

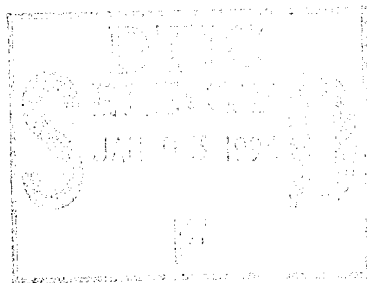
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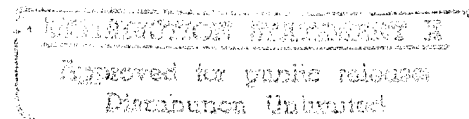


**RAND**

*United States Air Force  
Fighter Support in  
Operation Desert Storm*

*Raymond A. Pyles, Hyman L. Shulman*

19951228 045



**Project AIR FORCE**

DTC QUALITY TRANSLATED 2

The research reported here was sponsored by the United States Air Force under Contract F49620-91-C-0003. Further information may be obtained from the Strategic Planning Division, Directorate of Plans, Hq USAF.

**Library of Congress Cataloging in Publication Data**

Pyles, Raymond, 1941-  
United States Air Force fighter support in Operation Desert Storm  
/ Raymond A. Pyles, Hyman L. Shulman.  
p. cm  
"MR-468-AF."  
"Prepared for the United States Air Force."  
Includes bibliographical references (p. ).  
ISBN 0-8330-2291-1 (alk. paper)  
1. United States. Air Force—Procurement. 2. United States.  
Air Force—Aviation supplies and stores. 3. Fighter planes—United  
States—Maintenance and repair. 4. Persian Gulf War, 1991.  
I. Shulman, H. L., 1919- . II. United States. Air Force.  
III. Title.  
UG1123.P95 1995  
358.4 '141—dc20

95-33017  
CIP

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Published 1995 by RAND

1700 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138

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Justification .....	
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Distribution /	
Availability Codes	
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## Preface

Operations Desert Shield and Desert Storm were characterized by unanticipated levels of demands for U.S. Air Force (USAF) fighter logistics materials and services—sometimes high, sometimes low, but seldom what was predicted during peacetime planning. Peacetime predictions about the required kinds, quantities, and locations of critical logistics resources were frequently wrong—often substantially.

In this report, we discuss logistics support to USAF fighter aircraft in Operation Desert Storm. We review the ability of the logistics system to satisfy fighter units' needs for aircraft components, electronic countermeasures, and Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) pods, and for munitions during the conflict. Where that performance varied from expected or officially planned levels in either a positive or negative way, we sought to identify the underlying causes. From those findings, we draw inferences for the future logistics system, especially in light of post-Cold War changes in the global threat, USAF missions, force size, and future budgets.

This report should be of interest to logistics policymakers, wartime planners, and logistics analysts, because it challenges widely held assumptions about wartime support to fighters. Not only do we question the validity of analysts extrapolating peacetime demand experience into wartime predictions, but we observe that the logistics system for fighters performed best when logistics managers on the scene developed ad hoc processes to supplant standard processes and resource plans. Finally, we indicate the need for more-flexible resources and structures in future USAF logistics policies and plans.

This report is one of several that document a RAND Project AIR FORCE study of the Desert Storm air campaign. The study began in March 1991 under the sponsorship of the Air Force Vice Chief of Staff. Its objectives were to describe and assess (1) the effectiveness of air missions in Desert Storm, at both the strategic and tactical levels, in terms of the initial and evolving campaign objectives, (2) the use of airpower as the major instrument of achieving the withdrawal of Iraqi forces from Kuwait and its implications for future Air Force doctrine, missions, systems, logistics needs, force modernization, and R&D, and (3) the doctrine for planning and executing Desert Storm as a possible paradigm

for a doctrine for joint U.S. and allied operations. The following reports document the unclassified results of that study:

- *Project Air Force Assessment of Operation Desert Shield: The Buildup of Combat Power*, RAND, MR-356-AF, 1994
- *The Air Force Rapid Response Process: Streamlined Acquisition During Operations Desert Shield and Desert Storm*, RAND, N-3610/3-AF, 1992, by Michael G. Anderson
- *The Civil Reserve Air Fleet and Operation Desert Shield/Desert Storm*, RAND, MR-298-AF, 1993, by Mary E. Chenowith
- *Project Air Force Analysis of the Air War in the Gulf: An Assessment of Strategic Airlift Operational Efficiency*, RAND, R-4269/4-AF, 1993, by John Lund, Ruth Berg, and Corinne Replogle
- *Air Campaign Against the Iraqi Army in the Kuwaiti Theater of Operations*, RAND, MR-357-AF, 1994, by Fred Frostic.

## **Project AIR FORCE**

Project AIR FORCE, a division of RAND, is the Air Force federally funded research and development center (FFRDC) for studies and analyses. It provides the Air Force with independent analyses of policy alternatives affecting the development, employment, combat readiness, and support of current and future aerospace forces. Research is being performed in three programs: Strategy, Doctrine, and Force Structure; Force Modernization and Employment; and Resource Management and System Acquisition.

Project AIR FORCE is operated under Contract F49620-91-C-0003 between the Air Force and RAND.

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## Summary

When historical commentators remark that war is uncertain, they refer mainly to predicting combat events and outcomes. Even in a setpiece battle (as on a board game, where both protagonists can see everything except their opponent's intentions and plans), the two sides constantly jockey for position and other advantages, weaving a pattern that is difficult to perceive, analyze, and predict. In real conflicts, the jockeying intensifies as both sides endeavor to take advantage of changing, incomplete operational information.

That jockeying places unpredictable demands on the logistics system. Every shot fired, every bomb dropped, and every sortie launched requires that specific resources and services be delivered at the right place and at the right time. To be successful in the presence of a rapidly changing operational situation, a force must have a logistics system that can deliver markedly different resources from those envisioned during initial planning.

The Desert Shield and Desert Storm operations were no different. In response to challenges and opportunities that arose, Central Command Air Force (CENTAF) changed the forces that deployed, reassigned mission taskings, revised deployment schedules, and redeployed aircraft in combat. By all accounts, the logistics system responded quickly to meet the forces' needs, despite the many changes in plans.

In this study, we asked two questions about Desert Storm logistics operations: How did they achieve such high performance? and What implications does that achievement have for future planning? The answers to the first question may identify policies and procedures that provide more-efficient wartime and peacetime support; the answers to the second question may identify policies and procedures especially relevant in the emerging context of a reduced force whose primary missions focus on unpredictable global contingencies.

### **USAF Fighter Support Demands Were Unpredictable**

Operations Desert Shield and Desert Storm were characterized by unanticipated levels of demands for U.S. Air Force (USAF) fighter logistics materials and services—sometimes high, sometimes low, but seldom what was predicted during peacetime planning. Peacetime predictions about the required kinds,

quantities, and locations of critical logistics resources were frequently wrong—often substantially.<sup>1</sup>

For example, Code 3<sup>2</sup> “breaks,” or demands for aircraft maintenance, varied significantly from peacetime experience, as shown in Figure S.1: F-15Cs deployed to Desert Shield immediately experienced about two to three times the number of breaks per sortie, or “break rate,” of nondeployed aircraft. In contrast, deploying F-16Cs initially had fewer Code 3 breaks per sortie than home-station F-16Cs, but their break rates increased in January as Desert Storm approached. Finally, the deployed EF-111As had consistently fewer Code 3 breaks throughout both Desert Shield and Desert Storm.

These patterns of unpredictable demands extended far beyond aircraft maintenance to include aircraft spare parts, electronic countermeasure (ECM) pods, Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) pods, and munitions. In response, the continental United States (CONUS) depots pushed<sup>3</sup> additional material to the units, redistributed material within the theater, and cannibalized critical parts from nondeployed wings; the Material Air Command created Desert Express<sup>4</sup> to move critical cargo to meet unpredicted demands and created CENTAF REAR<sup>5</sup> to assemble and manage that movement.

### *The Specific Demand Patterns Were Unique to Desert Storm*

In hindsight, we can explain<sup>6</sup> what may have caused the specific patterns of demands. We still cannot predict future demands, because we cannot know that similar events will arise in future contingencies.

For example, most analysts attribute the increased F-15C demands to their immediate engagement flying combat air patrol (CAP) in theater. In that activity, almost every aircraft subsystem was required, and pilots facing an imminent

---

<sup>1</sup>How could they *ever* be right? The demands were extrapolated from peacetime flying, with one mix of flying operations, logistics structure, and aircrew expectations, to wartime combat, for which all those factors change *depending on the nature of the tasking*.

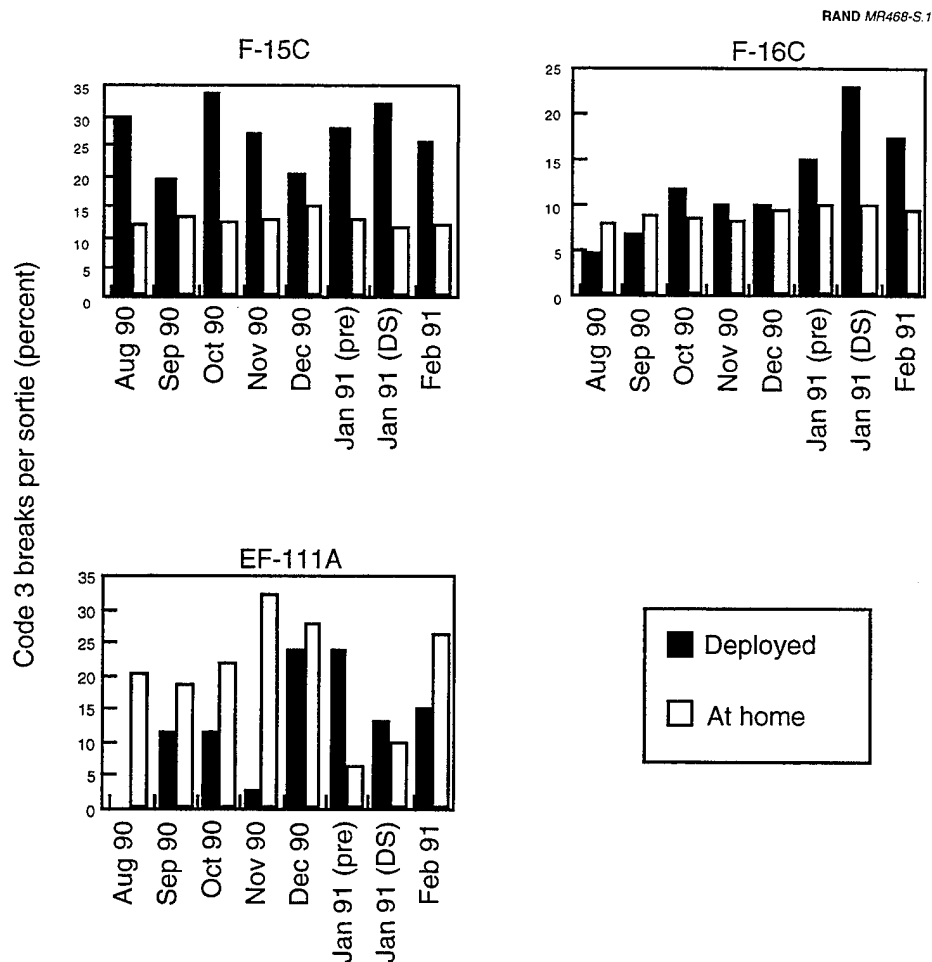
<sup>2</sup>When returning from a sortie, USAF aircrews rated the aircraft’s status as “Code 1” (mission ready), “Code 2” (mission ready, but needing minor maintenance), or “Code 3” (requires maintenance before the next mission). “Code 3” aircraft are called “broken” until the maintenance is successfully completed.

<sup>3</sup>USAF logistics managers extrapolated peacetime experience and *pushed* material, i.e., moved material without deployed units’ request or stated requirement.

<sup>4</sup>Desert Express: a daily C-141 express shipment of spare parts and other critical material to Dhahran airport for all Central Command (CENTCOM) forces.

<sup>5</sup>CENTAF REAR: support command-and-control center established at Langley AFB, Va., to coordinate CONUS support to USAF forces assigned to CENTAF.

<sup>6</sup>That is, we can construct a plausible explanation after the fact. Other, equally plausible, explanations may exist, which only compounds the difficulty of predicting future demands.



NOTE: Scales differ.

Figure S.1—Code 3 Break Rates Were Unpredictable

enemy attack were particularly scrupulous about ensuring that all aircraft subsystems were operating at their fullest potential. In contrast, the deployed F-16Cs and other attack aircraft operated under severe flight and mission restrictions until bombing ranges were made available and, later, mass training sorties were organized. Initially, deployed F-16C Code 3 reports diminished, relative to those of nondeployed aircraft. In October 1990, F-16C Code 3 reports increased sharply and peaked when Desert Storm began, because combat-oriented training sorties were first authorized, then later intensified, and, finally, combat began. Lastly, the deployed EF-111As initially operated without the benefit of immediate feedback from ground ranges regarding the effectiveness of their jamming equipment and tactics. After November 1990, the electronic combat Aggressor Squadron tested the ECM gear on 13 EF-111As, which

furnished feedback on the condition of the equipment and temporarily increased Code 3 breaks. Once combat operations began and the Iraqi Air Defense System became less active, aircrews received little feedback on their airborne jamming effectiveness, so break rates diminished again.

More important, demands on individual subsystems varied markedly from peacetime predictions. On the one hand, F-117As encountered substantially increased demands for inertial navigation systems (INS), because aircrews required more-accurate, more-stable INS for the much longer sorties in Desert Storm. On the other hand, F-111Es and F-111Fs did not need their terrain-following subsystems for the mid- to high-altitude Desert Storm missions, so demands for the related components fell. The redeployment of B-52s created a need to move substantial quantities of bombs to the new location. The development of F-111F "tank plinking"<sup>7</sup> led to an urgent need to move 500-lb bombs to the F-111F base.

In short, Desert Storm's changing operational strategies and tactics drove the demands for all manner of logistics resources. The next war may not have the same strategies or tactics. Thus, the logistics demands that will arise may also differ substantially.

## **Ample Resources and Management Adaptations Enabled High Force Capability**

Despite such unpredictable demands, the USAF fighter forces maintained exceptionally high levels of aircraft availability and sorties. Broadly, we attribute that performance to two factors: ample resources and management adaptations.

### ***Ample Resources Were "Pushed" to the Theater***

With the exception of a few aircraft mission design series (MDS, i.e., F-15E, F-111F, and F-117A), only part of the total USAF inventory of each MDS deployed to Desert Storm. The deployed forces were thus able to draw upon larger pools of highly trained personnel, spare parts, serviceable maintenance equipment, and bombs and other munitions.

Some of those resources were critical to maintaining high sortie levels and aircraft availability in theater, particularly aircraft maintenance personnel and

---

<sup>7</sup>Tank plinking: dropping laser-guided 500-lb bombs from F-111Fs with laser designators to attack tanks. Previously, the laser-seeking bomb heads had been used mostly with 2,000-lb bomb bodies to attack large, fixed installations.

equipment. Because the units had ample highly motivated and trained personnel, many units doubled their peacetime sortie rates. In many units, the breaks per sortie also increased twofold,<sup>8</sup> thereby quadrupling the workload. Even so, most deployed units were able to reduce the maintenance aircraft backlog. Units' ample flight-line capacity made it possible to support mass aircraft launches, even when they experienced the dramatically higher Code 3 break rates.

Air Logistics Centers (ALCs) used their deep stores and repair capacity to assemble and move—"push"—even more material into the theater. ALC repair shops surged, munitions and other consumables were "pushed" to the theater, ports at both ends swelled to overflowing—all based on *predictions* of what material the forces would need in the approaching battle.

No doubt, some of the material was actually used. But it was both too much and too little, because of the uncertainties in the demand processes. Despite deploying with full-up war reserve spares kits (WRSK), pushing follow-on spares kits (FOSK) forward, and surging spares production at the ALCs to meet the anticipated demands, deployed units experienced unpredicted demands that even those enhanced resource levels could not cover. The extra, unneeded parts, munitions, and other resources could not substitute for the material that was actually needed.<sup>9</sup>

### ***Responsiveness-Oriented Management Adaptations Filled the Gap***

Because demands emerged in unpredicted, even unpredictable, ways, the Desert Storm logistics system transformed itself and its operations to become more responsive to emerging demands being experienced on the battlefield. Inter-theater (Desert Express) and intra-theater (Camel routes) airlift of critical material was created, regional repair locations were set up at Rhein-Main Air Base (AB), Germany, and some U.S. Air Force, Europe (USAFE) bases, and CENTAF REAR was established to locate and assemble critical material from nondeployed forces.

Each of those adaptations had the effect of shortening the response time between the Desert Storm forces' recognition of a need and the meeting of that need, effectively letting the forces "pull" the really important material from the best

---

<sup>8</sup>A few aircraft, such as the A-10, flew fewer but longer sorties in Desert Storm. Overall, Desert Storm fighters flew about twice the sortie rate during the war as nondeployed aircraft (1.0 versus 0.51 sorties per day). Average daily flying hours increased even more, from 0.8 to 3.7 hours per aircraft (4.5 times the nondeployed force hours).

<sup>9</sup>Moreover, they sometimes got in the way by using limited air transportation resources that could have met the more relevant demands actually encountered by the forces.



source. Thus, critical spare parts were moved to the theater by Desert Express in slightly more than one day and distributed from the theater port to the flying units in a similarly short time. C-130 avionics and engine repair at Rhein-Main AB considerably shortened the time between the removal of a critical C-130 component and its return to a unit; similar activities at Hahn AB, Germany, and other USAFE air bases enhanced the responsiveness of support for F100 engines on F-15 and F-16 aircraft in theater; F-111F avionics and engine repair depended on home station (at RAF Lakenheath, United Kingdom). Finally, CENTAF REAR located unit-identified critical aircraft components at CONUS bases and directed their movement to Charleston Air Force Base (AFB), S.C., for Desert Express shipment.

### *Ample Resources and Management Adaptations Were Not Always Enough*

In some cases, sufficient assets did not exist to cover both the deployed and nondeployed forces' needs. In particular, some aircraft did not have a substantial nondeployed force, and some critical resources were not available in sufficient quantities.

The F-15E, F-111F, and F-117A MDS aircraft were almost fully deployed to Desert Storm, so they could not draw on the resources of the nondeployed forces for MDS-specific material and services. Furthermore, in some cases there were not enough spares to begin with. As a consequence, these aircraft experienced special difficulties in obtaining spares support.

Similarly, support to ECM pods suffered because of unpredictable demands and limited resources. USAF policy allocates sufficient ECM pods to each squadron to mount one pod per aircraft, as if the pods were highly reliable and easily maintained. They are neither. ECM pods require some of the most sophisticated, complex, sensitive technologies of any USAF equipment; test times, on equally complex, sophisticated and expensive automatic test equipment, are usually in excess of 18 hours, and multiple tests are typically required to detect, diagnose, fix, and confirm an effective repair. In Desert Storm, several deployed wings experienced a growing backlog of ECM pods awaiting repair because demands overwhelmed their ECM repair capacity; the shortfall was "solved" by deploying more pods from nondeployed forces. Thus, the unpredictably higher Desert Storm ECM pod removal rates<sup>10</sup> combined with a constrained repair capacity

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<sup>10</sup>Pod use is severely constrained in peacetime by security and range availability. The small sample sizes and constrained operating circumstances of peacetime operations make estimates of wartime demands highly unreliable, even when the differences in utilization are considered.

and limited pod availability to threaten the deployed forces' combat capabilities, and ultimately drew down the capabilities of the nondeployed forces. Some nondeployed units had as few as four operating ECM pods remaining by the end of Desert Storm.<sup>11</sup>

## **Many Desert Storm Logistics Options Will Not Be Available in the Future**

Clearly, the USAF and its supporting infrastructure will be downsized as a result of both serious U.S. government budget concerns and the demise of the Cold War. That downsizing will remove, or at least diminish, two important options exercised during Desert Storm: pushing resources forward from ample supplies and diverting resources from the nondeployed forces. While some low-tech material stockpiles may emerge temporarily from retiring older aircraft or from slowing munitions consumption, the critical, sophisticated state-of-the-art radars, engines, ECM pods, LANTIRN pods, and smart munitions materials so important in Desert Storm will probably still be in short supply, because the latest modifications will have been introduced in only a subset of the aircraft. For example, radar subsystems in different F-16 blocks differ substantially, so some F-16C radar components cannot be used to meet other F-16C spares demands.

More critically, future USAF and DoD policymakers may need to think twice before diverting resources between deployed and nondeployed forces whose combined size is just adequate to meet two major regional contingencies. Even if one force were not currently engaged, the world situation might change rapidly enough that diverting key resources from the non-engaged force might jeopardize its ability to respond to the second contingency.

Thus, the current fighter logistics system, with its long response times and its reliance on great quantities of previously acquired material, may not match the challenges of the 1990s and beyond. Material alone is insufficient to meet the uncertainties, and some of the backups inherent in the larger forces of the past will disappear.

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<sup>11</sup>A similar policy affects LANTIRN pods, and a similar result ensued—except that *all* the LANTIRN targeting pods were deployed to Desert Storm, leaving none for nondeployed units.

## Enhancing Logistics System Responsiveness Should Improve Wartime Support

Fortunately, Desert Storm also demonstrated the viability of a more responsive concept of logistics operations. Desert Express, more-responsive rearward (including CONUS depot, regional, and contractor) support, and more-aggressive command and control critically enhanced the combat capability of the Desert Storm fighter forces, even after accounting for the massive materials “pushed” to the theater. We anticipate a “Lean Logistics” system operating in both peace and war could achieve much the same performance levels as seen in Desert Storm, without relying on such massive quantities of materials or diverting material from nondeployed forces, even with the much higher demand uncertainties inherent in wartime operations. Initial analytic research<sup>12</sup> has already demonstrated the potential of such a system; USAF field demonstrations are under way to refine and implement such a system.

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<sup>12</sup>I. K. Cohen, R. A. Pyles, and R. Eden, in “Lean Logistics: A More Responsive, Robust, and Affordable System,” RAND, unpublished draft, describe and evaluate such a system for repairable components. I. K. Cohen, J. B. Abell, and T. F. Lippiatt summarize some peacetime and wartime uncertainties and propose mitigating management adaptations in *Coupling Logistics to Operations to Meet Uncertainties and the Threat (CLOUT): An Overview*, Santa Monica, Calif.: RAND, R-3979-AF, 1991.

## Acknowledgments

This report draws extensively on experiences reported by maintenance, supply, and transportation managers and technicians throughout the United States Air Force (USAF) combat air forces. Without their forthright help, our description and analysis of Desert Storm fighter logistics support would have been much more tentative, much less complete, and more error-prone. Their comments and observations helped us round out and explain events more richly than if we had to rely on formal data systems alone.

In addition, we would like to thank the USAF logistics analysts who willingly shared their data and insights about the data's relevance and accuracy. Special thanks go to Ed Merry in (then) Tactical Air Command, Lt Col Philip DeBuin in United States Air Forces, Europe, Jay King from Dynamics Research Corporation, and their staffs, who painstakingly acquired, recorded, and assembled the data.

We also appreciate the efforts of several RAND staff members, including Patricia Boren, who helped us sift the data and prepared the numerous graphs, and Regina Sandberg and Francine Scarantino, who prepared the various drafts. Marian Branch edited this report, and helped us clarify and present the material in a much more accessible and understandable fashion.

Finally, our work benefited from insightful reviews by participants in Desert Storm operations and logistics, including MGen Edward R. Bracken (USAF, Ret.), BGen Anthony Tolin (57FW/CC), and Col Clifford Wurster (then 48TFW/DCM). They clarified several key points, and helped us understand the various points of view and keep all the elements in perspective.

We alone accept responsibility for any remaining errors of fact or interpretation.

## Glossary

AAA	Anti-aircraft artillery
AB	Air base (USAF-operated base)
Abort rate	Fraction of scheduled sorties not generated (ground abort) or returned without completing mission (air abort)
AC	Active component
ACC	Air Combat Command
AFB	Air Force Base (USAF-owned base, i.e., on U.S. territory)
AFLC	Air Force Logistics Command
AFLIF	Air Force Logistics Information File
AI	Airborne interceptor
ALC	Air Logistics Center
BLSS	Base-level self-sufficiency (kit)
Break	A demand for aircraft maintenance
Break rate	Fraction of returning sorties needing repair
Broken	Designation of aircraft in repair until maintenance is complete
Camel route	Intra-theater airlift of critical material
CAMS	Core Automated Maintenance System
Cannibalization rate	Fraction of supply requests resolved by removing a part from another (already-NMCS) aircraft
CAP	Combat air patrol
C <sup>2</sup>	Command and control
CENTAF	Central Command Air Force
CENTAF REAR	Support command-and-control center established at Langley AFB, Va., to coordinate CONUS support to USAF forces assigned to CENTAF
CENTCOM	Central Command
CLOUT	Coupling Logistics to Operations to Meet Uncertainty and the Threat
Code 1 condition	Aircraft needs no maintenance, is mission ready
Code 2 break	Aircraft needs maintenance but can perform next mission (mission ready but needing maintenance)
Code 3 break	Aircraft needs maintenance before the next mission
CONUS	Continental United States

CSS	Combat Supplies System
CSSA	CENTAF Supplies Support Activity; after Desert Storm, renamed Combat Supply Support Activity
DCS	Deputy Chief of Staff
DDN	Defense Digital Network
Desert Express	A daily C-141 express shipment of spare parts and other critical material to Dhahran airport for all Central Command (CENTCOM) forces
DLA	Defense Logistics Agency
DoD	Department of Defense
EC	Electronic combat
ECM	Electronic countermeasures
EW	Electronic warfare
FAC	Force activity center
FAD	Force activity designator
FAX	Facsimile
FMC	Fully mission capable
FOSK	Follow-on spares kit
FW	Fighter Wing
HQ	Headquarters
IADS	Iraqi Air Defense System
INS	Inertial navigation system
IRADS	Infrared attack designation system
ISL	Initial spares levels
JCS	Joint Chiefs of Staff
JTF	Joint Task Force
LANTIRN	Low Altitude Navigation and Targeting Infrared for Night
LGB	Laser-guided bomb
Log CONOPS	USAF Wartime Logistics Concept of Operations
MAC	Military Airlift Command
MAJCOM	Major Air Command
MAS	MICAP Asset System
MC	Mission capable; generally means PMC
MDS	Mission design series
MESL	Mission essential systems list
MICAP	Mission capability
MILSTRIP	Military standard requisitioning and issuing procedures
MRC	Major regional contingency

MSK	Mission support kit
NATO	North Atlantic Treaty Organization
9BU	Special project code to enhance priority
999	Code indicating urgent need affecting units' immediate wartime capability
NMC	Not mission capable
NMCM	Not mission capable for maintenance
NMCS	Not mission capable for supply
Optempo	Operational tempo; sorties per day or flying hours per day
OR	Operationally ready; archaic equivalent of mission capable
PMC	Partially mission capable
POD	Port of debarkation
POE	Port of embarkation
POS	Peacetime operating stocks
RAF	Royal Air Force (British)
R&D	Research and development
SAC	Strategic Air Command
SAM	Surface-to-air missile
SBSS	Standard Base Supply System
SDS	SMART data system
SITREPS	Situation reports
STU	Secure telephone unit
TAC	Tactical Air Command
Tank plinking	Dropping laser-guided 500-lb bombs from F-111Fs with laser designators to attack tanks
TCTO	Time-change technical order
TFG	Tactical Fighter Group
TFS	Tactical Fighter Squadron
TFW	Tactical Fighter Wing
TO	Technical Order
TRADES	A formal repair and distribution model
USAF	United States Air Force
USAFE	U.S. Air Force, Europe
WRSK	War reserve spares kit
WSMIS	Weapon System Management Information System

## 1. Introduction

When historical commentators remark that war is uncertain, they refer mainly to predicting combat events and outcomes. Even in a setpiece battle (as on a board game, where both protagonists can see everything except their opponent's intentions and plans), the two sides constantly jockey for position and other advantages, weaving a pattern that is difficult to perceive, analyze, and predict. In real conflicts, the jockeying intensifies as both sides endeavor to take advantage of changing, incomplete operational information.

That jockeying places unpredictable demands on the logistics system. Every shot fired, every bomb dropped, and every sortie launched requires that specific resources and services be delivered at the right place and at the right time. To be successful in the presence of a rapidly changing operational situation, a force must have a logistics system that can deliver markedly different resources from those envisioned during initial planning.

### **Desert Storm Logistics: A Paradigm for Wartime Logistics Planning?**

The Desert Shield and Desert Storm operations were no different. Operations Desert Shield and Desert Storm were characterized by unanticipated levels of demands for U.S. Air Force (USAF) fighter logistics materials and services—sometimes high, sometimes low, but seldom what was predicted during peacetime planning. Peacetime predictions about the required kinds, quantities, and locations of critical logistics resources were frequently wrong—often substantially.<sup>1</sup>

In response to challenges and opportunities that arose, Central Command Air Force (CENTAF) changed the forces that deployed, reassigned mission taskings, revised deployment schedules, and redeployed aircraft in combat. By all accounts, the logistics system responded quickly to meet the forces' needs, despite the many changes in plans.

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<sup>1</sup>How could they *ever* be right? The demands were extrapolated from peacetime flying, with one mix of flying operations, logistics structure, and aircrew expectations, to wartime combat, for which all those factors change *depending on the nature of the tasking*.



Yet, peacetime logistics planning and resources acquisition take scant account of such uncertainties. They seek to improve the accuracy of the prewar material-consumption predictions, rather than to acquire flexible resources, such as repair and transportation, that can shift support quickly from one demand to another. (For example, a technician capable of repairing any of several components can quickly repair whichever component is needed, whereas stock for any one component is useful only to cover demands for that component.)

In the late 1980s, the USAF logistics community formally recognized those uncertainties and developed an Air Force Logistics Concept of Operations<sup>2</sup> that emphasized Coupling Logistics to Operations to Meet Uncertainty and the Threat (CLOUT).<sup>3</sup> By seeking ways to make logistics more responsive to operational changes, it was hoped that wartime logistics effectiveness could be improved substantially.

Nonetheless, the dominant paradigm for planning throughout the 1980s continued to rely on predictions for a worst-case scenario—the NATO–Warsaw Pact conflict—with an implicit assumption that all other wars were lesser, included cases. With the demise of the Cold War and the subsequent reductions in USAF forces (and logistics resources), that convenient planning paradigm may no longer be adequate—particularly if wartime logistics demands are as unpredictable as peacetime experience has suggested.<sup>4</sup>

As reported here, we reviewed the Desert Storm wartime experience for aircraft spare parts, electronic countermeasure (ECM) pods, Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) pods, and munitions. We found that the wartime demand uncertainties were even worse than was implied by the most pessimistic analysis of peacetime experience. Despite those uncertainties, logistics support in Desert Storm has been more widely applauded than the logistics support in all preceding conflicts.

In this study, we asked two questions about Desert Storm logistics operations: How did they achieve such high performance? and What implications does that achievement have for future planning? The answers to the first question may identify policies and procedures that provide more-efficient<sup>5</sup> wartime and

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<sup>2</sup>See Colonel Richard F. Trainor, "The Evolution of an Air Force Concept of Operations," *Air Force Journal of Logistics*, Winter 1988, pp. 1–4.

<sup>3</sup>See I. K. Cohen, John B. Abell, and Thomas F. Lippiatt, *Coupling Logistics to Operations to Meet Uncertainty and the Threat (CLOUT): An Overview*, Santa Monica, Calif.: RAND, R-3979-AF, 1991.

<sup>4</sup>Gordon B. Crawford, *Variability in the Demand for Aircraft Spare Parts: Its Magnitude and Implications*, Santa Monica, Calif.: RAND, R-3318-AF, 1988.

<sup>5</sup>To those who argue, "War is always inefficient," we reply, "One always faces choices when acquiring resources. More of a specific resource may be better, if it is not acquired by sacrificing something else more valuable."

peacetime support; the answers to the second question may identify policies and procedures especially relevant in the emerging context of a reduced force whose primary missions focus on unpredictable global contingencies.

## Scope of Analysis

In this study, we sought to identify the causes of any unexpectedly good or disappointing USAF fighter<sup>6</sup> support during Desert Storm. We limited our analysis to the fighters and combat equipment mounted on fighters (electronic pods and munitions)—because those resources contributed directly to the operation's outcome. Some noncombat resources, such as air and ground transportation, and component repair, are discussed because they materially affected fighter combat capability. Other support resources and functions, e.g., housing, food, vehicles, personnel, and finance, were certainly important, but we do not cover their support because their contributions did not affect combat outcomes so directly.

We also concentrated on understanding the general *flow* of events, rather than on identifying technical issues affecting a particular aircraft, munition, or subsystem. Thus, we used anecdotal evidence to illuminate the general logistics processes, including material flows, information flows, and decisionmaking.

## Organization of This Report

In the next section, we describe our approach and data sources. In Section 3, we recount key events and aircraft-support performance indicators in Desert Shield and Desert Storm. In Section 4, we describe performance for ECM and LANTIRN pods; in Section 5, we describe performance for munitions. Finally, we draw inferences from that performance for future logistics planning, in Section 6.

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<sup>6</sup>We use the word *fighter* to connote all tactical combat aircraft. Thus, we explicitly exclude airlift, command and control, and heavy bombers, but we include defense suppression, reconnaissance, and ground attack aircraft with the pure air superiority "fighters."

## 2. Approach and Data Sources

### Approach

Using two complementary approaches, we identified situations in which logistics performance deviated from planned levels. First, we identified changes in procedure that indicated some management adaptation was necessary to achieve or exceed planned levels of operational performance. Second, we compared logistics events and performance in Desert Shield and Desert Storm with planning assumptions and forecast performance for all aircraft mission design series (MDS), ECM pods, and munitions.

We then undertook a decision-tree analysis<sup>1</sup> to identify the possible causes of the unexpected performance. For example, we compared the percentage of aircraft that were fully mission capable (FMC) to the stated wartime goals of maintaining 75 percent aircraft FMC for a 30-day war without resupply. As shown in Figure 2.1, we then examined how changes in each of the three potential causal factors—demand rates, maintenance productivity, and supply responsiveness—may have contributed to that deviation from planned levels. Depending on which of those three factors varied from their planned levels, we identified and examined other contributory factors that may have caused those changes.

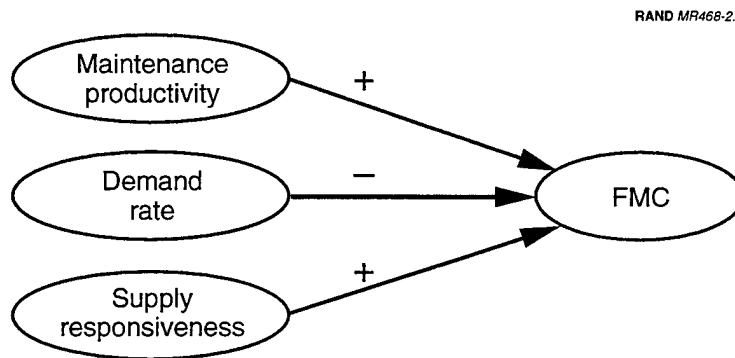


Figure 2.1—Factors Contributing to Full Mission Capability

<sup>1</sup>A decision-tree analysis starts with some extraordinary effect, such as the exceptionally high mission capable (MC) rates achieved in Desert Storm, and works its way back through a network of potential causes to identify what caused that effect.

## Data

### *The Data Not Used in This Study*

Support measures during peacetime operations at the home base, or home station, are tracked by several base-level data systems. The Core Automated Maintenance System (CAMS) provides a maintenance data-collection and -analysis capability that captures operationally relevant measures of support system performance (aircraft downtime for maintenance and supply, sortie-scheduling effectiveness, and reliability and maintainability measures at the aircraft, subsystem, and component indenture levels, plus shop production and measures by job and job category). In addition, the Standard Base Supply System (SBSS) maintains visibility and control over supply activities that can be used to estimate component reliability and maintainability, unused asset levels, asset-shortage frequencies (e.g., fill rates, backorder rates, and mission capability [MICAP] rates), and supply response times.

Those peacetime data sources were generally unavailable in Desert Storm. Whereas manually collected aircraft status data were needed to support real-time wing-level operational decisions and appeared to be valid, many of the detailed support actions behind those status changes did not appear in the databases, and we could rely only on participants' recollections.

