Multipoint Aerial Refueling

A Review and Assessment

Paul S. Killingsworth

NATIONAL DEFENSE RESEARCH INSTITUTE

RAND

Commission on Roles & Missions of
The Armed Forces

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Prepared for the Commission on Roles & Missions of The Armed Forces

PREFACE

A continuing discussion is taking place within the military force-projection community on the merits of multipoint aerial refueling. A number of studies have been done on the subject, using varying operational scenarios and assumptions. The work described in this documented briefing reviews five of these past studies to determine whether any general conclusions can be drawn.

This work is part of a larger effort undertaken by RAND at the request of the Commission on Roles and Missions of the Armed Forces, which sponsored the research. The Commission was created in 1993 by Congress to review and evaluate "current allocations among the Armed Forces of roles, missions, and functions" and to "make recommendations for changes in the current definition and distribution of those roles, missions, and functions" (National Defense Authorization Act for FY 1994, *Conference Report*, p. 198). As such, the document should be of interest to those Air Force and other U.S. military personnel, analysts, policymakers, and operational commanders who are broadly concerned with the employment of forces and with aerial-refueling operations in particular. The work was conducted in the National Defense Research Institute, a federally funded research and development center supported by the Secretary of Defense, the Joint Staff, and the defense agencies.

The objective of RAND's larger effort is to provide analytic support to the Commission's deliberations. The Commission does not necessarily endorse the options presented, the methodology involved, or the discussion contained in this documented briefing. This documented briefing represents one of many inputs provided to inform the deliberations of the Commissioners, who applied their own experience and judgment in arriving at the conclusions and recommendations that are found in the Commission's final report, *Directions for Defense.* The views expressed in this documented briefing are those of the author and do not necessarily reflect the opinions or policies of the sponsors.

CONTENTS

SUMMARY

The United States Air Force currently relies principally on boom-and-receptacle technology to conduct aerial-refueling operations for fixed-wing aircraft. With this approach, a single aircraft at a time may be refueled behind a tanker. An alternative concept, called *multipoint aerial refueling*, uses probe-and-drogue technology to enable more than one fighter aircraft to aerially refuel simultaneously from a tanker. Advocates of a transition to multipoint aerial refueling describe multipoint's benefits as follows: greater flexibility and interoperability of U.S. forces, and the possibility of budgetary savings resulting from the smaller tanker inventory that could be required.

Several studies in recent years have addressed the efficacy of multipoint aerial refueling for fighter-employment operations. Not surprisingly, since each study used different analytic approaches and assumptions, the results of the studies have varied. I reviewed five of these studies to understand the reasons for the differences among them and to determine whether any general conclusions could be drawn about the desirability of equipping U.S. tanker aircraft with the multipoint aerial-refueling capability.

STUDY REVIEWS

The first study I reviewed was conducted at RAND in 1990. Its purpose was to examine options for enhancing the effectiveness of the existing tanker force so that a perceived shortfall in capability could be ameliorated. It concluded that multipoint aerial refueling has great potential and recommended further study to evaluate its cost and engineering feasibility. The study evaluated the number of tankers required to support fixed numbers of fighters in three scenarios under single-point and multipoint conditions, using a range of employment tactics. The possible reductions in theater tanker requirements ranged from 30 to 50 percent. The study helped to focus attention on probe/drogue technology as an alternative with potential to enhance tanker force effectiveness.

As recommended by the RAND work, the Air Force in 1991 and 1992 conducted its own studies of the cost and effectiveness of multipoint. Some of the assumptions made by the Air Force Studies and Analyses Agency (AFSAA) in these studies were less favorable to multipoint than

those used by RAND. In particular, AFSAA used higher overall fuel-transfer rates, as well as relatively higher rates for transfers using the boom/receptacle than using the probe/drogue transfers. Since fuel was transferred more quickly in the AFSAA analysis, the time and distance limitations inherent in the scenarios were less constraining, making the additional offload points offered with probe/drogue technology less of an advantage.

Even with these different assumptions, AFSAA found that, with multipoint, 20 to 30 percent fewer tankers were needed to support the types of fighter-employment scenarios examined in the RAND study. The AFSAA study noted, however, that multipoint is only an advantage in "boom-limited" situtations, in which the number of fighters that can be employed are limited by the offload points available on the tankers—situations that often occur early in an air campaign, when the high tempo of fighter sorties makes the number of fuel-offload points in the air a limiting factor.

In 1993, the Air Mobility Command (AMC) conducted a study of the numbers of multipoint-equipped tankers needed to support Navy carrier-based operations during a contingency. Their study focused just on support to Naval operations, with their relatively small numbers of probe-equipped fighters, so that a direct comparison with the other studies was problematic. Because the scenarios used were not boom-limited, the AMC study showed little advantage to having multipoint-equipped tankers.

Also in 1993, the General Accounting Office (GAO) published a report that criticized the AFSAA and AMC studies and that supported the earlier RAND work. Specifically, the GAO questioned the higher fuel-transfer rates used in the AFSAA study and endorsed the advantages of multipoint to enhance the flexibility and interoperability of U.S. forces. The GAO urged that the DoD standardize its aerial-refueling operations on probe/drogue technology.

Finally, in 1995, Frontier Technology, Inc., conducted for the Air Force a cost/benefit analysis of the multipoint-refueling program. In contrast to earlier studies, which mainly looked at limited numbers of fighters flying to specific targets, the Frontier study addressed the multipoint issue from the perspective of an entire theater of operations. The study found that if all tankers were multipoint drogue-equipped, theater tanker requirements could be reduced 17 to 37 percent during a major contingency.

Despite the commonly held view that the conclusions of studies on multipoint have varied widely, and in accordance with organizational biases, I perceived a consensus on some issues. Clearly, the measured advantages of multipoint for reducing theater tanker requirements varied—from a low of 17 percent in the Frontier study under certain conditions to the theoretical maximum of 50 percent in the RAND study. The range of findings originates in the different scenarios and assumptions used in each study.

When viewing the studies as a whole, however, it is not unreasonable to make the following generalization: Under certain circumstances multipoint aerial refueling clearly has the potential to reduce the numbers of tankers needed to support particular fighter-employment operations. This is especially true in the initial days of an air campaign, when the high rate of fighter sortie generation makes the additional offload points advantageous. Although such circumstances are apparently uncommon, some planners consider them to be the most important scenarios for planning aerial-refueling operations. Multipoint tankers could also be important in the event of a second MRC, which would thinly stretch the tanker force over two theaters of operation and create more boom-limited situations.

In addition to sometimes reducing the number of tankers required, all of the studies agreed that equipping existing tankers with multipoint capability would enhance the operational flexibility of the tanker force, as well as the interoperability of Air Force, Navy, Marine, and allied fighter forces.

GULF WAR ANALYSIS

One of the contentions of those who advocate multipoint aerial refueling has been that boom-limited conditions are quite common during theater fighter-employment operations. If this were true, multipoint would have greater implications for tanker force structure, since the technology would enable almost all operations to be conducted with fewer tankers deployed to the theater.[1] From the accounts of those who planned the operation, it is clear that the intensive first three days of the Gulf War air campaign were indeed boom-limited. After that initial surge effort was over, the air campaign entered a period of more-sustained combat operations. On day D+32 of the war, however, the number of tanker sorties supporting fighter operations surged to 30 percent above the levels of the previous several weeks, in preparation for the ground phase of Desert Storm to commence. Except for the first days of the air campaign, this was the highest point of

[1]Even if it were *not* true, multipoint would still offer advantages during those exceptionally stressing times in which boom-limited conditions do prevail.

tanker employment during the war. Did boom-limited conditions occur on this day as well?

I examined the air tasking order (ATO) for tanker operations for day D+32. A boom-limited situation would have been indicated by the close scheduling of tankers and fighters for meeting the needs of a strike plan limited by the availability of offload points in the sky. If the operation was boom-limited, an additional hose on each tanker would have made possible either the use of fewer tankers or the refueling of more fighters. My analysis indicates that of 214 tanker sorties flown on that day, only 21 could have been deleted by combining fighter packages behind fewer tankers. Further analysis indicates that only one of these combinations would actually have *required* multipoint capability. The others could have been accomplished with the existing single-point boom/receptable approach; however, they were not, apparently for operational reasons.

Although this analysis of a single day of tanker operations failed to support the proposition that boom-limited conditions occur frequently, it says nothing about the value of multipoint during those critical times in which such conditions *do* occur. As indicated earlier, a less permissive air campaign environment or the commencement of a second MRC could make aerial refueling a frequent limiting factor on operations. These possibilities should be studied further and considered carefully before making a decision about whether to equip U.S. tankers with wing-tip drogue pods and future U.S. fighters with probes.

ADDITIONAL OBSERVATIONS

In the course of reviewing the five studies and examining the Desert Storm tanker ATO, I made the following related observations:

Fighter Retrofits

If the population of probe-equipped fighters could be increased in the U.S. inventory, the benefits of multipoint-refueling operations would more likely be realized. However, the USAF F-16s and F-15s that are candidates for retrofits with probes are already quite old and are scheduled to leave the inventory within 10 to 15 years. By the time a retrofit program was completed for almost 3,000 fighters, and over 500 KC-135s were outfitted with drogue pods, the F-22 and JAST (Joint Advanced Strike Technology) aircraft would be entering the inventory. Given this situation, a program to retrofit large numbers of current U.S. fighters with probes is probably inadvisable, but the apparent advantages of multipoint aerial refueling indicate that the installation of probes on follow-on fighter aircraft should be considered.

Planning Tools Should Be Improved

The GAO noted in their review of Gulf War tanker operations that much fuel taken aloft by tankers was returned to the base unused or dumped. This finding indicated to them that there were either more tankers in-theater than needed or that operations were constantly boom-limited as opposed to fuel-limited. The evidence actually shows that boom-limited periods during the Gulf War were quite rare, as well as brief in duration. After-action reports indicate to me that the situation observed by the GAO probably resulted more from the high degree of uncertainty with which operational planners were coping than from the limitations of the current single-point refueling system. Planners scheduled additional tanker missions to ensure mission success. With better, automated planning tools, the planners might have been able to schedule fewer tanker sorties, making more-efficient use of fuel.

Advantage for Naval Aviation

Since the Navy and Marines own the probe-equipped fighters in the U.S. inventory, they would benefit most from additional multipoint drogue-equipped tankers. Many observers believe that the effectiveness of Naval aviation during the Gulf War was limited by the availability of KC-135s equipped with drogue adapters for their booms. In addition, the proximity of aircraft carriers to target areas makes possible aerial-refueling tactics such as anchorpoints, which, acting as "gas stations in the sky," are advantageous when used with multipoint. Nevertheless, the Navy has yet to state a clear requirement for drogue-equipped tankers.

Program Difficulties

In the absence of clear advocacy for multipoint, programs to equip KC-135s and KC-10s with drogue pods have repeatedly had their funding preempted and drawn out in favor of programs with higher priorities, such as the purchase of precision-guided munitions and the upgrading of cockpit avionics so that fewer crew members are needed. The current plan is for 33 KC-135s to be equipped with wing-tip drogue pods. Planners have stated that such a limited number of drogue-equipped tankers will be dedicated to the support of Navy and Marine operations.

CONCLUSIONS

The differences in the results of the studies I reviewed stem from the range of employment scenarios and force structures used in the analyses. These differences led to varying assumptions about the key analytic parameters. However, considering the studies as a whole, I interpret their conclusions as being in agreement on some key issues.

In particular, it is clear that having more than one offload point on a tanker aircraft during very-high-intensity fighter operations can be an advantage. The studies also agreed that multipoint refueling using probe/drogue technology would contribute to operational flexibility, as well as to improved interoperability with Naval and allied forces.

However, the operational realities of fighter and tanker employment, as well as the two-MRC strategy, appear to limit the potential of multipoint for bringing about actual reductions in tanker force structure. Future major contingencies will continue to require such tanker tactics as track operations, which mitigate the potential benefits of multipoint by making boom/receptacle operations often just as efficient as multipoint operations. In addition, allowing for the possibility of another near-simultaneous MRC, tanker forces could well be stretched quite thinly, especially boom/receptacle tankers. Although standardizing on multipoint probe/drogue technology would improve the situation by increasing the effectiveness of the tanker force, it is still unknown whether multipoint could increase that effectiveness so that fewer KC-135s would be required in the inventory.

Although the possible effects of multipoint on tanker force structure are still unclear, it *is* clear that multipoint offers the advantages of improved flexibility and interoperability. If planners and programmers believe that these advantages outweigh the costs, then the emphasis should be first on how to economically increase the population of probe-equipped receiver aircraft. The best way to do so will not be by retrofitting the current aging fighter fleet but by ensuring that new fighters entering the inventory have refueling probes. Such an evolutionary approach to probe/drogue technology would allow the most feasible and cost-effective transition to multipoint aerial refueling.

ACKNOWLEDGMENTS

Several organizations and individuals offered information and perspectives to support the objectives of this work. Major Pete Szabo of HQ AMC (Air Mobility Command), Studies and Analyses Flight, gave generously of his time to explain past AMC analyses on the subject of multipoint aerial refueling. Mr. Joshua Schwartz of the Institute for Defense Analyses (IDA) also contributed insights derived from recent IDA research on tanker requirements. Mr. Don Copeland and Mr. Peter Johnson of Frontier Technology, Inc., were helpful in clarifying aspects of their past analyses, as well as in explaining more generally the issues involved in multipoint-refueling analysis. Finally, Captain Eric Briggs, U.S. Navy, of the Commission on Roles and Missions of the Armed Forces, sponsored the work and provided helpful insights and perspectives as well.

