DOCUMENTED BRIEFING

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Analyzing the Effects of Airfield Resources on Airlift Capacity

James P. Stucker, Laura Melody Williams

National Defense Research Institute

The research described in this report was sponsored by the Office of the Secretary of Defense (OSD). The research was conducted in RAND's National Defense Research Institute, a federally funded research and development center supported by the OSD, the Joint Staff, the unified commands, and the defense agencies under Contract DASW01-95-C-0059.

ISBN: 0-8330-2637-2

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Published 1999 by RAND
1700 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
1333 H St., N.W., Washington, D.C. 20005-4707
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PREFACE

This research investigated how differing levels and distributions of airfield resources can affect the quantity of airlift deliveries.

The research was conducted for the Force Projection Directorate in the Office of the Secretary of Defense within the Forces and Resources Policy Center of RAND's National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the unified commands, and the defense agencies.

The RAND analysts presented this briefing to the client and to representatives from the Joint Staff, the U.S. Transportation Command, the Air Mobility Command, the Air Force Studies and Analysis Agency, and other organizations at Scott Air Force Base, Illinois on July 9, 1997.

This report should be of interest to deployment planners and to air mobility resource programmers and managers.

SUMMARY

Airlift capacity—the number of passengers and the number of tons of cargo that can be delivered to a specific location in a specific period of time—depends on the characteristics of (a) the cargoes to be delivered, (b) the airfields and the routes linking the cargo originations with the cargo destinations, (c) the ground resources at the airfields supporting the air assets, and (d) the air assets—i.e., the aircraft and the aircrews flying those routes.

The major mobility studies performed by and for the Office of the Secretary of Defense (OSD) in the 1980s focused on the cargoes, the routes, and the air assets. In the 1990s the focus was expanded to include at least limited consideration of the en route, off-load, and recovery airfields. The air-mobility model of choice has become MASS (Mobility Analysis Support System), a large-scale simulation created and operated by the Air Force's Air Mobility Command (AMC). Ground resources are not modeled but are input as constraints to the airlift model.

More recently a series of developments has led to the creation of NRMO (the Naval Postgraduate School/RAND Mobility Optimization), a large-scale linear-programming model of military airlift, and ACE (Airfield Capacity Estimator), a relatively high-resolution model of airfield resources and operations. This study demonstrates the combined use of the ACE and NRMO models to improve and facilitate the analysis of the effects of airfield resources on airlift performance.

When our study was initiated, AMC analysts were briefing the findings of their study of the en route airfields needed to successfully execute the MRC-East deployment. Our sponsor asked that we use the AMC scenario to demonstrate how our models and methods could complement AMC's models and analyses and how our estimates might expand or validate theirs.

Our analyses accomplished both objectives. We validated AMC's findings that for the 1996 scenario the current European en route infrastructure would significantly constrain deliveries of military cargoes during a major deployment to Southwest Asia. Both we and AMC estimated that current en route resource shortages would reduce

cargo deliveries by roughly 20 percent from what they could be if those shortages did not exist.

Moreover, we expanded AMC's findings (a) by demonstrating the sensitivity of deliveries to assumptions concerning aircraft ground times at the on-load, en route, and off-load airfields and (b) by demonstrating how a better distribution of existing en route resources could significantly increase the amount of cargo delivered during the first 30 days of the conflict.

In a previous study for OSD and the Air Staff, we demonstrated that many of the standard ground times used in airlift studies were not long enough to allow necessary inspection and servicing of airlift aircraft.[1] In the present study, we have estimated specific ground times for on-load, en route, and off-load stopovers by each type of airlift aircraft and then compared estimates of airlift deliveries based on those times as inputs with estimates of deliveries based on the most recent Air Force–standard ground times. We found that use of the standard times overestimated deliveries by 12 to 13 percent.

Airlift simulation models use prespecified "rules" to allocate cargoes to aircraft and aircraft to routes. Similarly, the ground resources available at each airfield must be specified before each run. The models then estimate the flows and deliveries resulting from the use of those resources and the application of those rules. Airlift optimization models on the other hand, can search for the best allocations of cargoes to aircraft and aircraft to routes. They can also, as we have demonstrated, search for the best allocation of ground resources to en route airfields. The resulting analyses can be quite useful to decisionmakers looking for ways to expand airlift capacity when resources are limited.

For such a scenario, we estimate that negotiating with our European allies to redistribute the ramp space and fuel currently available to U.S. airlift operations, without increasing the total of either, could increase deliveries over the first 30 days of the 1996 scenario by 12 to 13 percent. For other scenarios and other baselines, the estimates will differ, but the relative strengths of the analyses and findings should remain the same.

This study demonstrates that ACE and NRMO can complement and expand the strategic mobility analyses needed by OSD and others. Together, these analytic tools detect capabilities and provide insights

[1]J. P. Stucker, R. Berg, et al., *Understanding Airfield Capacity for Airlift Operations*, Santa Monica, Calif.: RAND, MR-700-AF/OSD, 1998.

that are not available from other models. The authors recommend that ACE and NRMO be adopted for use by the air-mobility community.

CONTENTS

ACKNOWLEDGMENTS

Our project monitor, Lt. Col. Norman A. Weinberg of the Force Projection Directorate of the OSD Program Analysis and Evaluation unit, facilitated our research and data acquisition activities throughout the study and organized the meetings at which we presented this briefing.

Dave Merrill, senior analyst at the Air Mobility Command (AMC), coordinated and facilitated the transfer of data from AMC to RAND and was instrumental in our understanding of AMC's analysis methods and techniques.

Richard Rosenthal of the Naval Postgraduate School, David Morton of the University of Texas at Austin, and Steven Baker of the U.S. Air Force Academy provided productive consulting and intellectual support.

At RAND, Susan Hosek guided the study. She and Craig Moore oversaw an earlier, lead-in study, and both provided continuing counsel and support. Paul Davis and Richard Hillestad critiqued an earlier version of this briefing and provided comments and suggestions on this report. Carol Zaremba processed the final draft. Betty Amo skillfully edited and guided the document through final production.

GLOSSARY

ACE	Airfield Capacity Estimator
AF/XOFM	Mobility Division of the Directorate of Forces, Headquarters, U. S. Air Force
AFM	Airlift Flow Model
AFSAA	Air Force Studies and Analysis Agency
ALD	Available-to-load date
AMC	Air Mobility Command
APOD	Aerial Port of Debarkation
APOE	Aerial Port of Embarkation
BURU	Bottom-Up Review Update
C day	The unnamed day on which a deployment operation begins or is to begin
CINC	Commander in Chief
COEA	Cost and Operational Effectiveness Analysis
CONUS	Continental (contiguous) United States
CRAF	Civil Reserve Air Fleet
DoD	Department of Defense
JS	Joint Staff
JS/J8	Force Structure, Resources and Assessment Directorate of the Joint Staff
MAC	(Old) Military Airlift Command, now AMC
MASS	Mobility Analysis Support System
MIDAS	Model for Intertheater Deployment by Air and Sea
MOG	Maximum (aircraft) on Ground
MOM	Mobility Optimization Model
MRC	Major Regional Conflict
MRC-East	Major Regional Conflict in Southwest Asia
MRC-West	Major Regional Conflict in Southeast Asia
MRS	Mobility Requirements Study
nb	Narrow body (aircraft)
NPS	Naval Postgraduate School
NRMO	NPS/RAND Mobility Optimization
OSD	Office of the Secretary of Defense
PA&E	Program Analysis and Evaluation
POD	Port of debarkation
RDD	Required delivery date
RIMS	Revised Intertheater Mobility Study
TPFDL	Time-Phased Force Deployment Listing

UTC	Unit Type Code
UTE	Utilization (rate)
wb	Wide body (aircraft)

Project Overview

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Challenge: **Allocate scarce resources wisely in order to improve airlift throughput**

Project purpose:

- **Adapt and refine models and methods to provide better information to decisionmakers**
- **Demonstrate value of new analytic perspectives**

Objective of this briefing:

- **Demonstrate use of ACE and NRMO in estimating the capacities of airlift resources**

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INTRODUCTION

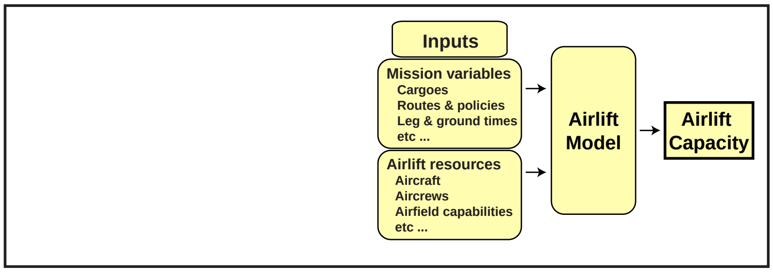
This research project was designed to expand OSD's (Office of the Secretary of Defense's) capability for conducting, understanding, and using mobility analyses.

More specifically, the research objectives were to find ways to use the ACE and NRMO models together to link airfield resources with airfield capacity. ACE is our Airfield Capacity Estimator, a model developed over the past several years at RAND for OSD and the U.S. Air Force. NRMO is the Naval Postgraduate School/RAND Mobility Optimization, an airlift model developed over the past year at RAND and the Naval Postgraduate School.

The objective of this briefing is to demonstrate how the two models can be used together to estimate the capacity of a specific airlift system—the 1996 airlift fleet, routes, and resources—in a specific scenario—MRC-East (major regional conflict in Southwest Asia).

Conceptual Overview (1)

NDRI



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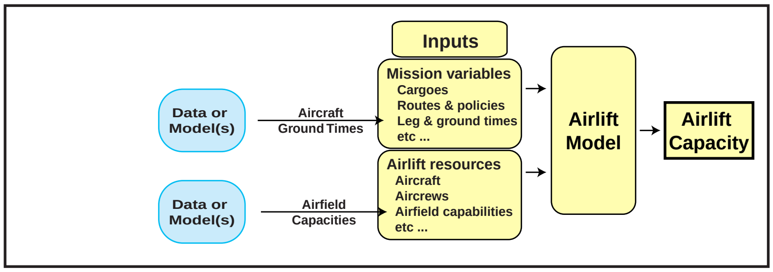
First, we will give a quick overview of our procedures. We're going to be using an airlift model to estimate airlift capacity—the number of passengers and the number of tons of cargo that can be delivered to a specific location in a specific period of time.

That capacity depends both on the characteristics of the missions we want the airlift to perform and on the resources we have available to perform and service those missions.

Conceptual Overview (2)

NDRI



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Airlift capacity also depends on the times—the minutes and hours—that we expect the airlift aircraft will need to be on the ground at the on-load points, at the en route stops, at the off-load points, and perhaps at recovery airfields; and it depends on the number and the quality of the resources available at each of those airfields.

We focus on these times and resource capacities in this briefing.

