# Combat Support Command, Control, and Communications (CSC3)

## Robust Methods to Mitigate Communications Disruptions

H. Wayne Gustafson

RAND | PROJECT AIR FORCE

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H. Wayne Gustafson

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# PREFACE

The Air Force's new logistics concept of operations (Log CONOPS) calls for specified management innovations to enhance the responsiveness of wartime combat support. One of these is lateral redistribution and repair of aircraft components among similarly equipped airbases within a combat theater. This report examines the nature of the command, control, and communications capability needed to accomplish lateral redistribution and repair efficaciously.

The study is a logical extension of research at RAND throughout the 1980s on flexible logistics management, ranging from an analysis justifying the European Distribution System Aircraft to the so-called uncertainty study (Coupling Logistics to Operations to Meet Uncertainties and the Threat) that contributed to the Log CONOPS. The work was performed within the Project AIR FORCE Resource Management and System Acquisition Program under the project titled "Combat Support C3: Needs and Design Options," and was sponsored by Headquarters USAF (AF/LEX) and the Air Force Logistics Command Logistics Operations Center (AFLC/LOC). The results should be of interest throughout the Air Force logistics community.

# SUMMARY

Historically, the combat support doctrine of the U.S. Air Force (USAF) has emphasized unit self-sufficiency, under which organizations deploying to war, or so deployed already, are equipped with the materiel and personnel to operate for 30 days and more without resupply. An obvious effect of such a doctrine in wartime would be to minimize the need for combat support command, control, and communications (CSC3) interlinking bases within a theater or linking bases to supply depots.

Recent years have witnessed the emergence of a new logistics concept of operations (Log CONOPS) calling for more flexible approaches to combat support, including systematic lateral sharing of critical supplies and maintenance capabilities among similarly equipped airbases, i.e., mutual support. Clearly, mutual support, unlike self-sufficiency, requires a CSC3 system. This report investigates the capabilities required of such a system.

Current Air Force thinking about CSC3 tends to place a premium on fast, efficient data processing and reliable, high bandwidth communications facilities. Once such a CSC3 system is implemented, however, it becomes vulnerable to wartime disruption. The orientation here, therefore, was to identify the most austere form of CSC3 that could do the required job. The analysis was guided by the following two questions:

1. What are the consequences for combat performance if, under Log CONOPS innovations such as mutual support, CSC3 breaks down?
2. If these consequences are severe, can backup procedures be applied to keep the Log CONOPS approaches working effectively? That is, can robust "workarounds" be identified to mitigate CSC3 disruptions?

The method of investigation was to simulate wartime supply and maintenance of USAF F-16 Fighting Falcons using RAND's Dyna-METRIC capability assessment model. A major war was postulated, with a 20-day peacetime mobilization period entailing time-phased deployment of aircraft to the NATO theater. Performance of the logistics system was measured by the number of fully mission capable (FMC) aircraft available at various times in the scenario, with primary interest focusing on day 30, the tenth day of combat. F-16s of allied countries were not included in the scenario.

Two base case wartime logistics systems were characterized, one representing airbase self-sufficiency, the other reflecting mutual support. Mutual support consisted of theaterwide lateral redistribution of spare components coupled with lateral sharing of component repair shops (intermediate level maintenance) between bases having such shops and bases lacking them. To administer the mutual support operation, highly capable CSC3 and transportation systems were set up as straw men, their foremost attributes consisting of high-speed computer-to-computer communications and two-day movement of materiel between any two airbases in theater.

The bulk of the study then consisted of disrupting the CSC3 system in ways that might be expected in war, estimating the consequences of these disruptions for FMC aircraft availability, and introducing workarounds in an effort to ameliorate the effects of the disruptions.

CSC3 deterioration was simulated by delays and breakdowns in transmission of data between operating bases and a hypothetical CSC3 decisionmaking authority. Workarounds consisted of manual transport of data media, daily exception reporting of only a few most critical supply and maintenance needs, and delegation of logistics command and control to geographical subregions.

F-16 units already stationed in potential combat theaters possess their own intermediate repair capability. However, F-16 squadrons deploying from the continental United States (CONUS) to allied colocated operating bases (COBs) are designed to do without such repair for the first 30 days of combat operations. This enables "have" and "have not" bases to be grouped together for purposes of simulating lateral intermediate repair.

During the mobilization interval, all aircraft in theater averaged one sortie per day of 1.5 hours duration. A wartime surge then commenced and continued for seven days. Combat attrition of aircraft also was introduced starting day 21, and this continued for the rest of the scenario.

All resupply from CONUS depots remained cut off throughout the scenario. Full cannibalization of equipment was practiced at both the flightline and intermediate maintenance levels. Under mutual support, all supply and maintenance activity was governed by priority rules aimed at maximizing the number of FMC aircraft throughout the total theater.

Both type A/B and type C/D F-16s were represented. These aircraft were composed of 229 and 226 line replaceable units (LRUs) classified as war reserve materiel, of which 46 and 41 were items testable by the automated test equipment (ATE) of the avionics intermediate shop (AIS). Both aircraft configurations had 102 of the total components

and 24 of the AIS-testable parts were common. Each unit was supplied with its full authorized quantity of war reserve and/or peacetime operating spares (circa 1988). Removal rates for the LRUs were adapted from Air Force data reflecting concurrent peacetime experience. Variance-to-mean ratios (VTMRs) for the removal rates were set uniformly to 2.30 failures per flying hour (fpfh).

For consistency, all findings were scaled to the level of a single squadron of 24 primary authorized aircraft (PAA). The maximum potential benefit of mutual support for any day of the scenario was defined as that day's difference in FMC aircraft between the mutual support and self-sufficiency base cases. As of day 30, this benefit was found to be 2.94 FMC aircraft per squadron.

To study disruptions and workarounds, it was assumed that base-case CSC3 would remain intact until the onset of war, at which time various forms of deterioration would set in and workarounds would be invoked to alleviate these conditions. Consequently, the baseline for measuring the effect of CSC3 degradations and the value of workarounds became a mixed case involving mutual support for 20 days followed by self-sufficiency for the remainder of the scenario. The key results are depicted in Fig. S1.

The baseline case represents what would happen if both CSC3 and interbase transportation were wiped out at the start of combat. The accrued benefit of mutual support as of day 20 would decay by day 30 to 0.83 FMC aircraft per 24 PAA squadron, or only 28 percent of the maximum possible benefit cited above. Thus, 72 percent of the potential value of mutual support would go unrealized.

If CSC3 is destroyed but base-case transportation retained, data media can be transported manually, arriving at destination two days out of date. This workaround yielded a mutual support benefit at day 30 of 2.31 FMC aircraft per 24 PAA squadron, or 79 percent of the maximum possible.

If message-grade communications as well as transportation are preserved, bases at least can "exception report" the components most responsible for not fully mission capable (NFMC) aircraft status. Exception reporting proved by far the most potent workaround investigated. Daily reporting of only the two worst offending components per base produced a day-30 mutual support benefit of 2.72 FMC aircraft per 24 PAA squadron, or 93 percent of the potential maximum.

If long distance communications and transportation are eliminated but local capabilities retained, the theater can be broken into regions for purposes of mutual support. Dividing the NATO theater into four such regions turned out to be the least promising workaround explored. Under this arrangement, the day-30 benefit of mutual support fell to

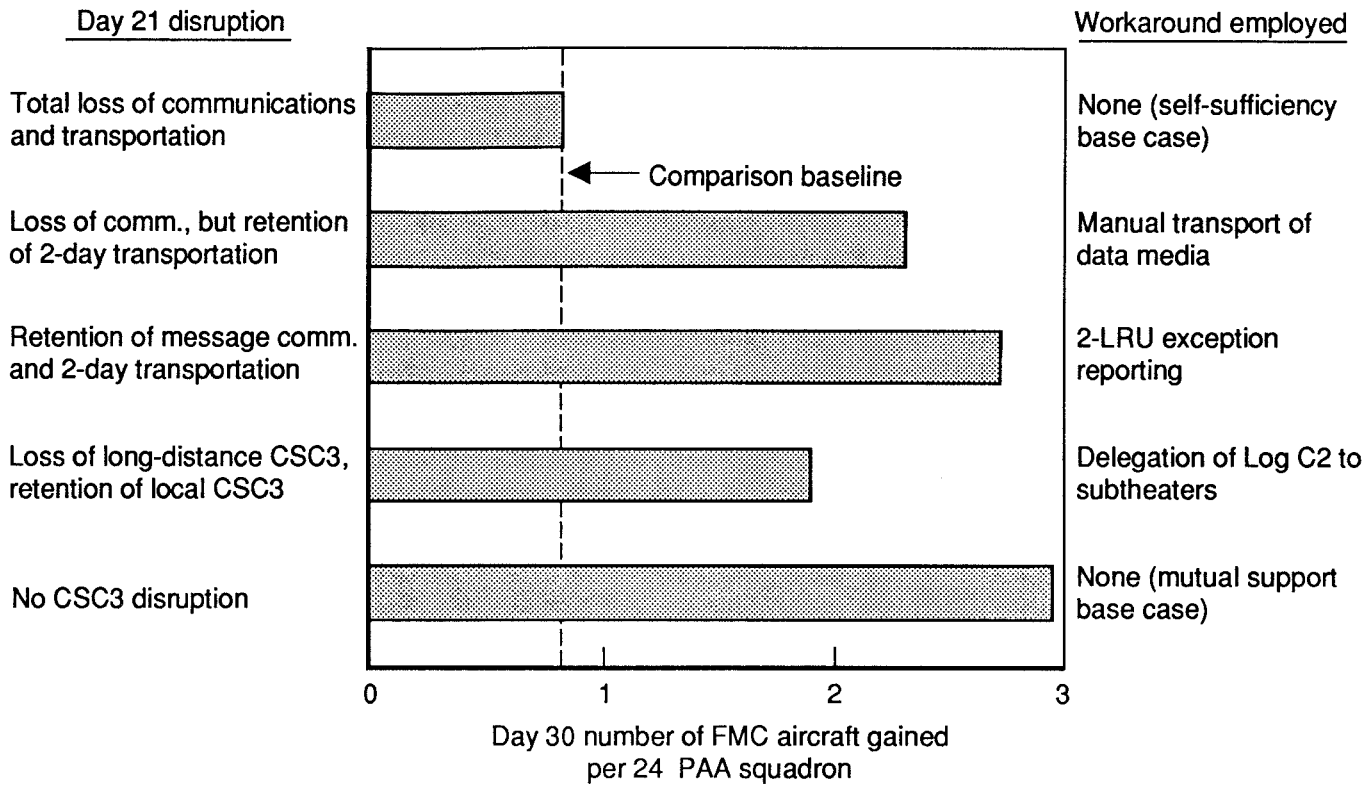


Fig. S1—Effectiveness of workarounds in response to CSC3 disruptions

1.91 FMC aircraft per 24 PAA squadron. The payoff from mutual support is highly sensitive to the scale of operations within which it is pursued, and regionalizing the theater greatly reduced this scale.

Contrary to a finding of RAND's so-called uncertainty study (Coupling Logistics to Operations to Meet Uncertainties and the Threat), lateral repair was found to be a relatively insignificant (i.e., 14 percent) contributor to the benefit of mutual support at day 30. The reason is that whereas the earlier research considered only AIS-testable parts, the present investigation included a wider range of components. Base-level maintenance covers AIS-testable components quite comprehensively, but not other component types. Of the 290 non-AIS-testable LRUs in the study, 116 must be sent to the depot to be fixed every time they break, whereas 61 of the 63 AIS parts can be repaired most of the time at base level. Furthermore, it is the components repairable mainly at depots that were found most responsible at day 30 for FMC aircraft conditions. Thus, the parts that cause aircraft to be NFMC are seldom among the ones that base-level maintenance can repair.

Considering the potency of exception reporting in keeping aircraft FMC, perpetual total visibility at theater level over base assets seems not required to support reactive lateral redistribution and repair of aircraft components in wartime. If mutual support is driven by reporting demands for parts after the parts have failed, then voice and telex communications are sufficient. Although a coordinated communications network centered in a facility like USAFE's (United States Air Forces in Europe) Logistics Readiness Center might be desirable and should be used if it already exists, it is conceivable that a reactive exception reporting system could be managed simply by round robin message transmittal among the participants.

However, if proactive mutual support is introduced to anticipate demands, data-grade, computer-to-computer communications are required along with a centralized, theaterwide management function. The cost of such an arrangement would have to be traded off against the increased benefit it produces relative to reactive mutual support. Appendix B shows that if transportation time is short, the potential marginal benefit of proactive mutual support is small. With two-day transportation, for example, the incremental benefit from proactive mutual support would be no more than 0.5 FMC aircraft per 24 PAA squadron even if prediction of future parts breakage were perfect.

Fast, assured transportation was found vital to effective reactive mutual support, a result that reinforces the extensive efforts put into the European Distribution System over the past 12 years or so. Further, it was learned that the coverage of the transportation system needs to be kept as broad as possible to reap the full advantages of

scale available. If assured interbase transportation is unavailable in peace, it must be quickly implementable in the threat of war.

In conclusion, three findings stand out above all others. The first is the potency of exception reporting, as dealt with above. The second is that the parts mainly reponsible for NFMC aircraft at day 30 are not reparable at base level. This dramatizes the need for timelier resupply of high NERTS-rate components from outside sources. It also suggests that if lateral repair is carried out from the start and responsive depot resupply becomes available following day 30, the cost-effectiveness of deploying intermediate maintenance facilities to COB-based F-16 squadrons may be questionable. And third, the benefit of mutual support degrades gracefully with increases in interbase transportation time (see App. B). All the same, the faster the transportation, the better.

# ACKNOWLEDGMENTS

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# ACRONYMS

| | |
|---|---|
| AAFCE | Allied Air Forces Central Europe |
| AFLC | Air Force Logistics Command |
| AFR | Air Force Regulation |
| AIS | Avionics intermediate shop |
| ALC | Air Logistics Center |
| ATE | Automated test equipment |
| BCS | Bench check serviceable |
| BLSS | Base level self-sufficiency spares |
| CAS | Combat Ammunition System |
| CCASE | Combat Communications Access for Support Elements |
| COB | Colocated operating base |
| CONOPS | Concept of operations |
| CONUS | Continental United States |
| CSC3 | Combat support command, control, and communications |
| CSMS | Combat Supply Management System |
| CSS | Combat Support System |
| D029 | WRSK/BLSS Authorization System |
| EDSA | European Distribution System Aircraft |
| FMC | Fully mission capable |
| fpfh | Failures per flying hour |
| ICBM | Intercontinental ballistic missile |
| JCS | Joint Chiefs of Staff |
| LOC | Logistics Operations Center |
| LRC | Logistics Readiness Center |
| LRU | Line replaceable unit |
| MAJCOM | Major command |
| MESL | Mission essential subsystems list |
| MOB | Main operating base |
| NFMC | Not fully mission capable |
| NOP | Non-optimized |
| NRTS | Not repairable this station |
| OSC | Operations Support Center |
| PAA | Primary authorized aircraft |
| PACAF | Pacific Air Forces |
| POS | Peacetime operating stock |
| RR | Remove and replace |
| RRR | Remove, repair, and replace |
| SBSS | Standard Base Supply System |
| SRU | Shop replaceable unit |

| | |
|---|---|
| TRAP | Tanks, racks, adapters, and pylons |
| TSS | Transportable Shelter System |
| USAFE | United States Air Forces Europe |
| VTMR | Variance-to-mean ratio |
| WCCS | Wing Command and Support System |
| WMP | War Mobilization Plan |
| WRSK | War reserve spares kit |

# I. INTRODUCTION

## BACKGROUND

### The Log CONOPS

**The Old Concept.** Historically the U.S. Air Force has pursued a policy of wartime base self-sufficiency in which combat units deploying to battle locations, or so deployed already, are equipped and trained to operate without outside support for substantial periods of time, typically 30 days.[1] The policy assumes that the transportation facilities normally employed for logistics support are likely to become unavailable at the onset of hostilities because of higher priority competing demands and other contingencies of war.

Research over the past several years has challenged the concept of self-sufficient operation on the grounds of the unpredictability of resource demands arising from wartime uncertainties. In the case of aircraft components, analyses both ancient (Astrachan, Brown, and Houghten, 1961; Brown, 1956) and recent (Crawford, 1988; Hodges, 1985) have demonstrated that failure rates are considerably less predictable even in peacetime than the statistical formulas used for provisioning spares for self-sufficiency would imply. When uncertainties of battle are factored in such as mission mix, rules of engagement, level of intensity, physical environment, and enemy interdiction, doubt is cast on the credibility of resource calculations for self-sufficient sustainment.

**The New Concept.** Accordingly, the Air Force logistics community has formulated a new logistics concept of operations (Bracken, 1987; Seaquist, 1988; Trainor 1988; USAF, 1987, 1989), or Log CONOPS, calling for a more nearly real-time type of wartime resource management in which parallel organizations routinely exchange critical supplies, depot support from the continental United States (CONUS) is brought into play earlier than previously contemplated, local repair facilities are shared, increased support of base operations is sought from host nation allies, and stocks of materiel for common use are maintained in the combat theater.

---

[1]This is not categorically true of all combat resources, as fuel and munitions, for example, are rarely stocked to 30-day levels. The statement does apply, however, to the weapon system supply and maintenance resources on which the present study focuses.

The theme of the Log CONOPS is to invoke management adaptations that make the most of existing assets through wiser utilization of resources and better prioritizing of such activities as equipment repair at base and depot shops. One such recommended adaptation, as mentioned, is lateral exchange of critical supplies among similar organizations. Lateral exchange has the effect of pooling resources to gain flexibility in meeting unforeseen demands—i.e., efficiency of scale. With respect to spare parts, this type of redistribution is practiced widely in peacetime today—to the extent in Europe that a fleet of C-23A Sherpas called the European Distribution System Aircraft (EDSA) was created to facilitate it (GAO, 1986; Young and Taylor, 1989). Regrettably, though lateral redistribution of spares continues, economic pressures lately have brought peacetime operation of EDSA to a halt.