CAMS was not fully deployed to Southwest Asia. CAMS terminals linked to home-station computers via satellite were ultimately deployed to some bases, but deployed maintenance personnel recorded relatively fewer per-sortie maintenance activities than home-station personnel. From interviews with maintenance personnel (and from operational aircraft break<sup>2</sup> data), we inferred that per-sortie demands for maintenance actually increased for many deployed aircraft, but that three factors combined to lower recorded maintenance actions to meet those demands: some noncritical demands were suppressed or delayed, some removal and replacements of failed components were not recorded on paper, and some maintenance-action paper records were lost before they could be recorded on CAMS.

Likewise, SBSS was only slowly and incompletely deployed to Southwest Asia. A deployable Combat Supplies System (CSS) designed to operate as a remote satellite to each deployed unit's SBSS was deployed, but electronic communications channel constraints and error-prone backup procedures rendered this system ineffective. In November 1990, the CENTAF Supplies

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<sup>2</sup>Break: a demand for aircraft maintenance.

Support Activity (CSSA) was instituted at CENTAF REAR<sup>3</sup> with a U.S.-based SBSS dedicated to terminals distributed across satellite accounts at theater bases. Unfortunately, CSSA history tapes covering theater supply activities prior to February 1991 were recycled (reused for more recent data), in accordance with standard operating procedure, before they could be retrieved and used for analysis.

We did have access to an electronic database of situation reports (SITREPS) and other messages to and from the CENTAF Directorate of Logistics. Those messages were frequently helpful in understanding the daily ebb and flow of logistics events and problems throughout the conflict; however, their episodic nature and their focus on short-lived, real-time, worst-case problems provided little insight into the underlying logistics processes. That is, they identified and documented specific material shortfalls and one-of-a-kind workarounds, but the problems and workarounds changed daily. As useful as these exception-reporting messages may have been for real-time decisionmaking, their content was too episodic and detailed to provide insights on the overall logistics processes.

### *Primary Data Sources*

Luckily, some aggregate data about fighter aircraft support that were needed to manage daily sortie-generation and -maintenance activities were collected and preserved by maintenance personnel. Immediately after a sortie, an air abort, or a ground abort, the aircrew filled out a maintenance debriefing form that describes equipment problems that may have occurred. Reports were filled out even if no problems occurred. Those reports were needed by maintenance personnel to track and diagnose aircraft problems, some of which needed resolution prior to the next sortie. We assume that those data were highly accurate, because they represented the only way for an aircrew to communicate to maintenance personnel any equipment problems during the previous sortie, and the only way for maintenance personnel to report back that the aircraft had been returned to mission capable (MC) status.

In addition, the Aircraft Maintenance Record (AF Form 781) was used by maintenance personnel to document aircraft operational status. As long as a critical problem remained open, the aircraft could not be used for combat sorties. Thus, the form recorded any aircraft status change.

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<sup>3</sup>CENTAF REAR: support command-and-control center established at Langley AFB, Va., to coordinate CONUS support to USAF forces assigned to CENTAF.

Given their critical purposes of tracking aircraft status and informing maintenance personnel about the nature of any performance problem, those records were carefully collected and filed. In peace and war, they report real-time aircraft status events that form the basis for statistical performance measures reported monthly by the units to the Major Air Commands (MAJCOMs). Thus, those records are the foundation for measuring aircraft availability, aircraft not mission capable for maintenance (NMCM), aircraft not mission capable for supply (NMCS), break rates per sortie, abort rates, and fix rates. Most important for our analysis, the data-recording and -collection processes remained invariant for both deployed and nondeployed units before, after, and during Desert Storm.

Thus, our primary sources of numerical data are Tactical Air Command (TAC)<sup>4</sup> and United States Air Forces, Europe (USAFE)<sup>5</sup> command summaries of wing-by-wing participation in Desert Shield and Desert Storm from August 1990 through February 1991. Those summaries drew on data provided by the wings in their formally required Monthly Maintenance Summaries, which report average aircraft status, reliability, supply supportability, and maintainability statistics, along with narrative descriptions of specific problems encountered. Those data, in turn, are based on the aircraft status and debriefing data used by both the deployed and the at-home units to manage and plan their daily sortie support.

Some statistics in those reports differ from the aircraft status reports generated for theater command and control during Desert Storm. In particular, the standard computation of MC rates reflects an *average* number of aircraft available throughout the day; the theater daily reports measured only the *snapshot* aircraft status, the status at 12:01 a.m. local.<sup>6</sup> The snapshot was taken several hours after most units had concluded flying for the day, so the snapshot measure did not reflect the degree to which flight-line maintenance backlogs may have constrained flying activities. We used the more conservative<sup>7</sup> average MC rate to enable unbiased comparisons between deployed and nondeployed units.

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<sup>4</sup>*Logistics Data from Desert Shield/Desert Storm*, Langley AFB, Va.: Tactical Air Command, Deputy Chief of Staff (DCS) Logistics, September 1991.

<sup>5</sup>*Command Management Review: Desert Shield, Desert Storm, Proven Force*, Ramstein Air Base (AB), Germany: United States Air Force, Europe, DCS Logistics, July 1991.

<sup>6</sup>Because their daily sortie profile differed, F-117A aircraft availability reports were submitted later in the day.

<sup>7</sup>We did not adopt the most conservative measure, fully mission capable aircraft. We judged that measure was not relevant to an assessment of Desert Storm support, because it would require that the aircraft be able to perform missions not relevant to that contingency.

We supplemented those numeric data with narrative descriptions of events during Desert Shield and Desert Storm, gathered mainly through interviews with deployed and nondeployed operations and maintenance personnel at wings, command centers, and support locations.<sup>8</sup> In addition, we reviewed written after-action summaries and briefings from the Air Combat Command (ACC), USAFE, and some units. Finally, we derived some observations from an electronic file of message traffic acquired by TAC during the conflict.

The most comprehensive data covered the status of aircraft in theater and at home station, because those statistics are based on operationally required management measures. Considerably fewer data were available about ECM, LANTIRN, and munitions, in part because the operational status of those equipment is not regularly measured and reported in peacetime.

For more-detailed data, we also used the aircrews' debriefing data from the F-117A SMART data system (SDS) to investigate which subsystems experienced break-rate changes during Desert Storm. In addition, we used that same data source to investigate potential changes in aircrews' reporting criteria in wartime.

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<sup>8</sup>In particular, we visited A-10A, F-111F, F-117A, and F-16 maintenance units in USAFE and ACC during July-September 1991.

### 3. Desert Storm Fighter Aircraft Maintenance and Supply

Support for Desert Storm fighter aircraft was built on the foundation laid by Desert Shield. In this section, we assess current USAF policies and procedures for wartime aircraft support by reviewing events and performance measures in both Desert Shield and Desert Storm. Subsequent sections review support events and performance for electronic countermeasures equipment and munitions.

To assess the aircraft support performance, we reviewed monthly maintenance summaries for tactical aircraft deployed from TAC and USAFE. In particular, we compared the deployed units' performance to two standards: the performance of the nondeployed units and the stated war reserve spares requirements computation goal of 75 percent FMC.<sup>1</sup> The performance of the nondeployed units is important, because it may have been degraded when the deployed units were given priority for resupply support.<sup>2</sup>

First, we report how both deployed and nondeployed units' aircraft MC rates changed throughout Desert Shield and Desert Storm for ten aircraft mission design series (MDS): F-15C, F-15E, F-16C, A-10A, F-4G, RF-4C, EF-111A, F-111E, F-111F, and F-117A. We then discuss, in turn, how changes in aircraft-maintenance demand rates, maintenance productivity and capacity, and spares availability and responsiveness may have caused the observed MC rate changes.

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<sup>1</sup>The 75 percent FMC aircraft availability goal is typically computed against a very demanding 30-day scenario, with limited base component repair, no base resupply, and an initial sortie surge well above peacetime rates. Thus, the wartime requirements computations explicitly demand considerably more resources (especially spares and unscheduled maintenance) than peacetime operations. Some of the added maintenance requirement is partially offset by an assumption that phased inspections of aircraft will also be delayed. None of these assumptions was honored in Desert Shield or Desert Storm. Nonetheless, we judged that the 75 percent FMC aircraft availability goal reflected an operational statement of the officially planned level of support performance. Thus, we paid special attention when it was not met.

<sup>2</sup>This effect is formalized in the military standard requisitioning and issuing procedures (MILSTRIP) priority system, whereby units engaged in wartime are assigned a higher force activity designator (FAD) that ensures that their requisitions receive higher priority. In addition, all units in Desert Shield and Desert Storm were assigned a special project code (9BU) that gave their requisitions overriding priority, both in being filled at depot warehouses and in being transported into the theater.



## Deployed Fighter Aircraft Availability Exceeded Peacetime Rates

By all accounts, the MC rates in theater were exceptionally high throughout Desert Shield and Desert Storm, as shown in Figures 3.1 through 3.10.<sup>3</sup> Those figures display the monthly<sup>4</sup> MC rates across all aircraft from Active Component (AC) units<sup>5</sup> by MDS in theater (including those assigned to Proven Force<sup>6</sup> at Incirlik AB, Turkey) and at nondeployed AC units in TAC and USAFE. In every case, USAF fighter MC rates for the deployed forces exceeded the 75-percent-available goal during Desert Shield.<sup>7</sup> For some MDS (F-15E, F-16C, and A-10), the deployed forces' MC rate exceeded the goal by over 10 percentage points, even during Desert Storm with its increased operational tempo. For other MDS (F-4G, EF-111A, F-111F, and F-117A), the deployed forces' MC rate was high during Desert Shield (August–December 1990 and the first half of January 1991) but diminished sharply during Desert Storm.

### *Deployed Aircraft Availability Decreased During Desert Storm*

All deployed units' MC rates fell during Desert Storm. Most fell less than 5 percent, but the F-4G, EF-111A, and F-117A fell by more than 10 percentage points (over 2 aircraft per squadron). In only one MDS, the F-117A, did MC rates rebound even partially during February.

### *Some Nondeployed Units' Aircraft Availability Slipped Notably*

More important, the deployed units' MC rates generally exceeded the nondeployed units' MC rates. In some cases, this difference was so strong that the nondeployed units' performance fell below the 75 percent wartime MC rate goal—even though they were only flying at peacetime levels. The few exceptions to the general rule are notable: EF-111A nondeployed units exceeded the

<sup>3</sup>Throughout this report, the data reflect the status of all units whose aircraft eventually deployed. Thus, individual "At home" units experienced MC rate decreases immediately after deploying aircraft; those decreases are not reflected in the overall averages. For example, the 11FW MC rate dropped to 75 percent in August from 83 percent in July after deploying 48 aircraft. When combined with other F-15C wings in Figure 3.1, the overall F-15C fleet MC rates showed little or no change from those of the previous month.

<sup>4</sup>Because Desert Storm was initiated on the night of 16 January 1991, the graphs show the first and second half of January separately.

<sup>5</sup>Reserve and National Guard units are not included.

<sup>6</sup>Joint Task Force Proven Force was a NATO flanking force informally supporting the allied forces in Saudi Arabia. Its purpose was to harass, distract, and temporarily immobilize forces in northern Iraq.

<sup>7</sup>We exclude the F-111E from this statement, because no F-111E aircraft were deployed until after hostilities commenced.

RAND MR468-3.1

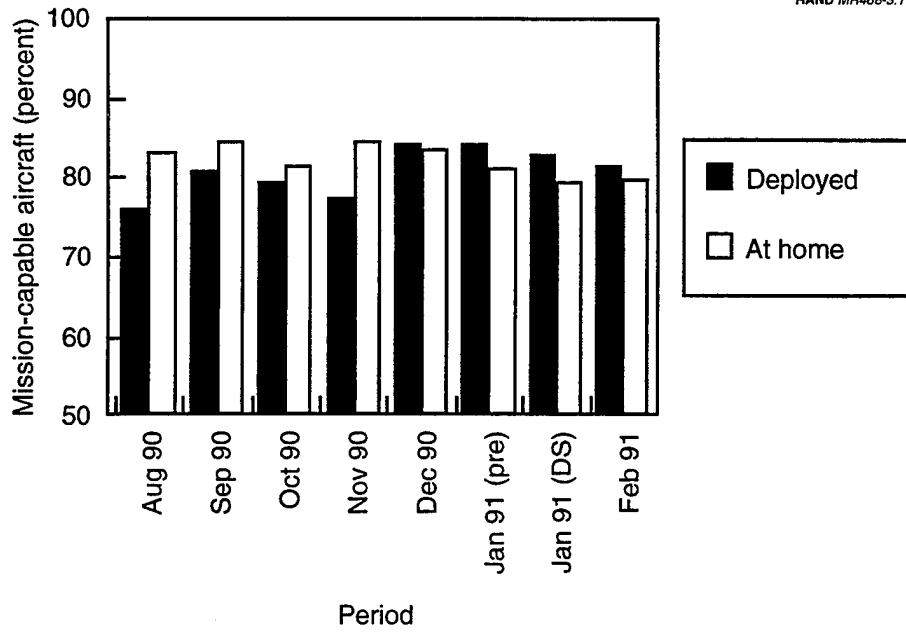


Figure 3.1—F-15C MC Rate

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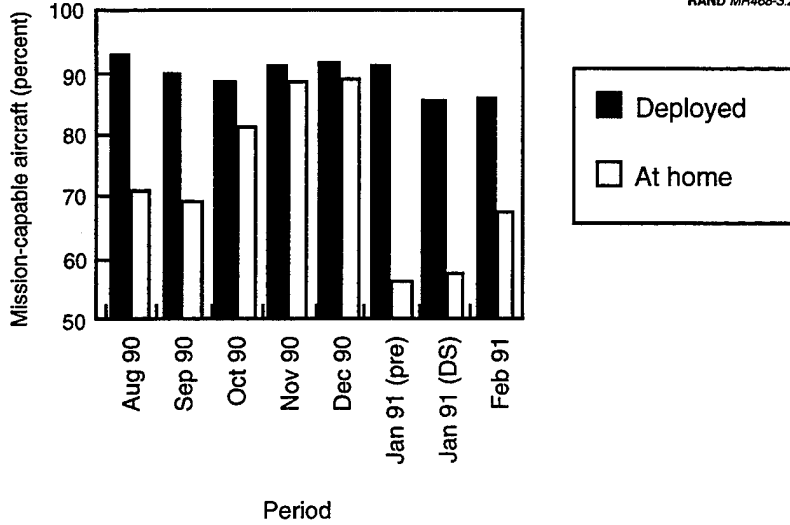


Figure 3.2—F-15E MC Rate

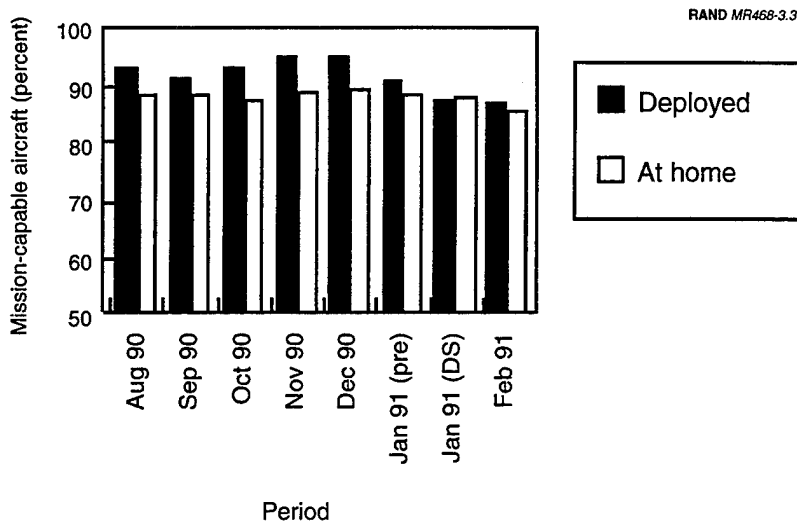


Figure 3.3—F-16C MC Rate

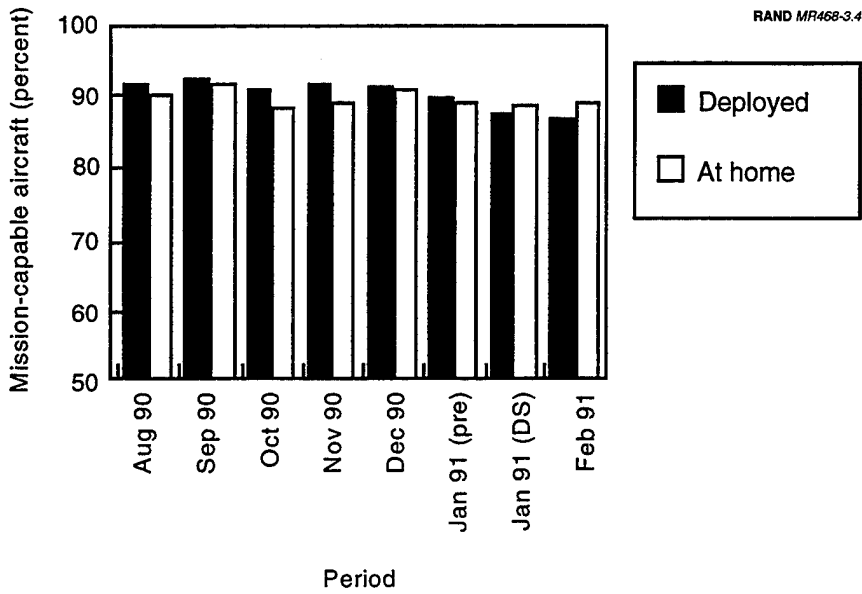


Figure 3.4—A-10 MC Rate

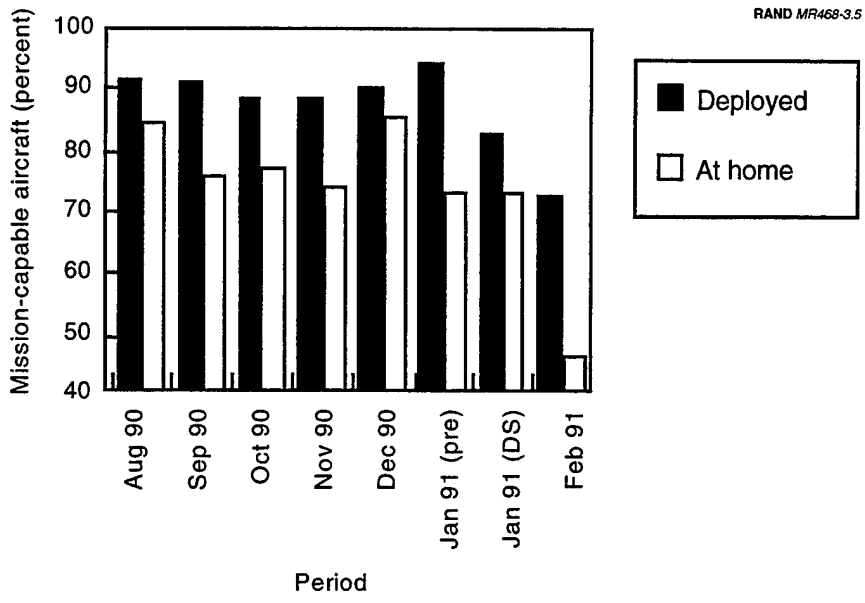


Figure 3.5—F-4G MC Rate

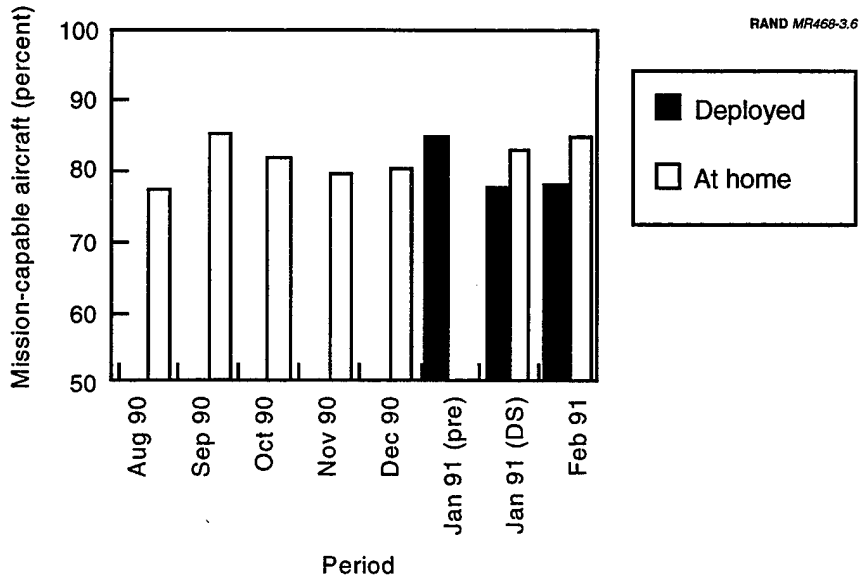


Figure 3.6—RF-4C MC Rate

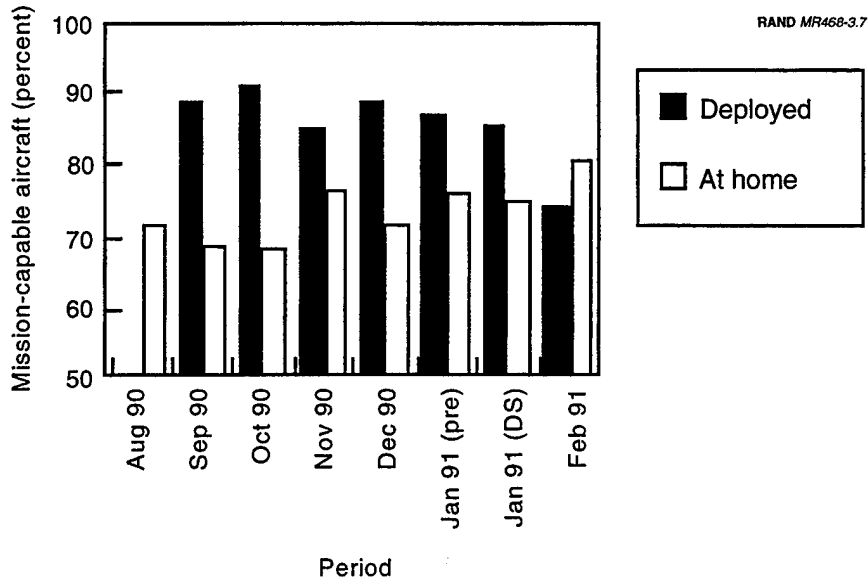


Figure 3.7—EF-111A MC Rate

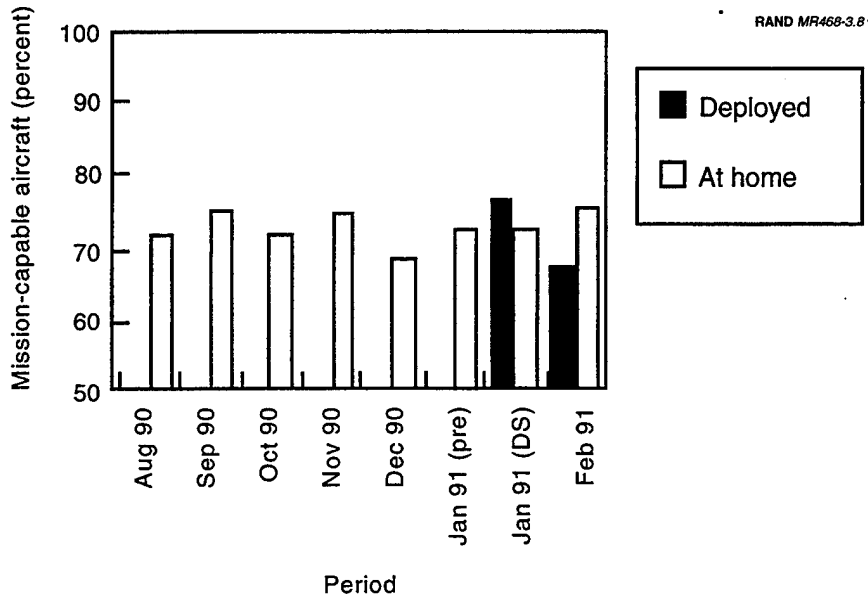


Figure 3.8—F-111E MC Rate

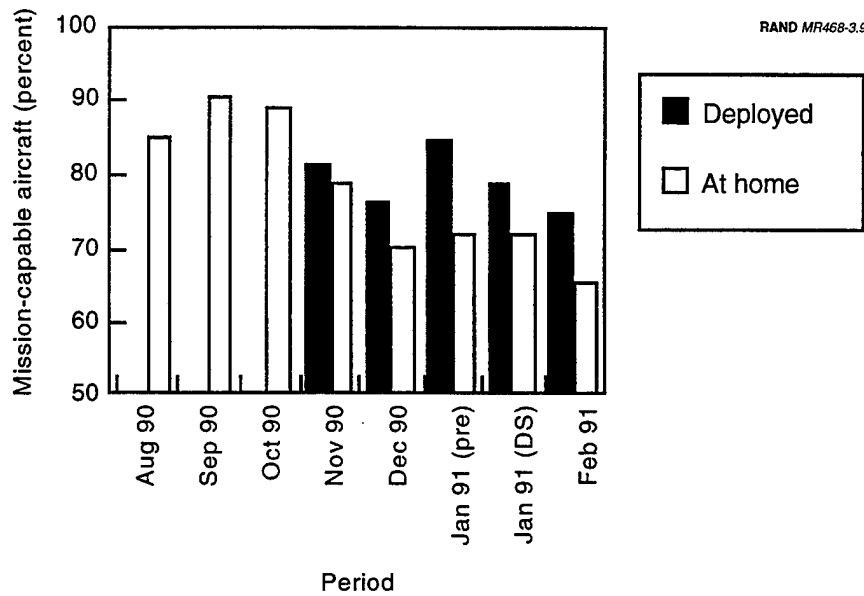


Figure 3.9—F-111F MC Rate

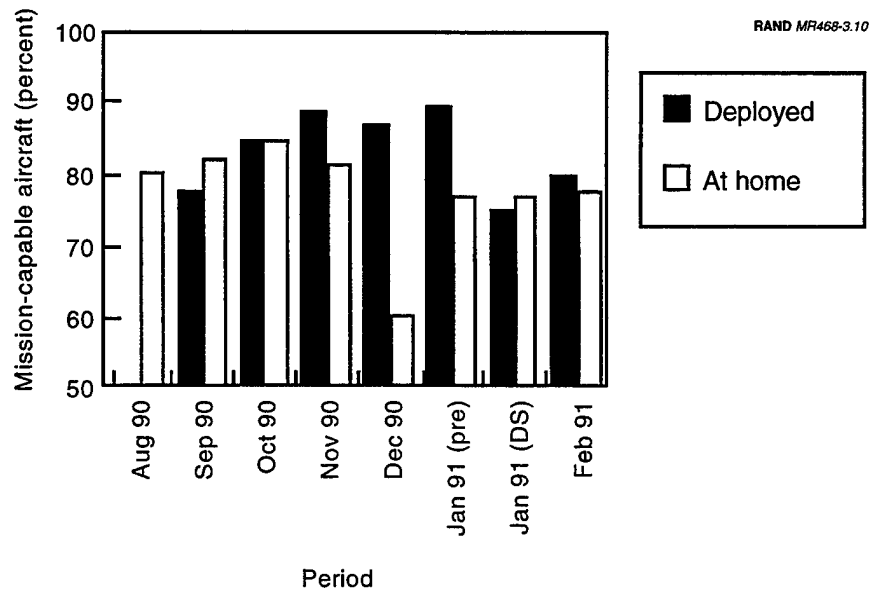


Figure 3.10—F-117A MC Rate

deployed MC rates in February by exceeding their prior months' MC rates when the deployed units' MC rates fell; F-16C nondeployed units did likewise, but only for the first two weeks of Desert Storm; A-10 nondeployed units maintained relatively high MC rates, even after Desert Storm commenced (while deployed A-10's MC rates fell slightly in Desert Storm); RF-4C nondeployed units also maintained relatively high MC rates despite the deployment.

Interestingly, many nondeployed units' MC rates decreased before Desert Storm began. The nondeployed F-15C, F-15E, F-16C, F-4G, F-111F, and F-117A units' MC rates decreased in December or early January (compared with those of the previous four months).

Clearly, some logistics phenomena or processes changed substantially during Desert Shield and Desert Storm. Deployed units' MC rates improved, even though they operated at increased optempos<sup>8</sup> farther from home station. More mysteriously, nondeployed units' MC rates degraded even though they maintained a nominal steady-state training schedule and constant location. To discover the underlying causes of those changes, we investigated how each of three support factors (maintenance demand rates, maintenance productivity and capacity, and spares availability and responsiveness) might have changed to improve MC rates.

Obviously, MC rates would improve if aircrews reported fewer failures. We first review previous research that theorizes that demand rates always decrease when optempo increases, then we examine the Desert Storm break-rate data to refute that earlier research.

## **Traditional Theories Predict Increased Demands and Decreased MC Rates**

Traditionally, analysts use spares-requirements and -assessment models, such as the D041 and Weapon System Management Information System (WSMIS), that assume increased operational tempo will lead to proportional increases in maintenance workloads and supply demands, increased backlogs, and increased aircraft NMCM or NMCS. If those models were correct, *Desert Storm's increased optempo should have decreased MC rates.*

But something else happened. The most popular prewar hypothesis that would have explained an increase in MC rates when optempo increases was that break rates (i.e., maintenance demands per sortie or per flying hour) would decrease in

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<sup>8</sup>Optempo: sorties per day or flying hours per day.

wartime so that the maintenance and supply systems could have achieved higher MC rates merely by maintaining their pre-conflict performance. But this did not happen in Desert Storm. Before we describe the Desert Storm experience, we review the logic and evidence underlying this hypothesis. We examine other hypotheses later in this report.

## **Some Pre-Desert Storm Research Theorized That Increasing Optempo Usually Reduces Demand Rates**

Some logistics and operations analysts have long argued that wartime demands, or at least demand rates per sortie or flying hour, would diminish compared with those of peacetime.<sup>9</sup> Some base their argument on a belief that pilots' high levels of training and morale would make it possible or even likely that they would ignore many minor system degradations that may affect peacetime safety but not wartime combat effectiveness. Others argue that "aircraft just like to fly," apparently implying that system failures and subsequent support demands will decrease (or at least increase more slowly than optempo) because they spend more time in the environment for which they were designed.

These views all derive from peacetime experience, especially during exercises. Although exercise sortie rates and flying hours increase substantially over those of normal peacetime operations, support demands often do not increase in proportion. Several explanations have been advanced, including the following:

1. Aircraft actually fail less when they fly longer sorties.<sup>10</sup>
2. Intense operations limit opportunities for in-depth ground inspections that may detect or even cause failures.
3. More-reliable aircraft can and will be selected for deployment to an exercise.
4. Aircraft fail without regard to usage intensity or operational tempo.

We found none of these theories rich enough to predict the Desert Storm experience. If any had been true, all ten MDS's Desert Storm break rates would have decreased. The Desert Storm demand patterns were much more varied and complex.

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<sup>9</sup>This hypothesis is usually advanced with great certitude after peacetime exercises. The facts of Desert Storm refute this hypothesis.

<sup>10</sup>These explanations usually observe that a subsystem can fail only once during a sortie, or that certain failure modes are associated with specific sortie events (power startup, change in altitude, etc.).



## Desert Storm Aircraft Break Rates and Logistics Demands Were Unpredictable

In fact, all three possibilities occurred: Break rates<sup>11</sup> increased as much as twofold for some MDS at some times; they decreased or stayed roughly constant for other MDS at other times.

*After the fact*, we can offer some plausible explanations of how and why break rates varied.<sup>12</sup> The underlying causes are invariably idiosyncratic to the aircraft, the Desert Storm deployment, the assigned Desert Storm missions for each aircraft, the Iraqi air defense capabilities and their tactics, and the USAF tactics used—factors all destined to change in other combat situations. For example, attack altitude, mission depth, target types, air defense intensity, distances to targets, feedback on mission effectiveness, and even instructions to aircrews appear to have affected maintenance demands. Because the demand rates were driven by such idiosyncratic, unstable, unpredictable factors, we observe that prewar predictions of aircraft logistics resource needs could not have been accurate and that the Desert Storm experience cannot be used to improve the accuracy of those predictions. First, we discuss the patterns of aircraft breaks, then we return to the resource-prediction-accuracy issues.

### *Most MDS Experienced a Twofold Increase in Aircrew-Reported Breaks Sometime in Desert Shield or Desert Storm*

Figures 3.11 through 3.20 tell the story. Except for the EF-111A and F-111E, *every deployed MDS experienced about twice as many Code 3 breaks per sortie*<sup>13</sup> during Desert Storm as the nondeployed units during Desert Shield. Most deployed aircraft (F-15C, F-16,<sup>14</sup> A-10, F-4G, F-111F,<sup>15</sup> and F-117A) experienced higher break rates

<sup>11</sup>That is, Code 3 breaks per sortie.

<sup>12</sup>Even though there is considerable variability in the aggregate data we report, there is even greater variability in the unit-level data. We have been able to construct plausible explanations for the aggregate break-rate data *after the fact*, based on the widely reported general characteristics of the contingency. We have been unable to explain the highly diverse break rates across units with the same MDS.

<sup>13</sup>When aircraft return from a sortie, aircrews and maintenance personnel assess the vehicle's readiness as Code 1 (able to sortie immediately with only refueling and rearming), Code 2 (has a noncritical failure that does not require immediate maintenance), or Code 3 (must have maintenance before the next sortie). The distinction between Code 2 and Code 3 depends on whether the subsystem affected is on the weapon's mission essential systems list (MESL), which identifies what aircraft subsystems must be fully functional to conduct a particular mission. Thus, different missions have different MESLs.

<sup>14</sup>The deployed F-16 break rates were initially lower than those of nondeployed units, but they exceeded the nondeployed units' during the remainder of Desert Shield.

<sup>15</sup>The high nondeployed F-111F break rates reported for December through February represent the activities of fewer than a dozen aircraft.

