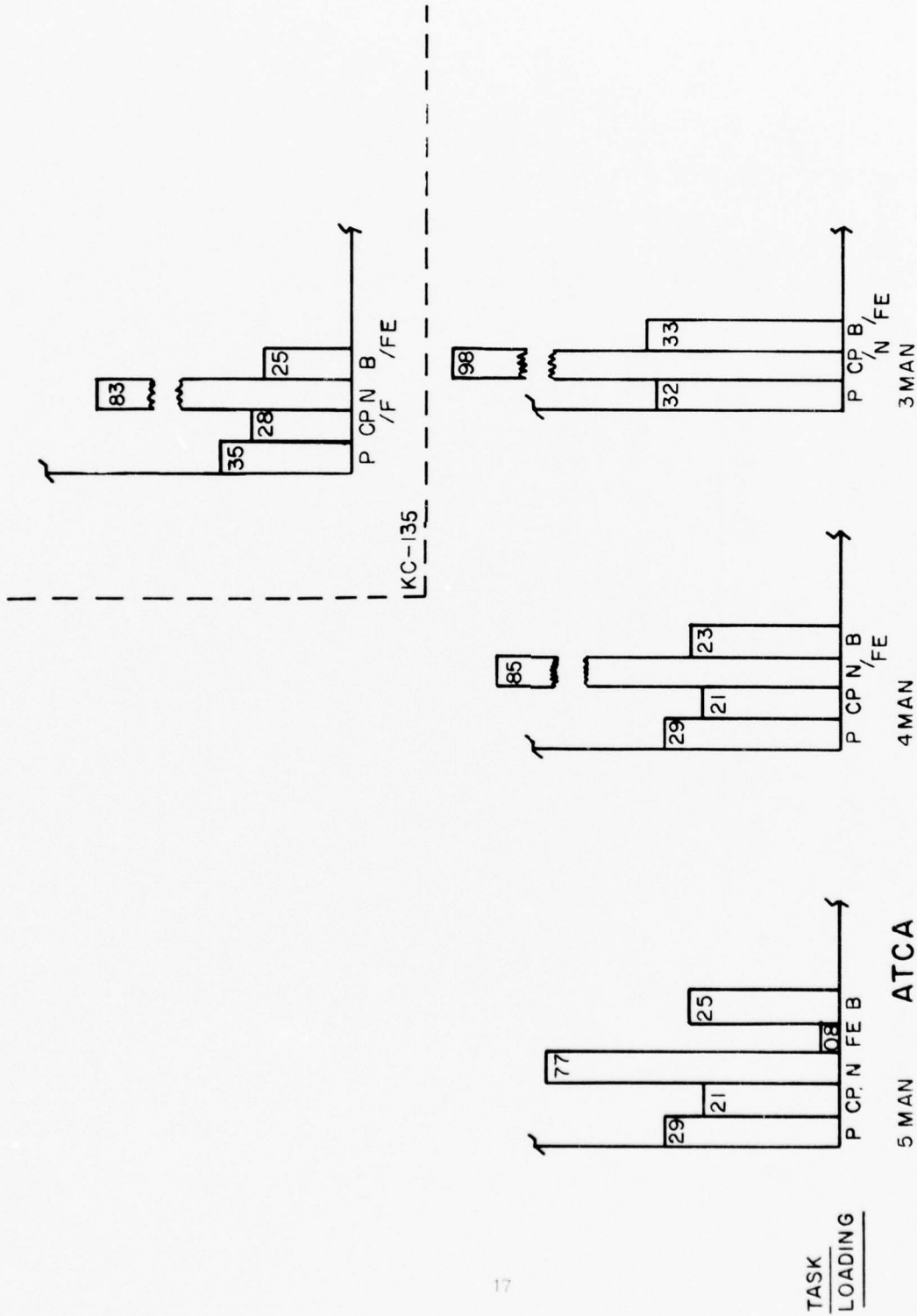


FIGURE 2—CREW WORKLOADING DURING RENDEZVOUS

TABLE 2
LIST OF EMERGENCY OR UNUSUAL OPERATIONS THAT MIGHT OCCUR
ON AN AERIAL REFUELING MISSION

ATCA
EMERGENCY / UNUSUAL OPERATIONS

- ☆ 1. RELOADING OF WAYPOINTS IN INS (AIR)
2. EMERGENCY WAR ORDER (EWO) SCENARIO - MESSAGE TRAFFIC
3. SECURE COMMUNICATIONS
4. WEATHER AVOIDANCE
- ☆ 5. MISSION CHANGE
6. ENEMY INTERCEPT
7. SYSTEM EMERGENCIES
- ☆ 8. MULTIPLE REFUELING

configuration and KC-135 with some minor exceptions. The KC-135 shows a higher task loading on the pilot, copilot, and boom operator than the four-man ATCA configuration. This difference could be attributed to less sophisticated equipment in the KC-135 or the fact that one analysis is theoretical (ATCA) and the other empirical. It is most likely a little of both. The navigator is slightly less loaded in the KC-135 because he does not have any flight engineer's duties assigned as he did in the Douglas study. If we were to extrapolate only navigation duties then the authors estimate the navigator's duties on the four-man ATCA crew would drop to 77 percent as they are shown on the five-man ATCA which carries a flight engineer. It is also estimated that the navigator's task load would drop to a similar figure in the KC-135 if it were equipped with an INS. Thus, if all factors are taken into consideration, four-man ATCA, five-man ATCA, and KC-135 all show similar workloads. When a three-man crew is postulated the combination copilot/navigator has a workload of 98 percent --close to, but within, his capacity. Based on recent observations during a mission flown with SAC a three-man crew in a KC-135 with an INS would have a similar workload figure. In summary, all configurations shown in Figure 3 indicate any of the crew compositions would successfully complete an air refueling mission.