**Management Mechanism.** Historically, redistribution of components as by EDSA has been informal and voluntary, like a barter exchange. For maximum effectiveness, priority rules are needed that take into account the combat capability of the force as a whole. In order to formulate and administer such force-wide rules, someone has to be in overall charge, and a degree of control must be maintained over the assets held by individual participating organizations. In other words, the assets possessed by the separate bases need to be managed—subject to appropriate limitations—as a common stock.

The optimum mechanism for effecting this kind of overall management remains to be decided. In the present study, the management agency was simulated as an all-seeing eye having full logistics command and control authority, but more distributed forms of decision-making might work as well. Indeed, once the rules are agreed to, it is conceivable that the participants could manage the operation themselves much as in a barter exchange. This topic will be revisited in Sec. IV.

## Current Views of Future CSC3

Under self-sufficiency, no horizontal channels for logistics interaction among parallel organizations are necessary. Under the Log CONOPS, however, some form of combat support command, control, and communications (CSC3) system to manage logistics interaction plainly is mandatory, as is an interbase transportation system to move materiel. The current investigation aims to shed light on the capabilities required of such a CSC3 and transportation system and how to substitute for capabilities lost owing to exigencies of battle.

Present-day thinking about wartime Air Force CSC3 places a premium on fast, efficient data systems and reliable, high bandwidth

communications facilities (AFLC, 1982; Tripp, 1987). In conjunction with a continuing program to upgrade its logistics data and communications capabilities (Morger, 1986; AFLC, 1987), the Air Force chartered a "Tiger Team" in 1987 (Cannava, n.d.) to formulate a system definition of logistics command and control (Log C2) for conducting wartime operations and measuring peacetime readiness and sustainability. Here is what that Tiger Team envisioned for CSC3 of the future:

> [C]ritical C2 elements of the Air Force logistics system will be linked on a near real-time basis in direct support of peace and wartime operations; be capable of supporting combat forces under highly dynamic operating conditions; be flexible, responsive, and survivable to ensure quick recovery from hostile actions that result in loss, damage, or disruption to key logistics processes; and be able to rapidly reallocate critical logistics resources to the highest operational priorities (USAF, 1988).

The "critical C2 elements" referred to include a complex array of extant, emergent, and contemplated Air Force data and communications systems intended for support of wartime operations, such as the Combat Support System (CSS), the Combat Ammunition System (CAS), the Combat Supply Management System (CSMS), the Wing Command and Control System (WCCS), the Standard Base Supply System (SBSS) and its associated Transportable Shelter System (TSS), and the Combat Communications Access for Support Elements (CCASE) system. Currently, all these systems and more are considered necessary for logistics support of combat even under self-sufficient operation. What is missing from this array, much more than data and communications capabilities, are the administrative linkages and integrated concept of operations to unite the many disparate components into a coordinated CSC3 structure.

## PROBLEM AND METHOD

### Problem

To achieve such an integration and keep it functional in combat would be, to say the least, a formidable undertaking. Moreover, once such a structure was implemented, it would become vulnerable to wartime disruption. Therefore, assuming the existence of a CSC3 system as envisioned above, two broad questions concerning the Log CONOPS arise:

1. What are the consequences for combat performance if, under management adaptations such as lateral redistribution, CSC3

deteriorates? How robust is the support system likely to prove under Log CONOPS adaptations?

2. In the event the consequences of CSC3 breakdown are severe, can "workarounds" be found to keep Log CONOPS adaptations operating effectively? Can robust methods be identified to mitigate CSC3 disruptions?

If, for instance, lateral redistribution deteriorates because high bandwidth communications channels ordinarily used to transmit inventory information from computer to computer become overloaded, can the benefits of redistribution be preserved either by transporting computer media physically or by transmitting limited inventory data by means of message-grade transmission facilities? Or, if the transportation system becomes unable to provide the rapid materiel movement essential for redistribution of spare parts throughout a whole force, can substantial advantages be retained from lateral redistribution within smaller groups of airbases close enough together to rely on local air or ground transportation? These and derivative questions bearing on CSC3 disruption constitute the problem for investigation.

## Method

The method adopted was to simulate wartime supply and maintenance of F-16 Fighting Falcon components using RAND's Dyna-METRIC capability assessment model, Version 6.3 (see App. A). Dyna-METRIC simulates the process of keeping aircraft in combat-ready condition through resupply and repair of defective parts.

A major NATO war was postulated, with a 20-day mobilization period preceding combat. During mobilization, a time-phased deployment of F-16s was simulated as projected by the Joint Chiefs of Staff (JCS) 1987 War Mobilization Plan (WMP) for the year 1990.

Two limiting, or base case, logistics systems were characterized, one corresponding to the tradition of unit self-sufficiency, the other reflecting the Log CONOPS initiatives of lateral redistribution and lateral intermediate repair (mutual support base case).

Next, an idealized CSC3 system was defined to manage mutual support and a comparison was made between the base cases in terms of fully mission capable (FMC) aircraft available at various times in the simulation scenario. The difference between the two cases was taken to be the maximum increment in performance to be expected from mutual support governed by an ideal CSC3 system.

The main body of the study then consisted of degrading the CSC3 system in ways that might be expected in war, estimating the con-

sequences of these degradations for supply and maintenance performance, and introducing workarounds in an effort to ameliorate the effects of the degradations. Table 1 summarizes the CSC3 disruptions simulated and the associated workarounds evaluated.

The top and bottom entries in Table 1 bound the possibilities for workarounds. With total loss of communications and transportation, no workaround is imaginable; and with no CSC3 disruption, the mutual support base case, no workaround is needed. The other entries define intermediate conditions of degradation in which workarounds are feasible.

The sequel will make the information in Table 1 clearer. Two points, however, should be noted now. First, although exception reporting is immediate, manual transport of data media delays arrival and ages the data by whatever transportation time is involved. On the other side of the coin, unrestricted quantities of data can be transported manually, but exception reporting, by voice or telex, must be limited in detail.

Second, transportation time and communications time are generally independent, and transportation is regarded semantically as distinct from CSC3. In the manual transport workaround, however, the carriers that move aircraft components become integral to the CSC3 system, and transportation time and communications time necessarily vary together.

Table 1

CSC3 DISRUPTIONS AND WORKAROUNDS

| Disruption Simulated | Workaround Evaluated |
|---|---|
| Total loss of theater communications and transportation | None (self-sufficiency base case) |
| Loss of all communications, but retention of transportation | Manual transport of data media |
| Retention of message communications as well as transportation | Oral or written reporting of limited critical needs (exception reporting) |
| Loss of long-distance CSC3 and/or transportation, but retention of local capabilities | Delegation of Log C2 to geographical subtheaters |
| No disruption | None (mutual support base case) |

## OUTLINE

Section II contains a fuller description of the study procedure. Readers familiar with combat sustainability concepts and scenarios may find it sufficient to skim this material for principal points. Section III then summarizes the main findings of the analysis, and Section IV discusses their implications for logistics applications and future research.

Finally, two appendixes provide information of methodological importance but ancillary to the central thrust of the report. First, App. A outlines the modifications made to Dyna-METRIC for this project; the generic extensions to the model obtained; the algorithms for priority redistribution, repair, and cannibalization used to simulate an ideal CSC3 system; and how statistical significance may be imputed to Dyna-METRIC outputs. After that, App. B analyzes factors bearing on the generalizability of the results in Sec. III.

# II. PROCEDURE

## MUTUAL SUPPORT

### The CSC3 System

The idealized CSC3 system for the mutual support base case was specified to have the following functional capabilities:

- Visibility over the current condition of all aircraft, components, and base-level repair facilities in the theater of operations. In the Dyna-METRIC simulations, this information was refreshed once each day after the close of flying operations.
- Timely, error-free data transmission between each aircraft base and the oversight function. In Dyna-METRIC, this transmission was, in essence, instantaneous; in practice, the window of timeliness might be several hours.
- Full decision authority over shipment of components between bases and, in the case of repair backlogs, which items to repair first.
- Sufficient computing capacity to prioritize the foregoing supply and maintenance actions so as to maximize the number of FMC aircraft available in theater at the start of each day.
- Two-day transportation between any two bases in the theater.[1]

Although no definite location for the CSC3 oversight and decision-making function was assumed, a conceptual model in the context of NATO and United States Air Forces in Europe (USAFE) might be the Operations Support Center/Logistics Readiness Center (OSC/LRC)[2] of long standing, while the model for the transportation facility would be EDSA. Whether such agencies are affordable in peacetime is beside the point. To implement the Log CONOPS in wartime, an assured transportation system comparable to EDSA is essential, as is also some sort of LRC.

USAFE some time ago introduced regional LRCs throughout NATO as well as a regionalized "hub and spoke" concept of operations for

[1]The parameter of two days was picked as the straw man for the ideal base case because it represents a hypothetical optimum for the NATO theater. Appendix B reports the results of varying this parameter.

[2]A logistics readiness center is an organization for managing wartime logistics within a region or theater. It may or may not be staffed and operative in peacetime.

EDSA similar to the radial operations of many commercial freight and passenger carriers. Division of the theater geographically to analyze Log C2 delegation to subtheaters approximated this regional LRC/EDSA arrangement. It also approximated NATO's division of the theater into tactical air force areas of responsibility.

## Lateral Repair

Mutual maintenance support consists of lateral redistribution and lateral repair. Lateral redistribution means just what it says, that any base needing a commodity can receive it from any base possessing excess. Lateral repair, however, is not quite so straightforward and requires brief digression.

Main operating bases (MOBs) are permanent U.S. airbases well endowed with repair resources. Several MOBs housing F-16s operate in the NATO theater during peacetime. Colocated operating bases (COBs) are bases belonging to allied nations—MOBs of their own—not occupied by the United States in peacetime but shared by deploying USAF units during crises.

As far as U.S. arrangements are concerned, COBs are furnished very sparsely with repair resources. To compensate for this lack, deploying units take their own peacetime intermediate repair facilities and personnel with them.[3] As a rule, however, delivery of these facilities and personnel is deferred for approximately 30 days. Meanwhile, the unit is unable to repair defective components and, under the doctrine of self-sufficiency, is expected to subsist on a stock of spare parts called a war reserve spares kit (WRSK).

The idea of lateral repair in these circumstances is for MOBs to share their intermediate capability with COBs lacking same. This process was simulated for study purposes by grouping the COBs of the scenario into clusters and tying each cluster to a MOB.[4] In forming the clusters, some attention was given to geography; but the main objective was to balance the numbers of aircraft served by the several MOBs.

Naturally, lateral repair would be expected to provide advantage primarily, if not wholly, to COBs rather than MOBs. Analysis quantifying this benefit is found in App. B.

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[3]Intermediate repair means anything between the flightline and the depot. Here it refers to repair accomplished at the base but in shops remote from the flightline.

[4]More generally, MOBs might share repair facilities with one another as well as with COBs, but that type of arrangement was not examined here. As a result, the benefits of lateral repair obtained in this analysis may underestimate the maximum benefits possible from theaterwide lateral repair.

## AIRCRAFT REPRESENTATION

### Spares Computation

Whereas deploying units take along WRSKs meant to last 30 days, MOBs in potential theaters of war are supplied with base level self-sufficiency spares (BLSS) plus peacetime operating stock (POS), the aggregate BLSS/POS intended likewise to suffice for 30 days. Obviously, the components making up the WRSK/BLSS/POS are those considered most likely to fail and render aircraft NFMC. These components therefore constitute the principal candidates for lateral redistribution and repair.

Components replaceable at the flightline are called line replaceable units (LRUs), which in turn are are made up of shop replaceable units (SRUs). The Dyna-METRIC model simulates an airplane as any desired collection of LRUs and constituent SRUs, the choice of components depending on the research objective. For the reason just cited, the aircraft in this study were configured as collections of WRSK/BLSS/POS LRUs. Further, to facilitate the study of lateral repair, aircraft configurations were limited to reparable, in contrast to consumable, LRUs.

Various computational procedures are employed to determine the quantities of different components to include in WRSK/BLSS/POS. For a large proportion of components, the quantities are calculated as a function of the flying hours expected in the first 30 days of war, the expected number of failures per flying hour, and the percent of aircraft required to be FMC at the end of some specified time, usually 30 days. This calculation is performed by a computer system known as the D029 WRSK/BLSS Authorization System (AFLCR 57-18).

### Non-Optimized Items

For many other components, war reserve quantities are arrived at by alternative approaches. For example, the number of spare tires included in WRSKs, though logically calculable by means of the D029 algorithm, is constrained by the bulk of the item in question and the competing higher priorities for available transportation. As another illustration, gun barrels wear out not as a function of flying hours, but of rounds (or bursts) fired. WRSK/BLSS/POS components such as these, whose quantities are ascertained by other than a D029 calculation, are called non-optimized (NOP) items.

While the basis for a D029-computed quantity is clear and the calculation reproducible, methods of determining the required quantities of

NOP items are many and varied, and there are hundreds of different NOP items in the WRSK/BLSS/POS for F-16s. Accordingly, aircraft representation in Dyna-METRIC was limited to reparable LRUs governed by the D029 algorithm. With few exceptions,[5] all such components were included in the simulation. Hence, nearly everything reparable that supposedly fails as a function of flying time was submitted to Dyna-METRIC analysis.

F-16s of both the A/B and C/D types appeared in the scenario and were separately represented in the database. Table 2 gives the total number of LRUs making up each aircraft configuration as well as the numbers unique to each and common to both. Similar information for the components testable by the automated test equipment (ATE) of the avionics intermediate shop (AIS) is shown at the bottom of the table. These AIS-testable items are subject to special maintenance policy and will become of interest later.

Table 2

F-16 AIRCRAFT REPRESENTATION IN THE SIMULATION

| Number of LRUs | Configuration | |
|---|---|---|
| | A/B | C/D |
| All Items | | |
| Total | 229 | 226 |
| Unique | 127 | 124 |
| Common | 102 | |
| AIS-Testable Items | | |
| Total | 46 | 41 |
| Unique | 22 | 17 |
| Common | 24 | |

[5]Approximately 20 D029-computed LRUs were dropped from the aircraft representation for various reasons. The deletions encompassed, for instance, a few LRUs found uniquely in Air Force Reserve and Air National Guard WRSKs. Reserve and Guard units, a number of which were involved in the present scenario, follow rules for composing WRSKs somewhat different from those for the active forces.

### Mission Capability

A minimum essential subsystems list (MESL) enumerates the major equipment items any aircraft must possess to perform its full range of assigned missions. An aircraft fitted with all MESL items in working order is said to be *fully mission capable* (AFR 65-110). If, in addition, the aircraft is fueled, armed, manned, and preflighted for combat, it is called *mission ready available* (AFR 55-15). Only the former property, mission capability, was considered in this investigation.

The rationale for using available FMC aircraft as a measure of merit in analyzing sustainability is explained in Ogan (1988) and Pyles and Tripp (1983) and need not be elaborated here. The operational definition of FMC for this analysis, however, bears comment.

Whether an aircraft is FMC depends, precisely speaking, on its MESL. In effect, therefore, the MESL for each of the two aircraft configurations was taken to be the full complement of LRUs indicated for that configuration in Table 2. To be FMC, an aircraft had to possess all its Table 2 parts in operating condition.

## SCENARIO CHARACTERISTICS

### Deployment

**Warning Period.** Although the WMP is explicit on how deployment is to take place following an order to mobilize, it does not specify the day that hot war is presumed to break out. For this study, the time of commencement of combat was designated as the morning of day 21, which gave a 20-day interval of peacetime for mobilization. During those 20 days, an in-theater training program was assumed involving one sortie per day per assigned aircraft, with each sortie 1.5 hours long. If a squadron deployed from CONUS to its COB on day 15 (ready to fight starting day 16), it would fly the next four days at the pace just indicated.

**Depot Cutoff.** Commensurate with the Air Force sustainability scenario most frequently adopted for analysis, it was assumed that resupply from CONUS would be cut off at the start of mobilization and would not resume before day 31. As a result, units lacking intermediate repair capability began living off their WRSKs on arrival, which, in the case of self-sufficient operation, conferred a relative supply advantage on units deploying late in the 20-day warning period. At the outbreak of war, the latter units would have used up fewer of their war reserves in training than units arriving sooner. Consequently, earlier deploying units tended to benefit more from mutual support. The extent of this effect is assessed in App. B.

**Combat Effects.** As of day 21, all units began flying at a surge rate and started to suffer combat attrition of aircraft. The surge continued for seven days (through day 27), and attrition continued throughout the scenario. Battle damage to aircraft was not simulated. Planes returned to base either whole or not at all. Also not treated were runway damage prohibiting return to base and other forms of collateral damage, such as destruction of fuel, that might restrict sortie generation. However, several excursions were run in which damage from enemy attack was inflicted on spare parts stocks and repair facilities. The latter analysis is contained in App. B.

## Demand Rates

Component demand rates—expected numbers of failures per flying hour—are estimated for different major commands on the strength of their own experience. Thus, the demand rate for a given part derived from USAFE data may differ, sometimes greatly, from the demand rate for the same part based on National Guard or Tactical Air Command data. The problem for the investigator, though, is not whose figures are right, but what demand rates are most likely to prevail in an actual crisis. Only peacetime data are available, and it is possible these do not afford reliable prediction of the demand rates to be encountered in combat.

The operational solution chosen was to form two sets of rates based on the highest and lowest values found for each part, and to use the high rates in running both base cases. The high rates are more stressful to the maintenance system, and many experts believe that higher rates are more likely in wartime than in peacetime. A comparison between the two sets of rates in terms of their effects on the benefit of mutual support appears in App. B.

## Variance-to-Mean Ratios

**D029 Assumption.** Both Dyna-METRIC and the D029 system assume that component failures occur as a function of flying time in accordance with a probability density function characterized by a failure rate and a parameter called the variance-to-mean ratio (VTMR). The VTMR associated with any component may be thought of as an index of the uncertainty with which failures beset that item. In general, the smaller the VTMR, the more regular the failures. Large VTMRs imply that failures tend to come in batches of unpredictable size with unpredictable intervals between batches. Clearly, therefore, the larger the VTMR, the harder it is to run a supply and maintenance operation efficiently.