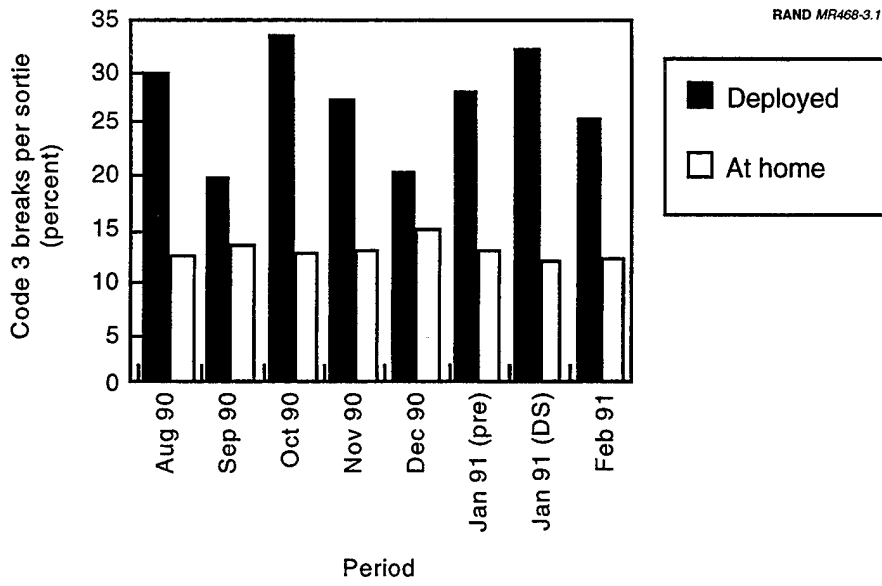


Figure 3.11—F-15C Code 3 Break Rate

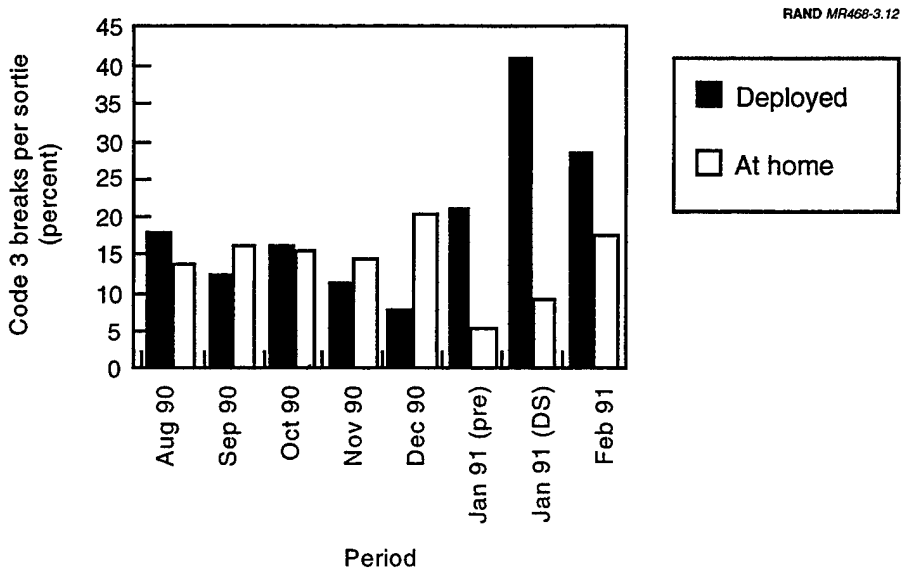


Figure 3.12—F-15E Code 3 Break Rate

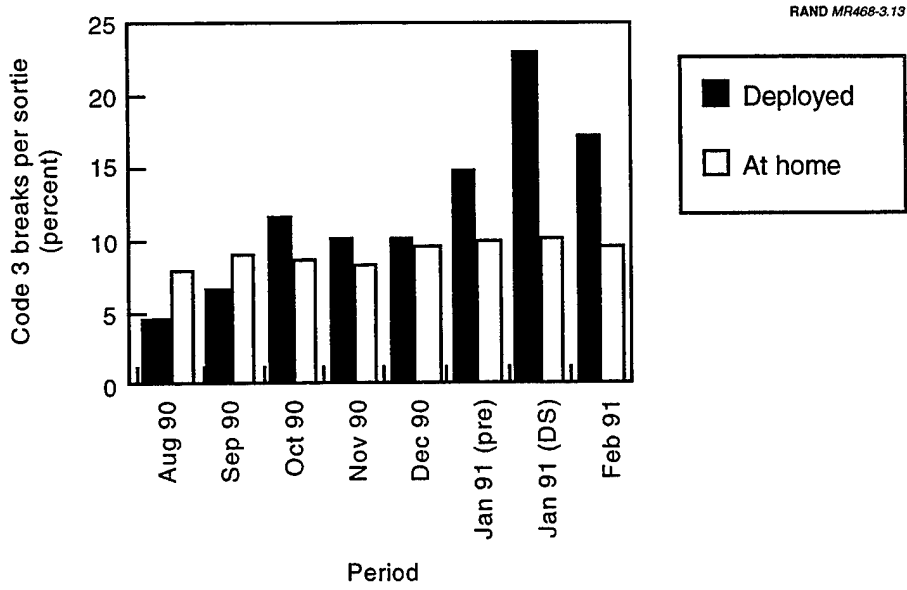


Figure 3.13—F-16C Code 3 Break Rate

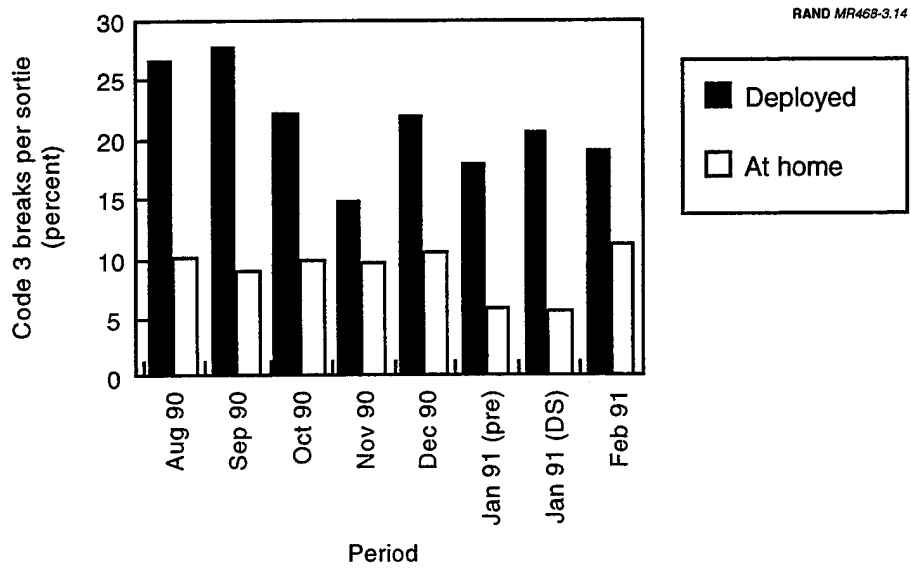


Figure 3.14—A-10 Code 3 Break Rate

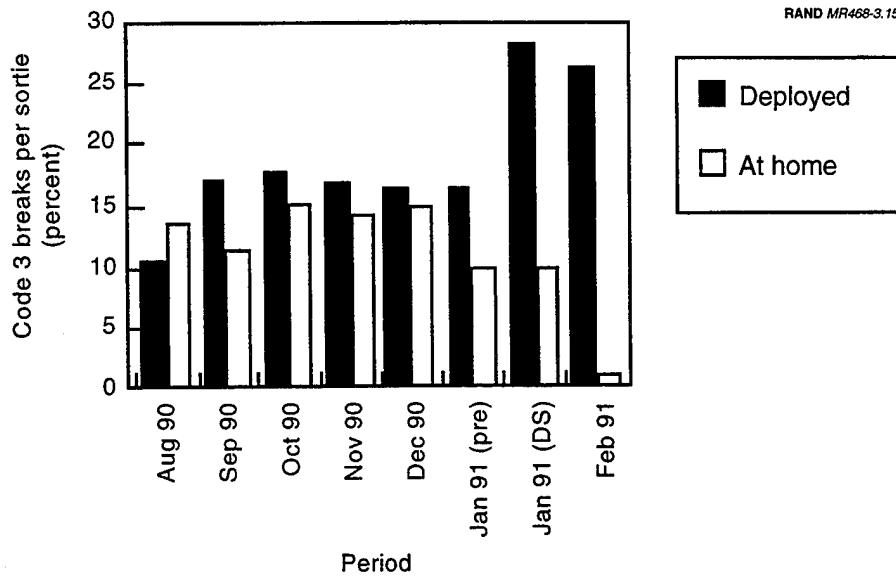


Figure 3.15—F-4G Code 3 Break Rate

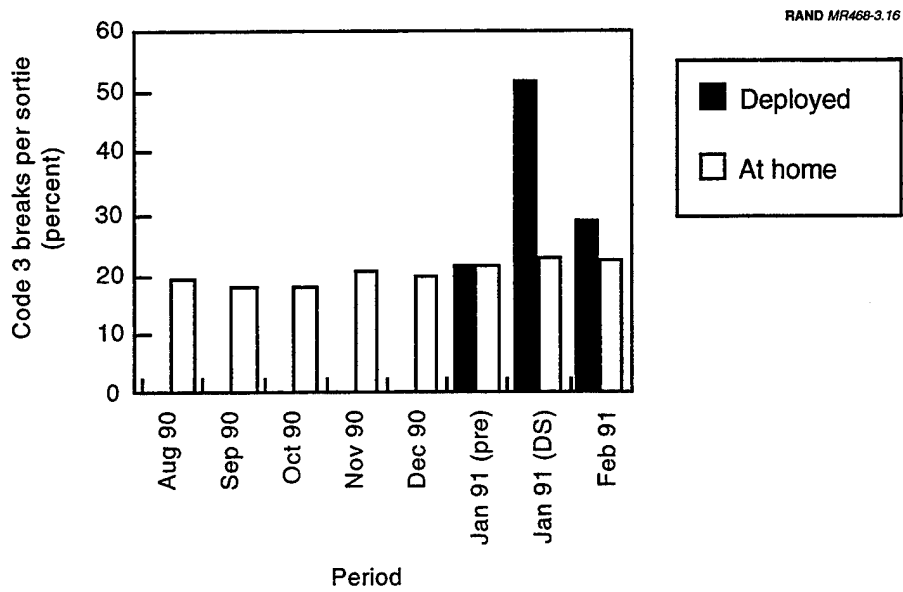


Figure 3.16—RF-4C Code 3 Break Rate

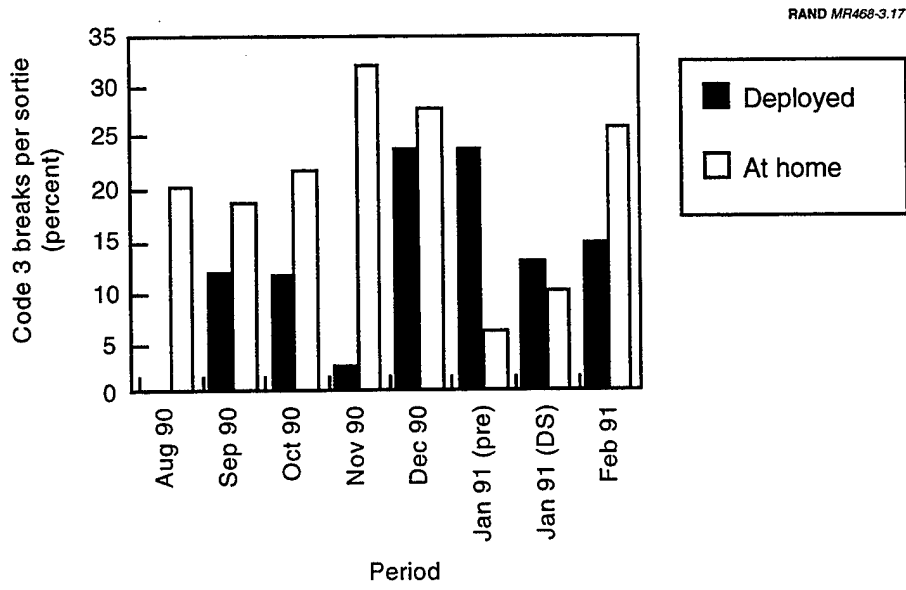


Figure 3.17—EF-111A Code 3 Break Rate

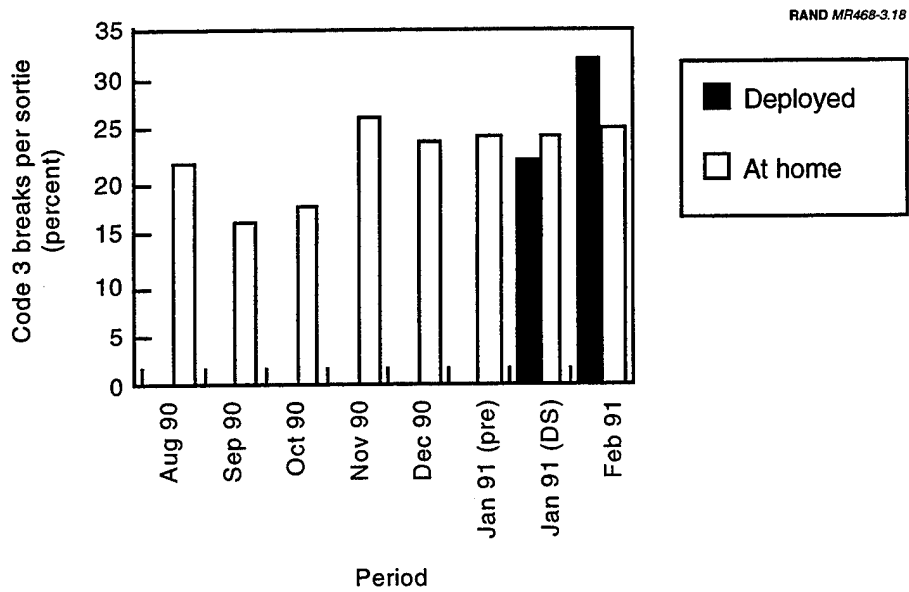


Figure 3.18—F-111E Code 3 Break Rate

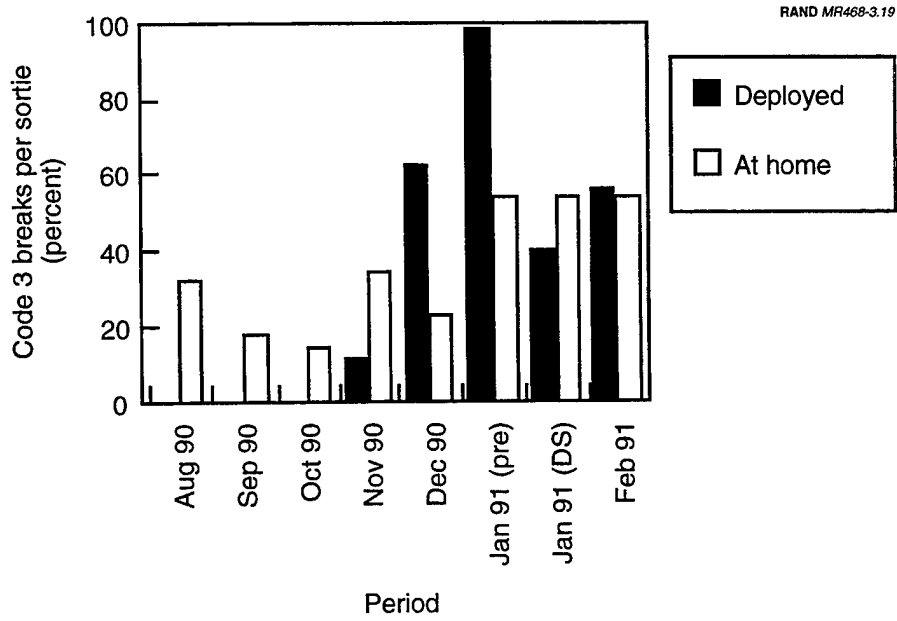


Figure 3.19—F-111F Code 3 Break Rate

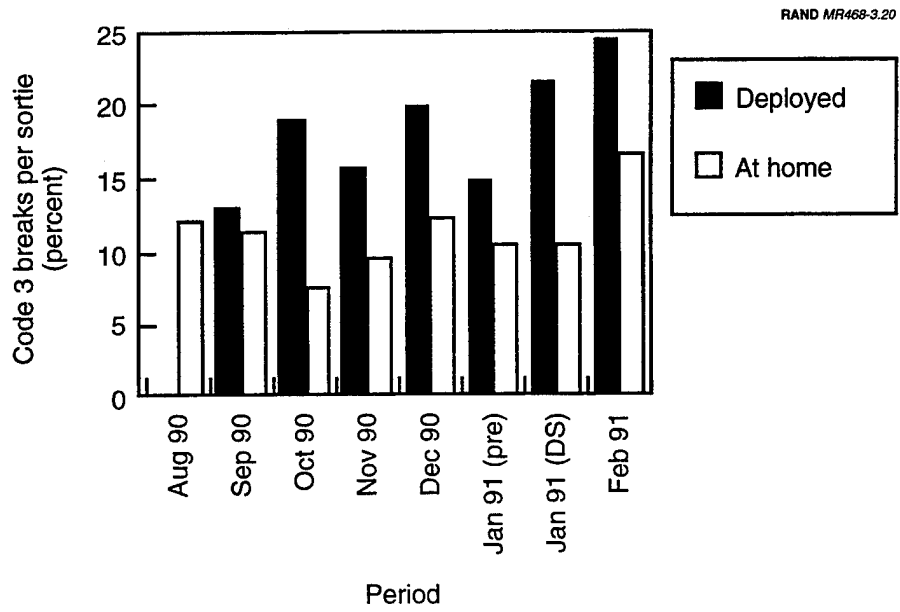


Figure 3.20—F-117A Code 3 Break Rate

during Desert Shield than nondeployed aircraft. Some MDS (F-15E, F-16, F-4G, RF-4C, and F-117A) also experienced heightened break rates after Desert Storm commenced. For most aircraft, aircrews' demands on the maintenance and supply system increased more than the sortie rate.

### ***Most MDS's Break Rates Did Not Increase Upon Initial Deployment***

The F-15E, F-16C, F-4G, RF-4C, EF-111A, F-111E, F-111F, and F-117A did not experience higher break rates immediately after deploying. Indeed, the F-15E did not experience a surge until Desert Storm commenced, and the deployed EF-111A units even had *lower* break rates than the home station for six of the seven months they were deployed. The F-111E's break rates may have increased slightly, but not nearly as much as other ground attack aircraft's.

Initially, training activities of attack aircraft (F-16C, A-10, F-111E, F-111F, and F-117A) and their direct mission support aircraft (F-4G, RF-4C, EF-111A) were limited in Desert Shield. In deference to host-country sensitivities, no low-level tactics were permitted, nor were any practice weapons delivered. Thus, substantial portions of those weapon systems' functional capabilities were not exercised during the early portions of Desert Shield, perhaps accounting for the drop in per-sortie break rates.

In contrast, the F-15C aircraft deployed in August immediately began conducting combat air patrol missions near the Saudi Arabia-Kuwait border. Those missions had mounted weapons that were tested, and they used wartime aircraft subsystems on every sortie; in peacetime training at home station, many missions use only a subset of the aircraft's total capabilities.

The EF-111A provides an example of how demands can actually decrease in wartime. EF-111A primary mission subsystem failures were difficult to detect during Desert Shield and Desert Storm. In Desert Shield, the jamming subsystem could not be fully tested without both an electronic countermeasures range and ground checkout equipment, because some failures and equipment degradations appear only when the equipment experiences flight stresses (vibration, cold temperatures, etc.). Once deployed to Desert Shield, no range could be set up in theater, because the aircraft could not emit without exposing USAF knowledge of Iraqi electronic defenses and command-and-control systems. Therefore, jamming subsystem failures occurring during a training sortie could not be detected. Lacking feedback on critical mission subsystems' operations, except for a one-time visit by the electronic combat Aggressor Squadron involving 13 of the

EF-111As, the aircrews and maintenance crews obviously could not report failures that they could not observe.

In Desert Storm, EF-111A aircrews received only ambiguous feedback about potential jamming system failures, because the Iraqi Air Defense System (IADS) substantially reduced its operations after the first few days of Desert Storm. Unless aircraft being escorted by the EF-111As were engaged by Iraqi installations or systems being jammed, the EF-111A aircrews would have few indications of jamming-system failure. Iraqi aircraft did not engage in extensive defensive counter-air, and Iraq's ground-based air defense systems reduced their exposure by limiting their operations after the first few days of conflict. Thus, potential EF-111A system deficiencies may have continued undetected, leading to a reduced Code 3 break rate.

Unanticipated wartime operating conditions also may have reduced F-111E demands. The 19 F-111E aircraft were deployed to Joint Task Force Proven Force at Incirlik AB, Turkey, where they carried out high-altitude night-bombing attacks against targets in northern Iraq. In peacetime, the F-111E terrain-following subsystem is a major contributor to aircraft Code 3 breaks, because aircrews train to penetrate dense radar nets by flying nap-of-the-earth routes through hilly and mountainous terrain. The high-altitude tactics used by almost all missions throughout Desert Storm obviated the need for such flying, and aircrews probably would have been unaware of any failures of the terrain-avoidance subsystem. In addition, flying at higher altitudes would also reduce turbulence and dust that inevitably compromise aircraft mechanical systems' reliability at lower levels.

Initial break rates for the F-15E probably had not reached "maturity"<sup>16</sup> because the F-15E was just entering the inventory as Desert Shield commenced. (The overall TAC F-15E FY91 break rate was 14.4 percent, compared with 13.4 percent in FY90 and 12.0 percent in FY89.) As important, the LANTIRN targeting pods were delivered to the unit just before Desert Storm. As those pods became available, more subsystems aboard the aircraft were used more often, uncovering problems that could not be detected without the pods.

## **Break-Rate Increases Had Several Causes**

Knowing the cause of and potential remedies for demand changes is a critical issue for planning future contingency support. Although we began our

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<sup>16</sup>New equipment often has "infant" failures as a result of undetected design or manufacturing flaws. Once those flaws are eliminated, the break rate decreases to a "mature" one.



investigation to analyze whether decreased breaks led to the increased aircraft availability, we now faced two more vexing questions, What caused these changes in break-rate patterns? and, How did the support system achieve such high performance in spite of them?

First, we tried to isolate the factors that might explain the increased break rates experienced by most aircraft, hoping that they might eventually lead to devising a means for suppressing those break rates<sup>17</sup> in some future conflict, or at least to improving predictions of demands in future contingencies. In fact, we found that many factors contributed to the increased break rates, and we found no specific way to prevent those demands nor any way to improve their prediction.

We identified four broad factors that increased Code 3 break rates:

1. Peacetime Code 2 breaks were reinterpreted to Code 3 as a result of qualitative mission essentiality judgments by aircrews.
2. More-stressful sorties in Desert Storm than at home induced greater stress on some aircraft subsystems.
3. Some mission-critical subsystems, less used in peacetime, were exercised more fully in Desert Shield and Desert Storm, and thus more failures were detected.
4. Aircrew and maintenance personnel's aspirations for overall aircraft quality increased.

We found that each factor contributed to the increased demands placed on some MDS. We discuss each in turn.

### ***Changes in Aircrew Judgments of Mission Essentiality Helped Increase Code 3 Break Rates***

Each MAJCOM maintains a mission essential systems list (MESL) intended to standardize the aircrews' decisionmaking regarding the airworthiness and mission worthiness of each aircraft before, during, and after a sortie. Essentially, the MESL is a checklist of subsystems that must be functioning properly to carry out a combat mission, depending on mission type. Some aircraft may have only one mission, but most modern aircraft have several. Thus, the MESL is commonly presented to the aircrews as a matrix, with a row for each subsystem, a column for each mission, and checks indicating which subsystems are required

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<sup>17</sup>That is, if the demands were mere "noise" that did not reflect truly necessary maintenance actions, it might be possible to find some way to eliminate such noise.

for each mission. Aircraft judged capable of performing all missions are rated fully mission capable (FMC); aircraft capable of at least one mission are partially mission capable (PMC); aircraft capable of performing an assigned mission are mission capable (MC). If any subsystem does not perform as needed for a mission, the aircrews are instructed to notify maintenance crews of the deficiency and to declare that the aircraft is not MC until maintenance has corrected the deficiency.<sup>18</sup>

In most cases, the mission effect of a particular subsystem failure is unequivocal. For example, a total failure of the oxygen-generation system or the radar display would lead inevitably to a Code 3 assessment. But some subsystem failures are more ambiguous. Thus, the loss of a particular radar mode may be either catastrophic or inconsequential, depending on the aircrew's skills or the mission. Furthermore, the aircrew's judgment about the relevance of that failure to the mission may vary widely. Thus, some aircrews may assess a particular failure as Code 2 or as Code 3, depending on their skills, training, or circumstance. In interviews with deployed maintenance personnel, they reported that part of the increased Code 3 break rates appeared to be peacetime Code 2 breaks that aircrews translated to wartime Code 3 breaks.

Maintenance crews' observations are confirmed in the F-117A aircrew debriefing data. There, we observed that the peacetime inertial navigation system (INS) had a near-zero Code 3 break rate and a substantial level of Code 2 breaks; however, the Desert Storm Code 3 breaks increased and Code 2 breaks decreased. Apparently, the aircrews judged the INS performance as less critical to completing their peacetime mission than during wartime. The INS may not be required for many peacetime training sorties; it is absolutely essential for ensuring precise weapon delivery in combat.

On the basis of both maintenance personnel interviews and the F-117A debriefing data, we concluded that many peacetime Code 2 breaks were transformed into wartime Code 3 breaks.

### ***Overall (Code 2 and Code 3) Breaks Increased, Too***

Yet maintenance crews also reported that demands increased overall, an increase that also seems to be confirmed by analysis of F-117A break data. If peacetime Code 2 breaks had merely been transformed into Code 3 breaks by the wartime

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<sup>18</sup>This assessment may occur before, during, or after a sortie, leading to a ground abort, an air abort, or a post-sortie Code 3, respectively. In any case, a Code 3 assessment results in an assessment that the aircraft is not mission capable (NMC), at least temporarily.

situation, the total Code 2 and Code 3 break rates would probably stay the same. That did not happen for the F-117As, as shown in Table 3.1. Instead, the total break rate increased by 24 percent (relative to that for the home station). (In contrast, the home-station break rates for the three months before and after Desert Storm differed by less than 0.005 breaks per sortie, a 2 percent increase.)

In further confirmation, interviews with F-117A maintenance personnel pointed out that some performance criteria were tightened locally after the unit deployed. For example, the INS position error specification was tightened substantially beginning in October 1990,<sup>19</sup> making many previously acceptable units unacceptable. The F-117A maintenance personnel reported that this change triggered substantial increases in component removals from aircraft on the flight line, component-repair-shop workloads, and requisition activity. Not only was there an initial flurry of removals of out-of-spec boxes, but there was both a follow-on surge as spares from supply were brought up to local standards, and a substantial increase in the steady-state level of removals after those surges. Total INS demands increased, mostly for Code 3 failures.

Therefore, whereas it appears that at least some of the Code 3 break-rate increase was due to aircrews' transforming peacetime Code 2 events into wartime Code 3 events, it also appears that tactical requirements changed as a result of contingency-specific factors (such as the distance from the base to the target), which contributed to some increased Code 2 and Code 3 break rates.

**Table 3.1**  
**F-117A Code 2 Plus Code 3 Break Rates**

Location	Sorties	Breaks	Break Rate
Deployed Desert Storm: 9/90-2/91	2918	1057	0.36
At Home 6/90-8/90 plus 3/91-5/91	2838	812	0.29

SOURCE: F-117 aircrew debriefing data, SMART data system, 6/90-5/91.

<sup>19</sup>Generally, these specifications were tightened by the wing to more stringent criteria than those specified in formal USAF Technical Orders (TOs). Such criteria conform with wing operational tactical needs that were based on the longer sorties required in Desert Storm. Tolerances were tightened simultaneously for the turret and the sensors, as well.

### *Increased Sortie Stresses Do Not Solely Explain Increased Break Rates, Except for A-10s*

Sortie ground or air aborts charged to maintenance occur shortly after applying power to the aircraft or shortly after takeoff. If more physical stresses generated *during* sorties (e.g., longer sorties, vibration, or heavier loads) caused the increased Code 3 breaks, the abort rates would not change, because the aborted aircraft would not yet have experienced those stresses by the time of the aircrews' abort decisions. Thus, aircraft whose break rates increased but had constant abort rates probably experienced increased mission-induced stresses.<sup>20</sup>

In any event, abort rates were not constant. As shown in Figures 3.21 through 3.30, the abort rates for the F-15C, F-15E, F-16C, RF-4C, F-111F, and F-117A also increased<sup>21</sup> during Desert Shield and Desert Storm. As with the break rates, some MDS (F-15C, F-16C, RF-4C, and F-117A) experienced increased abort rates shortly after deployment, whereas others (F-15E and F-111F) experienced them later, as Desert Storm approached. For at least these six MDS, some factor other than mission-induced stresses contributed to the increased break rates.

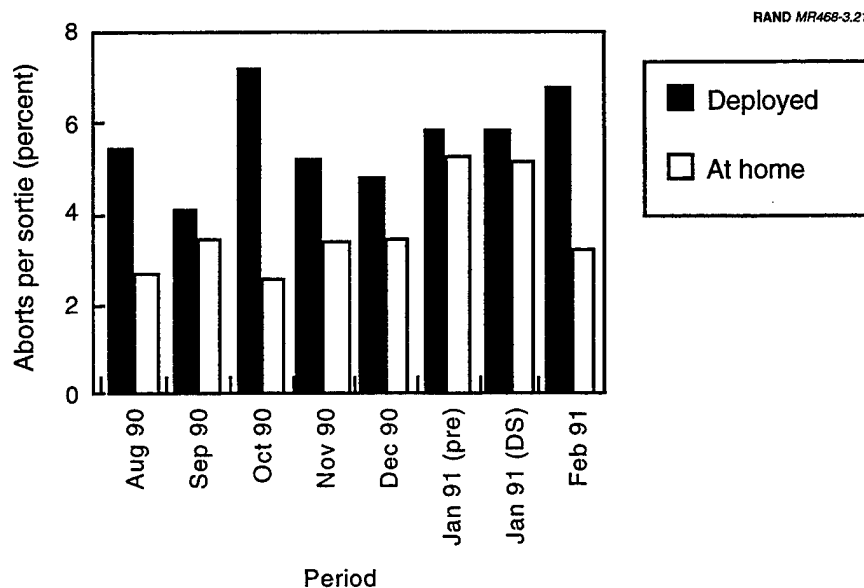


Figure 3.21—F-15C Abort Rate

<sup>20</sup>One aircrew reviewer suggested an alternative explanation: Once airborne, aircrews are inclined to complete the mission, and they aggressively seek workarounds to make that possible.

<sup>21</sup>These increases were *not* proportional to the Code 3 break-rate increases, leading us to surmise that these MDS also experienced more-stressful sorties in Desert Storm than in peacetime. However, the case for mission-induced breaks is clearer in the A-10 case.

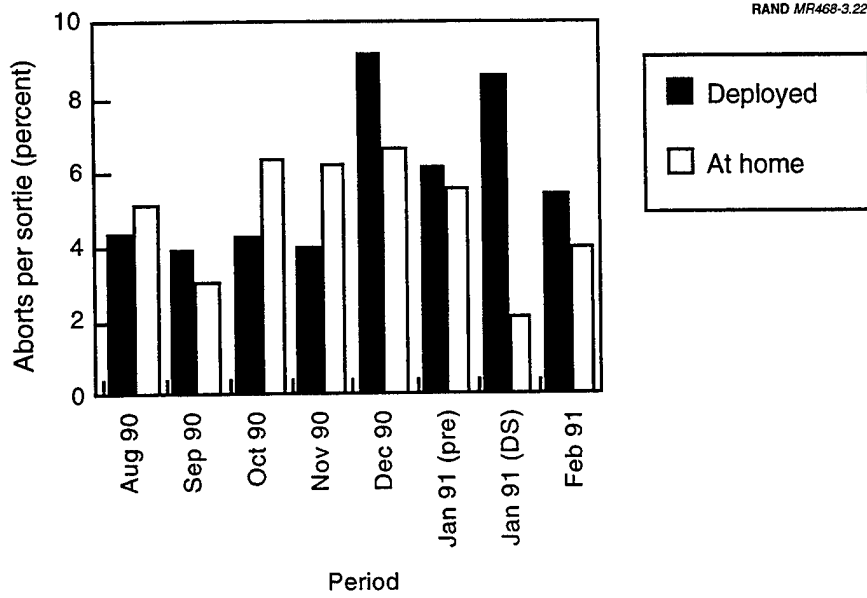


Figure 3.22—F-15E Abort Rate

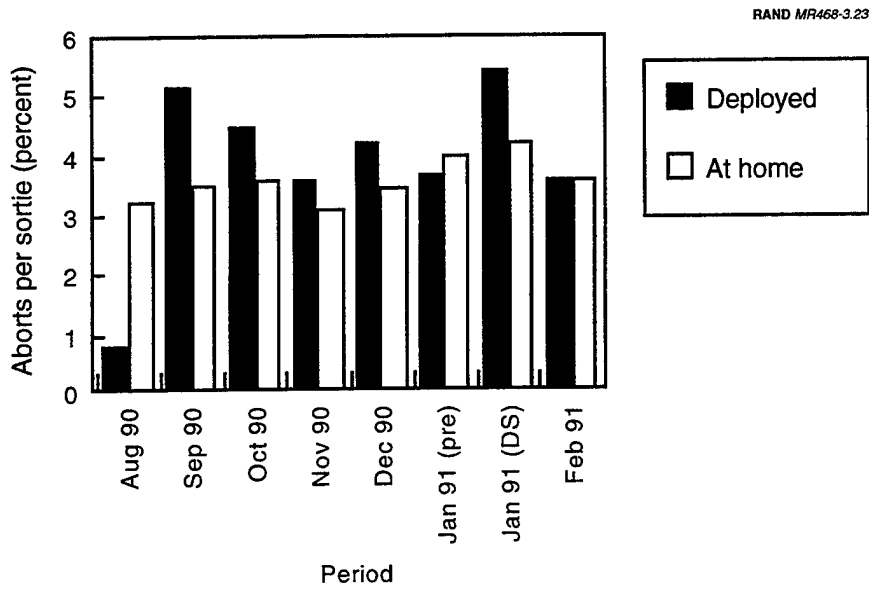


Figure 3.23—F-16C Abort Rate

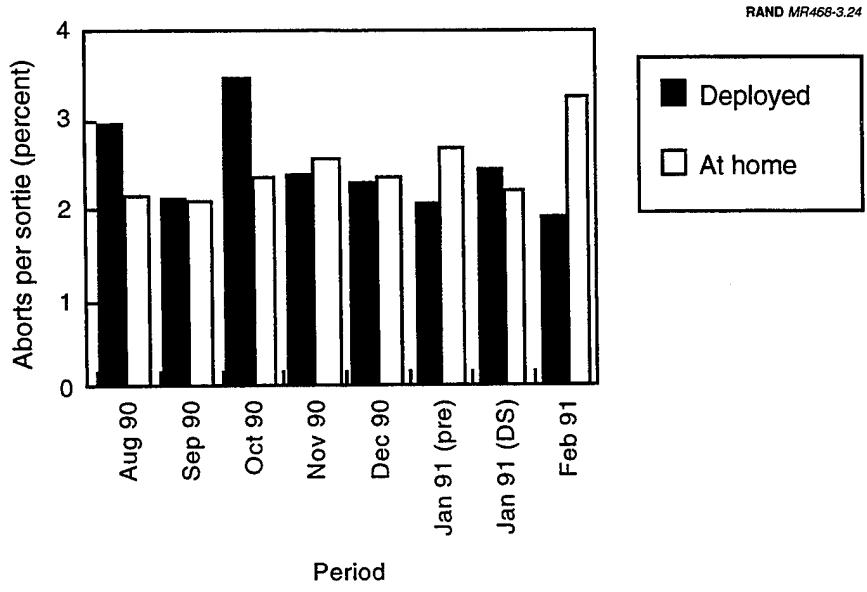
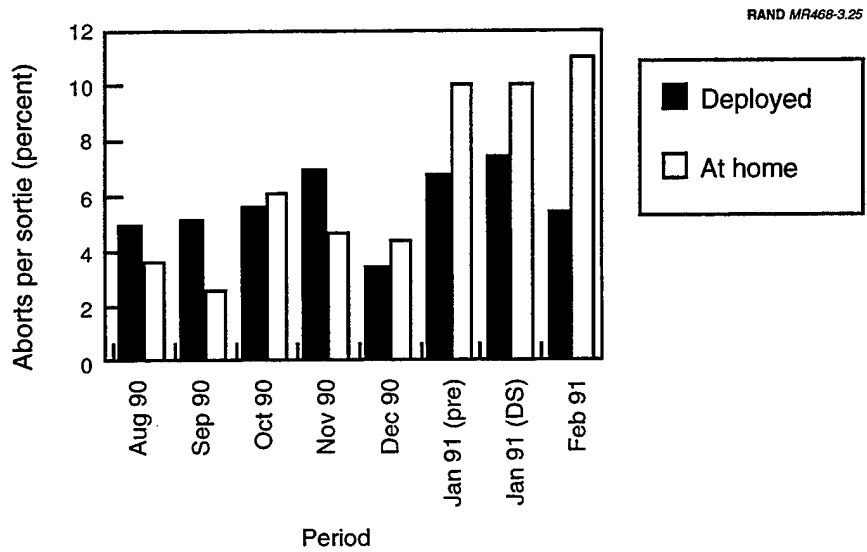


Figure 3.24—A-10 Abort Rate



NOTE: In January and February 1991, home stations had only 14 and 3 F-4Gs, respectively. The high home-station abort rates are probably due to this small sample size and some thoughtful aircraft-deployment selection policies.