The effects of a mission change during rendezvous were observed by ENECC personnel and based on this data the crew task loading percentages for the KC-135 were recomputed. These percentages are shown in Figure 3, and in the inset of Figure 3, and indicate a 15 to 20 percent increase for the navigator over a normal rendezvous. The task loading for the other crew members remains the same. For the KC-135 navigator this reflects a high task load

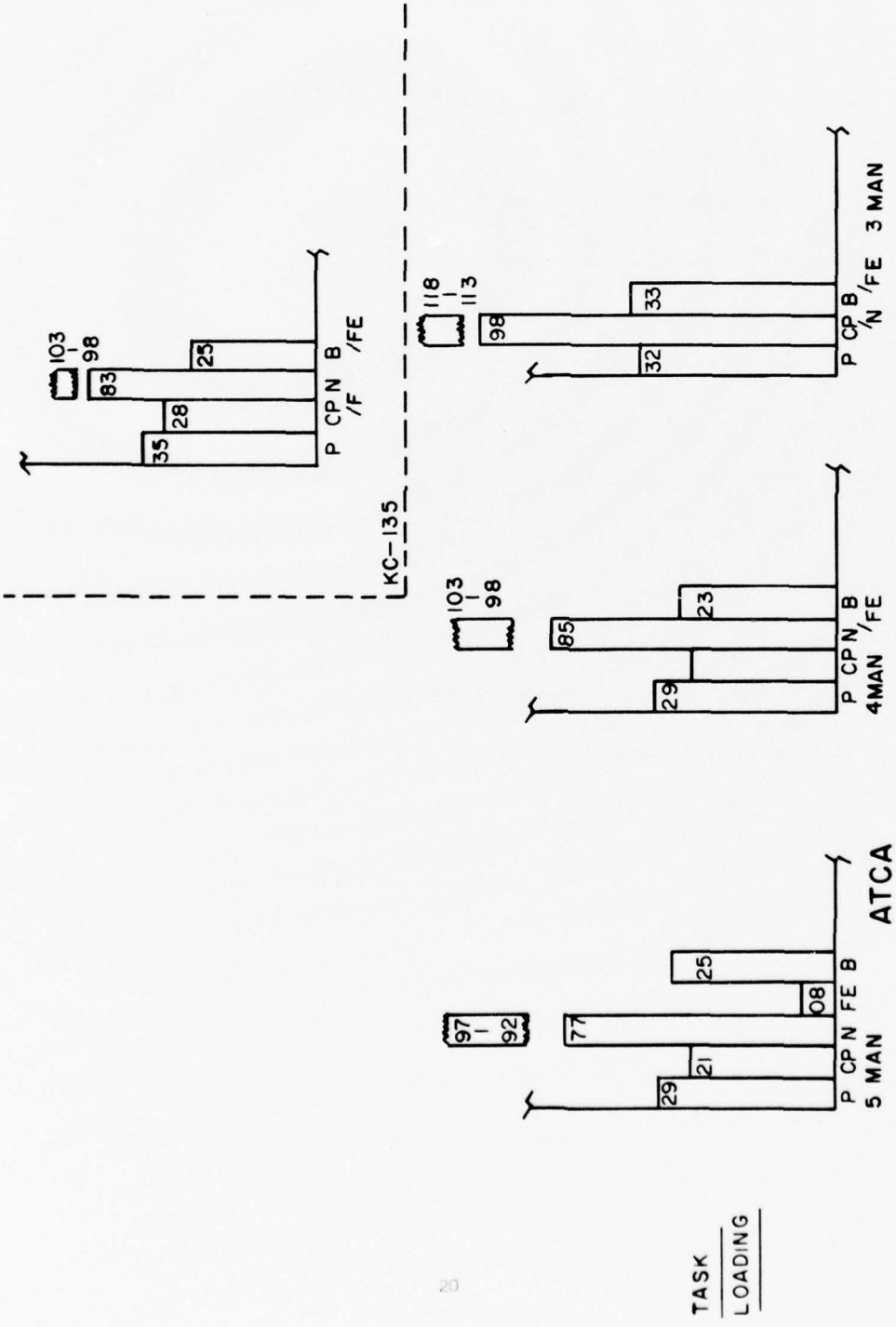


FIGURE 3 CREW WORKLOADING DURING MISSION CHANGE RENDEZVOUS

with some moderate overloading for short periods, this would certainly not degrade the probability of a successful mission. Projecting a 15 to 20 percent increase to the four-man/five-man ATCA, data shows similar workloads and reflects a high probability of mission success. However, when we inspect the three-man ATCA graph we see a task loading of 113 to 118 percent. This indicates an overload and could jeopardize the air refueling rendezvous.