The D029 computation of WRSK/BLSS/POS quantities incorporates a value of VTMR equal to 1.00 for all components, but all available empirical evidence indicates that the average VTMR tends to be larger than this in practice. However, the issue is complex, and experts differ as to what constitutes a typical VTMR value even under peacetime operating conditions. Certainly, therefore, no one can say what a typical value would be under the chaos of war. Still, available research indicates that VTMRs near 1.00 underestimate demand variability even in peacetime.

**Data Review.** Crawford (1988), for instance, computed peacetime VTMR values for approximately 800 F-15 Eagle parts, finding a median value of 2.30 failures per flying hour (fpfh).[6] The F-15 is a different airplane from the F-16; but both have some components in common, and there appears no necessary reason to think their parts would exhibit markedly different failure behavior.

In RAND's so-called uncertainty study (Coupling Logistics to Operations to Meet Uncertainties and the Threat, Seaquist, 1988) that contributed to the Log CONOPS and set the stage for the present investigation, F-16 aircraft were represented as assemblages of 50 avionics (weaponry) LRUs. The failure data bearing on these components were obtained and examined. The median VTMR turned out to be 2.05 fpfh, with the mean value equal to 2.37 fpfh.

VTMRs have the property that observed values tend to increase with the length of the data collection period over which they are estimated. Sherbrooke (1987) gives an empirical formula for projecting the mean VTMR for a set of components from any given data collection period to a longer one. In the present study the WRSK/BLSS/POS quantities were derived in 1988 but intended for application in a 1990 scenario. Therefore, using scrubbed data supplied by J. B. Abell of RAND on several hundred F-15 Eagle LRUs, Sherbrooke's formula was used to project a single-year mean VTMR to a three-year value. The answer came out to be 2.32 fpfh.

Since the three data sets examined differ considerably in composition, no meaning other than coincidence can be attributed to the near agreement in results obtained from them. However, there seems no basis for supposing that all three findings are grossly unrepresentative. Accordingly, it was decided to employ a value of VTMR = 2.30 fpfh for each LRU in the present study.[7]

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[6]More accurately, the measure is removals per flying hour due to *diagnosed* failure. The true failures are a subset of the removals. Parts presumed defective but later found usable are called bench check serviceables (BCSs).

[7]Subsequent to this decision, a RAND unpublished analysis of 32 LRUs of the Navy's F-14 aircraft yielded a mean VTMR of 2.50 fpfh with a median of 2.44 fpfh. Most of the

**Conservative VTMR Choice.** The choice of VTMRs to use for study purposes is important in that the larger the values employed, the greater the benefit likely to be seen from management adaptations such as lateral redistribution and repair. However, it is believed most authorities on the subject would agree that a mean VTMR of 2.30 fpfh is a reasonably conservative value to apply to the present scenario. In all likelihood, values actually encountered would be larger, especially after the start of war on the 21st day. The effect of employing a larger value is investigated in App. B.

## Priority Rules

**Priority Distribution.** Under lateral redistribution, the rule followed in exchanging parts among bases was to maximize the total number of FMC aircraft in the theater.[8] The NFMC status of individual bases entered into this determination only, so to speak, to resolve ties. If the theater would benefit equally whether a part was sent to one base or another, the part was shipped to the base with the larger fraction of NFMC aircraft. In the case of regionalizing the NATO theater into subtheaters, the priority distribution rule applied only within the subtheaters.

**Constrained Repair.** In the case of the F-16, many avionics components are not testable in the AIS and must be shipped to depots for repair. Those that are reparable at base level have been called AIS-testable LRUs (e.g., Table 2), which will be abbreviated henceforth just to "AIS" LRUs. The ability to repair AIS LRUs at base level was constrained by specifying the amount of avionics ATE at each intermediate maintenance facility, the fraction of time this equipment would be broken, and the time required to restore same when down. AIS items needing repair in excess of available capacity were queued to await their turn.

In lateral repair, the rule for deciding which component in a queue to repair next was analogous to that for priority distribution: repair the item that promises to release the most NFMC aircraft. However, because lateral repair extended only across clusters of bases rather than across the whole theater, application of the priority repair rule was confined within individual clusters.

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parts in the sample were randomly chosen, but four were included because of their known troublesome nature. Since these four extra components no doubt inflate the sample mean and median, a VTMR of 2.30 fpfh might not be a bad choice to represent these data also.

[8]Pyke (1990) shows that this rule is superior to a first-come-first-served procedure.

In the case of non-AIS components, no constraints were placed on repair capacity.[9] For each non-AIS LRU reparable at base level, a repair cycle time was specified; and whenever such an item failed, it was presumed to have been repaired as soon as its indicated time elapsed. The priority repair rule thus was devoid of meaning for other than AIS parts.

**Cannibalization.** Full cannibalization was assumed both of aircraft at the flightline and of components undergoing intermediate level repair. Hence, an LRU could be removed from one aircraft to fix another, as could an SRU be taken from one LRU to repair a second. In carrying out such cannibalization, the same priority rule of maximizing FMC aircraft availability was followed. Cannibalization, however, was confined within individual bases; cross-base cannibalization was not simulated.

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[9]As seen in the next section, this departure from reality can have had at most a trivially small effect on the outcomes obtained.

# III. CORE FINDINGS

## OVERALL BENEFIT OF MUTUAL SUPPORT

### Presentation Format

As stated, the dependent variable of this study is the number of FMC aircraft available at any given time in the scenario. However, in light of the time-phased WMP deployment that puts increasing numbers of aircraft in theater throughout the mobilization period, FMC aircraft figures for the total force could be misleading. Accordingly, a scaling of the FMC aircraft variable was sought that would permit all data to be presented in terms of a standard common denominator.

In similar circumstances, the usual approach is to employ percentages. It is believed that for most applications, however, commanders find aircraft counts more intuitive and meaningful than percentage figures. This led to the decision to cite absolute numbers scaled to the level of a standard sized combat unit. The unit size adopted was a 24 PAA squadron, and the scaling was accomplished by dividing total force outcomes for each day by the equivalent number of 24 PAA squadrons present in theater on that day. To provide familiarity with this data format, the following presentation of the central findings of the analysis will open with a detailed discussion of some important background findings concerning the overall benefit of mutual support.

### Disrupted CSC3 Rapidly Degrades Mutual Support

Each combat unit was assumed to come equipped with the same supply and maintenance resources whether under the self-sufficiency or mutual support base case. The difference lay in how these resources were managed. Figure 1 displays scaled FMC aircraft curves for the wartime portion of the scenario depicting the outcomes of the three principal bounding assumptions about resource management. The points on the abscissa refer to the ends of the indicated days, so the war begins at close of day 20 (or start of day 21). The upper curve gives the number of FMC aircraft per 24 PAA squadron in the mutual support base case, the bottom curve the FMC aircraft in the self-sufficiency case. The difference between the two curves assesses the benefit attained from uninterrupted mutual support, which at day 30 is a little under three (2.94) FMC aircraft per 24 PAA squadron.

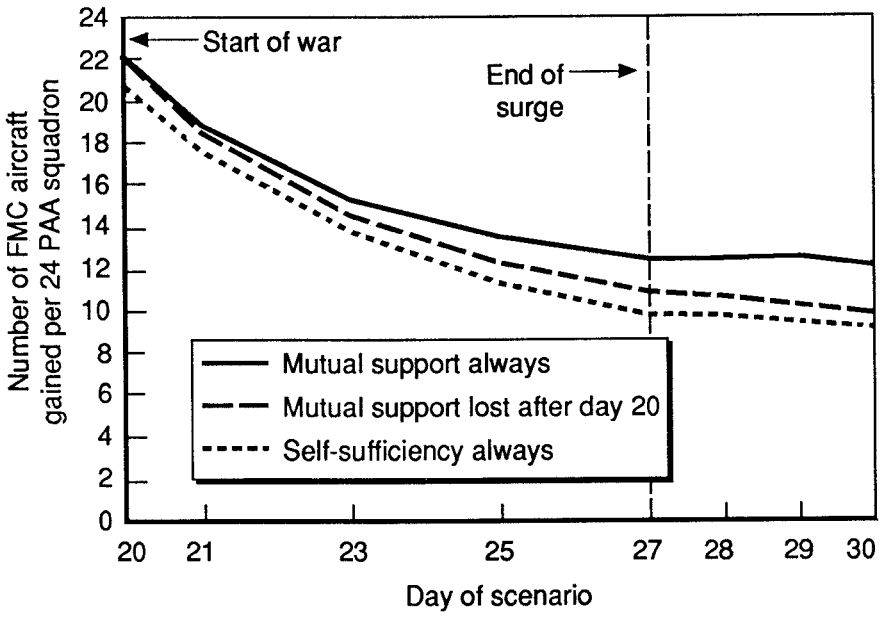


Fig. 1—Effect of losing mutual support at the outbreak of war

Based on PAA, this day 30 benefit comes to about 12 percent. But since combat attrition commenced at the start of war on the 21st day, the number of aircraft possessed at close of day 30 is less than 24 per squadron. As a percentage of *possessed* aircraft, therefore, the advantage of mutual support at day 30 is materially greater than 12 percent. This inflationary effect of attrition on percentages reinforces the decision to present scaled raw data instead. Whereas percentages depend on the choice of denominator, an additional FMC aircraft remains an additional FMC aircraft. Moreover, App. B shows that when performance is measured in raw numbers of FMC aircraft, attrition appears to have negligible influence on mutual support benefit.

The main message of Fig. 1 is expressed by the middle curve, which indicates what happens if mutual support is practiced during mobilization, then abruptly terminated when war begins. It is seen that the combat force remains somewhat better off to have conducted mutual support if only during mobilization, but loss of mutual support at war's outbreak leads to rapid decay of prospective benefits. By day 30, only

a little over one-fourth of the potential benefit, or 0.83 FMC aircraft per 24 PAA squadron, is preserved.[1] The obvious implication is that it is important to hedge against loss of CSC3 in the turmoil of combat.

It is of interest, consequently, to identify the most austere form of CSC3 still capable of yielding good mutual support results, which is the main object of the present section. If total loss of CSC3 occurs, the middle curve of Fig. 1 tells the story. But if lesser degrees of disruption are met with, there may be workarounds that can be used to lessen the gap between the middle and top curves.

## Effect of Base Size on Mutual Support

An important characteristic of mutual support is that small units reap greater benefits than large ones because even in a self-sufficient mode of operation, large bases already engage internally in the equivalent of mutual support. One of the units in the current scenario, for example, is a 72 PAA wing at a single MOB, and the three squadrons constituting this wing share in the aggregate base supply and repair resources under self-sufficiency much as would three separate COBs participating in mutual support. Indeed, absence of any interbase travel time penalty causes the MOB's internal mutual support to be more efficient than that of three disparate COBs.

Figure 2 portrays this effect of scale by dividing the bases of the scenario into those housing single squadrons and those accommodating larger, multisquadron units. This time the vertical axis shows the benefit of mutual support—i.e., the number of FMC aircraft *gained* per 24 PAA squadron, rather than the total number available—and the abscissa spans the full 30-day scenario. The upper curve reflects the average benefit realized by lone squadrons, the lower curve the average benefit received by the larger bases. The center curve is the mean of the other two (weighted by force size), or the benefit to the force as a whole. Thus, for the wartime period, day 20 through day 30, the middle curve is simply the difference between the top and bottom curves of Fig. 1 earlier.

This comparison between lone squadron and multisquadron bases is confounded in that both groupings are mixtures of units of varying size that are differently equipped with supply and maintenance resources. Still, the day 30 benefit to single squadrons of about four FMC aircraft is nearly twice the benefit to the larger bases, a difference too dramatic

[1]It is not so much that the benefit of mutual support declines precipitously if CSC3 is eliminated as that it ceases to increase. In fact, of the benefit realized by day 20, which amounts to 1.68 FMC aircraft per 24 PAA squadron, only about half (0.85 FMC aircraft) disappears over the ensuing ten days after losing mutual support.

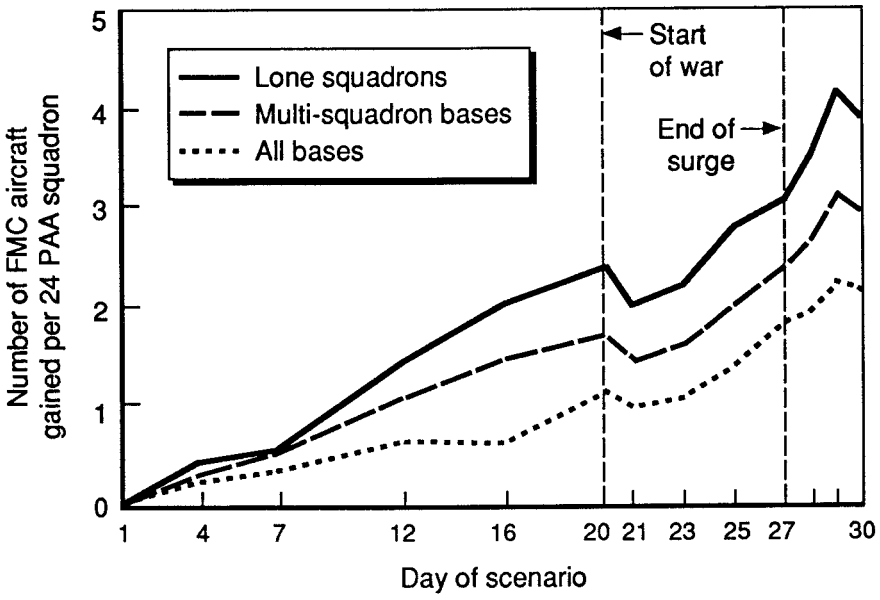


Fig. 2—Effect of unit size on the benefit of mutual support

to be accounted for by data confounding alone. The outcome of mutual support in a complex scenario such as the one here depends clearly on the mix of base sizes represented. A more precise quantification of the role played by base size is contained in App. B.

## Trial-to-Trial Variability

As Dyna-METRIC 6.3 is a Monte Carlo simulator, the data points in Figs. 1 and 2 are mean values of repeated random trials. In actual crisis, the force in question would experience not the mean result, but a situation more like one of the individual trials. It is pertinent to inquire, therefore, whether mutual support yields Dyna-METRIC trials that are closer together than in self-sufficient operation. That is, in addition to enhancing the FMC aircraft availability expected on the average, does mutual support also increase a commander's confidence that what will happen in a unique crisis will be close to the average result?

The answer seems to be partly "no" and partly "yes." Because measures of trial-to-trial variability vary markedly with unit size, the lone squadrons of exactly 24 PAA were singled out for separate analysis, thereby allowing the discussion of variability to stay consistent with the data scaling convention described above. Table 3 reveals that the average benefit of mutual support for these squadrons at day 30 was a highly significant 3.67 FMC aircraft (11.65 – 7.98),[2] but that the average standard deviation across 25 trials differed only minutely (0.10 FMC aircraft) between the mutual support and self-sufficiency base cases. In terms of absolute variability, therefore, mutual support was found to have little effect.

An alternative, and perhaps better, way to think about variability, however, is from the point of view of the coefficient of variation, $V$, which is the ratio of the standard deviation to the mean of a distribution, expressed as a percentage. For mutual support, $V = 24$ percent, a value appreciably smaller than the $V$ of 36 percent for self-sufficiency. Thus, relative to the mean, individual trial outcomes are considerably less variable under mutual support.

A practical translation might be that under self-sufficiency, the commander of a 24 PAA squadron would have about a two-thirds probability at day 30 of seeing a range of 5–11 FMC aircraft, whereas under mutual support the corresponding range would be 9–14 aircraft.[3] Although these ranges of uncertainty are about the same, the mutual

Table 3

DAY 30 AIRCRAFT VARIABILITY FOR 24 PAA SQUADRONS, MUTUAL SUPPORT vs. SELF-SUFFICIENCY, 25 TRIALS

| | Mean FMC A/C | Standard Deviation | Coefficient of Variation (%) |
|---|---|---|---|
| Mutual Support | 11.65 | 2.74 | 24 |
| Self-Sufficiency | 7.98 | 2.84 | 36 |

[2]Appendix A explains the rules followed in this report in drawing inferences about the statistical significance of Dyna-METRIC outputs. Based on the data of Table 3, for the average lone squadron of 24 PAA, the estimated standard error of the benefit is less than 0.81, rendering the benefit of 3.67 FMC aircraft more than 4.5 times its standard error. For precision, a $t$-test like this should be done, but was not, for each lone squadron separately rather than by averaging the squadrons together.

[3]The ranges expand, of course, as the confidence level increases. At the 90 percent confidence limit, for example, the corresponding ranges of uncertainty would be about

support case, with reasonable assurance of at least nine FMC aircraft, would afford far greater flexibility in operations planning.

## DISRUPTIONS AND WORKAROUNDS

### Overview of Core Results

Figure 3 summarizes the core findings of the study with respect to CSC3 disruptions and workarounds. The information in the figure is arrayed to match the outline of disruptions and workarounds in Table 1. The data represent performance at day 30, and the graph refers, as in Fig. 2, to mutual support benefit. Unimpaired mutual support is assumed to have been in operation during mobilization, with the disruptions listed at left of the figure taking place on day 21, immediately following the onset of war.

The top and bottom bars delineate the worst and best cases, respectively. As remarked previously, the worst case, total loss of communications and transportation, leaves a residual benefit of 0.83 FMC aircraft at day 30. This residual furnishes a suitable baseline, marked by the dashed vertical line, for evaluating workarounds in the face of disruptions that are less than total.

### Manual Transport of Data

The first such disruption (second bar from top of Fig. 3) assumes that electronic communications are lost completely but that two-day transportation between bases is retained. In the workaround, data concerning asset status are carried manually to the CSC3 decisionmaker and arrive two days out of date. The effect of this workaround is to increase the benefit of mutual support to 2.31 FMC aircraft per 24 PAA squadron, only 0.63 aircraft short of the 2.94 FMC aircraft benefit attained in the mutual support base case. Measuring from the comparison baseline, manual transport of data with two-day transportation time does about 70 percent as well as uninterrupted mutual support.