In the past, estimates of aircraft ground time and airfield capacity used as inputs in airlift studies were produced at least somewhat independently, perhaps even by different organizations. We will summarize several of the more important and recent airlift studies. But first, we'll introduce our procedures.

Conceptual Overview (3)

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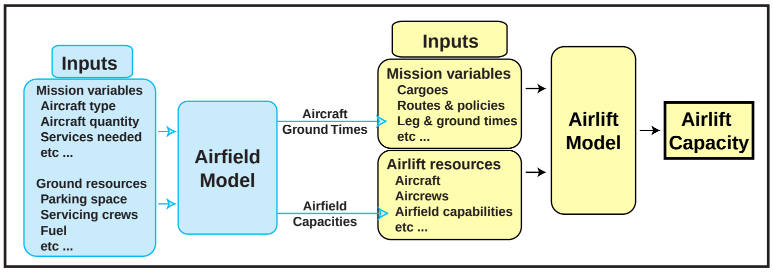

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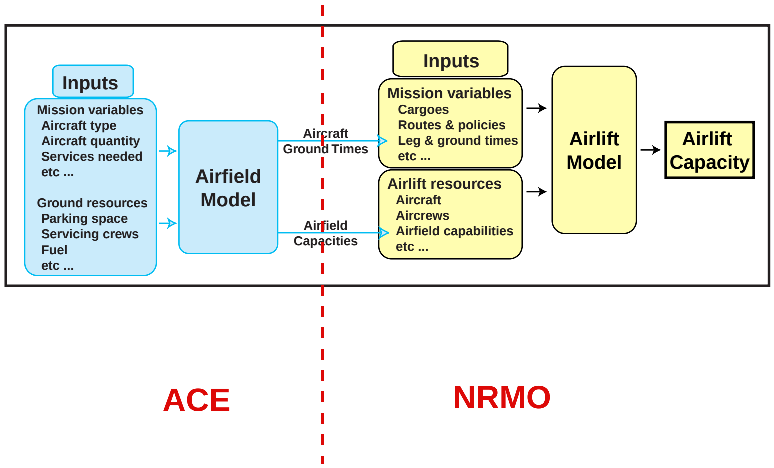
Our procedures involve using an airfield model to produce more-detailed and more-consistent estimates of aircraft ground times and airfield capacities.

Conceptual Overview (4)

NDRI



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In particular, our procedures will involve using ACE and using NRMO.

This Briefing

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Objectives:

Demonstrate use of ACE and NRMO in estimating the capacities of airlift resources

Plan:

- **I. Introduction**
- **II. Recent airlift studies**
  - – **RIMS, MRS, MRS-BURU**
  - – **AMC's Study of European Airfields**
- **III. The RAND study**
  - – **Approach**
  - – **Findings**
- **IV. Concluding remarks**

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RECENT AIRLIFT STUDIES

We will very briefly summarize the major mobility studies of the past decade: the Revised Intertheater Mobility Study (RIMS) that was conducted in the late 1980s and documented in a series of reports issued in 1989; the Mobility Requirements Study (MRS) that was done a few years later and published in 1992; and the MRS–Bottom-Up Review Update (MRS BURU) that was done a few years after that and published in 1996. Although these reports are classified because of some of the detailed information they contain, our purposes will be served by referring to the more general procedures and findings that are not classified.

Then, we will summarize the AMC study, conducted during 1996, of the MRC-East (MRC-E) en route airfields. This was called the European Air Mobility Infrastructure Analysis. And it is the study, or more correctly the scenario, on which OSD asked us to demonstrate our models and our techniques.

After that, we will describe the RAND study.

Summary of Studies (1)

NDRI

Title	RIMS
Year:	1989
Model:	MIDAS
Owner:	OSD/JS
Types of aircraft:	5
# ground times:	2
Types of airfields:	Off
Resources:	Ramp
Finding concerning enroute airfields:	n/a

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Revised Intertheater Mobility Study

RIMS was conducted in the cold-war era. Its scenario involved the USSR invading Iran, and then a consolidated attack by the Warsaw-Pact nations against Western Europe.

Airlift capacity in this study was estimated using MIDAS, the (then and now) major mobility model used by OSD and the Joint Staff (JS). MIDAS stands for Model for Intertheater Deployment by Air and Sea. It has been updated several times; at that time it modeled, in great detail, sealift—ships, their cargoes, and their routings and progress along those routings—but had only an equation or two dealing with airlift. Those equations related several exogenous variables—the number and types of aircraft, their cycle times, and their allowable-use rates—to airlift capacity.[1]

RIMS was coordinated by the Joint Staff and was supported by all the military services, including the Air Force, which (through AMC (then MAC, Military Airlift Command)) provided the estimates of aircraft ground times. The ground times at the off-loading sites were 2 hours

[1]J. Schank, M. Mattock, G. Sumner, I. Greenberg, J. Rothenberg, and J. P. Stucker, *A Review of Strategic Mobility Models and Analysis*, Santa Monica, Calif.: RAND, R-3926-JS, 1991.

and 20 minutes for relatively narrow-body (nb) aircraft like the C-141 and 3 hours and 20 minutes for wide-body (wb) aircraft like the C-5. On-loading, en route, and recovery airfields were assumed to have capacity sufficient not to constrain the airlift flow.

The only airfield resource investigated was ramp, or parking space: the space (and time) available for parking and servicing aircraft at the airfield.[2]

Airfield capacity was expressed as sorties per day by aircraft type. The analysis revealed some bottlenecks at the off-loading sites investigated.

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[2]In air-mobility studies, ramp space is often referred to as MOG, the maximum number of aircraft that can be parked (and/or serviced) on the ground at one time.

Summary of Studies (2)

NDRI

Title	RIMS	MRS
Year:	1989	1992
Model:	MIDAS	MOM
Owner:	OSD/JS	JS/J8
Types of aircraft:	5	8
# ground times:	2	8
Types of airfields:	Off	En / Off
Resources:	Ramp	Ramp
Finding concerning enroute airfields:	n/a	OK

RAND

Mobility Requirements Study

The Mobility Requirements Study, conducted a few years later, moved away from the European scenario and looked at the then new MRC-East and MRC-West (major regional conflict in Southeast Asia) scenarios.

Airlift capacity in this study was estimated using an optimization model newly developed by JS/J8 (Force Structure, Resources, and Assessment Directorate of the Joint Staff), called MOM, or the Mobility Optimization Model. Professor Richard Rosenthal of the Naval Postgraduate School was part of that development team, and more recently he was instrumental in the NRMO development, so MOM is like the grandfather (or, more appropriately, the grandmother) of NRMO.

Aircraft ground times and airfield capacities—in terms of sorties per day—were provided by the Air Force. Both en route and off-load airfields were studied; on-load and recovery airfields were not. Different ground times were specified for eight types of aircraft; airfield capacity still depended only on ramp space.

The study identified some APOD (Aerial Port of Debarkation) shortfalls but concluded that the en route airfields could handle the deployment traffic adequately.

Summary of Studies (3)

NDRI

Title	RIMS	MRS	MRS Buru
Year:	1989	1992	1994
Model:	MIDAS	MOM	MASS
Owner:	OSD/JS	JS/J8	AF/AMC
Types of aircraft:	5	8	8
# ground times:	2	8	32
Types of airfields:	Off	En / Off	En/Off/Rec
Resources:	Ramp	Ramp	Ramp, Fuel
Finding concerning enroute airfields:	n/a	OK	OK

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Mobility Requirements Study Bottom-Up Review Update

MRS BURU was run by the Joint Staff, with participation by OSD, the combatant commands, and the military services.

The Air Force had more visibility here. The airlift estimates were provided by AMC's computerized analysis system, MASS (Mobility Analysis Support System), and its primary simulation model, AFM (Airlift Flow Model).

Ground times were differentiated by aircraft type and by stopover type. That is, on-load stops were the longest; en route stops were only for refueling, a quick inspection, and minor servicing; and off-load stops usually did *not* involve the fueling, servicing, or crew changes that were handled at the recovery airfields.

This study investigated airfield capacity for en route, off-load, and recovery fields.[3] It considered fuel as well as ramp. Air Force planners specified the daily quantity or quota of fuel that was assumed to be available; then each aircraft used some of that fuel until it was all gone.

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[3]This study, as did those before it, assumed that the on-load airfields, mostly within the continental United States, would all have more than sufficient capacity to support the airlift.

Despite the increased focus on airfields, however, the study found the airfield resources, including those at the en route airfields, to be sufficient.

AMC's Study of MRC-E En Route Airfields (1996)

NDRI

MRC-E

Airlift estimated using MASS

Aircraft ground times

- C141, C5, C-17, KC-10, 747P, 747C, NBC
- On-load, en route, off-load

Airfield capacity for en route airfields

- Airfield capacity expressed as sorties per day by aircraft type
  - Based on MOG (nb, wb) and fuel
- Location, force limitations
- Some en route shortfalls

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En Route Structures

Most recently, AMC analysts have looked at both the European en route structure and the Pacific en route structure.

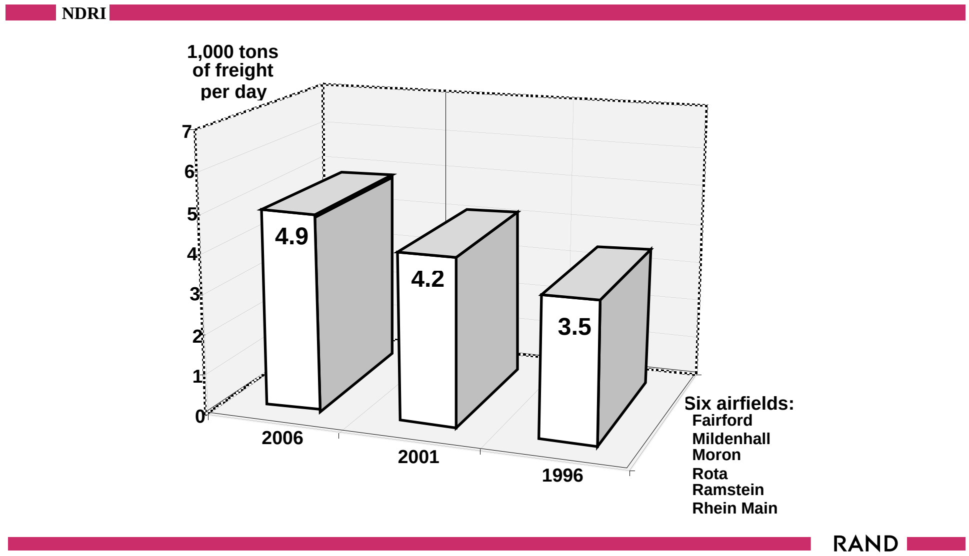
As our study was being structured, they were briefing their findings for the European scenario throughout the Air Force and OSD.

