DOCUMENTED BRIEFING

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Measuring Effects of Payload and Radius Differences of Fighter Aircraft

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Prepared for the United States Air Force

Project AIR FORCE

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PREFACE

This Documented Briefing develops and applies methods for measuring the consequences of payload and radius differences of F-15E and F-16C Block 50 fighter aircraft flying air-to-ground missions. The result of a special response effort by Project AIR FORCE (PAF) for the United States Air Force Office of the Principal Deputy for Acquisition (SAF/AQ), this research answers specific questions that were an outgrowth of another PAF project that examined alternative force structures for the future.[1]

Staff from the Investment Strategies for Future Tactical Air Capabilities study performed this work as part of the Force Structure and Modernization Program of Project AIR FORCE. It examines issues that should be of interest to personnel involved in acquisition planning, plans and operations, and programs and evaluation, including the analysis community.

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[1]Christopher Bowie, Fred Frostic, Kevin Lewis, John Lund, David Ochmanek, and Philip Propper, *The New Calculus, Analyzing Airpower's Changing Role in Joint Theater Campaigns*, RAND, MR-149-AF, 1993.

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FIGURES

SUMMARY

This research develops and applies an analytical framework to measure how inherent differences in F-15E and F-16C Block 50 payload and radius characteristics influence the ability of the two aircraft to deliver CBU- and GBU-class air-to-ground weapons against a variety of target sets.

F-15Es and Block 50 F-16Cs both carried LANTIRN navigation and targeting pods for air-to-ground missions to provide a qualitatively comparable precision attack capability. Several alternative assumptions were made about F-16C carriage of external fuel tanks to assess their potential for improving radius and loiter capability. The F-16Cs carried either standard 370-gallon tanks or larger 610-gallon wing tanks that only the Israeli Air Force currently uses. Excursions were also run replacing the F-16C's centerline electronic countermeasures (ECM) pod with a 300-gallon external tank.

COST CONSIDERATIONS

The historical ratio of F-15 to F-16 procurement costs has exceeded a factor of two over most of the common production run of F-15s and F-16s of all models, but appears to be declining with fighter production cutbacks of recent years. This trend provides impetus for reassessments of the relative cost-effectiveness of the two weapon systems when procured at low rates such as 24 aircraft per year.

> ***Current cost estimates indicate F-15Es cost about 50 percent more to buy and operate than Block 50 F-16Cs when both are equipped with LANTIRN pods (the configuration evaluated in this document). For the extremes of the cost estimates for each aircraft, F-15Es cost from 40 to 62 percent more than F-16Cs. This broad cost range is carried throughout the analysis to test for the robustness of conclusions.***
>
> ***The F-15E:F-16C cost relationship means the Air Force can buy and operate three squadrons of F-16Cs for every two squadrons of F-15Es. The value of this force structure advantage must be balanced against the relative capabilities of equal cost forces of F-15Es and F-16Cs.***

DELIVERING AIR-TO-GROUND WEAPONS

F-15Es and Block 50 F-16Cs were compared delivering GBU-24, CBU-87/-97, and notional 1000- and 2000-pound JDAM weapons against Southwest Asian and Korean target sets. Key elements of this assessment included payload-radius relationships for various aircraft configurations and for various assumptions about in-flight refueling, and characterizations of base-to-target distances for alternative assumptions about theaters and basing postures. This information was integrated with other data describing aircraft sortie, abort, and attrition rates in a transparent "bookkeeping model" to gain insights about the relative strengths and weaknesses of F-15Es and F-16Cs. Measures of effectiveness for 30 days of air-to-ground missions included the number and ton-miles of weapons delivered, the distribution of weapon deliveries by radius, the number of targets within range, and the number of bridges cut and tanks killed. These were combined with estimates of procurement and operating costs to evaluate cost-effectiveness.

For most of the air-to-ground cases examined, the effectiveness advantage of the F-15E relative to the F-16C was more than commensurate with its higher procurement and operating costs.

The F-15E cost-effectiveness advantage is most pronounced in larger theaters where it carries heavier payloads to a larger fraction of the target base.

The F-16C exhibits its best performance in more compact theaters that shaped its original design.

In-flight refueling improves the effectiveness of both aircraft, but does not alter their relative cost-effectiveness ranking.

Several actions, while not uniformly desirable from an operational and technical perspective, can collectively enhance the target coverage and payload carriage of the F-16C in larger theaters. These actions include (1) basing closer to target areas, (2) tanking closer to hostile territory when operationally prudent (tankers 100 nmi behind border), (3) in-flight refueling over the maximum takeoff gross weight limit (but below the limit set by its structure), (4) using larger 610-gallon wing tanks, and (5) substituting a 300-gallon centerline tank for an ECM pod when possible.

FUTURE CONSIDERATIONS

Looking to the future, the following observations are germane to the comparisons of the F-15E and F-16C addressed here.

Employment characteristics of inertially and GPS-aided weapons could allow the Air Force to more readily exploit the inherent payload carriage advantage of the F-15E.

Most regional conflict scenarios (Korea is a notable exception) involve long distances from bases to targets, favoring aircraft having greater combat radius, such as the F-15E.

As the force structure contracts, higher quality systems can help maintain force capability. This comparison of the F-15E and F-16C illustrates several key dimensions of these quality-quantity tradeoffs (size of equal cost forces, payload delivered, targets covered) for air-to-ground missions.

ACKNOWLEDGMENTS

John Matsumura performed early payload-radius calculations for this work and together with Walter Hobbs developed the data describing the distribution of distances from airbases to targets. Dave Dreyfuss and Donna Hoffman assisted in estimating aircraft procurement and operating costs. Gary Massey helped in the acquisition of cost data. Dan Raymer assisted in the development and evaluation of aerodynamic drag estimates and reviewed selected payload-radius calculations. John Green provided guidance about weapon lethality. Dave Spencer served as technical reviewer.

SYMBOLS

a/c	aircraft
ACC	Air Combat Command
AF	Air Force
AFR	Air Force Regulation
AWACS	Airborne Warning and Control System
BES	Budget Estimate Submission
CAP	Combat Air Patrol
CBU	Cluster Bomb Unit
CEM	Combined Effects Munition
CFT	Conformal Fuel Tank
CL	Centerline
CONUS	Continental United States
DCA	Defensive Counterair
DoD	Department of Defense
ECM	Electronic Countermeasures
FPLAN	Flight Planner
ft	feet
FY	Fiscal Year
F-16C/370	F-16C with 370-gallon wing tanks
F-16C/610	F-16C with 610-gallon wing tanks
gal	gallon
GBU	Guided Bomb Unit
GPS	Global Positioning System
HHH	High-High-High
HLLH	High-Low-Low-High
IFR	In-flight Refueling
JDAM	Joint Direct Attack Munition
LANTIRN	Low-Altitude Navigation and Targeting Infrared System for Night
LDGP	Low-Drag General Purpose
Mk	Mark
MRF	Multirole Fighter
NBC	Nuclear-Biological-Chemical
nm/nmi	Nautical mile
NVP	LANTIRN navigation pod
O&S	Operations and Support
OWE	Operating Weight Empty
PAA	Primary Aircraft Authorization
PAF	Project AIR FORCE

POM	Program Objective Memorandum
PPBS	Program Planning and Budgeting System
PW	Pratt & Whitney
RAND	Research And Development
RF	Radio frequency
SAF	Secretary of the Air Force
SAR	Selected Acquisition Report
SFW	Sensor Fuzed Weapon
SLSU	Sea Level Static Uninstalled
SWA	Southwest Asia
TAC	Tactical Air Command
TER	Triple Ejection Rack
TGP	LANTIRN targeting pod
TMD	Tactical Munitions Dispenser
TOGW	Takeoff Gross Weight
USAF	United States Air Force

1. INTRODUCTION

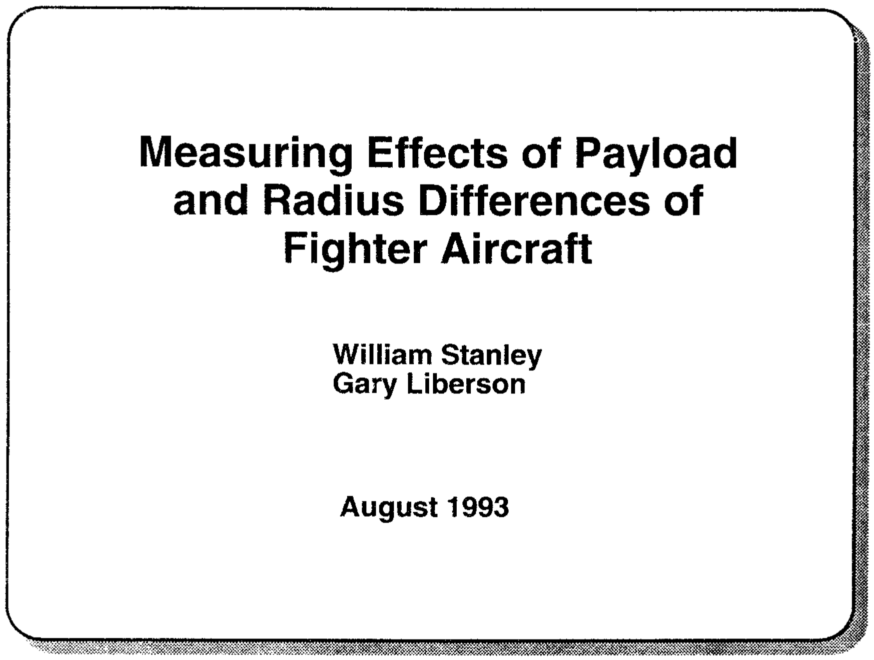

Figure 1.1—Measuring Effects of Payload and Radius Differences of Fighter Aircraft

This briefing documents the results of a Project AIR FORCE special response analysis first presented to the Air Staff in December 1992. Revised versions of the briefing were presented in April and August 1993.

Background

- **RAND Base Force briefing raises issue of relative cost-effectiveness of F-15Es and F-16Cs in terms of payload and radius performance**
- **Air Force (SAF/AQ) suggests that PAF compare the cost-effectiveness of the two aircraft on air-to-ground missions**

Objectives

- **Develop rapid, transparent method for measuring effects of payload and radius differences**
- **Use method to compare F-15E and F-16C Block 50 aircraft**

Figure 1.2—Introduction

This effort is an outgrowth of another Project AIR FORCE study that raised questions about the relative cost-effectiveness of F-15Es and F-16Cs in air-to-ground missions arising from their differences in payload-radius characteristics. In consultation with the Air Force, Project AIR FORCE agreed to make some limited comparisons of the two aircraft.

To be consistent with the nature of the request and the time available to respond, this effort has, with a few exceptions, used rapid, transparent methods that permit outputs to be easily explained in terms of model or process inputs. F-15E and F-16C Block 50 aircraft were used to exercise the methodology developed.

- **Broader questions about the desirability of further F-15E and/or F-16C production exceed the scope of this analysis**
- **Minimum force size constraint for quality-quantity tradeoffs not directly assessed**
- **Possible differences in F-15E and F-16C survivability and weapon delivery precision not directly addressed**

Figure 1.3—Scope

As budgets decline, questions arise about the comparative desirability of continuing production of one or more fighter systems. Such questions involve issues beyond the scope of the current analysis, such as the health of the industrial base, foreign military sales effects, hedges for multirole fighter replacements, etc.

Some of the results to be shown here illustrate that one weapon system can in some circumstances provide more capability than another despite being bought in smaller quantities. The results do not, however, establish a quantity floor for making quality/quantity tradeoffs.

This document illustrates the comparative ability of aircraft to deliver various payloads of air-to-ground weapons against particular target distributions. Comparative lethality and survivability are not addressed.[1]

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[1]The air-to-ground assessment uses standard Air Force planning factors for attrition that reflect expected losses from air-to-air fighters and ground-based defenses.

- **Emphasize parameters that help differentiate aircraft**
- **Emphasize relative comparisons**
- **Compare the relative cost-effectiveness of several aircraft configurations**

Aircraft	Missions	Weapons	Target sets
F-15E	Air-to-ground	AIM-9/AIM-120	SWA - GBU/CBU tgts
F-16C Blk 50/370	DCA CAP	GBU-24	SWA - close basing
F-16C Blk 50/610		CBU-87/97	SWA - in-flight refueling
		JDAM	Compact

Figure 1.4—Approach

The analytical approach adopted deliberately avoids exhaustively modeling tactical missions, but instead focuses on major parameters that differentiate the F-15E and F-16C and uses those parameters to make relative comparisons. The cost-effectiveness of the systems was compared for several aircraft configurations, mission types,[2] weapon loads, and distributions of target radii noted above.

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[2]The principal focus was air-to-ground missions. A brief examination of how differences in loiter performance influence the ability of aircraft to fill defensive counterair (DCA) combat air patrol (CAP) orbits is described in the appendix.

	F-16C	F-15E
Internal fuel, JP8 (lb)	7,162	23,626*
Operating weight empty (lb)	20,185	38,357
Engine	F100-PW-229	(2) F100-PW-229
Thrust lb (SLSU)	29,400	58,210
Length (ft)	49.3	63.8
Wing area (sq ft)	300	608
Max TOGW (lb)	42,300	81,000
Max in-flight GW limit (lb)	48,000	81,000?

* Includes CFTs.

SOURCE: ASC/XR; Lockheed-Fort Worth Company.

Figure 1.5—Aircraft Physical Characteristics

The physical characteristics of the two aircraft are shown above. Note that maximum gross weight limits for the F-16C differ for takeoff and in flight. The former limit is set by braking constraints and the latter by structural limits. These limits influence the extent to which the F-16C can take advantage of larger 610-gallon external wing tanks, particularly on heavily loaded air-to-ground missions. In-flight refueling cases will illustrate how the performance of the F-16C compares with that of the F-15E for both assumptions about gross weight limits.

McDonnell Aircraft Company has examined various means for carrying more fuel on F-15Es, including configurations with 900-gallon external wing tanks, 750-gallon external centerline tanks, larger conformal fuel tanks (CFTs), and new internal fuel tanks using free space in the airframe. Realizing the benefits of this greater fuel capacity on air-to-ground missions when carrying heavy weapon payloads would generally require operating beyond the current 81,000-pound gross weight limit. An assessment of aircraft changes that might be required to operate at weights beyond 81,000 pounds is not available at this time (hence the question mark in the figure above). Our analysis assumes the 81,000-pound limit applies for both takeoff and in flight.

- **Ratio of F-15E to F-16C procurement costs getting smaller**
  - **Can buy and support about 3 sqdns of F-16Cs for 2 sqdns of F-15Es**
- **For most cases examined, equal cost buy of fewer F-15Es can carry more air-to-ground weapons to target areas than larger buy of F-16C Block 50s**
- **Large payload/long radius vehicles consistent with**
  - **Future payloads--JDAM**
  - **Larger regional theaters--Iraq, Iran**
  - **Desire to maintain or enhance force capability despite force structure cuts**

Figure 1.6—Preview of Conclusions

Figure 1.6 previews some of the key findings of this analysis. At the extremely low production rates of today, the ratio of F-15E to F-16C procurement costs is getting smaller. At today's costs, one can buy and support two F-15Es for three F-16C Block 50 aircraft, assuming both aircraft are equipped with LANTIRN navigation and targeting pods. This analysis examines whether the F-15E offers a capability advantage commensurate with its greater costs.

Over a wide spectrum of cases, our analysis suggests that an equal cost but smaller force of F-15Es is a more cost-effective carrier of weapons to the target area than an alternative larger force of F-16Cs. Looking to the future, the employment characteristics of future precision weapons, the size of many potential regional conflict theaters, and the reality of expected force structure contractions seem consistent with the capabilities offered by large payload, long radius vehicles such as the F-15E.

The remainder of the briefing illustrates how we arrived at these conclusions.

2. PROCUREMENT AND O&S COST COMPARISONS

- Introduction
- **Procurement and O&S costs**
- Air-to-ground weapon delivery cost-effectiveness
- Sensitivities
- Conclusions

Figure 2.1—Outline

The briefing compares the costs of the aircraft, shows assumptions and results for air-to-ground assessments, explores the sensitivity of the air-to-ground findings to alternative assumptions, and draws conclusions.