The same effect as the foregoing would be seen if electronic data communications were not lost but only delayed two days owing to priority restrictions or overloading of facilities. However, in circumstances where data-grade communications are not eliminated, neither, probably, would be message-grade communications; and if that

3–13 FMC aircraft under self-sufficiency, and 7–16 aircraft under mutual support. These figures should not be taken as precise, however, in that they assume the trial-to-trial FMC aircraft data to be distributed exactly as Student's $t$.

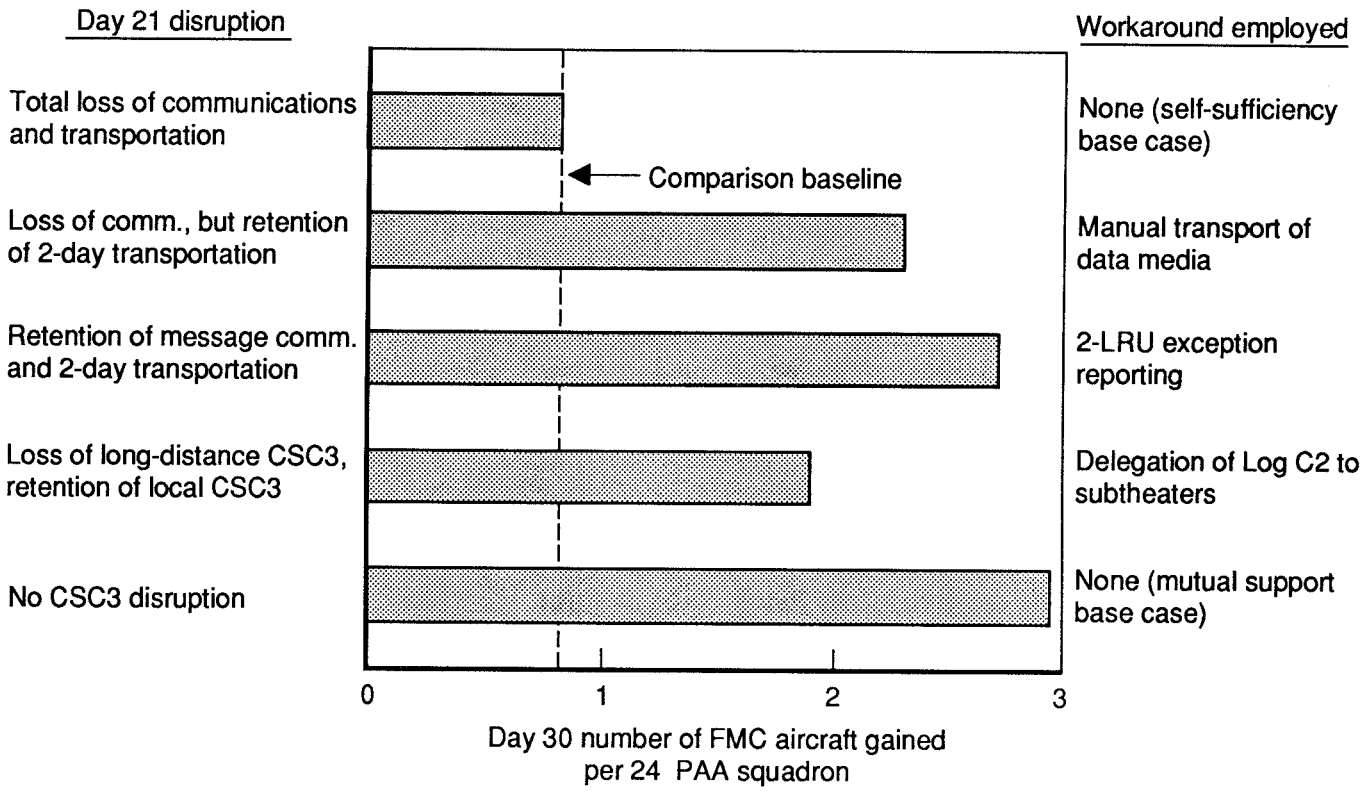


Fig. 3—Effectiveness of workarounds in response to CSC3 disruptions

were so, a better workaround would be available, as shown by the middle bar of the figure, in the form of exception reporting.

## Exception Reporting

Exception reporting presumes that a complete picture of theater assets exists at the CSC3 oversight function as of the close of day 20. From then on, each base updates its asset status once a day by reporting only the number of aircraft possessed, the number that are FMC, and the LRUs most responsible for NFMC aircraft status.[4] The center bar of the figure gives the result for two-LRU exception reporting. Daily reporting of just the two most troublesome LRUs per base produces a mutual support benefit only 0.22 FMC aircraft per 24 PAA squadron below the mutual support base case. Again measuring from the comparison baseline, exception reporting of two LRUs yields 90 percent as large a benefit as full mutual support. Reporting of greater numbers of LRUs further improves the merit of this workaround. For instance, ten-LRU exception reporting (not shown) brings the benefit of the workaround to 97 percent of that of full mutual support.

If the CSC3 decisionmaker starts out with perfect information about theater assets, then begins to receive updates through exception reporting only, theater-level knowledge of asset details is bound to deteriorate over time. To ascertain what effect this deterioration might have on the efficacy of exception reporting over a longer interval, the scenario was extended to day 50—i.e., 30 days of war following the mobilization period—with findings as in Fig. 4. As shown, two-LRU exception reporting remains virtually as effective at day 50 as the mutual support base case.

The extended scenario of Fig. 4 is not, it should be noted, a continued unfolding of the WMP or Air Force logistics support plan, but rather a straight extrapolation of events as they were occurring at day 30. Thus, depot support from CONUS stays cut off, and no filler aircraft arrive to replace combat losses.[5]

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[4]One can conceive of employing exception reporting throughout the scenario rather than just from day 21 onward. In the confusion and crush of a large-scale mobilization, it is possible that CSC3 would become jammed and unserviceable before the outbreak of war. Limits on the study had to be drawn somewhere, however, so excursions along this line were not pursued.

[5]The benefit of mutual support is greater at day 50 than at day 30 by approximately one FMC aircraft per 24 PAA squadron. Why this should be so bears further investigation. The hypothesis would be that as the scenario progresses and base stocks become increasingly depleted, about the only way to repair a newly NFMC aircraft is to obtain a part from someone else.

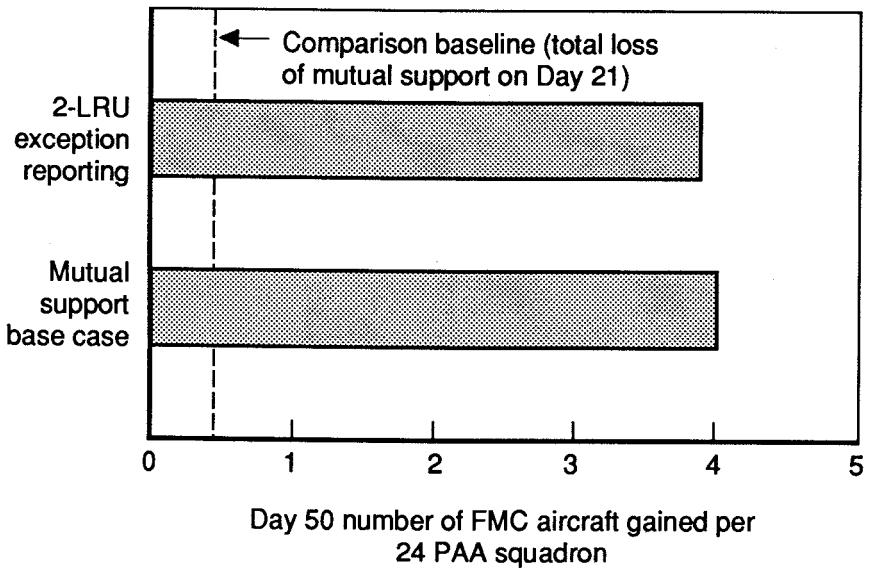


Fig. 4—Results of 30 days of exception reporting

## CSC3 Regionalization

In the event of losing long distance communications or transportation while retaining local capabilities, the workaround considered was delegation of logistics command and control to four geographical subtheaters corresponding generally to USAFE wartime plans and arrangements for EDSA and Logistics Readiness Center (LRC) regionalization. The only consequence of such regionalization for mutual support would be to curtail its scope of operations.[6] Bases in Turkey, say, no longer could exchange spares with bases in Norway.

However, as shown by the next to bottom bar of Fig. 3, the inhibiting effect of reduced scale on lateral redistribution and repair is rather powerful. Once more measuring from the comparison baseline, Log C2 delegation generates only 51 percent of the mutual support benefit obtained in the mutual support base case. Although not to be shunned in time of need, Log C2 delegation is by far the least attractive of the workarounds explored.

[6]Regionalization also might reduce transportation time, but the two-day base case figure was retained here.

The loss of scale arising from regionalization of CSC3 is compounded in the current scenario by the simultaneous presence in most of the regions of both A/B and C/D F-16s, the two configurations sharing only 45 percent of their LRUs. Had only a single configuration been involved, or had bigger regions been employed, Log C2 delegation undoubtedly would have proved more beneficial.

### Conclusion

The message of Fig. 3 seems to be that whereas it is important to retain mutual support on as large a scale as possible, this can be done, through exception reporting, with communications capability of message caliber only. The constraint most likely to be encountered, therefore, is lack of assured transportation. In all but the self-sufficiency case, the CSC3 variations in Fig. 3 presume items can be moved between bases anywhere in the theater in two days' time. An analysis of the effects of varying this transportation time appears in App. B.

## LATERAL REDISTRIBUTION vs. LATERAL REPAIR

### AIS vs. Non-AIS LRUs

To ascertain the relative contributions made by lateral redistribution and lateral repair to the benefit of mutual support, a variation on the mutual support base case was run in which lateral repair was suppressed. From this came the unexpected finding that 86 percent of the total benefit of mutual support at day 30 derived from lateral redistribution alone. Only 14 percent, or 0.41 FMC aircraft per 24 PAA squadron, could be attributed to lateral repair.

The reason for this ineffectiveness of lateral repair is that the components mainly responsible for NFMC aircraft at day 30 were not reparable at base level in the first place, because of maintenance policy. Thus, the broken parts holding aircraft down were primarily parts that lateral repair is unable to do anything about.

When a component cannot be repaired at a given level of maintenance, it is declared not repairable this station (NRTS). A high NRTS rate for a part implies that only depots (or manufacturers) have full facilities to fix the item. Table 4 reports the intermediate (base) level NRTS rates for the 353 LRUs subjected to Dyna-METRIC analysis.[7] Because of gross differences between the two groups of components,

[7]Dyna-METRIC decides whether to NRTS a component by simulating a coin toss with $p$ equal to the component's NRTS rate. In the present study, a NRTSed part in

Table 4

NRTS-RATE DATA, AIS vs. NON-AIS LRUs

| Type of LRU | Number of LRUs | NRTS Rate = 100 | Median NRTS Rate |
|---|---|---|---|
| AIS | 63 | 2 | 0.28 |
| Non-AIS | 290 | 116 | 0.96 |

data are presented separately for AIS and non-AIS LRUs. For the non-AIS parts 116, or 40 percent, cannot be repaired at base level at all, and the median part[8] can be fixed there only 4 percent of the time. In the case of AIS components, by contrast, only two of the 63 cannot be serviced at base level, whereas the median part can be repaired there 72 percent of the time. Clearly, unless a handful of the non-AIS LRUs with lower NRTS rates are major causes of NFMC aircraft, intermediate maintenance is bound to be of small value for other than AIS parts.

Dyna-METRIC's output identifies the components at each base most responsible for that base's NFMC planes on any given day. In the mutual support base case, the two most troublesome parts on day 30 at almost every airbase were high NRTS-rate, non-AIS LRUs. With the exception of two parts having NRTS rates below 0.20, all NRTS rates for the troublesome parts ranged from 0.83 to 1.00. Much the same also was true in the self-sufficiency case except for a single airbase where AIS LRUs stood out as the two main NFMC aircraft causes.

There was, moreover, no peculiar subset of the high NRTS-rate, non-AIS items that could be earmarked for specific remedial attention, for no single component turned up consistently within any airbase as a primary culprit across Dyna-METRIC trials. In terms of causing NFMC aircraft, no LRU was the worst offender at any base on as many as 25 percent of the simulation trials run. Hence, on any individual trial—which is all that actual war would afford—the likely causes of NFMC aircraft would be impossible to predict. However, one

effect disappeared from the scene. Under self-sufficiency, units at COBs could not repair AIS components whether NRTSed or not, so non-NRTSed AIS reparables simply would pile up to await arrival of the AIS's ATE. In all other cases, parts not NRTSed were repaired as described in Sec. II.

[8]If the components in either row of the table are rank ordered by NRTS rate, then the median part is the one at the 50th percentile.

LRU did turn up as a leading cause of NFMC aircraft at several airbases and on that account suggests itself for possible further consideration. It is a component involved in aircraft environmental control and has a NRTS rate of 0.86.[9]

Base-level repair of non-AIS components was unconstrained by any limitations on repair capacity. Now it is seen, inasmuch as little such capacity exists, that constraining it would have made at most a small difference. The items for which intermediate level repair capability is not available produced the greatest problem.

Since repair provides a portion of the parts available for redistribution, one might expect to observe a form of synergy when lateral repair and lateral redistribution are operating simultaneously. In this study, however, the effects of the two processes were found to be almost exactly additive.

## Comparison with the Uncertainty Study

Contrary to the 14 percent above, the uncertainty study (Seaquist, 1988) found 33 percent of the benefit of mutual support at day 30 to be owed to lateral repair. There were, however, several procedural differences between that study and this one. Among these were a VTMR of 4.00 fpfh and demand rates for AIS components 30 percent higher than here.[10] To achieve better comparability, an excursion on the present scenario was run incorporating these uncertainty study parameters. This led to a slight but insignificant increase, from 14 to 16 percent, in the proportion of mutual support benefit attributable to lateral repair.

The important difference from the previous research, therefore, is that the uncertainty study addressed AIS components only. Since most of these items are highly reparable at base level, lateral repair proved of considerable value in correcting NFMC conditions. In the present analysis, however, non-AIS components with high NRTS rates were chiefly responsible for NFMC aircraft status at day 30. Presumably, the latter situation is the one more likely to prevail in practice.

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[9]Still, some LRU in any list of offenders has to be the worst of the lot. This does not necessarily make the item a problem.

[10]The Air Force omits bench check serviceables in computing demand rates for AIS components (but not for other components). The heightened demand rates in the uncertainty study were to compensate for these omitted BCSs.

# IV. IMPLICATIONS

## CSC3 REQUIREMENTS

### Historical Note

Writing over 30 years ago about CSC3 requirements for intercontinental ballistic missiles (ICBMs), Geisler (1959) observed, "Uncertainty is the characteristic environment within which logistics decisions must be made," adding that logistical uncertainty probably cannot be met, even in the case of single-sortie ICBMs, by "having everything everywhere." Rather, a "highly responsive communications and control system can, and probably must, substitute for such a large stockpiling of resources throughout the system."

Now the USAF Log CONOPS calls for changes in combat support methods calculated to make this prophecy come true. The aim of this study has been to discover what specific requirements must be satisfied by the "highly responsive communications and control system" foreseen by Geisler.

### Mutual Support Data Requirements

**The Reactive Case.** The appropriate rules for cannibalizing one aircraft to fix another within an individual base are obvious to the personnel involved and simple enough to require no data mechanization. To extend the cannibalization process across bases would complicate matters only to the extent of requiring someone in charge to keep track of interactive events taking place among several locations. The problem would get larger, but not intellectually harder.

Inasmuch as lateral redistribution is analogous to cannibalizing one organization's stocks to replenish those of another, the rules for lateral redistribution are not very difficult either, nor are the Dyna-METRIC algorithms that simulate mutual support, explained more fully in App. A. In practice, a computer would facilitate the necessary computations, but they could be readily performed as well by a clerk at a greaseboard.

During surge warfare, the 229 LRUs of the F-16 A/Bs in the present investigation would generate an average of about 40 new demands per day per 24 PAA squadron. This figure approximately bounds the number of data records a base would have to transmit to the CSC3 decision function to carry out mutual support as simulated here (see App. A). Even if on a given day the transmission requirement were

many times 40 records per base, elaborate communications capability still would not be essential. Message-grade facilities can pass many hundreds of records per hour.

**The Proactive Case.** A two-day transportation time was adopted as the base case ideal value for this study. Hence, a component supplied through lateral redistribution never arrived at destination until two days after it was needed. If proactive redistribution were undertaken, as by the DRIVE algorithm (Abell and Lippiatt, 1990; Tripp, Berman, and Tsai, 1990), demands would be forecast two days beforehand and items shipped to arrive just in time. Lateral repair would be handled similarly, except that the forecast of demands would be projected to cover expected repair times in addition to transportation time.

Although the analysis did not address the communications and computing capabilities necessary for proactive mutual support, it is apparent these would be greater than required for the reactive system treated. Data-grade communications from computer to computer probably would be essential rather than just a convenience. Therefore, the decision whether to install such facilities would hinge on the added benefit to mutual support occasioned by a proactive system.

As far as lateral redistribution is concerned, the best performance a proactive system could produce, assuming a needed component is available in theater, would be to deliver that component to an NFMC aircraft the instant the broken part is removed. Dyna-METRIC can simulate this kind of perfect responsiveness by reducing the interbase transportation time to zero. Appendix B reports the results of such an excursion as part of a more general analysis of transportation time effects.[1] Zero transportation time was found to increase the benefit of mutual support by 0.47 FMC aircraft per 24 PAA squadron, or 16 percent, above the base case value of 2.94 FMC aircraft per squadron.[2]

The amount of benefit potentially added by proactive CSC3 depends heavily on transportation time. Under four-day transportation, double the base case value, perfect proactive CSC3 might enhance the benefit of mutual support by up to 1.17 FMC aircraft per 24 PAA squadron, 52 percent over the benefit of 2.24 under reactive CSC3. With ten-day transportation, the conceivable range of improvement would be 255

[1]Perfect responsiveness in lateral repair likewise can be simulated by reducing LRU repair times to zero. However, since lateral repair makes a fairly small contribution to the benefit of mutual support, excursions with zero repair times were not run.