AMC analysts used MASS, their airlift system simulation. They again used aircraft ground times based on aircraft type and stopover type, and they looked at both ramp and fuel constraints at each of the en route airfields.

They also considered, but in qualitative ways, study factors as the weather at the different airfields and the potential political constraints that might affect the different nations and regions.

They ran MASS to establish requirements for infrastructure needed at en route airfields. They used standard AMC operating rules for allocating aircraft and cargoes to routes and airfields. They derived average en route needs over days 0–29. They assessed airfield capability at packages of en route airfields. And they estimated airlift throughput associated with each of those packages. As a result of that analysis, they estimated a need for additional airfield resources.

AMC's Findings



Major Regional Conflict in Southwest Asia (MRC-East) 1996 Scenario

For MRC-East, our scenario of interest, AMC analysts modeled the movement of cargoes under three scenarios:

- the 1996 aircraft fleet and the 1996 airfield resources;
- the 2001 fleet and resources; and
- the 2006 fleet and resources.

Considering both military and CRAF (Civil Reserve Air Fleet) capabilities, they estimated that current airfield resources would significantly constrain the delivery of MRC-E cargoes: The 1996 airlift fleet would be capable of delivering an average of 4.3 thousand tons of cargo per day for the first 30 days of the conflict, but limitations at the en route airfields would constrain those deliveries to about 3.5 thousand tons per day.

AMC analysts estimated that the situation would be improved substantially by 2001: The acquisition of C-17s would more than offset the retirement of C-141s, and the improvements in ramp and fueling at the en route airfields could increase throughput to about 4.2 thousand tons per day. Further additions and improvements to the en route infrastructure by 2006 would increase throughput to nearly 5 thousand tons per day, at which point the binding constraint would be the aircraft, not the en route airfields.

This Briefing

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Objectives:

Demonstrate use of ACE and NRMO in estimating the capacities of airlift resources

Plan:

- **I. Introduction**
- **II. Recent airlift studies**
- ⇨ **III. The RAND study**
  - – **Approach**
  - – **Findings**
- **IV. Concluding remarks**

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THE RAND STUDY

As mentioned before, this study was being initiated when AMC's briefing on the European en route infrastructure was being worked through the Department of Defense (DoD). Consequently, our sponsor suggested that we use that same scenario and much of the same data to demonstrate how our newly developed models and methods could complement AMC's models and analyses, as well as how our estimates might expand or validate AMC's.

Our Procedures

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MRC-E scenario

- Movement requirements
- Origins & destinations

AMC's parameters

- Enroute airfield constraints
  - But no onload or offload constraints
- Aircraft fleets & availabilities
  - Military & CRAF
  - CRAF enroutes independent

RAND / NPS models

- Days C + 0 through C + 29
- ACE: Aircraft ground times
- NRMO: Optimized allocations

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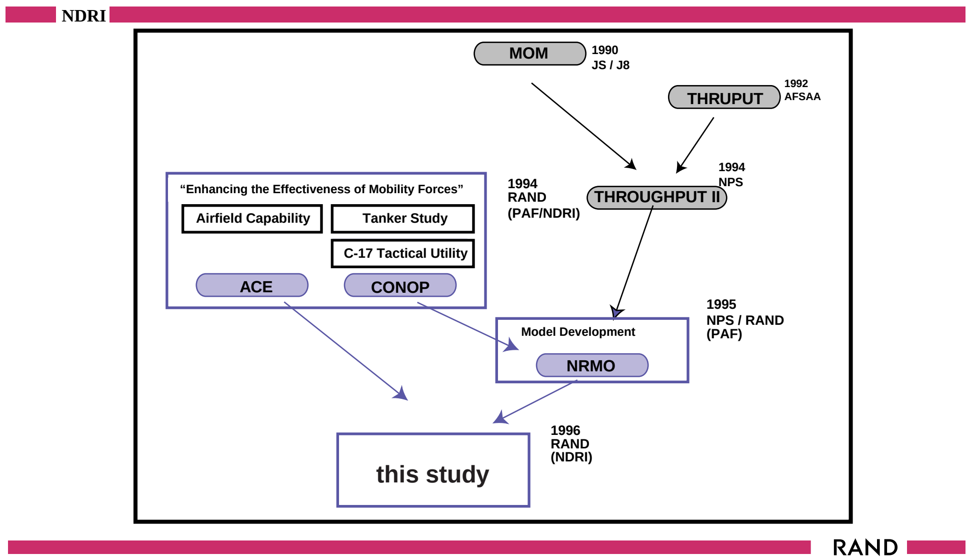
Approach and Procedures

We used the airlift, aircraft, and airfield parameters provided by AMC, the same parameters used in its MRC-E study.

But we used new models: Instead of using the Air Force's standard estimates for the ground times of airlift aircraft at the various types of airfields, we used our airfield operations model, ACE, to generate newer estimates. Then we used those estimates in our optimization model, NRMO.

The next several charts briefly describe ACE and NRMO.

Genealogy of the Models



Note: PAF is Project AIR FORCE, RAND's federally funded development center for the U.S. Air Force.

This slide shows the background of the models we've developed over the past several years.

On the NRMO side of the graph:

- MOM, the Mobility Optimization Model, developed by JS/J8 and used in the Mobility Requirements Study, represented time adequately but allowed little geographical detail.[4]
- THRUPUT, developed by the Air Force Studies and Analysis Agency (AFSAA), was, on the other hand, a steady-state model allowing extensive representation of the geographical network.[5]
- THROUGHPUT II was developed by the Naval Postgraduate School (NPS) under contract with AFSAA. It combined the best of

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[4]V. F. Wing, R. E. Rice, R. W. Sherwood, and R. E. Rosenthal, *Determining the Optimal Mobility Mix*, Washington, D.C.: JS/J8, Force Design Division, October 1, 1991.

[5]K. A. Yost, *The THRUPUT Strategic Airlift Flow Optimization Model*, Air Force Studies and Analyses Agency, June 30, 1994.

THRUPUT and MOM, allowing extensive elaboration of both time and geographical detail.[6]

- CONOP is a RAND model that extended and applied those principles. It has been used in policy analyses addressing (a) the optimum deployment and employment of tankers, exploiting their cargo-carrying as well as their refueling capabilities, and (b) the utility of the C-17s in tactical, strategic, and combined roles.[7]

NRMO is a true merger/offspring of this lineage. Although it was specified and programmed from scratch, it contains many of the contextual, analytic, and programming techniques developed in association with the earlier models described.

ACE, on the other hand, was created in response to a specific need. In the spring of 1994, OSD was coordinating the Airlift Requirements Study, in which MASS was to be used to analyze alternative fleets of passenger and cargo aircraft. But the then-recent Cost and Operational Effectiveness Analysis (COEA) for the C-17 had seriously questioned certain MASS inputs: (a) the utilization rates for aircraft and crews and (b) capacity estimates for airfields. In response, AMC undertook to improve the estimates of the utilization rates, and OSD and the Air Staff funded RAND to develop methods for estimating airfield capacity.

That initial development of ACE was sponsored by the Projection Forces Division, OSD Program Analysis and Evaluation (PA&E), and the Mobility Forces Division, Headquarters Air Force. Subsequent development and this application have been funded by Projection Forces.[8]

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[6]D. P. Morton, R. E. Rosenthal, and T. W. Lim, "Optimization Modeling for Airlift Mobility," *Operations Research,* Vol. 1, No. 3, 1995. (Also available as NPS-OR-95-007, Monterey, Calif.: Naval Postgraduate School.)

[7]P. Killingsworth and L. Melody, *Should C-17s Be Used to Carry In-Theater Cargo During Major Deployments?* Santa Monica, Calif.: RAND, DB-171-AF-OSD, 1997; and unpublished RAND reasearch by P. Killingsworth and L. Melody on "Tankers: Air Mobility Roles for the 1990s."

[8]J. P. Stucker and R. Berg, with A. Gerner, A. Giarla, W. Spencer, L. Arghavan, and R. Gates, *Understanding Airfield Capacity for Airlift Operations*, Santa Monica, Calif.: RAND, MR-700-AF/OSD, 1998.

Airfield Capacity Estimator

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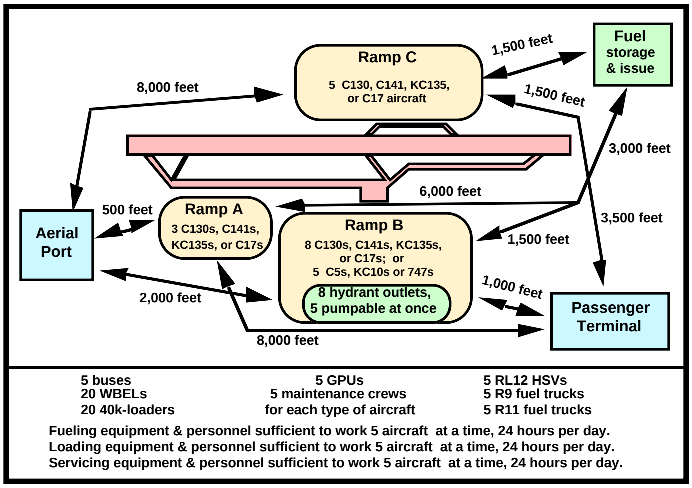

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Note: WBEL = widebody elevator loader, GPU = ground-power unit, and HSV = hydrant-service vehicle.

To run ACE, the user first describes the airfield. He can specify up to six separate and distinct parking areas, or ramps; each with a specific setup for hydrant fueling, and all sharing tanker-trucks and crews for truck-based fueling. Each ramp is located a specified distance from the cargo-dispensing and storage area, the passenger terminal, and the fuel-dispensing facilities.

ACE estimates the number of aircraft—assigned to particular missions and thus requiring particular services and servicing—that the airfield can service in a typical day.

ACE

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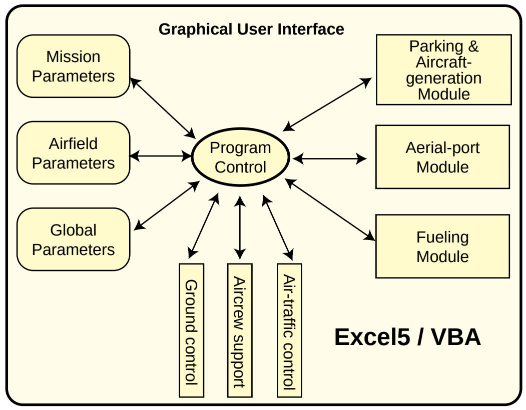

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ACE is a Microsoft Excel application. The ACE package consists of 7 Excel workbooks, containing 52 worksheets and 16 code modules (the code is Visual Basic for Applications (VBA)); the model itself consists of 4 workbooks containing 34 worksheets and 13 code modules.[9]

ACE represents the parking and servicing, loading and unloading, and fueling operations in detail. It also represents air-traffic control, ground control, and air-crew servicing, but with little detail.