- **Procurement and 20-year O&S costs**
  - **F-15Es and F-16C Block 50s with LANTIRN**
  - **72 PAA CONUS-based active wings**
- **Buy 100 aircraft per wing plus 20-year attrition reserve**
- **Costs for low production rates--24 aircraft per year to the USAF**
- **O&S cost data from AFR 173-13 data base**
- **Compare cost ratios (F-15E to F-16C Block 50) to effectiveness ratios**

Figure 2.2—Cost Comparisons

The aggregate costs of procurement and 20 years of operations and support (O&S) constitute the basis for cost comparisons. No new major production initiative is assumed for either aircraft. Costs are those associated with low-rate production at 24 aircraft per year. Having 72 PAA (Primary Aircraft Authorization) aircraft in the field implies a need to procure more aircraft—about 100 aircraft per wing to cover not just combat-coded aircraft, but also those used for training, testing, and aircraft to compensate for those in the maintenance and logistics system.[1] Sufficient attrition reserve aircraft were procured to cover normal peacetime losses for 20 years of operations.

Combining Air Force data on aircraft O&S costs (AFR 173-13), F-16 procurement cost estimates from the fall 1992 Budget Estimate Submission (BES), and F-15E data forwarded to the Air Staff from the F-15 program office, we developed the aggregate costs for wings having 72 F-15E or F-16C Block 50 aircraft, assuming both were equipped with LANTIRN

[1]Air Combat Command planning assumes an inventory of 100 aircraft is needed to maintain one combat ready wing of 72 fighter aircraft. The remaining aircraft include 2 for test and evaluation, 18 for initial aircrew training, and 8 for depot maintenance and modifications. *Fighter Roadmap, 1991-2001*, Air Combat Command Headquarters, October 1991 (not releasable to the general public).

navigation and targeting pods. Overall assessments of cost-effectiveness were developed by comparing effectiveness ratios with ratios of F-15E to F-16C costs.

- **Assume continuity in USAF and Saudi F-15 buys**
- **F-16Cs use inventory ECM pods at no additional cost**
- **F-16C costs do not reflect possible need for new computer to accommodate computing needs for LANTIRN and other future enhancements**
- **JDAM integration costs not included**
- **Broad range of costs used as hedge against imprecise estimates of future costs**

Figure 2.3—Cost Caveats

Figure 2.3 lists several of the more important caveats regarding the development of aircraft costs. They are consistent with our approach of defining a large band of plausible relative costs for the two aircraft and seeking to identify only unambiguous distinctions between aircraft.

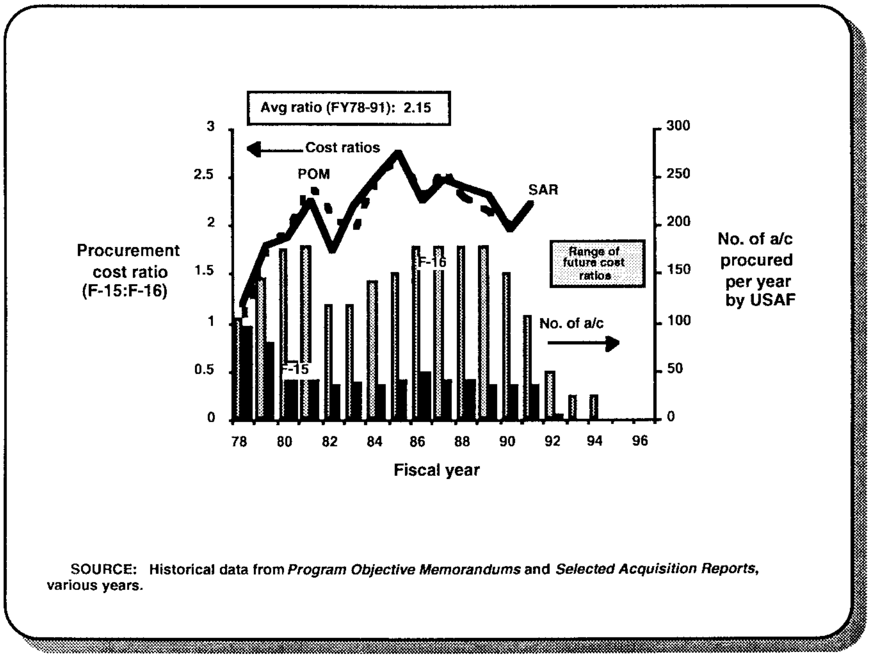

Figure 2.4—Historical Ratio of F-15:F-16 Procurement Costs

Figure 2.4 shows a retrospective and prospective picture of the relative procurement costs of F-15s and F-16s (the solid and dashed lines). The F-16 has cost substantially less than the F-15 for most of its production run (less than half as much), not only because it is inherently a smaller and less costly aircraft to produce than the F-15, but also because of the economies offered by its large base of production and high production rates. We will illustrate on subsequent charts that the Air Force is paying much more for both aircraft now than it has in the past as production rates have fallen. Cost estimates for future procurement suggest that the cost relationship between the two aircraft may be changing when both are produced at low rates, as illustrated at the right of the chart.

F-16 procurement for the USAF has fallen from 180 aircraft per year during the mid- to late-1980s to 24 in FY93 (the columns in the chart), plus some additional foreign sales in both cases. Procurement of F-15Es has, for now at least, concluded for the Air Force, although several years of procurement for Saudi Arabia remain at 24 aircraft per year. Measured relative to peak F-15E buys of 42 aircraft per year, and more commonly 36 aircraft per year, the fall in production rate to 24 per year for the F-15E has not been so precipitous.

FY	USAF buy	Saudi buy	USAF recurring unit flyaway cost	USAF non-recurring cost per a/c	Total USAF flyaway cost	Unit procurement cost (1.24x flyaway
93	24	24				
94	24	24				
95	24	24				
96	24					
97	24					
98	24					
99	24					

	Lowest	Average	Highest	*Avg (1st 200)*
Unit procurement cost (FY93-97):				*45.3*

(Millions FY93$)

SOURCE: Personal communication, United States Air Force, Principal Deputy for Acquisition (Fighter Division), September 19, 1992.

Figure 2.5—F-15E Procurement Costs

Depicted in Figure 2.5 is the framework used to develop projections of possible F-15E procurement costs for the future.[2] We used flyaway costs developed by the F-15 program office and forwarded to RAND by the Office of the Principal Deputy for Acquisition (Fighter Division) during the fall of 1992. We applied factors based on historical program experience to add nonrecurring costs and allowances for initial spares, peculiar support equipment, training, etc., to arrive at the range of unit procurement costs shown at the bottom of the chart. These costs are significantly higher than the average cost for the first 200 F-15Es purchased by the Air Force.

[2]Refer to DB-102/1-AF (not releasable to the general public), for the cost estimates used.

FY	USAF buy	USAF unit procurement cost	LANTIRN pod set cost (million FY93$)	Total unit procurement cost
93	24		4.2	
94	24			
95	24			
96	24			
97	24			
98	24			
99	24			

	Lowest	Average	Highest
Unit procurement cost (FY93-97):			

SOURCE: *USAF BES*, Air Force Studies and Analysis Agency, December 1992 (not releasable to the general public); *Selected Acquisition Report: LANTIRN*, December 31, 1991.

Figure 2.6—F-16C Block 50 Procurement Costs

The framework used to develop F-16C costs is shown in Figure 2.6. F-16C costs were developed using the fall 1992 Budget Estimate Submission and a separate evaluation of LANTIRN costs using a recent LANTIRN *Selected Acquisition Report* (*SAR*). Although shown above as an incremental cost to the cost of 24 aircraft each year, LANTIRN would probably have to be produced in a large production lot to keep costs at the level shown. Historical SAR data illustrating cost as a function of production rate were used to develop LANTIRN costs. Overall F-16 costs are considerably higher at 24 per year than at historically higher production rates, and contribute to reducing the ratio of F-15E costs to F-16C costs.[3] Of course, these Block 50 F-16Cs, while costing more than earlier model F-16s, also offer considerably more capability.

Operations and support costs were developed from factors contained in the database for AFR 173-13 for CONUS basing of active wings having 72 PAA aircraft.

[3]The cumulative average unit procurement cost for all USAF F-16s procured between 1977 and 1993 was $18.6 million (FY 93 $). The cost for the FY93 buy of 24 (which does not include LANTIRN pods) was about $32 million each. *F-16 Selected Acquisition Report*, December 31, 1992.

	F-16C Block 50 with LANTIRN	F-15E
Avg unit procurement		
Avg O&S per year per wing (FY93$)	$204.5 M	$308 M
Total for 72 PAA wing for 20 yrs (126 F-16Cs, 120 F-15Es)		
Cost ratio: F-15E/F-16C	1.50 avg.	(1.40 - 1.62)
"Wing" size for same 20-yr investment	72 PAA	48 PAA

SOURCE: *USAF BES*, Air Force Studies and Analysis Agency, December 1992 (not releasable to the general public); *Selected Acquisition Report: LANTIRN*, December 31, 1991; personal communication, United States Air Force, Principal Duty for Acquisition (Fighter Division), September 19, 1992; Air Force Regulation 173-13.

Figure 2.7—Cost Summary

Combining procurement and O&S costs for the two aircraft, we find that the F-15E costs about 50 percent more to buy and support than the F-16C. Thus, the Air Force can buy and operate about three squadrons of F-16Cs for the cost of two squadrons of F-15Es. For the extremes of costs examined (highest F-15E costs to lowest F-16C costs and vice versa), F-15E costs exceed those of the F-16C with LANTIRN by 40 to 62 percent.

This analytical approach establishes a broad range of costs for making comparisons. For example, holding the F-16C at its nominal cost, the F-15E cost must rise by more than $8 million per aircraft to hit the high end of the cost range (F-15E to F-16C ratio of 1.62). Conversely, holding the cost of the F-15E constant at its nominal value, the cost of the F-16C must rise by more than $5 million per aircraft to hit the low end of the cost range (ratio of 1.40).

This range of costs should cover most, if not all, reasonable costs of near-term system additions to either aircraft. The analytical approach adopted looks for unambiguous rather than subtle differences in cost-effectiveness, which are apparent even when using broad characterizations of possible relative aircraft costs.

3. AIR-TO-GROUND WEAPON DELIVERY COST-EFFECTIVENESS

- Introduction
- Procurement and O&S costs
- **Air-to-ground weapon delivery cost-effectiveness**
  - Payload-radius assessment model and inputs
  - Cost-effectiveness servicing several target sets
- Sensitivities
- Conclusions

Figure 3.1—Outline

This research has focused on air-to-ground payload delivery comparisons. This section describes the methodology adopted to make those comparisons and the results from applying that methodology to F-15Es and F-16Cs.

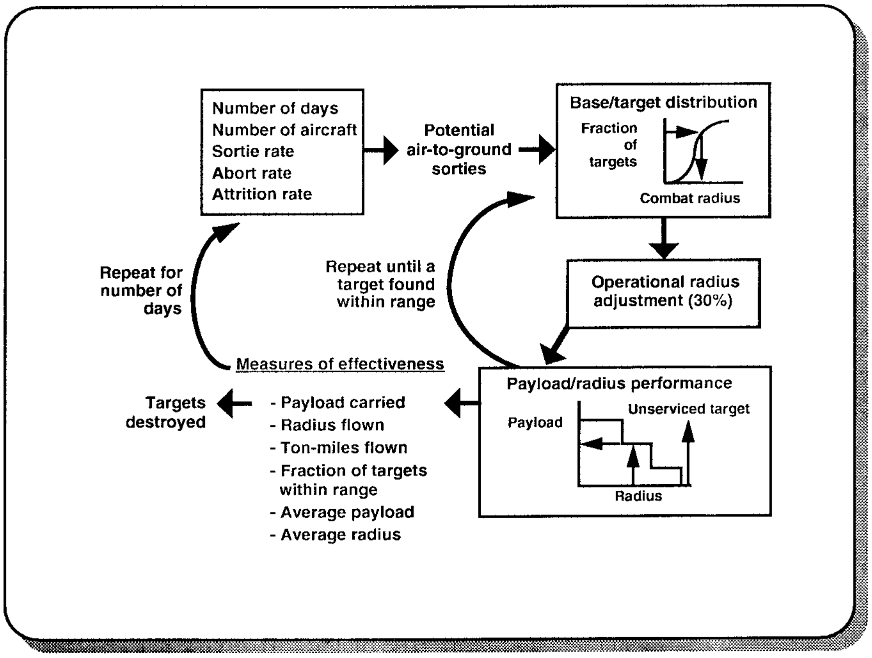

Figure 3.2—Payload-Radius Assessment Model

We developed a simple payload-radius model that compares the ability of various aircraft configurations to service alternative target sets. The model evaluates a specific quantity of one type of aircraft carrying one kind of weapon store for a specified number of days, at a specified sortie rate over time, with specified attrition and abort rates, to arrive at the daily number of sorties for air-to-ground missions. In all cases, aircraft flew for 30 days, with the number of aircraft flown either equal in number or sized to yield equal cost forces. We used standard Air Force planning factors for sortie rates and losses to air-to-air fighters and ground defenses. Personnel from Air Combat Command Headquarters (ACC/LGPY) provided abort rate data.

Differences in F-15E and F-16C sortie, attrition, and abort rates do not drive the conclusions of the analysis. If we apply these factors over 30 days, a force of F-15Es flies about 5 percent more sorties than an equally sized force of F-16Cs. For equal cost forces, that is, 72 F-16Cs and 48 F-15Es, the F-16C force flies 43 percent more sorties. We later compare the bomb delivery potential of such equal cost forces.

For each potential sortie, for a particular basing and theater scenario, the model draws a random number that is used with a distribution of targets as a function of distance to obtain the straight-line distance between the base and target. The model increases that radius by 30 percent to account for factors that add to mission fuel consumption over what would normally be expected if straight-line flight paths were flown—factors such as threat avoidance, routing, rendezvousing, and so forth.[1]

Using payload-radius curves developed by the TAC Ranger model, the payload-radius assessment model determines the payload that can be carried to the desired radius (including the 30 percent operational allowance). If the required radius exceeds the capability of the aircraft, the model notes that fact and then repeats the process until a target is found that is within range. For each sortie, the model records the payload carried, the distance flown, integrative measures such as ton-miles of payload delivered, targets within range, and the like. The model repeats this process for the specified number of days as attrition draws down the size of the force day by day, and then tabulates the results, which can then be compared with results for other aircraft carrying the same type of weapon.

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[1]This is essentially consistent with factors developed by the Joint Studies Group of the Air Combat Command using Desert Storm data in support of multirole fighter studies. Because we assumed the same factor for all aircraft in the analysis, and stress relative comparisons, the specific value selected for the operational radius adjustment is not critical.

- **GBU-24 used as surrogate for JDAM-2000**
  - **Weight, drag, and loading assumed the same**
- **CBU-87 (CEM in a TMD) used as surrogate for CBU-97 (SFW)**
  - **Weight, drag, and loading assumed the same**
- **JDAM-1000**
  - **Weight and drag: Mk 84 is to GBU-24 as Mk 83 is to JDAM-1000**
  - **Loading: analyst judgment, analogous to Mk 83**

Figure 3.3—Weapon Assumptions

We used flight manual values for the weight and drag of the 2000-pound-class laser-guided GBU-24 and the CBU-87 (Combined Effect Munition). We also developed estimates for notional 1000- and 2000-pound-class Joint Direct Attack Munitions (by our notation, JDAM-1000 and JDAM-2000).[2] The CBU-87 acted as a surrogate for the Sensor Fuzed Weapon (SFW), since both are packaged in a Tactical Munitions Dispenser (TMD) having identical drag and loading characteristics.

No definitive estimates exist for the weight, drag, and loading characteristics of JDAM weapons. The JDAM program office indicated the drag of the initial 2000-pound JDAM would likely fall somewhere between the comparatively low drag of a Mk-84 LDGP and would certainly be no greater than the much higher drag of a GBU-15.[3] Lacking

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[2]For convenience, we adopted the naming convention JDAM-1000 and JDAM-2000 to connote 1000- and 2000-pound-class JDAM weapons. The Air Force uses JDAM-1, -2, and -3 to refer to successive versions of a 2000-pound-class weapon with progressively better accuracy characteristics.

[3]A 3-g maneuver capability is desired for JDAM-1. Movable fins the size of those on the Mk-84 can yield only about a 1-g capability. JDAM-1 might use strakes, although they would probably be smaller than those used on the GBU-15. To ensure correct weight and balance characteristics for subsequent versions, JDAM-1 might have a ballasted can on its nose that could later be replaced with a terminal seeker. Phone conversation with

more definitive information, we assumed JDAM-2000 weight, drag, and loading characteristics would be the same as the GBU-24, which falls between the Mk-84 and the GBU-15 in drag. Hence, results for the GBU-24 can also be regarded as applying to a 2000-pound-class JDAM.