Figure 3.25—F-4G Abort Rate

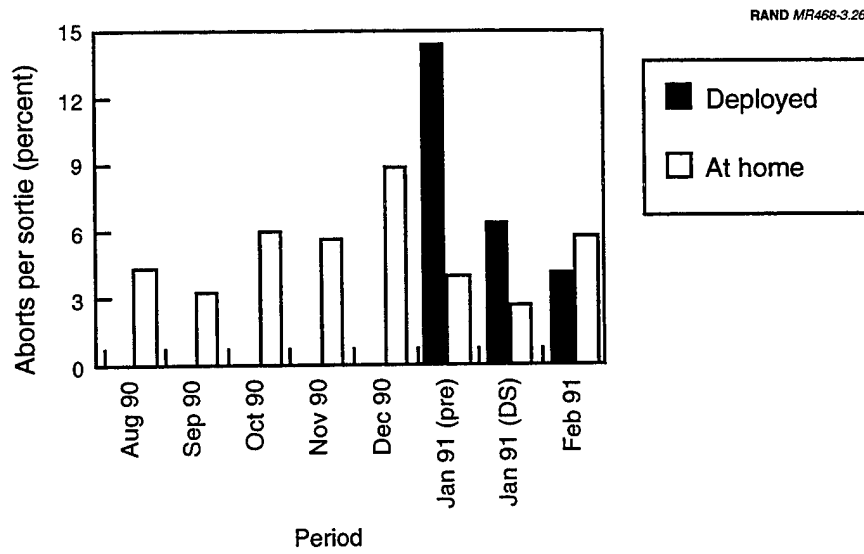


Figure 3.26—RF-4C Abort Rate

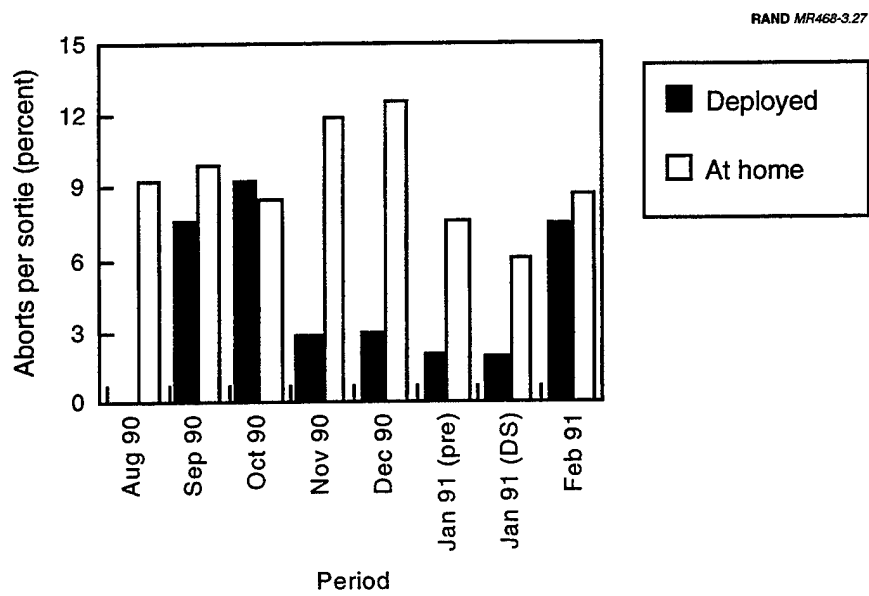


Figure 3.27—EF-111A Abort Rate

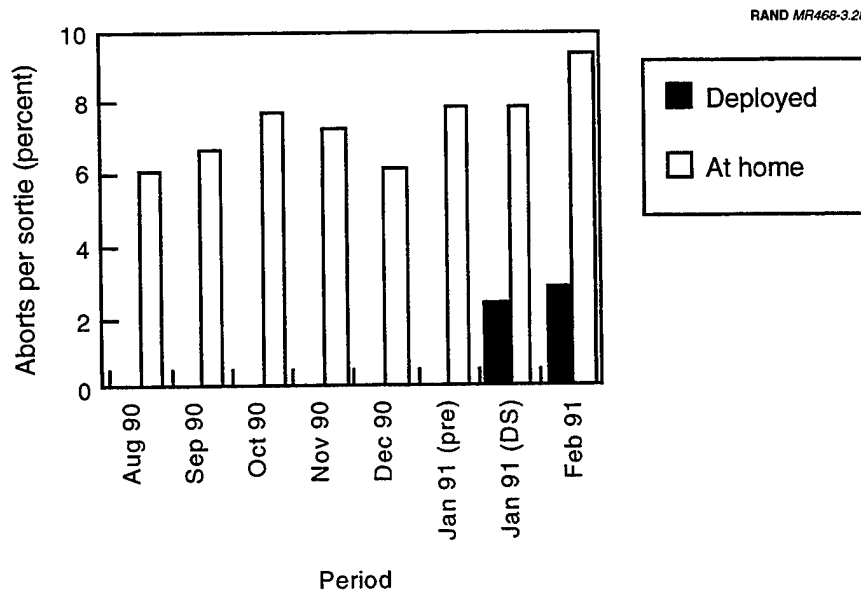


Figure 3.28—F-111E Abort Rate

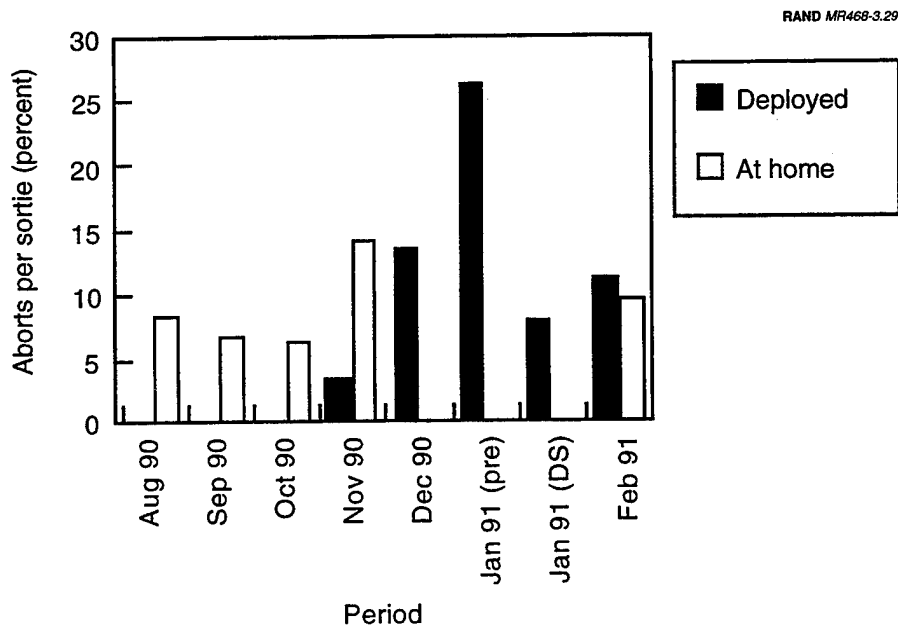


Figure 3.29—F-111F Abort Rate



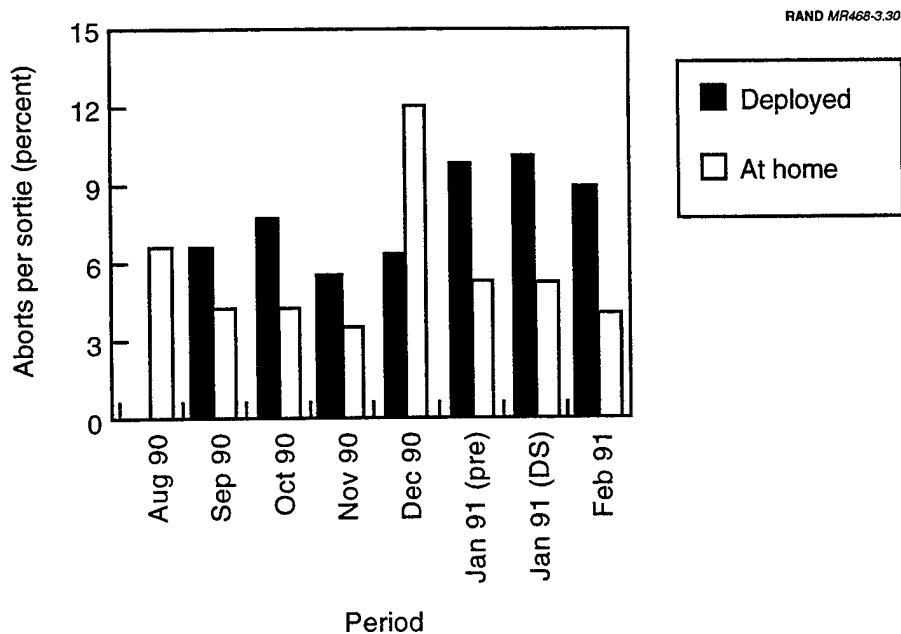


Figure 3.30—F-117A Abort Rate

But what about the other MDS? First, the F-111E and the EF-111A were difficult to assess because their break rates did not change. Nevertheless, we note that the deployed aircraft abort rates generally fell well below those for the nondeployed forces, with the exception of September, October, and February for the EF-111A. Again, we suggest that changes in mission tactics and lack of feedback on operational performance diminished both the abort rates and the break rates for those aircraft.

The F-4G experience could also be interpreted as reflecting increased abort rates, if one discounts the nondeployed forces' abort-rate increases in January and February.<sup>22</sup> Thus, we found that deployed F-4G abort rates did increase during Desert Shield and Desert Storm. Again, it would appear that at least some of the maintenance demands were caused by factors other than sortie-related stresses.

<sup>22</sup>The home-station abort-rate fluctuations in those months represent the experience of only a few aircraft remaining at Spangdahlem AB, Germany, after the other base aircraft deployed to participate in Proven Force. One explanation might be a statistical fluke arising from the small number of home-station aircraft. Even though those aircraft flew over 150 sorties in February, the 4-percentage-point change in home-station abort rate (i.e., January and February compared with November and December) would reflect only 6 additional aborts. Any number of uncontrollable events might cause an additional 6 aborts, particularly if the home-station aircraft were left behind because of inconsistent operational performance (i.e., if they were "bad actor" aircraft identified by the wing as less reliable than others).

But the A-10 clearly had increased Code 3 break rates without any increase in abort rates. As shown in Figure 3.24, the deployed A-10 units maintained roughly the same abort rates as the nondeployed units, even though they immediately experienced higher per-sortie break rates (Figure 3.14). Some events or processes during the Desert Storm sorties clearly contributed to increased post-sortie breaks without affecting air or ground aborts. Figure 3.14 shows that the A-10 break-rate increase was first large, then decreased as the sortie length increased.

Some might argue that the increased A-10 break rates were caused by the longer sorties in Desert Storm. Typical home-station sorties for the A-10s during the period averaged about one hour. By October, A-10 sorties in Desert Shield were over 40 percent longer, and by November, over 95 percent longer. If the stress were due to increased flying time per sortie, then the A-10 break-rate increase would have been modest initially but would have increased still further by November.

Thus, only the A-10 experienced increased break rates that were caused mainly by increased sortie-related stresses. Other factors affected break rates for other MDS, as evidenced by changes in their abort rates. At the same time, we found that A-10 breaks were not caused by stresses solely related to sortie length.<sup>23</sup>

### ***More-Stressful Sorties Did Increase Other MDS's Breaks, Too***

The abort data also suggest that increased sortie-related physical stresses affected all other MDS except the EF-111A and the F-111E. Generally, the increase in abort rates was not proportional to the increase in break rates.<sup>24</sup> If the two increases had been due solely to the same causes (e.g., a generally heightened aircrew standard for quality or an increased use or observation of a particular subsystem), their increase could be expected to be roughly proportional. As shown in Figures 3.31 through 3.38, break rates increased proportionally more than abort rates for all MDS except the F-111F during Desert Storm. In addition,

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<sup>23</sup>Some suggest that the A-10 medium-altitude bombing in Desert Storm should actually be *less* stressful than the low-altitude tactics practiced in peacetime. Lt Col David Peterson (AF/LGSY) suggested that the increased A-10 break rate may be related to increased firing of the Gatling gun. Whatever the cause, the A-10 break-rate and abort-rate patterns are consistent only with some unknown added stress *during* the sortie.

<sup>24</sup>These increases were calculated by averaging the nondeployed units' abort rates (or break rates) over the August 1990–February 1991 period, then dividing the monthly abort rates (or break rates) by that average. Thus, the break rate of deployed F-15C units in August 1990 was 230 percent of the average nondeployed F-15C break rate, and the deployed abort rate was only 150 percent of the nondeployed abort rate (Figure 3.31).

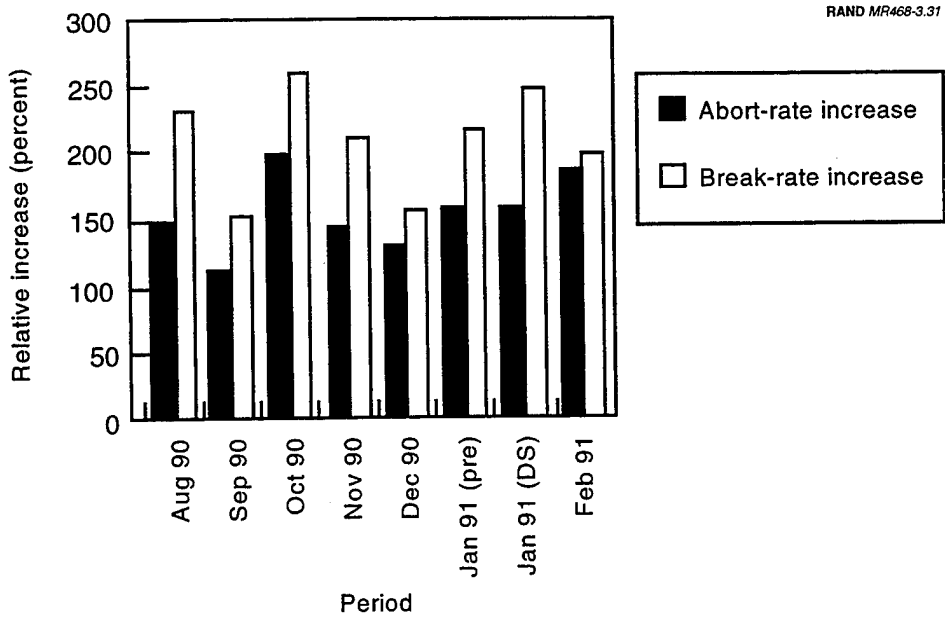


Figure 3.31—Relative Increases in F-15C Abort and Break Rates

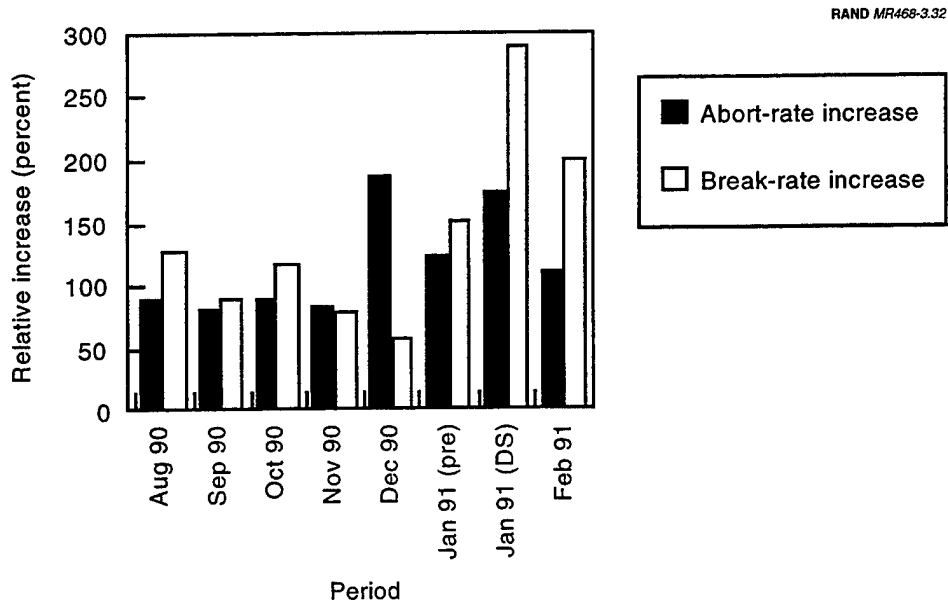


Figure 3.32—Relative Increases in F-15E Abort and Break Rates

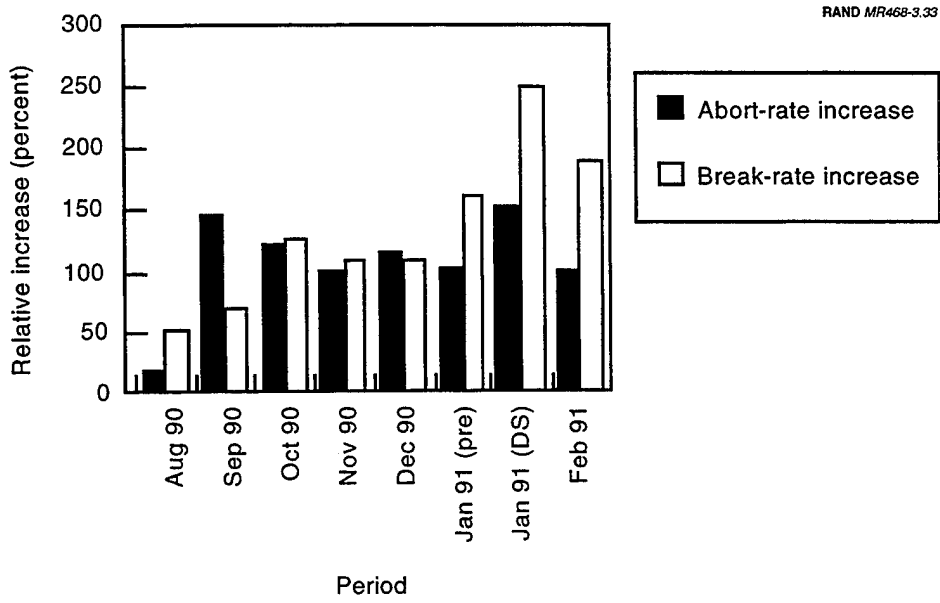


Figure 3.33—Relative Increases in F-16C Abort and Break Rates

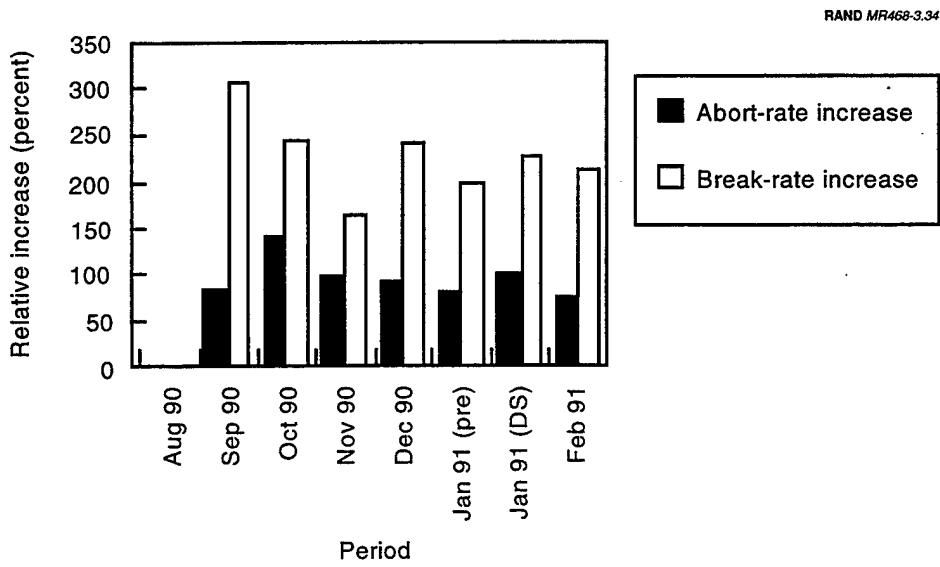


Figure 3.34—Relative Increases in A-10 Abort and Break Rates

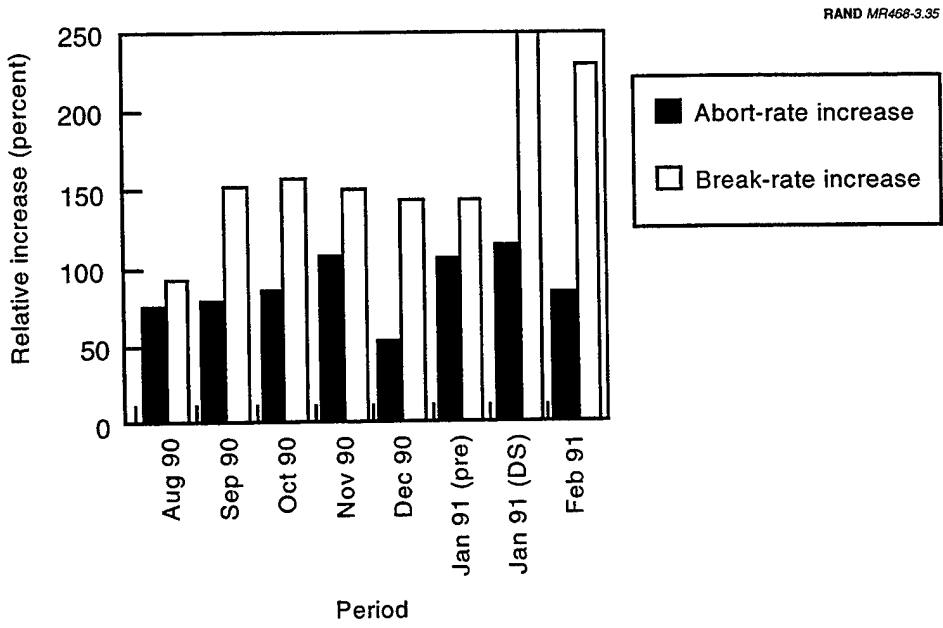


Figure 3.35—Relative Increases in F-4G Abort and Break Rates

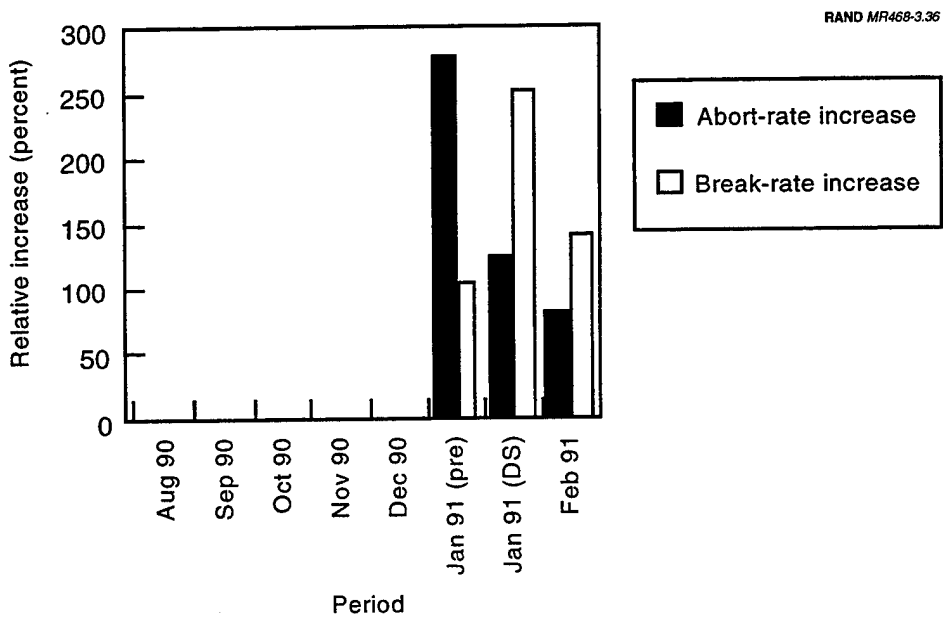


Figure 3.36—Relative Increases in RF-4C Abort and Break Rates

RAND MR468-3.37

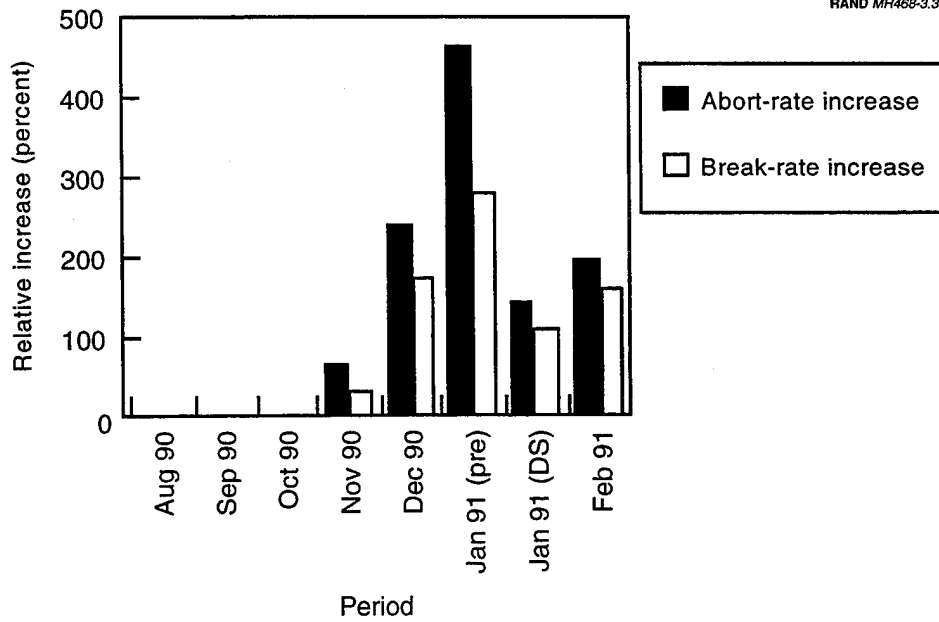


Figure 3.37—Relative Increases in F-111F Abort and Break Rates

RAND MR468-3.38

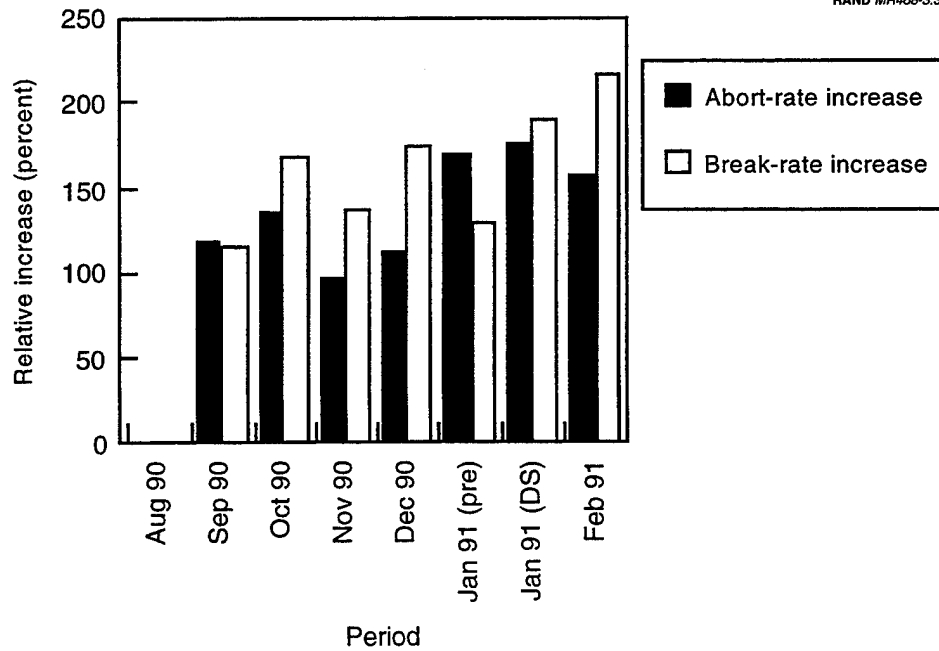


Figure 3.38—Relative Increases in F-117A Abort and Break Rates

the break-rate increase was substantially greater than the abort-rate increase throughout both Desert Shield and Desert Storm for three MDS (F-15C, A-10, and F-4G), which implies that part of the break-rate increases were due to events that affected some aircraft in both Desert Shield and Desert Storm, but affected others only after the air war began. (The RF-4C increase in early January appears to be a sample-size problem: Only 42 sorties were flown in theater with 5-6 aircraft.)

Thus, sortie-induced stresses contributed to, but do not fully explain, the increase in break rates for the F-15C, F-15E, F-16C, F-4G, RF-4C, and F-117A MDS. At the same time, sortie-related stresses *do* appear to fully explain the A-10 break rates, but *non-sortie-related* stresses explain the F-111F break rates.

### ***Mission-Specific-Subsystem Use Increased Code 3 Breaks***

Now we turn to the third potential explanation: Some change in mission-related demands might have caused the surge in breaks. One might speculate that a few key aircraft subsystems perform wartime-critical functions that are not fully utilized in peacetime.<sup>25</sup> In that case, the demands for support to those subsystems might increase substantially in combat or in realistic exercises. Consequently, the increase in demands for support might be concentrated in a few mission-critical subsystems.

We investigated this hypothesis using the F-117A aircrew debriefing data. If a mission-critical subsystem's breaks surged during deployment or combat, but other subsystem breaks did not, those critical subsystems would constitute a larger percentage of total demands.

Two key F-117A systems for mission accomplishment are the infrared attack designation system (IRADS) and the INS. The IRADS enables the aircrew to designate and deliver precision-guided bombs at night; the INS provides the precision position and velocity data needed to acquire the target and deliver the weapon within the mission parameters. Without those two subsystems, the F-117A is still airworthy but cannot perform its primary wartime function. If one contributor to the increased overall F-117A break rate was an increase in failure of those two systems, those subsystems would constitute a larger percentage of the operational breaks.

Figures 3.39 and 3.40 show combined Code 2 and Code 3 breaks for IRADS and INS as a percentage of total breaks for aircraft at home station and deployed.

<sup>25</sup>An example is peacetime training sorties that focus on ensuring that aircrews can perform some functions but not all functions that may *always* occur in wartime.

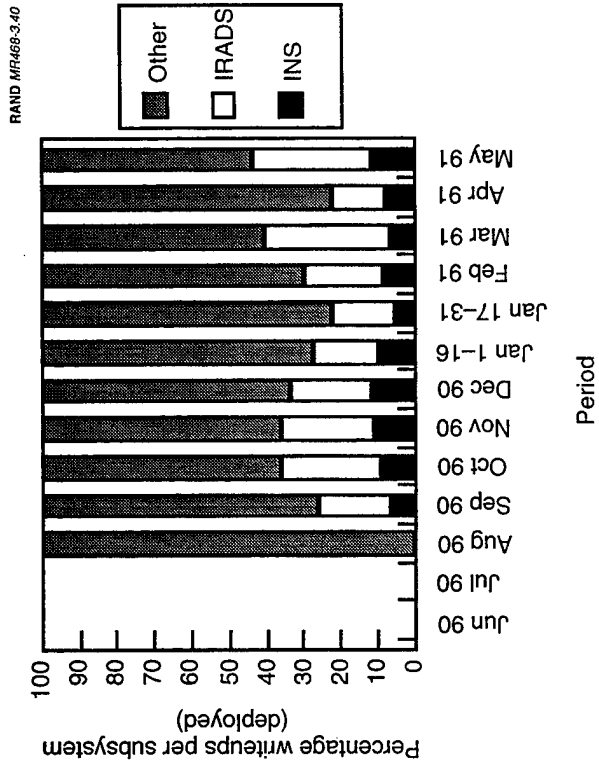


Figure 3.40—Deployed F-117A Mission-Specific-Subsystem Break Rates

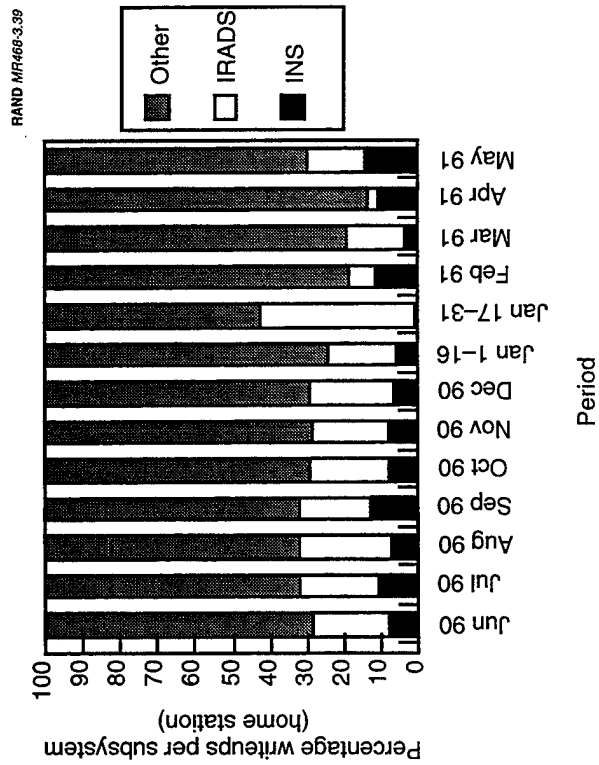


Figure 3.39—At-Home F-117A Mission-Specific-Subsystem Break Rates



Comparing the two figures, it is difficult to distinguish any percentage increase in IRADS and INS breaks<sup>26</sup> between the deployed and the nondeployed forces.<sup>27</sup> Indeed, average demands for support to those two subsystems over the entire period were 30.6 percent of deployed forces' total breaks and 29.0 percent of nondeployed forces'.

Thus, we find no support in the F-117A data for the theory that mission-specific subsystems' break rates increased proportionately over those of non-mission-specific subsystems. If the IRADS and INS subsystem breaks had increased significantly more than those of other non-mission-specific subsystems, they would have constituted a larger fraction of the total failures.

However, the F-117A mission-specific subsystems' data conflict with anecdotal evidence from other MDS. As described above, the F-111E and EF-111A appear to have experienced significantly *decreased* subsystem demands during Desert Shield and Desert Storm for terrain-following and jamming subsystems, respectively. The 10TFW (A-10) February 1991 maintenance summary stated that "[the deployed units] had a period of hard breaks which affected their weapons release, engines, and other systems. At home, the 509th TFS also exceeded the break rate [standard]; primary culprits were flight controls, weapons, and instruments." While breaks surged in both places, the affected subsystems were different for the deployed and at-home units. The specific subsystems and the direction of the changes in demand were different for each MDS; however, it appears from anecdotal evidence that at least some MDS experienced significant mission-specific-subsystem demand changes during Desert Shield and Desert Storm: some up and some down, but unpredictably.

Indeed, this analysis illustrates how difficult it is to predict demands at a subsystem level, even when one knows the scenario, as we did (after the fact). We fully expected to find a disproportionate increase in F-117A INS and IRADS demands, because of the centrality of those systems to every Desert Storm F-117A mission and their lesser peacetime role. We felt confident that aircrews would demand much greater performance improvements from those systems than from other systems. In fact, we found only an increase that was proportional to other systems' increases, suggesting a general concern for improved quality.

<sup>26</sup>We find it curious that the INS did not experience an overall greater increase in Code 2 and Code 3 breaks than other subsystems, especially after the INS drift-rate specifications were tightened. Apparently, total (i.e., Code 2 and Code 3 together) INS breaks increased in the same proportion as those for other subsystems, which would reflect an aircrew desire for higher quality across the board.

<sup>27</sup>We do not know why no IRADS or INS breaks were recorded in August 1990. The lack may only reflect the limited operations permitted early in Desert Shield.

Likewise, if the F-111E's break-rate increase was moderated by medium-altitude target approaches, why weren't the F-111F break rates similarly affected? Did target-designation and weapon-delivery demand increases offset the terrain-following demand decreases?

If one were to use the Desert Storm experience to improve predictions for the next war, should those predictions be calculated on the basis of the terrain-following-subsystem breaks of the F-111E or of the F-111F? Would break patterns change if low-level approach tactics were required? Will INS demand increases be moderated if the F-117s are based closer to their targets?

### *Increasing Aircrew Vigilance and Expectations Increased Code 3 Breaks*

Given that the break rates for at least one aircraft (the F-117A) increased for reasons other than increased use and inspection of mission-specific subsystems, we speculate that some break-rate increases can only be attributed to increased aircrew vigilance or performance expectations.

Contingency-specific training and CENTAF instructions may have heightened the aircrews' concerns for aircraft quality as hostilities approached. First, mass training raids patterned after the planned Desert Storm raids were conducted as early as October 1990 and increased in size and frequency throughout December and early January 1991. Many potential problems that aircrews might regard as marginal in peacetime may have been highlighted in that training. If so, aircrews would have reported them and would have remained alert to any recurrence, thereby contributing to increased Code 3 break rates, perhaps even before Desert Storm commenced—consistent with the experience of the F-16, EF-111A, and F-111F aircraft (Figures 3.13, 3.17, and 3.19, respectively).