Within RAND, Richard Stanton made an indispensable contribution to the effort. His well-organized database of Desert Storm tanker missions made possible the analysis of a day of Gulf War tanker operations. Richard also reviewed the draft of the text, providing valuable comments that enhanced the final product. Paul Davis provided very useful perspectives that helped make the report a more balanced document. Craig Moore read several drafts of the briefing and report, and made many useful suggestions. Ruth Berg graciously made available her extensive files on the subject. David Adamson gave useful guidance to enhance the effect and readability of the briefing and text. Finally, David Chu provided oversight and continuing support to the research.

Although the help of the individuals mentioned here is much appreciated, the views expressed in this documented briefing are those of the author. Similarly, any errors or omissions are solely his responsibility.

ABBREVIATIONS AND ACRONYMS

AB	Air base
AFSAA	Air Force Studies and Analyses Agency
AMC	Air Mobility Command
AR	Aerial refueling
ARC	Air Reserve Component
ARCT	Aerial-refueling control time
ATO	Air tasking order
AWACS	Airborne Warning and Control System
BDA	Boom drogue adapter
CMARPS	Combined Mating and Ranging Planning System
GAO	General Accounting Office
GMT	Greenwich Mean Time
JAST	Joint Advanced Strike Technology
JSCP	Joint Strategic Capabilities Plan
JSTARS	Joint Surveillance and Target Attack Radar System
MP	Multipoint
MRC	Major regional contingency
NEA	Northeast Asia
NEF	Not enough fuel
nmi	Nautical mile
NSE	Not soon enough
PAA	Primary authorized aircraft
ppm	Pounds per minute
rcvr	Receiver
SP	Single point
SWA	Southwest Asia
TAI	Total aircraft inventory
TOT	Time over target
USAF	United States Air Force

1. INTRODUCTION

Motivation for Study

- Numerous studies have been performed on the concept of multipoint aerial refueling.
- The study results have seemed to vary widely.
- Can any general conclusions be drawn?

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The principal aerial-refueling approach currently in use by the U.S. Air Force relies on boom/receptacle technology that can refuel a single aircraft at a time. With this approach, the aircraft receiving fuel is given directions to position itself behind and below a KC-135 or KC-10 tanker aircraft while an operator "flies" the fuel-transfer boom into a receptacle in the forward nose area of the receiver. Once the boom is seated in the receptacle, the fuel-transfer operation commences. Originally intended for refueling large, less-maneuverable bombers, the boom/receptacle approach has the continuing advantages of high reliability and high fuel-transfer rates, as well as having been tried and proven in a wide variety of operational settings.

An alternative approach, used by the U.S. Navy and by most allied air forces, is probe/drogue technology. This technology, which can be used by fighter and attack aircraft, consists of a tanker aircraft extending behind it a flexible hose with a basket-shaped drogue on the end to stabilize it in the slipstream. The receiver maneuvers to place its fuel-transfer probe into the center of the basket, making contact with the hose and initiating the transfer of fuel. Hoses can be extended from the centerline of the tanker fuselage or from each of the wing tips. This latter configuration is called *multipoint aerial refueling*, since it can allow more than one fighter or strike aircraft to receive fuel simultaneously. Advocates of more-widespread use of the probe/drogue approach by the U.S. Air Force cite the advantages of flexibility and interoperability with other Services and air forces, as well as the prospect that fewer tanker aircraft might be needed during fighter-employment operations.

Several studies have been conducted since 1990 to evaluate the costs and benefits of moving toward multipoint probe/drogue operations, and there has been considerable give-and-take between advocates on both sides of the question. My objective for the work described in this documented briefing was to understand the differences among these past study efforts and to gauge whether there are any areas of agreement that could form the basis for a consensus about multipoint. In addition, to better understand the opportunity for multipoint refueling to benefit fighter-employment operations, I performed an analysis of a single high-tempo day during Operation Desert Storm.

Tanker Force Structure Is Substantial

	PAA	TAI
KC-10	54	59
KC-135	478	551
Totals	532	610

- **Are there opportunities for substantial savings?**

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The current tanker force structure of 532 primary authorized aircraft (PAA) normally available for operations and 610 total aircraft inventory (TAI) is a large force and could present an opportunity for budgetary savings (i.e., for downsizing). Cutbacks and declining budgets have been the rule in the U.S. military since the end of the Cold War. The number of USAF fighter wings has declined from over 30 during the 1980s to the current level of around 20. This represents a decline in aircraft of 34 percent, from 4,540 fighters in 1986 to 2,992 in 1994. Strategic bomber squadrons have also declined, from a high of 25 in 1988 to 11 today—translating to a cut in bombers of 53 percent, from 422 to 198.

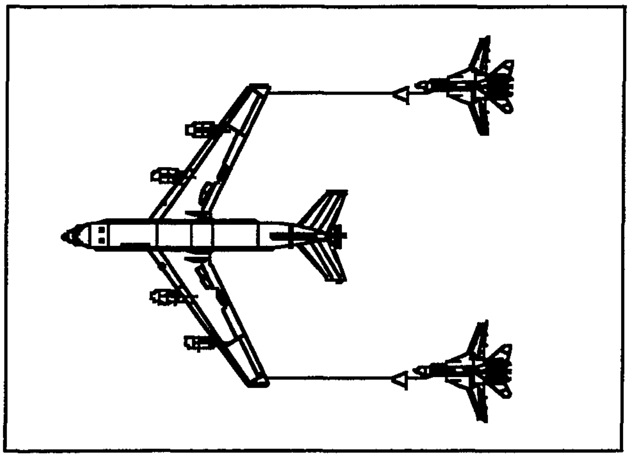
Tanker force structure has shrunk as well, although somewhat less than that of the fighters and bombers. The tanker TAI has declined 13 percent, from 698 in 1986 to 610. Some observers, looking at the substantial cuts in the numbers of receiver aircraft and comparing them to the relatively small decline in tankers, have concluded that the tanker force structure could be a candidate for further downsizing. The issue, however, is somewhat more complex than it might seem on first examination.

Coincident with the decline in numbers of tankers has been the movement of more of them into the Air Reserve Component (ARC). In 1986, 126 were in the ARC, amounting to 18 percent of the force. Today, there are 287 in the ARC, constituting 53 percent of the total force. The active tanker force has shrunk 43 percent, from 572 to 326 aircraft.[2] As a result, there is the perception of a shortage of tankers to support peacetime needs for training, peacekeeping operations such as Deny Flight and Southern Watch, and the downsized nuclear-deterrent mission. Others claim that since there has always been a shortage of aerial-refueling capability, the smaller relative decline in the tanker force simply makes smaller a still-substantial deficit.

The resolution of these issues must await a comprehensive examination of aerial-refueling requirements, for both peace- and wartime operations. Adding complexity to such an analysis will be the necessary determination of whether deeper cuts in the tanker force structure might be possible if a transition to multipoint aerial refueling were made.

[2]Statistics used in this discussion were derived from the "Air Force Almanac," *Air Force Magazine*, May 1986 and May 1994.

Does This Concept Offer an Opportunity for Savings?



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I show here a representation of how multipoint aerial refueling might be implemented on a KC-135 tanker aircraft, depicted refueling two Navy F-14 fighters. Those who advocate greater use of multipoint cite that greater commonality and interoperability would be possible between U.S. Air Force tankers and Navy, Marine Corps, and allied fighter aircraft. Such commonality and interoperability would simplify the planning for joint and combined operations. In addition, they would enhance operational flexibility by giving each tanker greater capability. That is, as plans inevitably go awry, additional unscheduled refuelings often become necessary, and the extra offload point on the tankers could become essential for accommodating these unforeseen requirements. Multipoint operations imply the refueling of fighter aircraft as opposed to large bombers or transports. The greatest advantages would be obtained during high-intensity fighter-employment operations during major regional contingencies (MRCs). It is these operations that are considered to be the driving requirement behind the size of the tanker force structure today.

Those who support the continued emphasis on the single-point approach in use by the U.S. Air Force today make reference to the high reliability of boom/receptacle technology, as well as its successful employment in a wide variety of operational settings. In addition, the boom method also provides the highest fuel-transfer rates, which is an important factor in determining the relative effectiveness of the system. Less training on the part of fighter pilots is needed, since the burden is placed primarily on the boom operator to make the connection, rather than on the receiver having to maneuver skillfully to fit a probe into a moving basket. For this reason, the Air Force takes the position that boom/receptacle offers the greatest safety and reliability during conditions of poor visibility and adverse weather.

In addition to a refueling boom, the KC-10 tanker already has a centerline drogue, which can refuel a single probe-equipped aircraft at a time. This drogue gives it the capability to refuel both probe- and receptacle-equipped aircraft on the same mission. These versatile aircraft are limited in number, however, and although available to probe-equipped receivers for peacetime training, have historically had limited availability during combat operations to refuel probe-equipped receivers. The KC-135 can have a hose and drogue assembly installed on its boom, called a "boom drogue adapter" (BDA). This system was not designed as a long-term solution to the refueling needs of probe-equipped receivers, and has the added disadvantage of requiring the BDA-equipped KC-135 to be dedicated to probe-and-drogue operations during a given mission. To date, several efforts have been made to expand the multipoint probe/drogue capabilities of the Air Force. However, those efforts have resulted in programs to equip only limited numbers of KC-10s and KC-135s with multipoint capability.

Current Plans

- Fiscally constrained decision to equip 33 KC-135s with drogue pod sets
  - $180 million program
  - Primarily for Marine fighter deployment
- 15 pod sets being purchased for KC-10s
  - 20 aircraft to be modified to receive them

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The multipoint programs currently funded will equip 33 KC-135s with wing-tip drogue pods and will purchase 15 sets of pods for installation on KC-10s. The history of these programs is long and convoluted, however.

The multipoint program for the KC-135 began in 1990, when a development-and-acquisition effort was initiated by the Office of the Secretary of the Air Force to modify 100 KC-135s with wing-tip drogue pods and to retrofit existing F-15s and F-16s with probes. This decision was based primarily on a 1990 RAND study of measures to improve aerial-refueling capabilities, in which multipoint refueling was the outstanding alternative.

Based on further Air Staff analysis in 1991, however, the retrofit of F-16s with probes was judged to be infeasible, owing to the aerodynamic effects of the probes, and was canceled. In 1992, Air Mobility Command was asked by the Air Staff to reexamine the 100-aircraft multipoint program in light of the fact that fewer probe-equipped receivers would be available. Their analysis indicated that only 75 KC-135 aircraft need to be fitted with drogue pods, primarily in support of the operational requirements of Naval aviation. Based on this study, the program was changed accordingly. However, Congress entirely deleted the FY 1993 funding for the program, based on the Air Force decision not to retrofit the F-16s with probes. Later, the Air Force canceled the remaining plans to retrofit F-15s with probes.

Multipoint still existed as a "validated requirement," despite its cancellation by Congress for FY 1993. In December 1993, the Office of the Secretary of Defense re-funded the program for FY 1995 at the lower level of 42 KC-135s, a number based solely on the available funding. This number has since been further decreased to 33, and the limited remaining capability is primarily focused on support to Marine fighter squadrons deploying during contingencies.

The history of the KC-10 modification program is less complicated but just as extended. It was initiated in 1986, with plans to purchase 40 drogue pod sets for installation on KC-10s as needed. Currently, the program is still in the test phase, and the intent now is to eventually purchase 15 sets of pods and to modify 20 KC-10s to use them. The planned user of the capability is the U.S. Navy. However, the actual availability of KC-10s to the Navy during major fighter-employment operations is considered by many to be an uncertain proposition, because the KC-10 is a very efficient hauler of bulk cargo. After its initial use as an aerial refueler during the deployment of fighter units, many in the Air Force believe that the most effective use of the aircraft is to carry sustainment cargo. This change in usage would make the KC-10 less available in-theater to support fighter operations.

2. REVIEW OF PAST ANALYSES

Past Studies on Multipoint Refueling

- RAND, *Enhancing USAF Aerial Refueling Capabilities*, 1990 (for government use only; not available to the public).
- AFSAA, *Utility of KC-135 Multipoint Modifications*, 1992 (for government use only; not available to the public).
- AMC/XPY, *Impact of Multipoint/Receptacle Modifications*, 1993.
- GAO, *Aerial Refueling Initiative*, 1993.
- Frontier Technology, *Multipoint Refueling Program Cost Benefit Analysis*, 1995 (for government use only; not available to the public).

RAND

In the 1980s, technical studies on multipoint refueling were conducted, and a few papers were written on the subject at senior Service schools. Shown here are the studies that have informed the debate on multipoint refueling since 1990 and that I reviewed in this study. The 1990 RAND study provided the initial impetus to the process, predicting substantial payoffs for installing drogue pods on KC-135s and fitting probes on F-15 and F-16 fighters.

The Air Force Studies and Analyses Agency (AFSAA) conducted its own analysis of the issue and predicted smaller benefits from multipoint operations. Other AFSAA work looked at the feasibility of placing probes on existing fighters and concluded that doing so would adversely affect the performance of the F-16.

In 1993, Air Mobility Command (AMC) conducted a study at the request of the Air Staff to determine the numbers of multipoint tankers required to support existing Naval probe-equipped fighter and strike aircraft.

Also in 1993, the General Accounting Office (GAO) conducted a review of the entire process to that date. Its result was supportive of the RAND findings and critical of the Air Staff and AMC analyses.

The most recent contribution to the debate is a study by Frontier Technology, Inc., conducted for the Air Force's Aeronautical Systems Center. Frontier Technology found that multipoint could yield benefits in requiring fewer tankers during fighter-employment operations.