Weight and drag characteristics of a 1000-pound-class JDAM were developed by analogy to the JDAM-2000. We used flight manuals and professional judgment to infer aircraft loading constraints for JDAM-1000.

Program Director, Colonel Harrison, and Chief Engineer for JDAM, Gerald S. Brown, ASC/YH, December 1992.

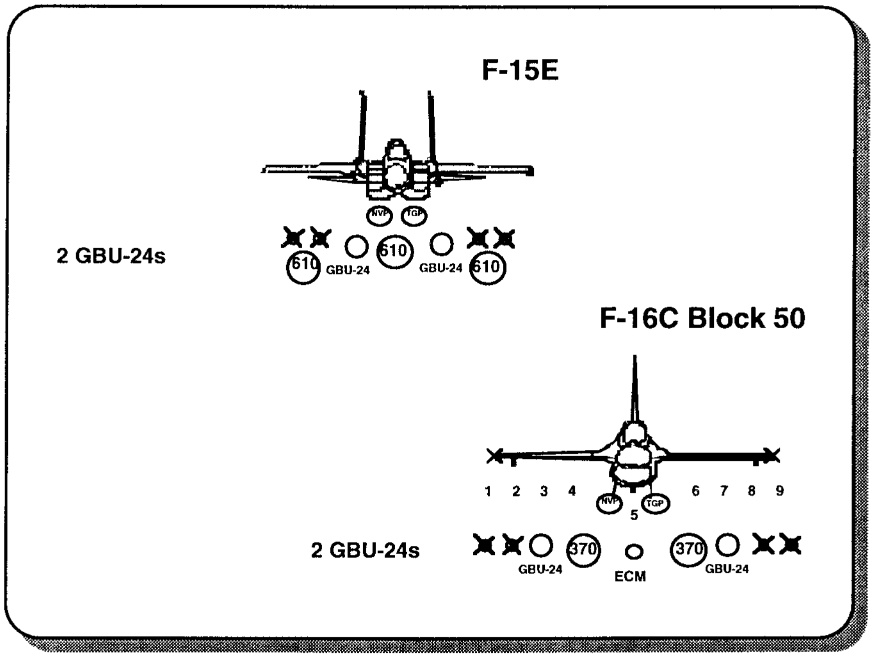

Figure 3.4—Example of an Air-to-Ground Configuration

The configuration of bombs and fuel tanks carried depends on the radius of the mission and weapon-loading constraints, which can change for each sortie evaluated. Figure 3.4 illustrates an example of the weapon-loading arrangement when each aircraft carries two GBU-24 weapons. Both aircraft carry LANTIRN targeting (TGP) and navigation (NVP) pods for all air-to-ground missions we evaluated.

For our baseline cases, we assumed the F-16C carries an electronic countermeasures (ECM) pod on its centerline station. Our sensitivity analysis shows the effect of substituting a 300-gallon fuel tank for the ECM pod. When mission radius requirements dictate, the F-16C carries either 370- or 610-gallon external wing tanks. Otherwise, these wing stations can be used to carry heavy stores. Today, only Israeli F-16s carry 610-gallon tanks.

The F-15E carries as many as three external 610-gallon tanks in addition to its conformal fuel tanks. It can carry weapons on wing stations or its conformal fuel tanks. For missions having shorter radii, weapons can displace the external tanks.

In most cases, both aircraft also carry two AIM-120 and two AIM-9M air-to-air missiles for self-protection. We consulted Air Force flight manuals and personnel from the Seek Eagle office at Eglin Air Force Base to develop proper weapon loadings. We inferred appropriate loadings for postulated future weapons such as JDAM-1000 by examining loadings of existing weapons of similar size and weight.

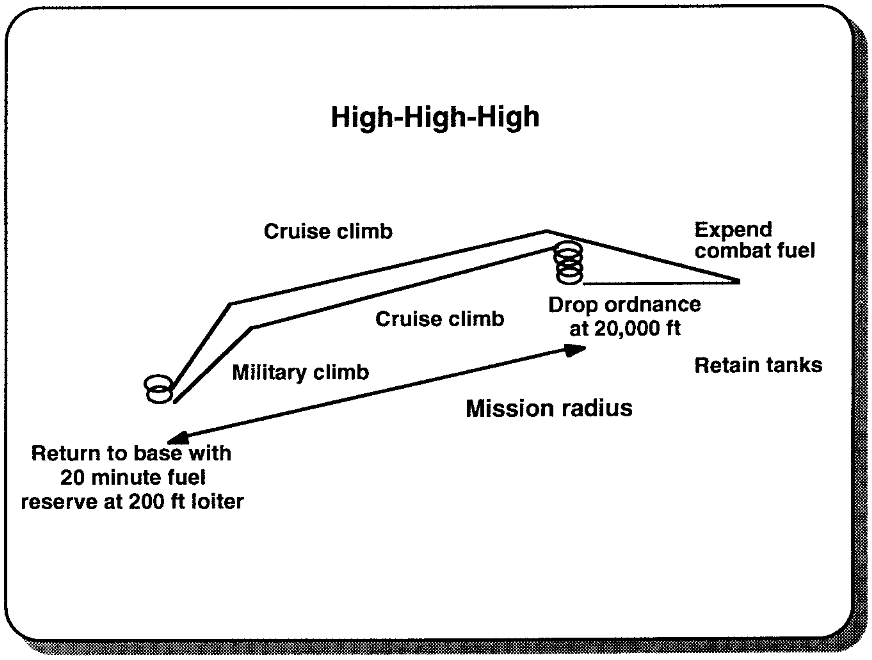

Figure 3.5—Air-to-Ground Flight Profile

A High-High-High (HHH) mission profile was used for all cases examined. This choice illustrates our philosophy of making relative comparisons of aircraft rather than tailoring the analysis to make absolute estimates of air-to-ground capability. An actual campaign might involve several days of High-Low-Low-High (HLLH) operations before defenses would be suppressed enough to permit High-High-High mission profiles. We concluded, however, that multiple mission profiles added complexity to the analysis without contributing to differentiating among the aircraft, hence our consistent use of High-High-High profiles.[4]

[4]We made this decision only after examining the degradation in payload-radius performance for HLLH operations to ensure that neither aircraft suffered a disproportionate degradation that would influence our relative comparisons.

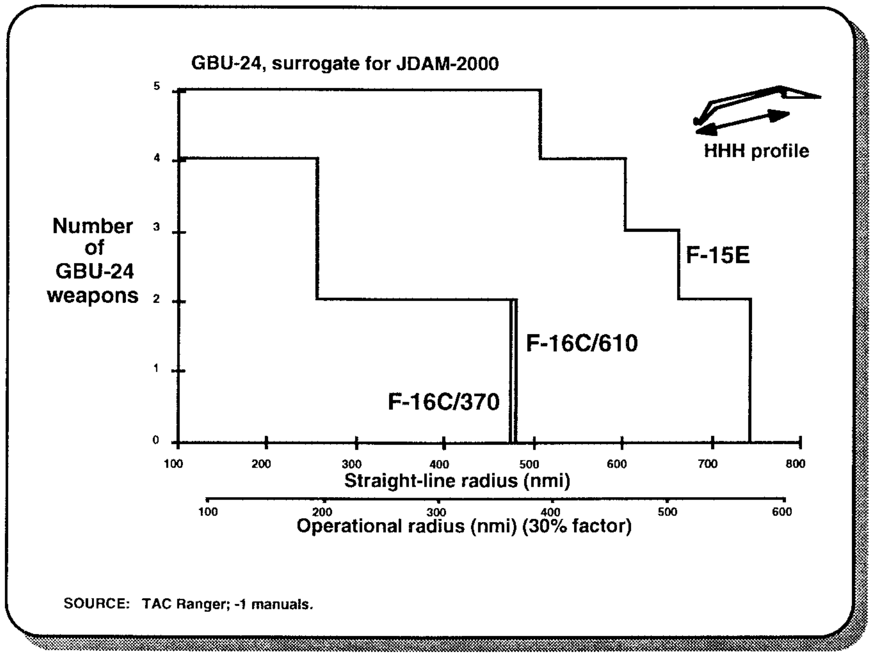

Figure 3.6—Payload Radius Comparison for GBU-24 Weapons

Figure 3.6 illustrates the radius to which the aircraft can deliver payloads with and without application of the 30 percent operational radius adjustment factor. The F-15E has a large radius and payload advantage over the F-16C when carrying GBU-24 (or JDAM-2000) weapons on the HHH mission profile. Use of larger, 610-gallon tanks in this case offers only a comparatively small increase in radius because they cannot be filled to capacity without exceeding the F-16C's takeoff gross weight limit of 42,300 pounds. Two 610-gallon tanks have a capacity of 7900 pounds of fuel, whereas in this situation they can only be loaded with 5700 pounds of fuel before reaching the takeoff gross weight limit.[5]

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[5]Braking capability limits the maximum takeoff gross weight although the airframe is designed for a heavier load. We will illustrate later the performance benefit from refueling the F-16C in flight beyond its takeoff gross weight limit.

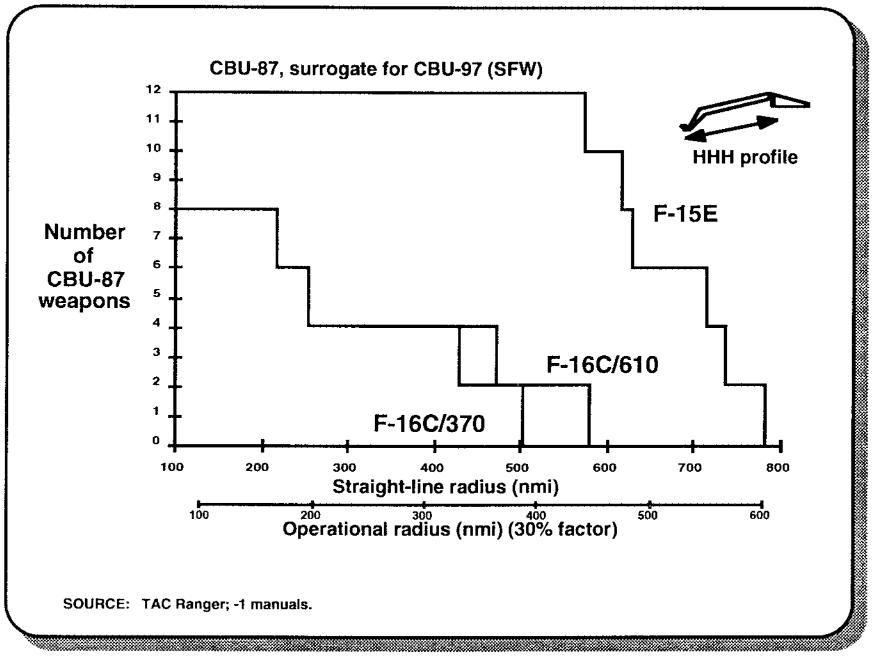

Figure 3.7—Payload Radius Comparison for CBU-87 (CEM)

The F-15E has a particularly large advantage in carriage of CBU weapons, since its conformal fuel tanks are ideally suited for carrying large numbers of such weapons (e.g., as many as 12 CBU-87s).[6]

The F-16C uses Triple Ejection Racks (TERs) to carry multiple weapons per station and pays a large drag penalty for doing so. For limited loadings of the lighter CBU-87, the F-16C realizes a greater benefit from the use of 610-gallon wing tanks than was the case when carrying GBU-24s, since it can carry a full load of fuel in the larger tanks.

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[6]We assumed the F-15E exclusively carried CBU-87s on CFTs, which is consistent with the loadings shown in the F-15E flight manual.

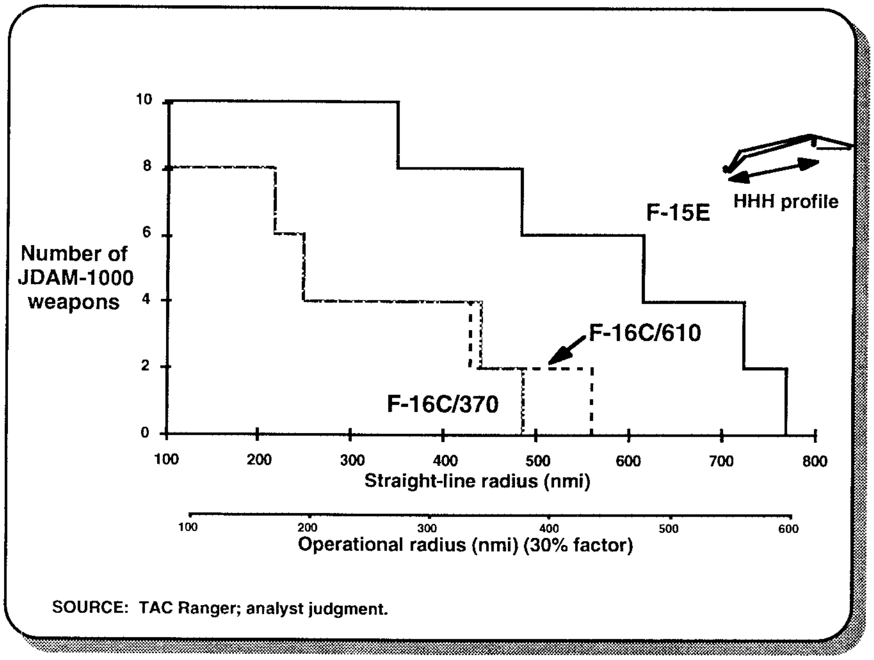

Figure 3.8—Payload Radius Comparison for JDAM-1000

Figure 3.8 shows the estimated payload-radius performance for our loadings of a notional 1000-pound JDAM. For much of the mission radii spectrum, the F-15E carries two to three times as many JDAM-1000s as the F-16C. Note that when the F-16C carries four JDAM-1000s, it actually pays a penalty for using 610-gallon tanks, since the tanks are only partially full and offer proportionately more drag than 370-gallon tanks. The larger tanks show a payoff when the F-16C carries a comparatively light load of two JDAM-1000s.

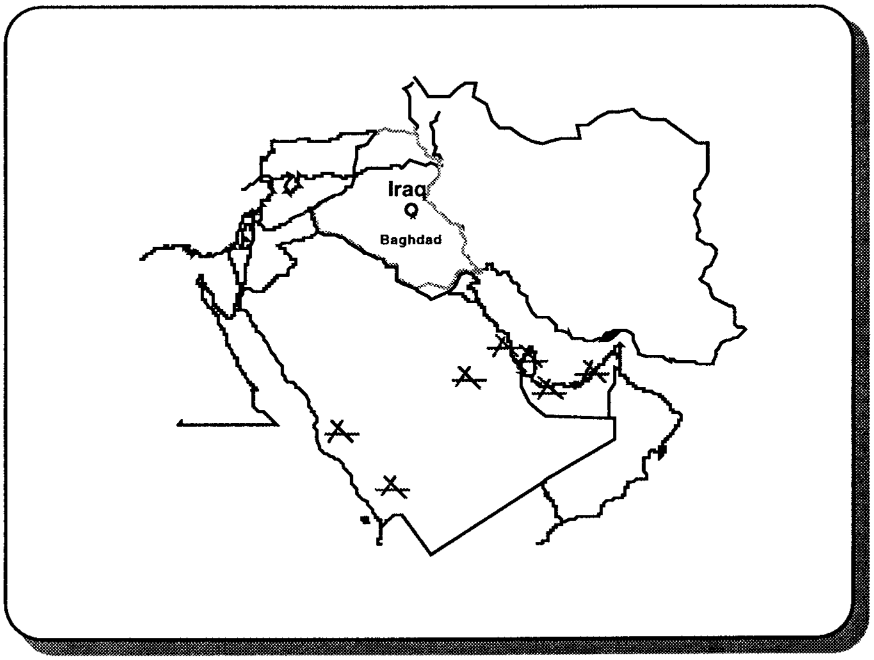

Figure 3.9—Airbases in Baseline Case

We constructed a spectrum of basing and target assumptions to illustrate the comparative strengths and weaknesses of the various aircraft when operating in large and compact theaters. Our baseline case includes seven bases on the Saudi Arabian peninsula that were used during Operation Desert Storm by F-16s, F-15Es, F-117s, and F-111s. We used these bases for operations against targets in Iraq and Kuwait. For reference, the straight-line distance to Baghdad from these bases varies from 430 to 835 nmi, with an average distance of 645 nmi.