But some MDS did not experience a break-rate surge until Desert Storm began. Just prior to Desert Storm, senior CENTAF leaders visited the deployed units and instructed aircrews that "[t]here is nothing on Iraqi soil worth dying for. Do not take any unnecessary risks."<sup>28</sup> Aircrews heeding such an instruction should decrease their tolerance for marginal aircraft performance—consistent with an increase in reported breaks in late January, as experienced by the F-15E, F-4G, RF-4C, and F-117A (Figures 3.12, 3.15, 3.16, and 3.20, respectively).

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<sup>28</sup>When the ground war commenced, this instruction became, "There is now something worth dying for. Take whatever risks are necessary to support the ground forces and protect them from attack."

### *No Single Factor Explains All Break-Rate-Pattern Changes*

Each factor discussed above was partially responsible for changes in the demand patterns for at least one MDS: changed MESLs, more-demanding sorties, changes in criticality of mission-specific subsystems, and changed aircrew's quality standards. We also found that many of the changes in demand pattern depended heavily on the operational situation and events that characterized Desert Storm. Some arose out of the availability or nonavailability of certain testing equipment and ECM ranges, others from such changed tactics as higher-altitude raids, others out of particular training and instructions given the aircrews prior to hostilities, and still others out of distances between the deployment bases and the targets. The next contingency will likely produce different situations and events with different aircraft equipment and tactics, and a different pattern of demands will almost certainly emerge.

### *Inevitably, Logistics-Demand Predictions Were Wrong*

To prepare for a pattern of demands, logisticians attempt, in peacetime, to predict, acquire, position, train, and maintain the human and physical resources necessary to meet future wartime needs. To accomplish this formidable task, they rely on operators' expressions of likely operations (optempo and location), their own previous experience (especially peacetime and wartime factors tying resource consumption to optempo), and some purposely pessimistic, worst-case assumptions about the availability of some shared resources (principally airlift, sealift, and ground transportation).

As we have seen in this analysis, actual wartime demands also depend heavily on operational strategies (long buildup without immediate engagement), tactics (high-altitude versus low-altitude sorties and subsystems needed), physical sortie stresses, presence or absence of system-failure indicators (e.g., EF-111A jamming ambiguities), and even the aircrews' qualitative assessments of the aircraft's mission effectiveness.

Clearly, demands for maintenance of particular subsystems are especially sensitive to the tactics employed, which depend, in turn, on a wide range of situational combat variables that vary widely according to the enemy's capabilities, the locale, and the military objectives. As we have seen here, even the aggregate breaks across the entire aircraft may vary by a factor of 2 from peacetime experience. Unless those (and perhaps other) operational factors could be known in advance, detailed predictions of specific base-level logistics

labor-skills, equipment, and material needs for a future war can never be absolutely precise.

### **If Demands Increased So Much for Some MDS, Why Didn't MC Rates Decrease?**

Most troublesome, MC rates increased even though the aggregate break rates for several MDS (F-15C, F-15E, F-16C, A-10A, F-4G, RF-4C, F-111F, and F-117A) increased during Desert Storm. Under normal circumstances, one would expect the aircraft experiencing heightened break rates to have lower MC rates, as a result of both increased maintenance backlogs and increased supply shortages. In this subsection, we first assess maintenance performance, then supply.

Break rates per sortie increased by a factor of 2 for many MDS, and the sorties increased by nearly the same factor in Desert Storm. Therefore, the unscheduled flight-line maintenance demands for those MDS must have increased by nearly a factor of 4. If the flight line did not have sufficient personnel, equipment, and material to resolve those unscheduled demands quickly, we could expect to see a larger backlog of NMCM aircraft during Desert Storm.

Aircrew-reported breaks are not the only source of maintenance and supply workload. The other large source is scheduled maintenance in the form of phased inspections, time-change items,<sup>29</sup> and time-change technical orders (TCTOs).<sup>30</sup> Phased inspections and some time-change items' workloads increase with optempo, but TCTOs remain constant.

While Desert Shield fighter operations typically increased sortie and flying-hour levels only slightly over those of peacetime, Desert Storm operations were much more intense. For example, F-117A sortie rates increased (from 12 to 19 sorties per aircraft per month), as did its average sortie duration (from 1.5 to 5.2 flying hours per sortie). Such intensity increased the requirement for F-117A phased inspections and replacement of some time-change items over fivefold. Other MDS experienced smaller, but still large, flying-hour increases. Demands for phased maintenance and some time-change items increased in proportion.

Even without queueing, those demands would have increased the number of NMCM hours each aircraft spent in scheduled maintenance each month, thus

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<sup>29</sup>Time-change items (e.g., batteries or pyrotechnical devices) are changed after a specific interval, depending on either the calendar days or the flying hours since the last change. They are typically, although not always, accomplished during phased inspections.

<sup>30</sup>Time-change technical orders are the mechanism whereby the USAF manages small to large field changes to existing aircraft subsystems. To ensure that all affected aircraft maintain the same configuration over time, the upgrades are accomplished according to a prescribed schedule.

increasing the NMCM rate proportionally to the flying hours. If some aircraft had to wait for another to finish before starting scheduled maintenance, NMCM would have increased at an even higher rate than flying hours.

Here, we assess how maintenance generally affected aircraft availability, by comparing deployed and nondeployed NMCM rates reported by TAC and USAFE. Although the deployed NMCM rates often turned out to be higher than nondeployed rates, they did not increase proportionally to flying hours or sorties. Thus, we examined how each of the three maintenance activities (scheduled maintenance, sortie generation, and unscheduled maintenance) was able to maintain relatively low NMCM rates, based on after-action interviews with maintenance personnel deployed during the war.

### *Aircraft in Maintenance Status Did Not Increase Proportionally to Inspection and Flight-Line Demands*

We found smaller-than-expected increases in NMCM aircraft in Desert Storm. As shown in Figures 3.41 through 3.50, NMCM increases were experienced by six MDS (F-15C, F-15E, F-16, A-10, F-111F,<sup>31</sup> and F-117A) in Desert Storm. Of those, three (F-15E, F-16, and F-117A) experienced increased NMCM rates at the same time their break rates surged. In contrast, the A-10 apparently experienced a slowly growing NMCM rate, beginning in early January, rather than a sudden surge. The F-15C and the F-111F (with more-prolonged high break rates in Figures 3.11 and 3.19, respectively) also experienced higher NMCM rates throughout Desert Shield.

As important, some MDS (F-4G, RF-4C, EF-111A, and F-111E) experienced little or no increase in NMCM rate. We were not surprised that the EF-111A and F-111E NMCM rates did not increase, because we already knew that their Code 3 break rates did not increase. We were somewhat more surprised by the F-4G and the RF-4C, which exhibited no NMCM increase despite their higher break rates. Interviews suggest that the F-4G and RF-4C steady break rates and the less-than-proportional break-rate increases for other aircraft can be attributed to increased maintenance productivity.

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<sup>31</sup>Here we compare F-111F NMCM rates in theater to early, nondeployed (August to November) rates at home station. The later home-station rates represent the experience of only a few aircraft, presumably in heavy maintenance status.

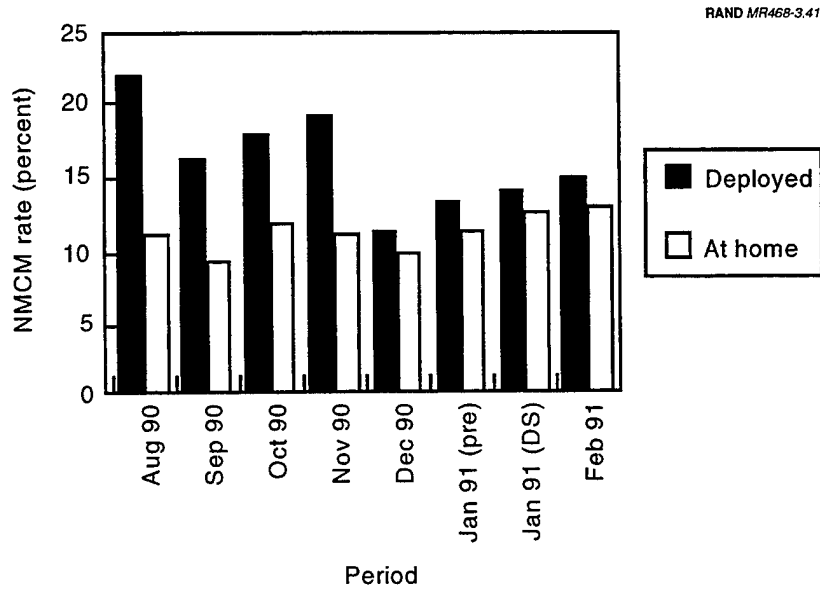


Figure 3.41—F-15C NMCM Rate

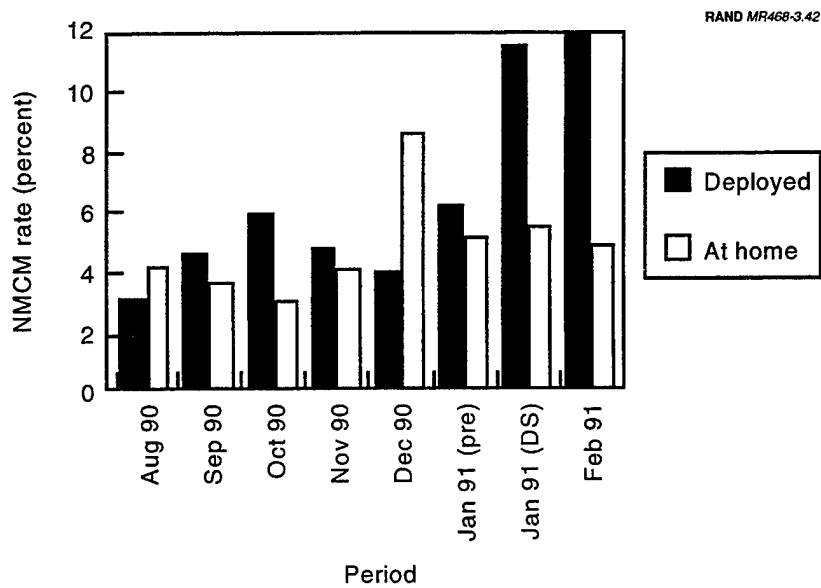


Figure 3.42—F-15E NMCM Rate

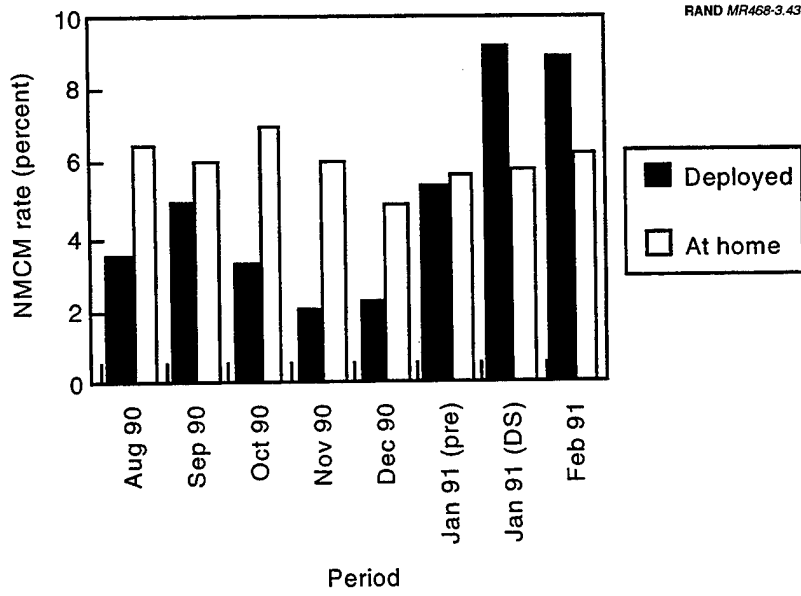


Figure 3.43—F-16C NCMCM Rate

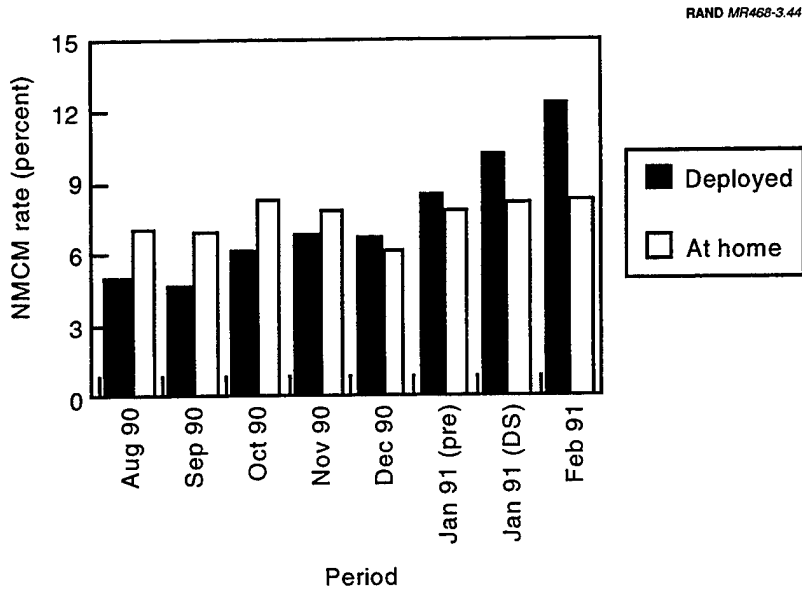


Figure 3.44—A-10 NCMCM Rate

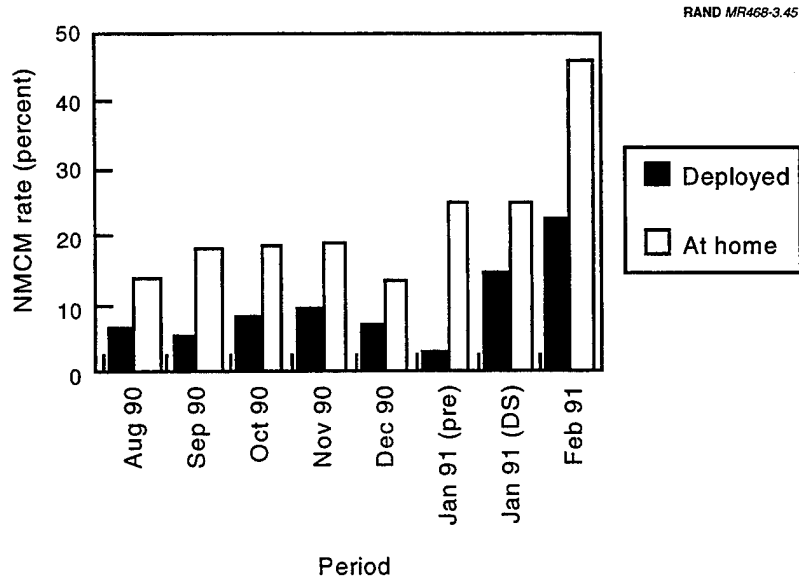


Figure 3.45—F-4G NMCM Rate

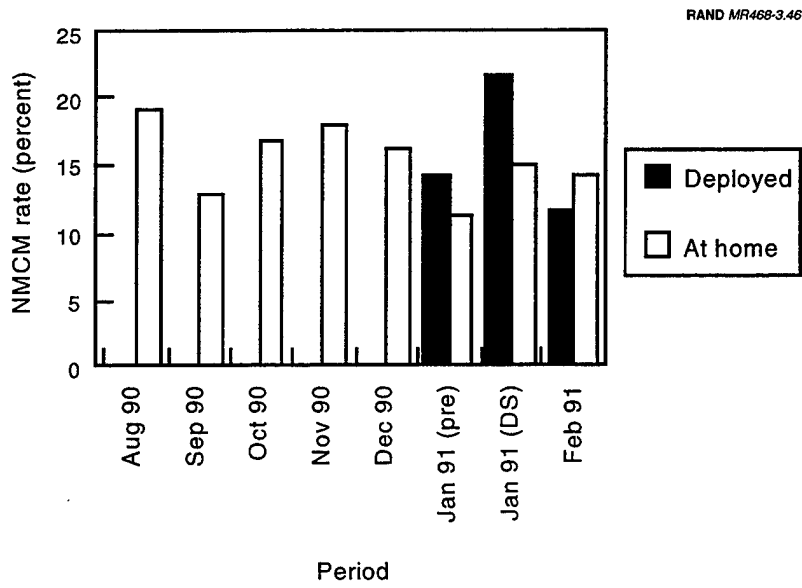


Figure 3.46—RF-4C NMCM Rate



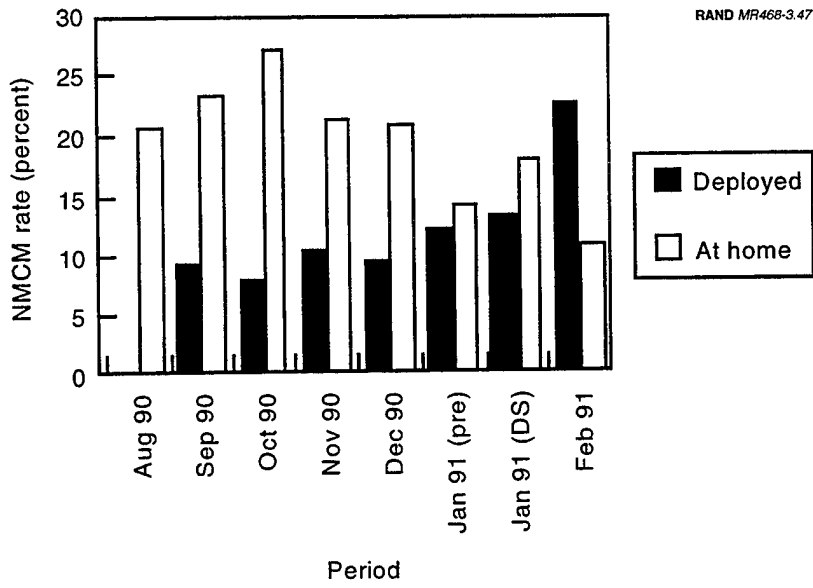


Figure 3.47—EF-111A NMCM Rate

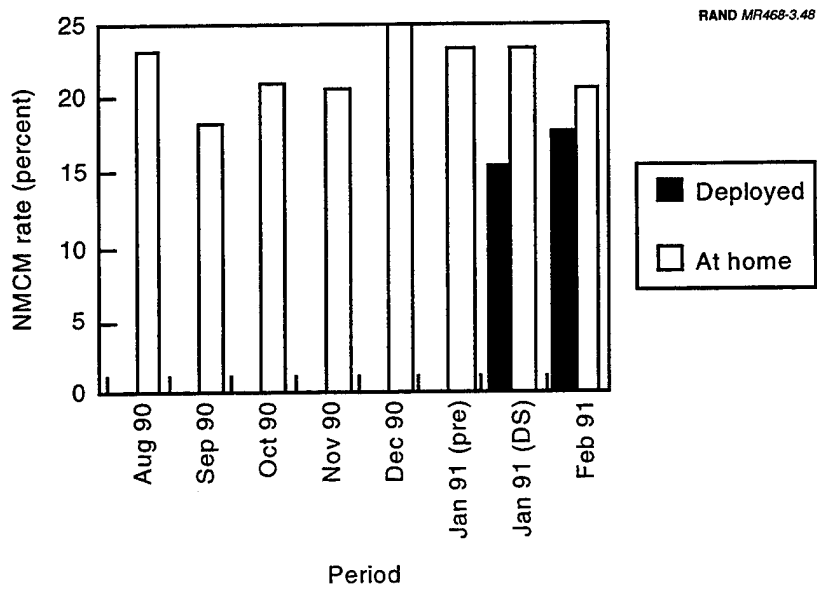


Figure 3.48—F-111E NMCM Rate

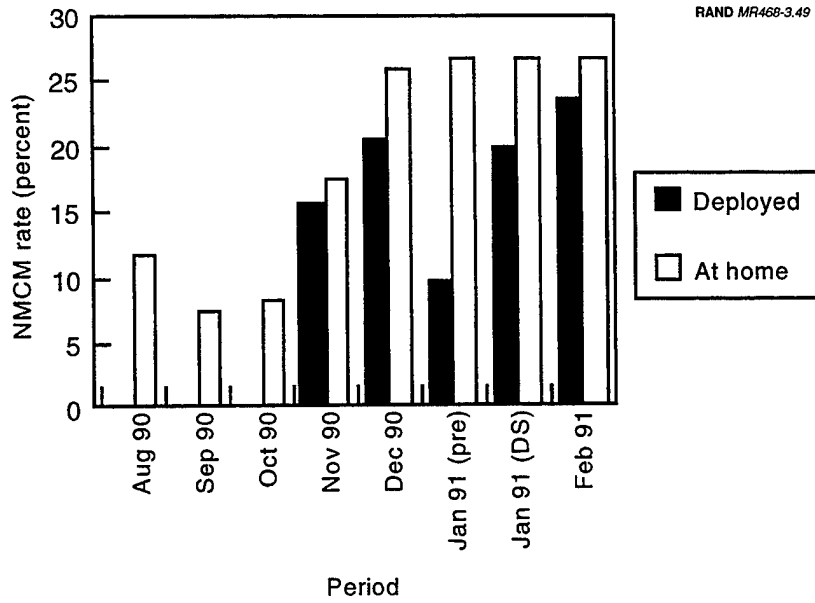


Figure 3.49—F-111F NMCM Rate

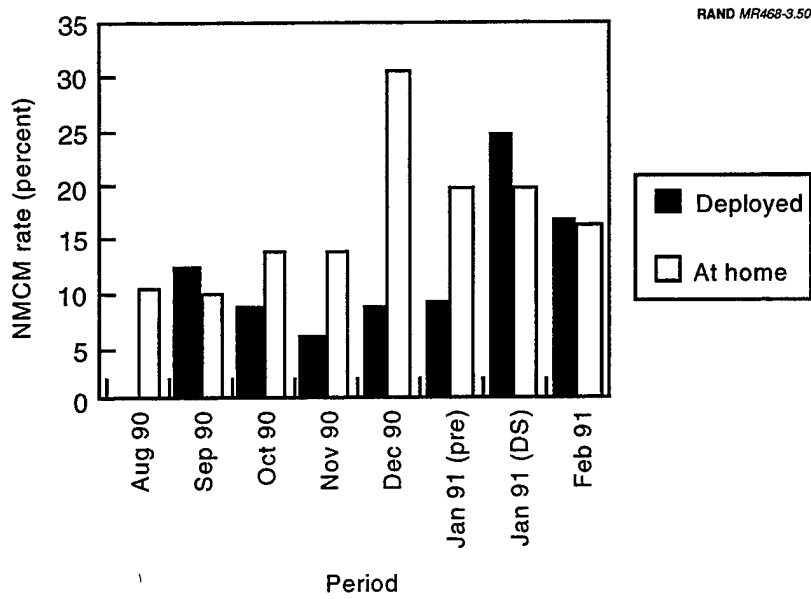


Figure 3.50—F-117A NMCM Rate

### *Base-Level Aircraft Maintenance Became More Productive*

Most significant, the NMCM rates did not increase proportionally to either the flying hours or the Code 3 demands. Therefore, aircraft spent less time in maintenance per inspection, time change, or Code 3 incident during Desert Storm than in peacetime.<sup>32</sup> Overall maintenance productivity must have improved, at least in some crews.

Thus, we next discuss how three kinds of maintenance activities—scheduled maintenance, sortie generation, and unscheduled maintenance, in turn—were managed in Desert Storm to minimize the effects of higher workloads on maintenance backlogs and NMCM aircraft.

**Maintenance Management and Enhanced Scheduled Maintenance Improved Productivity.** Scheduled aircraft maintenance includes phased inspections and other time-scheduled activities that typically require extensive time and labor to accomplish. In Desert Storm, units scheduled aircraft, maintenance personnel, and other resources to ensure that aircraft downtime was minimized. In one unit, phased-inspection teams and material were assembled to begin the inspection immediately after an aircraft landed, inspection tasks were scheduled to maximize simultaneity, and work was scheduled tightly to ensure a continuous workflow. Using this process, they were able to complete a nominally 3- or 4-day peacetime inspection in less than 24 hours during wartime.

In addition, the Air Force Logistics Command (AFLC) promulgated amended technical orders that streamlined combat phased inspections for some aircraft. Such streamlining limited the inspections of some aircraft areas that were both difficult to access and had low probabilities of failure since the last inspection.

Maintenance personnel we interviewed insisted that the shortened phased inspections were not achieved by bypassing or eliminating inspection tasks other than those approved by AFLC. Rather, they emphasized using fully manned, round-the-clock inspection teams (made possible in part by the longer wartime work days); having the needed material assembled, unpacked, and ready for use; and working on multiple inspection tasks simultaneously, when possible.

That is not to say that queueing for critical maintenance resources never occurred. For example, the two F-117A exhaust manifolds had to be replaced every 200 flying hours. That component is shaped roughly like a right triangle

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<sup>32</sup>If broken aircraft immediately received maintenance with little or no queueing and average maintenance time was unchanged, the increased frequency of Code 3 breaks and phased inspections would cause proportionally more aircraft to be undergoing maintenance at any time. This situation would worsen substantially if maintenance resources were so few that queueing occurred.

10–15 feet on a side, so it requires the presence of a small crane throughout the approximately 5-hour-long replacement process to avoid damaging the new component or the airframe. When the number of aircraft needing an exhaust manifold replacement exceeded the number of available cranes, some aircraft necessarily waited before work could begin.

But queueing was rare for such scheduled maintenance tasks as time changes and phased inspections. Desert Storm's extraordinary increase in flying could easily have exacerbated the frequency of such conflicts, but aircraft schedulers minimized such incidents by maintaining an even flow of aircraft reaching the critical scheduled-maintenance event. By judiciously selecting which aircraft would fly each sortie, they sped up some aircraft and slowed down others approaching a phased-inspection or time-change interval.

Where possible, they also scheduled time-change-item replacements and phased inspections to occur simultaneously, thereby permitting simultaneous access for both the phased inspection and the time-change maintenance personnel. In some cases, phased-inspection procedures naturally provided access to implement a time-change-item replacement so that duplicate panel removal and other preparatory tasks were eliminated.

As a result of the careful scheduling, conflicts of scheduled-maintenance resources and personnel were apparently rare at all units. Rather, it appears that units had sufficient manpower, equipment, and procedures to reduce phased-inspection times substantially, thereby contributing to the less-than-proportional increase in NMCM aircraft as flying hours increased.

**Sortie-Generation Production Rates Increased.** Sortie generation includes normal post- and preflight maintenance—such as fueling, loading munitions, and a panoply of lesser inspection-based tasks—required for a combat sortie with a fully operational aircraft. Whereas scheduled maintenance holds some aircraft out of the sortie flow, sortie-generation teams recycle returning Code 1 and Code 2 aircraft by preparing them for other planned sorties.<sup>33</sup> Units' maintenance personnel generally agreed that they could have generated more sorties from the flight line if more aircraft had been available or if sorties had been shorter. Specifically, they commented that the long sorties and massed operations in Desert Storm limited the sortie flows, leaving them with unused sortie-generation capacity between mass launches.

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<sup>33</sup>Aircraft reported Code 3 by returning aircrews are diverted to unscheduled maintenance, where crews work to return such aircraft to operational status so that they may reenter the sortie flow.

We concluded from those statements that the resources needed to accomplish combat turns (refueling and rearming, mostly) were more than sufficient to meet the demands of the Desert Storm air campaign. Desert Storm sortie rates may have exceeded nominal peacetime training rates at home base, but they did not approach those of surge sortie-generation exercises.

**Unscheduled-Maintenance Production Rates Increased.** Demands on the unscheduled-maintenance resources obviously increased for most MDS as a direct result of the increased Code 3 discrepancies. Each Code 3 report must be closed by a maintenance technician inspecting, testing, and, perhaps, repairing some problem before the aircraft can be returned to service. The large, unpredicted increase in unscheduled flight-line maintenance demands could easily create a backlog if the flight line could not increase its production rate accordingly.

We found that the flight-line unscheduled-maintenance production rates<sup>34</sup> increased to meet the increase in demands. To get a sense of the increased flight-line maintenance production rates, we multiplied the average fix rate<sup>35</sup> by the monthly number of Code 3 breaks per aircraft to compute the monthly Code 3 breaks per aircraft *repaired with minimum delay*. In an intense operation such as Desert Storm, that measure reflects the unscheduled-maintenance production rate.<sup>36</sup> Increases in that number indicate a unit's ability to return broken aircraft to service quickly to meet combat needs. As demands for flight-line support increase, the production rate will increase proportionately, *until the unscheduled maintenance production capacities are exceeded*. Thereafter, the production rate would have reached its maximum, and further demand increases would not increase the unit's production rate.

Figures 3.51 through 3.60 show the unscheduled-maintenance production rate for each MDS in Desert Shield and Desert Storm. The unscheduled-maintenance production rate for all MDS except the EF-111A and F-111E<sup>37</sup> increased three to six times normal peacetime levels.

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<sup>34</sup>This measure, we admit, is somewhat unusual. It reflects the flight line's *capacity* to deliver mission-capable aircraft, controlled by the fleet size. It is measured as monthly 8-hour (Code 3) fixes per aircraft possessed. It is only a *lower bound* on that capacity, because it is limited by the aircraft break rate.

<sup>35</sup>The 8-hour fix rate is the percentage of Code 3 aircraft returned to mission-capable status in 8 hours.

<sup>36</sup>Obviously, units can return all aircraft to combat status, *given sufficient time*. This measure reflects the units' abilities to repair aircraft *to meet an operational sortie requirement*. At some level, that maintenance production cannot be increased because of the units' production capacity.

<sup>37</sup>The F-111E production may have surged slightly in February, but not to the extent of other aircraft. Neither aircraft had substantial break-rate increases, as noted earlier, although both flew longer, more frequent sorties than in peacetime.