Approach to the Reviews

- Identify essential parameters affecting multipoint utility.
- Examine how each study characterized those parameters.
- Assess how characterization affected results.

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It was an instructive exercise to review the five studies. Each study used different methods and measures of effectiveness, and it was therefore necessary to define a process that would allow an objective comparison. I took the straightforward approach shown in this chart.

Multipoint Parameters

- Tanker tactics
- Track length
- Distance to target
- Probe receiver availability
- Fighter-package size
- Fuel-transfer rate
- Operational intensity
- Offload availability

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Shown here are the key parameters that can affect the analysis of multipoint-refueling utility. I evaluated these parameters for each of the past studies on multipoint aerial refueling.

Tanker tactics refers mainly to two alternative approaches in refueling fighter aircraft during combat operations. In the first, the track approach, a "package" of fighters is escorted by a tanker along a route, or *track*, that originates well within friendly airspace and extends as near as possible to the combat zone. At the end of the track, the fighters commence their combat mission with fuel received from the tanker, and the tanker usually returns to its base. The effective range of the entire fighter package at the combat entry point is limited by the fuel remaining in the first fighter to refuel along the track. Tracks allow a large number of strike aircraft to marshal themselves outside of the enemy radar range, and to arrive at the battle area nearly simultaneously, overwhelming defenses with a mass attack.

In the second approach, the anchorpoint approach, a tanker simply orbits near the combat zone as a "gas station in the sky." From its anchorpoint, the tanker can refuel a large number of fighter packages sequentially, providing for more-efficient use of the tanker and more-complete usage of the fuel available for offload. Anchorpoint tactics are ideal for missions such as combat air patrols, in which the fighters must stay in the same airspace for a period of time. However, for strike aircraft, this tactic does not allow the same operational security or massing of aircraft as does the track approach.

High levels of tanker efficiency can be achieved by using anchors together with multipoint refueling. Use of the anchorpoint tactic in studies tends to favor the multipoint alternative because it enables more aircraft to be refueled per tanker. With tracks, however, the benefits of multipoint refueling are limited by other parameters, described below, including the length of the track and the maximum number of fighters allowed in a package.

When tracks are used, the **track length** affects the utility of multipoint relative to that of single-point operations. Short tracks tend to show multipoint as yielding higher benefits, since this type of operation is constrained by the time and distance to the track exit point, and an additional refueling point allows more receivers to be refueled simultaneously in the limited time available. However, longer tracks tend to negate the benefits of multipoint, especially if there are limitations on the number of fighters in a package. With long tracks, there is enough time for large packages of fighters to be refueled with single-point boom/receptacle operations. If the first aircraft to be refueled is "topped off" just before reaching the combat entry point, the range of even large packages of fighters can be relatively unaffected. For long tracks, analyses often show that the same number of tankers, whether multipoint or single point, is usually required.

Distance to target refers here to both the distance from the fighter operating base to the target and the distance from the last refueling point to the target. If the fighters are based far from their target areas (for example, to keep them outside the range of enemy ballistic missiles), then a track system of aerial refueling will be dictated and multipoint tanker capability will seem less advantageous. On the other hand, if the distance is short, then either the tracks will be short or anchorpoints will be used, both of which tend to favor multipoint operations.

The distance from the aerial-refueling point to the target area drives the fuel-onload requirement of the fighters (i.e., the amount of fuel needed to get to the target and back). If this requirement is large, then multipoint may be more advantageous, since the aircraft in the package with the least fuel at the exit point will usually have more than it would have had with single-point operation.[3]

Probe receiver availability. Obviously those studies that assumed that most or all receiver aircraft had probes observed greater benefits from having tankers with multipoint probe/drogue capability. The studies that assumed few probe-equipped fighters showed less benefit.

Fighter-package size. This parameter addresses those analyses' assumptions about the number of receivers that can be assigned to a single tanker. Although there are no strict rules governing package size, Air Force operational experience and practice have led to eight being considered an upper bound on the number of fighters in a single fighter package. Nevertheless, Operation Desert Storm witnessed a number of occasions when fighter-package sizes were greater than eight, especially by the probe-equipped Navy and Marine fighters.[4] In general, larger package sizes favor multipoint refueling in analyses: In those situations in which a single-point tanker can support eight fighters, and time and distance are limited, a multipoint tanker could theoretically accommodate 16. Analyses that limit fighter-package size for safety reasons or to minimize risk to mission accomplishment, place a cap on the possible benefits of multipoint.

Fuel-transfer rate is a key parameter affecting comparisons between single-point and multipoint operations. When fighters are the receiver aircraft, they usually limit the overall fuel-transfer rate, since the tankers generally have more capability to pump fuel than the fighters have to accept it. A transfer rate that is assumed to be low overall will be advantageous to multipoint operations, because it will take longer to refuel individual receivers, and the capability to refuel more than one at the same time will be more important. Low assumed fuel-transfer rates place the operation into a "boom-limited" situation, in which the number of fighters that can be employed is limited by the offload points available on the tankers.

Operational intensity refers to the number of receiver aircraft requiring aerial refueling during a unit of time. High-intensity operations such as might occur early during a contingency will tend to be boom-limited,

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[3]As stated earlier, with multipoint tankers, the first receivers to refuel will have more fuel remaining at the combat entry point than if a single-point tanker were used, assuming no top-offs by the single-point tanker.

[4]In many cases, larger Navy fighter-package sizes were facilitated by the presence of a Navy KA-6 tanker, which could receive fuel from the Air Force tanker and provide an additional offload point to the fighters.

since there will probably be more demand for fighter missions than tankers to support them. In this situation, multipoint tankers would enable more fighter missions to be flown. However, in most cases, the tempo of fighter operations is not so high that it is constrained by tanker availability, and multipoint and single-point operations yield the same numbers of tankers required.

Offload availability addresses whether the tanker itself has enough fuel to allow multipoint refueling of larger packages of fighters. The chief advantage of multipoint over single-point is in allowing the refueling of larger numbers of receivers per tanker, when time and distance limitations prevail. However, if the tanker itself does not have additional fuel available because it operates far from its base, then the advantages of multipoint operations are negated. In addition, the type of tanker used will dictate the available fuel offload. KC-10s have a substantially larger offload capability than the KC-135, especially at the greater distances.

RAND: 1990

Bottom Line: Multipoint could allow a substantial reduction in theater tanker requirements.

Treatment of Parameters:

- **Tanker tactics:** anchorpoints and time-constrained tracks
- **Operational intensity:** range of intensity from low to high
- **Offload availability:** tankers matched to fixed strike package
- **Fuel-transfer rates:** 1,000 pounds per minute (ppm) for all fighters
- **Track length:** 400 nmi for Pacific scenario
- **Distance to target:** 150 nmi
- **Fighter-package size:** not limited
- **Probe receiver availability:** high; all fighters have probes

RAND

The purpose of the RAND study, published in 1990, was to investigate options for extending the capabilities of the existing U.S. tanker fleet.[5] In addition to fighter employment, this work looked at tanker support to deployment, bomber operations, and continental air defense. With respect to fighter operations, it investigated three alternative scenarios. The first scenario, a fighter strike from Clark AB in the Philippines against Cam Ranh Bay in Vietnam, found that from 30 to 50 percent fewer KC-135 tankers would be required if all fighters and tankers were multipoint probe-/drogue-equipped. The second scenario postulated the defense of Iran against a Soviet invasion. The potential reduction in required tankers to support individual fighter packages with multipoint ranged up to 33 percent. The third scenario involved the operation of fighters conducting defensive counter-air operations in Europe. In this case, the study found that a reduction of 50 percent was possible under the most likely set of operational circumstances.

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[5]Bowie, C. J., et al., *Enhancing USAF Aerial Refueling Capabilities*, Santa Monica, Calif.: RAND, R-3801-AF, 1990 (for government use only; not available to the public).

For this study, as well as for each study that follows, I first address the key analysis parameters, then comment generally on the work.

Tanker tactics: The RAND study examined the employment of fighters and tankers for scenarios in the Pacific, Southwest Asia, and Central Europe. Anchorpoints were used in Europe and Southwest Asia, and tanker tracks were used for operations in the Pacific.

Operational intensity: The effect of intensity was investigated for the European scenario by assuming time windows of various lengths in which to refuel an air-interdiction force consisting of 200 fighters. The Pacific and Southwest Asia scenarios did not address operational intensity.

Offload availability: This parameter was not a limiting factor in the analysis. In each case, fighter packages of fixed sizes were examined; tankers were matched to the package in order to meet all fuel needs.

Fuel-transfer rates: A planning factor of 1,000 pounds per minute (ppm) of fuel per offload point was used in the analysis. This rate was intended to be an overall transfer rate that took into account not only the actual transfer of fuel but also the additional time for positioning and hook-up of the fighters. Therefore, the actual fuel-transfer rate used was higher than 1,000 ppm, but how much higher is unclear. By using a relatively low rate, all scenarios were boom-limited, giving advantage to the additional offload points available with multipoint.

Track length: It is usually difficult to show an advantage for multipoint when track operations are assumed, since there is normally enough time and distance with this tactic to refuel all the fighters in a reasonably sized package using single-point operations. Although the Pacific scenario used a track length of 400 nmi, the operation was, nevertheless, boom-limited mainly because of the relatively low assumed fuel-transfer rate.

Distance to target: The distances from fighter bases to targets dictated track operations for the Pacific scenario, and allowed anchorpoints to be used in the Southwest Asia and Central Europe scenarios.

Fighter-package size: This was assumed not to be constraining. Package sizes ranged from 8 to 11 fighters.

Probe receiver availability: The study contrasted operations with single-point boom/receptacle operations with equivalent operations that assumed 100-percent use of multipoint probe/drogue operations.

Comments on RAND Study

- One of the first studies to quantitatively assess multipoint (MP) utility
- Mission-level analysis looked at individual strike packages
- Identified multipoint as a good candidate for further study

RAND

The RAND study was one of the first analyses to investigate quantitatively the utility of multipoint refueling. It examined individual fighter packages within the context of three regional scenarios, and examined how many tankers each package required under both single-point and multipoint assumptions. It used these results as indicators of possible savings on tanker requirements generally, at the theater level.

The study was not intended to definitively evaluate the feasibility of multipoint; instead, it screened a number of options for extending the effectiveness of the tanker fleet. Multipoint probe/drogue operations were identified as a concept having excellent potential, and further study and evaluation were recommended.

AFSAA: 1992

Bottom Line: Multipoint reduces tankers needed in boom-intensive and airspace-limited environments.

Treatment of Parameters:

- **Tanker tactics:** anchor operations only
- **Operational intensity:** range of intensity from low to high
- **Offload availability:** tanker force size held constant
- **Fuel-transfer rates:** F-15 3,400 ppm; F-16 2,600 ppm
- **Track length:** not applicable
- **Distance to target:** 150 nmi for F-15Es; 100 nmi for F-16s
- **Fighter-package size:** not explicitly limited
- **Probe receiver availability:** high; all fighters have probes

RAND

In 1992, the Air Force Studies and Analyses Agency was asked by senior Air Force leadership to conduct its own evaluation of multipoint refueling, as well as to review the RAND study. Its conclusions can be summarized as follows:

> In general, multipoint tankers have an advantage over single boom equipped tankers in high tempo (boom intensive) situations and also where airspace constraints limit the number of tankers. For whatever reason that causes fighters to be stacked up waiting in line to receive their fuel, whether it be bad weather, large marshaling times, large onloads, or slow tanker or receiver throughput rates, multipoint drogue tankers get the job done quicker or in the same length of time with fewer numbers than the single boom alternative. Unfortunately, however, not twice as fast and not with 50 percent fewer tankers as first thought, but closer to a 20 to 30 percent improvement level and only after system maturity has been achieved.[6]

[6]George, William L., Lt Col, USAF, *Utility of KC-135 Multipoint Modification*, Washington, D.C.: Air Force Studies and Analyses Agency, 1992, p. 52 (for government use only; not available to the public).

Tanker tactics: AFSAA conducted an analysis of Central European corridor operations, in which fixed numbers of tankers were placed in orbits, or anchorpoints, to support successive waves of fighters.

Operational intensity: Low- and high-intensity levels were addressed by allowing fighter ingress corridors to remain open 2 hours in the low-intensity case and 1 hour in the high-intensity case.

Offload availability: The low-intensity cases are fuel-limited rather than boom-limited, because the analysis used a fixed number of tankers and measured the number of fighters that could be supported by them.

Fuel-transfer rates: While the 1,000-ppm rate used in the RAND study encompassed the times for positioning and hookup, AFSAA addressed these issues separately and applied transfer rates only to the actual refueling operation. AFSAA's fuel-transfer rate was governed by either the offload capability of the tanker or the onload capability of the fighter, whichever was most limiting. The offload rate of KC-135s was assumed by AFSAA to be 6,000 ppm with a boom and 2,560 ppm with a drogue. The F-15s were limited by their maximum onload rate to 3,400 ppm in single-point boom/receptacle operations and by the tanker offload rate to 2,560 ppm in drogue operations. F-16s were limited in both cases by their capability to on-load fuel: to 2,600 ppm for the boom/receptacle configuration and 1,660 ppm for the probe/drogue configuration—64 percent of the 2,600-ppm figure. The 64-percent factor was used to account for the assumed complexity of the probe plumbing on the F-16.

Track length: This parameter was not applicable for the Central European scenario, since anchorpoint tactics were used.

Distance to target: The distances from the fighter bases to the targets in the European scenario allowed the use of anchorpoint tactics. The distances from the refueling point to the target determine the fuel onload amount, which for F-15s was 6,000 pounds and for F-16s was 4,000 pounds.