These bases and targets represent a rather large theater, but they do not define an upper bound on distances Air Force fighters might have to fly in future conflicts. For example, operations from Saudi Arabia into Iran would involve even greater distances.

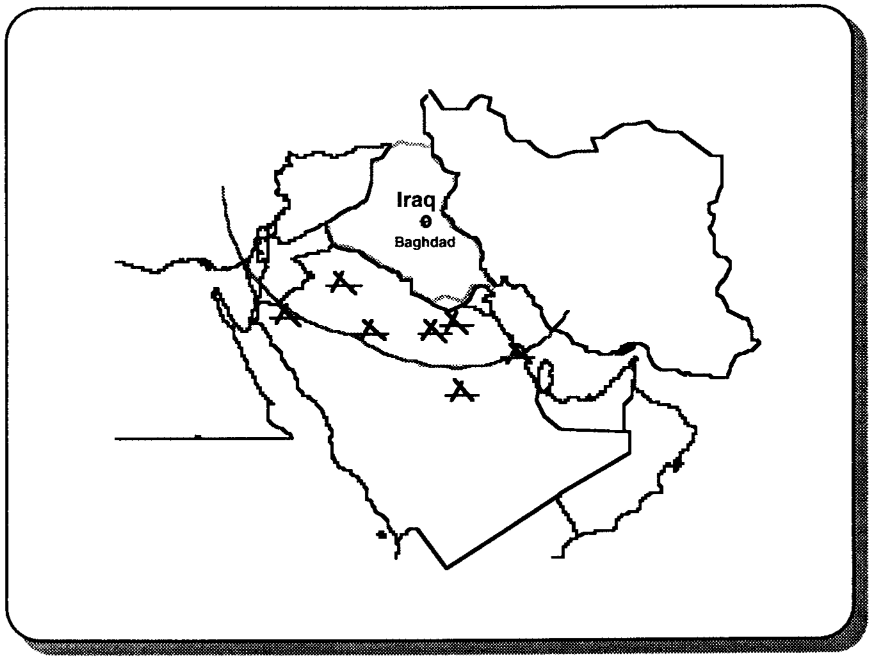

Figure 3.10—Airbases in Close Basing Case

We also compared aircraft effectiveness when operating from an alternative set of bases (illustrated in Figure 3.10) closer to Iraq. These bases all found use during Operation Desert Storm, although not necessarily by USAF ground attack aircraft. The straight-line distance to Baghdad for this set of bases varies from 295 nmi to 500 nmi, with an average distance of 374 nmi. More targets are within range of this basing set, but most of the bases have the undesirable attribute of being within range of surface-to-surface missiles.

We also compared aircraft effectiveness when operating in a compact theater (not shown here) characteristic of South Korea, and when operating from tankers set back 100 or 200 nmi behind the border in Southwest Asia.

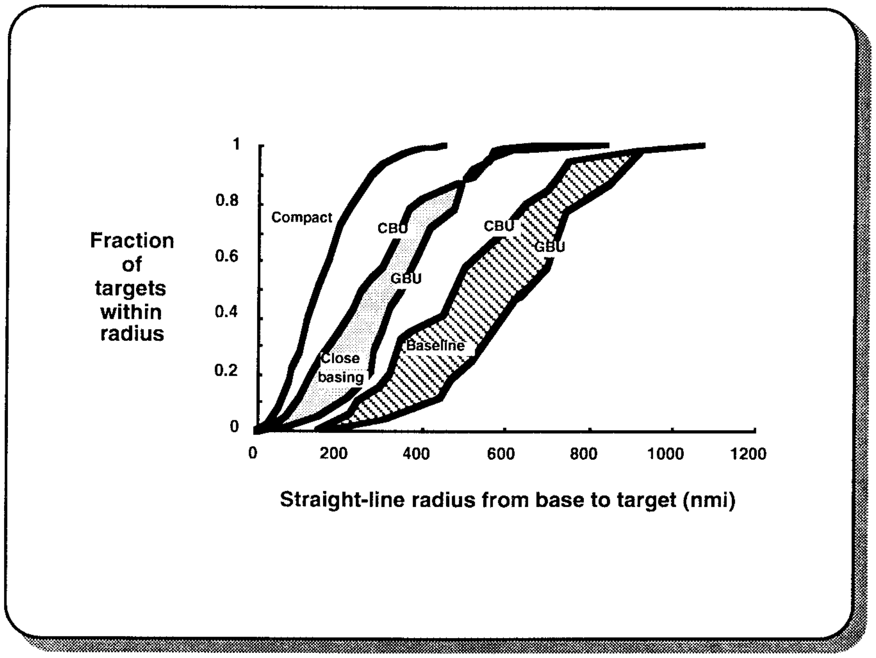

Figure 3.11—Base-to-Target Radius Distributions by Weapon Class

We calculated the distance between each base-target pair to develop the distribution of distances shown in Figure 3.11. For Southwest Asia, we put together weapon-specific target distributions by distinguishing between targets attacked with GBU- and CBU-class weapons. The resulting curves provide a broad set of operationally meaningful target distributions with which to evaluate aircraft payload-radius performance.

A sensitivity analysis will also compare how in-flight refueling influences the ability of the F-15E and the F-16C to service targets in Southwest Asia.

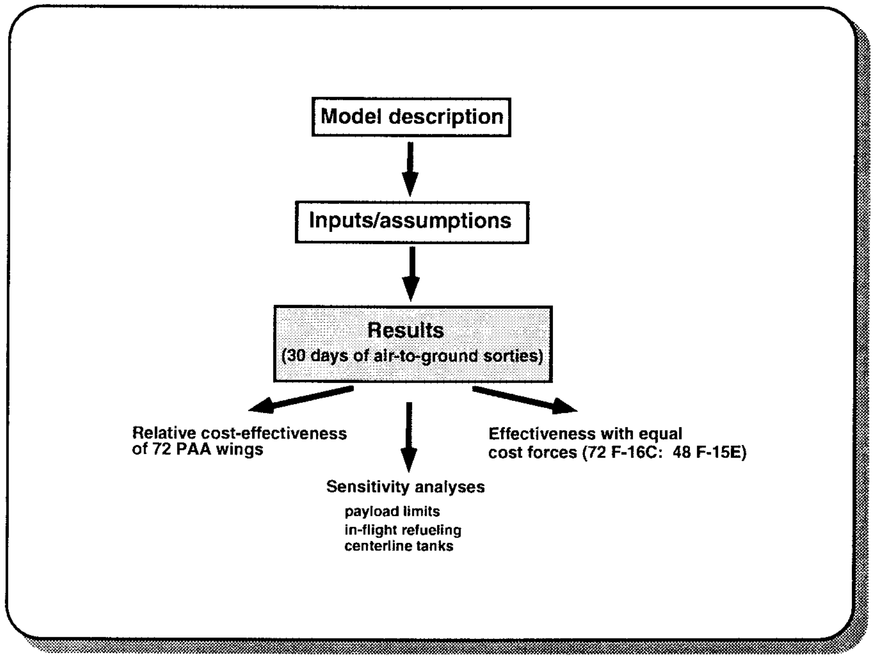

Figure 3.12—Air-to-Ground Payload/Radius Assessment

For 30 days of air-to-ground sorties, we (1) compare equal numbers of aircraft and develop cost-effectiveness ratios, and (2) compare the effectiveness of equal cost forces of aircraft. Sensitivity analyses will illustrate changes in results as the size of air-to-ground payloads is limited, when in-flight refueling is used, and when the F-16C carries a centerline fuel tank instead of an ECM pod.

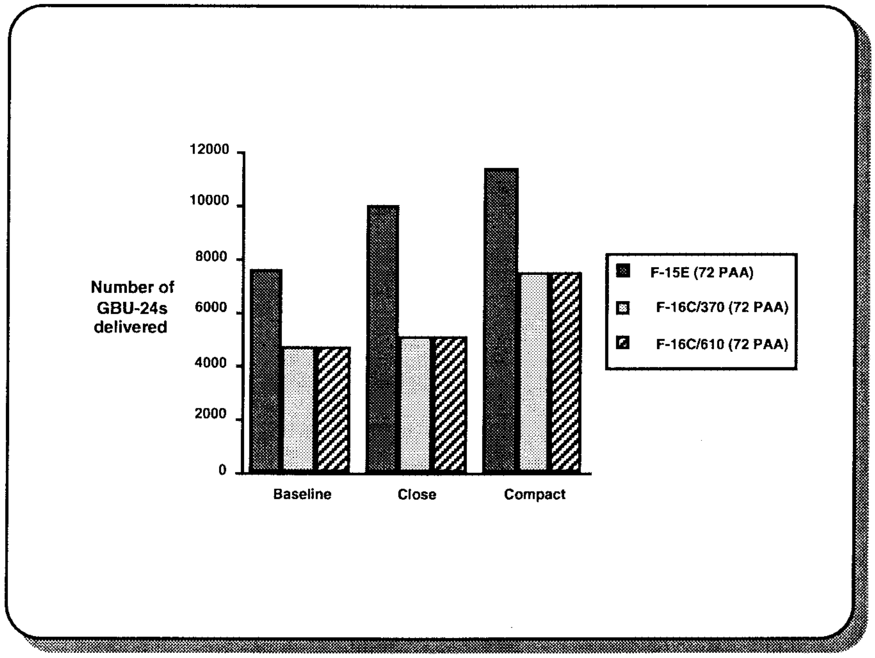

Figure 3.13—Number of GBU-24s Delivered

Figure 3.13 illustrates the number of GBU-24s delivered by 72 PAA of each aircraft configuration over 30 days. In moving from the baseline to the close case, the F-15E is able to reach most of the target set with its maximum payload of bombs. The F-16C services most targets with two bombs, so there is not an appreciable difference in the first two basing cases. Both aircraft deliver more bombs in the compact theater and the ratio of bombs delivered (F-15E/F-16C) diminishes as the theater becomes compact.

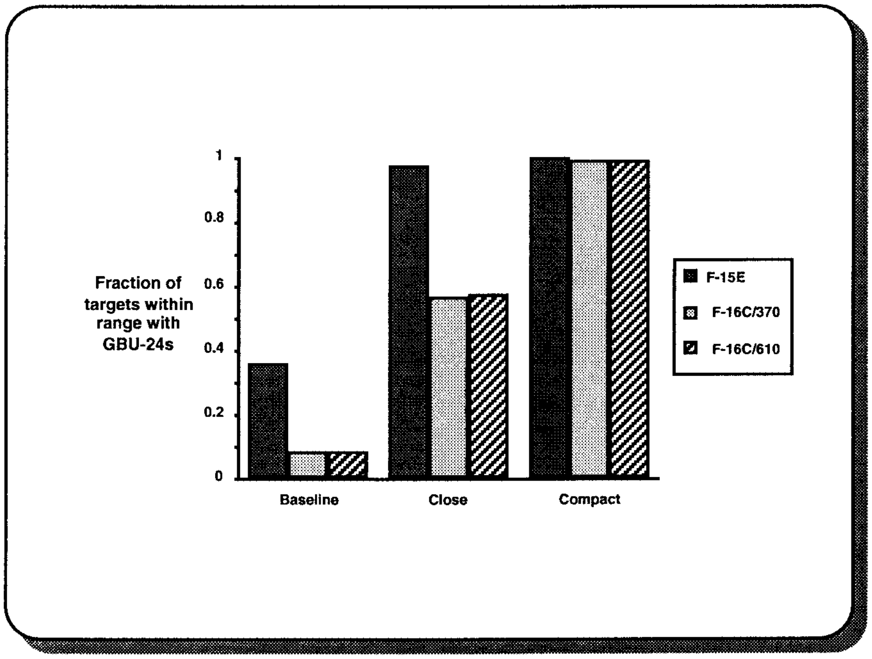

Figure 3.14—Fraction of Targets within Range with GBU-24s

Comparing only the magnitude of bombs delivered misses an important dimension of aircraft capability—the extent of their ability to service the target set. Figure 3.14 illustrates that 36 percent of the target set is within range of the F-15E from the baseline bases, whereas about 8 percent is within range of the F-16C. The difference in the ability to cover targets is still large for the close basing case. The improvement in target coverage for the F-15E in the close basing case translates into an ability to cover many more of the targets with large payloads, whereas the improvement for the F-16C means it can reach more targets with a two-bomb payload. Target coverage is not much of an issue in the compact theater, because of the close proximity of the bases to the targets in that theater.

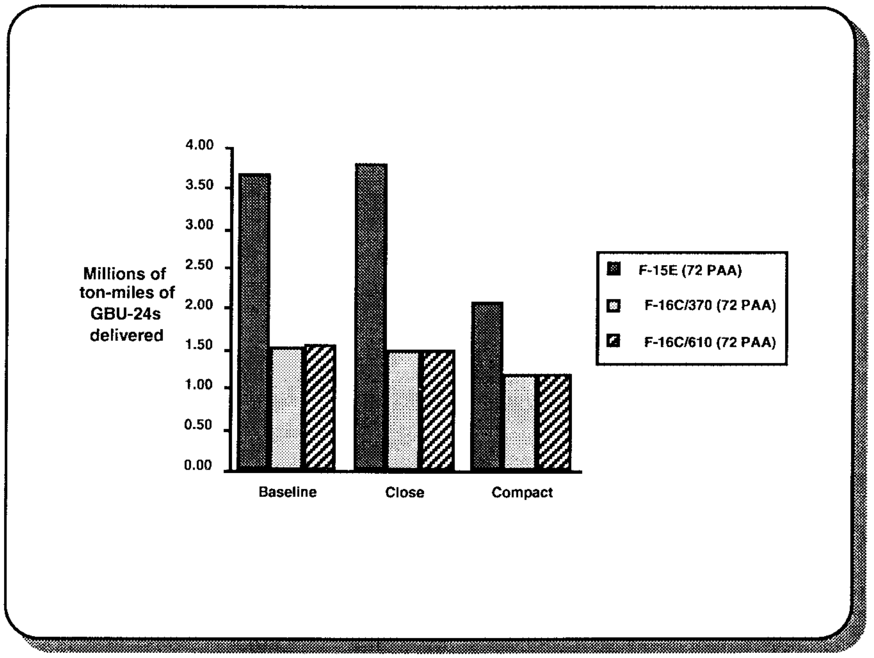

Figure 3.15—Ton-Miles of GBU-24s Delivered

To measure the integrated ability of the aircraft to carry payloads to particular distances, we show in Figure 3.15 the ton-miles of payload each aircraft configuration delivers for each basing situation. The ratio of F-15E to F-16C performance increases in this case, as the F-15E delivers more bombs to greater depths than the F-16C does. The ratio of ton-miles generated is significantly less in the compact theater as both aircraft essentially service the full target set flying comparable distances.

This, and the preceding comparisons, have been for equal numbers of aircraft, not for equal costs of aircraft, so naturally the larger, more costly F-15E shows up as having an effectiveness advantage. The essential question then is whether the ratio of effectiveness measured in terms of the ratio of ton-miles of payload delivered exceeds the ratio of costs (1.4 to 1.62).