As stated earlier such a task loading could cause the copilot/navigator to drop some task, force him into a stress situation, or cause a schedule slip. An alternative is to relieve the copilot/navigator of some tasks. Figures 2 and 3 show the breakdown of the navigator's tasks for a normal and mission update during rendezvous for the five-man ATCA crew and the three-man ATCA crew. As previously stated, the five-man ATCA crew would reflect a similar workload as a KC-135 with INS. During a normal rendezvous the navigator's workload (when he has no other non-navigation duties) is 77 percent, 35 percent of which is on navigation duties, 31 percent on communications and 4 percent on scanning the INS. He also has a 4 percent workload on flight instrument cross-checks and a 3 percent loading on miscellaneous tasks. When a mission change is required during rendezvous the total task load goes up to 92 percent. As can be seen from Table 3, this causes an increase of 8 percent in navigation tasks, 5 percent in communications tasks and 2 percent in scanning the INS ---all other duties remain unchanged. These increases present no problem for the four or five-man crew, nor a KC-135 with or without an INS, and no function reallocation is necessary. The same increases on the three-man crew take the task loading to an overload percentage of 113. This workload could be reduced to 100 if we could assign some of the increased duties to other crew members. In the case of the increased communications these activities would require little

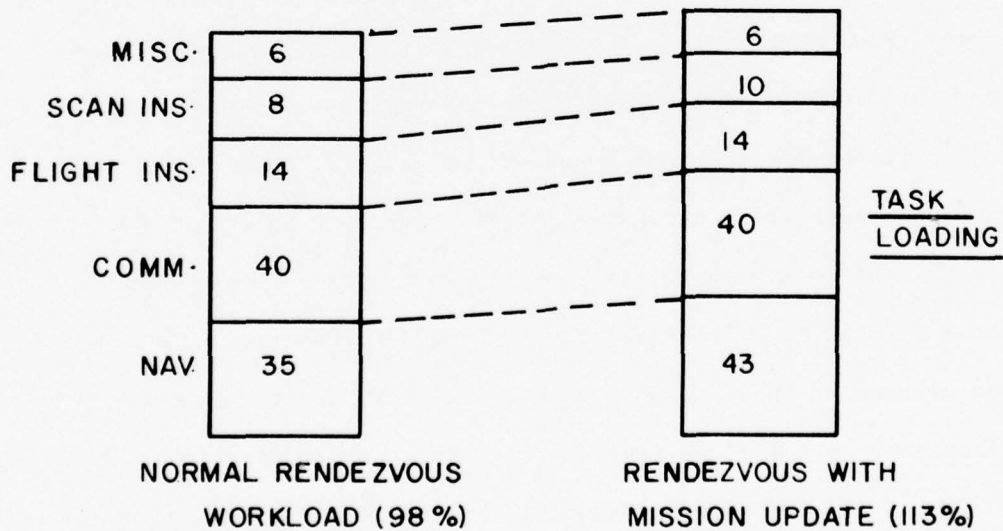
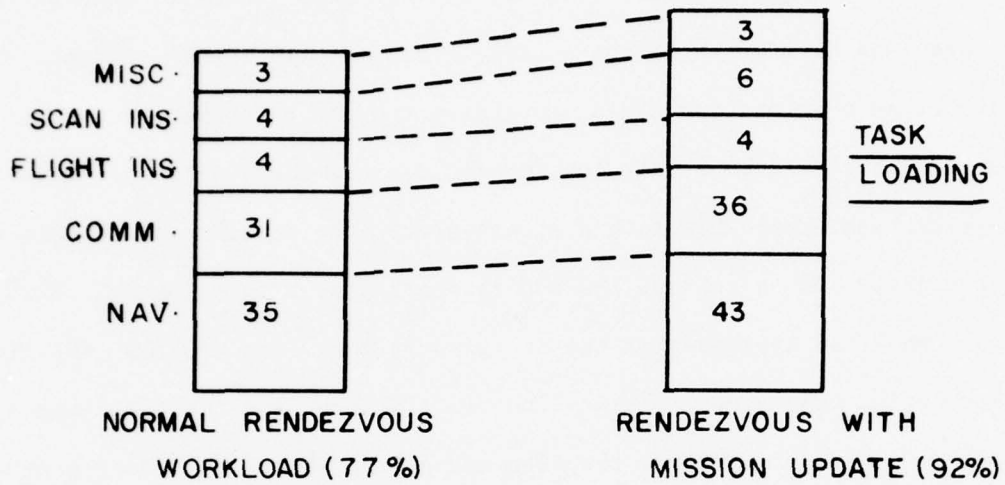