[2]Figure B.6 of App. B offers persuasive evidence regarding the statistical reliability of the generic functional relation between increasing FMC aircraft performance and decreasing transportation time. As it happens, the specific change of 0.47 FMC aircraft cited here also is statistically significant well beyond the 90 percent confidence level, the choice of which criterion is explained in App. A.

percent.[3] Accordingly, a realistic estimate of wartime transportation capability would play a part in any tradeoff decision.

## Exception Reporting

Short of implementing proactive CSC3, the data and communications capabilities needed to support lateral supply and repair of aircraft components in a theater of combat appear less formidable than heretofore imagined. Owing to the potency of exception reporting in keeping aircraft FMC, not even continuous total visibility at theater level over base assets seems required. Given a snapshot of theater asset status to start with, daily reporting of only the two components at each base most responsible for NFMC status was found to suffice for mutual support and to hold up well over long periods. This suggests that CSC3 requirements could be served adequately in the NATO arena, or any other large-scale combat theater, by a data and communications facility on the order of USAFE's EDS Log C3 system (Duda, 1987; GAO, 1986). Also probably adequate would be a system such as AAFCE's[4] EIFEL, used by USAFE in the command and control of air operations.

The reason exception reporting worked so well in Dyna-METRIC undoubtedly is that the number of components involved in mutual support on any given day was small. As was mentioned, the new demands for spare parts within a 24 PAA squadron might total to 40 or thereabouts on a day of surge flying. Of these 40 demands, most are filled from local stocks (including, at a MOB, LRUs exiting from intermediate repair), others are satisfied by local cannibalization, and some cannot be met at all by resources available in theater. Only the remainder are candidates for lateral sharing, and it is only these exceptions for which mutual support C3 is required. As a result, there was little for Dyna-METRIC's all-seeing eye to keep track of, which naturally casts question on the need for an all-seeing eye.

Some interesting issues for empirical research therefore arise concerning the efficacy of informal mutual support as practiced today and in the past, and the type of management facility required to administer mutual support in peace and war. How well do the simulations reported here mirror Air Force reality? How many new demands for LRUs actually emerge in a day of surge flying, and how variable is this number? How many of these demands are satisfied, or could be

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[3]These figures may be misleading in that perfect proaction implies exact prediction of future needs, and exact prediction of an event becomes less probable the farther away the event is in time. Prediction of spare parts demands is an especially uncertain enterprise in an already uncertain world.

[4]Allied Air Forces Central Europe.

satisfied, by mutual support? How many lateral exchanges were carried out per day per squadron in USAFE when EDSA was operative? How many are carried out now, and what is the interbase transportation time today? How much lateral exchange takes place among CONUS bases, and how fast is the available transportation? In short, exactly how does the present system of mutual support operate throughout the Air Force, and how much leverage is there for improvement through better administration, transportation, and communications?

### Study Limitations

Appendix B provides encouraging evidence of the generalizability of the present findings beyond the specific scenario simulated. Nevertheless, the study was limited in scope, and there are several notable ways in which CSC3 capabilities could be taxed beyond the levels explored. Further investigation of these complicating factors is indicated. They include:

1. Expanding mutual support to include components common to different airframes, such as accessories for the F-100 engines that power both F-16s and F-15 Eagles.
2. Extending formal mutual support to cover other combat-essential commodities such as POL (petroleum, oil, and lubricants), munitions, flightline ground equipment, TRAP (tanks, racks, adapters, and pylons), civil engineering equipment, and medical supplies.
3. Internationalizing mutual support to include American weapon systems also owned and operated by allies, such as the F-16 A/B and the C-130 Hercules.
4. Integrating mutual support with depot resupply and maintenance, perhaps to include shortening of the 30-day depot cutoff postulated here.
5 Extending lateral repair theaterwide, MOB to MOB as well as COB to MOB.
6. Extending mutual support across multiple theaters of operation.
7. Instituting proactive CSC3.

Besides the preceding research extensions, there remain important needs for field studies to confirm that the findings of Dyna-METRIC simulations match reality and offer appropriate directions for implementation efforts. Some questions along these lines have been raised above; more are introduced below.

## INTERMEDIATE LEVEL REPAIR POLICY

Because they are expensive and hard to troubleshoot, AIS LRUs have received the lion's share of attention in recent years from logistics researchers and practitioners. Yet, according to the present analysis, AIS parts are not the foremost causes of NFMC aircraft. With negligible exceptions, the chief contributors to NFMC status were determined to be non-AIS LRUs with high (above 0.80) NRTS rates, items that only rarely can be repaired at base level. It appears that providing for supply and maintenance of base-reparable LRUs has been done so well that priority might be shifted to this other component area.

Whether the NFMC-causing behavior of non-AIS LRUs should be regarded as a problem is a matter of perception. Every broken airplane has to be down for some reason, and all this study says is that the predominant reason was other than AIS parts. Even so, in the self-sufficiency base case, there were fewer than six NFMC aircraft per 24 PAA squadron at day 30; and in the mutual support case, fewer than three. Once mutual support is operative, the margin for further improvement is limited. But if the Air Force logistics community wants to do even better than now with respect to wartime supply and maintenance, the high NRTS-rate, non-AIS arena is evidently the place to turn.

A major step in response to former maintenance problems with AIS LRUs consisted of equipping individual combat units with their own AIS ATE. This equipment is expensive, subject to maintenance problems of its own, and requires three C-141 loads to transport per deploying F-16 squadron. Moreover, it is not delivered to the base until approximately the 30th day of deployment.[5] Also, as shown above, the repair it provides appears not all that valuable compared with lateral redistribution.

The latter conclusion is further supported by Appendix Fig. B.12, which separates the bases of the scenario into those giving lateral repair and those receiving it. Even the receiving bases obtain only 28 percent of their total day 30 mutual support benefit from lateral repair, the other 72 percent arising from lateral redistribution. Although excursions were not run to test the proposition, it is doubtful that the receiving bases would have gained a great deal of additional benefit from intermediate repair had they possessed their own AISs. Hence, inasmuch as depot resupply is slated to come into play after day 30, further study seems indicated into the cost-effectiveness of delivering

[5]The F-15, whose AIS is deployed early, is an exception.

squadron AISs to combat theaters to all.[6] Of course, the squadron AIS does afford a degree of hedge against continued disruption of depot resupply beyond 30 days and, in the case of units deploying their AISs early, the unavailability of lateral redistribution in the first weeks of a crisis.

Nevertheless, if supply and maintenance of non-AIS items are to be improved, pushing greater repair capability down to intermediate level might not be the way to go.[7] More promising might be to consider ways of achieving greater responsiveness from resupply sources not currently available in theater. These would include CONUS depots; forward stockage facilities, such as Support Group Europe at RAF Kemble in the UK; other combat theaters; and foreign sources, such as allied air forces and host-nation parts banks. Although quantitative assessment of the potential benefit was not carried out, it seems obvious that more timely resupply of high NRTS-rate parts could make an important contribution to improving aircraft FMC rates. Accordingly, additional simulation research is indicated to model the depot resupply process and study the effect of reducing resupply cutoff below the 30 days assumed here.

For openers, field studies should be done to ascertain whether high NRTS-rate components are really the chief culprits in NFMC aircraft status or whether other factors not examined in the present research are more significant. If the simulation findings are confirmed, then practice deployments might be carried out, roughly along the lines of the Coronet Warrior exercises (Rhodes, 1988), to assess the affect on FMC performance of AIS repair as provided both laterally from another base and organically at squadron level.

## OTHER CONSIDERATIONS

### Unit Size

There can be no question that mutual support is of greatest value to small units. Consequently, USAF should continue paying particular heed to CSC3 in relation to scenarios where fairly dispersed operations are envisioned, for example in the NATO COB arrangement.

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[6]The problem would be to make depot resupply responsive enough to compete with base-level AISs in regard to turnaround time. Since repair ought not take any longer at a depot than at a base, the tradeoff issue would be mainly one of fast materiel shipment between depots and bases.

[7]Especially in that no specifiable subset of non-AIS components dominates the scene. Generic capability at base level to repair many kinds of parts would be required.

Moreover, with large withdrawals of forces from overseas bases imminent, the prospect of fighting future wars with units of squadron size or smaller, scattered across several austerely equipped bases, appears very much in the cards.

Also, with increased emphasis on the Reserves and National Guard, the disposition of forces within CONUS is likely to become more dispersed and the average base smaller than now in terms of PAA. Thus, a formal process of peacetime mutual support within CONUS could prove economically attractive. This would allow peacetime implementation and exercise of the very same type of CSC3 system that could turn out to be invaluable in war.

### Transportation

Appendix B shows that each increase of one day in interbase transportation time brings about a decrease of about one-fourth FMC aircraft per 24 PAA squadron in the benefit of mutual support at day 30. Fast, assured transportation is therefore a vital factor in making effective use of CSC3, a finding that reinforces the extensive analytic and implementation efforts put into EDSA over the past decade and more.

Furthermore, it would appear, the transportation system needs to be kept as broad based as possible to gain maximum advantage of scale. Regionalizing into four autonomous subtheaters as in Fig. 3 chopped the benefit of mutual support approximately in half. If, in consequence, a multiple hub-and-spoke form of operation is employed, attention needs to be paid to achieving speedy interaction both across spokes and between hubs.

## IMPLEMENTATION

### Basic CSC3 Requirements

As the first purpose of the study was to establish general requirements for a CSC3 system under the Log CONOPS, issues of implementation were addressed only to the extent of confirming feasibility.

To review, the findings indicate that the essential underpinnings for carrying out mutual support in a reactive mode are:

- Assured transportation capability, which in Europe would be along the lines of EDSA (or in peacetime, perhaps commercial express agencies).
- A theaterwide mutual support management agency along the lines, perhaps, of the USAFE LRC (the agency being greatly

simplifiable, even reducible to passive oversight, if exception reporting were adopted).

- Interbase message communications capability along the lines of the EDSA Log C3 system or the EIFEL system. If the communications facilities can support computer-to-computer data transmission, so much the better.

Should these capabilities not exist in peacetime, they need to be readily implementable at the onset of crisis. The transportation requirement is listed first because little or nothing can be done in the way of mutual support if it is not satisfied. Ground transportation alone might serve within geographical subregions, but in that case the loss of logistical operating scale would severely limit the benefits.

For maximum advantage in NATO, the C-23 Sherpas of EDSA should be augmented by aircraft having trans-Europe, transmountain capability. The latter capability would be needed likewise for mutual support applications in PACAF or, for that matter, in CONUS.

Exactly how the transportation network should operate to best advantage—whether radial or circular, scheduled or unscheduled, with or without dedicated ground supplementation—would require further analysis. Responsiveness, however, is vital. With base-to-base transportation much in excess of four days, the benefit of mutual support begins to fall to levels where reactive CSC3 may lose attractiveness.

### Communications and Administration

The limited amount of data exchange required to administer mutual support makes it unnecessary for the theater CSC3 management agency to process large volumes of information. Presumably, therefore, personnel involved would spend most of their time at communications terminals, which might be no more than telephones, acting as spare parts brokers. The primary difference between this and an informal system is only that the brokers would have a degree of command authority over their clients.

As far as communication with repair shops is concerned, if nothing better were available, voice facilities would be adequate, but repair shops would not have to be tied directly to the CSC3 management function. As long as the bases housing the shops were connected to the management agency, messages could be relayed without difficulty, even, in a pinch, manually.

All this assumes that data systems on the order of CSMS are operative in peacetime so that a comprehensive snapshot of theater asset status is available at the start of war for exception reporting to build

on. Since CSMS and related systems currently exist, no excursions were run to see what would happen in their absence. But even if communications should deteriorate during the mobilization period to render the initial picture of theater assets already out of date at war's outset, there still is every reason to believe (e.g., Fig. 4) that exception reporting would stand up sturdily.

Indeed, the power of exception reporting is so impressive that it is tempting to suggest running mutual support without any formal central management. If one is willing to settle for the small deterioration in FMC aircraft performance that may occur under exception reporting as opposed to full-blown CSC3, then maybe what the Air Force traditionally has done all along, especially given the rapid transportation formerly afforded within USAFE by EDSA, is nearly good enough. In the same vein, perhaps an LRC equipped with telephones, fax, and greaseboards is all the administrative capability required. Indeed, a daily round robin of messages among the participating bases conceivably could obviate the need even for an LRC.

# Appendix A

# CONCERNING DYNA-METRIC

## ENHANCEMENTS

### New Features

The objectives and basic principles of the Dyna-METRIC readiness assessment model are explained by Pyles,[1] and the technical characteristics by Isaacson et al.[2] The most recent edition of the model supported by published documentation is Version 5.[3]

As the present study, together with work by other investigators, required capabilities not available in former editions, Version 6 was undertaken. The present working version at RAND is Dyna-METRIC 6.3. Of its many new features, the principal ones the current analysis uses are:

- Data transmission delays rendering asset status information *n* days out of date. Under this feature, reports of base asset status received at the CSC3 decision function refer to conditions as they were *n* days ago. The purpose is to simulate communications overloads and interruptions, priority queueing of transmissions, and manual transport of data media.
- Exception reporting to ameliorate effects of data delays. Regardless of data transmission delays as above, partial reports of base asset status are permitted to be transmitted on an up-to-date basis (as if high bandwidth circuits were disrupted but voice/telex capability retained).
- Change of lateral repair affiliation in midstream. A base (e.g., a COB) connected to another facility (e.g., a MOB) for lateral repair may be detached and reconnected to a different repair facility at any desired point in a scenario. The application here was in regionalizing the whole theater into subtheaters on the 21st day of the scenario.
- Zero lateral redistribution time. To allow estimation of upper bounds on the benefit of lateral redistribution, instantaneous redistribution can be simulated.

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[1]Pyles, July 1984.

[2]Isaacson et al., May 1988.

[3]Isaacson and Boren, 1988.

- Random or deterministic loss of spare parts and repair capability. To simulate lost stock and repair capacity due to enemy interdiction or other causes, specified fractions of spares and repair equipment can be deleted at each airbase. The proportion destroyed of each stock item or each set of repair equipment may be either a fixed value or a random variable. The consequences of base damage are examined in side excursions covered in App. B.

### Base Damage

Damage may be inflicted separately, but one time only, on serviceable stock, repair facilities, and broken parts queued for repair. Any day of the scenario may be selected for each of these events. In App. B, all damage was inflicted on day 21.

To delete 35 percent of serviceable stock on day 21, as was done, is very different from destroying 35 percent of stock on day 1. The latter destroys a great deal of materiel; the former, in all probability, rather little.[4] However, ascertaining the absolute quantity of serviceable stock in existence on a given day of a Dyna-METRIC scenario (other than day 1) is exceedingly laborious and was not attempted in the present instance.

The capability to destroy stock queued for repair was not used. In the case of non-AIS LRUs, repair was unconstrained, so there were no queues. In the case of AIS ATE, whole stands of equipment were destroyed at a time. Once a test stand is gone, the carcasses queued for repair at that stand are equally useless whether destroyed or not. This is not quite true at repair facilities housing multiple strings of ATE, for then Dyna-METRIC diverts items queued at a damaged stand to another stand of the same type. Since the scenario included several facilities with two ATE strings, the findings of App. B pertaining to lateral repair under base damage may be slightly optimistic.

## PRIORITIZATION ALGORITHM

Section IV points out that even a day of surge flying creates an average of only about 40 new LRU demands per 24 PAA.[5] If the CSC3 oversight

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[4]At any rate, it had small effect on FMC aircraft availability. Appendix B shows that in the baseline case—mutual support for 20 days, self-sufficient operation thereafter—base damage reduced day 30 aircraft availability by only 0.70 FMC aircraft per 24 PAA squadron.

[5]As explained in Sec. II, only parts whose demands are related to flying hours were included in this study. An airplane has many hundreds of additional parts that can fail, and their inclusion would increase the total daily demand count. To be on the conservative side, therefore, the reader may wish to double or even triple the cited figure of 40.

function has an accurate picture of each base's asset condition at a given point and from then on is informed of each day's new demands, the decisionmaker can keep fairly accurate track of base stock levels, cannibalization activity, and NFMC aircraft status by logically second guessing the behavior of the base supply and maintenance personnel. Strictly speaking, therefore, the only communications required for mutual support are reports of combat attrition and new LRU demands.

Whenever an LRU is removed from an aircraft leaving a "hole" that cannot be filled from local parts stocks or by cannibalization, the CSC3 decisionmaker looks for a way to fill it through lateral redistribution or repair. In general, there are several new holes each day at each base, all competing for attention and requiring prioritization. The priority rule in Dyna-METRIC is to begin with whatever mutual support action promises to restore the most NFMC aircraft to FMC status, then take the action that will restore the next most NFMC aircraft to FMC status, and so on. Since the number of new holes per day is small, this prioritization exercise is not difficult and could be performed in a matter of minutes using pencil and paper.

If there were differential aircraft availability goals in the theater, the prioritization procedure would become slightly more complex, but only slightly. Suppose, for example, the objective is to have $x$ percent FMC aircraft availability in the center, but $y < x$ percent availability on the flanks. The prioritization algorithm then might resolve matters either by serving the center until it meets its goal, then turning to the flanks, or by serving first whichever sector is at any moment furthest below its goal. In either case, the necessary calculations would be simple to do.

Prioritization does not preclude low priority supply and repair activities from continuing. It is not that top priority actions are taken exclusively, only that top priority actions are taken first.

In exception reporting, all a base transmits each day to the CSC3 decision function are its attrition, any change in number of FMC aircraft, and some specified number of LRUs causing the most holes. The decision function has to draw inferences about everything else. For instance, if Base A is directed to send a part to Base B, but Base B continues reporting the same part as its chief problem, the decisionmaker infers that Base A is out of that part and so directs Base C to send one instead. As Sec. III shows, this process of partly factual reporting and partly inferring appears to work remarkably well.

## STATISTICAL INFERENCE

A Dyna-METRIC run consists of multiple random trials, the outputs of a run including the mean number of FMC aircraft and the

FMC aircraft variance across trials for selected days of the scenario. These data permit comparisons to be made between any two runs for a given scenario day by doing a *t*-test of the difference between uncorrelated means as explained in most statistics textbooks.[6] Where references to statistical significance appear in the report, it is this procedure that was followed.