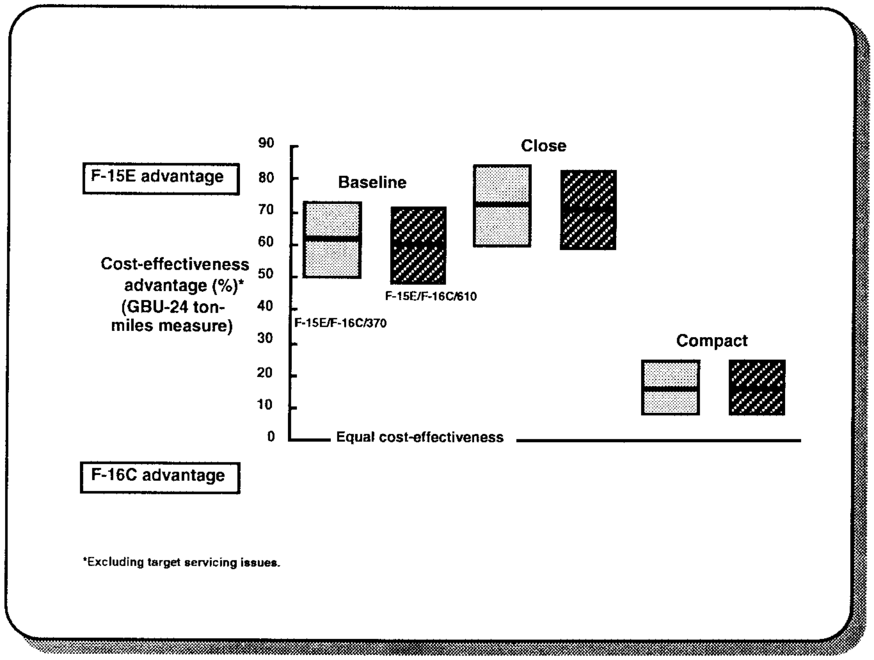

Figure 3.16—Relative Cost-Effectiveness F-15E/F-16C: Ton-Miles of GBU-24s Delivered

The F-15E exhibits a cost-effectiveness advantage over either configuration of the F-16C (coded with solid and cross-hatched shading in Figure 3.16) across all three basing cases and all extremes of cost ratio, ranging from an advantage of about 10 to 85 percent. The metric shown on the vertical axis is the ratio of ton-miles of GBU-24s delivered divided by the cost ratio of the aircraft, which reduces to the ratio of ton-miles of payload delivered per dollar of procurement and O&S cost. In this format, bars plotted above the horizontal axis indicate an F-15E advantage, while those plotted below (none in this case) represent an F-16C advantage. The bars show the cost-effectiveness advantage for the range of cost ratios of the F-15E to F-16C (from 1.40:1 to 1.62:1), with the line crossing the bars indicating the cost-effectiveness advantage for the nominal cost ratio of 1.5:1.

No meaningful distinction can be drawn between the cost-effectiveness of the 370- and 610-gallon configurations of F-16C. The 610-gallon tanks cannot be completely filled because of gross weight limits.

In this example, both aircraft deliver the maximum payload they can carry consistent with the radius to which they must deliver the payload (including the conservatism of the aforementioned 30 percent operational radius adjustment factor). For a variety of reasons, aircraft will not always operate in this manner; hence, we will later reexamine the relative cost-effectiveness of the F-15E and F-16C for arbitrary payload carriage limits ranging from two to five GBU-24s.

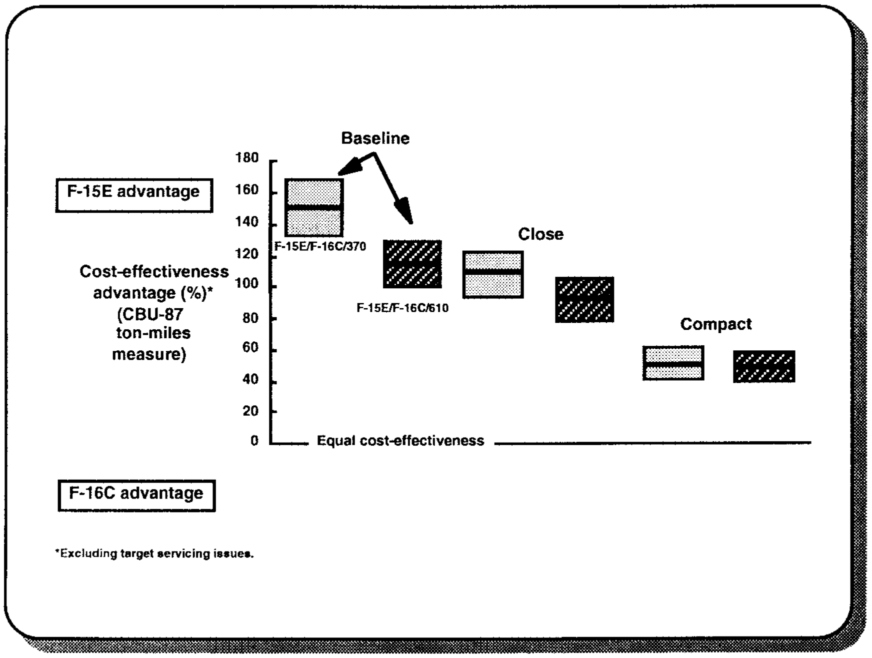

Figure 3.17—Relative Cost-Effectiveness F-15E/F-16C: Ton-Miles of CBU-87s Delivered

We repeated the analysis for CBU-87 weapon carriage and found that the F-15E has a greater advantage for this weapon, because of its ability to carry large numbers of such weapons on its conformal fuel tanks. For lighter loadings of CBU-87, the F-16C can better exploit the additional fuel capacity of the 610-gallon tanks, and hence we see some distinction between the two F-16C configurations.

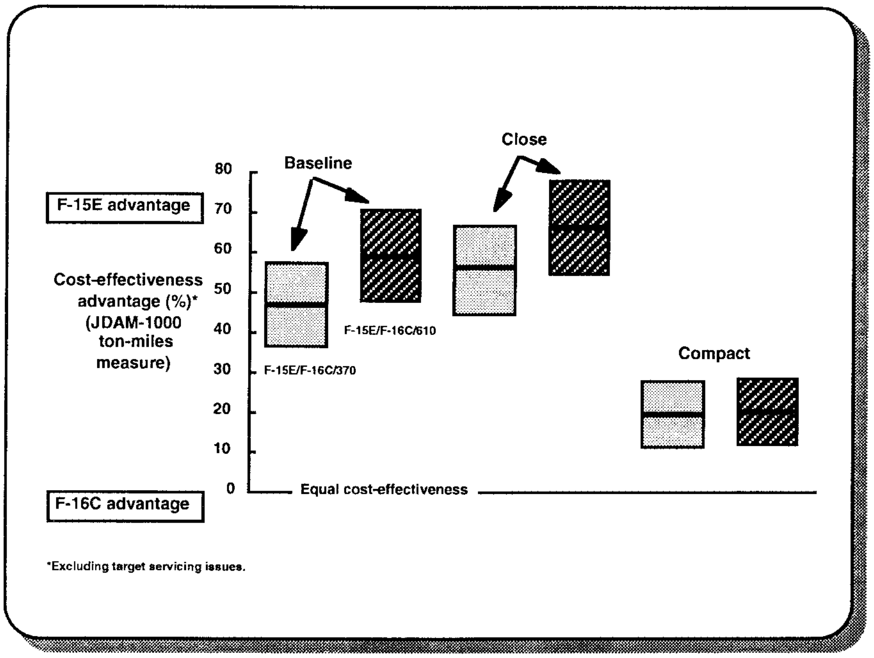

Figure 3.18—Relative Cost-Effectiveness F-15E/F-16C: Ton-Miles of JDAM-1000s Delivered

The cost-effectiveness advantage of the F-15E when carrying JDAM-1000 is comparable to its advantage when carrying GBU-24. Larger, 610-gallon tanks do not offer an advantage for the F-16C in this case because of high aerodynamic drag and insufficient gross weight margin to fill them completely when carrying typical loads of four JDAM-1000s.

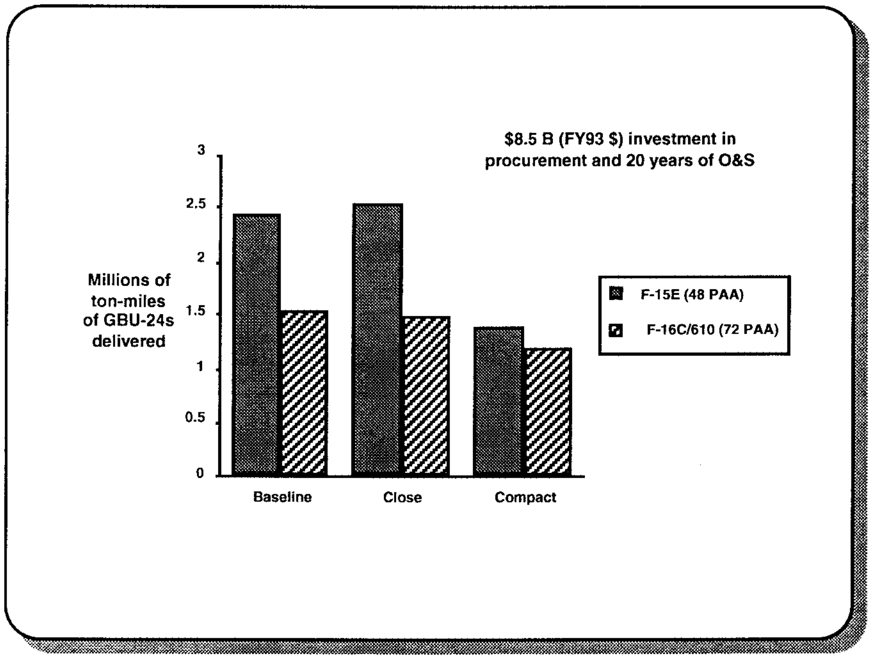

Figure 3.19—Ton-Miles of GBU-24s Delivered for an Equal Investment in Aircraft

An alternative means for comparing cost-effectiveness is to operate equal cost forces and directly measure the difference in payload delivered. For the nominal procurement and operating cost ratio of 1.5, we can buy and operate a full wing of 72 PAA F-16Cs, but only 48 F-15Es. However, this smaller number of F-15Es delivers more ton-miles of payload than the larger F-16C force for each basing case.

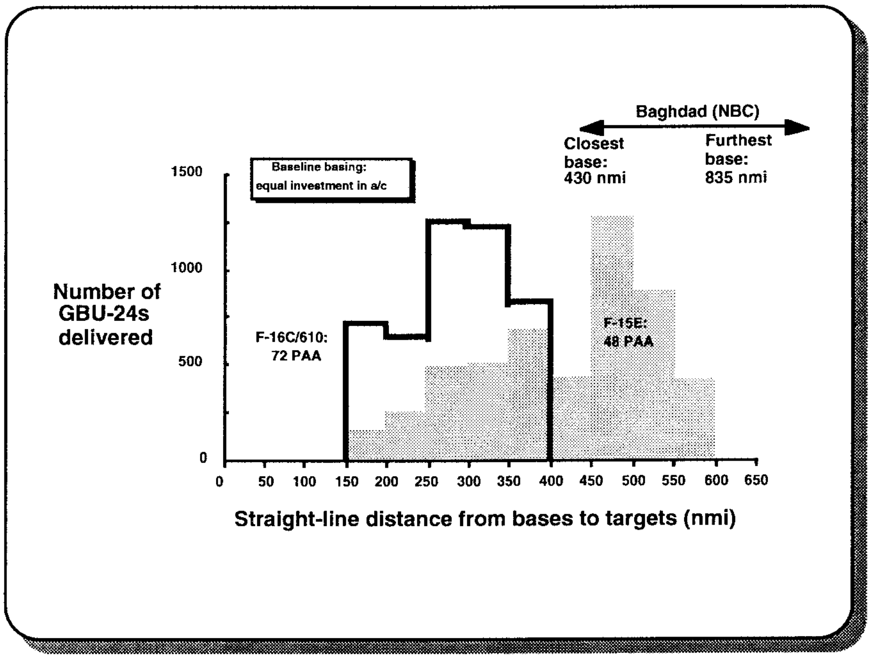

Figure 3.20—Distribution of Bomb Deliveries for Baseline Basing for an Equal Investment in Aircraft

We shall demonstrate in a moment that the quantity of bombs delivered in the baseline case is not dramatically different for equal cost forces of F-15Es and F-16Cs, but Figure 3.20 illustrates the significant difference in where those bombs are delivered. The F-15E can deliver its payloads against targets at much greater depths, such as targets in the vicinity of Baghdad. Open literature sources have reported that high-priority nuclear, biological, and chemical facilities clustered around Baghdad came under attack during Operation Desert Storm.

For the baseline set of bases, the F-16C cannot reach Baghdad unrefueled. The F-15E can reach Baghdad from some but not all of these bases.

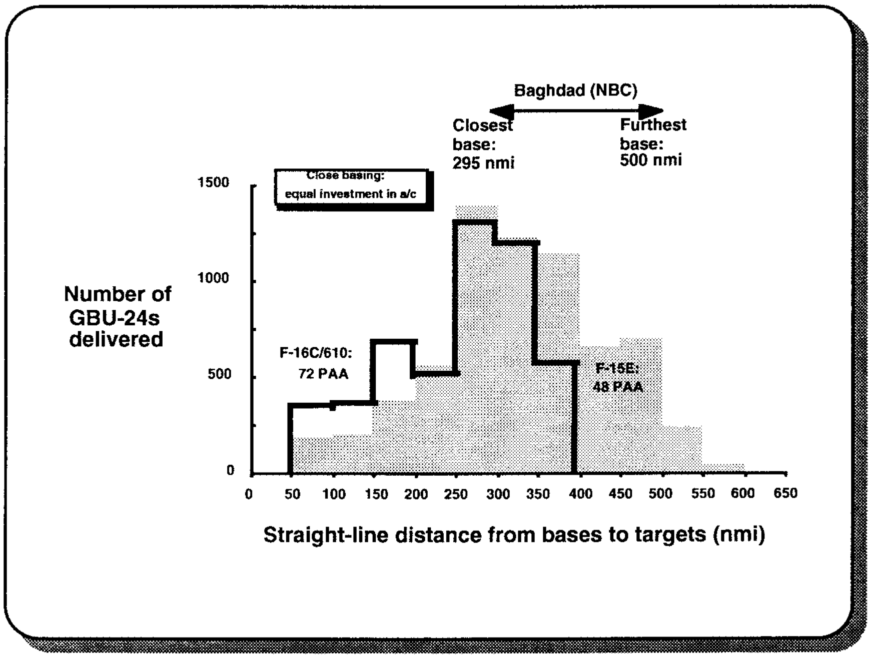

Figure 3.21—Distribution of Bomb Deliveries for Close Basing for an Equal Investment in Aircraft

For the close basing case, the F-16C force can reach more targets than in the baseline case, including Baghdad from some of the bases. The F-15E can reach Baghdad from all of the bases, and is able to service targets 200 nmi deeper than the F-16C.

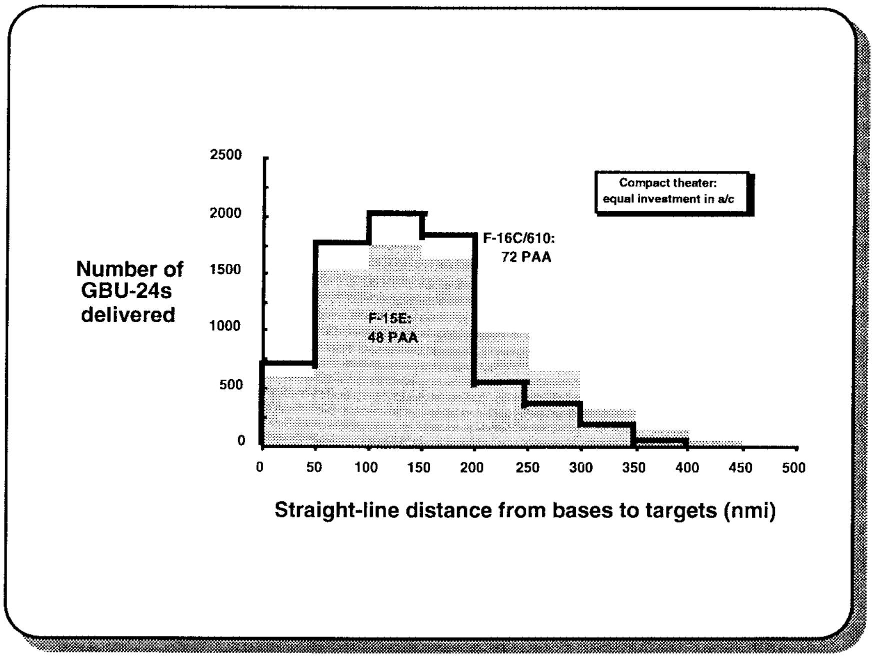

Figure 3.22—Distribution of Bomb Deliveries for Compact Theater for an Equal Investment in Aircraft

The differences in the distribution of bomb deliveries by the F-15E and F-16C diminish as theaters become more compact. The F-15E loses most of its radius advantage but does deliver larger quantities of bombs against deep targets than the F-16C.