TABLE 3—BREAKDOWN OF NAVIGATORS TASK DURING RENDEZVOUS AND MISSION CHANGE RENDEZVOUS

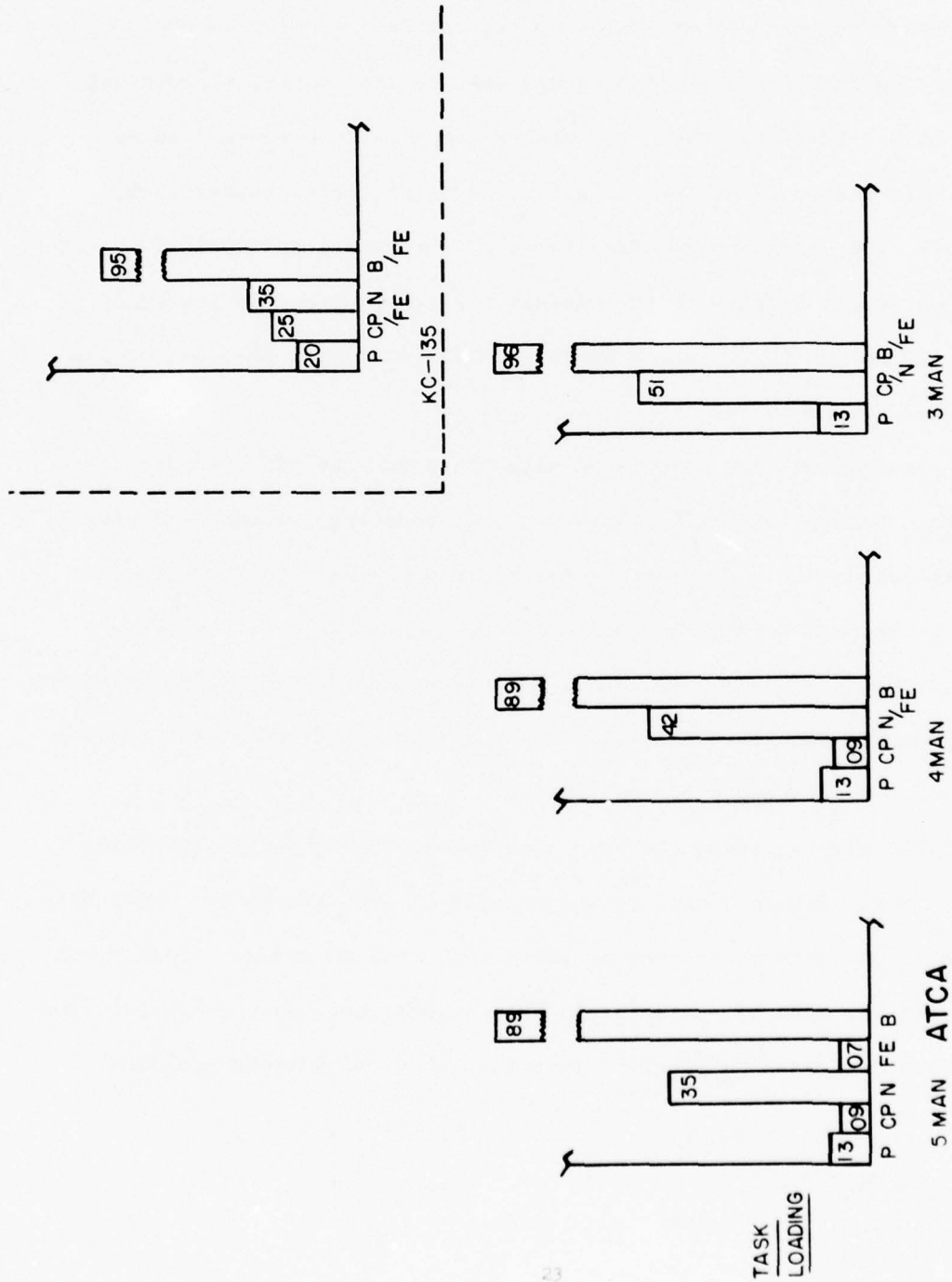


FIGURE 4- CREW WORKLOADING DURING AIR REFUELING

training and could easily be transferred to the pilot. There is an increase of 8 percent in navigation duties during mission change that could possibly be reassigned to other crew numbers. While these additional duties seem minimal they are critical to mission success and in the event of a mission change must be implemented rapidly and correctly. Briefing other crew members on mission changes such as alternate tasks, off-loads, insertion waypoints, etc, is feasible, however, the decisions required to make appropriate and optimal inputs rely on skills already in the navigator's repertoire. Consequently, reassignment of these duties would require additional training of the selected crew members.

A navigation task associated with operating the INS is updating to maintain correct aircraft position. This updating procedure is usually accomplished with a doppler system and is a periodic task which would need to be performed by a copilot in the three-man crew. Celestial navigation is an additional required task now performed by the navigator and boomer. Necessary skills would need to be acquired by the copilot to assume these task responsibilities.

ENECC also analyzed the crew workloading during aerial refueling operations. Figure 4 depicts the results of this analysis. These data are self explanatory and show no particular problem areas. Finally, an analysis was made of an in-flight INS calibration. As one can see from the data presented in Figure 5 this also shows no serious problems.