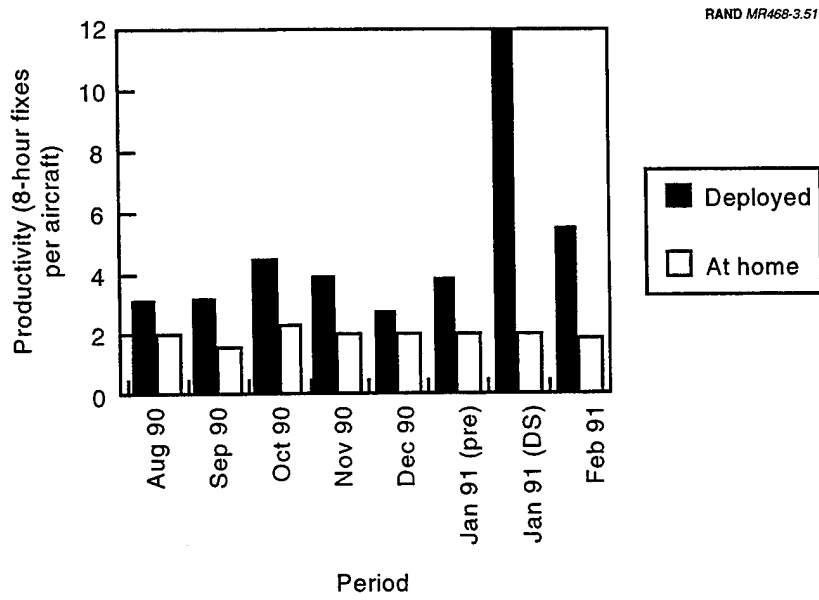


Figure 3.51—F-15C Unscheduled-Maintenance Production Rate

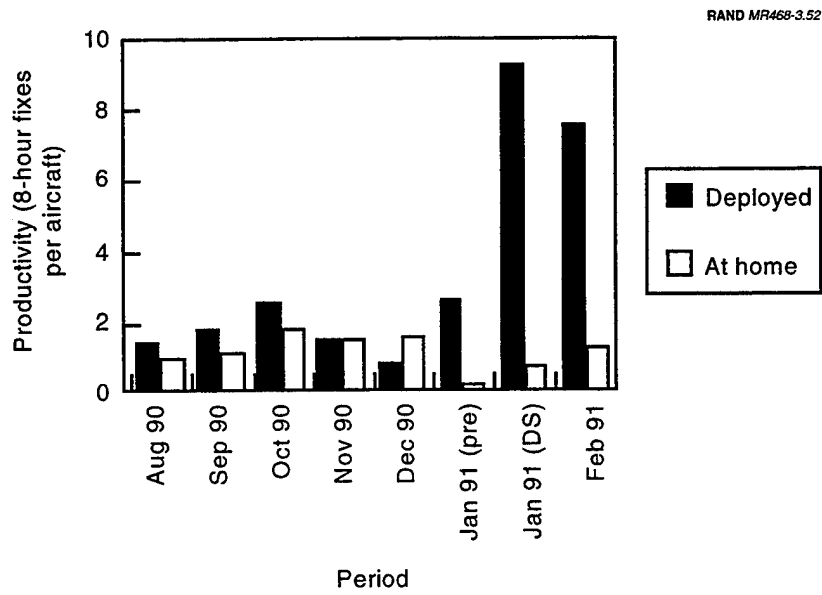


Figure 3.52—F-15E Unscheduled-Maintenance Production Rate

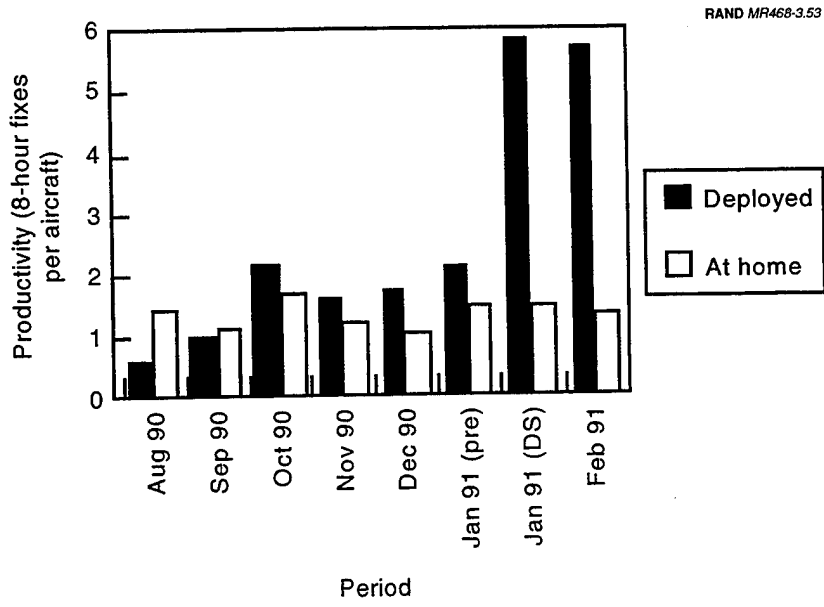


Figure 3.53—F-16C Unscheduled-Maintenance Production Rate

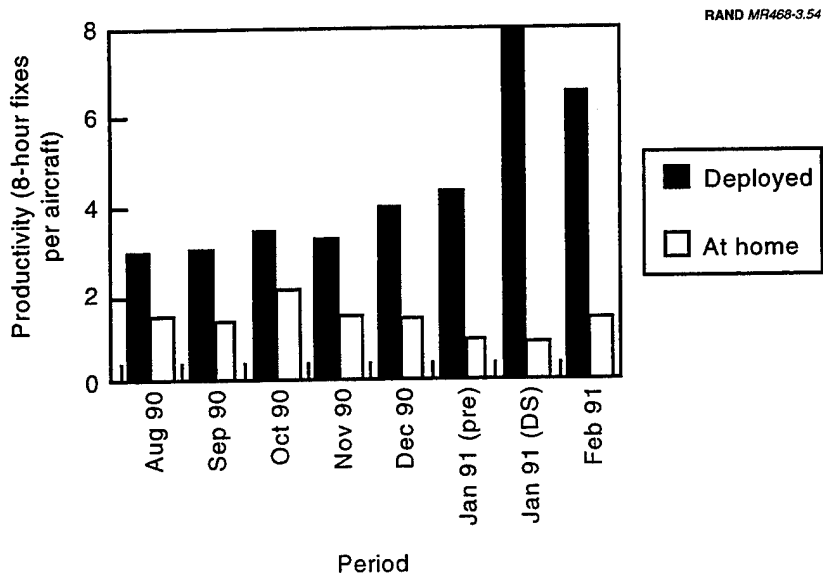


Figure 3.54—A-10 Unscheduled-Maintenance Production Rate

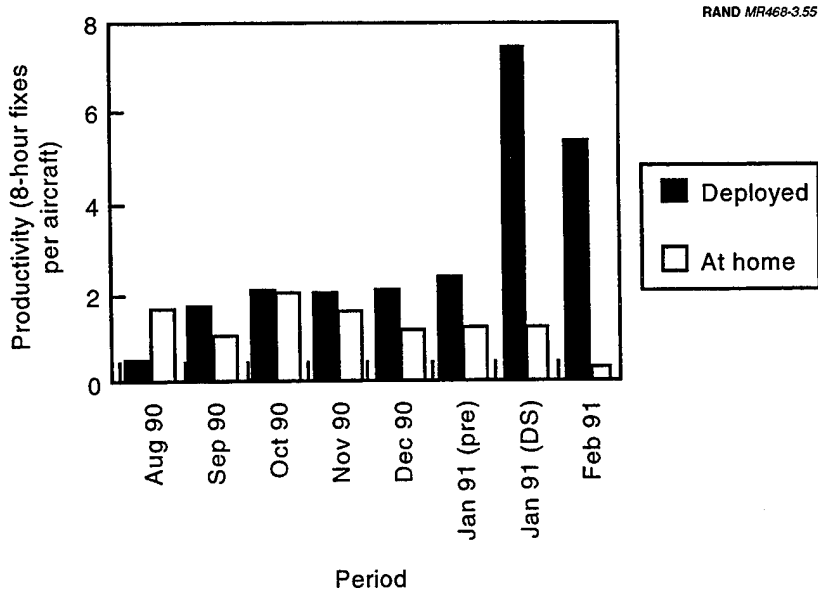


Figure 3.55—F-4G Unscheduled-Maintenance Production Rate

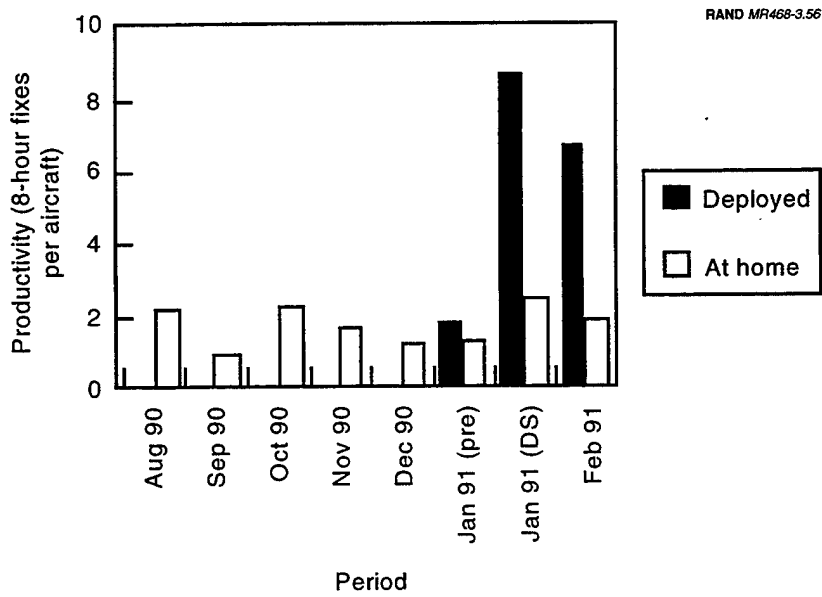


Figure 3.56—RF-4C Unscheduled-Maintenance Production Rate



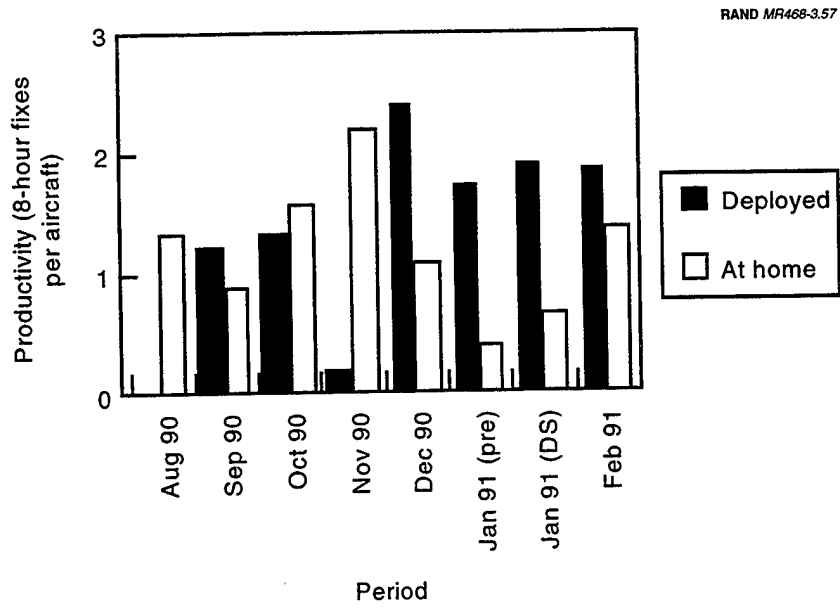


Figure 3.57—EF-111A Unscheduled-Maintenance Production Rate

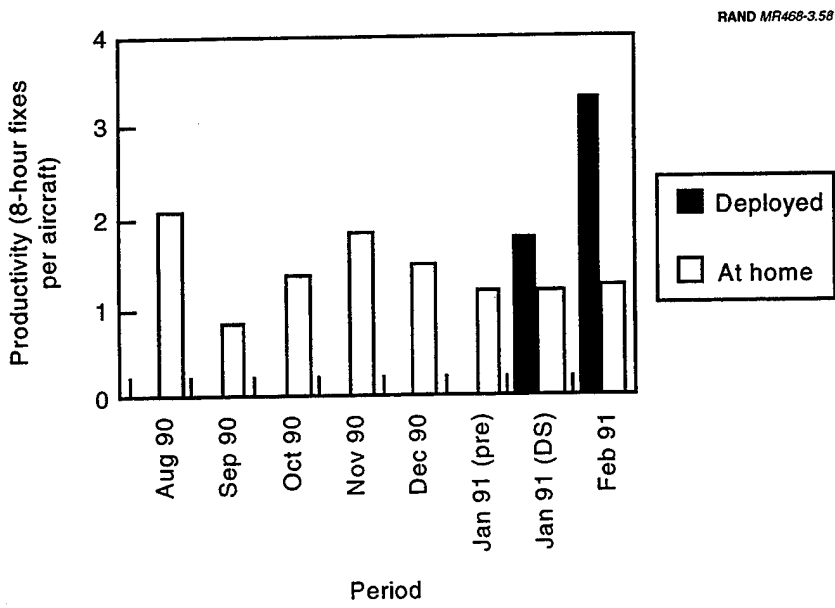


Figure 3.58—F-111E Unscheduled-Maintenance Production Rate

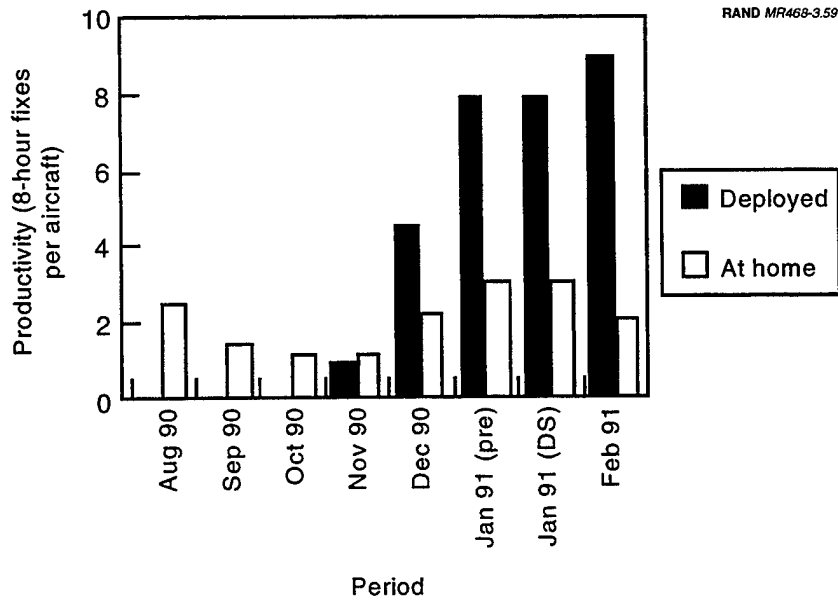


Figure 3.59—F-111F Unscheduled-Maintenance Production Rate

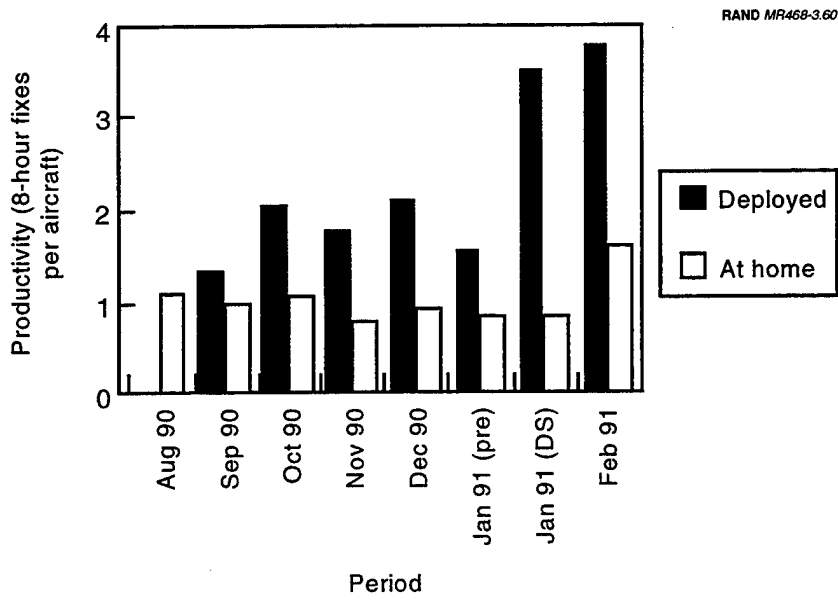


Figure 3.60—F-117A Unscheduled-Maintenance Production Rate

Because the unscheduled-maintenance production increases for most MDS were proportionally greater than the Code 3 break increases, we concluded that the deployed units' unscheduled-maintenance production capacities were not exceeded. If the flight-line resources had been more fully utilized, we would expect the unscheduled-maintenance production rate to level off at some lower point and a backlog of NMCM aircraft to emerge.

More directly, the 8-hour fix rates remained relatively constant (between 80 and 90 percent, depending on the MDS) throughout the deployment and ensuing air campaign. The relatively constant fix rate suggests that there was little additional queueing for unscheduled maintenance as a result of the increased demand rate. Had increased queueing occurred, the backlog of work would have built up rapidly and fewer Code 3 aircraft could have entered work simultaneously. Had there been more delays before maintenance was begun, more breaks would have required more than 8 hours to fix. Thus, we concluded that the flight-line unscheduled-maintenance capacity of most units was not exceeded during Desert Storm.

At the same time, the relatively constant fix rate indicates that units were unable to shorten the unscheduled-maintenance times using methods such as those used to shorten phased-maintenance inspections.<sup>38</sup> Unlike phased inspections, which contain many predictable, sequential tasks that permit advance positioning of personnel, equipment, and other resources, and simultaneous work on multiple tasks, unscheduled maintenance must respond as work is discovered. As a consequence, management could not reduce unscheduled-maintenance times.

But the main point is that unscheduled-maintenance times did not increase. Given the increased demands, unscheduled maintenance could easily have fallen behind unless some maintenance-productivity improvements were achieved.

**Sources of Increased Unscheduled-Maintenance Productivity.** In some after-action reports and interviews, theater maintenance personnel argued that the productivity increase was due mainly to enhanced maintenance personnel morale and the lack of distracting peacetime influences, particularly daily family concerns and alcohol (the absence of which was near total).

No one disputes the important factors of morale and eliminating peacetime distractions, but we suggest that four other factors may be equally important:

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<sup>38</sup>In the early 1980s, TAC had worked hard to streamline flight-line maintenance procedures, place decisionmaking on the flight line, and place spares closer to the aircraft. Given the significant improvements in throughput time that had been achieved, it may not be surprising that the Desert Storm fix rates were only marginally better.

increased maintenance capacity, increased technician productivity, increased availability of spare parts, and suppressed demands. We discuss each factor in turn.

First, wings universally adopted wartime work rules (nominally 12 hours daily for 6 days a week, with leave and other military duties suspended). As a result of this factor alone, effective maintenance production capacity increased threefold (from 60 percent of a nominal 40-hour work week to 100 percent of a 72-hour work week). Most likely, this tremendous increase in capacity was the occasion for the maintenance personnel comments that it would have been difficult to create this capacity and use it productively without good morale and minimal distractions.

Second, average flight-line maintenance technicians' productivity was significantly enhanced by deploying mainly skill level 5 and above journeyman technicians. Such a select group of technicians produce at higher-than-average rates and make fewer rework-generating mistakes. Further, the resulting work environment did not burden them with training and supervisory duties.

Third (as we describe in our discussion on spares support in the following section), spares levels, requisitioning, and delivery were enhanced for units participating in Desert Storm. Here, we note only that more easily accessible spares minimized the time technicians wasted in searching for a non-existent spare or cannibalizing parts from other aircraft. As a result, maintenance personnel were able to spend more time actually maintaining aircraft and repairable components, rather than locating and acquiring spare parts to enable maintenance.

Fourth, some less critical maintenance problems, such as Code 2 aircrew reports, were suppressed or delayed.<sup>39</sup> The evidence for suppressed demands is purely anecdotal, yet it is convincing. Maintenance crews described two methods that either delayed or suppressed some maintenance activities: delaying maintenance on Code 2 breaks and using ad hoc fixes, detailed below.

When asked how their procedures changed in wartime, maintenance personnel stated directly that some maintenance actions were temporarily delayed. Specifically, they stated that they delayed maintenance of Code 2 breaks they would have given immediate attention in peacetime if the aircraft could have

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<sup>39</sup>Some may argue that these delayed discrepancies constitute "gold-plating" or cosmetic work that could be eliminated in peacetime, too. We cannot agree in general, because, sometimes, early-maintenance actions against a less serious discrepancy can prevent further deterioration and sympathetic failures of a more catastrophic nature.

been pulled from the sortie flow without disrupting the scheduled plan. Rather, most Code 2 breaks were "collected" until the aircraft received a Code 3 writeup. Even after a Code 3 break was reported, some Code 2 breaks were not tackled if the work would have further delayed returning the aircraft to operational status. For example, if the diagnosis or repair required removing several panels or components to get access, Code 2 discrepancies would be carried over until other work facilitated access or the aircraft became less essential to generate required operational sorties. In extreme cases, they reported that hard-to-reach Code 2 discrepancies were resolved only when the war was over. The strong emphasis on meeting the next sortie temporarily suppressed or delayed maintenance actions (and NMCM status), sometimes for the duration of the war.

Maintenance personnel also stated that ad hoc, temporary workarounds were employed more frequently, especially when it was known that a needed component was not available in base supply. Specifically, flight-line maintenance personnel reported that flight-control computers were reloaded and reinitialized rather than always replaced, components were removed and reseated, serviceable-but-imperfect components were left installed, intervals for time-change items were extended, and subsystems were demodified to an earlier configuration when replacement parts for the new configuration could not be obtained.<sup>40</sup> As with the suppressed Code 2 demands, some of these actions were taken "just to get one or two more sorties out of an aircraft." And, as with suppressing Code 2 breaks, the temporary flight-line fixes suppressed demands on supply.<sup>41</sup>

Overall, increased maintenance capacity, select technicians, increased availability of spare parts, and demand delays enhanced unscheduled-maintenance productivity. Even though the increased unscheduled-maintenance production rates were not sufficient to maintain pre-hostility levels of NMCM aircraft, they and more-efficient phased-inspection times were directly responsible for moderating the increase in NMCM rates during Desert Storm.

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<sup>40</sup>We do not want to leave the impression that temporary, or ad hoc, fixes were the dominant maintenance approach. They were atypical for most aircraft and subsystems. Nevertheless, when demands exceeded supplies, such fixes became necessary to meet the deployed units' taskings.

<sup>41</sup>The temporary fixes might have either increased or decreased the aircrew-reported break rates. On the one hand, aircrews observing an inadequately corrected problem might report it again if they believed it would be fixed; on the other, aircrews observing recurrent problems in noncritical systems might stop reporting them altogether.

## Critical-Component-Resupply Times Were Sharply Reduced

Some analysts and policymakers credit the exceptional Desert Storm MC rates to the high levels of spares funding over the 1980s.<sup>42</sup> But that funding was based on peacetime demand rates extrapolated to a higher wartime optempo. Given the twofold increase in flight-line break rates, higher-than-planned sortie rates, and longer sorties,<sup>43</sup> some factor other than funding must have helped.

We have already observed that some MDS maintenance demands decreased even as others increased, depending on the MDS, the operating conditions, the novel, non-Warsaw Pact threat, and the changed relative importance of individual subsystems (e.g., terrain following) in Desert Storm. If demands for spare parts reflected the changed maintenance demands, the agencies buying spares in the mid- to late 1980s could not have known which spares might require much more stock and which might require much less. Who could have predicted the enemy, the threat, the air campaign plan, and the tactics to be used, let alone the twofold increase in break rates for some aircraft?

In this analysis, we trace the spectacular NMCS rates achieved in Desert Storm to several procedural changes adopted in Desert Shield and Desert Storm.

### *NMCS Rates Remained Nearly Constant in Desert Storm*

First, we note that the spares support to deployed units was remarkable. In contrast to the increase in the number of NMCM aircraft, the number of NMCS aircraft remained low and nearly constant for all MDS deployed during Desert Shield and Desert Storm (Figures 3.61 through 3.70). Most deployed MDS did not exceed even 10 percent NMCS, in stark contrast to the support planned by war reserve spare kits (WRSK) requirements computations, which allow for up to 25 percent of the aircraft to be NMCS after 30 days of wartime operation. This accomplishment is all the more remarkable because it occurred when demands for serviceable replacement spares probably surged beyond all expectations as a result of the much-increased aircraft break rates reported earlier in this section for most MDS during Desert Storm.

<sup>42</sup>See Thomas A. Keaney (USAF), *Gulf War Air Power Survey: Volume III, Logistics and Support*, Washington, D.C.: U.S. Government Printing Office, 1993, for an expression of this viewpoint.

<sup>43</sup>At the time of this analysis, no reliable data existed on component demands at the flight line. We assume in this analysis that those demands would be proportional to Code 3 breaks, if sufficient supplies were available. That is, we assumed most Code 3 breaks culminated in removal and replacement of a line replaceable unit on the aircraft, if a spare was available. As we report below, every effort was made to make plenty of spares available.

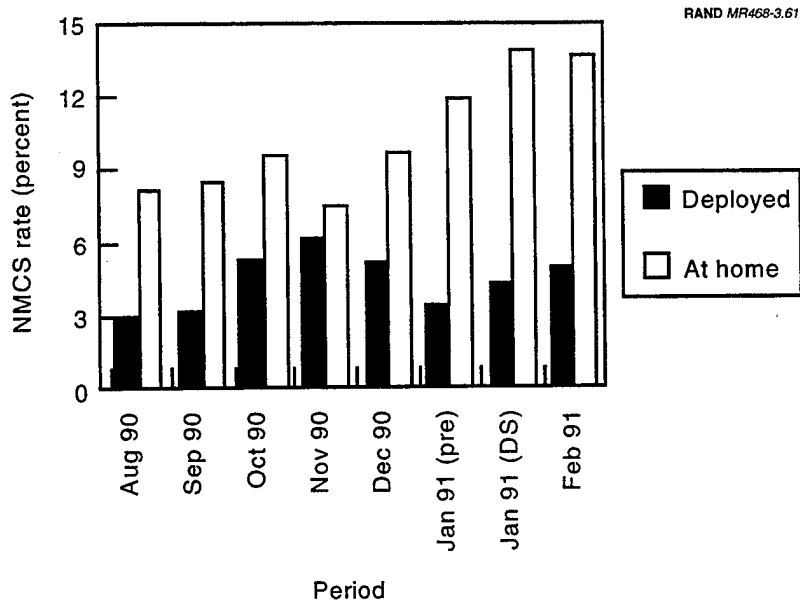


Figure 3.61—F-15C NMCS Rate

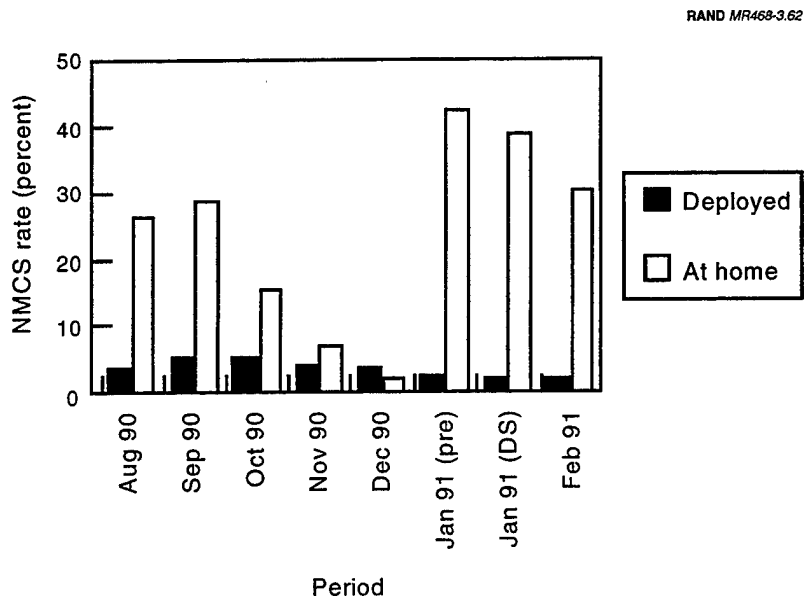


Figure 3.62—F-15E NMCS Rate

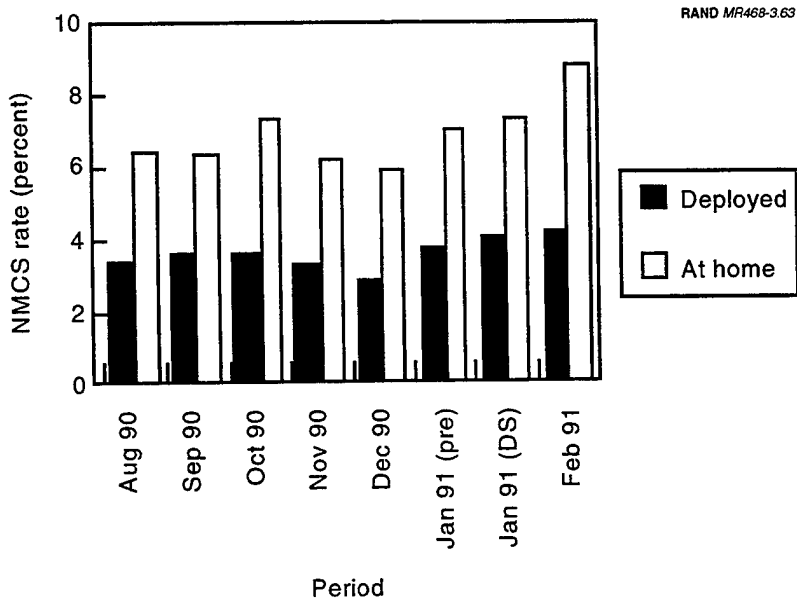


Figure 3.63—F-16C NMCS Rate

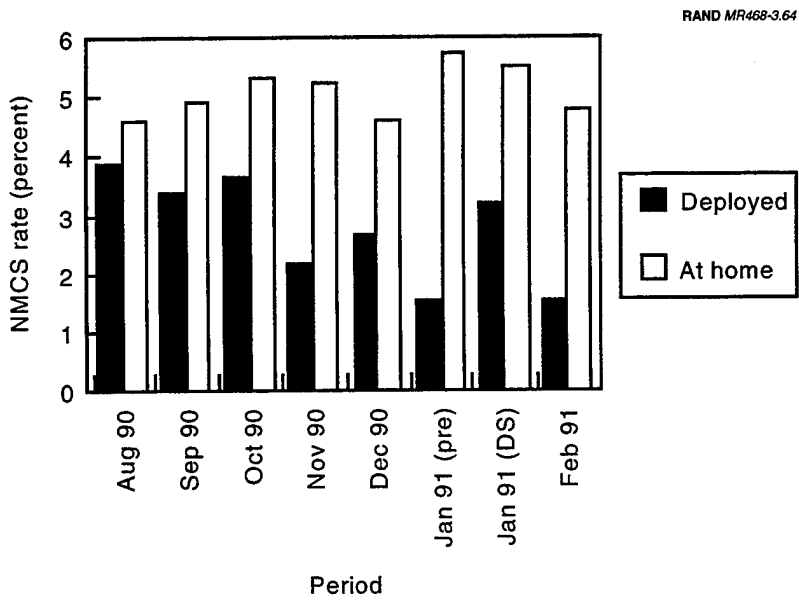


Figure 3.64—A-10 NMCS Rate



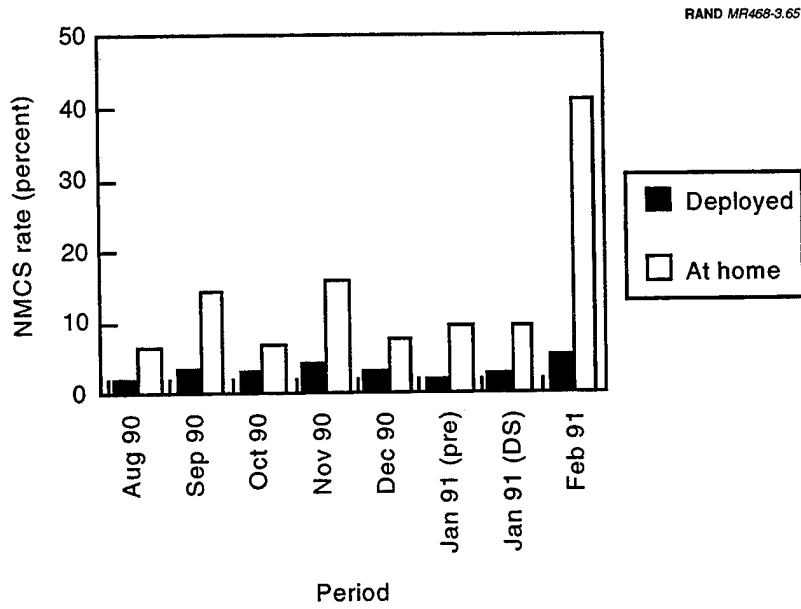


Figure 3.65—F-4G NMCS Rate

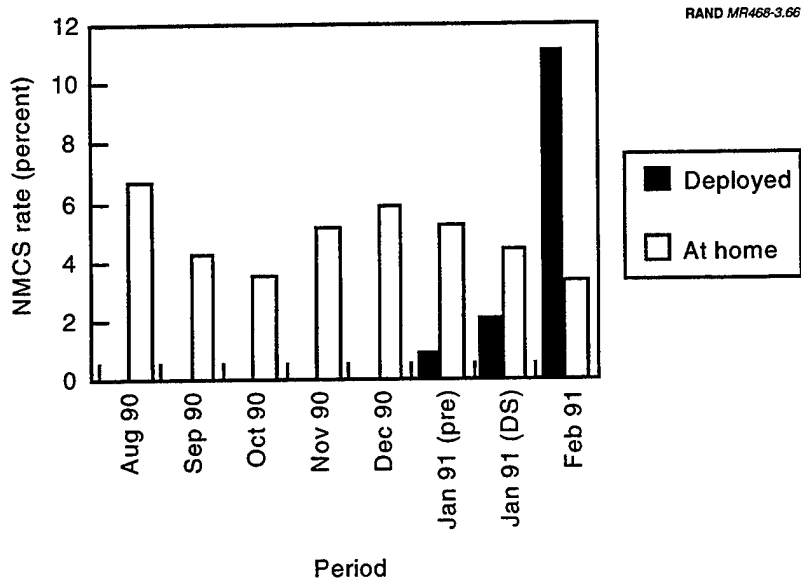


Figure 3.66—RF-4C NMCS Rate

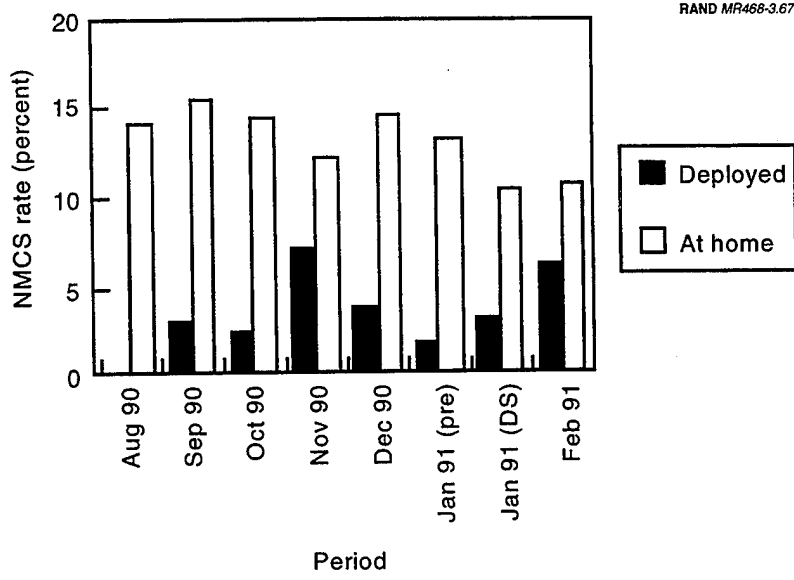


Figure 3.67—EF-111A NMCS Rate

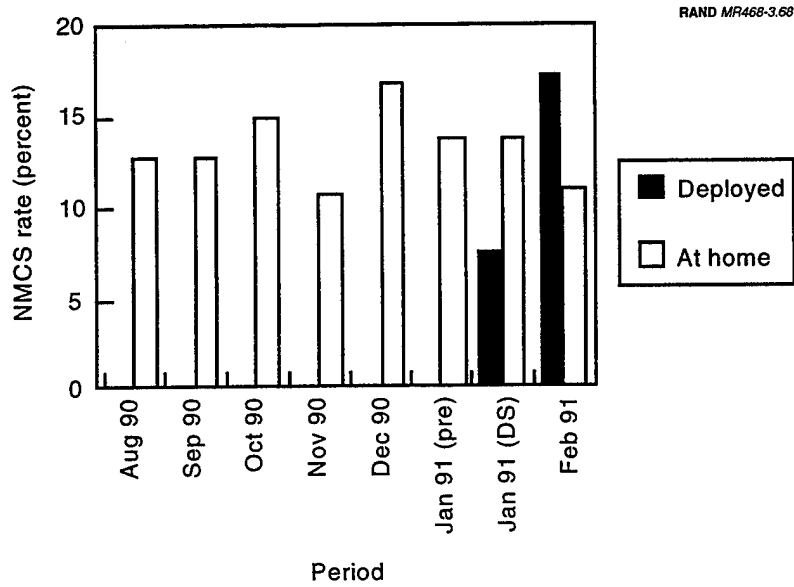


Figure 3.68—F-111E NMCS Rate

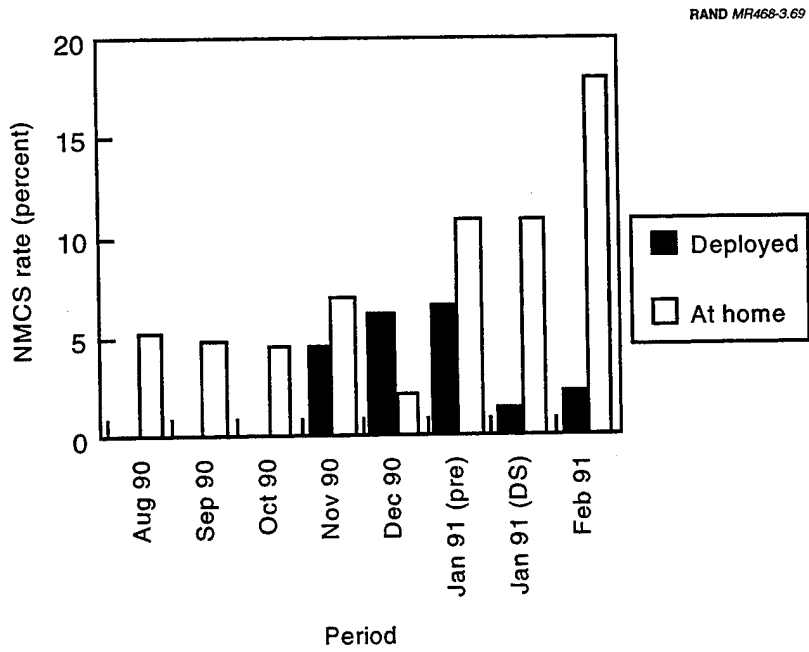


Figure 3.69—F-111F NMCS Rate

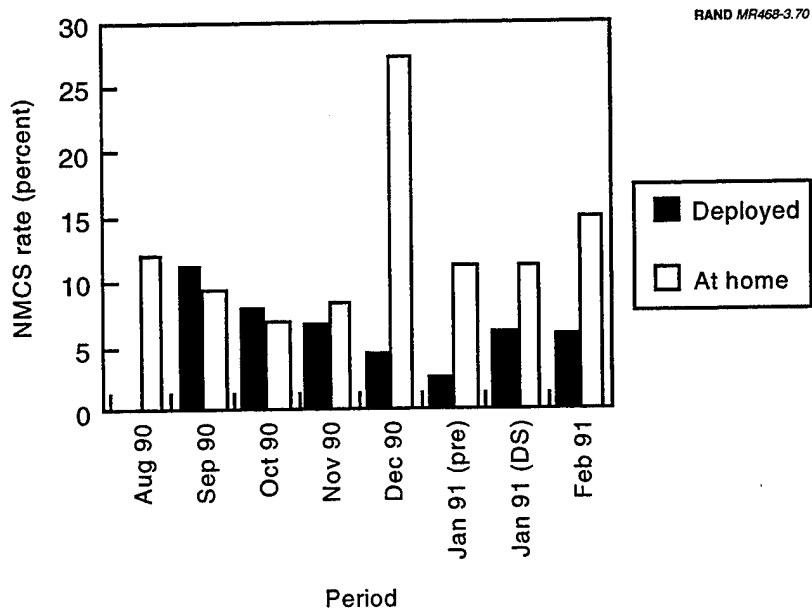


Figure 3.70—F-117A NMCS Rate

Perhaps surprising to some, supply problems did arise at the nondeployed units. In fact, many nondeployed MDS (F-15C, F-15E, F-4G, A-10, F-111E, F-111F, and F-117A) experienced higher NMCS rates in December or early January *prior to Desert Storm* than during the prior three months. To anticipate our analysis a bit, these increased NMCS rates were caused by diverting spares support to the deployed units.

### *Spares Support Evolved Through Three Stages*

Naturally, we asked how such good performance could be achieved for the deployed units, in light of a planning system that intended to provide resources to maintain only 75 percent MC rates for spares.<sup>44</sup> The component-spare-support concepts evolved rapidly through three successive stages to improve that support during the Desert Shield buildup to Desert Storm: deploying units with a self-sufficient WRSK; a theaterwide "push" priority system, including a follow-on spares kit (FOSK); and a "pull" system.<sup>45</sup> As shown in Table 3.2, those phases overlapped somewhat, but each had distinctly different characteristics. We discuss the phases and their characteristics in chronological order.

**The Self-Sufficiency Phase Was Short-Lived.** First, all deploying units except those from European bases<sup>46</sup> were deployed with a "full complement"<sup>47</sup> of

<sup>44</sup>We chose this criterion rather than peacetime MC rates because it reflects an official USAF policy statement about what MC rate is needed in wartime. Resource requirements (for spares, mainly) are computed to achieve that rate under fairly pessimistic support assumptions (e.g., no resupply and minimal component repair). Desert Storm's operating situation was less extreme, with continuous resupply, substantial deployed repair, and lateral resupply and repair at European bases. (*Lateral resupply* is an informal arrangement whereby one base draws another's serviceable stocks when its own stocks are exhausted; *lateral repair* is usually more formal, but it enables one base to use another's repair shops for selected components.)