A flaw in this approach is that the series of trials in any two runs are not independent but (in order that the results of each run be exactly reproducible on subsequent reruns) have been triggered by a common stream of random numbers; all runs start with the same random-number seed. Thus, the means of pairs of runs are correlated, but the degree of the correlation is not reported in current DynaMETRIC output and, in general, is prohibitively difficult to determine ex post facto. Consequently, the correlation term that should be used in estimating the standard error of the difference between two means has been omitted throughout.

The effect of this omission is to make all estimates of mean-difference standard errors larger than they should be, which renders all *t*-ratios smaller than they should be, which in turn makes all inferences about statistical significance conservative. That is, if the text says a mean difference is significant, then it probably is; and if a difference is said not to be significant, it very well may be. To counterbalance this conservatism, an unconservative 90 percent confidence level was adopted as the standard for the analysis.

All runs reported consist of 25 trials, which in the case of correlated means give 24 degrees of freedom for looking up levels of reliability in tables of the *t*-distribution. At the 90 percent confidence level with 24 degrees of freedom, a value of $t$ in excess of 1.71 is required for statistical significance. This criterion has been applied in all the report's statistical comparisons.

The *t*-test assumes normal distributions of the variates' parent populations, whereas in this study the obtained sample distributions frequently are skew, especially when the mean lies near a limit of a variable's range. Interest here, however, is in the distribution of trial-to-trial differences between pairs of runs, and distributions of differences often are found to approach normality even when the separate variable distributions do not. It has been assumed without evidence that this is the case in the present study. An empirical check of the distributions in question was too formidable a task to undertake.

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[6]Such as Guilford, 1956.

# Appendix B

# GENERALIZABILITY ANALYSES

## INTRODUCTION

Never are two combat scenarios identical in all details, nor would any given scenario be executed in war precisely as conceived. A question is in order, therefore, concerning the extent to which the findings of this study reflect generalizable principles rather than scenario peculiarities.

There are two sides to generalizability, one having to do with generic properties of the scenario, the other with experimentally uncontrolled variables within the scenario that may confound interpretation of results. These concerns will be considered in turn. Factors on which data will be reported are:

### Generic Scenario Characteristics

- Lost spares stock and repair capability.
- Combat attrition of aircraft.
- Deployment pattern and warning time.
- Component demand rates.
- Variance-to-mean ratios.
- Interbase transportation time.

### Confounding Factors

- Date of deployment.
- Aircraft configuration.
- Type of maintenance.
- Size of base.

## GENERIC SCENARIO CHARACTERISTICS

### Lost Spares Stock and Repair Capability

To determine how the findings of the study would bear up under increased stress on supply and maintenance resources, excursions were run against an assumption of lost spare parts stock and damaged repair equipment ostensibly arising from enemy attack.

**Damage Infliction.** In war, WRSKs are vulnerable to combat attrition en route to as well as after arrival at destination COBs, and both repair facilities and spares stocks at MOBs are subject to damage if attacked. Stock loss and repair facilities damage as several of studies employing the TSARINA computer model[1] have shown, are likely to be distributed in very unbalanced fashion. Some bases may absorb crippling damage while others go almost unscathed. Further, enemy attacks probably would not hit all at once but would strike different bases at different stages of the battle. As a result, it is difficult to know how to simulate base damage realistically.

This study elected to simulate a randomly inflicted distribution of damage in which the average base suffered 35 percent loss of its serviceable WRSK/BLSS/POS and 40 percent loss of intermediate repair capacity.[2] All losses occurred during day 21, taking their initial toll on FMC aircraft status at the start of day 22. In the case of serviceable stock, attrition was introduced binomially by item. If a specified base held a given component in quantity $N$, then the number destroyed of that part at that base became a binomial random variable with $p = 0.35$ and mean $pN$.

As for repair facilities, AIS ATE strings consisted of four test stands each. The number of stands of each string destroyed was decided in the same manner as preceding but with $p = 0.40$. In the case of non-AIS repair equipment, the capability to repair each type of non-AIS component was eliminated by simulated coin toss, item by item, also with probability 0.40.[3] More complete explanation of the base damage procedure appears in App. A.

**Findings.** Though anything can happen in war, the above level and form of base damage seems fairly severe. Yet only a modest effect on FMC aircraft performance was experienced. In the case, for instance, where mutual support is entirely lost after day 20, the day 30 difference

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[1]Emerson and Wegner, 1985.

[2]Although these parameters were formulated in light of previous TSARINA findings, they cannot be said to typify those findings. TSARINA outcomes vary so widely that practically any assumption about damage due to enemy attack would be supportable.

[3]Because of the high NRTS rates of these components, there was in most instances little or no non-AIS repair capability to destroy.

in FMC aircraft between the base damage and no-damage environments turned out to be 0.70 aircraft per 24 PAA unit. This is a noticeable (and statistically significant) reduction in capability but far from disabling.

This limited effect on FMC aircraft availability of a seemingly high level of base damage appears to reinforce the conclusion that the components likely to cause NFMC status are unpredictable. One cannot know, therefore, which items of stock will lead to deficiencies if lost. If all of an item is destroyed, demands may never arise for it; and if none of an item is destroyed, excessive demand for it may occur anyway. Thus, random destruction of stock may add only marginally to the uncertainty about NFMC causation already operative. Also, destruction of repair facilities has little adverse effect because the main causes of NFMC status are components having high NRTS rates.[4]

Since loss of stock and repair facilities did not have great effect on combat capability, mutual support might be expected to perform under base damage much as in benign circumstances; and that it did so is seen in Fig. B1, which is styled directly after Fig. 3 of Sec. III. It is assumed that full mutual support was enjoyed for the first 20 days, with CSC3 disruptions, as well as base damage, taking place during day 21. For reference, the vertical dashed line at right denotes the familiar day 30 mutual support benefit of 2.94 FMC aircraft per 24 PAA squadron in the benign-environment case.

The more stressful the environment, the better the benefits expected from mutual support, and, as anticipated, all the bars in Fig. B.1 are slightly longer than they were in the case of no base damage. In particular, the comparison baseline, which marks the residual benefit of mutual support at day 30 in the event of total cutoff on day 21, is 0.95 FMC aircraft per 24 PA squadron here, as against 0.83 FMC aircraft in Fig. 3 of Sec. III. However, the overall pattern of results in the two environments is almost identical. The mutual support system responded to disruptions and workarounds essentially the same as it did before. This suggests that all conclusions drawn about CSC3 disruptions and workarounds are generalizable to a base damage situation.

**Previous Research.** The RAND uncertainty study also investigated the effects of lost spare parts stock on FMC aircraft availability under both self-sufficiency and mutual support.[5] However, the results were sufficiently different from those here to raise questions for further resolution. The important quantities for comparison are given in

[4]If the destroyed repair facilities were to remain out of business indefinitely and not be backed up by responsive depot resupply after day 30, their absence surely would start to take a toll after a time.

[5]Unpublished RAND research by Cohen, Abell, and Lippiatt.

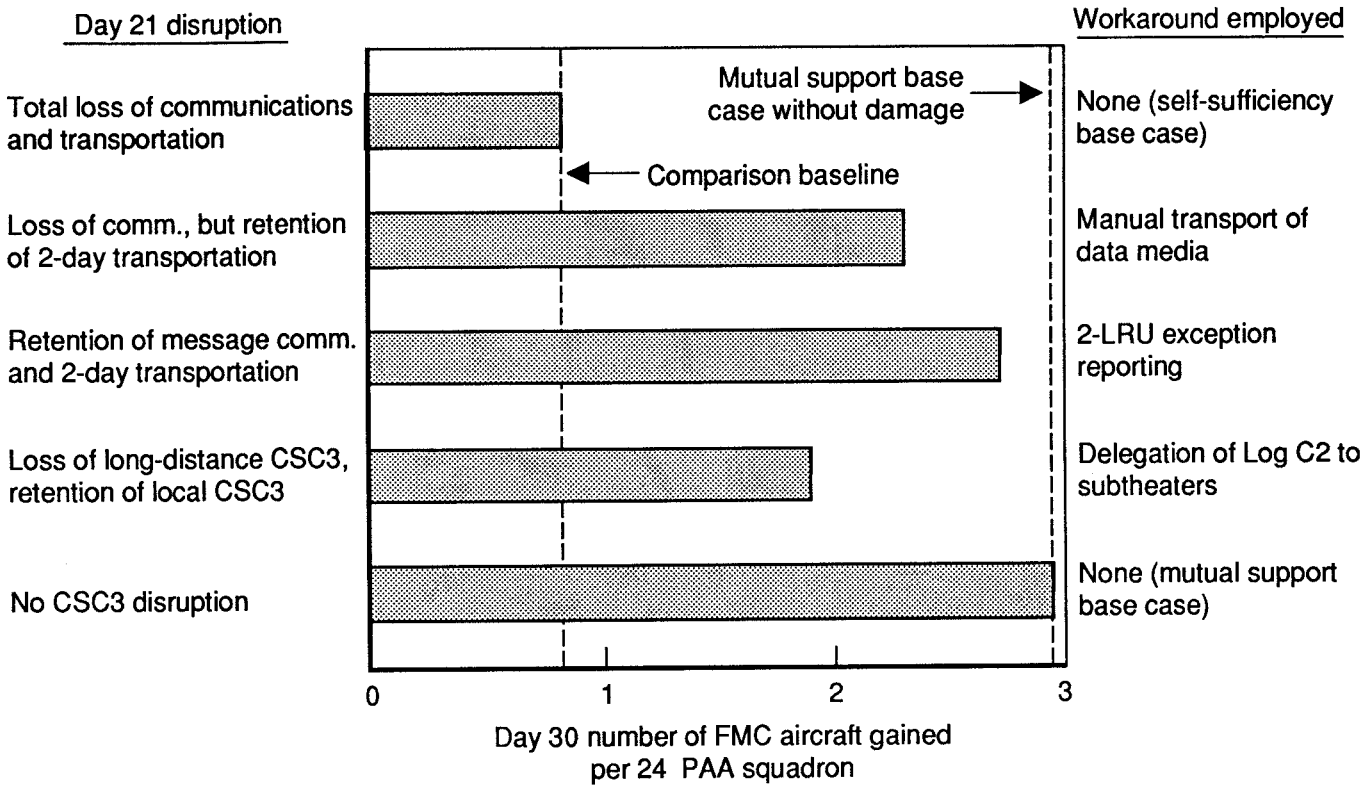


Fig. B.1—Effectiveness of workarounds in response to CSC3 disruptions, following partial loss of stock and repair capability

Table B.1. Case 1 and Case 2 refer to two different patterns of damage inflicted on spare parts stock in the uncertainty study.

The large difference in numerical magnitudes between studies[6] undoubtedly can be attributed to variations in scenario having to do with aircraft representation by kinds and numbers of LRUs, LRU demand rates and VTMRs, mobilization and deployment pattern, and how and when base damage was introduced. So many such variations occurred, however, that it is impossible to pinpoint exact reasons for the relative magnitudes without further research.

More important to the present discussion than numerical differences between studies is the seeming reversal in direction of the effect of base damage on the benefit of mutual support. Where in the present investigation the benefit remained the same under base damage (2.97 vs. 2.94 FMC aircraft per 24 PAA squadron), in the uncertainty study it declined (from 5.0 to either 4.1 or 4.3 FMC aircraft per 24 PAA squadron).[7] This leaves at issue how far one can generalize about the relation between mutual support and base damage. The direction of

Table B.1

EFFECTS OF BASE DAMAGE AT DAY 30, UNCERTAINTY STUDY AND PRESENT STUDY COMPARED

| | Uncertainty Study | | This Study |
|---|---|---|---|
| | Case 1 | Case 2 | |
| Reduction in FMC aircraft per 24 PAA squadron, self-sufficiency case | 1.7 | 2.2 | 0.70 |
| Benefit of mutual support: (FMC aircraft per 24 PAA squadron) | | | |
| Base damage | 4.1 | 4.3 | 2.97 |
| No base damage | 5.0 | | 2.94 |

[6]Supposing the uncertainty study experienced about the same trial-to-trial variability as the present investigation, all the differences shown would exceed four times their estimated standard errors.

[7]If, again, the Dyna-METRIC trials were about as variable in the uncertainty study as in the present one, then both declines would exceed twice their estimated standard errors.

change in benefit under base damage seems to vary with the scenario according to factors thus far undetermined.

## Combat Attrition of Aircraft

It is somewhat unusual to play aircraft attrition in a combat sustainability scenario as done here, but inclusion of WMP attrition factors does not appear to have had a notable biasing effect on main outcomes. This conclusion is inferred from Fig. B.2, which plots the mutual support benefit for the combat phase of the scenario. Any separation between the "with" and "without" attrition cases is scarcely discernible up to day 30, and even at day 30 the difference amounts to less than one-third of an FMC aircraft per 24 PAA unit. Since the latter difference is smaller than its estimated standard error (so does not attain statistical significance), the most tenable conclusion is that the two curves in the figure are the same.[8]

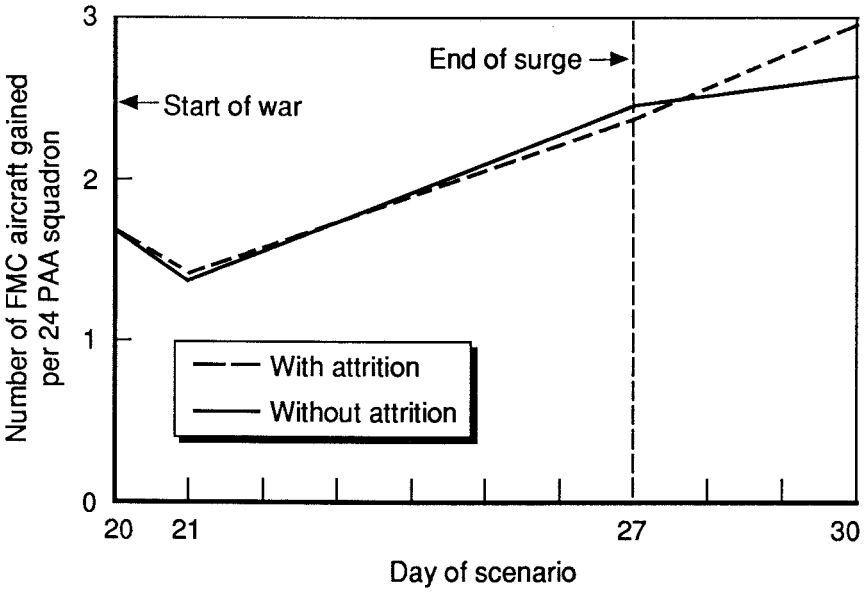


Fig. B.2—Benefit of mutual support with and without aircraft attrition

[8]The data presentation format needs to be recalled here. If the mutual support benefits were shown not as raw FMC aircraft but as percentages of aircraft surviving after attrition, the curves of Fig. B.2 would differ considerably. The inflationary influence of

### Deployment Pattern and Warning Time

A common type of scenario for investigating sustainability is one that assumes zero warning and simultaneous deployment. All units arrive in place on day 0, and surge flying begins at the start of war on day 1. If attrition is played, cumulative aircraft losses are heavier than in a scenario where war is preceded by a mobilization period, so the number of FMC aircraft available at day 30 is bound to be smaller. In the self-sufficiency base case, as a matter of fact, the zero warning, simultaneous deployment scenario yields 7.81 FMC aircraft per 24 PAA unit at day 30 rather than 9.16 FMC aircraft for the 20-day warning, phased deployment scheme of the current analysis.

As seen in Fig. B.3, the two sets of assumptions also produce very different behavior for mutual support benefit. The curves diverge widely throughout the scenario because the zero-warning condition imposes a more stressful flying program early on. More aircraft are in

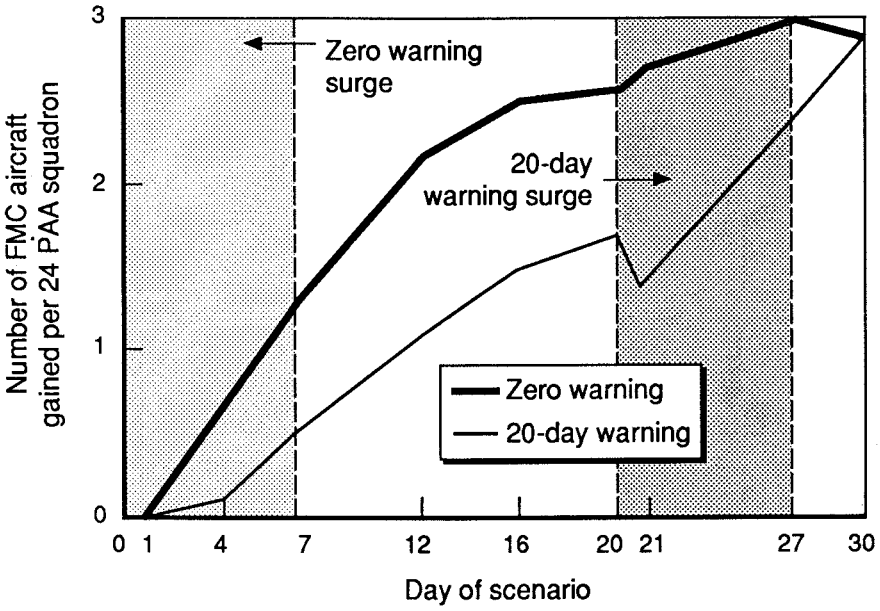


Fig. B.3—Benefit of mutual support under zero warning and 20-day warning

attrition on percentages would make the case with attrition appear much superior to the case without.

theater at day 1, and they fly at a surge rate for the first week. The 20-day warning scenario begins to catch up, however, as soon as its war commences; and by day 30, both scenarios generate the same mutual support benefit.[9]

To sum up, if the only figure of merit of interest were the benefit of mutual support at day 30, a zero-warning/instantaneous-deployment scenario would be indistinguishable from a 20-day-warning/phased-deployment scenario. To the extent that day 30 results are cited, the choice of warning period and deployment pattern appear to have little or no biasing influence on the conclusions drawn.[10]

## Component Demand Rates

As described in Sec. II, the empirically estimated demand rate for a given LRU may vary by major command. Examination of the sets of high and low rates formed for this study indicated only 22 percent of all LRU demand rates varied between high and low estimate; but in this minority of instances, many differences were dramatic, the median difference amounting to 47 percent. Across all LRUs in the study, however, the mean discrepancy between high and low rates was only 10 percent.