ACE covers many ground operations, tasks, and resources, but we have not attempted to model all of the resources and their uses. For the most important areas—parking, servicing, loading, and fueling—ACE contains both an aggregate resource—the packages, or Unit-Type Codes (UTCs), of skills and equipment that the Air Force regards as necessary to perform those functions—and several individual resources that experts have identified as being especially (or most visibly) associated with airfield capacity. If the user has information on those individual resources, that information can be input and the model will calculate the limits of those resources and test to see if any of them are more constraining than the aggregate resource. On the other hand, if the user has no information on some of the individual

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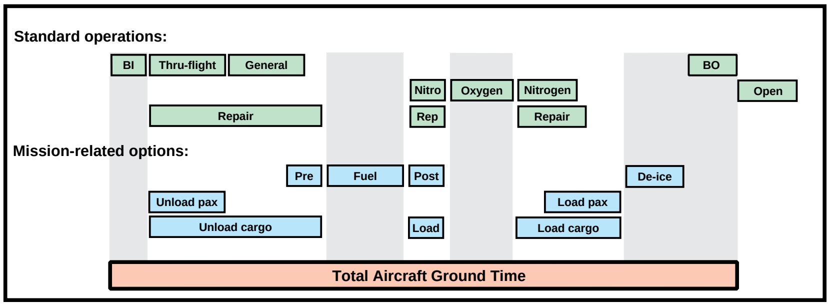
[9]In early 1998, software for the ACE model became available on the RAND homepage on the World Wide Web at http://www.rand.org/publications/MR/MR700/ACE/.

resources, or even of the aggregate resource, he can set their quantities to 9999 and the model will consider them as unlimited and never constraining.

ACE Servicing Profile: Quick Turn

NDRI



$$AGT^{t} = BI + \mathrm{Max}\begin{bmatrix} I^{t1} + \left(G^{ta} + N^{ta}\right) + F_1 \\ D_p \\ D_{ca} + U_{ca} \\ M^{ta} \end{bmatrix} + F_2 + \mathrm{Max}\begin{bmatrix} F_3 + \left(G_b^{t} + N^{tb}\right) \\ D_{cb} + U_{cb} \\ M_b^{t} \end{bmatrix} + \beta_2 O^{t} + \mathrm{Max}\begin{bmatrix} \left(G_{ct} + N^{tc}\right) \\ U_p \\ D_{cc} + U_{cc} \\ M^{tc} \end{bmatrix} + \beta_4 DI + BO$$

RAND

ACE recognizes airfield resources, operations, and tasks; using those, it constructs servicing times for each resource and then the total time that each aircraft must spend on the ground at that particular airfield. That is, depending on the tasks and quantity requirements for a particular mission, the model computes the amount and time required of each type of resource (e.g., GPU-hours, parking-space–hours, etc.).

ACE considers 17 ground operations, more than 40 types of ground resources, up to six tasks in each operation for each resource; up to six distinct areas for parking and servicing aircraft (each area may have a distinct hydrant-fueling system; all may be serviced by common fueling trucks and teams); and up to nine types of aircraft, with up to six of those intermingling operations in a typical day.[10]

We show here the operations associated with a "quick turn," one of our ground-servicing profiles. The time lines indicate the sequencing of the servicing operations; they also show the operations that can be

[10]ACE was developed over two years of study and experimentation. We interviewed scores of service personnel, technicians, and planners during visits to more than a dozen airfields around the world, and we made multiple visits to the headquarters of the Air Mobility Command at Scott Air Force Base, Illinois. We collected much of our C-17 data during its surge testing under "austere" conditions at Barstow / Daggett Air Field and Fort Irwin, California, in July of 1996.

conducted concurrently (such as inspections, repairs, off-loadings, and some servicing operations), and those that must be conducted in isolation (such as fuel transfer, oxygen servicing, and de-icing).

A quick turn is normally associated with servicing at en route and off-load airfields. More comprehensive servicing, normally associated with home-field or CONUS (Continental (contiguous) United States) stopovers, is called “full-service.” In addition to quick turns and full-service stops, the model also enables the user to customize the ground-servicing profiles for any group of aircraft, allowing concurrency of fuel transfer and servicing, “engine-running off-loads,” and many other sequences.

Of the 17 operations we model, we use average times (by aircraft type) for eight, because we believe that their duration and resource demands vary little for missions or airfields. The other nine are treated in one of two ways. For five of them—fueling (transfer), passenger and cargo loading, and passenger and cargo unloading—we calculate specific times for each mission at each airfield by accumulating times for particular tasks—e.g., driving a fuel truck to the aircraft, hooking up, loading one pallet onto a k-loader, or moving one pallet from the k-loader onto the aircraft. This allows us to account for load types and sizes and for the distances that loads and fuels must be transported. Furthermore, it allows us to identify and quantify aircraft delays when resources are limited. That is, when fueling and loading are involved, aircraft ground time depends on the quantity of airfield resources as well as on the type of aircraft, the type of stopover, and the particular ground operations specified for the stopover.

Times for the remaining four operations—nitrogen servicing, oxygen servicing, repair, and de-icing—do seem to vary widely, even for aircraft of a specified type and assigned to a specified mission.

Break Rates and Servicing Times

α_1 = probability of needing nitrogen service	β_1 = dummy for needing nitrogen service
α_2 = probability of needing oxygen service	β_2 = dummy for needing oxygen service
α_3 = probability of needing repairs	β_3 = dummy for needing repairs
α_4 = probability of needing de-icing	β_4 = dummy for needing de-icing

$$AGT = \text{Max}\begin{cases} \displaystyle\sum_{\beta_1=0}^{1}\sum_{\beta_2=0}^{1}\sum_{\beta_3=0}^{1}\sum_{\beta_4=0}^{1}\prod_{i=1}^{4}\left\{\begin{bmatrix}\left[1-\beta_i+\left(2\beta_i-1\right)\alpha_i\right] \\ * \; AST\left(\beta_1,\beta_2,\beta_3,\beta_4\right)\end{bmatrix}\right\} \\ \\ \text{Minimum Ground Time} + DI + BO \end{cases}$$

ACE handles the variability of these four operations in either of two ways, at the user's option. In one option, the user can specify expected-value calculations to estimate average resource-use times, aircraft-ground times, and airfield capacities. This process does not yield the true "expected value" of capacity because both the service-time equations and the capacity equations are nonlinear, but in all the cases we have tested, it yields a close approximation to that value, and it is quick.

Alternatively, the user can specify that ACE conduct Monte-Carlo experiments, drawing values (for each aircraft in each mission) for those operational times from empirically derived distributions of past times.[11] The random draws for each set of missions can be iterated 10, 20, or even 1,000 times, producing representations of the output distributions for use times, aircraft ground times, and airfield capacity. This process insures that some exceptionally long and some exceptionally short repair times will occur, at least occasionally. Given valid data, this process produces "better" estimates than the expected-value approximation, but it takes substantially longer.

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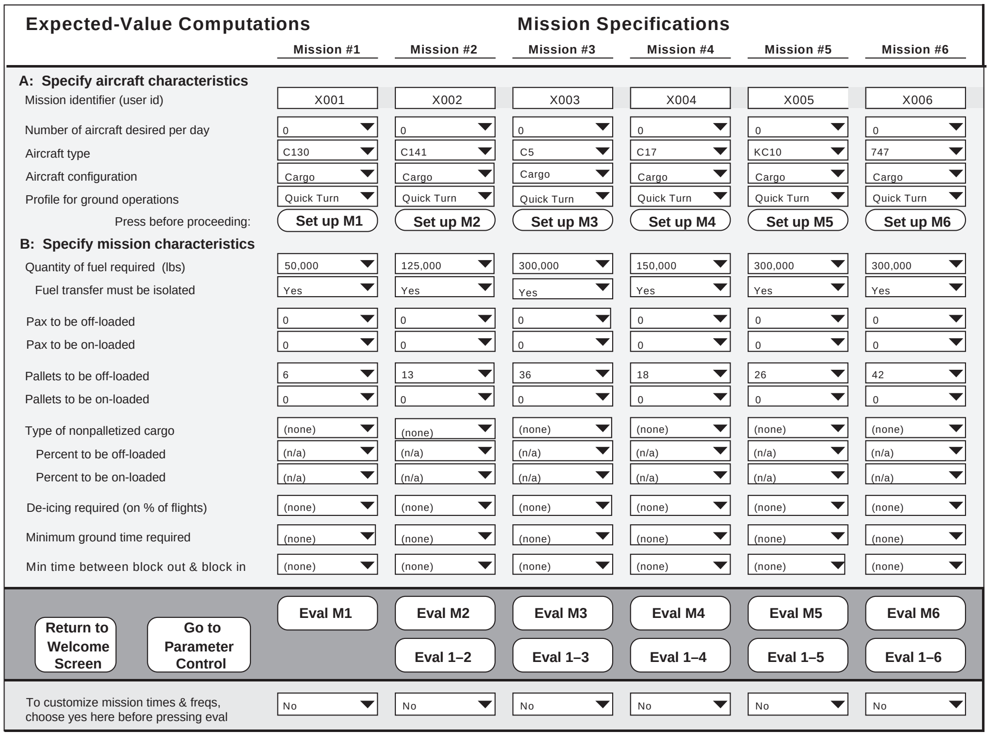
[11]D. A. Goggins, *Stochastic Modeling for Aircraft Mobility*, Master's Thesis, Monterey, Calif.: Naval Postgraduate School, 1995, Appendix B.

ACE Mission-Specification Screen



The ACE mission-specification screen looks like this. A user can set up as many as six mission types at a time, working from right to left. An ACE mission type, usually just called a mission, is some number of aircraft of a particular type and configuration, each requiring the same ground servicing.

For each mission, working from top to bottom, the user must specify the following, using the drop-down menus:

- number of aircraft required to perform the mission;
- type of aircraft (C-141, C-5, C-17, etc.);
- configuration of those aircraft (maximum cargo, maximum passenger, mixed);
- the ground-servicing profile (quick-turn, full-service).

Entering this information gets the user through the upper portion of the screen. Then he must push the “set it up” button, which tells the model to bring in the specific parameters associated with that aircraft type, configuration, and servicing profile and sets up specialized menus for the drop-down in the lower portion of the screen.

Continuing down the column associated with the mission, the user then selects:

- the quantity of fuel to be on-loaded;
- whether that transfer can be concurrent with other servicing;
- how many passengers to off-load during this stopover;
- how many passengers to on-load;
- how many pallets to off-load;
- how many pallets to on-load;
- what type of nonpalletized cargo to off-load and on-load;
- the percentage of this particular aircraft type's capacity for the type of cargo to off-load;
- the percentage to on-load;
- the percentage of the time that de-icing may be required (may be zero);
- the minimum ground time for this stopover (may be zero); and
- the "open time" between aircraft using a particular parking spot.