<sup>45</sup>"Push" and "pull" are two philosophically different concepts for supporting military forces. The "push" concept assumes that a central logistics agency (or group) can independently predict future force demands by extrapolating standard consumption-rate estimates (derived from peacetime or even previous wars) to the forces and activity levels planned for the forces. The "pull" concept denies that such estimation is possible in light of wartime uncertainties, and relies on real-time requisitioning to meet the deployed units' actual, realized demands. In the past, armies (and air forces and navies) have relied rather more heavily on "push" than on "pull" in their peacetime planning and initial wartime execution, then have shifted to more "pull-oriented" techniques to expedite critical cargo as ports and transportation channels became clogged with well-intended, but unneeded, "pushed" materials. As we will see, Desert Storm continued that tradition.

<sup>46</sup>The Cold War wartime plans of many European bases called for fighting in place, so they had a smaller base-level self-sufficiency (BLSS) kit from which to draw. Where possible, they also drew on the nondeployed units' spares to create a mission support kit (MSK), but they usually could not match a WRSK in size. We use the term "WRSK" generally in this report to refer to both WRSKs and MSKs.

<sup>47</sup>Specifically, each squadron deployed with an "independent" WRSK, even when multiple squadrons were deployed to the same location from the same base. Standard deployment policy prior to Desert Shield had been to deploy the first squadron to a forward base with a large "independent" WRSK, which would theoretically support that unit for 30 days, covering even some relatively rare spares demands. That same policy would deploy the second squadron to that same location with a smaller, "dependent" WRSK, which relied on the independent WRSK to cover the rarely demanded items.

**Table 3.2**  
**Three Desert Storm Resupply Phases**

Logistics Component	Phase (dates [approx.])		
	"Self-sufficient" (Aug–Sept 1990)	"Push" (Sept–Oct 1990)	"Pull" (Oct 30–Cease Fire)
Stocks	WRSK	WRSK+FOSK	WRSK+FOSK
Resupply	MILSTRIP+ Project Code	MILSTRIP+ Project Code	Desert Express
Intermediate Repair	Some Deployed	Regional	Regional
Depot Repair	Surge	Surge	Requisition
Stock Visibility	SBSS/CSS (none beyond unit)	SBSS/CSS (Deteriorating)	CSSA
Logistics C <sup>2</sup>	MICAP, via home station	MICAP, via MAJCOM	CSSA+MAS (MICAP Asset System)

WRSK spares. Most units did not deploy more than two-thirds of their aircraft (F-15Es, F-111Fs, and F-117As were the exceptions). Because at least one squadron at most wings did not deploy, assets from its WRSKs were used to fill out the deploying units' WRSKs. Some deploying units were also able to increase their allowances for certain critical WRSK components. On many occasions, those WRSKs were filled partly by cannibalizing flyable aircraft at the nondeployed units to bring on-hand assets up to planned levels.

The WRSK is computed to achieve "satisfactory" (75 percent FMC) aircraft availability throughout 30 days of operations, after deploying to a location with limited component repair and with *no* resupply. This availability is difficult to achieve in practice because of the well-documented instabilities of demand processes, *even in peacetime*.<sup>48</sup> Because these instabilities are so severe, it is common for a few aircraft to be NMCS in peacetime, despite the double protection of peacetime operating stocks (POS) and WRSK. Thus, we and other

<sup>48</sup>See G. Crawford, *Variability in the Demands for Aircraft Spare Parts: Its Magnitude and Implications*, Santa Monica, Calif.: RAND, R-3318-AF, 1988, for a description of those instabilities. I. K. Cohen, J. B. Abell, and T. F. Lippiatt describe a management concept for a logistics system to deal with those demand variabilities, in *Coupling Logistics to Operations to Meet Uncertainty and the Threat (CLOUT): An Overview*, Santa Monica, Calif.: RAND, R-3979-AF, 1991.

observers of the demand process expected that the WRSK predictions would fall short for many components<sup>49</sup> in a real wartime operation.

The basic WRSK operational concept was to support initial wartime operations with stock and minimum deployed repair alone while instituting resupply channels and deploying additional repair capacity. Essentially, the WRSK was to cover demands that could not be met while resupply transportation was interrupted for deploying other forces.

In Desert Storm, no such cutoff from repair and resupply was anticipated, nor did one occur. By simply resupplying the units' WRSKs at normal priorities in response to normal requisitions, the supply system, theoretically, *should* have had more than enough assets to achieve at least the 75-percent-FMC rate judged adequate for an all-out NATO conflict. But the Desert Storm logistics system encountered three surprises: a fragile requisitioning system, uncertain demand rates, and increased FMC aircraft goals.

*Fragile Requisitioning System.* The demand uncertainty of component resupply was exacerbated by the unexpectedly fragile concept of operations for linking the Combat Supplies System (CSS) to the home-station Standard Base Supply System (SBSS). Specifically, the CSS was designed to deploy with the squadrons and their inventory of WRSK spares, capture supply transactions at the deployed unit, track on-hand assets, and *relay the transactions to the home-station SBSS for management reports and requisitioning.*

Unfortunately, the necessary electronic communication links initially could not be established reliably between the deployed units and their home stations. The direct communications channels via the Defense Digital Network (DDN) were not initially available in theater data communications facilities' deployment schedules. Backup data channels via standard modems on public telephone networks were not reliable, and mailed floppy disks failed because transactions arrived at the home-station SBSSs out of order and were rejected. Requisitions were not always generated to replace deployed units' assets withdrawn from their WRSKs, because the home-station SBSS's version of actual deployed-unit on-hand assets grew progressively less accurate from missing and out-of-date data.

In this phase, the availability of a reasonably reliable commercial (Saudi Arabian) telephone system, the latest secure telephone units (STU-IIIs), and FAX machines

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<sup>49</sup>Obviously, the WRSK predictions also would have exceeded the demands for many other components, if only mere statistical uncertainties were operating. As we noted earlier in this section, maintenance demands appeared to increase *across the board* for all subsystems in most MDS.

were critical to working around the CSS-SBSS interface and WRSK prediction shortfalls. Deployed units *de facto* began to rely on non-automated procedures: They telephoned their home stations and identified their critical needs. The home stations took it from there.

***Uncertain Break Rates.*** Many MDS experienced unpredicted Code 3 break rates when deployed to Desert Storm. Even in the initial few weeks of Desert Shield, many deployed units' aircraft break rates increased twofold, and those higher break rates almost certainly caused the affected units' flight-line maintenance personnel to remove and replace more components, which led to increased demands for base repair and depot resupply, and noticeable shortages in the unaugmented WRSKs.

At the end of a long pipeline, the affected units saw those shortages as a threat to their ability to maintain adequate FMC aircraft if hostilities ensued. Consequently, they intensified their requests for support from their home stations, who scoured their own bases and bases worldwide to meet the deployed units' demands. Units facing the higher demand rates had to worry whether the available WRSK assets were sufficient. In effect, their *concerns* for having adequate supplies rose.

***Increased FMC Aircraft Goals.*** At CENTAF, TAC, AFLC, and the Air Staff, concerns also arose about whether the deployed WRSK assets were sufficient to cover both a prolonged buildup and training period *and* any ensuing hostilities: How well would the deployed units face combat after drawing down their WRSKs for prehostility operations, then surging flying operations to meet the wartime operational taskings? Although continuous resupply *should* have maintained "adequate" (i.e., at least 75 percent) FMC aircraft with only the WRSK assets, logistics policymakers took actions to ensure even higher aircraft availability levels by supplementing the WRSKs with FOSKs that would constitute POS to keep WRSKs nearly full until hostilities commenced.

Follow-on operating stock kits were originally conceived as stocks to take over as deployed WRSKs in the NATO scenario were depleted after the initial 30 days of conflict. There was great concern in the NATO contingency that transportation would be unavailable initially; consequently, it was expected that the retrograde<sup>50</sup> transportation of the failed WRSK assets to depot repair would also be delayed. The original FOSK concept was to repair, assemble, and deploy the

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<sup>50</sup>Retrograde transportation of failed, but repairable, material is key to the long-term support of aircraft. Production lines for most components on modern combat aircraft have long since been mothballed or disestablished altogether. Repair of the high-tech, expensive, and scarce components is the only way to maintain high aircraft availability beyond the WRSK period.

POS left behind by the deployed units near the end of the initial 30-day period; the unserviceable WRSK items would be returned to the Air Logistics Centers (ALCs) or repaired by deploying maintenance facilities. *Thus, the original FOSK operational concept was to cover the period after the WRSK was exhausted, not to prevent drawing down the WRSK before the conflict.*

In Desert Storm, the FOSK concept was redefined to protect the WRSK. Shortly after the initial mid-August deployments, the FOSK computations were changed to estimate asset requirements to cover prehostility operations, essentially to keep the aircraft at a high FMC level at the prehostility optempo, *and save the WRSK assets as additional insurance for wartime operations.* In effect, this redefinition reflected a reevaluation of the 75-percent-FMC policy by HQ USAF, AFLC, TAC, and Strategic Air Command (SAC) policymakers, on both operations and logistics. As one participant in this policymaking commented, "They wanted all jets OR<sup>51</sup> from day one." That is, they wanted additional confidence that the deployed units could carry out their assigned missions—even more than was promised by the 75-percent-FMC goal. To increase that assurance, senior policymakers changed the declared logistics policy and put more stocks on the deployed units' shelves.

*Net Effect of the Self-Sufficiency Surprises.* Together, the three surprises increased the concerns of all logistics participants about the adequacy of aircraft-component-supplies support. Supply technicians (and wing commanders) became increasingly concerned about getting replacement spare parts through the fragile requisitioning system; units facing higher demand rates became concerned about the adequacy of the WRSK to meet its stated goal; and higher headquarters became concerned about whether the stated goal would meet the operational needs. While different participants saw different problems, they all agreed on the solution: "More is better." Hence, they began, in various ways, to *push* assets to the theater, as when they pushed FOSKs.

**The "Push" Phase Was Frustrated by Priority Conflicts.** In the second phase, starting as early as mid-September 1990 and extending through October, additional resources were "pushed" to the deployed units through the same air transportation system used for all Central Command (CENTCOM) cargo. As a result, the high-priority parts were forced to compete for airlift with other USAF and other services' high-priority material, both deploying and resupply. Three management concepts dominated this phase: depot surge, "pushing" spares into the theater, and expediting "all" cargo to the theater.

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<sup>51</sup>Operationally ready; archaic equivalent of mission capable.



*Depot Surge.* Immediately after the first units began to deploy in Operation Desert Shield, the USAF Air Logistics Centers surged<sup>52</sup> their depot repair shops, both organic and contractor: Overtime and multiple-shift operations were initially authorized to backfill the POS and WRSKs of stateside units with some 90,000 assets<sup>53</sup> that had been used to fill deploying squadrons' WRSKs and to fill the newly authorized FOSKs. After this initial surge, the depots produced some 60,000 parts per month throughout Desert Storm.

To guide their repairs, the depots used a variety of methods for predicting demands for repaired components from Desert Storm units. WRSK backfill requisitions from the deployed units depended on WRSK calculations that were based on peacetime experience. That experience was one year old when the calculations were made and certainly did not reflect Desert Storm demands. Requisitions from the nondeployed units were based on local predictions of peacetime flying needs and the same WRSK calculations for the squadrons left behind. FOSKs were calculated centrally, then sent to the ALCs as additive requirements to be filled immediately.<sup>54</sup> In addition, AFLC identified still other "potential problem parts" for the deployed units, using its Weapon System Management Information System. Finally, each Air Logistics Center convened surge committees drawn from the ALC senior staffs, who used their own experience and technical expertise to project likely force needs.

In the end, no prediction technique sufficed. Traditional extrapolations from peacetime missed the all-important changes in aircraft break rates; even the surge committees, with their more sophisticated understanding of the technical issues, missed important changes in tactics and other operational factors that affected demands.<sup>55</sup>

Regardless of the prediction method, the net result was that additional acquisition, production, repair, and distribution actions were directed and

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<sup>52</sup>ALCs purposely design their repair shops with reserve capacity for wartime. Thus, most shops work only a nominal 40-hour week, and the residual capacity is held back so that the shops can "surge" their production output in time of war.

<sup>53</sup>The support activities of the Air Force Logistics Command have been documented more fully by Michael Self and Edward Kozlowski in *Air Force Logistics Command Operations in Desert Storm*, Wright-Patterson AFB, Ohio: AFLC, July 1991.

<sup>54</sup>Unlike the original FOSK concept, which used the deployed unit's peacetime operating stock as an asset base to be rounded out for deployment, the Desert Storm FOSK concept did not require collecting the POS that was left behind. Thus, AFLC filled the FOSK requisitions from repairable backlogs and normal repair operations.

<sup>55</sup>Here, the best example of experts' inability to predict demands is that the widely anticipated surge in F100 jet engine demands from desert operations never occurred. Prior engineering design changes combined with altered low-level tactics to substantially eliminate the expected failure increase. In contrast, unpredicted surges were experienced for critical weapon-delivery components and inertial navigation systems. (See the discussion of F-117 Code 3 aircraft breaks earlier in this section.)

expected. One senior logistician who participated in this strategy said, "We just surged . . . everything, betting on the come [the "come" line in craps]."

*"Pushing" Spares into the Theater.* Once the FOSKs were computed according to the redesigned operational concept, those FOSK levels were assigned to the overseas units to supplement their WRSKs. As units automatically generated requisitions against those new, increased levels, they placed additional demands for stock on the ALC warehouses and shops and on the overseas transportation system. Importantly, those demands were met in part by sending items that otherwise would have backfilled nondeployed units' WRSKs. *Regardless, those stocks were essentially pushed to the deployed units as additional assets that they would probably need, based on the best estimates available in CONUS.*

*Expediting All Cargo.* Meanwhile, the deployed units, working through their home stations, continued to requisition the critical parts that threatened to affect aircraft operations. As the home stations drew down their asset levels, they in turn requisitioned replacement assets from the AFLC wholesale depots, sometimes at high priorities when nondeployed aircraft were downed. Meanwhile, the critical parts were packed and shipped to the theater units at the highest possible priority.

*Everything destined for Desert Shield units in this phase was shipped at the highest possible priority. Thus, nothing had priority.*

All Desert Shield units were given a force activity designator (FAD) of 2,<sup>56</sup> which denotes units deployed to a combat theater with the potential for immediate engagement. Thus, their requisitions, when received at AFLC or the Defense Logistics Agency (DLA), were accorded especially high priority. Further, their shipments, arriving at any air-, land-, or seaport, were accorded first access to departing transportation that would move them closer to their final destination.

Dissatisfied with that mechanism alone, the Joint Chiefs of Staff (JCS) also directed that all Desert Storm units be given a special project code, 9BU, to further enhance the priority that would be accorded their requisitions and transportation needs. With that designation, their requests had higher priority than those of all other overseas units in Europe and the Pacific.

In addition, many of the units' requisitions were coded with the special priority designation "999," indicating an urgent need that affects the units' immediate wartime capability.

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<sup>56</sup>A FAD of 1, the highest level, is reserved for a few especially critical units, generally with special national command-and-control missions. Other peacetime units' FADs range from 3 to 5.

When the deployed units' critical parts from the nondeployed forces arrived at ports of embarkation<sup>57</sup> (POE) or debarkation<sup>58</sup> (POD), they waited with all the other equally high-priority cargo that had arrived earlier. The relatively low-volume, highly important spares that kept aircraft in NMCS status were delayed by other high-priority (but high-volume) cargo, including FOSKs and other administratively designated high-priority material that *no unit in theater had designated critical*.<sup>59</sup>

To gain a measure of control over critical material flows, CENTAF established CENTAF REAR<sup>60</sup> at Langley AFB, Va., near the end of the "push" phase, and that organization undertook (among other things) to ensure that the requisitions from the theater were coordinated. Thus, they established a single point to coordinate TAC bases' responses to events that reduce units' MICAP events, and they instituted procedures with CENTAF FORWARD, in Saudi Arabia, to ensure that deployed units first tried to satisfy their MICAP events through intra-theater lateral resupply before calling on CONUS bases. Together, these management activities increased asset movement efficiency, tracked MICAPs, and ensured MICAP resolution.

About the same time, AFLC developed its Air Force Logistics Information File, or AFLIF. This data system exploited existing data transactions to track the in-transit serviceable aircraft components and other critical material. Using this information, AFLC decisionmakers could locate critical cargo, inform units of its location, and intercede occasionally to expedite particularly critical cargo.

**The "Pull" Phase Improved Resupply Responsiveness.** On October 30, 1990, Desert Express operations commenced. Desert Express provided near-overnight service for service-designated critical cargo from CONUS (Charleston AFB) to the theater airport of debarkation (Dhahran AB) via a daily C-141 flight. Overall, it reduced the requisition-to-receipt for critical (MICAP) items from 10 to 4 days.

That limited special channel could have been choked as well with too much expedited cargo, but each service managed its allotment carefully, ensuring that

<sup>57</sup>Generally, Charleston AFB, S.C., or Dover AFB, Del., were the POEs for air-qualified cargo during Desert Storm.

<sup>58</sup>With few exceptions, Dhahran, Saudi Arabia, was the single POD for air cargo in Desert Storm.

<sup>59</sup>The subsequent delays for high-priority assets may have actually exacerbated the queueing problem, because units issued multiple requisitions for items they believed "lost," and because the poor visibility of the "in-transit" pipeline caused AFLC item managers to believe the same.

<sup>60</sup>Formally, CENTAF was the air component commander tasked with coordinating all air operations and support in Desert Storm. As a practical matter, his logistics staff was located in two places: CENTAF FORWARD, in Saudi Arabia, and CENTAF REAR, at Langley AFB, Va. The CENTAF FORWARD logistics staff focused on intra-theater logistics; CENTAF REAR coordinated support from CONUS.

only the most critical cargo—as identified by in-theater MICAPs and in-theater priority designations—was sent to the Desert Express POE.<sup>61</sup> In addition, the in-theater logistics decisionmakers flexibly renegotiated their shares of Desert Express as their relative needs fluctuated. Thus, the concept shifted from a push system, whereby material needs were estimated centrally, to a pull system, which monitored actual requisitions and priorities from units.

Shortly after implementing the Desert Express system, CENTAF also instituted an intra-theater system (Camel routes) to transport critical cargo (especially from Desert Express) from Dhahran to the bases and between bases. This system was critical in making lateral resupply effective in theater and in ensuring the onward movement of Desert Express cargo to its ultimate destination.

In November, CENTAF REAR brought the new CENTAF Supplies Support Activity (CSSA) on-line. The CSSA provided SBSS services from a single computer at Langley AFB, a theater MICAP control center, and the MICAP Asset System (MAS) to support all deployed units via satellite. With that capability, theater-supply activities could at last requisition directly from AFLC depots. As important, they could quickly look into other theater units' asset files and identify potential lateral-supply opportunities.

Together, CSSA, the Camel routes, and Desert Express increased the visibility of critical theater needs, increased visibility of potential ways to meet those needs (especially lateral resupply), and moved assets quickly to rebalance supplies in light of the latest base demands.

In related developments, both the Military Airlift Command (MAC) and CENTAF set up rearward repair facilities at European bases. MAC's support from Rhein-Main AB, Germany, focused on C-130 engines, avionics, and propeller repair; USAFE used its other bases in Germany and England to repair engines, engine modules, and some F-111F avionics. MAC used a formal repair prioritization and distribution model (TRADES), whose input of detailed base asset counts, consumption rates, and forecast flying programs was used to prioritize distribution of serviceable components. USAFE managed the engine module repair and distribution manually. Both methods provided satisfactory results, as reported by their customers. Again, both relied on adequate visibility, rapid distribution, and rapid redistribution in theater. Special transportation channels were set up to ensure that the repaired products were delivered quickly to the deployed forces.

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<sup>61</sup>To expedite similar cargo, AFLIF, with its visibility of the entire forward pipeline, helped in identifying critical cargo already en route.

Some units were not so well served by standard management systems applied across all aircraft. European units, in particular, sometimes found it difficult to get special support from their own home stations, because CENTAF REAR (in CONUS) was so remote from Europe. For example, intermediate shop equipment for the F-111F avionics is unique, and some repair capabilities existed only at RAF Lakenheath, United Kingdom. CENTAF REAR was able to provide no special support that could not be arranged more efficiently between the deployed unit and its home station. In some instances, the deployed unit was able to arrange informally for direct asset movements to and from home station via a VC-10 cargo plane serving deployed British forces.

The shift to a high-speed pull system for aircraft components brought to a close a period of rapid change and innovation in the Desert Storm logistics system. With rapid CONUS-to-theater and intra-theater transportation, and a critical parts-management system in place (at least for NMCS aircraft and WRSK replenishments), the USAF operated that system for the remainder of the war, with only minor refinements. Critical material could at last be moved from CONUS to a unit needing it in only a few days.

But where was that material obtained, and was it sufficient? Clearly, a great deal was obtained from the standard depot repair and resupply channels. On the other hand, if those channels had been sufficient, the CSSA and Desert Express would have been redundant. As much as the ALCs surged their depot repair, they could not respond quickly enough to satisfy the most-critical, time-urgent needs of the deployed units.

To meet the most-critical, time-urgent needs of the deployed forces, the CSSA resorted to drawing down nondeployed units' WRSKs and even to cannibalizing parts from nondeployed units. In essence, the CSSA would select the nondeployed unit most able to release a needed part to a Desert Storm unit, then would direct that unit to take the necessary action via a Desert Express shipment.

As one might imagine, the nondeployed unit had a strong preference for keeping as many of its aircraft MC as possible, so its preferred action was to withdraw the needed asset from its own WRSK, rather than cannibalizing it from an aircraft. Thus, increased cannibalizations would be a last resort from the unit's perspective.

Yet we found that many nondeployed units had increased their cannibalization rate just before or during Desert Storm—indicating that they had already withdrawn all available assets from their POS and WRSK, and that they had no choice but to remove them from aircraft.

### ***Cannibalization of Nondeployed Forces Enhanced Desert Storm NMCS Rates***

As Desert Storm approached, cannibalization rates at most nondeployed units increased (Figures 3.71 through 3.79). Assets were cannibalized from those units' aircraft to ensure that the deployed units' WRSKs were full prior to Desert Storm. (Only the A-10 and the F-4G nondeployed units' cannibalization rates did not increase from November to early January.)

As important, those diversions also diminished the need for the theater bases to cannibalize aircraft, thereby increasing the efficiency of unscheduled maintenance at the flight line. As cannibalizations increased at home stations, they diminished in theater.

We were told by nondeployed maintenance personnel from several units that they "often" cannibalized home-station aircraft so that an asset could help fill a theater WRSK and preempt creation of a potential NMCS aircraft during the December-to-February period. The simultaneous drop in in-theater cannibalizations over this period would be consistent with such a preemptive action.

As important, we observed that some A-10 WRSKs were nearly as full at the war's end as at the beginning (75 percent versus 85 percent). This observation further supports the conclusion that assets were diverted to fill deployed units' shelves, even if doing so meant creating additional holes in home-station aircraft.

### ***The Supply Problems of Small Aircraft Fleets Were Never Fully Resolved***

Despite the support from the nondeployed forces, several Desert Storm units constituted nearly all the worldwide fleets for some MDS (F-15E, F-4G, RF-4C, F-111F, and F-117A). Those units reported that they had special difficulties, even with the advent of CSSA and Desert Express. In some cases, they had to compromise the performance of nondeployed forces; in others, they had to draw on extraordinary support measures.

The F-15E was just being introduced into the fleet when Desert Shield commenced, so it had less than a full wing of aircraft and only initial spares levels (ISLs) for support of additional replacements. Once those spares were gone, the only sources were the few aircraft left at home station and in depot repair. Cannibalization rates at home station soared to over 100 percent per

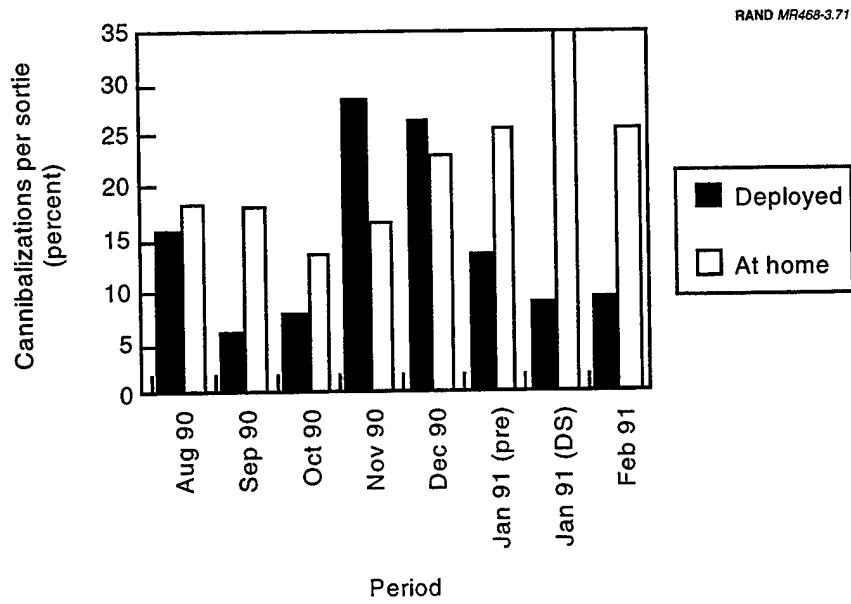


Figure 3.71—F-15C Cannibalization Rate

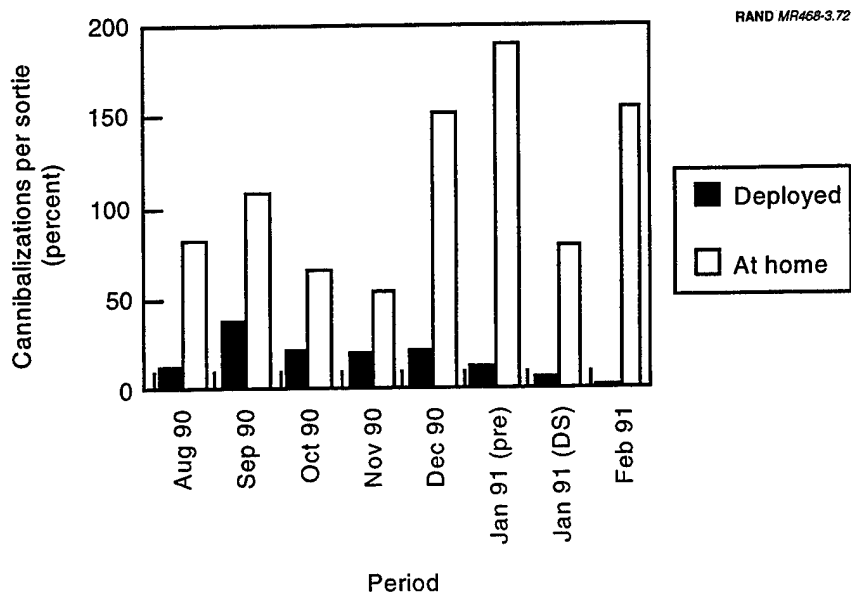


Figure 3.72—F-15E Cannibalization Rate

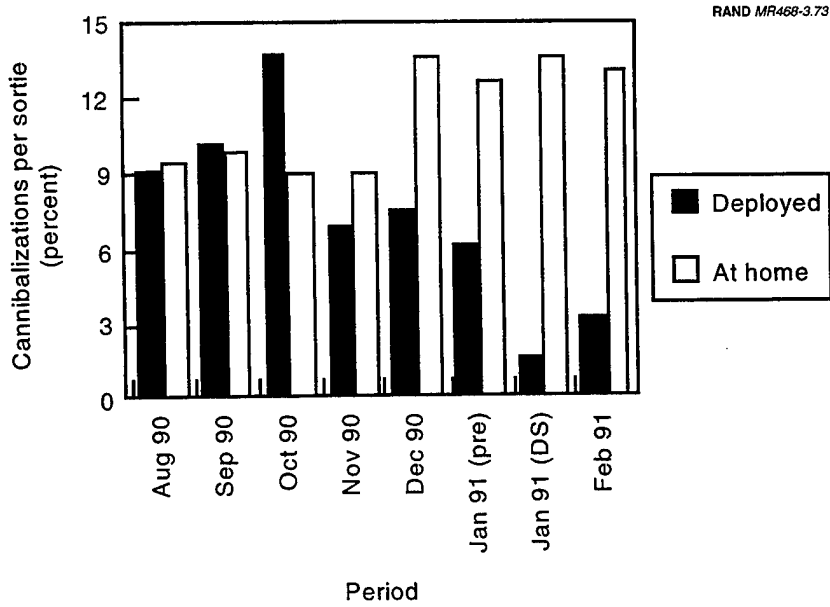


Figure 3.73—F-16C Cannibalization Rate

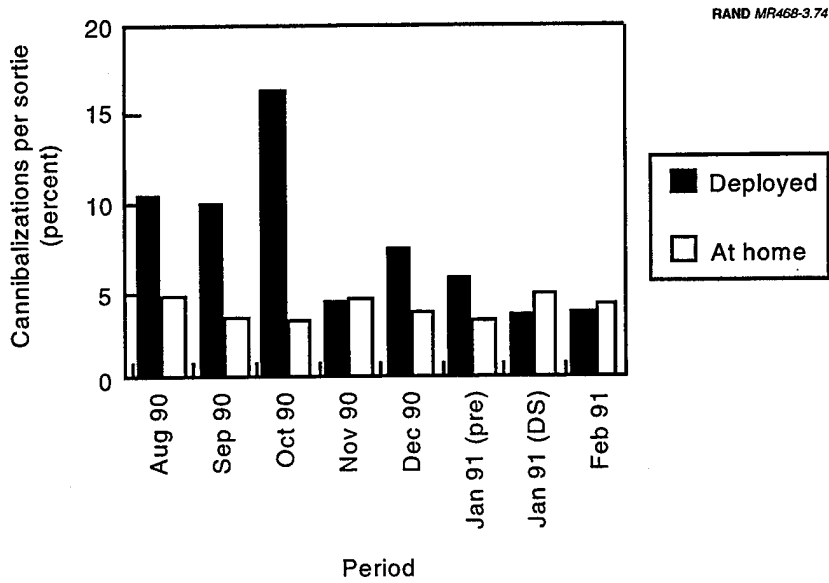


Figure 3.74—A-10 Cannibalization Rate



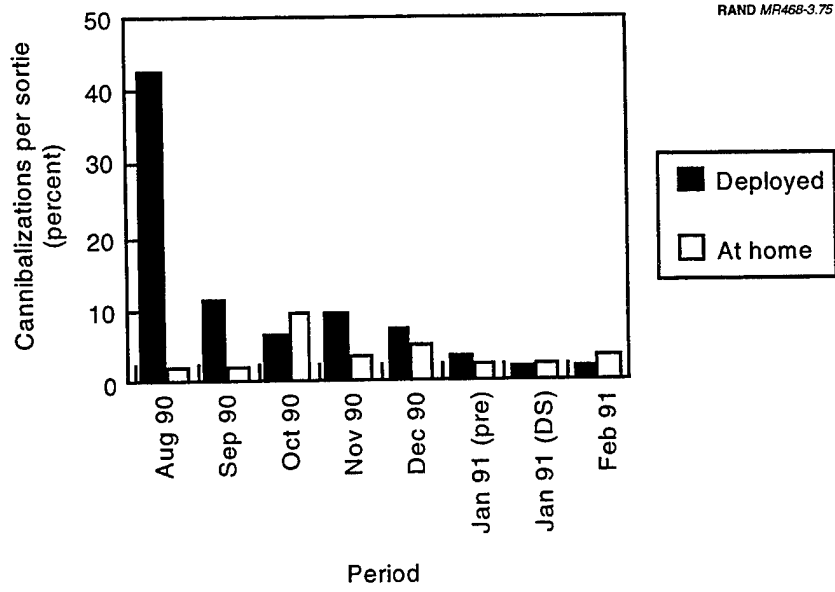


Figure 3.75—F-4G Cannibalization Rate

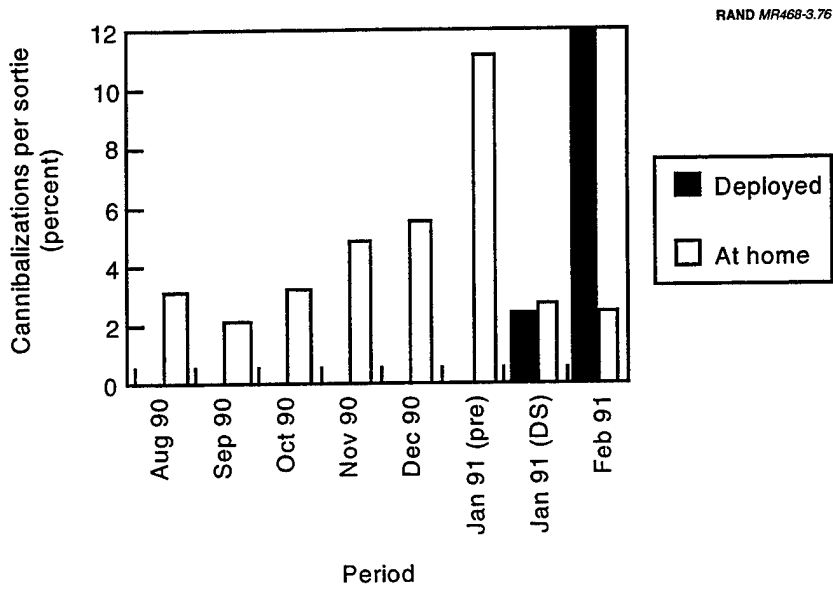


Figure 3.76—RF-4C Cannibalization Rate

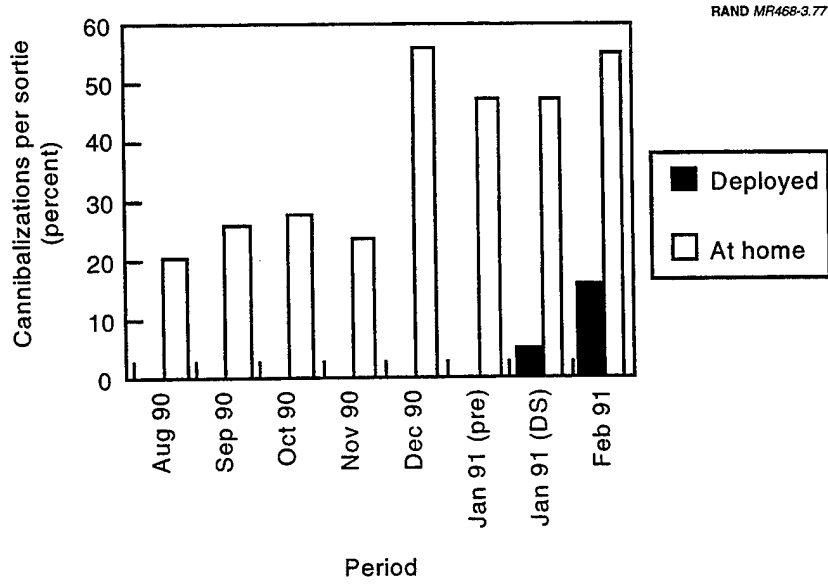


Figure 3.77—F-111E Cannibalization Rate

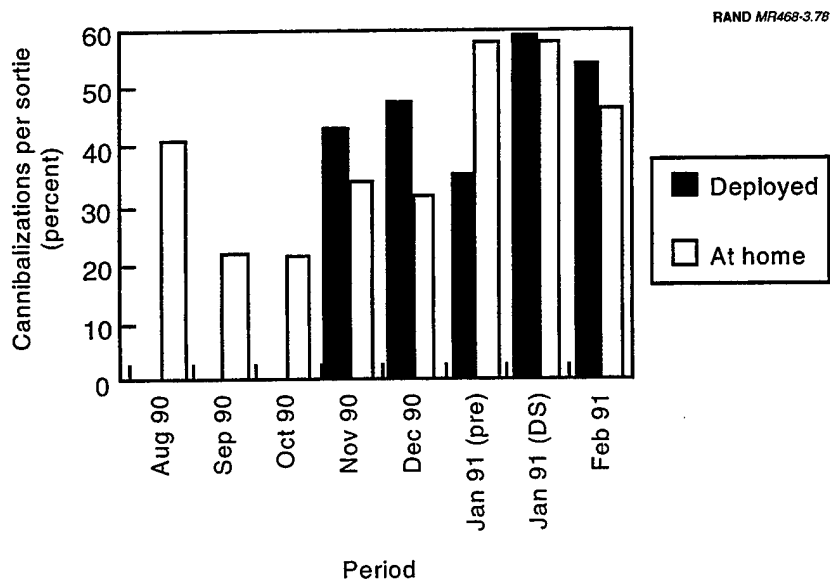


Figure 3.78—F-111F Cannibalization Rate

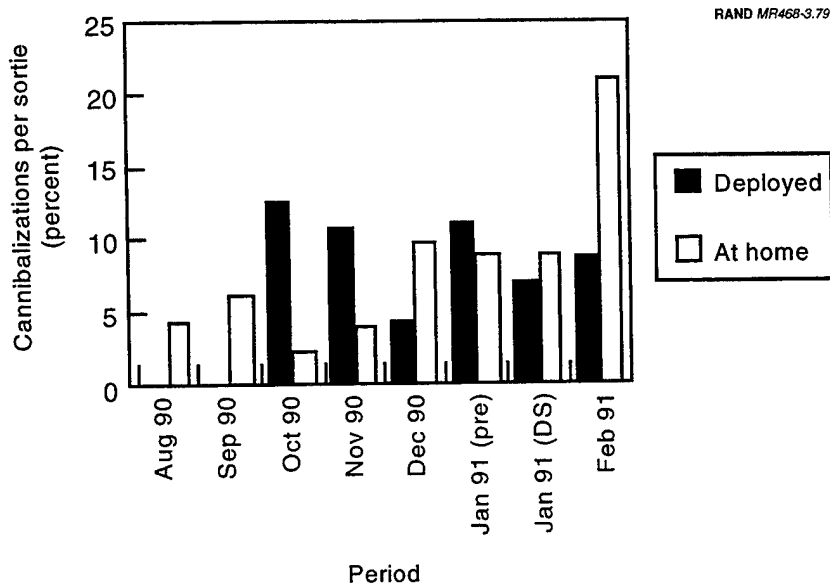


Figure 3.79—F-117A Cannibalization Rate

sortie from December through February (see Figure 3.72), and home-station NMCS rates doubled.