Fighter-package size: In the AFSAA study, this number varied from 4 to 6 fighters per fighter package. However, each tanker was allowed to refuel several packages while at its anchorpoint.

Probe receiver availability: The availability of probe-equipped receivers was not a constraining parameter for this analysis. Multipoint operations were being evaluated, so all receivers were assumed to be probe-equipped.

Comments on AFSAA Study

- Considers multiple strike packages
- Finds 23 percent fewer tankers needed with MP in high-tempo environment
- Anchorpoint tactics and population of probe-equipped fighters favor MP
- Maintains that RAND 1,000-ppm assumption causes overly boom-limited environment

RAND

The AFSAA study considered multiple waves of fighter packages being supported by fixed numbers of tankers at anchorpoints. The analysis resulted in 23 percent fewer tankers being needed in the multipoint case for high-intensity operations. The availability of additional offload points meant that the multipoint case was never boom-limited. Instead, it was fuel-limited, using all of the fuel available on the tankers and still having time remaining in the corridor. On the other hand, the single-point case was boom-limited, using up all the available corridor time and leaving fuel in the tankers.

The assumptions of anchorpoint tactics and large numbers of probe-equipped receivers favor multipoint operations. If other scenarios had been examined, tanker tracks instead of anchorpoints might have been used. Such tracks could be long enough not to be boom-limited and would have allowed fighters to arrive at the corridor nearly simultaneously. With these assumptions, single-point and multipoint performance would have been very similar. Anchorpoints can have the disadvantages of requiring fighters to be based relatively close to the combat area and to be massed within enemy radar range.[7] Most fighter-operations planners assume that track operations will be used, at least in the early days of an air campaign.

The AFSAA study, by assuming higher overall transfer rates in combination with lower rates for probe/drogue, gave greater advantage to boom/receptacle operations than did the RAND study. Nonetheless, it still found a substantial possible savings in tanker requirements ranging between 20 and 30 percent.

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[7]These disadvantages can be mitigated by using more than one anchorpoint along a route in order to extend fighter ranges and by conducting the refuelings at lower altitudes to remain below enemy radar coverage.

Air Mobility Command: 1993

Bottom Line: No reductions in required numbers of tankers are possible.

Treatment of Parameters:

- **Tanker tactics:** track operations
- **Operational intensity:** low
- **Offload availability:** tankers matched to fixed strike package
- **Fuel-transfer rates:** F-15 3,400 ppm; F-16 2,100 ppm
- **Track length:** 600 nmi
- **Distance to target:** 150 nmi
- **Fighter-package size:** 8 maximum
- **Probe receiver availability:** low

RAND

Air Mobility Command was asked by the Air Staff in 1993 to examine the operational uses to which KC-135s modified for multipoint could be put.[8] The focus was on support for Navy fighters operating in Southwest Asia.

Tanker tactics: Track operations were used so that Navy fighters from an aircraft carrier could be refueled as near as possible to their targets.

Operational intensity: The tempo of operations was low. That is, the tracks were long enough so that time was not a constraint in performing the necessary refueling operations.

Offload availability: Tankers were matched to a fighter package of fixed size. Since operations were not time-constrained, numbers of tankers required were generally determined by the tanker offload availability. Because of additional aerodynamic drag from the drogue pods on multipoint-modified KC-135s, it was assumed that the offload capability of multipoint tankers would be less at long ranges, actually resulting in more tankers being needed.

[8]Szabo, Pete, Maj, USAF, *Impact of Multipoint/Receptacle Modifications*, Headquarters, Air Mobility Command, Scott AFB, Ill., briefing, 1993.

Fuel-transfer rates: These assumptions were similar to those used in the AFSAA study.

Track length: Approximately 600 nmi. This distance, in combination with the fuel-transfer rates, resulted in mainly fuel-limited rather than boom-limited operations.

Distance to target: 760 to 1,000 nmi from the aircraft carrier to target, requiring track operations. Distance from the track exit point to the target was 150–200 nmi.

Fighter-package size: Fighter packages were limited for safety reasons and to reduce mission risk.

Probe receiver availability: Since only Navy receivers were addressed, and all of these aircraft have probes, probe-equipped receiver availability can be considered high for the purposes of the analysis.

Comments on AMC Study

- Low-tempo operations, limited mainly by offload availability
  - Same number of tankers generally required, whether MP or SP
- Operational realities place limitations on multipoint advantages
- The interoperability and flexibility benefits of MP are acknowledged

RAND

AMC was asked to investigate the effectiveness of multipoint to support Navy fighters flying off of aircraft carriers stationed distant from the targets. For this reason, relatively long tracks were required, along which there was ample time to conduct all of the aerial refueling that was needed, whether by single-point (SP) or multipoint tankers. As a result, the scenario could be described as low intensity, limited primarily by fuel-offload availability. In such a non–boom-limited environment, the same number of tankers is usually required, whether single-point or multipoint. This is the situation that occurs most frequently and extensively during fighter-employment operations.

Because the AMC study was focused on determining the level of support needed by limited numbers of probe-equipped Navy fighters, it is difficult to compare this study with the others. The others usually assumed a 100-percent probe-equipped fighter inventory. Nevertheless, the AMC study does not dispute the value of multipoint on those occasions in which fighter operations are constrained by time, distance, or available airspace. In addition, the study acknowledges the benefits of multipoint for planning flexibility, as well as interoperability with other Services and air forces.

GAO: 1993

Bottom Line: Standardizing completely on the probe-and-drogue system is probably a good idea.

Treatment of Parameters:

- **Tanker tactics:** tanker tracks are a unique circumstance
- **Operational intensity:** describes Desert Storm experience
- **Offload availability:** not specifically addressed
- **Fuel-transfer rates:** drogue as good as boom for fighters
- **Track length:** describes effect of tracks during Desert Storm
- **Distance to target:** not specifically addressed
- **Fighter-package size:** discussed in context of Desert Storm
- **Probe receiver availability:** assumes large number

RAND

The GAO work, published in 1993, is mainly a review of the past analyses on multipoint refueling, as well as a critique of the Air Force's management of the program.[9] Consequently, the report does not give specific quantitative values to the parameters being focused on here. However, the GAO does take positions on what it believes is the most appropriate way to handle some of the parameters. The overall conclusion of the analysis is that the Air Force is not moving fast enough on multipoint refueling, and that it would be cost-effective to standardize U.S. aerial-refueling systems on the multipoint probe/drogue technology.

Tanker tactics: The GAO acknowledges the predominant use of tracks during Desert Storm, which it terms a "unique circumstance." It suggests that more-extensive use of anchorpoints would have been possible after

[9]Ochinko, Walter, *Aerial Refueling Initiative*, Washington, D.C.: GAO, GAO/NSIAD-93-186, 1993a.

the United States achieved air superiority. Anchorpoints would have made multipoint operations more advantageous.[10]

Operational intensity: Multipoint shows the most benefit during surges of fighter activity. Such surges occurred not only during the first days of Desert Storm and at the start of the ground campaign, but throughout the war, especially for Naval aircraft. An additional constraint on tanker operations was the limited airspace in which to conduct aerial refueling—another condition under which tankers with multipoint capabilities can be of benefit.

Offload availability: This was not addressed specifically. The focus of the report is on boom-limited operations and the benefits of multipoint for interoperability and flexibility.

Fuel-transfer rates: This parameter is important to the analytic outcomes in all of the analyses of multipoint. The GAO criticizes the AFSAA report for overestimating the transfer rates possible with the boom/receptacle approach and underestimating the rates achievable with the probe/receptacle approach. The GAO work found that the transfer rate for fighters should be about the same with both systems.

Track length: GAO acknowledges that when longer tracks are used, ample time is available for conducting the required aerial refuelings. Longer tracks result in multipoint operations' having less utility.

Distance to target: This parameter was not discussed specifically.

Fighter-package size: The report proposes that the number of fighters assigned to a tanker was small in Desert Storm because there were more than enough tankers to go around. They reason that multipoint would have allowed larger fighter packages, resulting in less fuel needing to be dumped or returned to base.

Probe receiver availability: The GAO conclusions about the possible benefits of multipoint refueling presuppose that enough probe-equipped receivers are available to make the concept worthwhile.

[10]In addition, the commencement of another, concurrent major contingency could have stretched tanker forces more thinly, possibly motivating the greater use of anchorpoints instead of tracks.

Comments on GAO Study

- Not intended as a stand-alone analysis
- Critical of Air Force treatment of fuel-transfer rates and other parameters
- Describes advantages of MP interoperability and flexibility

RAND

Again, I should point out that the GAO work was not of itself an analysis of multipoint refueling; instead, it was a review of past analyses and a critique of the Air Force program. The GAO addressed principally the findings of the AFSAA study and, to a lesser extent, those of the AMC study.

The GAO focused on AFSAA's treatment of several issues, including the fuel-transfer rate. AFSAA assumed that a tanker, using its boom and all four of its available pumps, could achieve a relatively high offload rate of 6,000 ppm. GAO noted that it is standard procedure for a KC-135 to use only two pumps when refueling fighters, which would reduce its offload rate to approximately 2,880 ppm. This 2,880-ppm rate would become the limiting number for the transfer rate of the F-15 using the boom, a reduction from the 3,400 ppm that AFSAA assumed.

The GAO further criticized the AFSAA rate assumptions with respect to the F-16. The 2,600-ppm maximum onload rate of the F-16 used by AFSAA for boom operations was higher than the 2,000 ppm published in technical orders. Furthermore, GAO said that AFSAA's limiting of the probe-equipped F-16 to an onload rate 64 percent of that achieved with a boom was a misinterpretation of the technical data. Using the GAO's interpretation, the onload rate of the probe-equipped F-16 would have remained close to 2,000 ppm.

Finally, the GAO report emphasized the findings of the RAND report: that multipoint would enhance the efficiency, operational effectiveness, interoperability, and safety of U.S. aerial-refueling operations. They noted that the limited numbers of drogue-equipped tankers (using boom/drogue adapter kits) available during Desert Storm presented scheduling problems and increased the complexity of operating with the Navy and allied air forces. GAO maintained that standardizing on the probe/drogue technology would solve these problems.

Frontier Technology: 1995

Bottom Line: Significantly fewer tankers required in all scenarios when multipoint used.

Treatment of Parameters:

- **Tanker tactics:** tracks and anchors; no top-offs assumed
- **Operational intensity:** "high" and "low" levels both intense
- **Offload availability:** tankers matched to specific receivers
- **Fuel-transfer rates:** detailed treatment
- **Track length:** realistic (theater-level) scenarios used
- **Distance to target:** realistic (theater-level) scenarios used
- **Fighter-package size:** not specifically limited
- **Probe receiver availability:** 24 percent for NEA; 43 percent for SWA

RAND

Frontier Technology, Inc., analyzed the costs and benefits of the multipoint program for the Air Force's Aeronautical Systems Center.[11] It modeled both Northeast Asia (NEA) and Southwest Asia (SWA) scenarios under a variety of assumptions about tactics and operational intensity. It concluded that if multipoint aerial refueling were used, significantly fewer tankers would be needed.

Tanker tactics: Frontier set up theater-level scenarios using anchorpoints and combinations of tracks and anchorpoints.

Operational intensity: The tempo of operations was addressed by varying the length of time that fighter attack corridors were kept open. For the high-tempo cases, the corridors were open for 20 minutes. For the low-tempo cases, they were open 1 hour.

Offload availability: In each case, tankers were scheduled as required to support theater-level fighter strikes. Offload availability was therefore not a limiting factor.

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[11]Copeland, Donald, et al., *Multipoint Refueling Program Cost Benefit Analysis Final Report*, Santa Barbara, Calif.: Frontier Technology, Inc., 1995 (for government use only; not available to the public).

Fuel-transfer rates: Frontier modeled the fuel-transfer rates in the greatest detail yet, making the fighter onload rates sensitive to how much fuel was still remaining in the fighters' tanks. In addition, the KC-135R offload capability using a boom was set at 2,880 ppm, assuming two pumps in operation. The offload rate through a drogue was 2,272 ppm, based on the capability of the drogue pods currently in the multipoint program.

Track length: For the Southwest Asia scenario, track lengths varied from 210 to 770 nmi. For Northeast Asia, the tracks ranged from 70 to 280 nmi.

Distance to target: The distances varied with the missions that were planned. Distances from track exit or anchorpoints to the target areas varied from 50 to 250 nmi.

Fighter-package size: The number of fighters assigned to a tanker for track operations was limited only by the length of the track and the fuel remaining at the exit point in the first fighter refueled. For anchorpoints, fighters assigned to a given tanker were limited by the time window defined by the strike corridor availability.

Probe receiver availability: Twenty-four percent of the sorties flown in the Northeast Asia scenario were by probe-equipped receivers. Forty-three percent were probe-equipped in the Southwest Asia scenario. However, not all the sorties in each scenario were aerial-refueled. Of the sorties that used aerial-refueling support, 57 percent were probe-equipped in NEA and 46 percent were probe-equipped in SWA.

Comments on Frontier Study

- Most-thorough theater-level analysis to date
- Detailed treatment of fuel-transfer rates
- Assumptions on operation tempo and strike-package sizes are somewhat favorable to multipoint
- Multipoint payoff ranged from 17 to 37 percent reduction in required tankers

RAND

To perform this work, Frontier used its TacRefueler model, a Monte Carlo simulation. This tool models the theaterwide employment of tankers at an appropriate level of detail for an analysis of this type, and has been validated by comparison to CMARPS (Combined Mating and Ranging Planning System), a more high-fidelity aerial-refueling-planning model used by the Air Force. The model allowed the treatment of fuel-transfer rates in the most realistic (based on the expected amount of fuel remaining in fighters' tanks) manner of all the studies I reviewed. The Frontier analysis also considered the fact that many fighter missions in a theater can fly directly to their targets and back again without refueling, so any possible benefits from multipoint were applied only to the subset of fighter missions actually requiring aerial refueling.