Making these selections fully specifies the mission.

Next comes the evaluation process. Near the bottom of the screen are a number of "eval" buttons. One for each mission tells the model to evaluate that particular mission; and below that, one for each of the right-most five missions tells the model to evaluate all of the missions from the first through the particular mission associated with the button.

Missions are evaluated, as they were prioritized, from left to right. Aircraft associated with the first mission have access to all the resources available at the airfield. Aircraft associated with the second mission have access to all the resources not used by the first mission. In other words, when non-zero numbers of aircraft are associated with each mission, the estimated capacities are "and" capacities. That is, the resources available at the airfield can service the number of aircraft associated with the first mission *and* the number of (the type of) aircraft associated with the second mission, *and* so on, until the airfield resources are depleted.

If the user specifies that zero aircraft should be associated with a (or with each) mission type, then the model estimates the total number of aircraft on that (those) mission(s) that could be serviced with the available resources. If the user specifies zero aircraft for every mission, then the model estimates “or” capacities: The resources at this airfield could support X1 aircraft assigned to mission 1, *or* X2 aircraft assigned to mission 2, etc.*

When a user specifies some missions with zero aircraft and others with some aircraft, ACE estimates combinations of “ands” and “ors.”

---

*Note that a user can run the model for mission 1, then consider the resulting output and set up the second mission and run it, etc., so long as he understands that each mission has access only to the resources available at the conclusion of the last run (except for the first mission, which always has access to all of the airfield’s resources). That is, if the user evaluates four missions and then attempts to evaluate some version of mission 2 again, the model will provide estimates for that mission 2, but those estimates will be based only on the resources remaining after the evaluations of the previous four missions. Only (re)evaluating mission 1 resets the airfield resources to their original levels.

ACE “Output” Screen

Mission and Capacity Estimates

Expected-Value Computations | **Medium Sized Airfield** | Execution time (minutes) = 3.22

	Mission 1	Mission 2	Mission 3	Mission 4	Mission 5	Mission 6
Mission specifications						
Mission ID	X001	X002	X003	X004	X005	X006
Aircraft on Mission	0	0	0	0	0	0
Aircraft type	C130	C141	C5	C17	KC10	747
Aircraft configuration	Cargo	Cargo	Cargo	Cargo	Cargo	Cargo
Servicing profile	Quick Turn	Quick Turn	Quick Turn	Quick Turn	Quick Turn	Quick Turn
Fueling must be	Sequential	Sequential	Sequential	Sequential	Sequential	Sequential
Fuel needed (lbs)	50,000	125,000	300,000	150,000	300,000	300,000
Passengers off, on	0 0	0 0	0 0	0 0	0 0	0 0
Pallets off, on	6 0	13 0	36 0	18 0	26 0	42 0
Nonpalletized cargo	(none)	(none)	(none)	(none)	(none)	(none)
NPC percent off, on	(n/a) (n/a)	(n/a) (n/a)	(n/a) (n/a)	(n/a) (n/a)	(n/a) (n/a)	(n/a) (n/a)
Mission outputs						
Capacity used (aircraft per day)	0	0	0	0	0	0
Average mission times (hours, minutes)						
Loading & unloading	0 ' 0 "	0 ' 0 "	0 ' 0 "	0 ' 0 "	0 ' 0 "	0 ' 0 "
Fuel transfer	0 ' 0 "	0 ' 0 "	0 ' 0 "	0 ' 0 "	0 ' 0 "	0 ' 0 "
Aircraft ground time	0 ' 0 "	0 ' 0 "	0 ' 0 "	0 ' 0 "	0 ' 0 "	0 ' 0 "
Marginal (FPA) times (hours, minutes)						
Loading & unloading	0 ' 23 "	0 ' 31 "	1 ' 14 "	0 ' 36 "	0 ' 58 "	2 ' 17 "
Fuel transfer	0 ' 46 "	1 ' 4 "	1 ' 57 "	1 ' 12 "	1 ' 57 "	1 ' 57 "
Aircraft ground time	1 ' 41 "	2 ' 50 "	4 ' 24 "	2 ' 52 "	4 ' 46 "	4 ' 33 "
Capacities remaining:						
Parking (total)	323	176	27	182	25	26
Aircraft servicing	66	37	23	36	21	22
Loading	72	72	27	54	30	14
Aircrew support	250	250	250	250	250	250
Air-traffic control	240	240	240	240	240	240
Fueling	42	42	42	42	42	42
Ground control	80	80	80	80	80	80

Return to Mission Control

This graphic shows the ACE “output” screen. Again, six missions can be shown from left to right. The upper portion of the screen repeats the major specifications of the missions. It shows the number of aircraft requested for each mission.

The center portion shows the time estimates for servicing, loading, and fueling, as well as the total required ground time for the aircraft. It shows the number of requested aircraft that the model estimates could be serviced using the airfield’s available resources.

The lower portion shows the resource capacities remaining, by service function, after the aircraft assigned to each mission are serviced. Each of these capacities is expressed in terms of the particular mission specified. (A more general capacity cannot be estimated at that time because, at the completion of each mission evaluation, the model must stand ready to evaluate *any* specification of the next mission.)

Thus, when the user asks for zero aircraft for a mission, the lower portion of the screen shows the total capacity of the airfield for servicing aircraft assigned to that mission. The smallest capacity reported here will, of course, be the binding capacity and will identify the constraining function.

When the user asks for some positive quantity of aircraft for a mission, the total capacity of the airfield for aircraft assigned to that mission is the sum of the estimate reported in the center portion and the lowest residual capacity reported in the lower portion.

Caveat Regarding the Use of ACE in This Study

NDRI

We do not have details on airfield resources, (inventories, availabilities, and uses) at these en route airfields.

- **We can estimate ground times by aircraft type, and by mission (type of stop, quantity of needs) at each airfield.**
- **We cannot estimate capacities for resources not investigated by AMC.**

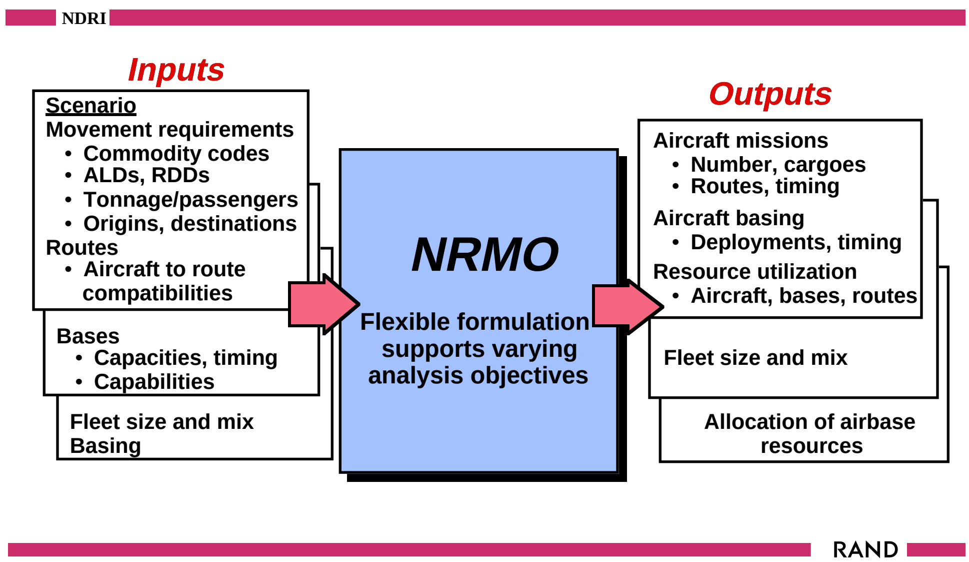
Hence, our analyses and findings will necessarily be exploratory and complementary.

RAND

ACE is a powerful, flexible model. In the analyses associated with this study, however, we have been able to use only a few of its capabilities, because we have no information on the specific resources available at any of the bases. We have access only to the Air Force's estimates of the ramp space or working ramp and the fuel available at each airfield. Thus, we can consider only constraints based upon those items.

Our contribution is to use ACE's specification of the ground operations associated with each type of stopover, and its data on the times required for those operations on each type of aircraft, to estimate the specific parking and working capacity of each type of aircraft at each airfield.

The NPS / RAND Mobility Optimizer



Note: ALD = available-to-load date, RDD = required delivery date.

Now we will briefly summarize the operation of NRMO.[12] NRMO, like all models, transforms inputs into outputs. Required inputs for NRMO include

- movement requirements, including the unit affiliation, available-to-load date, required delivery date, commodity code, and number of tons and passengers. These data are commonly input in the form of a time-phased force deployment listing (TPFDL);
- route data, including the names and locations of the airfields and way points along each route and the aircraft types that are allowed to fly each route;
- airfield data, including location (specified in latitude and longitude), capacity (in terms of the number of narrow-body and/or wide-body aircraft that can be serviced simultaneously), and usages (such as on-load or off-load, crew staging, tanker or shuttle beddown, recovery base, or divert base for use during aerial refueling operations); and

[12]Unpublished RAND research by L. Melody, S. Baker, R. Rosenthal, D. Morton, and P. Killingsworth on “NPR/RAND Mobility Optimization (NRMO): A New Model for Air Mobility Analysis” provides a more detailed description.

- fleet data, including the number of aircraft of each type and the day each enters service, and the characteristics of each type of aircraft, such as its payload, airspeed and allowable-use rate.

Model outputs include

- mission data, including the number of aircraft flying on each route, carrying each cargo, each day;
- numbers and types of aircraft deployed as tankers and as intratheater haulers on each day and from each assigned airfield;
- utilization information on aircraft, routes, and bases; and
- marginal operational value of a unit increase in each resource.

Conceptual Formulation

NDRI

Maximize:	**On-time deliveries**
	+ air assets measure of performance
	+ ground assets measure of performance
Subject to:	
Meet time-phased demands:	**by line identification, cargo type**
Aircraft allocation/balance:	**by type, airfield, time, for strategic, tanker, and tactical missions**
Cargo/passenger capacity:	**by line identification, aircraft type, time**
Aircraft utilization rates:	**by aircraft type, time**
Airfield capacity (MOG):	**by airfield, time**
Aerial refueling capacity:	**by location, time**
Crew availability:	**by aircraft type, stage base, time**

RAND

NRMO attempts to maximize on-time deliveries. It accomplishes this mathematically by minimizing the penalties associated with late or non-delivered cargo. It may also include secondary objectives, such as minimizing fleet usage or costs, or minimizing infrastructure costs.