Figure B.4 compares the two sets of rates with respect to mutual support benefit. The difference between curves remains small throughout the scenario, rising at 30 days to just one-fourth an FMC aircraft per 24 PAA unit.

In the uncertainty study, sets of high and low demand rates were formed that differed by 30 percent. With VTMR set to 1.0 fpfh for every component, the higher rates produced an increase in mutual support benefit of 2.4 FMC aircraft per 24 PAA unit, a change almost an order of magnitude greater than found here, or over three times what would be predicted by straightforward linear extrapolation.

This discrepancy in results suggests an interaction between demand rates and VTMRs such that the smaller the mean VTMR, the greater the effect of a specified variation in mean demand rate, and conversely. Thus, the hypothesis would be that when VTMRs are large enough to reproduce the turbulence of mobilization and war, mutual support is

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[9]Again, it must be understood that assertions such as this are subject to stochastic uncertainty. That the two curves should precisely match at day 30 is undoubtedly a statistical coincidence. Similarly, the slight deceleration in the zero-warning curve between days 16 and 20 is probably a random fluctuation. The substantial dip in the 20-day warning curve at day 21, however, marks the first day of surge flying and is statistically as well as practically meaningful.

[10]Although not specifically analyzed, it is obvious that the critical variable is cumulative flying hours per PAA; and by day 30, cumulative flying time is likely to be about the same in most sustainability scenarios.

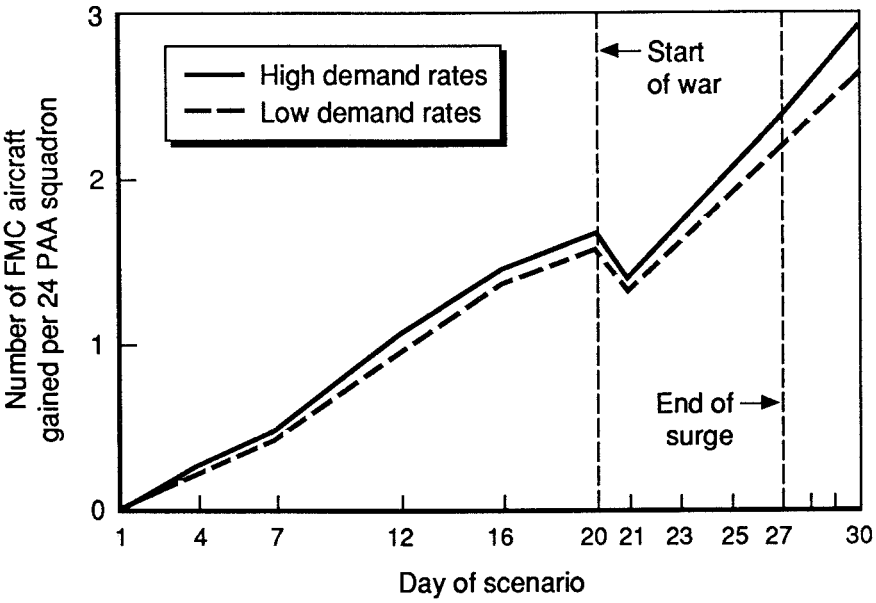


Fig. B.4—Benefit of mutual support under high and low demand rates

fairly insensitive to demand rate fluctuations. This conjecture is supported by the discussion of variance-to-mean ratios, next.

## Variance-to-Mean Ratios

**Relation to Demand Rates.** To evaluate the effect of larger VTMRs, excursions were run with VTMRs for all LRUs set to 4.00 fpfh. In one case, the high demand rates just discussed were used; in a second case, the latter demand rates were increased still further by adding 30 percent to the demand rate of each AIS LRU to compensate for bench check serviceables. This had the effect of raising the mean demand rate across all LRUs by another 7 percent.[11] In other words, "low," "high," and "highest" rates were examined, with the high mean = low mean + 10 percent and the highest mean = low mean + 17 percent. Figure B.5 summarizes the findings.

[11]Table 2 of Sec. II showed 63 AIS and 290 non-AIS LRUs. Raising the demand rates of the former by 30 percent hiked the average demand rate of all 353 LRUs by 7 percent.

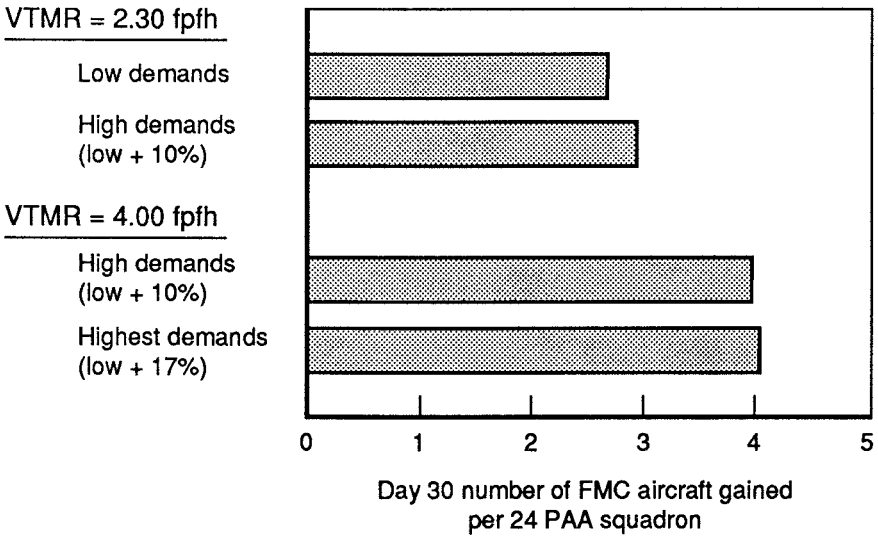


Fig. B.5—Effect of VTMRs on the benefit of mutual support

Comparison of the two middle bars indicates that the benefit of mutual support rises steeply, by more than a full FMC aircraft per 24 PAA squadron, in response to an increase in VTMRs from 2.30 to 4.00 fpfh. Thus, as was previously seen in the uncertainty project, absolute numerical results arising from a Dyna-METRIC sustainability study are highly sensitive to VTMRs. The other point to Fig. B.5 is that whereas a small change in demand rates produces a noticeable difference in mutual support benefit with VTMRs of 2.30 fpfh, a similar small change in demand has little effect with VTMRs of 4.00. Hence, study outcomes appear less sensitive to demand rate fluctuations as VTMRs become larger.

Since the size of the benefit realized from mutual support is so dependent on the choice of VTMRs, much hinges on either selecting "realistic" values for research or exploring a range of values.[12] As a rule, increased VTMRs can be expected to increase the benefit of

[12]The VTMR is only one of many ways of expressing variability in demand rates and is emphasized here only because it is a parameter of the stochastic distribution employed by Dyna-METRIC to represent the pattern of spare parts demands. The real issue is realistic characterization, not of VTMRs but of demand variability. The VTMR just happens to be the way that variability was characterized for this research.

mutual support. Whether this rule would hold for all the disruptions and workarounds of this study needs further analysis.

**Relation to Lateral Redistribution and Lateral Repair.** In the uncertainty study, the day 30 benefit of lateral redistribution without lateral repair was 3.4 FMC aircraft per 24 PAA squadron. This result assumed VTMRs of 4.00 and demand rates commensurate with the "highest" rates of Fig. B.5. In this study, also applying these high VTMRs and demand rates, the corresponding benefit of lateral redistribution was identical (3.40 FMC aircraft per squadron). In the uncertainty study, however, the additional benefit of lateral repair was found to be 1.7 FMC aircraft per 24 PAA squadron, whereas it was only 0.65 FMC aircraft here. In consequence, any differences between the two analyses with respect to day 30 mutual support benefit lies entirely in the domain of lateral repair, which topic was treated in Sec. III and will be returned to once more below.

### Interbase Transportation Time

As evident from Fig. B.6, the day 30 benefit of mutual support turned out to be a linear function[13] of the base-to-base transportation time over a substantial range of the independent variable. For each added day of transportation, a penalty is paid at day 30 in the neighborhood of one-quarter of an FMC aircraft per 24 PAA squadron. Therefore, if the base case transportation time cannot be achieved, or can be achieved in peacetime but deteriorates at the onset of war, the result would be detrimental but not necessarily catastrophic.

The top bar in Fig. B.7 depicts what happens at day 30 if, for example, two-day transportation changes to four-day transportation on day 21. Measuring from the comparison baseline of 0.83 FMC aircraft per 24 PAA squadron, about 30 percent of the base case benefit of mutual support (bottom bar) is lost; but measuring from the origin, a total benefit of 2.30 FMC aircraft per 24 PAA squadron is retained. The loss of benefit is considerable, but so is the amount remaining.

If, however, communications are completely lost on day 21 so that data must be hand carried by four-day transportation, the result truly *is* catastrophic. In such instance, as the second bar from the top of the figure reveals, the incremental benefit of mutual support (beyond the baseline) is less than one-half of an FMC aircraft per 24 PAA squadron. But if, message communications are preserved so that two-LRU exception reporting can be done instead of transporting data manually,

[13]The straight line in the figure was simply passed through the two end points.

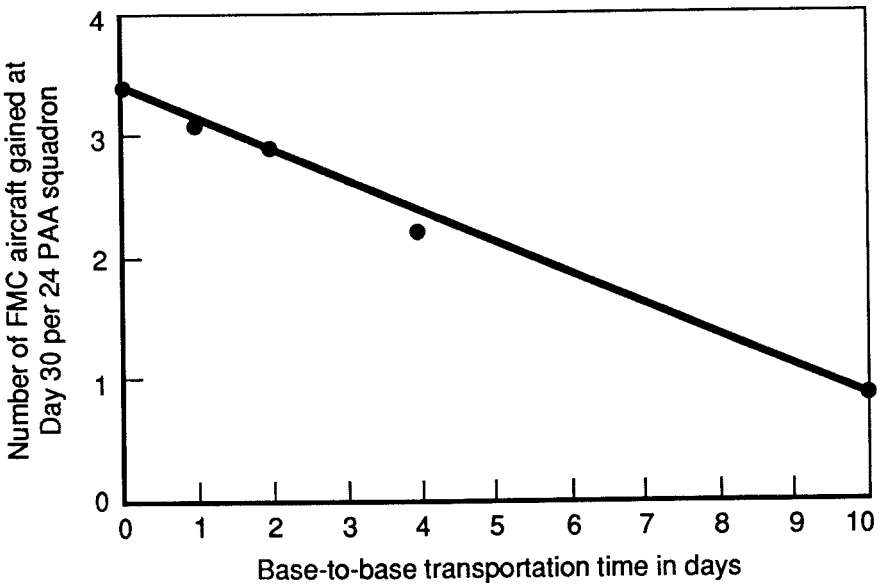


Fig. B.6—Effect of transportation time on the benefit of mutual support

the incremental benefit of mutual support more than doubles. This latter finding illustrates again the strength of exception reporting.

If transportation time is $t$ days, then materiel arriving at a base on day 30 will contribute to fixing aircraft that broke on day 30 – $t$, but not, except accidentally, aircraft broken later than that. In a steady-state environment with a constant flying program and no combat attrition, one would intuitively expect the pile-up of broken airplanes between day 30 – $t$ and day 30 to increase fairly regularly day after day. As a result, Fig. B.6's linear increase in day 30 mutual support benefit as transportation time grows shorter is somewhat predictable. The picture is confounded, however, in that the flying program was not constant across the period examined and attrition was played throughout. Perhaps the answer is that even if not all breakage increases regularly day by day, that portion susceptible to repair through mutual support does so.

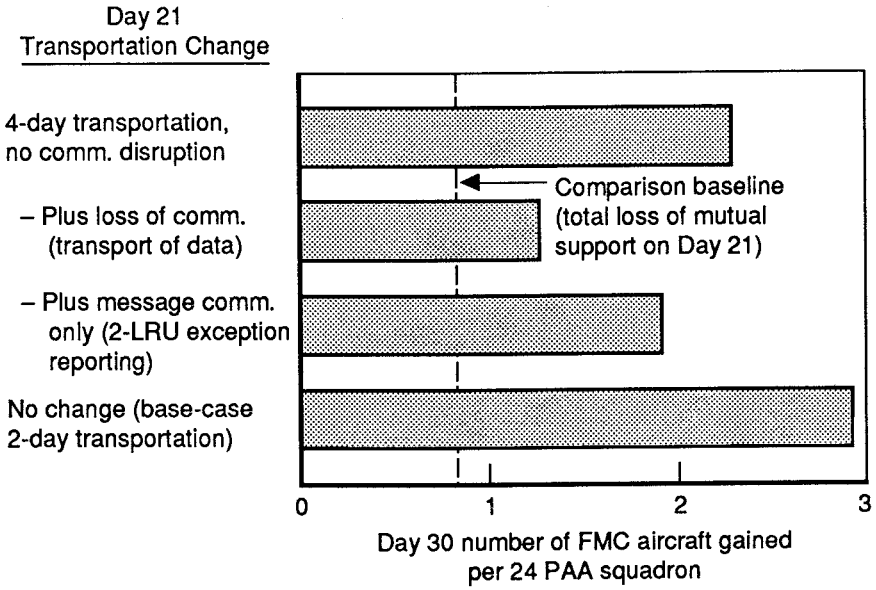


Fig. B.7—Effect of transportation degradation at the onset of war

## CONFOUNDING FACTORS

### Date of Deployment

Fig. B.8 shows how a ten-day separation in deployment dates affects mutual support benefit. The curves pertain to specific 24 PAA squadrons alike in all particulars (same aircraft type, same WRSK, etc.) except deployment date. One squadron arrives on day 5 (ready to fight day 6), the other on day 15. The earlier arriving unit has participated in mutual support for ten days before the other unit appears in theater. The difference in benefit is considerable, albeit not statistically reliable, amounting to 1.2 FMC aircraft at day 30.[14]

Under self-sufficiency, the early arriving squadron would be worse off throughout the scenario by virtue of consuming relatively more of its spare parts. Mutual support, though, as indicated in Fig. B.9, almost exactly cancels this disadvantage as, of course, one would

[14]Elsewhere in the analysis, a difference this large generally would be statistically significant, but here the entities in the comparison are only single squadrons.

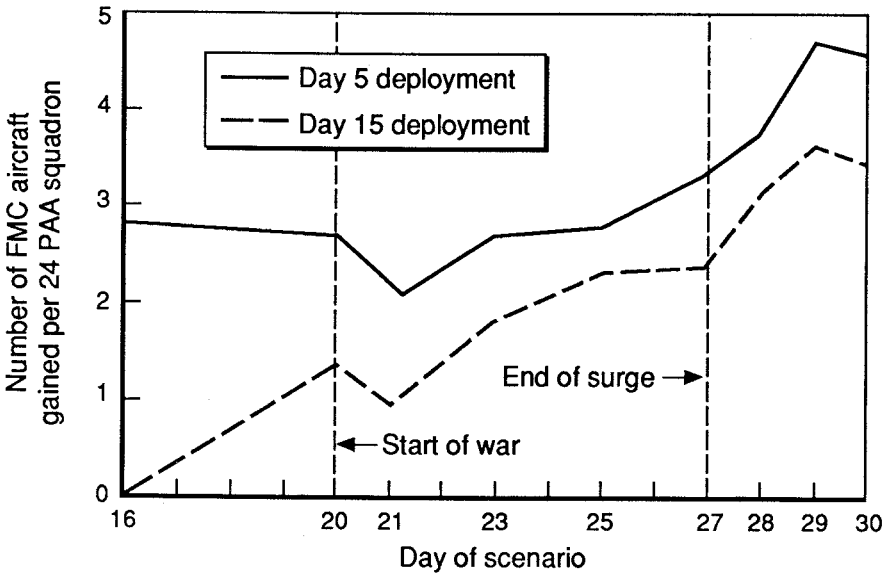


Fig. B.8—Effect of date of deployment on the benefit of mutual support

imagine it should. The earlier deploying squadron catches its counterpart shortly after the start of the surge, and the two run neck and neck from then on.

In any event, when the measure of merit is mutual support benefit, date of deployment has a clear and significant biasing effect. The later the arrival, the less the benefit. The phased deployment of the present scenario therefore renders the findings concerning the benefit of mutual support conservative in relation to a simultaneous deployment scenario. Although other factors such as VTMRs probably are more important, simultaneous deployment explains in part the superior mutual support benefit obtained in the uncertainty study (Table B.1).

### Aircraft Configuration

**24 PAA Units.** As it happens, the scenario includes two pairs of 24 PAA squadrons alike in all respects except that one member of each pair has type A/B aircraft while the other has type C/D, and the A/B squadron in each case deploys two days sooner. In the self-sufficiency

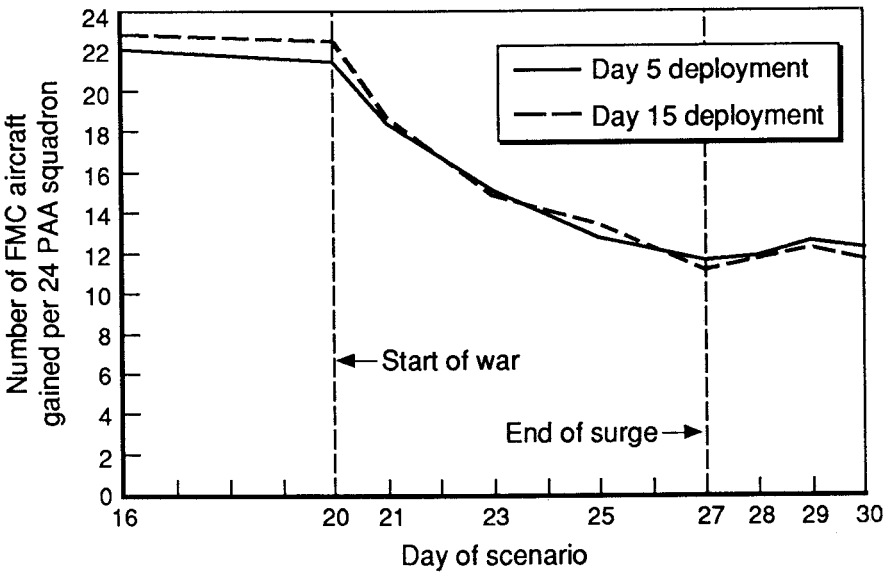


Fig. B.9—Mutual support base case performance as a function of deployment date

base case, with the data combined according to aircraft configuration, the C/D units wind up ahead of the A/B units at day 30 by 0.40 FMC aircraft per 24 PAA unit. This difference is numerically small, not statistically significant, and, if genuine, would be accounted for by the two-day earlier deployment of the A/B squadrons. Under self-sufficiency, that is to say, A/B and C/D aircraft appear to perform the same.