The assumptions related to the operational intensity make the low-tempo cases boom-limited as well as the high-tempo cases. As I demonstrate shortly, it may not be that all surges in fighter activity necessarily result in boom-limited situations. In addition, the treatment of fighter-package sizes could also be favorable to multipoint. No strict limitations were placed on how many fighters could be supported by a single tanker.

Nevertheless, the realistic treatment of fuel-transfer rates and the theaterwide application of multipoint only to those missions that required aerial refueling make this study the most thorough and detailed to date. Frontier found that the reductions in tankers made possible with multipoint in the scenarios they examined ranged from 17 to 37 percent.

General Comments on Studies

- Balance of opinion: Multipoint has the potential to reduce tanker requirements, but only in boom-limited environments.
- All agree that multipoint refueling would enhance flexibility and simplify planning for joint and combined operations.

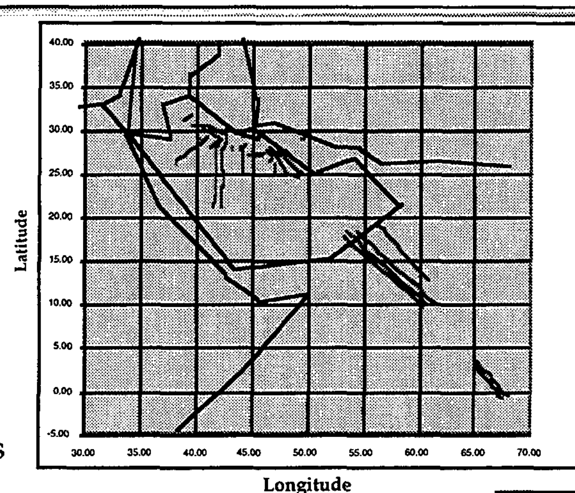
Despite the varying objectives and assumptions of the five studies reviewed here, all the studies have some areas of common ground. All agree that multipoint is beneficial when the tempo of fighter operations is high enough to make the number of fuel-offload points in the air a limiting factor on the number of fighters flown. That is, boom-limited situations occur when there is a large number of planned fighter missions in a brief amount of time, and the high volume of combat air traffic requires that the number of aerial-refueling tracks and anchorpoints be limited. In addition, there simply may not be enough tankers to go around, because there are few bases at which to bed them down or because a second MRC commences. *The desirability of transitioning to probe/drogue technology depends both on the frequency of these situations and on the emphasis planners place on them.*

Finally, all parties agree that multipoint would enhance planning flexibility and interoperability with the Navy, Marines, and allied air forces.

3. GULF WAR DAY D+32 ANALYSIS

D+32: Surged Tanker Operations

- 214 tanker missions
- 1,201 receivers
- 17 million pounds of fuel transferred
- 31 active aerial-refueling tracks and anchorpoints



RAND

Advocates of a transition to multipoint aerial refueling have maintained that the boom-limited conditions that make these operations advantageous occur often during theater fighter-employment operations. If this were true, the possibility of reducing tanker force structure would increase markedly, because multipoint would enable fewer tankers to meet all demands during most operations. Reports on the Gulf War clearly indicate that the intensive first three days of the war were indeed limited by the number of fuel-offload points in the air. After this initial effort, the air campaign began a period of more-sustained combat operations. For boom-limited conditions to have occurred during the latter period as well would support the proposition that boom-limited conditions are common.

To test whether boom-limited conditions occurred at some point after the period of initial air attacks, I examined the tanker air tasking order (ATO) for day D+32 of Desert Storm (February 17–18, 1991). In preparation for the start of the ground war a week later, day D+32 experienced a surge in tanker sorties that was 30 percent above the levels of the previous weeks. This was the highest peak of tanker employment during the entire war, except for the initial air campaign. On that day of operations, 214 tanker missions supported 1,201 receiver aircraft of many types. Seventeen million pounds of fuel were transferred, and the aerial-refueling structure involved 31 active aerial-refueling tracks and anchorpoints. The possibility seemed good that this day of operations experienced boom-limited conditions. I examined the opportunities for multipoint aerial refueling to enable the use of fewer tankers.

Assessing the Opportunity to Employ Multipoint Refueling

- Data: Desert Storm tanker ATO, D+32
- Assume:
  - All receivers probe-equipped
  - All refuelers multipoint drogue-equipped
  - Fighter TOTs drive tanker ATO, not vice versa
- Objective: Perform detailed analysis to identify opportunities to use fewer tankers

RAND

To determine whether the receiver aircraft could have been accommodated with fewer multipoint-equipped tankers on day D+32 of Desert Storm, I assumed that the receivers scheduled to be supported in the ATO were probe-equipped and that the tankers were multipoint drogue-equipped. Implicit in the procedure was the assumption that the fighter time-over-target (TOT) requirements, not the availability of tankers, determined the refueling schedule reflected in the ATO. This turned out to be a very reasonable assumption, since examination of the ATO indicated that there was ample opportunity for the schedule to be "tightened up" by planning more refuelings with the available tankers in a shorter period of time.

In other words, the intervals between the refuelings on the tracks could have been shortened considerably, indicating that the fighter ATO did not require intensive refueling operations.

Analytic Approach

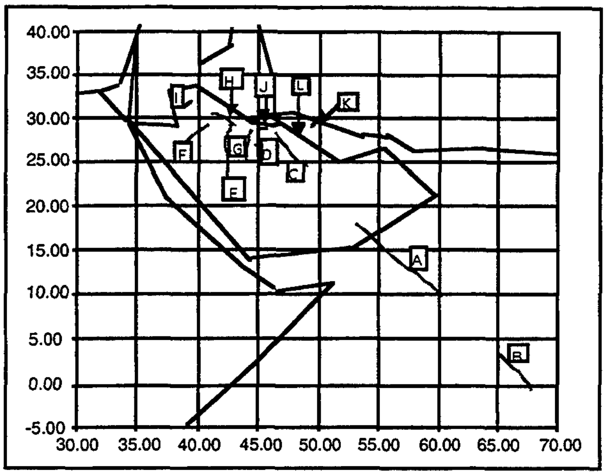
- ✔ Consolidate adjacent aerial-refueling tracks
- ✔ Sort receivers in order by ARCT
- ✔ Combine receiver packages if
  - times are within 30 minutes
  - another tanker has unused offload capability
  - aircraft in package are compatible

In my analysis, I sought to identify opportunities for multipoint to have enabled packages of fighters to be combined behind fewer tankers. To do so, I gave greater opportunity for the combination of packages by consolidating the refuelings scheduled on adjacent tracks.

I next sorted the fighter packages on the consolidated tracks by their aerial-refueling control time (ARCT; the time at which the fighter will rendezvous with the tanker), then looked for opportunities to combine the packages behind fewer tankers. I used three criteria for allowing a combination. First, I required that combined fighter packages have an ARCT within 30 minutes of each other. Second, one of the tankers already scheduled must have enough fuel to service the new, combined package of fighters. While using this criterion, I assumed that the tanker aircraft took off with its maximum allowable quantity of fuel. Third, I did not combine flights of incompatible receiver aircraft, such as A-10s and F-15s.

This approach does not attempt to optimize the tanker schedule so that the number of tankers needed is minimized. Instead, it assumes that the fighter schedule is fixed to within 30 minutes and that the tankers scheduled in the ATO were the only ones available. More-flexible assumptions about the availability of the high-offload KC-10s and KC-135Rs and the scheduling of those aircraft would have been possible. However, they would have required me to second-guess the combat planners, with little knowledge of the operational constraints under which they were working.

Tracks and Anchors Used



31 tracks and their receivers were combined into 12.

RAND

Shown here is a graphical representation of the result of my track-consolidation process. The 31 tracks shown earlier were combined into the 12 shown on this slide. The fighter packages on the consolidated tracks were sorted by ARCT, then each was examined for opportunities to use other tankers that were in the air at the same time, besides the one specifically assigned to it in the ATO.

Mission-by-Mission Analysis

Tanker Mission	Tanker Type	Track	Rcvr Type	No. of Rcvrs	ARCT Day/Time	Onload (000s lb)	Fuel Remain	Time Req'd	Time Remain	Rationale for Combining/ Not Combining
147	KC-135E	I	F-15	4	171230Z	80	20	30.9	29.1	Mission 148 NSE
148	KC-135E	I	F-15	4	171420Z	60	40	25.1	14.9	Mission 149 NEF
149	KC-135E	I	F-15	4	171445Z	76	24	33.8	81.2	Missions 150,151 NEF
150	KC-135E	I	F-15	2	171500Z	40	60	15.4	104.6	*Combine w/Mission 151
151	KC-135E	I	F-15	2	171500Z	40	60	15.4	104.6	Mission 152 NSE
152	KC-10	I	F-15E	12	171615Z	170	60	72.6	107.4	Mission 153 NSE/NEF
153	KC-10	I	F-111	8	171800Z	112	118	48.0	132.0	*Combine w/Mission 154 (16 ac!)
154	KC-10	I	F-111	8	171800Z	112	118	48.0	132.0	Mission155 NEF(after comb w/153)
155	KC-10	I	F-111	8	171800Z	112	118	48.0	132.0	Mission 156 NEF
156	KC-10	I	F-4G	10	171800Z	158	72	73.4	96.6	Mission 157 NSE
157	KC-10	I	F-15E	12	171900Z	160	70	69.7	125.3	Mission 159 NEF
158	KC-135E	I	F-15	2	171900Z	40	60	15.4	104.6	*Combine w/Mission 157 (14 ac!)
159	KC-135E	I	F-15E	4	172015Z	60	40	25.1	34.9	*Combine w/Mission 160
160	KC-135R	I	F-15E	4	172015Z	60	60	25.1	34.9	Mission161 NEF(after comb w/159)
161	KC-135E	I	F-15	2	172100Z	40	60	15.4	104.6	Mission 162 incompatible/NSE
162	KC-135E	I	RC-135	1	172230Z	35	65	7.8	22.2	Missions 163,164 incompatible
163	KC-10	I	F-15E	12	172300Z	160	70	69.7	125.3	Mission 165 NEF/NSE
164	KC-135E	I	F-15	2	172300Z	40	60	15.4	104.6	*Combine w/Mission 163 (14 ac!)
165	KC-135E	I	F-15E	4	180015Z	60	40	25.1	34.9	Mission 166 NSE
166	KC-135E	I	F-15	2	180100Z	40	60	15.4	104.6	*Combine w/Mission 167 (6 ac)
167	KC-135E	I	F-15E	4	180100Z	50	50	22.3	127.7	Mission 165 not late enough

NSE: Not soon enough **NEF: Not enough fuel**

RAND

After I identified all the tanker missions for day D+32, I combined them with adjacent tracks and sorted by ARCT. For example, tanker mission 147 was a KC-135E assigned to consolidated track "I"; it refueled a fighter package of 4 F-15s at 1230 hours GMT on February 17. The scheduled onload for the fighters was a total of 80,000 pounds of fuel, leaving 20,000 pounds in the tanker available for offload. The time required to conduct the refuelings was 30.9 minutes, leaving 29.1 minutes available on the track for additional refueling operations. This mission could not be combined with mission 148, because it was "not soon enough," i.e., not within the 30-minute criterion I specified. Missions 148 and 149 were scheduled closely enough to combine, but neither had enough fuel remaining on their assigned tankers to support both packages. Mission 150 was combined with 151 because both were scheduled at the same time, there was enough fuel in one of the tankers to support both flights of fighters, and all the aircraft were compatible.

Analysis Results: Few Opportunities to Combine Tanker Missions

- 21 out of total of 214 tanker missions could be combined with other missions under the analysis criteria.
- However, 13 of the combinations would have resulted in package sizes greater than 8.
- Only one mission combination, No. 139, was limited by time. The other combinations could have been accomplished with single-point.

RAND

The result of my examination of the ATO for one day of the Gulf War was that 21, or about 10 percent, of the 214 tanker missions could be combined. In other words, from our vantage point distant from the actual wartime planning, it seems that there was enough fuel and opportunity to have deleted 21 of the missions.

However, note that 13 of the mission combinations would have resulted in fighter packages with more than eight fighters in them. Eight is sometimes used as a benchmark for the size of fighter packages, although there were over 30 examples of larger packages scheduled in the ATO using the available single-point boom/receptacle technology. Package sizes greater than eight may therefore not be an important limitation on multipoint usefulness.

Perhaps more interesting is the fact that the estimated times remaining on track indicate that all but one of the consolidations could have been accomplished with single-point operations. In other words, in only one mission was the time remaining on track so short that multipoint would have been needed to accomplish the refueling of the combined package of fighters.

It is readily apparent, both from the looseness of the scheduling of the tankers in the ATO and from the more detailed mission-by-mission analysis, that day D+32 of the Gulf War was *not* boom-limited. That day was apparently a day of surged operations; therefore, the hypothesis that boom-limited conditions occur quite ofter during theater fighter-employment operations is not supported and, in my opinion, such conditions are probably quite rare.

This analysis of the day D+32 tanker ATO supports the position of those who maintain that boom-limited conditions occur only very rarely, thereby limiting the opportunity of multipoint to reduce tanker force structure. The frequency of such conditions is clearly of interest in considering whether having a multipoint capability is desirable. However, the analysis does not address the importance that multipoint could have during those times when such conditions *do* occur.