NONE KC-135

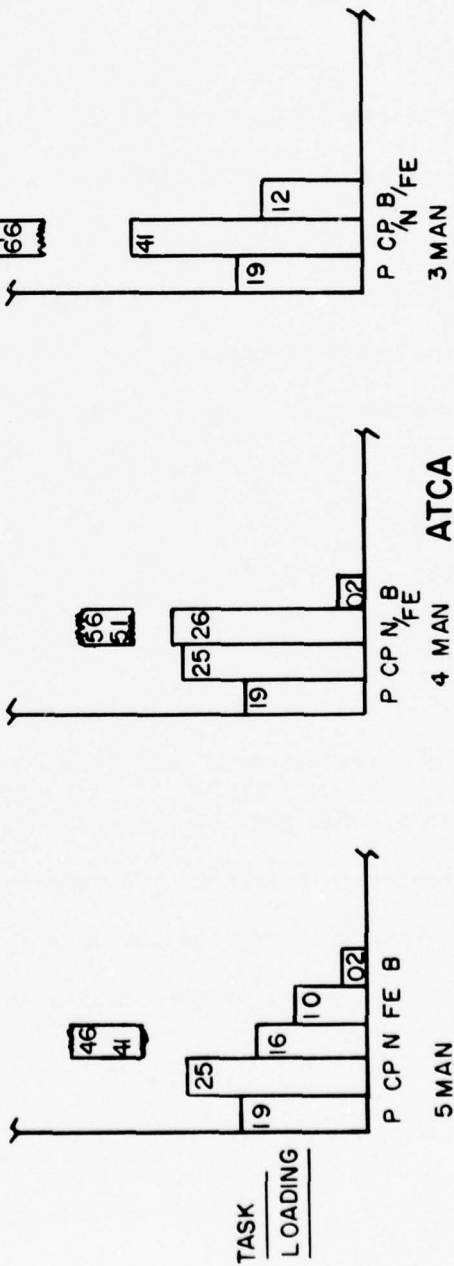
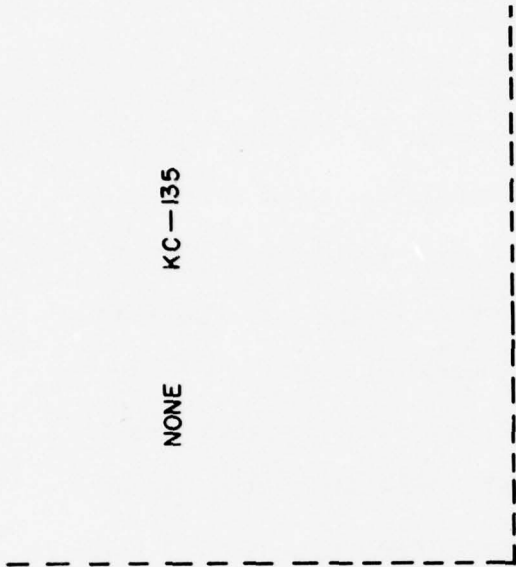


FIGURE 5— CREW WORKLOADING DURING INS CALIBRATION

SECTION V

DISCUSSION

There are a number of problems in treating workloading as an unidimensional factor--a single number indicating percent loading per unit time. This measurement value indicates the amount of activity expended per unit time but does not indicate the quality or difficulty of work during this period. For example, a pilot and a navigator could expend 50% of their time on two unitary tasks such as a rollout on an aerial refueling heading ahead of the receiver (pilot task), or an exchange of a Distance Measuring Equipment (DME) radial with the receiver during a turn (navigator task). These two tasks would require different skills, knowledge, and physical exertion and are not equivalent. Yet they carry the same numerical value in determining task loading. In addition, the level of responsibility inherent in accomplishing specific tasks must be taken into account. While a simple time-line analysis of functions performed would indicate low performance levels for a pilot during a refueling run, the fact that he is in command of a multimillion dollar system servicing several other multimillion dollar aircraft on a critical EWO mission necessitates that he maintain a complete awareness and capability to handle any situation which could arise. These kinds of pressures are difficult to quantify in terms of "switchology" functions. One must be careful when reallocating functions to take such differences into account. A task which loads a navigator, say 25%, when reallocated to a copilot who is not as experienced as the navigator, may generate a loading of 30-35% with this same task.

Another problem which may be encountered in reallocating functions is caused by sequencing of tasks. It is not always feasible or desirable to break up tasks to relieve an overload. For example, if a copilot/navigator must insert a new series of way points it would not be feasible or desirable for the copilot to load half the coordinates and the pilot to load the other half.

Interpretation of workload percentages presents a dilemma. The consequences of overloading are not easily ascertained and there is little research data in this area. For instance, the effects of stress induced by overloading are not always predictable. The scientific literature indicates such stress in some cases enhances performance while in other cases seriously degrades performance, depending on operator characteristics. Furthermore, such stress over a short period can be tolerated but on a continuing basis it slowly leads to degradation in performance which can result in a catastrophic situation.

Overloading frequently leads to an operator working faster with a corresponding increase in errors. These can be either major errors or minor errors occurring at critical times and can also lead to catastrophic situations. These kinds of events may very well increase accident rates but there is no model for accurately predicting such an outcome. Accurate assessment of the effects of these overload conditions can only be obtained through an empirical simulator study.

Another factor that presents a problem in reallocating the navigator's tasks to other crew members is the fact we are dealing with lower experience levels among SAC crews than we have had in the past. With the

energy crunch this experience level may be low for some time to come.

Finally, SAC has indicated the workload increase during an EWO mission may far exceed the 15 to 20 percent figure calculated for a mission change. This will make the overload situation even worse. Also, not included in our task loading figures is the workload associated with coding and decoding on an EWO mission. These problems will be addressed during ENECC participation in "GIANT CHANGE" and are discussed in Technical Report ASD-TR-76-19, A Study of Task Loading Using A Three Man Crew on a KC-135 Aircraft.