The major system constraints include the following:

- Meeting the time-phased demand. Note that the demand may be met with late or even undelivered cargo. This constraint simply insures that every cargo is accounted for, and it allows a feasible solution even when deliveries are severely constrained.
- Balancing equations to ensure that the model does not create or destroy aircraft or cargo.
- Limiting cargo and passenger capacity to ensure that the cargo delivered does not exceed the capacity of the aircraft delivering it.
- Limiting the number of hours per day that aircraft may fly.
- Limiting the number of aircraft that may be serviced at each airfield or air-refueling point.
- Ensuring that no aircraft proceeds without a rested crew.

Note, however, that with some minor reformulations, the model can itself determine some of these values. For example, we often used the earlier CONOP model to determine the minimum-cost fleet to satisfy particular scenarios.

In this study, we simply minimize the penalties attached to late and nondelivered cargoes.

We Simplify En Route Airfield Structure (1)

NDRI

Airfield	MOG	Fuel
England		
Mildenhall	xx	xx
Fairford	xx	xx
Germany		
Rhein Main	xx	xx
Ramstein	xx	xx
Spain		
Moron	xx	xx
Rota	xx	xx

RAND

One further point needs to be addressed before we go on to discuss our findings—that is, to simplify our analysis, we simplified the en route structure of the problem.

AMC worked with seven en route airfields: two in England, two in Germany, and three in Spain. This allowed them to consider, at least qualitatively, the effects of leg length (and hence the need for fuel and the resulting allowable cargo loads) and weather, as well as the political factors important in the specific regions of the involved nations.

We Simplify En Route Airfield Structure (2)

NDRI

Airfield	MOG	Fuel
England		
Mildenhall	xx	xx
Fairford	xx	xx
Germany		
Rhein Main	xx	xx
Ramstein	xx	xx
Spain		
Moron	xx	xx
Rota	xx	xx

Airfield	MOG	Fuel
England	xx	xx
Mildenhall		
Fairford		
Germany	xx	xx
Rhein Main		
Ramstein		
Spain	xx	xx
Moron		
Rota		

RAND

We simplified that structure. We represent the system as having only a single airfield in each country. The one in England is located at Mildenhall and has the combined capabilities of Mildenhall and Fairford. The German airfield is located at Ramstein and has the combined capabilities of Ramstein and Rhein Main. The Spanish airfield is located at Moron and has the combined capabilities of Moron and Rota.

This simplification reduced the size of our model and allowed it to solve faster, providing us with additional time for interpreting outputs, reformulating inputs and constraints, and conducting more runs. Moreover, it has little effect on our quantitative findings. The differences in leg lengths between nations are slight, as we shall illustrate later, but are still significantly greater than the differences between airfields within a country. Weather and politics also probably differ more between than within countries, but we considered neither quantitatively in this study.

Summary of Our Approach

NDRI

To complement AMC's work

- **With our airfield capacity model, we**
  - **produce more detailed and consistent estimates of airfield capacities and aircraft ground times.**
- **With our airlift optimization model, we**
  - **directly determine constraining resources;**
  - **estimate marginal contributions of ground resources at each airfield to airlift throughput; and**
  - **estimate best distribution of the ground resources among the airfields.**
- **We can therefore suggest better rules and allocations of scarce resources for trial in simulations and operations.**

RAND

In summary, our approach uses ACE to produce more detailed and consistent estimates of aircraft ground times and airfield capacities, and it uses NRMO (a) to directly determine the constraining resources, (b) to estimate the marginal contributions of ground resources specific to each airfield, and, as we will describe more fully later, (c) to estimate the best distribution of the ground resources among the airfields. "Best" means within the confines of our model and our working assumptions.

This Briefing

NDRI

Plan:

I. Introduction

II. Recent airlift studies

III. The RAND study

– Approach

– Findings

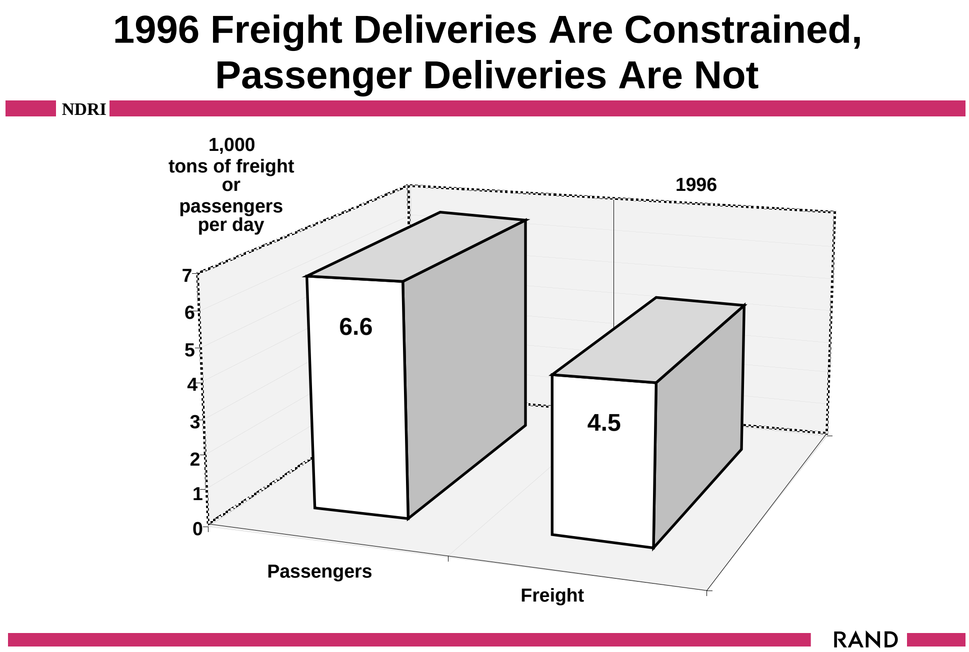
- The 1996 baseline
- Effects of longer ground times
- Effects of optimizing

IV. Concluding remarks

RAND

FINDINGS

Now let's discuss our findings.



The 1996 Baseline

Remember that we use the MRS-BURU, MRC-E scenario and cargoes, with most parameter values taken from AMC's recent study. However, we use our airfield and airlift models.

We use only the 1996 airlift fleet and the 1996 airfield resources. We do not model the 2001 and the 2006 scenarios.

For the 1996 scenario, we estimate that all of the passenger movements included in the TPFDL can be delivered within their allotted time windows. The average is some 6.6 thousand passengers per day over the first 30 days of the conflict. We estimate that all of these passengers can and will be carried by CRAF (Stage 2) aircraft.

We estimate that nearly 135 thousand tons of freight will be delivered by a combination of military and CRAF aircraft over the first 30 days of the deployment. This is an average of 4.5 thousand tons of cargo per day.[13]

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[13]In all of the cases discussed in this briefing, we assume that AMC's 1996 fleet of 95 C-5s, 18 C-17s, 174 C-141s, and 37 KC-10s is available for use.

Our Estimates of Freight Deliveries Exceed AMC's (1)

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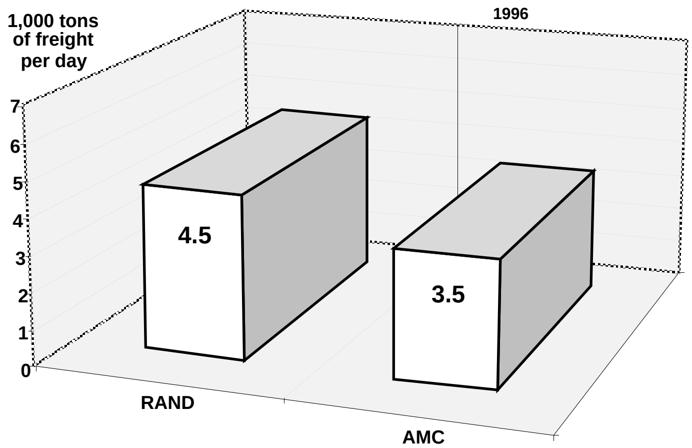
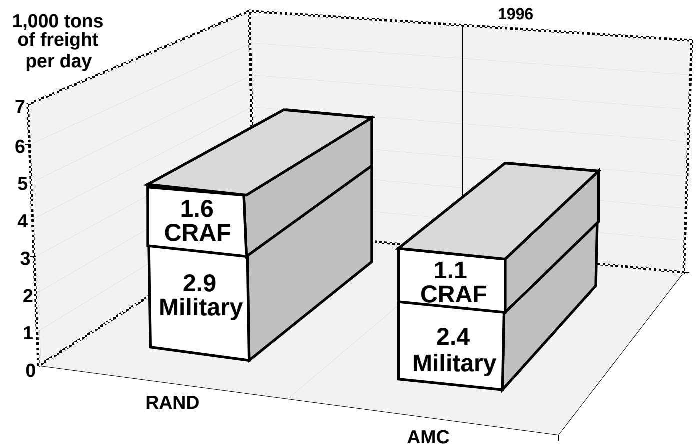


RAND

Our estimate of cargo deliveries exceeds the estimate produce by AMC. Their estimate was 3.5 thousand tons per day; ours is 4.5 thousand tons per day, or about 30 percent greater.

A minor portion of the remainder of this briefing will be devoted to discussing and explaining that difference. Our purpose here, however, is not to calibrate either our model or theirs. Most of our discussions will focus on ways of using the models to better understand the relationships between airfield resources and airlift flows.

Our Estimates of Freight Deliveries Exceed AMC's (2)



Looking closer at the estimates, we see that our estimates of both deliveries by CRAF aircraft (the upper portions of the bars) and of deliveries by military airlift aircraft (the lower portions of the bars) exceed AMC's.

Our estimate of CRAF capacity is roughly 40 percent greater. And our estimate of military airlift capacity is roughly 20 percent greater.

Why do the estimates differ?

Two major procedural differences between our study and AMC's immediately draw suspicion: The first is our use of longer ground times derived from ACE; the second is our use of an optimization model rather than AMC's simulation model.

Other factors, such as differences in assumptions and in other inputs, probably also contribute, but, as just noted, most of those differences will not be pursued here. Our objective in this study is to explore and contrast the optimization and simulation procedures, not to produce definitive estimates of airlift capacity.

We focus on the effects of ground times and of optimization.

Both Optimization and Longer Ground Times Are Important (1)

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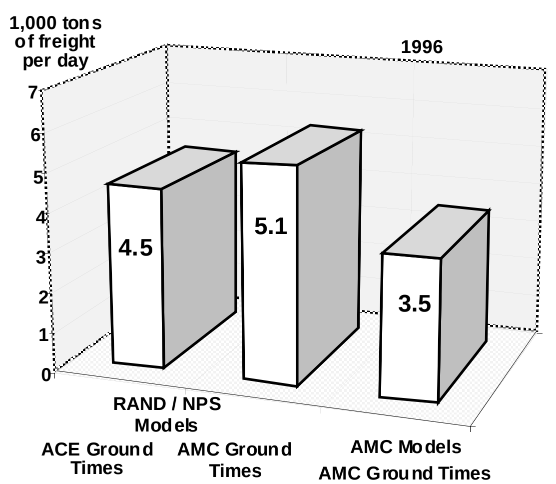

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First, let's look at what our model would do using the Air Force's standard ground times.