The "rareness" of an event during war is not a valid measure of that event's importance as a planning scenario. In addition, an air campaign environment that was less permissive than that experienced during the Gulf War, or a less one-sided ground campaign, or the shift of tankers to a second MRC would undoubtedly make an aerial-refueling capability a more limiting resource. These possibilities should be weighed carefully in any decision about whether to equip U.S. tankers and fighters with probe/drogue technology.

4. ADDITIONAL OBSERVATIONS

Retrofit of USAF Fighters with Probes

- Probe retrofits would increase the utility of multipoint operations.
- However,
  - current fighters replaced in 10 to 15 years
  - other programs have taken priority
- Evolutionary approach more feasible:
  - Probes on F-22s, Joint Advanced Strike Technology (JAST)

In examining the past studies on multipoint refueling, I came to conclusions on a number of related issues. I provide these here as additional observations on retrofitting the current fighter force, the need to improve planning for aerial refueling, the needs of Naval and Marine aviation, and the sources of difficulties in the current multipoint program.

An issue related to multipoint refueling is whether USAF fighters, which today exclusively use receptacles, should be fitted with probes. Some advocate probe retrofitting because, by increasing the population of probe-equipped receivers, the benefits of multipoint refueling (i.e., a decreased requirement for tankers) would be more fully realized. In this study, I did not have the time or resources to address the question of whether a probe retrofit program could pay for itself by allowing the retirement of tankers from the force.

However, some budgetary and programmatic realities weigh against such a rapid movement to probe/drogue technology. First, the fighters in the inventory today are approaching the end of their design life and are scheduled to be phased out over the next 10 to 15 years. By the time a program was funded, was under way, and all of the fighters were retrofitted, many fighters would already be leaving the inventory. Other, competing programs (e.g., for procuring precision-guided munitions and improved cockpit avionics) have tended in the past to take priority over both multipoint and probe retrofit programs.

An evolutionary acquisition approach would be more realistic. Barring technical difficulties, it would make sense to consider equipping both the F-22 and the JAST aircraft with aerial-refueling probes. With both a receptacle and a probe, these aircraft would have the maximum amount of flexibility with respect to aerial-refueling options.

Employment Planning and Operational Efficiency

- GAO reported much fuel was returned to base or dumped during Gulf War.
- Planners reported a lack of automated tools.
- Multipoint flexibility helps most when plans break down, e.g., post-strike phase.

RAND

The efficiency of tanker employment has also been an issue. It may be another opportunity for savings on tanker costs. The GAO reported in its 1993 report that 85 percent of the tankers transferred less than 50 percent of their available fuel.[12] The remaining fuel was returned to base or, sometimes, when necessary, dumped prior to landing. To GAO, these facts were evidence that a boom-limited environment was the norm during Desert Storm. There is, however, an alternative explanation.

After-action reports indicate that the situation observed by the GAO probably resulted more from the high degree of uncertainty with which operational planners were coping than from the existence of a boom-limited environment. In the absence of automated planning tools, planners used planning factors to estimate the numbers of tankers required in order to ensure mission success. Better planning aids could possibly have enabled the same levels of mission assurance to be achieved with fewer tankers.

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[12]Ochinko, Walter, *Operation Desert Storm: An Assessment of Aerial Refueling Operational Efficiency*, Washington, D.C.: GAO, GAO/NSIAD-94-68, 1993b, p. 6.

Also, from the planning perspective, it appears that the flexibility afforded by multipoint is most useful when plans break down and when fighter/tanker assignments are lost in the confusion of combat. One of these situations mentioned most often has been aerial-refueling support to fighters egressing from the combat zone after making their strikes. There are many reports of 12 or more fighters queued up to receive fuel from a single tanker so that they can make it back to base after a strike. Perhaps better mission planning would ameliorate the situation. But, to reduce mission risk, it is likely that more offload points are needed in the post-strike phase. Multipoint would be one way to provide more points. However, such a requirement is more difficult to quantify than the well-planned pre-strike refueling requirement.

Support to Naval Aviation

- Multipoint is advantageous for Navy and Marine operations
  - All receivers probe-equipped
  - Targets close to littoral; anchorpoint tactics work well
- Navy requirement has yet to be defined

RAND

During the Gulf War, the effectiveness of Navy and Marine aviation was possibly constrained by the availability of compatible land-based tankers. It is clear, just from the substantially larger size of the Navy and Marine fighter packages assigned to the BDA-equipped KC-135 tankers, that there were fewer tankers available to support each fighter.

Regardless of whether a move to probe/drogue technology makes sense for the Air Force in the future, the Navy is the chief current beneficiary of the multipoint program. The targets of Navy fighters are often closer, since the fighter "base" can be moved to where it is needed. Closer targets enable the use of anchorpoint tactics and enable multiple attack packages to be supported by a single tanker mission. Despite these advantages for Naval aviation, the Navy has yet to be a strong advocate of multipoint aerial refueling and has not defined its requirements in this area.

Program Difficulties

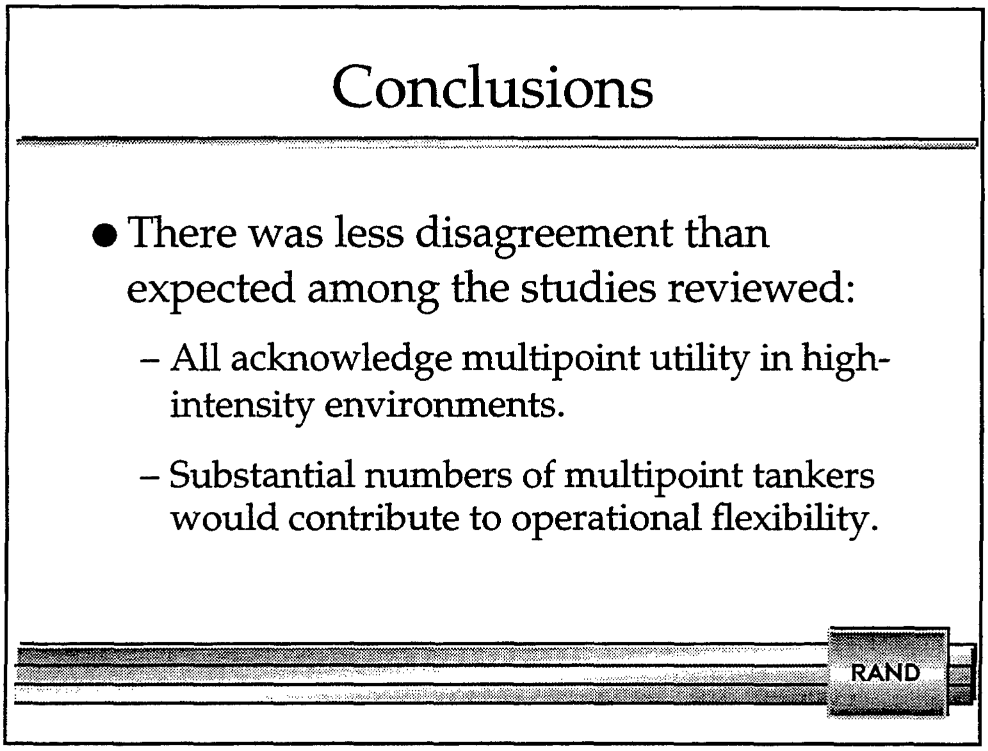
- Acquisition budgets extremely constrained
- Multipoint lacks advocacy and funding
- Limited numbers of drogue-equipped tankers may present scheduling and planning problems

RAND

Because budgets for weapon system acquisition are constrained today, even if multipoint is a good idea, its costs must be gauged in terms of lost opportunities to invest in other programs. For example, would transitioning to multipoint give the United States more operational effectiveness than procuring precision-guided munitions in greater numbers? Even if multipoint does offer advantages, some say the advantages are on the margin and that the United States already has a serviceable system to perform aerial refueling. Changing the approach to aerial refueling must therefore get in line behind other competing priorities. Since the Air Force is satisfied with the current boom/receptacle approach to aerial refueling, program advocacy and funding must come from elsewhere.

The current multipoint program will equip only 33 KC-135Rs with wing-tip drogue pods. Some planners predict that the peacetime basing and employment of such a limited number of tankers will present a dilemma. Differences among aircraft in the force often limit flexibility of aircraft deployment and operation. Conversely, if all tankers were drogue-equipped, flexibility would be enhanced.

5. CONCLUSIONS



The varying results of the studies I reviewed stem primarily from the range of employment scenarios and force structures used, each of which could be considered valid in the context of the particular study objectives. These differences led to varying assumptions about the key analytic parameters and to differing quantitative results. Nevertheless, viewing the results of the studies together, I interpret them as being in agreement on some of the important issues. In particular, there is little disagreement that having more than one offload point on a tanker aircraft during very-high-tempo fighter operations can be of great help. Obviously, just how many tankers can be saved as a result depends on the scenario assumptions. The savings in tanker requirements for high-tempo operations ranged from 17 percent in the Frontier study to 50 percent in the RAND study.

There is also little disagreement that multipoint refueling using probe/drogue technology would contribute to operational flexibility. In the past, BDA kits have had to be installed on KC-135 tankers in order to support probe-equipped receivers. Consequently, the modified tankers had to be dedicated to the support of probe/drogue aircraft, tending to segregate Air Force and Navy/Marine packages from each other.[13] In addition, tanker units had to set aside additional alert aircraft, some with BDAs and some without, to ensure mission reliability. These flexibility and interoperability problems could be solved by having substantial numbers of tankers with both drogues and booms in the inventory.

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[13]To fly joint combat missions, two KC-135s can be required—one that is BDA-equipped for the probe-equipped receivers, the other configured normally.

Conclusions (cont'd)

- In addition to high-tempo operations, multipoint is advantageous
  - where airspace is limiting
  - when fighter bases are close to target areas
  - during the post-strike phase
  - for Naval aviation
  - for a second MRC

RAND

I observed, in my review of the studies, that particular operational circumstances can also create situations in which multipoint capability is advantageous.

In addition to high-tempo fighter operations, limitations related to airspace availability also result in boom-limited environments. In any combat theater, rules must be followed to keep aircraft safely separated. Corridors and tracks are set up by planners to keep ingressing and egressing fighters from conflicting with each other and with their supporting tankers. Airspace near the forward line of battle is also occupied by many other aircraft types, including AWACS, JSTARS, and search-and-rescue aircraft. Limited airspace can be allocated to aerial-refueling operations, which imposes an upper limit on the number of tankers that can be aloft. In this situation, additional offload points on each tanker are advantageous.

When fighter bases are close to the targets, aerial-refueling tracks are shorter, imposing time and distance limitations that make it more difficult for single-point tankers to refuel larger packages of fighters. In addition, shorter mission radiuses allow the greater use of anchorpoint tactics in lieu of tracks. Anchorpoints allow a tanker to be used to support multiple packages of fighters. Unlike track operations, in which the tanker usually returns to base upon reaching the end of its track, anchorpoints place a tanker near the forward line of battle as a "gas station in the sky." Since multipoint can often enable more fighters per package to be supported by a tanker, it can multiply the efficiency of the anchorpoint tactic.

When fighters emerge unpredictably from the battle area during the post-strike phase, operational flexibility is at a premium. Detailed plans have often long since gone awry, and the demand for aerial refueling over short periods of time and in limited areas of airspace may be very high. In such situations, the extra offload points provided by multipoint probe/drogue operations can be very useful, an observation that is supported by much anecdotal evidence from the Gulf War.

As seen during the Vietnam War, aircraft carriers can sometimes station themselves close to coastal target areas. This practice makes anchorpoints a useful refueling tactic and could allow the use of fewer multipoint tankers to support an operation. Nevertheless, the Navy may not need multipoint as much as it simply needs more drogue-equipped tankers.

The circumstances above for which multipoint capabilities on tankers would be advantageous relate primarily to localized boom-limited situations. Probably less common are *theaterwide* boom-limited conditions for large operations in which there is ample opportunity to do detailed planning. Nevertheless, the commencement of a geographically distant second MRC could require the redeployment of tankers from the first. If redeployment resulted in a shortage of tankers in both theaters of operation, then multipoint capabilities could be an important tanker force multiplier. The effect of this possibility is still unknown, however, and requires further study.

Conclusions (cont'd)

- Operational necessity and tactics may reduce multipoint advantages
  - A detailed look at an ATO saw little opportunity for benefits
- Better planning and more-efficient usage have great potential for savings.

RAND

Although multipoint is a possible force multiplier, a consideration of the realities of fighter and tanker employment places limits on the theoretical potential of multipoint to reduce theater tanker requirements.

It is probable that future major contingencies will continue to use tanker tracks to conduct aerial-refueling operations—especially in the early, high-tempo phases of the air campaign, which provide the most stressing requirement for theater aerial-refueling support. Fighter bases and aircraft carriers will often be distant from their targets because of the threat of ballistic missile attack. In addition, tracks allow the fighters to mass far outside of the radar range of the enemy and to arrive almost simultaneously at the defensive perimeter in overwhelming numbers. In these situations, the tracks can be expected to be long enough that fighter-package size would be limited either by fuel-offload availability or by safety considerations, not by the number of offload points.

Nonetheless, the localized situations discussed in Section 2 (airspace limitations, short tracks, unpredictable post-strike events) will frequently make multipoint a big advantage in specific circumstances. To prevent these localized situations, planners have often scheduled additional tankers just to ensure mission success. In the Gulf War after-action reports, planners frequently cited a lack of automated tools with which to plan complex aerial-refueling operations, as well as a lack of prior training. These problems led them to employ simple planning guidelines and factors, and to sometimes overemploy tankers just to be safe. Better planning tools and training could conceivably result in great savings in required tanker sorties during major operations.