Figure B.10 compares the two configurations with regard to mutual support benefit. The difference of 1.00 FMC aircraft per 24 PAA unit at the left of the graph (day 20) reflects the earlier arrival of the A/B squadrons. By day 23, however, the C/D units start to catch up and, by the end of the surge, have passed the A/Bs in mutual support benefit. Differences between configurations at particular days are not statistically significant, but the overall trend suggests a mutual support bias in favor of C/D aircraft.

**48 PAA Units.** By way of additional data, Fig. B.10 supplies the same kind of comparison for two 48 PAA units of differing aircraft configuration that likewise vary slightly in deployment date. This time

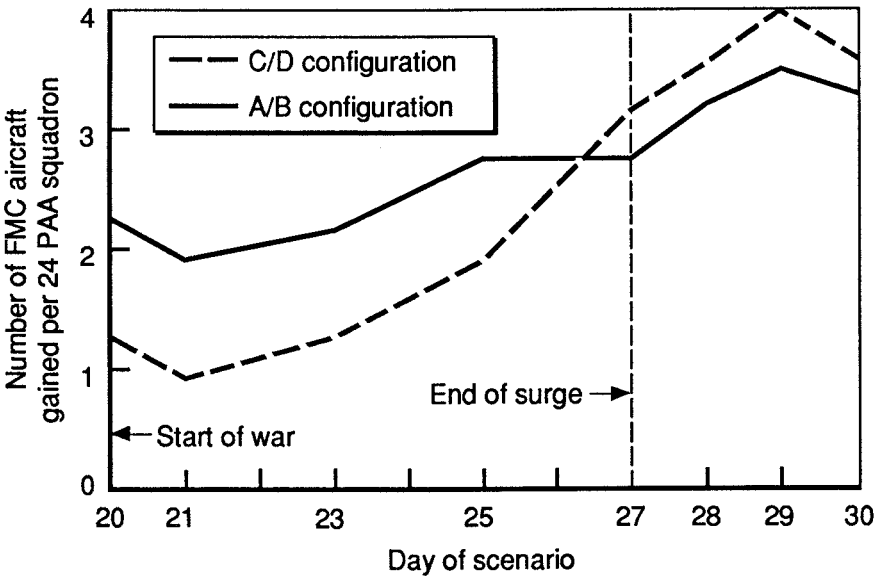


Fig. B.10—Benefit of mutual support by aircraft configuration, 24 PAA units

the C/D unit is the earlier arriver and starts out a little ahead. If there is no mutual support bias due to configuration, this lead on the part of the C/D unit should dissipate over time, and that is just what appears to happen at days 20 and 21. Thereafter, however, the C/D unit regains and apparently continues to increase its relative advantage, although the day 30 difference between curves of 0.75 FMC aircraft per 24 PAA unit does not (given the 25 Dyna-METRIC trials run) reach statistical significance.

Figure B.10 is less than decisive in that the meeting of the curves at days 20 and 21 may be a random coincidence. Nonetheless, Figs. B.10 and B.11 exhibit similar patterns subsequent to the onset of war, and a likely interpretation applicable to both would be that once the increased stress of surge flying is felt, type C/D aircraft start to gain an edge in mutual support benefit over the A/B configuration. If so, such bias very likely is explained by the circumstance that the scenario includes greater numbers of C/D aircraft. The larger the scope for mutual support, the better the benefit.

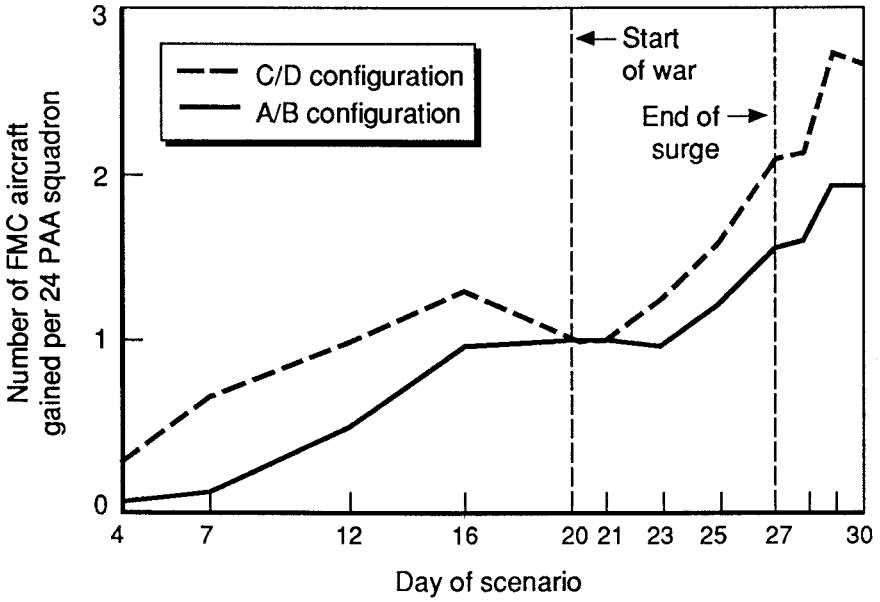


Fig. B.11—Benefit of mutual support by aircraft configuration, 48 PAA units

About the only way a mutual support bias in favor of the C/D configuration could affect the findings of the report would be where airbases are separated into lone squadrons and larger bases as in Fig. 2 of Sec. III. Since most of the lone squadrons are composed of A/Bs and most of the larger units of C/Ds, the difference between the top and bottom curves in that figure may be slightly exaggerated from day 21 onward.

### Type of Maintenance

Organizations designed to operate without base-level intermediate repair capability are called RR (double-R), for "remove and replace." Those capable of component repair are called RRR (triple-R), for "remove, repair, and replace."[15] The point of lateral repair is to extend the facilities of RRR units to those coded RR. To the degree that lateral repair is effective in generating FMC aircraft, therefore, mutual

[15]F-16 squadrons deploying to COBs are RR until arrival of their AISs on or around day 30, whereupon they become RRR.

support must be expected to afford more benefit to RR than to RRR units.

Figure B.12 provides a measure of this bias by sorting out what would happen to RR and RRR units by way of mutual support benefit if mutual support were confined to lateral repair alone. As seen, the RRR units gain only negligible advantage (0.16 FMC aircraft per 24 PAA squadron),[16] whereas the RR units benefit to the tune of 1.18 FMC aircraft per 24 PAA unit at day 30. To put this in better perspective, the lateral redistribution benefit to the same units is 2.99 FMC aircraft per 24 PAA unit. Hence, RR units get about 28 percent of their day 30 mutual support advantage from lateral repair.

It follows as no surprise that the more RR bases in a scenario, the greater the value of lateral repair to the force as a whole—so long, that is, as the available repair shops do not become overloaded. More

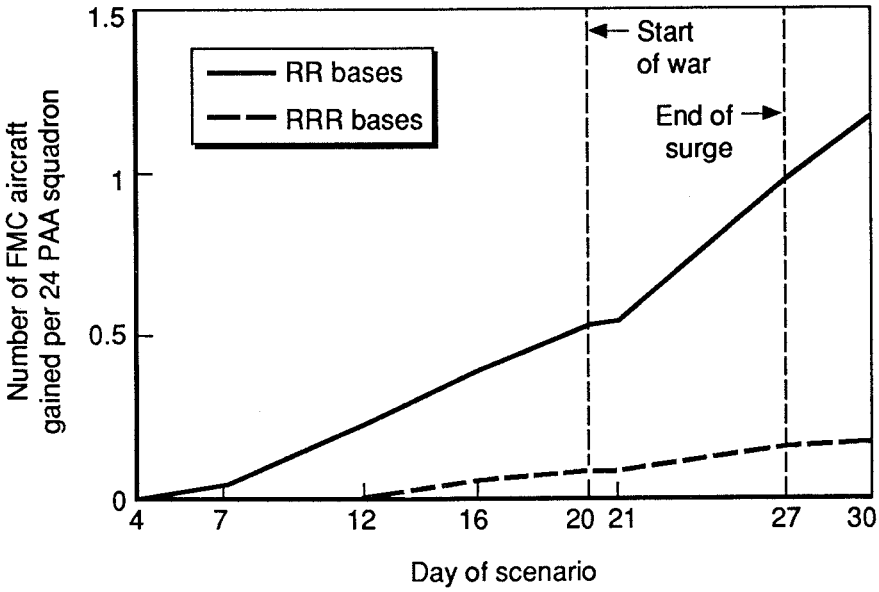


Fig. B.12—Benefit of lateral repair by type of maintenance

[16]The consistency of the trend line indicates that, though the benefit is very small, it is not a chance result. The benefit to RRR units probably is owed to the increased scope for cannibalizing LRUs under lateral repair. The repair shops receive a wider variety and greater quantity of broken LRUs from which to remove and replace SRUs.

surprising, and disappointing, was the finding that under present NRTS policy, lateral repair is of small value at best relative to lateral redistribution.

Since the RRR bases themselves benefited slightly from lateral repair, provision of their services to RR bases in the manner simulated in the present scenario can hardly have overtaxed their shops. Thus, the repair service received by RR bases was very likely almost as good as if they had had their own AISs. The only drawback, compared with organic AISs, was the two days of transportation time required to ship broken parts to the remote repair shops. Excursions to evaluate the effect of this two-day time penalty were not run, but Fig. B.6 makes it clear that the consequences could not have been severe. Therefore, if lateral repair is available during the first 30 days and responsive depot resupply can be counted on thereafter, the cost-effectiveness of deploying AISs to RR bases such as COBs would be thrown into question.

### Size of Base

The present scenario affords a precise illustration of the effect of base size on mutual support benefit by including three bases that are very similar in all ways other than their sizes, which are 72, 48, and 24 PAA. One slight difference is that whereas all three bases are RRR, the largest one has use of its intermediate maintenance facilities three days longer than the others. Also, the 72-PAA base has two strings of AIS ATE, the other bases one string each.

Another difference is in WRSK/BLSS/POS composition. The largest base is supplied with BLSS/POS, the smallest with a WRSK, and the middle one with a WRSK plus a "dependent" WRSK, the latter containing fewer articles than a basic WRSK. In terms of comparative quantities, what all this means is that the smallest base is the most richly endowed per PAA with both spare parts stock and test equipment. Of the other bases, the largest has the most repair capacity per PAA, but the middle one has the second most stock per PAA. All in all, therefore, self-sufficiency resources tend to be inversely related to base size.

Figure B.13, which graphs the benefit of mutual support for the three bases, tells much the same story as Fig. 2 of Sec. III but with better control over confounding variables. Because the upper curve is predicated on only a single 24 PAA unit, it is less statistically reliable than the other two and tends to wander erratically. Still, the evidence is that mutual support benefit increases sharply in inverse ratio to unit

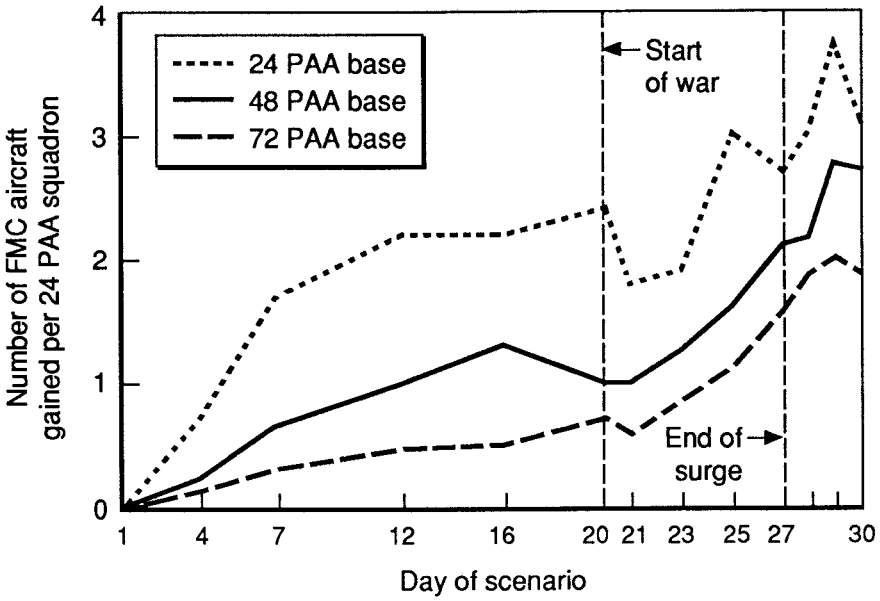


Fig. B.13—Benefit of mutual support by size of base, like aircraft similarly deployed and equipped

size,[17] with size alone here demarked as the operative variable. Indeed, the separation shown between the top and bottom curves is conservative because in the self-sufficiency base case, the 24 PAA squadron is better equipped per PAA than the 72 PAA wing.

## CONCLUSIONS AS TO GENERALIZABILITY

### Generic Scenario Characteristics

Conclusions about generalizability with respect to generic characteristics of the scenario are necessarily limited by the number and range of simulation excursions carried out. By exploring further, future research may temper the judgments reached here.

Base damage to spare parts stock and repair facilities is perhaps the most tenuous generalizability issue. The evidence suggests that the

[17]Even so, the total benefit of mutual support to the 72 PAA unit at day 30 is some 5.6 FMC aircraft, a number by no means to be scorned in the midst of war.

CSC3 workarounds of manual data transport, exception reporting, and Log C2 delegation may be expected to work the same, if not a little better, under fairly severe base damage as in a benign environment. However, base damage as inflicted in this study—on the first day of war following a mobilization period of peacetime flying—had small effect on FMC aircraft availability compared with RAND's earlier uncertainty study, where the scenario differed from this one in a variety of aspects. In the uncertainty study, moreover, base damage reduced the benefit attained from mutual support. Thus, base damage is a tricky variable that appears to interact in an undetermined manner with other scenario features. More study is indicated.

Whether combat attrition of aircraft is played in a sustainability scenario seems to make no difference in mutual support benefit provided the benefit is measured in raw numbers of FMC aircraft. However, percentages based on possessed aircraft are inflated under attrition relative to scenarios without attrition. Consequently, studies that play attrition and report percentages as figures of merit need to be interpreted with due circumspection. Otherwise, attrition seems not to affect generalizability.

The choice of warning time and deployment pattern for a combat scenario can have a profound effect on sustainability results at many points in the scenario. At day 30, however, mutual support benefit came out the same for a zero warning, instantaneous deployment scenario as for the 20-day warning, phased deployment scenario used here. Since the two cases examined are highly discrepant and bracket a range of alternative possibilities, study results pertaining to mutual support benefit and phrased in terms of FMC aircraft at day 30 may be generalizable across many combinations of warning time and deployment pattern.

As was known from the uncertainty study, demand rates can have major effect on the benefit of mutual support; the higher the rates, the bigger the benefit. Evidently, demand rates interact with VTMRs; the larger the VTMRs, the smaller the effect of a given change in demand rates. The important issue from the point of view of generalizability, therefore, is to come to grips with what constitute realistic VTMR values for wartime. This is a hard, but unavoidable, question.

Apart from incidental excursions, only the single value of 2.30 fpfh was used for LRU VTMRs in this analysis. It was assumed that larger values would only accentuate the findings, not alter basic relationships. Although this continues to be a reasonable assumption, it plainly stands in need of additional investigation.

Within the range of zero- to ten-day interbase transportation time, the benefit of mutual support appears to degrade linearly as

transportation time increases. Should this finding persist in the face of future scenario variations, it would make transportation time the most readily generalizable scenario characteristic of those analyzed. One then could predict not only the direction of the outcome expected from a change in transportation time, but also its magnitude.

### Confounding Factors

Early arrival in theater in a phased deployment scenario has a negative influence on sustainability under self-sufficient operation and a matching positive effect on mutual support benefit. Though definitely a biasing factor in this way, the net result of phased deployment is only to make the overall benefit of mutual support smaller than it would be in a simultaneous deployment scenario.

Probably there is a small bias in mutual support benefit in the present analysis favoring type C/D aircraft over type A/B. In all probability, this is owing to the presence of more C/D aircraft in theater, enhancing the value of lateral redistribution for that configuration. As configuration differences no doubt always will be found in every fleet of aircraft, this bias hardly limits the study's generalizability in any important way.

RR bases benefit more from mutual support than RRR bases, the difference arising chiefly from lateral repair. Hence, in a deployment lacking RR units, such as the case with F-15s, the aggregate benefit of mutual support might be expected to be slightly less than found here.

Other things equal, smaller bases benefit more from mutual support than larger ones. The more dispersed the force, therefore, the greater the potential of mutual support. The present scenario involved NATO's system of scattered COBs. A still more dispersed basing arrangement would show better mutual support benefits, whereas a scenario confined to MOBs would generate substantially reduced benefits.

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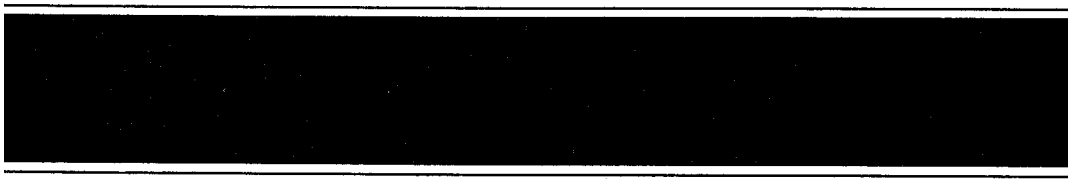
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