This procedure adds a third estimate to our graph. The center box in this chart is our estimate of cargo deliveries using AMC's standard ground times.

This estimate is greater than AMC's estimate because it uses our optimization model. The use of NRMO increases the estimated flow by about 45 percent.

This estimate is also greater than our baseline estimate—about 12 percent greater—because it uses AMC's shorter ground times.

Both Optimization and Longer Ground Times Are Important (2)

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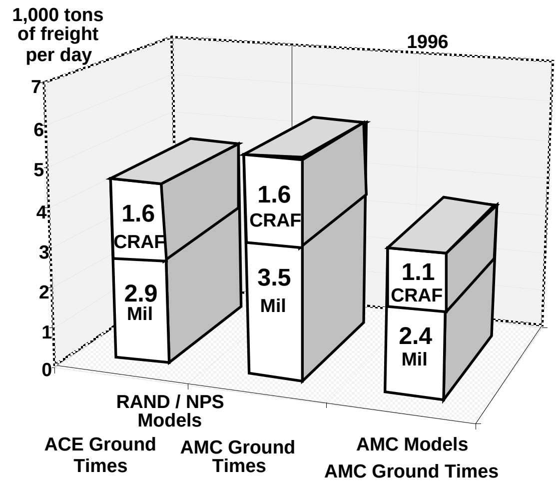


RAND

Effects of Longer Ground Times

Here we show those estimates again, differentiating between the two types of carriers: CRAF and military.

Note first that the increases between the right-hand case and the center case are quite similar for deliveries by CRAF aircraft and deliveries by military aircraft. Both increase by more than 40 percent.

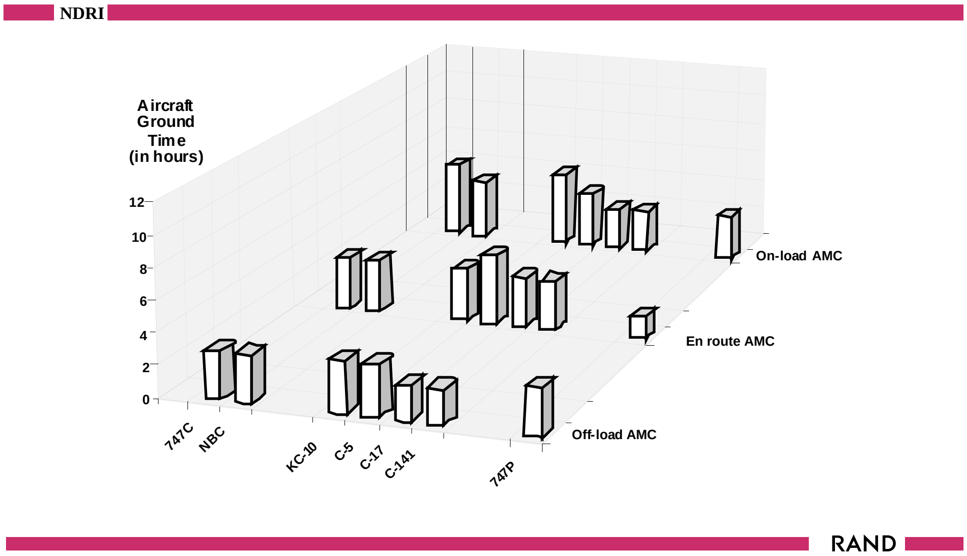
But then, when we introduce the longer ground times, the deliveries of the military aircraft are reduced from an average of 3.5 thousand tons per day to an average of 2.9 thousand tons per day. The deliveries by CRAF aircraft remain at about 1.6 thousand tons per day. Why is this?

This is because the CRAF fleet represented here has excess capacity. As we will see later, CRAF aircraft can carry only bulk cargo, and in our scenario there are sufficient CRAF aircraft to carry *all* the bulk cargo contained in the flow for the first 30 days of the TPFDL. The CRAF fleet can carry that cargo even with our longer ground times.

Deliveries by the military aircraft, on the other hand, decrease because those aircraft are being used as intensively as possible, in both the standard-ground-time case and the longer-ground-time case.

Now, let's look more closely at the differences in ground times.

Standard Ground Times



This chart shows the standard ground times used in Air Force studies since MRS-BURU.

They range from 2 hours and 50 minutes (C-141s and C-17s) to 5 hours (KC-10s) for on-loads; from 3 hours and 15 minutes (C-141s and C-17s) to 4 hours and 30 minutes (C-5s) for en route stopovers; and from 2 hours and 15 minutes (C-141s and C-17s) to 3 hours and 20 minutes (KC-10s) for the off-loading stopovers.

Our Ground Times Are Significantly Longer Than Standard Ground Times

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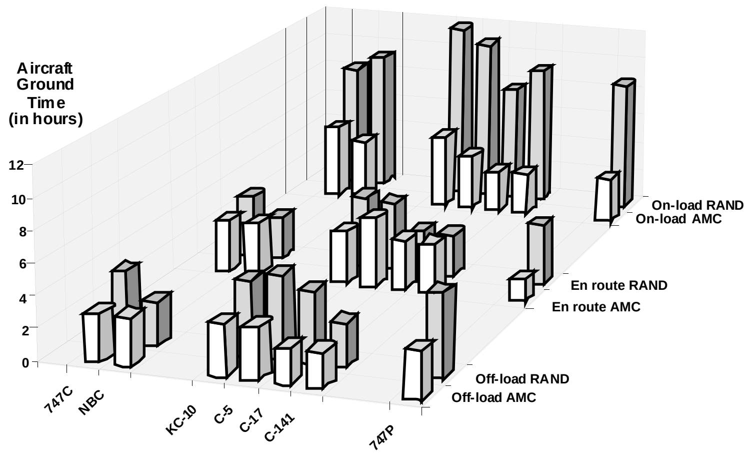


RAND

Now we add our ground times, which are significantly longer, especially for the on-loads. (Detail on both the standard times and the ACE-generated times are shown in Table 1 below.)

Our off-loads range from 2 hours and 45 minutes (C-141s, NBCs) to 5 hours and 15 minutes (C-5s). These are roughly 40 percent greater than the standards.

Our en route stopovers range from 2 hours and 45 minutes (C-141s, C-17s, and NBC aircraft) to 4 hours and 45 minutes (KC-10s). These are roughly 11 percent longer than the standard times.

And our on-loads range from 7 hours and 45 minutes (C-17s) to 11 hours and 45 minutes (KC-10s). These are about 150 percent greater than the standards.

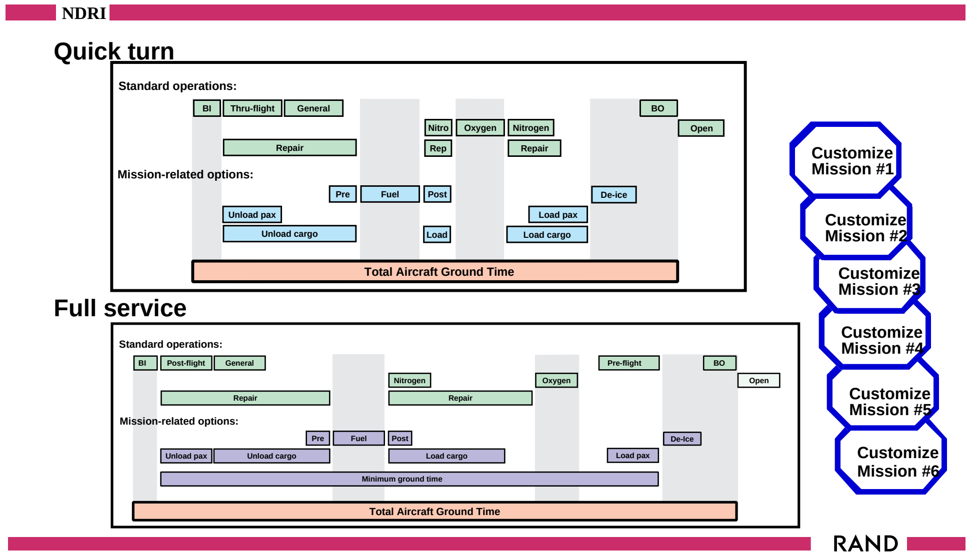
To see why the ACE-generated times are so much longer, we need to look more closely at the manner in which ACE builds up estimates of ground time from estimates of operations' and tasks' times.

Table 1

Aircraft Ground Times
(hours)

Source, Aircraft Type	On-load	En route	Off-load
Standard times			
747 Cargo	5.00	3.44	3.00
NBC	3.88	3.49	3.00
KC-10	5.00	3.44	3.32
C-5	3.75	4.53	3.25
C-17	2.87	3.23	2.25
C-141	2.87	3.23	2.25
747 Passenger	3.00	1.50	3.00
ACE-generated times for this scenario			
747 Cargo	8.25	4.00	4.50
NBC	9.25	2.75	2.75
KC-10	11.75	4.75	4.75
C-5	10.75	4.50	5.30
C-17	7.75	2.75	3.50
C-141	9.25	2.75	2.75
747 Passenger	8.75	4.00	5.25

ACE Builds Ground Times from Servicing Operations and Tasks



Note: BI = block-in, BO = block-out.

As we mentioned before, ACE computes aircraft ground times in three ways: using a quick-turn profile (which we used in estimating the en route and off-loading stopovers), using a full-service profile (which we used in estimating the times for the on-loading CONUS stopovers), or using some customized profile.

The upper portion of this graphic illustrates the quick-turn profile.[14] It comprises 15 ground operations, several of which can be performed simultaneously. The four operations on the top line (recovery, through-flight inspection, general servicing, and launch) are operations that must be performed for every aircraft on every mission.[15]

The other operations may need to be performed only on some missions or only or some aircraft (regardless of their assigned mission). The fueling and the aerial-port operations are mission-level specifications. The nitrogen service, oxygen service, and repair operations, on the other hand, are aircraft-level specifications. Finally, the de-icing operation is both a mission and an expected-value specification. Its need, as a percent of the aircraft on the mission, is explicitly specified by the user for each mission.

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[14]These servicing profiles and many of the servicing-operation times were established for us by Captain Andre Gerner during his Air Force Fellowship at RAND.

[15]Unless, of course, the user creates a customized mission profile.

The unshaded portions of the figures represent intervals of time during which several concurrent operations can be performed on the aircraft. The shaded areas represent times when a single operation precludes the performance of other operations: during block-in and block-out, the aircraft is still in operation, if not in motion; fuel transfer, oxygen servicing, and de-icing are considered hazardous operations and are normally isolated.