Conclusions (cont'd)

- There is little program advocacy on the part of those who would benefit most.
- Fiscal realities imply an evolutionary approach toward multipoint may be best.

RAND

Some of the potential benefits of multipoint refueling are apparent: employment flexibility and interoperability among the Air Force, Navy, Marines, and allied air forces. However, because the cost/benefit picture of possible savings on tanker force structure is murky, and because support by the Navy and Marines is lacking, it is not surprising that the multipoint program has been slow-moving. Since the Air Force believes it already has an effective and serviceable system for its own purposes in the boom/receptacle approach, competing priorities have often taken precedence for limited funding. If multipoint probe/drogue operations are to be adopted more widely by the U.S. military as a whole, a case for them needs to be made by those who will benefit most.

Today, the acquisition budgets of all the Services are more constrained than ever; a tug-of-war is taking place between current readiness and modernization. Even if multipoint operations offer an opportunity to reduce the number of tankers required, the savings would be achieved over the span of years or decades. On the other hand, the costs of retrofitting fighters and tankers with probes and drogues would be incurred in the near term and would be paid for by the delay or cancellation of other high-priority programs.

If defense planners decide that multipoint aerial refueling offers sufficient operational benefits, then the focus should be on increasing the number of probe-equipped receivers in the inventory in the most affordable way possible. It is likely that an evolutionary approach toward a transition to multipoint refueling, involving the installation of refueling probes on the new fighter designs entering the inventory, may be most realistic. This approach would avoid the retrofit of aging current fighters and would provide a clear justification for the installation of drogue pods on the existing tanker fleet.

Appendix

TANKER MISSIONS ON DAY D+32 OF OPERATION DESERT STORM

Table A.1

Opportunities to Combine Tanker Missions on Day D+32 of Desert Storm

Tanker Mission[a]	Tanker Type	Track	Rcvr Type	No. of Rcvrs	ARCT Day/Time	Onload (000s lb)	Fuel Remain	Time Req'd	Time Remain	Rationale for Combining/ Not Combining[b]
1	KC-10	A	B-52G	3	171620Z	150	80	31.0	35.0	Safety/NEF on other tankers
2	KC-10	A	B-52G	3	171620Z	150	80	31.0	35.0	Safety/NEF on other tankers
3	KC-10	A	B-52G	3	171620Z	150	80	31.0	35.0	Safety/NEF on other tankers
4	KC-10	A	B-52G	3	171925Z	150	80	31.0	35.0	Safety/NEF on other tankers
5	KC-135R	A	B-52G	1	172330Z	99	21	18.5	94.5	Safety/NEF on other tankers
6	KC-135R	A	B-52G	1	172330Z	99	21	18.5	94.5	Safety/NEF on other tankers
7	KC-135R	A	B-52G	1	172330Z	99	21	18.5	94.5	Safety/NEF on other tankers
8	KC-135R	A	B-52G	1	172335Z	99	21	18.5	52.5	Safety/NEF on other tankers
9	KC-135R	A	B-52G	1	172335Z	99	21	18.5	52.5	Safety/NEF on other tankers
10	KC-135R	A	B-52G	1	180300Z	99	21	18.5	94.5	Safety/NEF on other tankers
11	KC-135R	A	B-52G	1	180300Z	99	21	18.5	94.5	Safety/NEF on other tankers
12	KC-135R	A	B-52G	1	180300Z	99	21	18.5	94.5	Safety/NEF on other tankers
13	KC-10	B	B-52G	3	171430Z	210	20	41.0	1.0	Safety/NEF on other tankers
14	KC-135R	B	B-52G	2	171430Z	140	0	27.3	14.7	Safety/NEF on other tankers
15	KC-135R	B	B-52G	1	171430Z	70	50	13.7	28.3	Safety/NEF on other tankers
16	KC-135R	B	B-52G	2	171735Z	140	0	27.3	14.7	Safety/NEF on other tankers
17	KC-135R	B	B-52G	1	171735Z	70	50	13.7	28.3	Safety/NEF on other tankers
18	KC-135A	C	F-16	4	170245Z	16	59	14.4	60.6	Incompatible w/19 (pre/post)
19	KC-135E	C	F-15	4	170300Z	80	20	30.9	29.1	Mission 20 NSE
20	KC-135E	C	F-16	10	170345Z	84	16	53.6	21.4	Mission 22 NEF
21	KC-135E	C	F-16	8	170400Z	64	36	41.6	48.4	Mission 22 incompat/23,24 NEF
22	KC-135E	C	A-10A	12	170405Z	36	64	38.4	41.6	Incompatible mission
23	KC-135A	C	F-16	16	170430Z	64	11	57.6	17.4	*Combine with Mission 25 (30 ac!)
24	KC-135E	C	F-16	8	170430Z	68	32	43.2	31.8	Mission 25 NEF left after comb
25	KC-10	C	F-4G	14	170500Z	120	110	76.0	94.0	Mission 26 NEF
26	KC-135E	C	F-16	4	170515Z	28	72	19.2	85.8	Mission 27 NSE
27	KC-135E	C	F-16	8	170600Z	68	32	43.2	46.8	Mission 28 NSE/NEF
28	KC-135E	C	F-16	12	170645Z	70	30	52.0	68.0	*Combine w/Mission 29 (26 ac!)
29	KC-10	C	F-4G	14	170650Z	120	110	76.0	94.0	Mission 30 NSE/NEF
30	KC-135E	C	F-16	8	170745Z	72	28	44.8	135.2	Missions 31,32 NEF
31	KC-135A	C	F-16	16	170800Z	64	11	57.6	17.4	Mission 32 NEF
32	KC-135E	C	A-10A	20	170805Z	60	40	64.0	106.0	Mission 33 NSE
33	KC-10	C	F-4G	12	170940Z	120	110	72.0	98.0	Missions 34,35 NEF
34	KC-135E	C	F-16	12	170945Z	80	20	56.0	0.0	*Combine w/Mission 33 (24 ac!)
35	KC-10	C	F-16	4	171045Z	20	210	16.0	104.0	Missions 36,37 NEF
36	KC-135R	C	F-16	16	171100Z	120	0	80.0	70.0	*Combine w/Mission 35 (12 ac!)
37	KC-135R	C	F-16	16	171115Z	100	20	72.0	78.0	Mission 35 NEF remaining
38	KC-10	C	F-16	16	171200Z	160	70	120.0	120.0	Missions 39–41 NEF
39	KC-135E	C	A-10A	12	171205Z	36	64	38.4	41.6	Incompatible mission
40	KC-135A	C	F-4G	2	171215Z	36	39	18.4	71.6	*Combine w/Mission 38 (18 ac!)
41	KC-135A	C	EF-111	4	171230Z	60	15	25.1	74.9	Incompatible w/42 (pre/post)
42	KC-10	C	RF-4	16	171300Z	140	90	88.0	82.0	Mission 43 NEF
43	KC-135A	C	EC-135L	1	171330Z	30	45	7.0	8.0	Mission 44 NSE/NEF
44	KC-135R	C	F-16	16	171445Z	128	0	83.2	21.8	Missions 45, 46 NEF
45	KC-135E	C	F-15	4	171500Z	80	20	30.9	29.1	Mission 46 NEF

Tanker Mission[a]	Tanker Type	Track	Rcvr Type	No. of Rcvrs	ARCT Day/Time	Onload (000s lb)	Fuel Remain	Time Req'd	Time Remain	Rationale for Combining/ Not Combining[b]
46	KC-135R	C	F-16	14	171500Z	110	10	72.0	33.0	Mission 47 NSE
47	KC-135E	C	A-10A	12	171605Z	36	64	38.4	41.6	Mission 48 NSE
48	KC-135R	C	F-4G	10	171720Z	88	32	55.2	124.8	Mission 49 NSE
49	KC-135E	C	F-15E	8	171820Z	80	20	38.9	161.1	Missions 50, 51 NEF
50	KC-135E	C	F-4G	8	171830Z	72	28	44.8	45.2	Mission 51 NEF
51	KC-135E	C	F-4G	8	171830Z	72	28	44.8	45.2	Mission 52 NSE
52	KC-135E	C	A-10A	12	172005Z	36	64	38.4	41.6	Mission 53 NSE
53	KC-135E	C	F-16	8	172045Z	80	20	48.0	42.0	Mission 54,55 NEF
54	KC-135E	C	F-16	8	172045Z	80	20	48.0	27.0	Mission 55 NEF
55	KC-135A	C	E-3	1	172300Z	50	25	10.3	48.7	Incompatible mission
56	KC-10	C	F-4G	12	172330Z	146	84	82.4	207.6	Mission 58 NSE
57	KC-135E	C	F-15E	8	172350Z	80	20	38.9	161.1	*Combine w/Mission 56 (20 ac!)
58	KC-135E	C	A-10A	12	180005Z	36	64	38.4	41.6	Incompatible/Mission 59 NSE
59	KC-135A	C	F-15E	4	180050Z	60	15	25.1	45.9	Mission 60 NSE
60	KC-135A	D	F-15	4	170230Z	60	15	25.1	64.9	Mission 61 NSE
61	KC-135A	D	F-4G	4	170400Z	40	35	24.0	41.0	Mission 62 incompatible/NEF
62	KC-135E	D	RC-135	1	170400Z	85	15	16.2	43.8	Mission 63 NSE
63	KC-135E	D	F-16	14	170500Z	84	16	61.6	33.4	Mission 64 NSE
64	KC-135A	D	A-10A	6	170600Z	30	45	24.0	116.0	Incompatible
65	KC-135E	D	RF-4	6	170635Z	70	30	36.6	93.4	Mission 66 NSE/incompatible
66	KC-135A	D	RC-135	1	170930Z	55	20	11.2	18.8	Mission 67 NSE/incompatible
67	KC-135E	D	F-16	14	171015Z	84	16	61.6	18.4	Mission 68 NEF
68	KC-135A	D	F-4G	2	171040Z	20	55	12.0	28.0	Mission 69 NSE
69	KC-135A	D	RF-4	4	171200Z	40	35	24.0	76.0	Mission 70 NSE
70	KC-135A	D	F-111	4	171415Z	80	0	30.9	14.1	Mission 71 NEF
71	KC-135A	D	F-111	4	171445Z	80	0	30.9	14.1	Missions 71,72 NEF
72	KC-135A	D	F-4G	2	171500Z	20	55	12.0	28.0	*Combine w/Mission 73 (6 ac)
73	KC-135E	D	F-111	4	171515Z	80	20	30.9	14.1	Mission 74 NSE
74	KC-135A	D	F-111	4	171545Z	80	0	30.9	14.1	Missions 75,76,77 NEF
75	KC-135E	D	E-3	1	171600Z	95	5	17.8	42.2	Missions 76,77 NEF
76	KC-135E	D	RC-135	1	171600Z	85	15	16.2	43.8	Mission 77 NEF
77	KC-135A	D	F-111	4	171615Z	80	0	30.9	14.1	Mission 78 NSE
78	KC-135E	D	F-111	4	171645Z	80	20	30.9	14.1	Missions 79, 80 NEF
79	KC-135A	D	EF-111	4	171650Z	70	5	28.0	102.0	Mission 80 NEF
80	KC-135A	D	F-111	4	171715Z	80	0	30.9	14.1	Mission 81 NEF
81	KC-135E	D	E-3	1	171730Z	95	5	17.8	42.2	Mission 82 NEF
82	KC-135A	D	E-8	1	171800Z	50	25	10.3	49.7	Mission 83 NSE
83	KC-135A	D	EF-111	4	172050Z	70	5	28.0	102.0	Mission 84 NSE/incompatible
84	KC-135A	D	E-3	1	172130Z	50	25	10.3	49.7	Mission 85 NEF
85	KC-135A	D	RC-135	1	172130Z	35	40	7.8	22.2	Mission 86 NEF/incompatible
86	KC-135R	D	F-111	6	172200Z	120	0	46.3	23.7	Mission 87 NSE
87	KC-135R	D	F-111	6	172300Z	120	0	46.3	23.7	Mission 88 NSE/NEF
88	KC-135A	D	EF-111	2	172340Z	40	35	15.4	44.6	Mission 89 NEF
89	KC-135R	D	F-111	6	172400Z	120	0	46.3	23.7	Mission 88 NEF
90	KC-135R	E	F-117	4	171735Z	90	30	44.0	176.0	Mission 91 NEF/safety
91	KC-135R	E	F-117	4	171735Z	90	30	44.0	176.0	Mission 92 NSE/safety
92	KC-135R	E	F-117	4	172120Z	90	30	44.0	176.0	Missions 93–97 NEF/safety
93	KC-135R	E	F-117	4	172120Z	90	30	44.0	176.0	Missions 93–97 NEF/safety
94	KC-135R	E	F-117	4	172120Z	90	30	44.0	176.0	Missions 93–97 NEF/safety