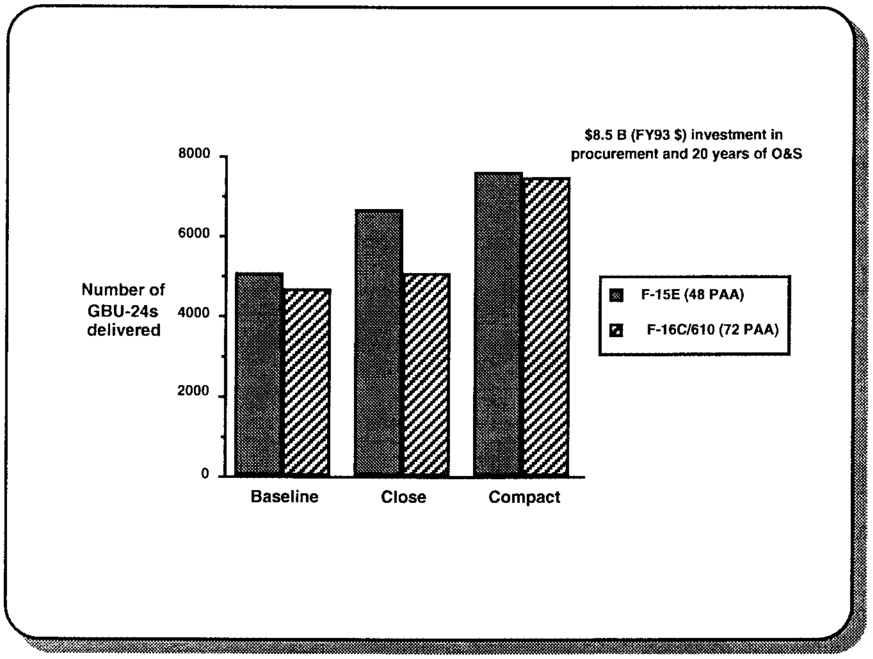

Figure 3.23—Number of GBU-24s Delivered for an Equal Investment in Aircraft

Figure 3.23 summarizes the number of bombs delivered for each basing case for equal cost forces of aircraft. We then asked whether the illustrated differences in bomb delivery potential would translate into meaningful differences in target kill potential. Figure 3.24 addresses that question for the full range of equal cost forces we examined.

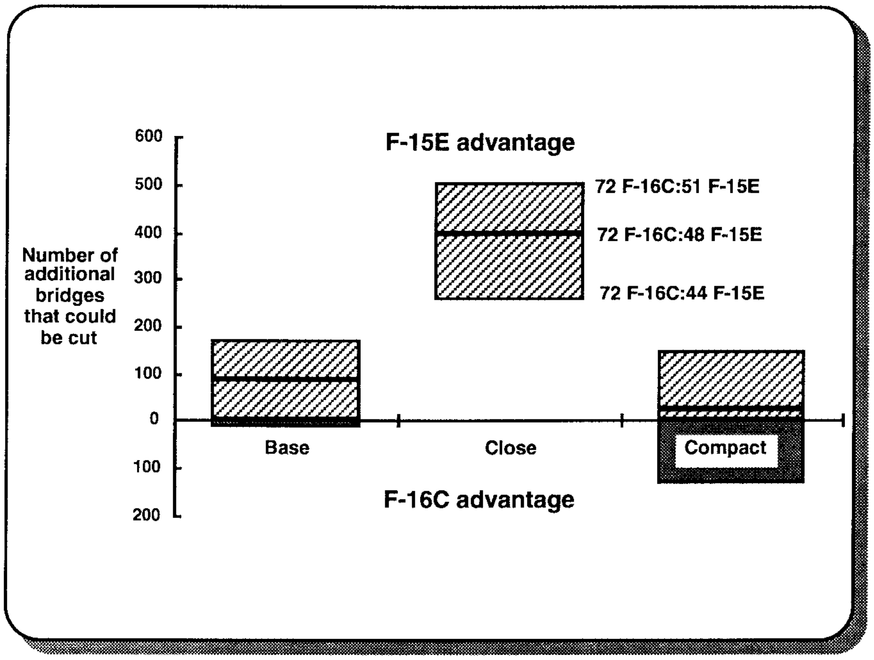

Figure 3.24—Additional Bridge-Cutting Potential Using GBU-24s (equal cost forces)

Figure 3.24 illustrates the number of bridge cuts that could be made for the difference in bombs deliverable by equal cost forces of F-16Cs and F-15Es, not only for the nominal cost ratio of 1.5:1, which yields a 72:48 aircraft ratio, but also for the extremes of cost ratio, which yield aircraft forces of 44 and 51 F-15Es. When only 44 F-15Es are in the force (corresponding to the highest ratio of F-15E to F-16C costs), the F-16C has an advantage in bombs delivered in the baseline and compact theaters. In all other cases, the F-15E has an advantage that translates into an ability to damage from tens to hundreds of bridges more than an equal cost force of F-16Cs.

Similar calculations for equal cost forces delivering CBU-87 weapons against enemy armor showed that the F-15E advantage in target kill potential ranged from 600 to 1800 tanks, which exceeds the tank inventories of most nations.

4. SENSITIVITIES

- Introduction
- Procurement and O&S costs
- Air-to-ground weapon delivery cost-effectiveness
- Sensitivities
  - Weapon carriage limits
  - In-flight refueling comparisons
  - F-16C with centerline tank
- Conclusions

Figure 4.1—Outline

We performed several sensitivity analyses to explore how relative cost-effectiveness changed with limits on weapon carriage, with the use of tankers, and when the F-16C carried a 300-gallon fuel tank on its centerline station rather than an ECM pod.

- Pilots in general
  - High threat environment—smaller payloads/single target attacks
  - Lesser threat environment—larger payloads/multiple target attacks
- Desert Storm anecdotal accounts about F-15E (RAND discussions with pilots/AF Mag Jan 93)
  - Multiple target attacks
  - Large GBU loads—4 GBU-10; 8 GBU-12
  - Large unguided loads—12/6 CBU-87; 5 Mk84; 12 Mk82
- Desert Storm mission reports for F-15E
  - Multiple target attacks indicated
  - Tend to support accounts about loadings of 8 GBU-12s
  - Ambiguous about frequency of loadings of 4 GBU-10s
- Future payloads—JDAM
  - Most pilots assert weapon characteristics will permit larger payloads

Figure 4.2—Observations About Size of Operational Payloads

If the F-15E cannot use its large payload capability, then its apparent advantage over the F-16C will diminish. We sought to quantify the extent to which that advantage diminishes as weapon carriage limits are made progressively more restrictive.

The size of operational payloads will vary depending on the threat situation, as noted above. Desert Storm provided a reference point that included periods of intense threat activity and periods during which the threat offered little opposition. In general, in discussing F-15E operations with Desert Storm pilots and reviewing published accounts, it appears that the F-15E tended to carry heavy loads during Desert Storm that exploited its inherent payload capability.

These kinds of accounts were understandably anecdotal in nature, so we also analyzed Desert Storm mission reports in an effort to quantify typical weapon loads. This proved difficult, because mission reports often reported total weapons carried by all aircraft on a mission, rather than weapons carried by individual aircraft, although we could sometimes infer the probable distribution of those weapons across aircraft.[1] These

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[1]Mission reports did not have a specific data field for entering weapon loadings. Reports on weapon loadings were buried in free format textual accounts of the missions. This

reports supported accounts of frequent multiple target attacks, which would exploit the substantial payload capability of the F-15E, and also the use of heavy loads of GBU-12s (500-pound laser guided bombs) for "tank plinking." We were not able to extract unambiguous information about GBU-10 loadings (2000-pound laser guided bombs), although we inferred that aircraft were frequently loaded with two GBU-10 bombs.

"Smart" bombs today rely on laser designation to impact, requiring that aircraft linger in the target area and designate each individual desired impact point. Future inertially aided/GPS-aided JDAM weapons will allow aircraft to target multiple impact points, release multiple weapons, and exit the target area without having to linger to perform laser designation. Air Force pilots we spoke to who were familiar with JDAM characteristics were virtually unanimous in asserting that this mode of operation should make it much more practical to carry larger operational payloads.

These findings demonstrate that there is no one "typical" value of bomb load that generally applies. They do, however, provide some context for interpreting the parametric results for GBU-24 and CBU-87 loadings that appear in Figures 4.3 and 4.4.

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reporting technique did not encourage consistency in the reporting of information and made it almost impossible for us to infer with confidence the distribution of weapon loadings. This is simply an uncritical observation about limits on the quality of data collected during wartime operations.

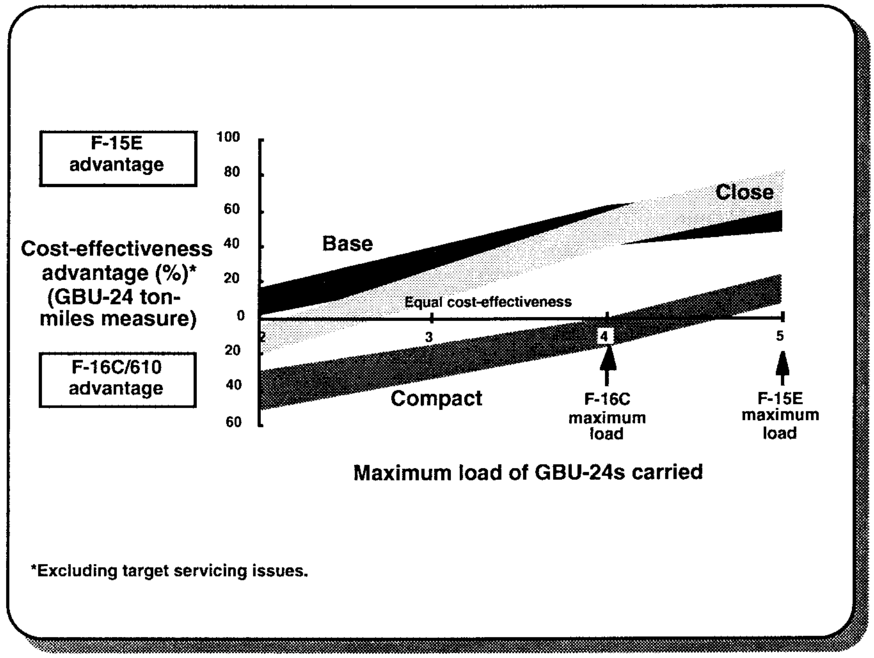

Figure 4.3—Sensitivity of Cost-Effectiveness to Maximum GBU-24 Load

We varied the maximum allowed bomb load from five to two and reassessed cost-effectiveness for the three basing cases.[2] The F-15E exhibits a clear advantage over the F-16C for the full range of cost ratios for the two Southwest Asian basing cases, except when weapon carriage is limited to two bombs.

In the compact theater, the F-15E range advantage is almost completely negated because the targets are simply closer. As the maximum bomb load is reduced, the F-15E loses its other clear advantage—greater payload—so that when only two weapons are carried, the F-16C appears to have a clear cost-effectiveness advantage.

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[2]Although drawn as continuous curves, the F-16C carries either two or four bombs, whereas the F-15E can carry any combination of GBU-24s and external tanks adding to five.

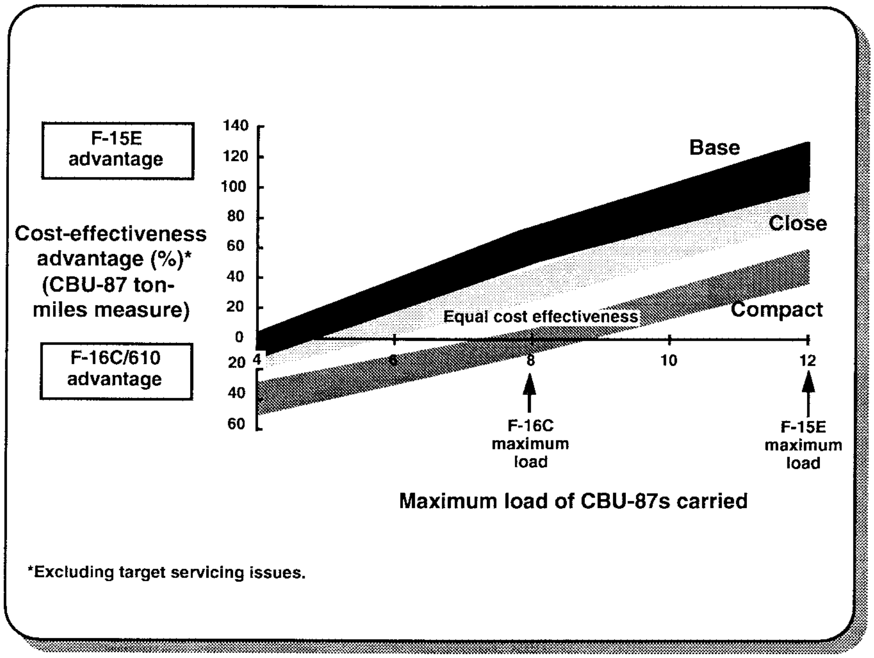

Figure 4.4—Sensitivity of Cost-Effectiveness to Maximum CBU-87 Load

We performed a similar parametric excursion for the CBU-87, varying the maximum dispenser load from 12 to 4; results were generally similar, except that for most CBU-87 loadings, the F-15E cost-effectiveness advantage is larger than was the case with GBU-24 loadings. The aircraft are similar in cost-effectiveness, or the F-16C holds a slight advantage for lighter loadings of four CBU-87 dispensers when operating from Southwest Asian bases. When the F-15E is limited to the same maximum load as the F-16C in the compact theater—eight dispensers—they are comparable in cost-effectiveness, with the F-16C holding an advantage for lighter loadings.

Parametric results for various GBU-24 and CBU-87 loadings demonstrate that our earlier results are generally robust even for rather significant changes in weapon loads. The F-16C tends to appear relatively more cost-effective in a compact theater that has less demanding radius requirements—the kind of theater for which it was designed.

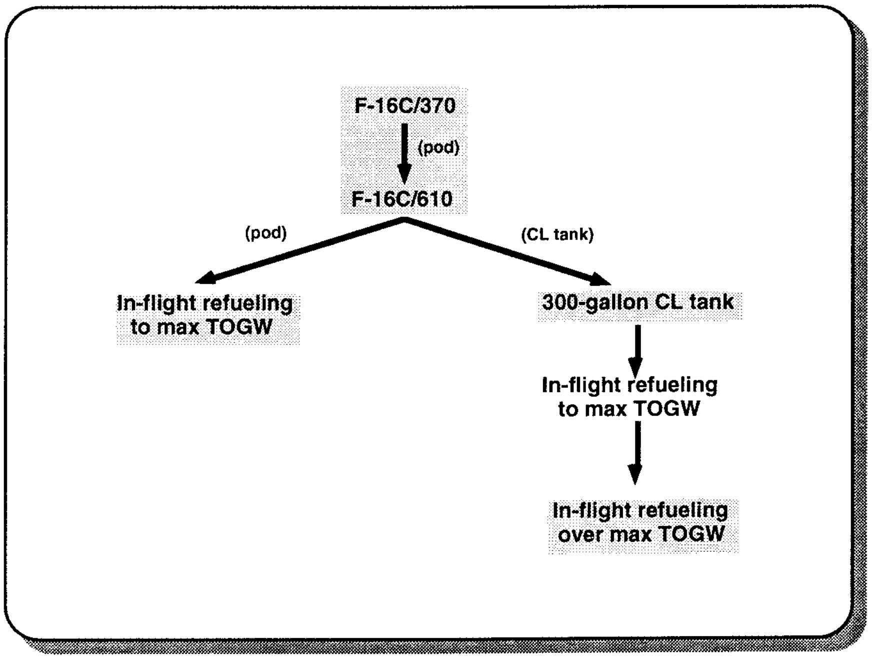

Figure 4.5—Combat Radius Extension Cases

We have illustrated those circumstances in which 610-gallon wing tanks contribute to improving the combat radius of an F-16C carrying a centerline ECM pod. We will now show how a similar F-16C configuration can benefit from in-flight refueling to its maximum takeoff gross weight, from replacing its ECM pod with a 300-gallon centerline fuel tank, and from the collective addition of the fuel tank and in-flight refueling above its maximum takeoff gross weight but below the limit set by its structural design. The objective is to illustrate the extent to which these actions might change the relative cost-effectiveness of the two aircraft.