SECTION VI

CONCLUSIONS

From the evidence available at this time (the Douglas, Boeing, and ENECC analyses) the following conclusions are drawn:

(1) The four-man ATCA crew consisting of pilot, copilot, navigator/flight engineer, and boom operator is most advantageous in that it is the minimum crew composition which can handle most required crew tasks below 100 percent task loading under all operational conditions. This crew composition affords maximum flexibility for mission change and EWO activities. It also requires the least amount of training required to operate the avionics/navigation systems.

(2) The three-man ATCA crew shows an overload situation in most departures from a standard air refueling mission profile and would appear to generate an unacceptably high workload in the EWO environment. However, further empirical studies under actual or near actual conditions are required to definitively establish the feasibility of a three-man ATCA crew composition. The GIANT CHANGE test program now under way may reduce the uncertainty of such a crew composition.

APPENDIX

APPENDIX

PRELIMINARY TASK KC-135 ANALYSIS

Segment 1 (Takeoff & Climb)

Turn the RGA Power switches to OFF.
(P, CP)

Check SIF/IFF operation with an ATC facility. (CP, N)

Check that the mode 4 caution light is out. (CP, N)

Check mode C operation is ground station is available. (CP, N)

Set altimeters to 29.92 at FL 180. (P, CP, N)

Turn cargo compartment
A/C Master switch to
ON. (BO)

Set radio altimeters. (P, CP, N)

Set temperature control
to AUTOMATIC and tempera-
ture as desired. (BO)

Set radio altimeter MDA index to 2000 feet.
(P, CP)

Set radio altimeter to
ON if applicable. (N)

Check cargo compartment. (BO)

Check that cargo is
properly secured. (BO)

Set radio altimeters to the STANDBY mode
if they fail to move in the RESET Mode.
(P, CP)

Record level-off time.
(N)

Check cargo compartment for fumes. (BO)

Check that APU inlet and exhaust valves
are closed. (BO)

Check boom. (BO)

Check SIF/IFF operation prior to operating
on radar controllable airways or positive
controlled air space. (N)

Take navigation fix at completion of
instrument departure. (N)

Log entries to direct A/C Arcp. (N)

Compute ETA to ARCP. (N)

Plot course to most practical entry to racetrack orbit. (N)

Set EPR for corresponding cruise Mach. (P, CP)

Check cruise altitude (altimeter) at frequent intervals. (P, CP)

Check Mach indicator accuracy. (P, CP)

Convert desired Mach number to IAS. (P, CP)

Adjust EPR to maintain calculated IAW and starting altitude for the gross weight. (P, CP)

Check fuel flow for fluctuations. (P, CP)

Perform fuel icing function when icing is suspected. (P, CP)

Periodically vary the throttle setting to dislodge ice particles if fuel icing is suspected. (P, CP)

Periodically determine center of gravity using stabilizer trim wheel. (P, CP)

Know and execute standard log and chart procedures. (N)

Record adequate information to permit accurate reconstruction of the mission. (N)

On a fix line in the log record proper symbol, time, and information to compute a wind and ETA. (N)

For a DR position, record adequate information to justify the position. (N)

Use check marks only to indicate NO CHANGE from previous entry. (N)

Indicate on the log the source of each wind used if other than doppler. (N)

Record unplanned altitude changes at the point where they occur. (N)

Indicate all positions in the log on the chart. (N)

Compute and use deviation on long straight legs over water. (N)

When deviation is computed and used, record corrected magnetic heading in log. (N)

(Recommended) Use two log lines to record a planned turning point. (N)

Record pertinent observations on the chart or log at the time they take place. (N)

If concerns weather tune in APN 59. (N)

Monitor UHF scheduled A/R frequency. (P, CP, N)

Monitor HF back-up A/R frequency. (N)

Plan track to pass over ARCP enroute to ARCP.
(N) (Point Parallel)

Determine Heading by using: (N)

N-1 compass.

T. S.

G. S.

DR

Time (ETA)

ASN-7

Contact ARTC clear to Falmouth. (N)

Give pilot crew heading and station passage. (N)

30 min prior to ARCT
15 - 20 prior to
orbit. (Rx)

Establish operability of Rz equipment
30 minutes prior to control time. (P, CP, N)

25 min prior to ARCT
establish radio contact
with Rx.

Check to determine correct tanker. (Rx)

30 min prior to ARCT

Determine compatibility
of Rz equipment.
(P, CP, N)

Establish radio contact
with Rx. (N)

Facilitate Rx's
identification of tanker.
(N)

Place APN-69 to STANDBY.
(N)

Place APN-69 to OPERATE.
(N)

Segment 2 (Cruise & Initial Contact with Rx)

Exchange A/R data with Rx. (N)

Confirm Rx ETA to ARIP. (N)

Report any alternate plans to Rx
as soon as possible. (N)

Designate alternate Rz area in case
of weather. (N)

Report information on avoiding
Hazardous weather. (N)

Confirm Rz equipment to be used. (N)

Delay 10 minutes if Rx is late and
no radio contact has been established. (N)

Delay entering orbit
if no contact with
receiver.