Tanker Mission[a]	Tanker Type	Track	Rcvr Type	No. of Rcvrs	ARCT Day/Time	Onload (000s lb)	Fuel Remain	Time Req'd	Time Remain	Rationale for Combining/ Not Combining[b]
95	KC-135R	E	F-117	4	172120Z	90	30	44.0	176.0	Missions 93–97 NEF/safety
96	KC-135R	E	F-117	4	172120Z	90	30	44.0	176.0	Missions 93–97 NEF/safety
97	KC-135R	E	F-117	4	172120Z	90	30	44.0	176.0	Missions 93–97 NEF/safety
98	KC-135R	E	F-117	4	180235Z	90	30	44.0	176.0	Mission 99 NEF/safety
99	KC-135R	E	F-117	4	180235Z	90	30	44.0	176.0	Mission 98 NEF/safety
100	KC-135A	F	EA-6B	1	170740Z	50	25	52.0	8.0	Missions 101–104 NEF
101	KC-135A	F	F-14	2	170740Z	50	25	54.0	6.0	Missions 102–104 NEF
102	KC-135A	F	FA-18	8	170740Z	60	15	76.0	0.0	Missions 103,104 NEF
103	KC-135A	F	FA-18	8	170740Z	60	15	76.0	0.0	Mission 104 NEF
104	KC-135A	F	E-3	1	170800Z	50	25	10.3	49.7	Mission 105 NSE
105	KC-135E	F	FA-18	8	170915Z	70	30	86.0	0.0	Mission 106 NEF
106	KC-135E	F	FA-18	8	170915Z	70	30	86.0	0.0	Mission 107 NSE
107	KC-135E	F	E-3	1	171430Z	95	5	17.8	42.2	Mission 108 NSE
108	KC-135E	F	F-14	2	171735Z	60	40	64.0	11.0	Missions 109,110 NEF
109	KC-135E	F	FA-18	8	171735Z	60	40	76.0	0.0	Mission 110 NEF
110	KC-135E	F	KA-6D	2	171735Z	60	40	64.0	11.0	Mission 111 NSE
111	KC-135A	F	F-14	2	171940Z	50	25	54.0	6.0	Missions 112–114 NEF or time
112	KC-135A	F	FA-18	4	171940Z	50	25	58.0	2.0	Missions 113,114 NEF or time
113	KC-135A	F	FA-18	8	171940Z	50	25	66.0	0.0	Mission 114 NEF
114	KC-135A	F	E-3	1	172000Z	50	25	10.3	49.7	Mission 113 NEF
115	KC-135Q	G	EF-111	2	170350Z	30	45	12.6	32.4	Mission 116 NEF/incompatible
116	KC-135A	G	F-16	12	170400Z	60	15	48.0	2.0	Mission 117 NSE/incompatible
117	KC-135A	G	A-6E	4	170745Z	60	15	68.0	7.0	Mission 118 incompatible
118	KC-135Q	G	EF-111	2	170815Z	30	45	12.6	32.4	Mission 119 NEF
119	KC-135A	G	F-16	12	170830Z	60	15	48.0	2.0	Mission 120 NSE
120	KC-135A	G	A-6E	4	171015Z	60	15	68.0	0.0	Mission 121 NSE/incompatible
121	KC-135A	G	F-16	12	171300Z	60	15	48.0	2.0	Mission 122 NSE/incompatible
122	KC-135E	G	FA-18	8	172030Z	80	20	96.0	114.0	Mission 123 NEF
123	KC-135E	G	FA-18	8	172030Z	80	20	96.0	114.0	Mission 124 incompatible/NEF
124	KC-135A	G	F-4G	8	172100Z	48	27	35.2	24.8	Mission 125 NEF
125	KC-135A	G	F-4G	8	172100Z	48	27	35.2	24.8	MIssion 124 NEF
126	KC-10	H	F-15	4	170200Z	99	131	36.3	158.7	*Combine w/Mission 127 (8 ac)
127	KC-10	H	F-15	4	170230Z	99	131	36.3	173.7	Mission 128 NEF
128	KC-135E	H	F-15	4	170600Z	80	20	30.9	74.1	Mission 129 NEF
129	KC-135E	H	F-4G	4	170620Z	72	28	36.8	103.2	Mission 130 NEF
130	KC-135E	H	F-15	4	170645Z	80	20	30.9	74.1	Mission 131 NSE
131	KC-10	H	F-15	4	170830Z	99	131	36.3	158.7	Mission 132 NSE
132	KC-10	H	F-15	4	170915Z	160	70	53.7	141.3	Mission 133 NSE/NEF
133	KC-135A	H	EF-111	2	171250Z	30	45	12.6	32.4	*Combine w/Mission 134 (10 ac!)
134	KC-10	H	F-15	8	171315Z	160	70	61.7	118.3	Mission 135 NSE
135	KC-135A	H	F-15	2	171915Z	30	45	12.6	32.4	Mission 134 not late enough
136	KC-10	I	F-15	4	170300Z	99	131	36.3	173.7	Mission 137 NSE
137	KC-135R	I	F-4G	6	170520Z	102	18	45.9	14.1	Mission 136 not late enough
138	KC-135E	I	F-15	4	170630Z	80	20	30.9	119.1	Mission 139 NSE/NEF
139	KC-135A	I	F-4G	2	170705Z	36	39	18.4	41.6	*Combine w/Mission 141 (33 ac!)
140	KC-135A	I	A-10A	10	170710Z	30	45	32.0	208.0	Incompatible mission
141	KC-135E	I	F-15	4	170720Z	60	40	25.1	14.9	Mission 142 NSE
142	KC-10	I	F-15	4	170900Z	99	131	36.3	173.7	Mission 143 NEF

Tanker Mission[a]	Tanker Type	Track	Rcvr Type	No. of Rcvrs	ARCT Day/Time	Onload (000s lb)	Fuel Remain	Time Req'd	Time Remain	Rationale for Combining/ Not Combining[b]
143	KC-135E	I	F-14	4	170915Z	40	60	48.0	147.0	Mission 144 NSE
144	KC-135E	I	F-4G	6	171200Z	116	0	49.3	380.7	Mission145 incompat/146,147 NEF
145	KC-135A	I	A-10A	10	171210Z	30	45	32.0	228.0	Incompatible mission
146	KC-135E	I	F-15	4	171230Z	80	20	30.9	119.1	Mission 147 NEF
147	KC-135E	I	F-15	4	171230Z	80	20	30.9	29.1	Mission 148 NSE
148	KC-135E	I	F-15	4	171420Z	60	40	25.1	14.9	Mission 149 NEF
149	KC-135E	I	F-15	4	171445Z	76	24	33.8	81.2	Missions 150,151 NEF
150	KC-135E	I	F-15	2	171500Z	40	60	15.4	104.6	*Combine w/Mission 151
151	KC-135E	I	F-15	2	171500Z	40	60	15.4	104.6	Mission 152 NSE
152	KC-10	I	F-15E	12	171615Z	170	60	72.6	107.4	Mission 153 NSE/NEF
153	KC-10	I	F-111	8	171800Z	112	118	48.0	132.0	*Combine w/Mission 154 (16 ac!)
154	KC-10	I	F-111	8	171800Z	112	118	48.0	132.0	Mission155 NEF(after comb w/153)
155	KC-10	I	F-111	8	171800Z	112	118	48.0	132.0	Mission 156 NEF
156	KC-10	I	F-4G	10	171800Z	158	72	73.4	96.6	Mission 157 NSE
157	KC-10	I	F-15E	12	171900Z	160	70	69.7	125.3	Mission 159 NEF
158	KC-135E	I	F-15	2	171900Z	40	60	15.4	104.6	*Combine w/Mission 157 (14 ac!)
159	KC-135E	I	F-15E	4	172015Z	60	40	25.1	34.9	*Combine w/Mission 160
160	KC-135R	I	F-15E	4	172015Z	60	60	25.1	34.9	Mission161 NEF(after comb w/159)
161	KC-135E	I	F-15	2	172100Z	40	60	15.4	104.6	Mission 162 incompatible/NSE
162	KC-135E	I	RC-135	1	172230Z	35	65	7.8	22.2	Missions 163,164 incompatible
163	KC-10	I	F-15E	12	172300Z	160	70	69.7	125.3	Mission 165 NEF/NSE
164	KC-135E	I	F-15	2	172300Z	40	60	15.4	104.6	*Combine w/Mission 163 (14 ac!)
165	KC-135E	I	F-15E	4	180015Z	60	40	25.1	34.9	Mission 166 NSE
166	KC-135E	I	F-15	2	180100Z	40	60	15.4	104.6	*Combine w/Mission 167 (6 ac)
167	KC-135E	I	F-15E	4	180100Z	50	50	22.3	127.7	Mission 165 not late enough
168	KC-135E	J	F-15	4	170230Z	80	20	30.9	119.1	Mission 169 NSE
169	KC-10	J	F-15	4	170415Z	160	70	53.7	156.3	Mission 170 NEF
170	KC-10	J	F-16	8	170415Z	150	80	76.0	164.0	Mission 171 NSE
171	KC-135E	J	F-15	4	170500Z	80	20	30.9	89.1	Mission 172 NSE/NEF
172	KC-135E	J	F-15	4	170700Z	80	20	30.9	104.1	Mission 173 NSE/NEF
173	KC-135E	J	F-15	10	170800Z	80	20	42.9	47.1	Mission 174 NSE/NEF
174	KC-135E	J	F-15	4	170915Z	80	20	30.9	104.1	*Combine w/Mission 177
175	KC-135R	J	F-15	4	170930Z	110	10	39.4	125.6	Missions 176,177 NEF
176	KC-135R	J	F-15	4	170930Z	99	21	36.3	128.7	Mission 177 NEF
177	KC-10	J	F-16	10	170945Z	135	95	74.0	151.0	Mission 178 NSE/NEF
178	KC-135E	J	F-15	4	171100Z	80	20	30.9	74.1	Mission 179 NSE
179	KC-10	J	F-16	10	171245Z	135	95	74.0	181.0	Missions 180,181,182 NEF
180	KC-135R	J	F-15	6	171245Z	100	20	40.6	139.4	Missions 179, 181,182 NEF
181	KC-135R	J	F-15	4	171300Z	110	10	39.4	110.6	Missions 179,180,182 NEF
182	KC-135R	J	F-15	4	171300Z	99	21	36.3	113.7	Missions 179, 180,181 NEF
183	KC-135A	J	F-15	2	171530Z	40	35	15.4	104.6	*Combine w/Mission 185
184	KC-135A	J	F-15	4	171530Z	60	15	25.1	19.9	Missions 183,185 NEF
185	KC-135E	J	F-15	2	171545Z	60	40	21.1	83.9	Mission 186 NSE
186	KC-135A	J	F-15	2	171730Z	40	35	15.4	104.6	*Combine w/Mission 187
187	KC-135R	J	F-15	4	171730Z	80	40	30.9	149.1	Mission 188 NSE
188	KC-135E	J	F-15	5	171915Z	75	25	31.4	13.6	Mission 189 NEF
189	KC-135A	J	F-15	2	171930Z	40	35	15.4	104.6	Mission 190 NSE
190	KC-135R	J	F-15	2	172030Z	80	40	26.9	123.1	Mission 191 NSE/NEF
191	KC-135A	J	F-15	2	172130Z	40	35	15.4	104.6	Mission 192 NSE/NEF

Tanker Mission[a]	Tanker Type	Track	Rcvr Type	No. of Rcvrs	ARCT Day/Time	Onload (000s lb)	Fuel Remain	Time Req'd	Time Remain	Rationale for Combining/ Not Combining[b]
192	KC-135A	J	F-15	2	172330Z	40	35	15.4	104.6	Mission 193 NSE/NEF
193	KC-135A	J	F-15	4	180030Z	60	15	25.1	19.9	Mission 194 NSE
194	KC-10	J	F-15	4	180130Z	120	110	42.3	197.7	Missions 196,197 NEF/incompatible
195	KC-135A	J	F-15	2	180130Z	40	35	15.4	104.6	*Combine w/Mission 194 (6 ac)
196	KC-135R	K	A-6E	6	170200Z	90	30	102.0	78.0	Mission 197 NEF
197	KC-135R	K	F-14	6	170200Z	90	30	102.0	78.0	Mission 198 NSE
198	KC-135R	K	F-14	6	170420Z	60	60	72.0	188.0	Mission 199 NSE/NEF
199	KC-135R	K	A-6E	6	170500Z	90	30	102.0	78.0	Mission 200 NEF
200	KC-135R	K	F-14	6	170500Z	90	30	102.0	78.0	Mission 201 NSE/NEF
201	KC-135A	K	EA-6B	3	170750Z	30	45	36.0	74.0	*Combine w/Mission 202
202	KC-135R	K	A-6E	6	170800Z	90	30	102.0	78.0	Mission 203 NEF
203	KC-135R	K	F-14	6	170800Z	60	60	72.0	48.0	Mission 204 NSE/NEF
204	KC-135R	K	A-6E	6	171100Z	90	30	102.0	78.0	Mission 205 NSE/NEF
205	KC-135A	K	EA-6B	3	171220Z	30	45	36.0	144.0	Mission 206 NEF
206	KC-135A	K	EF-111	4	171230Z	60	15	25.1	134.9	Mission 207 NSE
207	KC-135R	K	A-6E	6	171400Z	60	60	72.0	108.0	Mission 208 NSE/NEF
208	KC-135R	K	A-6E	12	171700Z	90	30	114.0	66.0	Mission 209 NSE/NEF
209	KC-135R	K	A-6E	6	172000Z	90	30	102.0	78.0	Mission 210 NSE/NEF
210	KC-135R	K	A-6E	6	172300Z	90	30	102.0	77.0	Mission 209 not late enough
211	KC-135E	L	F-14	8	170330Z	60	40	76.0	224.0	Mission 212 NSE/NEF
212	KC-135E	L	F-14	8	171000Z	60	40	76.0	224.0	Mission 213 NSE/NEF
213	KC-135E	L	F-14	8	171530Z	60	40	76.0	224.0	Mission 214 NSE/NEF
214	KC-135E	L	F-14	8	171530Z	60	30	76.0	224.0	Mission 213 not late enough/NEF

NOTES: ac—aircraft; ARCT—aerial-refueling control time; NEF—not enough fuel; NSE—not soon enough.

[a]Boldface numbers indicate mission identified as able to be combined with another mission.
[b]Asterisk (*) signals reason for combining.

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