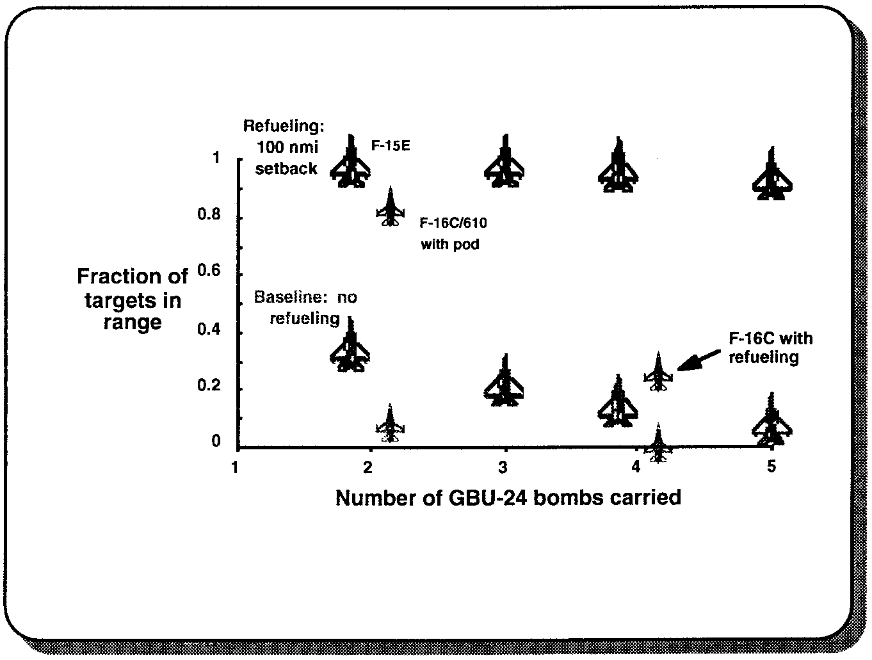

Figure 4.6—In-flight Refueling (IFR) Allows More Targets to Be Reached with Larger Payloads

Figure 4.6 shows how in-flight refueling expands the fraction of the target set that is within range, and how a greater fraction of that target set can be serviced with heavier bombloads.[3] With the benefit of refueling, the F-15E can reach almost the entire target set with its maximum load of bombs. Refueling allows the F-16C to reach 84 percent of the targets with two bombs and 26 percent of the targets with a payload of four bombs.

In summary, with respect to the two aircraft, in-flight refueling

- narrows target coverage differences
- narrows the difference in mission radii flown
- widens the payload differential (in-flight refueling allows the F-15E to substantially increase its average payload).

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[3]This refueling case assumes tankers are set back 100 nmi behind the Saudi Arabia-Iraq border in the Southwest Asian theater. A 100 nmi setback is probably the closest one would prefer to station tankers to allow some response time to defend them against enemy air threats, whereas a 200 nmi setback might be considered more operationally prudent. While examining many cases for both setbacks, we chose to emphasize the 100 nmi setback cases to assess whether this assumption is enough to help the F-16C overcome at least some of its radius shortfall relative to the F-15E.

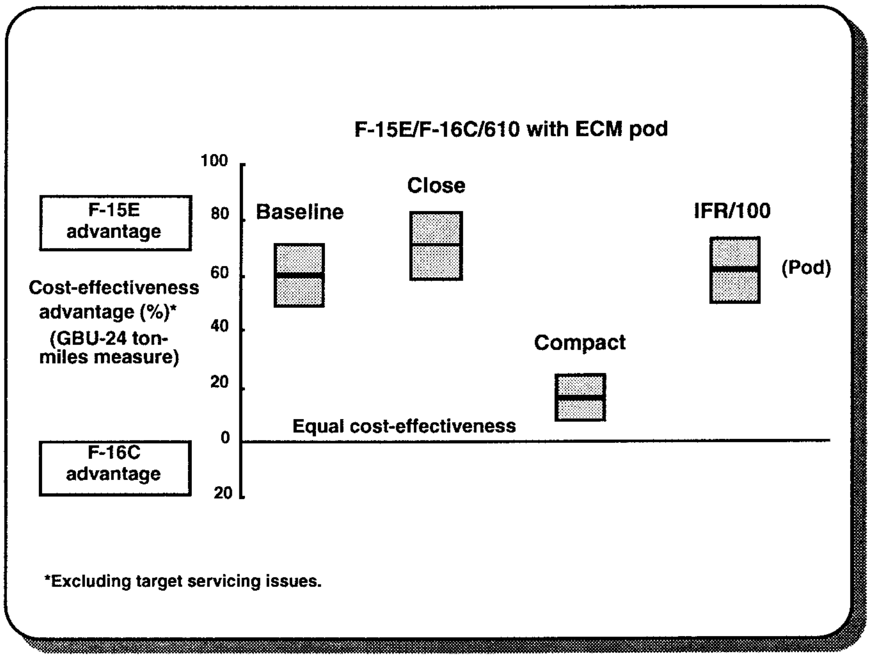


Figure 4.7—Minimal Change in Relative Cost-Effectiveness with In-flight Refueling (IFR)

Both aircraft perform more effectively with in-flight refueling, but the relative cost-effectiveness does not change much from the baseline case with no refueling.

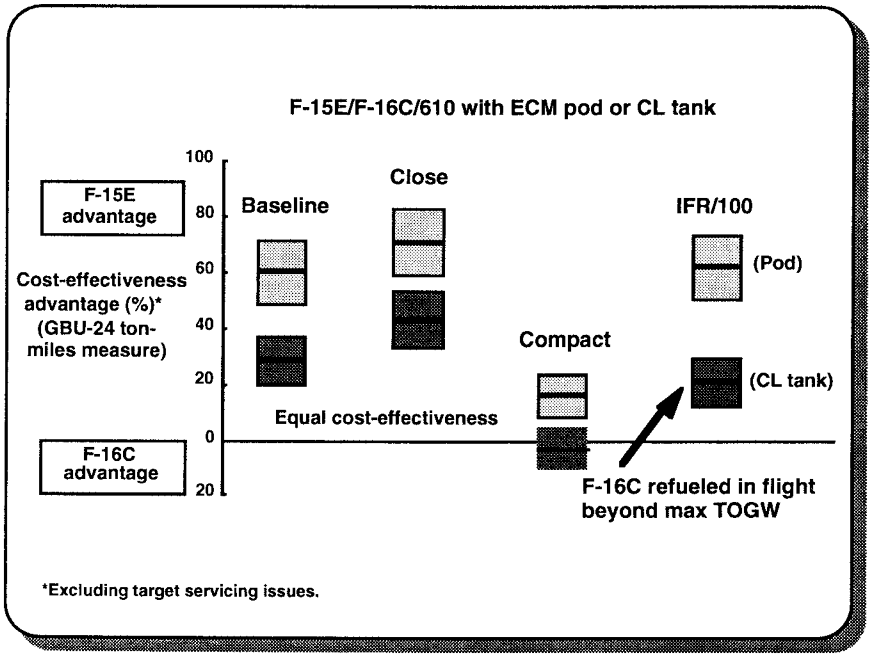


Figure 4.8—Change in Relative Cost-Effectiveness When F-16C Carries 300-gal Centerline Tank Instead of ECM Pod

The cost-effectiveness of the F-16C improves relative to the F-15E when it carries a 300-gallon centerline fuel tank instead of an ECM pod. Unlike some of our other excursions, only the F-16C benefits from this change in assumptions.

When carriage of the centerline fuel tank is coupled with in-flight refueling (100 nmi setback) beyond the F-16C's maximum takeoff gross weight, the F-15E's cost-effectiveness advantage is reduced, but still ranges from 12 to 30 percent when carrying GBU-24 weapons. In this case, all three of the F-16C's external fuel tanks, including the 610-gallon wing tanks, can be filled to capacity. This case represents perhaps the most favorable combination of assumptions for the F-16C. Recall that the F-15E generally has a greater advantage when it carries cluster bomb unit (CBU) weapons.

5. CONCLUSIONS

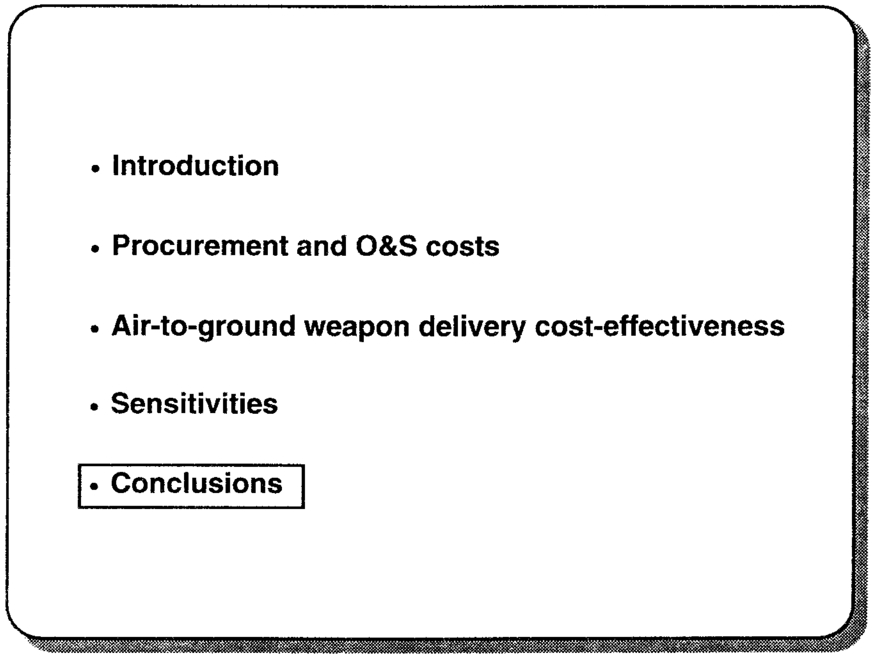


Figure 5.1—Outline

We can now summarize our conclusions about these comparisons of the F-15E and the F-16C Block 50 aircraft.

- **Ratio of F-15E to F-16C procurement costs appears to be getting smaller with fighter production cutbacks**
- **F-15E procurement and 20-year O&S costs about 50% greater than F-16C Block 50 with LANTIRN**
- **Can buy and support a larger force structure of F-16Cs (3 squadrons of F-16Cs for every 2 squadrons of F-15Es)**

Figure 5.2—Cost Conclusions

The historical ratio of F-15 to F-16 procurement costs has exceeded a factor of two over most of the common production run of F-15s and F-16s of all models, but appears to be declining with fighter production cutbacks of recent years. This trend provides impetus for reassessing the relative cost-effectiveness of the two weapon systems when procured at low rates such as 24 aircraft per year.

If the Air Force wants to emphasize quantity in its fighter force structure, the cost relationship between the F-16C and the F-15E will permit it to buy and operate three squadrons of F-16Cs for every two squadrons of F-15Es. The value of this quantitative force structure advantage must be balanced against the relative capabilities of equal cost forces of F-15Es and F-16Cs documented in this briefing.

- **For most air-to-ground cases examined, additional capability of F-15E tends to more than offset its greater costs relative to the F-16C Block 50**
- **F-15E advantage is most pronounced in larger theaters where it carries heavier payloads to a larger fraction of the target base**
- **F-16C exhibits its best performance in more compact theaters that shaped its original design**
- **In-flight refueling does not alter relative cost-effectiveness ranking (F-16C refueling over max TOGW reduces F-15E advantage)**

Figure 5.3—Air-to-Ground Payload/Radius Conclusions

For most of the air-to-ground cases examined, the effectiveness advantage offered by the F-15E relative to the F-16C was more than commensurate with its higher procurement and operating costs. The larger, heavier F-15E was most cost-effective in larger theaters where its payload and radius capability were best demonstrated. The smaller, lighter F-16C exhibited its best performance in more compact theaters where combat radius was not as important.

Only under a restrictive set of circumstances did the F-16C erode or erase the F-15E's cost-effectiveness advantage. If combat radius requirements lessen, such as in a compact theater, and if payload carriage is progressively more constrained for whatever reason, two of the principal attributes of the more costly F-15E—long radius and large payload—become less of a factor and the F-16C begins to gain a cost-effectiveness advantage.

In-flight refueling improved the effectiveness of both aircraft, allowing the F-16C to service more targets at greater depths and the F-15E to service more targets at greater depths with heavier payloads. In-flight refueling does not alter the relative cost-effectiveness ranking of the aircraft, although when the F-16C fully utilizes the capacity of its external tanks by refueling above its maximum takeoff gross weight, it can reduce the F-15E's advantage.

- **Several actions, not uniformly desirable, collectively enhance the target coverage and payload carriage of the F-16C in larger theaters**
  - **Close basing**
  - **Tanking relatively shallow**
  - **In-flight refueling over maximum TOGW**
  - **Using 610-gallon wing tanks**
  - **Substituting centerline fuel tank for ECM pod**
- **Except for light loads, payoff from use of 610-gal tanks for F-16C air-to-ground missions depends on in-flight refueling above maximum TOGW**
  - **Service life impact?**
  - **Flying qualities degradation?**

Figure 5.4—More Air-to-Ground Payload/Radius Conclusions

One of the thoughts that prompted this effort was an early assertion that 610-gallon tanks could help solve shortcomings in F-16C combat radius for air-to-ground missions. Larger tanks can improve the range performance of the F-16C, but some other conditions must be attached to their use to realize meaningful improvements in performance. Except for very lightly loaded configurations—two CBU-87s or two JDAM-1000s, for example—the larger tanks provide only a limited increase in range for unrefueled operations. There is not enough takeoff gross weight margin to fill the tanks to capacity and hence meaningfully improve the F-16C's fuel fraction.

If in-flight refueling is the norm, then the F-16C may take off at maximum TOGW with the larger tanks partially filled and subsequently fill them to capacity in flight, in the process exceeding takeoff gross weight limits but not airframe weight limits. This mode of operation can provide sizable increases in combat radius. Discussions with F-16 program office engineers about the effect this might have on the F-16C's service life were inconclusive. This kind of operation might also have some adverse effect on handling qualities.

Additionally, if operationally prudent, the F-16C can tank relatively close to enemy territory—100 nmi, substitute a centerline fuel tank for an ECM pod, and rely on other means for protection from radio frequency (RF) threats. Collectively, the aforementioned set of actions, while not uniformly desirable from an operational and technical perspective, can help the F-16C put more targets at risk with larger payloads.

- **Employment characteristics of inertially/GPS-aided weapons could exploit the inherent payload carriage advantage of the F-15E**
- **Most regional conflict scenarios involve long distances from bases to targets, favoring aircraft having greater combat radius**
- **As the fighter force structure contracts, higher quality systems can help maintain force capability**

Figure 5.5—Looking to the Future

Both the F-16C and the F-15E fill important niches in the Air Force's fighter force structure. In the future, these aircraft will deliver weapons having employment characteristics different from those of today, in theaters different from the ones for which these aircraft were originally designed, and be part of a considerably smaller fighter force structure. These emerging factors evoke the following observations.

Inertially/GPS-aided weapons such as JDAM are emerging as a key weapon type for the future. Freed from the operationally undesirable need to linger in a target area to laser designate and attack individual aim points, aircraft with large payload capabilities such as the F-15E will be in a better position to carry heavy loads in more operational situations. Moreover, in terms of radius requirements, the compact size of the Korean theater would appear to be the exception rather than the rule. Most regional conflict scenarios involve large theaters that are well-suited for aircraft having long combat radius capabilities.

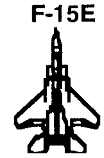
To maintain force capability as its force structure contracts, the Air Force may need to strive for a higher quality mix of forces. The Air Force should be alert to opportunities for maintaining and in some cases enhancing overall force effectiveness despite cuts in force structure. This comparison of the F-15E and F-16C has illustrated several key dimensions of these quality-quantity tradeoffs, including the size of equal cost forces, payload delivered, and targets covered on air-to-ground missions.

Appendix

AIR-TO-AIR DCA CAP COST-EFFECTIVENESS

Air Force interest in comparing F-15Es and F-16Cs and their expectations about usage are heavily weighted toward air-to-ground missions; however, in certain circumstances, the Air Force might employ the F-16C in a Defensive Counterair (DCA) Combat Air Patrol (CAP) role. Differences in costs and loiter performance will influence the ability of F-15Es and F-16Cs to fill CAP orbits.