Many senior logisticians familiar with supporting new aircraft have attributed those difficulties to the relatively immature state of the aircraft and its logistics processes. Although those factors may have contributed, the small fleet size also limited the ability of the deployed unit to draw more heavily on the nondeployed unit without cannibalization.

If immaturity were the sole cause, the F-111F should have had no support problems. The F-111F was a relatively old aircraft design, with a reputation for being especially difficult to maintain at high MC rates. In Desert Storm, some high-failure-rate components could not be obtained anywhere but in the deployed unit, from the handful of aircraft left at home station, or from depot repair. Cannibalization rates increased in both deployed and nondeployed units from November through February (see Figure 3.78), and NMCS rates at home station quadrupled in February.

Clearly, the difficulties experienced by the F-111F were not due to its recent introduction into the fleet nor to the incomplete acquisition of initial spare parts. While its reputation as a maintenance nightmare may be deserved, those base-level maintenance difficulties would appear in NMCM rates throughout Desert

Storm and the prehostility buildup (see Figure 3.49),<sup>62</sup> not in NMCS at the end of the conflict. Something besides youth or old age caused the parts shortfall; again, we suspect the small fleet size.

The F-117A, with its initial operational capability in 1983, was neither new nor old, but its supporters met their in-theater needs mainly by cannibalizing heavily from the few nondeployed aircraft at home station and by drawing on depot (including contractor) repair. They had the added advantage that all their components were classified, so a courier was required to escort them.<sup>63</sup> Home-station NMCS rates soared in December, apparently owing to cannibalization of the handful of nondeployed F-117As in anticipation of Desert Storm action (see Figure 3.79). More important, those rates crept up again in February as more and more home-station aircraft were cannibalized to meet critical theater needs.

All three aircraft, new, old, and in between, had difficulties achieving low Desert Storm NMCS rates without affecting home-station NMCS rates.<sup>64</sup> What if there had been no nondeployed forces for the other seven aircraft?

## **An Assessment of Fighter Aircraft Support**

By all measures, overall support to Desert Storm units exceeded all expectations. Despite incredible increases in both aircrew-reported discrepancies and scheduled-maintenance workloads, MC aircraft rates hardly diminished. Both improved base-level-maintenance efficiencies and enhanced supply support contributed to sustaining those rates.

Nevertheless, the events in Desert Storm raise several questions for a future, smaller force. Such a force may find it much more difficult to draw on the assets of the nondeployed forces in a major contingency, as they did in Desert Storm. If nearly all the force is deployed and the remainder cannot divert assets from WRSKs or cannibalize from nondeployed aircraft, it will be difficult to maintain NMCS rates like those seen in Desert Storm.

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<sup>62</sup>F-111F NMCM rates also increased substantially.

<sup>63</sup>In the military transportation system, cargo escorted by a courier is accorded the highest possible priority. Even before Desert Express, such cargo moved quickly worldwide. The relatively rapid depot repair and delivery consequently cleared many NMCS incidents more quickly. Even so, the pressures built up until the home-station cannibalization rates quadrupled in February.

<sup>64</sup>Similar NMCS and cannibalization-rate stress patterns were observed for the F-4G and RF-4C aircraft. Inventories of those aircraft were more plentiful than the F-15E, F-111F, and F-117A, but they were far less plentiful than the F-15C, F-16C, and A-10s. NMCS rates for the more plentiful aircraft increased at home station, but they did not double or quadruple at any time during Desert Shield or Desert Storm.

A similar downsizing problem may arise with maintenance personnel and equipment, as well. If most of the force must deploy, the force may not be able to deploy only highly skilled 5-level technicians. Productivity rates may not surge, training and administrative workloads may not diminish, and the maintenance efficiencies supported by a supply-rich environment may not arise. In addition, the easy redeployment of maintenance equipment or material from a nondeployed unit will be difficult to arrange if most units are deployed, or if most of the serviceable equipment is deployed in the initial deployment.

On the brighter side, some concepts long advocated by the Wartime Logistics Concept of Operations<sup>65</sup> were operationalized during Desert Storm. Specifically, a new logistics command-and-control center (CSSA), enhanced priority intra-theater transportation (Camel routes), and enhanced inter-theater transportation (Desert Express) were developed and used with great success. These enhancements, coupled with a responsive rearward regional repair system such as the MAC facility at Rhein-Main AB, the USAFE facilities at Hahn AB, Germany, and Bitburg AB, Germany, and the SAC facility at Andersen AFB, Guam, enable us to imagine a wartime component support system that compensates for the lack of substantial nondeployed forces and excess assets by exploiting rearward repair, including more-responsive depot repair, to the maximum extent possible.

It is clear that deployed units and senior USAF policymakers were not satisfied with standard, pre-Desert Shield, resupply system performance. Consequently, many innovations were hastily introduced. One challenge for the support system is to institute as many effective innovations from Desert Storm in peacetime as possible so that they need not be reinvented during the next contingency.

Finally, deploying large quantities of spares may have been both ineffective and wasteful, because many critical needs were met through logistics command-and-control actions and large fractions of the surged, "pushed" assets were "still on the shelf" when the conflict concluded. The balance among all the resource elements of the support system needs review.

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<sup>65</sup>The USAF Wartime Logistics Concept of Operations advocates greater reliance on intra-theater transportation, inter-theater transportation, lateral resupply, lateral repair, host-nation support, depot resupply, and logistics command and control in lieu of purely self-sufficient operations.

## 4. Desert Storm Electronic Countermeasures and LANTIRN Support

Mirroring the support for aircraft components, the ECM and LANTIRN support concepts and processes encountered special problems because of the lack of opportunities to test and use this equipment prior to the war. Both systems had insufficient information about failure rates and an unrealistic spare equipment policy.

Nonetheless, logistics command and control, support from nondeployed units, and special ECM support teams played key roles in achieving the performance seen during the war. First, we discuss ECM support, then we turn to LANTIRN support.<sup>1</sup>

### Limited Peacetime Use of ECM Systems Hid Potential Support Problems

Aircraft ECM systems are used primarily to defeat an enemy's radar-directed surface-to-air missile (SAM), airborne interceptor (AI), and anti-aircraft artillery (AAA) attacks. In most systems, an external pod is mounted on the aircraft and interfaces with equipment in the cockpit. The F-15 has an integral onboard ECM system and does not use external pods. The pods provide automatic jamming of guidance or other signals. In this study we were able to obtain only data about ECM pod performance.

Obviously, most peacetime training sorties do not experience radar-directed attacks. Likewise, attacks are rarely even simulated, partly because of security concerns (exposing knowledge of the enemy's frequencies, encoding techniques, etc.) and limited ECM range availability. Further, the personnel, equipment, and facilities needed to simulate enemy electronic activities and evaluate the aircrew and aircraft responses are very expensive and scarce. Thus, there is little peacetime opportunity to test ECM equipment in a full-scale simulated operational environment.

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<sup>1</sup>Data on electronic warfare (EW) and LANTIRN pod support activities are even more sporadic than data on aircraft support. Thus, we can present data only for selected units or selected snapshots in time.

### *ECM Test Teams In Theater Detected Problems and Helped Keep ECM Pods Operational*

To test ECM in wartime, one innovation, roving "ramp check"<sup>2</sup> teams, increased ECM mission capability in Desert Shield and Desert Storm. These teams were instituted by TAC after the mid-1980s Coronet Warrior exercises<sup>3</sup> revealed significant problems in maintaining operational pods in exercises. During Desert Shield and Desert Storm, they were expanded from two to five teams, and they provided a portable, periodic test of ECM pod operability at all units in theater. The visiting teams could detect and correct a wide range of pod failures that might have made the aircraft more vulnerable to radar-guided engagements.

A comparison of the pre- and postcontingency ramp test pod failure rates (Figure 4.1) indicates that fewer pods responded correctly to test stimuli on the first test after deployment than later in the war.

We conclude from this observation that many fewer pods would have been operational during Desert Storm if the ECM ramp teams had not deployed. By visiting each unit frequently, the teams were able to catch developing problems often enough that only a relatively few pods had degraded in the meantime. Thus, their visits reduced the probability that an aircraft would be shot down because the ECM system did not work.

### *Some Operational Failures Probably Went Undetected*

Those ground tests of the pods could not detect failures that occurred when aircraft maneuvered in combat at high altitude; however, they screened out pods whose failure modes were less situation-dependent. Experience in the Coronet Warrior exercises indicated that as many as 30 percent of ECM pod failures are not detectable on the ground, because this extremely complex, densely packaged, delicate, state-of-the-art equipment is quite sensitive to the effects of vibration, high-g maneuvering, extreme cold, and atmospheric-pressure changes likely to occur on a typical combat sortie. Not only do these factors induce stresses that may cause subsequent failures,<sup>4</sup> but they induce *temporary* changes in the equipment operating characteristics that occur only during sortie operations.

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<sup>2</sup>These teams were so called because they would check the ECM pods on the ramp or flight line while the pods were installed in the aircraft. As a consequence, the teams could perform end-to-end tests to verify the correct radiated response to the test stimulus.

<sup>3</sup>Among other things, the Coronet Warrior exercises sought to assess and improve the operability of ECM equipment. Procedures developed and demonstrated during those exercises provided the basis for the Desert Storm ECM support.

<sup>4</sup>Wiring shorts that may damage a complex component are an example. Such "hard" failures would likely be detectable during a subsequent ramp check.

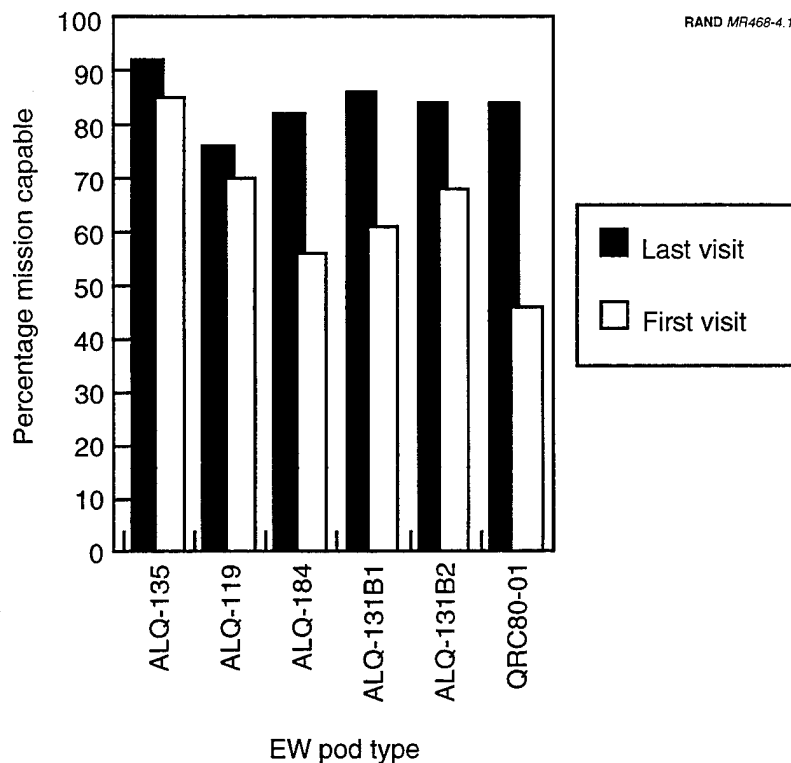


Figure 4.1—Improvement in ECM Pod MC Rates

Ground checks such as the ramp tests simply cannot reproduce the more stressful operating environment.

Only an ECM range can test for such intermittent, environmentally induced failures. An in-theater ECM test range like that implemented for the B-52s at Diego Garcia would probably have screened out additional failed pods. Unfortunately, most ECM pods carry only a single setting, which may require as long as 8 hours to reprogram<sup>5</sup> and prevents testing the pod's operation at altitude without jeopardizing operational security, unless the wing and higher headquarters are willing to have many aircraft NMCM for pod reprogramming. If security problems could have been resolved, a test range would undoubtedly have further reduced the vulnerability of deployed aircraft in Desert Storm by detecting additional failures in flight.

<sup>5</sup>The ALQ-131 Block 2 pods support dual-mode operation: combat and training. The pilot can switch modes in the cockpit, enabling a less classified, but still comprehensive, equipment test in the air. (Obviously, such a test could not verify that the combat mode was properly programmed.) This new, and quite expensive, pod was available to only a few units in Desert Storm.



### *Reported Failures Exceeded Bases' Repair Capacities*

Even though many ECM pod failures probably went unrecognized, the reported ECM pod failures far exceeded the bases' repair capacities. When combat operations commenced, few units recorded and reported their ECM pod availabilities daily, as they did aircraft availability. However, the experience of the 169TFG, shown in Figure 4.2, seems to typify many units' experiences. For the first two weeks of the war, their ECM pods steadily made the transition from MC to NMCM status, until nearly half (13 of 28) of their pods were in repair or, more likely, were waiting for the repair of other pods. Clearly, pods were failing faster than the units' ECM shops could repair them.

To some degree, the growing backlog of ECM pods was induced by the very long repair times for individual pods. With single-pass computerized test times ranging up to 18 hours, it was not uncommon for a single pod to require several days of hands-on repair time to detect, diagnose, repair, and retest a pod with multiple internal failures. While one pod was in repair, the test equipment was fully utilized, so other pods had to wait their turns. As soon as demands occurred more frequently than repairs could be completed, a backlog of NMCM pods would first appear, then grow. Apparently, the 169TFG experienced that growth early in Desert Storm.

And they were not alone. By January 30, 1991, more units began to record and report their ECM pod status daily. As shown in Figure 4.3, the F-4G and RF-4C

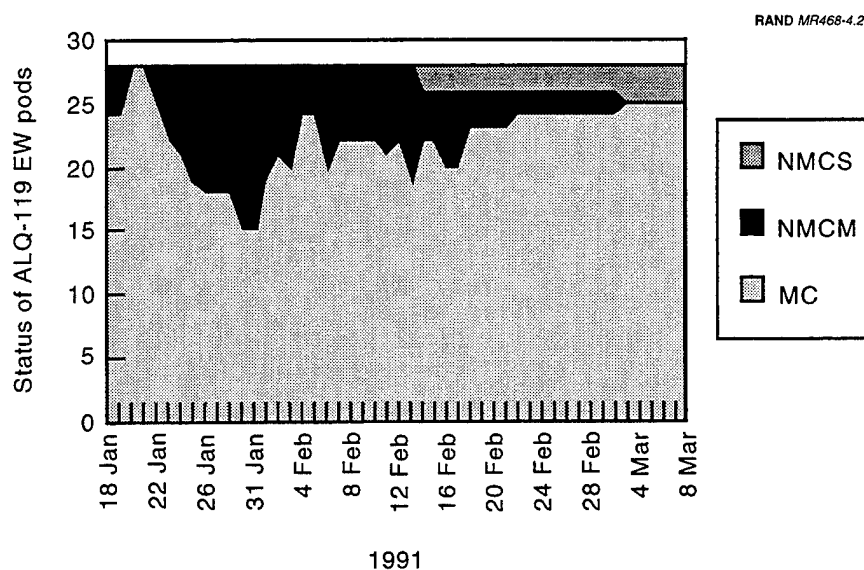


Figure 4.2—Status of 169TFG (ALQ-119) ECM Pods in Desert Storm

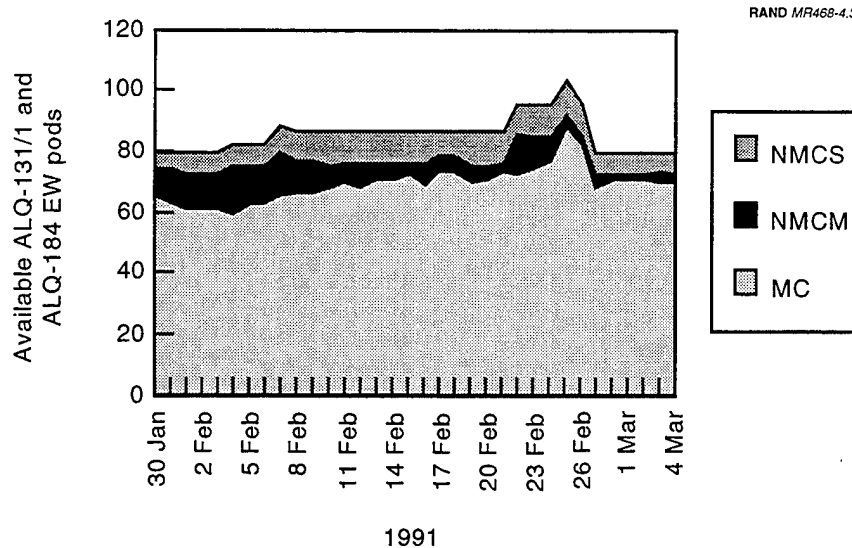


Figure 4.3—F-4 Aircraft (ALQ-131 Block 1 and ALQ-184) ECM Pod Status in Desert Storm

aircraft in theater did not experience the extremely high NMCM ECM pod rates experienced by the 169TFG, but they had only 60 mission-capable pods for their 78 aircraft during portions of the initial peak flying period of the war. As shown in the figure, they could not reduce the NMCM and NMCS pods below some level, so they did the next best thing: They obtained more pods. (Note how the total number of pods continues to grow until near the end of February.)

They were not alone. With only one pod per aircraft and with concerns for sending aircraft without operational pods into the potentially intense SAM environment over Iraq and Kuwait, all units apparently encountered problems with ECM pods. By February 1, theaterwide ECM pod mission-capability rates were approaching seriously low levels, as shown in the first two bars for each pod in Figure 4.4. To remedy this situation, additional pods were deployed, as shown by the third bar for each pod.

Thus, the ECM systems' limited peacetime use obscured potential supportability problems. Seldom having engaged pods in full-scale use, the forces discovered that it was not possible to provide adequate ECM pod support without acquiring additional pods or additional maintenance capacity. Although the specific channels for acquiring additional ECM pods varied, the net effect was the same: Assets at nondeployed units were reduced. In one extreme case, a squadron left at home station had only four operational ECM pods by the end of Desert Storm. Its other pods had been deployed to the theater. As with many aircraft

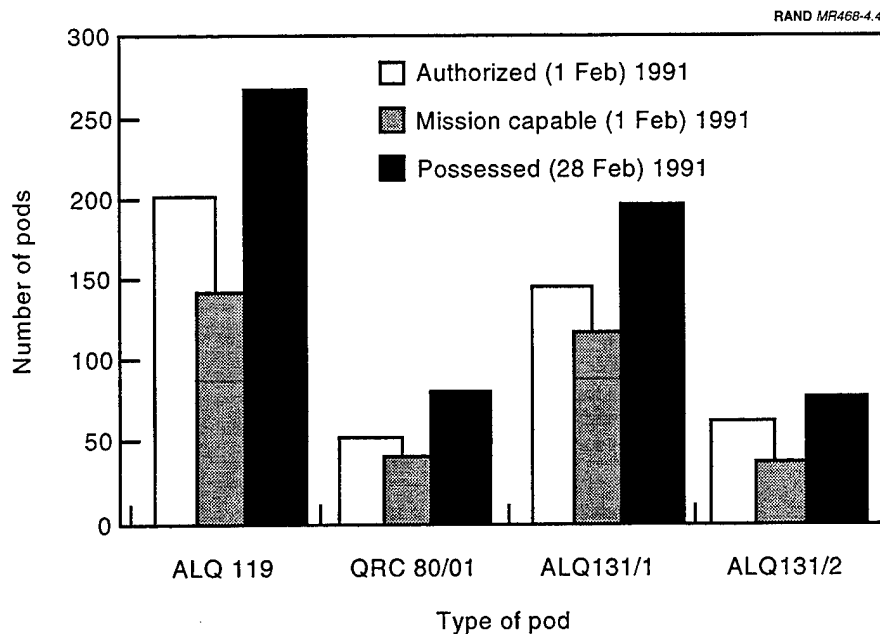


Figure 4.4—Additional ECM Pods Deployed to Desert Storm

component shortages, this problem was resolved by relying on logistics command and control (i.e., the CSSA and Desert Express) and the nondeployed units. The logistics command-and-control system moved the additional pods from nondeployed units to theater units as soon as the problem was recognized.

## LANTIRN's Recent Deployment Limited Prior Experience

LANTIRN was a new night-navigation and targeting capability just entering the inventory prior to Desert Storm. The navigation pod had been recently deployed to both F-15E and F-16C (Block 40/42) units; the targeting pod had just begun deployment to the F-15E aircraft when the Desert Shield deployment was initiated in August.<sup>6</sup>

A chain of events similar to those for ECM pods affected the LANTIRN targeting pods. As with the ECM pods, LANTIRN targeting pods experienced failure rates that exceeded the maintenance system's ability to repair malfunctioning spares (Figure 4.5). In contrast to the ECM pods, that failure rate did not diminish after the first few days. Luckily, the decrease in availability was neither as sharp nor

<sup>6</sup>F-16Cs did not receive the targeting pod during Desert Storm.

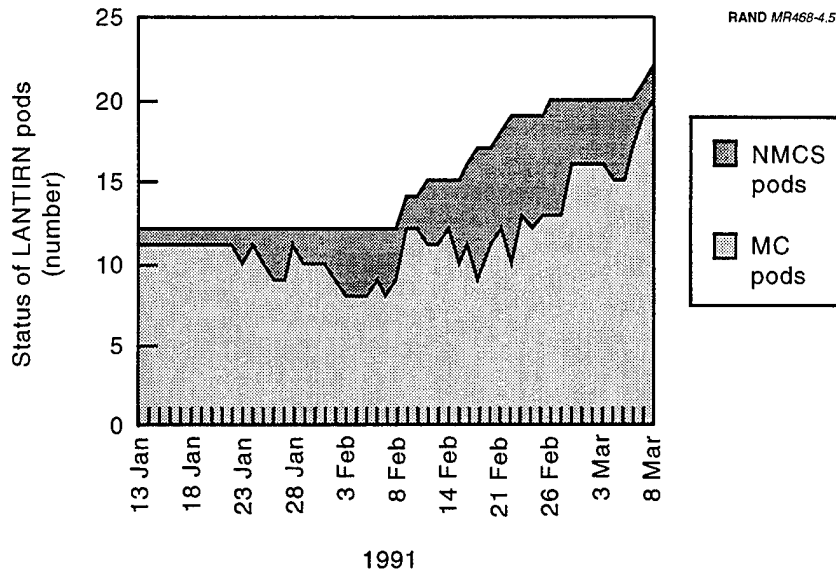


Figure 4.5—Status of LANTIRN Targeting Pods

as deep. Nevertheless, as soon as more targeting pods became available, they were deployed to theater to augment support to F-15E operations.

For both the ECM pods and the LANTIRN pods, the crucial support came from ad hoc command-and-control actions. As with the ECM pod support discussed earlier, it was essential to deploy additional assets quickly, and most of those assets came from units whose aircraft had not been deployed.

## 5. Desert Storm Munitions Support

Finally, we turn to munitions. As with aircraft spares, ECM pods and LANTIRN pods, munitions required highly responsive, unplanned support actions to meet operational needs. Even more than these other resources, surges in munitions support activity were exacerbated by the dynamic swings introduced as tactics and campaign objectives changed throughout the conflict.<sup>1</sup>

### Most Munitions Were Moved by Sea and Ground

The key munitions problem was one of geography and tonnage. The 69 thousand tons of munitions dropped by USAF aircraft during Desert Storm would have required 2,500 C-141 sorties just to deliver them (to say nothing of Army and Navy munitions) to theater.<sup>2</sup> Clearly, the munitions could not be moved by air.<sup>3</sup> Slower, higher-volume, sealift vehicles were required for movements from CONUS to theater, and ground transportation was needed in theater.

Prior to the Desert Shield deployment, some munitions were already prepositioned in depots at Thumrait, Masirah, and Seeb in Oman, and on Diego Garcia. Other munitions were stored aboard three Maritime Prepositioned Ships. These facilities and ships contained mostly general-purpose bombs and older-model cluster bombs. Also, munitions that had been stocked at Incirlik AB in Turkey were available to JTF Proven Force.

At the outset of Desert Shield, those prepositioned munitions were dispatched to the initial aircraft-deployment bases. Some munitions were also airlifted from CONUS to supplement the prepositioned material. Over time, the additional munitions were sealifted to the port of Jeddah, placed on ground transport there, and delivered to the theater USAF bases to prepare for Desert Storm.

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<sup>1</sup>Still fewer data exist on munitions, and most of those data are classified. In this unclassified document, we report only on significant munitions support events and procedures reported by operations and maintenance personnel.

<sup>2</sup>A C-141B can carry up to 41 tons of cargo. Allowing for 30 percent dunnage (packing and tiedown materials to prevent load shifting during flight), it can carry 28 tons of munitions.

<sup>3</sup>Some exceptions were made. The highest-volume exception was the critical initial munitions moved from CONUS to the theater during the very first days of Desert Shield. A few one-of-a-kind weapons, such as the bombs to penetrate deep bunkers, were also moved by air. Relatively lightweight munitions components (fuzes, fins, etc.) were also moved on occasion to meet critical needs.

## Redeployments, and Changes in Tactics and Target Allocation Drove Intra-Theater Munitions Support Efforts

By and large, the USAF had satisfactory levels of munitions and munitions components in the theater when combat commenced—although they were sometimes in the wrong place. On occasion, unplanned tactics changes caused flurries in demands for some munitions components. For example, B-52s redeployed to Jeddah AB in the opening days of the battle and, thus, substantial quantities of Mark 117 bombs needed to be moved. In addition, the standard bomb configurations featured “retarding” tail fins to facilitate safe low-altitude bomb drops. The unit required a special airlift of tail cones so that it could convert the bombs to a “slick”<sup>4</sup> configuration that could be dropped accurately from high altitudes. In this case, the special support need was due not only to the units’ movement but to a change in tactics for bomb delivery—from low altitude to high altitude, because of the relatively lighter activity of radar-directed anti-aircraft and SAMs, and simultaneously avoiding undirected anti-aircraft fire.

Changes in basing also required munitions movements. For example, after initial attacks had diminished Iraq’s threat to the Coalition’s air bases, A-10s and F-16s began to operate from forward operating locations, at which, to maintain security of wartime operational plans, munitions had not been prepositioned.

In one case, the inability to preposition or rapidly transport bombs and other equipment early in the war actually dictated the aircraft basing. Because JTF Proven Force was approved just as hostilities commenced, it was not possible to disperse the munitions from the storage facilities at Incirlik AB, Turkey, to other regional bases in time to generate combat sorties from them in the first few days and weeks of Desert Storm. As a result, Proven Force’s 114 fighter, special operations, ECM, and other aircraft representing nine different MDS remained concentrated at Incirlik.

Target changes also caused fluctuations in munitions movements. For example, the F-111F was initially tasked to attack aircraft shelters and other hardened targets with 2,000-lb laser-guided bombs (LGBs). In early February, the “tank

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<sup>4</sup>A “slick” bomb is one whose physical configuration is streamlined, rather than having air-retardant fins that cause the more abrupt, steeper drop required for proper detonation at low altitudes.

plinking" concept was demonstrated with 500-lb LGBs.<sup>5</sup> Laser seekers (bomb heads capable of homing on laser designators) were available in quantity at the F-111F base, but 500-lb bomb bodies were not. Once the basic concept was demonstrated to be effective, the F-111Fs were tasked to attack tanks, and substantial quantities of 500-lb bomb bodies had to be transferred quickly between bases in theater.

In each case, the theater had the munitions resources, but those resources were sometimes in the wrong configuration or in the wrong place. Again, logistics command and control and responsive transportation provided the keys to reallocate theater resources and respond to changing operational priorities. For munitions, the responsive transportation was generally provided by the Army, which controlled ground transportation in the theater.

### **Saudi Arabia's Well-Developed Infrastructure Was Key for Munitions Support**

The munitions movements required to support this dynamic reallocation depended on ample capacity for surface cargo movement, and on excellent ports and transportation infrastructure. All those factors were available on the Arabian Peninsula. Excellent air- and seaports, road structures, and navigable waterways eased transportation of the large quantities of munitions required for Desert Storm. Without that infrastructure, it would have been difficult to deliver adequate munitions to the theater, let alone redistribute them as the campaign objectives and tactics evolved.

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<sup>5</sup>Tank plinking: dropping laser-guided 500-lb bombs from F-111Fs with laser designators to attack tanks. Previously, the laser-seeking bomb heads had been used mostly with 2,000-lb bomb bodies to attack large, fixed installations.

## 6. Commentary: Support Lessons Learned

Although we cannot know what the next war will be like, we have been struck by some emerging implications of the Desert Storm experience for how to best prepare for future wartime support. Those implications emerged from more than one Desert Storm situation. We identified four areas for which the implications were most pertinent: (1) relying on the logistics concept of operations; (2) supporting a downsized force; (3) achieving a trade-off between transportation, repair, and spares; and (4) depending heavily on host-nation infrastructure.

### Relying on Logistics Concept of Operations

First, Desert Storm forcefully reminded us of the inherent unpredictability of wartime demands for logistics support. No matter what we thought we knew about what to expect in the Desert Storm data, it turned out differently—*explainable after the fact perhaps, but different from what anyone predicted*. Six broad sets of factors—changing tactics, new technologies, changing campaign plans and missions, changing performance criteria or tolerances, changing demand processes, and unexpected support constraints—drove those demand variations.

Worse than the statistical variations considered by spares and maintenance requirements models, uncertainties in these six factors defy assigning names, much less numbers, to them. For example, who knows what new tactic or technology may emerge in the next war? Without that information, how should the logistician forecast what resources might be needed for support?

We conclude that logisticians cannot rely entirely on forecasts. Rather, we would emphasize relying more heavily on the USAF Wartime Logistics Concept of Operations (Log CONOPS), which provides for enhanced responsive support in the form of mutual base support, transportation, logistics command and control, and depot support. The Log CONOPS outlines a conceptual framework for making the logistics system more responsive to changing operational demands. As seen in Desert Storm, improved logistics command and control and transportation were the centerpieces of a responsive support system that reallocated aircraft components, ECM pods, LANTIRN pods, whole munitions rounds, and munitions components in response to unplanned operators' needs. Without such command and control, aircraft availability would have been lower,



aircraft vulnerability to SAMs would have been higher, F-15E LANTIRN night-attack accuracy would have been limited, and tank plinking would have been constrained.

Much of that logistics command and control was provided by agencies in theater, but a critical new element was provided by the CSSA and Desert Express. Those arrangements certainly did not meet deployed units' every need, but they demonstrated a prototype for a more comprehensive system to provide logistics C<sup>2</sup> service to all forces in peacetime and wartime.

## **Supporting a Downsized Wartime Force**

The support problem will probably become more complicated for the downsized USAF forces currently being conceived and implemented. If the force is smaller but retains the same number of MDS, fewer of each MDS will be in the fleet. Then, more of the force in some future contingency will face the support difficulties faced by the F-111F, the F-117A, and the F-15E, whose fleets were almost completely deployed in wartime. If more aircraft MDS have smaller fleet sizes, maintenance personnel will not be able to count so heavily on the nondeployed units' support in future contingencies. Without that large pool of readily available, nondeployed serviceable stock, it will be difficult to achieve the high levels of aircraft availability as in Desert Storm.

This constraint would be especially severe in the "two major regional contingencies" (2-MRC) strategy now being considered. In such a strategy, the *current logistics system would not be able to achieve the Desert Storm performance levels for one force without affecting the other force's ability to meet its commitments to the other contingency*. Even if material could be moved quickly from one contingency to another, policymakers may be reluctant to jeopardize either contingency for the other. They may even be reluctant to reallocate material in a single MRC, if that would jeopardize the nondeployed forces' ability to remain vigilant and prepared for the second contingency.

## **Striking a New Balance Between Transportation, Repair, and Spares**

The Desert Storm logistics experience and real-time reorganization may indicate an effective direction for solving the 2-MRC logistics dilemma. By meeting unpredicted needs quickly, the Desert Storm innovations demonstrated how improving logistics system responsiveness can enhance combat capabilities—even beyond the levels possible in a "push" system with ample spares.

Although nondeployed units' spares cannot be used to achieve responsive resupply, there appear to be other ways to improve responsiveness. Desert Storm logistics staffs invented Desert Express, rearward regional repair, and the CSSA, which made it possible to move repairables and serviceables quickly to repair shops and back to the units. New "lean production"<sup>1</sup> innovations might be applied to depot-level (both contractor and organic) repair, and could be combined with the Desert Storm innovations to approach a similar level of responsiveness—*without* degrading support to nondeployed units.<sup>2</sup>

## Depending on Infrastructure of Host Nation

Finally, we must emphasize how much the well-developed infrastructure of the Arabian Peninsula contributed to the Air Force's ability to prosecute the war. Without the excellent airports and seaports, the extensive air base network, a commercial trucking industry, an extensive road network, and a modern telephone system, the logistics buildup (especially of munitions) would have been much slower, the continuing support would have been less robust, and the logistics constraints would have been more severe.

Many regions in the world do not have such a robust infrastructure. In such regions, it would be exceedingly difficult to mount a Desert Storm-scale operation with fighter aircraft.

As important, it would be folly to assume that the infrastructure in future contingencies will experience only the relatively low level of counterattack seen in Desert Storm. Whereas the Scud attacks were intended to achieve mainly political ends in this contingency, future weapons may be more effective and future enemies' war plans may be better conceived. Even if the enemy does not attack the air bases, attacks against larger, critical rearward logistics facilities could have a telling effect on the air forces' effectiveness.<sup>3</sup>

If attack aircraft are to play a critical role in more-austere future contingencies, new support methods for air-delivered weapons must be developed. The current dependence on extensive, uninterdicted lines of communication to deliver large

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<sup>1</sup>"Lean production" is a term coined by J. P. Womack, D. T. Jones, and D. Roos in *The Machine That Changed the World*, New York: Harper-Collins, 1990, to describe a number of production, design, and distribution techniques that dramatically improve responsiveness to customers by cutting process times, improving quality, and reducing costs.

<sup>2</sup>I. K. Cohen, R. A. Pyles, and R. Eden, in "Lean Logistics: A More Responsive, Robust, and Affordable System," Santa Monica, Calif.: RAND, unpublished draft, outline and evaluate such a system.

<sup>3</sup>Indeed, this interdiction campaign—shutting off resupply, reinforcements, and communications for over a month—was a key element of the allies' successful air campaign against Iraq's ground army.

volumes of fuel and munitions to meet the forces' consumption rates could be the Achilles' heel for future fighter forces, especially in regions where the initial logistics infrastructure is limited.

Of course, improved weapons technology might overcome such a limitation. If more-reliable, more-accurate, more-weather-insensitive weapons were available, fewer fighter sorties might be required to eliminate the targets of interest. Then the force would depend less on moving and managing a vast volume of both fuel and general-purpose bombs. Until then, the force depends critically on airports, seaports, roads, and fuel pipelines.