Two minutes prior to orbit determine
orbit pattern. (N) _____

Establish the orbit pattern. (N)

Attempt to establish visual contact
if Rx is early. (P, CP)

Log a fix or position at orbit entry
point. (N)

Complete required log entries. (N)

Obtain current wind data. (N)

Use of current wind data to
complete orbit lines of log. (N)

Plan arrival in orbit 15 minutes
ahead of ARCT. (N)

2 min after orbit _____ 2 min after orbit
Establish electronic contact with Rx. (N) _____ OR _____ Transmit blind

10 minutes prior to
ARCT if no contact is
made. (N)

Use airborne beacon to establish
contact with Rx. (N)

Flash Rz beacon 10
minutes prior to reaching
the ARCT if no contact
has been made. (N)

Jettison fuel if
necessary to establish
contact with Rx.
(CP, BO) (visual aid)

Facilitate Rx's identification of tanker.
(N)

Place APN-69 to STANDBY. (N)

Check to determine
correct tanker. (Rx)

Place APN-69 to OPERATE. (N)

30 min prior to ARCT

Determine if Rx has APN-69 beacon. (N)

If Rx has APN-69, switch APN-59
to BEACON. (N)

Make positive identification of Rx. (N)

ON/OFF to confirm

Confirm A/R altitude to be used, and other
information required. (N)

Notify Rx of any change in ARCP. (N)

Confirm altimeter setting of 29.92. (N)

Confirm number of tankers. (N)

Determine Rx inbound drift. (N)

Confirm off load. (N)

Confirm A/R heading. (N)

Confirm/determine visibility conditions
for A/R. (N)

Segment 3 (ARIP Arrival & Departure)

Acknowledge 100-nm range call from Rx. (N) _____ 100nm (Rx in ARIP)

Acknowledge that Rx is departing
ARIP at approximately 100 nm. (N)

Acknowledge 90-nm range call. (N) _____ 90

Acknowledge 80-nm range call. (N) _____ 80

Acknowledge Rx is beginning
descent at approximately
80-nm. (N)

Acknowledge 70-nm range call. (N) _____

Turn reciprocal of Rx inbound track at 70-nm range call. (P, N)

If heading is not recipricol,
execute left turn, 30 bank. (P)

Main tain heading if correct.

Acknowledge 60-nm range call. (N) _____

Acknowledge Rx level-off at
below base A/R altitude. (N)

Check operation of AN/ARA-25 UHF/DF. (P, N)

Use orbiting tanker's
AN/APN-69 beacon for Rz. (BO)

Use bomber's AN/APN-69 beacfor backup.
(N) (Tanker using boomer)

Acknowledge 50-nm range call. (N) _____

Continue to monitor Rx beacon. (N)

Inform Rx of UHF/DF check prior to 40 nm. (N)

Request tone button or mike switch
without talking. (N)

Acknowledge 40-nm range call. (N)

Acknowledge 30-nm range call. (N)

Acknowledge 25-nm range call. (N)

Acknowledge position
from Rx calls.

Approximately 5 min prior to 21 nm (turning to inboard track)

Boomer starts the following activities:

Begin Preparation for Contact
checklist by changing from
forward to aft duty station. (BO)

Turn O₂ OFF, forward
station; set for 100%. (BO)

Plug into portable O₂ bottle
to transfer to aft duty
station. (BO)

Remain connected to walkaround
portable O₂ bottle, as desired. (BO)

OPTION FOR BOOMER - Turn O₂
ON at aft duty station and
set A/R O panel for 100%

Open sighting door to enable
location of Rx as soon as possible.

Turn to inbound ARCP track at computed turn range. (P, CP, N)

Start inbound turn. (P) (distance variable).

Segment 4 (Air Refueling)

Turn to inbound track at UHF/DF bearing of 26 left heading if using ARA-25. (P)

Turn to inbound track at slant range of 21 nm if using TACAN/VORTAC DME. (P)

Note that A/A TACAN reads 21 nm before executing turn. (P)

If necessary for manual boom operation, test signal coil. (BO)

Place telescope-at-disconnect switch as desired. (BO)

Know to place telescope-at-disconnect switch to MANUAL for FB-111 fighters or Rxs without disconnect capability. (BO)

Notify Rx that inbound turn is starting. (N)

Exchange DME/radial information with Rx during switch to AUTOMATIC for inbound turn. (N)

Set extension and elevation switches to ACTIVE. (BO)

Place emergency override switch in OVERRIDE. (BO)

AS REQUIRED-Checks
"Good" use normal -Checks
"Be use override

Call Rx for visual sighting attempt when halfway through turn. (P)

Turn receiver director light switches to ON and FULL for day, DIM for nigh A/R. (BO)

Continue to acknowledge
range calls: 20 nm,
19 nm - 3 nm. (N)

Lower and check the
boom. (BO)

Notify pilot "BOOM
COMING DOWN" and lower
boom. (BO)

1. Place rudder control
stick in NEUTRAL. (BO)
2. Place hoist level in HOIST
to raise boom for
unlatching. (BO)
3. Move boom latching level to
UNLATCH to unlatch boom.
(BO)
4. Place telescope-at-disconnect
switch to MANUAL. (BO)
5. Place emergency override
switch OVERRIDE. (BO)
6. Completely lower and fully
extend boom. (BO)