We assessed the cost to buy and support the aircraft needed to perform a 24-hour DCA CAP mission defending a 30-degree sector 200 nmi deep with three orbits of two aircraft, each operating without in-flight refueling but with AWACS support. The analysis was limited to assessing the cost of maintaining the CAP presence, and did not assess comparative air-to-air engagement lethality and survivability, which could be influenced by differences in missile payload, fire control systems, aircraft survivability features, and other factors.

	F-16C Block 50	F-15E
		
Internal Fuel (lb)	7162	23,626*
Tanks (gallons)	2/370 + (300)	3/610
or	2/610 + (300)	
Armament (AIM-120 + AIM-9)	4 + 2	6 + 2
ECM	ALQ-131 & 2 wing tanks or no pod & 3 tanks	Internal ALQ-135

* Includes CFTs.

Figure A.1—DCA Configuration

The F-15E and F-16C Block 50 were configured in their best DCA weapons loadout, 4 + 2 (four AIM-120 + two AIM-9M) for the F-16C, and 6 + 2 for the F-15E. The F-15E is equipped with an internal electronic countermeasures (ECM) suite, whereas the F-16C carries an ALQ-131 or ALQ-184 ECM pod externally on its centerline station. We also evaluated F-16C performance with a 300-gallon external fuel tank on the centerline station replacing the ECM pod to cover those circumstances in which an ECM pod might not be required, either because the threat level does not demand it or because the F-16C relies on other means for protection from RF threats.

We compared the loiter performance of the F-15E equipped with conformal fuel tanks (CFTs) and three 610-gallon external tanks, the F-16C with 370-gallon external wing tanks, and the F-16C with 610-gallon external wing tanks. U.S. Air Force F-16Cs do not carry 610-gallon tanks operationally today, but the Israeli Air Force has used them to improve the range performance of their F-16s. With the exception of the 610-gallon tanks, the F-16Cs evaluated in the loiter analysis are the same Block 50 aircraft that are in production today for the USAF inventory.

The flight profile used in our analysis includes a fuel allowance for taxi and takeoff, a military power climb, a combat fuel allowance equivalent to

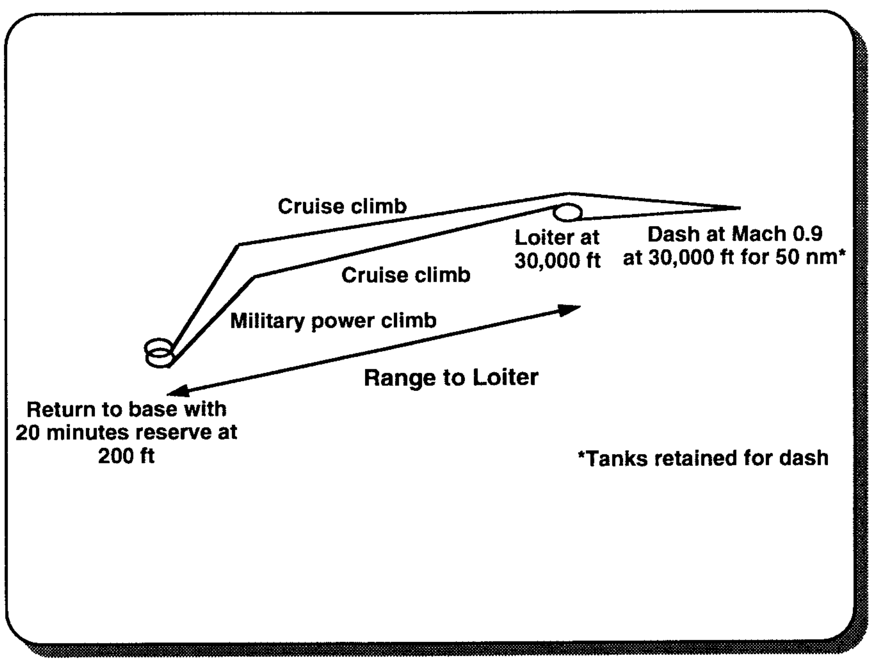


Figure A.2—DCA Loiter Flight Profile

that used for a dash at 30,000 feet at Mach 0.9 for 50 nautical miles retaining external fuel tanks, a return to base at best cruise conditions, and fuel reserves for a 20 minute loiter at 200 feet altitude. Figure A.3 will illustrate how time on station (loiter time) varies as a function of the radius from the home base.

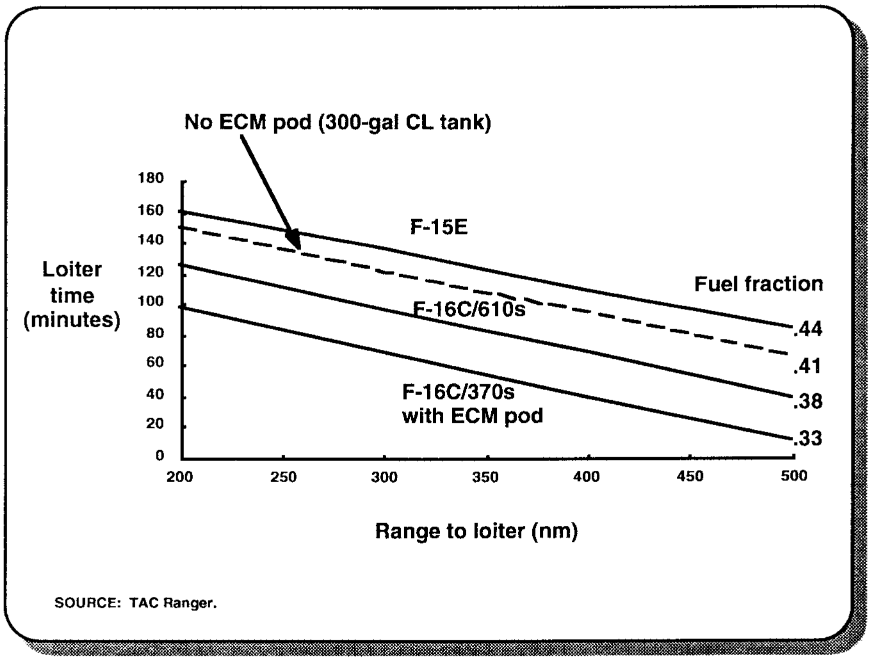


Figure A.3—Loiter Time for a DCA Scenario

The F-15E can loiter at a given radius longer than any of the F-16C configurations examined.[1] Replacing the F-16C's 370-gallon wing tanks with 610-gallon tanks adds about 25 minutes to its loiter capability. Further, replacing the ECM pod on the centerline station with a 300-gallon fuel tank adds another 25 minutes of loiter time (dashed line in figure above), increasing the fuel fraction to a value reasonably close to that of the F-15E. These two actions collectively improve the overall loiter time of the F-16C by about 50 percent.

[1]Loiter estimates were developed using the Air Force's range-payload model, TAC Ranger. Aerodynamic drag and engine data were obtained from the manufacturers in the form of TAC Brawler datasets that were translated for use in TAC Ranger. TAC Ranger results were also checked against results from the Air Force's flight planning model, FPLAN 9.0, and other RAND models that estimate range-payload performance. Aircraft loading assumptions were derived from Air Force -1 flight manuals unless otherwise specified.

In the lightly loaded, relatively low-drag, air-to-air configuration, the larger 610-gallon tanks offer a considerable performance improvement over the 370-gallon tanks. The same tanks offer less improvement for the F-16C on air-to-ground missions, which are characterized by heavier payloads having higher aerodynamic drag counts. With heavy bomb loads, there frequently is not enough gross weight margin remaining to fill the 610-gallon tanks to capacity.

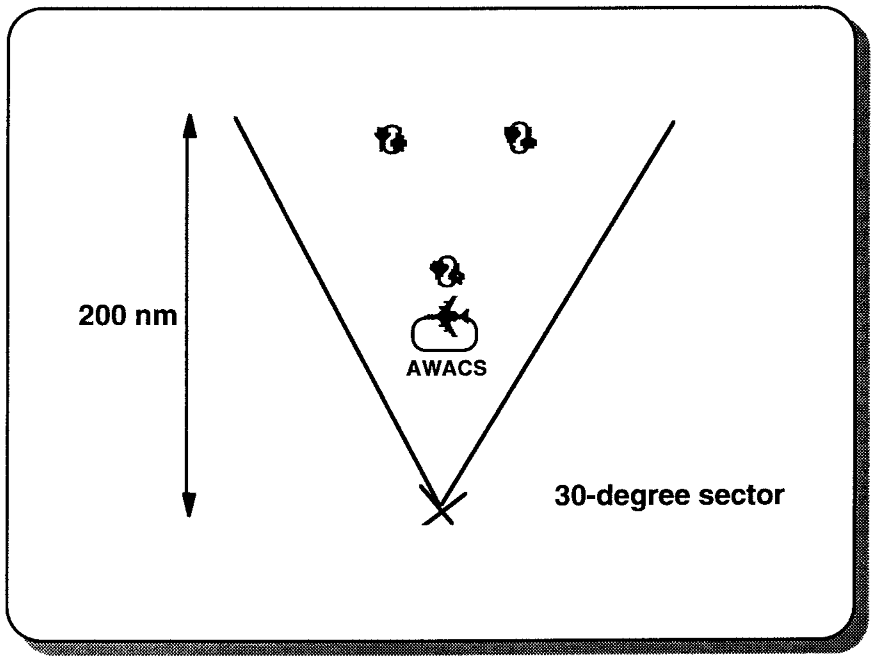


Figure A.4—Possible DCA Scenario

Based on loiter performance, sortie rate, and abort rate, we computed the number of Combat Air Patrol aircraft required to protect an airbase around the clock along a 30-degree sector extending forward 200 nmi.[2] This involved keeping two CAP positions forward and one to the rear filled with pairs of aircraft. We assumed Airborne Warning and Control System (AWACS) aircraft were available and that aircraft did not use in-flight refueling.

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[2]We used standard Air Force planning factors for sortie rates for the first 30 days of a conflict. Abort rates of 3.2 percent for F-16s in the combat air forces worldwide and 4.5 percent for F-15Es based at Seymour Johnson Air Force Base were obtained from Air Combat Command/LGPA in October 1992.

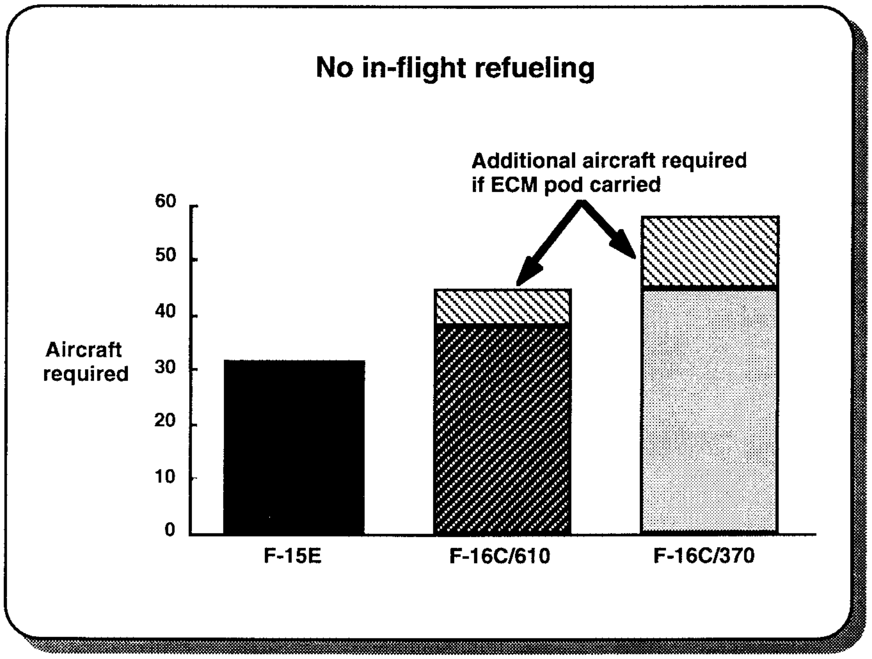

Figure A.5—Aircraft Required to Maintain a 24-Hour CAP

F-15E aircraft perform the CAP mission with fewer aircraft than the F-16C. The use of 610- rather than 370-gallon tanks reduced the number of F-16Cs required to man the CAP stations by about seven aircraft. The substitution of the 300-gallon centerline tank for the ECM pod reduced aircraft requirements by 7 to 12, depending on whether the F-16C operated with 610- or 370-gallon wing tanks.

These results illustrate how the loiter capabilities of the various aircraft translate into mission performance in the absence of tankers. If tankers were employed, they would undoubtedly be used to reduce the number of aircraft assets required to perform the DCA CAP mission. The use of tankers would tend to even out the loiter capability differences between the aircraft, with the result that pilot endurance or perhaps the lubricant supply on either aircraft could become more important as limiting factors.

Whether the F-15E is more cost-effective in filling DCA CAP orbits than the F-16C depends on whether the savings from needing fewer F-15Es is enough to offset the greater cost of each individual airplane. The answer to that question appears to be yes when the F-15E is compared to an F-16C carrying 370-gallon tanks and an ECM pod. The answer is no when the F-15E is compared to F-16Cs carrying 610-gallon tanks and/or centerline fuel tanks.

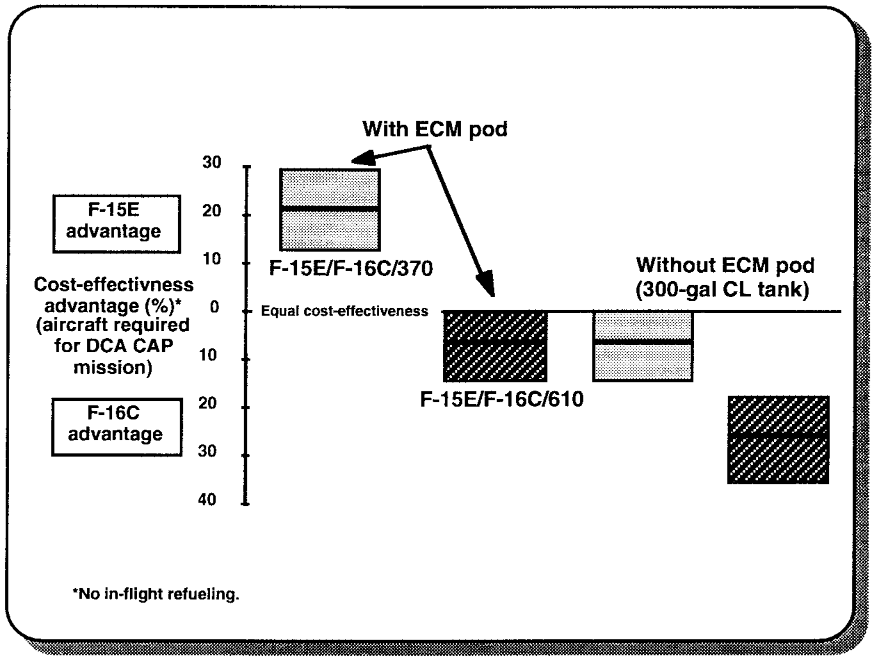

Figure A.6—Cost-Effectiveness Comparison of F-15E/F-16C in Filling DCA CAP Orbits

Cost-effectiveness in this case represents the cost of the aircraft needed to fill the CAP orbits. The bars in Figure A.6 show the cost-effectiveness advantage for the range of cost ratios of the F-15E to the F-16C (from 1.40:1 to 1.62:1), with the line crossing the bars indicating the cost-effectiveness advantage for the nominal cost ratio of 1.5:1.[3] Bars above the horizontal axis indicate an F-15E advantage, whereas bars below the axis indicate an F-16C advantage.

The F-15E advantage ranges from about 12 to 30 percent when compared with F-16C/370s carrying an ECM pod. The F-16C exhibits equal or better cost-effectiveness in filling CAP orbits for the other configurations examined. For this DCA CAP mission, the F-16C benefits from the use of 610-gallon tanks. Moreover, for those situations in which an ECM pod is not needed, the F-16C with 370-gallon wing tanks and a 300-gallon centerline fuel tank can offer good time on station at a cost competitive with or better than that for the F-15E.

[3]LANTIRN pods are not used on this mission, but their costs are included in the cost-effectiveness calculation because the aircraft would be bought principally for air-to-ground missions that use LANTIRN.

To obtain a more complete picture of the comparative cost-effectiveness of F-15Es and F-16Cs on DCA CAP missions, one would have to assess not just the cost of filling orbits but also the comparative lethality and survivability of the two aircraft in air-to-air engagements with potential adversary aircraft.

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