LOCKED RUDDEVATORS

Know that steps 1 thru 6
must be repeated twice to
free ruddervators if they
remain locked. (BO)

Know procedures for
unlocking ruddervators
if eating steps 1 thru 6
fails to unlock them.
(BO)

1. Place hoist level in
RAISE. (BO)
2. Hold rudder control
stick full up. (BO)
3. Place hoist level to FREE
WHEEL while holding
ruddervator control stick
up. (BO)

4. Lower boom to trail and extend 10 feet. (BO)

Check boom operation and controls for instability within operating envelope ($30^\circ \pm 2^\circ$ lower, 12° R or L azimuth, and $18^\circ - 45^\circ$ elevation.) (BO)

Determine if boom lags or leads controls. (BO)

Determine requirement to use 3° L or R azimuth on contact. (BO)

Do not cycle sighting door with hoist lever in RAISE. (BO)

Limit boom azimuth movement to 20° or less. (BO)

Assume communications with Rx at 3 nm. (P)

Set TACAN to A/A, if required, using channel which was assigned with A/R track. (P or CP)

Turn radar/Rz beacon to OPERATE (or leave in Operate) if visibility is bad when Rx is 3 nm in trail. (N)

Return command radio to A/C pilot when Rz is complete with Rx 3 nm in trail. (N)

Acknowledge receiving command radio from navigator (Rz complete/Rx 3nm in trail). (P)

Resume radio communications with Rx A/C. (P)

Segment 5 (Refueling)

Notify pilot "GOING TO
COMMAND." (BO)

1/2 nm (Takes approximately 5 min
for boomer hookup 2-5 fighter)

Continuously monitor interphone at all times during A/R unless specific
duties interfere. (BO, P, CP, N)

Establish contact with Rx
pilot. (BO)

Turn underbody, underwing, and
nacelle lights to DIM or as
desired by Rx pilot. (BO)

Notify Rx pilot to stabilize in
precontact position. (BO)

Notify Rx pilot that he is
cleared to contact. (BO)

Clear Rx to contact position only
when it is clear that Rx is in a stable
precontact configuration. (BO)

Request Rx pilot to restabilize
in precontact if necessary. (BO)

Request Rx pilot to note his
altimeter reading. (BO)

State "CONTACT" to the Rx pilot
when contact is established. (BO)

Acknowledge Rx pilot's contact
acknowledgement. (BO)

Monitor BO-Rx calls. (CP)

Monitor CONTACT MADE light
on pilot instrument panel.
(CP)

Transfer fuel by turning A/R
pump switches to ON. (CP)

Record initial contact time
and position. (N)

Monitor offload totalizer
guage. (CP)

Cross check totalizer
against tank guages. (CP)

Use tank guages as primary
reading of amount of fuel
transferred. (CP)

EARLY DISCONNECT PROCEDURES

Know procedures in case of disconnect
before completion of A/R. (BO)

Advise Rx to back off 5 feet. (BO)

Actuate disconnect switch. (BO)

Retrack boom to 15 feet, then
fully extend. (BO)

Notify Rx when ready for new
contact. (BO)

Say ("call sign) READY." (BO)

Notify Rx pilot of
any excessive spillage
or fuel leak upon
contact. (BO)

If siphon occurs (excessive fuel escaping), discontinue A/R. (P, CP, BO)

Turn A/R pump switches OFF upon
completion of fuel transfer. (CP)

Record amount of fuel transferred. (CP)

Record number of contacts and A/R time. (P or N)

Record radio contacts during A/R. (N)

Inform BO "OFFLOAD COMPLETE"
when the offload fuel amount
has been transferred. (CP)

Inform Rx "OFFLOAD COMPLETE." (BO)

Acknowledge Rx reply
"OFFLOAD COMPLETE." (BO)

Accomplish disconnect. (BO)

Acknowledge Rx call for disconnect
"GIVE ME A DISCONNECT." (BO)

Inform Rx pilot "DISCONNECT (on
my count of three)." (BO)

Monitor Rx confirmation of
DISCONNECT. (BO)

Notify Rx pilot that dis-
connect is complete only
after visual confirmation.

Provide Rx when ARIC,
frequency, and instructions. (N)

Provide Rx with position at the
completion of A/R, if requested. (N)

Provide Rx with any additional
information as requested. (N)

Turn radar/Rz beacon OFF. (N)

Reset or turn OFF TACAN (AN/ARN-90)
if Q mission. (N)

Reset and monitor radios. (N)

DISCONNECT

Retract boom. (BO)

Know to avoid excessive retraction
rates if telescope-at-disconnect
switch is in MANUAL upon
disconnect. (BO)

Know that the boom must be wetted down after
five dry contacts if additional contacts are requested. (CP, BO)

Actuate the contact simulation
switch. (BO)

Turn A/R pumps ON. CP)

Record final disconnect
time and position. (N)

Complete Post Air Refueling Report. (CP, N)

Provide Rx with the amount
of fuel transferred. (CP)

_____ PRIOR TO THIS, NAVIGATOR CONTACTS ARTC CENTER _____