ACE consolidates times for all these operations—specific times for fueling and loading based on mission specifications, and standard times (by aircraft type and configuration) for the others—to construct its estimates of aircraft ground time.

Note that we do not require the repair operation or cargo loading to be accomplished in a single application: These procedures can be broken up for fuel transfer or for oxygen servicing. This keeps the total ground time from becoming unnecessarily long.

The full-service stopovers involve both more inspections and, typically, longer servicing times. Table 2 shows the expected ground-operation times for C-17 aircraft under both quick-turn and full-service stopovers.

Customizing can be done in many ways. As one example, the user might desire to make a quick turn even quicker by setting the times for the through-flight inspection and for general servicing to zero. Then the stop would consist only of the block-in of 5 minutes, the off-loading time which is calculated within the model, and the block-out of 15 minutes. That is, the aircraft would be in the ramp area only 20 minutes plus the time for the off-load.

Table 2

Expected Ground Times for C-17s (minutes)

	Quick-Turn Times		Full-Service Times	
Ground Operation	Operation	Aircraft	Operation	Aircraft
Standard operations				
Block-in	5	5	5	5
Through-flight inspection	42	42		
Post-flight inspection			120	120
General servicing	20	20	30	30
Repairs	6	0	12	12
Nitrogen servicing	1	1	2	2
Oxygen servicing	7	7	17	17
Pre-flight inspection			96	96
Block-out	15	15	15	15
Subtotal		90		297
Optional operations				
Fueling				
Pre-fuel	5	5	5	5
Fuel transfer (150,000 lb)	72	72	72	72
Post-fuel	5	5	5	5
Loading				
Set up aircraft for loading	6	6	6	6
Set up aircraft for pallets	5	5	5	5
On-loading pallets	32	0	32	0
Off-loading pallets	32	0	32	0
Set up aircraft for NPC	6	6	6	6
On-loading rolling stock	75	75	75	75
On-loading other oversized	150	115	150	150
On-loading outsized cargo	150	115	150	150
Off-loading rolling stock	45	15	45	0
Off-loading other oversized	150	120	150	0
Off-loading outsized cargo	150	120	150	0

SOURCE: Inputs and output of ACE.

NOTE: These estimates based on the following assumptions; de-icing is not required for any aircraft; resource shortages do not increase the expected aircraft-servicing times; and all aircraft are parked one mile from the aerial port. See J. P. Stucker and R. Berg, RAND, MR-700-AF/OSD, p. vi, for details.

Table 3

Expected Values for the Probabilistic Operations, C-17s (minutes)

Ground Operation	Duration, when Needed	Proportion of Time Needed	Expected Duration
Repairs			
Quick turn	60	0.10	6.00
Full service	60	0.20	12.00
Nitrogen servicing			
Quick turn	15	0.10	1.50
Full service	20	0.10	2.00
Oxygen servicing			
Quick turn	45	0.15	6.75
Full service	45	0.38	17.10

SOURCE: Inputs to ACE; originally from AMC.

As another example, the user might wish to customize on-loads, perhaps performing several operations in parallel, or perhaps using a quick-turn profile rather than full service.

We caution the user, however, against severely shortening the ground times. After an aircraft has flown 3,000-some nautical miles, spending seven or eight hours or longer in the air, it requires at least routine servicing and inspection.

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Plan:

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- –**Approach**
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IV. **Concluding remarks**

RAND

Now let's examine how the optimization model affects our estimates of cargo deliveries.

We begin by discussing the meaning of a "good" airlift flow and how such flows are normally estimated by mobility simulations and optimizations.

Airlift Objectives

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Support major deployments

- Delivers specified cargos
  - On time
  - Safely

Support other air-transport operations

Employ airlift assets effectively and efficiently

RAND

Effects of Optimizing

An airlift system must be able to support major deployments—delivering the required cargoes on time and safely—at the same time that it continues to support other national operations. To do this with limited resources, it must employ those resources as effectively and as efficiently as possible.

Planners specify their movement requirements in a TPFDL, a time-phased force-deployment listing. This listing specifies both the cargoes and their priorities: cargoes specified to arrive in the theater on day x are expected to arrive before those specified to arrive on day x+1.[16]

Each "cargo," represented on a "line" in the TPFDL, can consist of passengers, bulk (palletized) freight, oversized (larger) freight, and outsized (fits only in a C-5 or C-17) freight, all associated with one of some 33 commodity classes of military resources and organizations. Each cargo has an available-to-load (earliest) date and a required-delivery (latest) date. These dates determine its location in the TPFDL.

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[16]Additional priorities are sometimes assigned using fields designated as POD (port of debarkation) priority, POD priority add-on, CINC's (commander in chief's) RDD (required delivery date), etc., but these are treated less systematically.

Mobility systems and mobility models attempt to move those cargoes in their prioritized order.

Models Mimic Airlift Flows

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Mobility simulations

- **Deal with cargoes one at a time**
- **Select a type of aircraft according to rules**
- **Route that aircraft according to rules**
- **Handle many cargoes, aircraft, routes**

Mobility optimizations

- **Look at all cargoes together**
- **Select best aircraft for each cargo**
- **Select best route for each type of aircraft**
- **Handle fewer cargoes, aircraft, routes**

RAND

Mobility simulations typically work with cargoes and aircraft one at a time, as they appear in the requirements file and as they become available for use. In MASS, when an aircraft becomes available, the model looks for the location of its preferred cargo type, with the earliest availability date; and then it looks for the least-congested preferred route. Then the next available aircraft looks for its preferred type of cargo, and so on. This rule-based behavior allows simulation models to handle many cargoes, many aircraft of many types, and many airfields.

Mobility optimizations such as NRMO, on the other hand, consider all possibilities and then select the best cargo and route for each aircraft in each time period. This difference results in much larger decision spaces; consequently, optimizations have been able to handle fewer cargoes, aircraft, and routes. Over time, however, with continuing increases in computing power and algorithmic techniques, the size of feasible problems has increased substantially.

NRMO solved the linear problems reported here in less than an hour on a Sun SPARC 20 with 256 megabytes of RAM. The more-complex runs incorporating integer constraints took several hours.

NRMO Allocates Cargoes to Aircraft Efficiently

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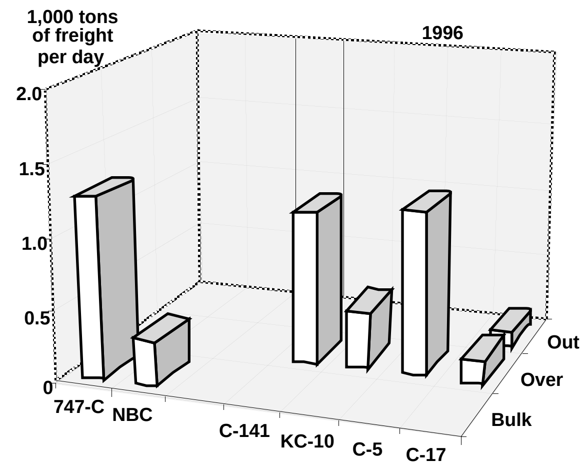

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Allocating Cargoes to Aircraft

As we noted before, NRMO attempts to maximize on-time deliveries by minimizing the penalties associated with late or non-delivered cargo.

NRMO attaches a penalty to each cargo (and to each portion of that cargo assigned to a different aircraft). This penalty increases in value each day the cargo is late (that is, estimated to be delivered after its RDD), thus encouraging the delivery of cargoes in their TPFDL-ordered sequence. Cargoes are delivered out of sequence only when appropriate aircraft are not available or when slighting a delivery now will allow a more-than-compensating increase later.[17]

This graph shows our estimated cargo flows by aircraft type.

The CRAF aircraft—the cargo version of the 747 and the narrow-body cargo aircraft—handle bulk cargo (that is, cargo packed into standardized pallets) efficiently. But with their low wings, high bodies, and small doors, they handle oversized and outsized cargoes (such items as HMMWVs, aircraft engines, and even helicopters) quite inefficiently. Consequently, in these runs they transport only bulk

[17]Most penalties are set to level off after a certain number of days so that a few especially difficult-to-deliver cargo do not disrupt the entire airlift flow.

cargo. We estimate that in these runs we have sufficient CRAF aircraft to deliver all of the bulk cargoes.

Military aircraft, in contrast, with their high wings, low bodies, and wide doors, are designed to efficiently transport oversized cargo. The C-5s and C-17s are also designed to efficiently transport outsized cargo.

In this cargo-allocation scenario, however, we estimate that the C-5s and the C-17s have insufficient capacity to deliver all of the required cargoes. Here they deliver 70 percent of the oversized cargoes and only 13 percent of the outsized.

This short-shrifting of the outsized cargoes reflects the structuring of the TPFDL—that is, the prioritizing of the cargoes—more than any other factor. But to some extent, when the model is considering the allocation of either oversized or outsized cargoes of equal lateness to a C-5 or C-17, it also reflects the fact that, for this set of movement requirements at least, the oversized cargoes (fully-loaded trucks and C-5 engines, for example) carried are substantially more dense than the outsized cargoes (helicopters and the like). That is, more tons of oversized cargo can be carried than tons of outsized cargo, and thus the total penalty value is reduced. See Table 4.

This depiction represents the baseline operation of NRMO. However, if we have some information suggesting that the warfighters have a significant preference for outsized cargoes, and if for some reason the TPFDL can/should not be changed, the NRMO penalties can be adjusted to increase those deliveries.

Table 4

Average Tons Carried, by Aircraft Type
(the 4.5 thousand ton-per-day run)

Type of Aircraft	Bulk	Over	Out
C-17	41	48	33
C-5	82	64	43

SOURCE: Outputs of NRMO.

NOTE: Entries are averages of the more than 30 different types of cargoes (commodity codes) carried by each type of aircraft.

NRMO Allocates Cargoes to Aircraft Efficiently but Allows for Other Priorities

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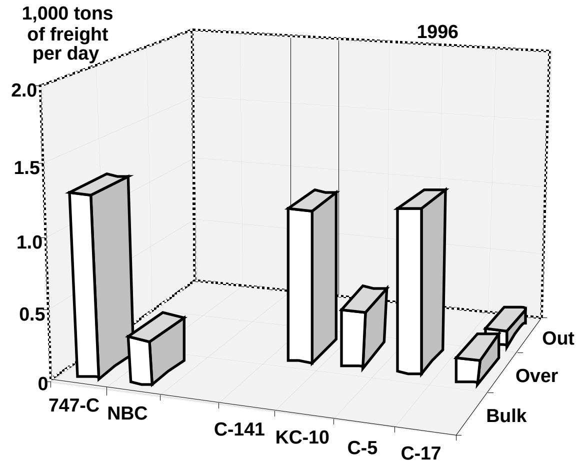

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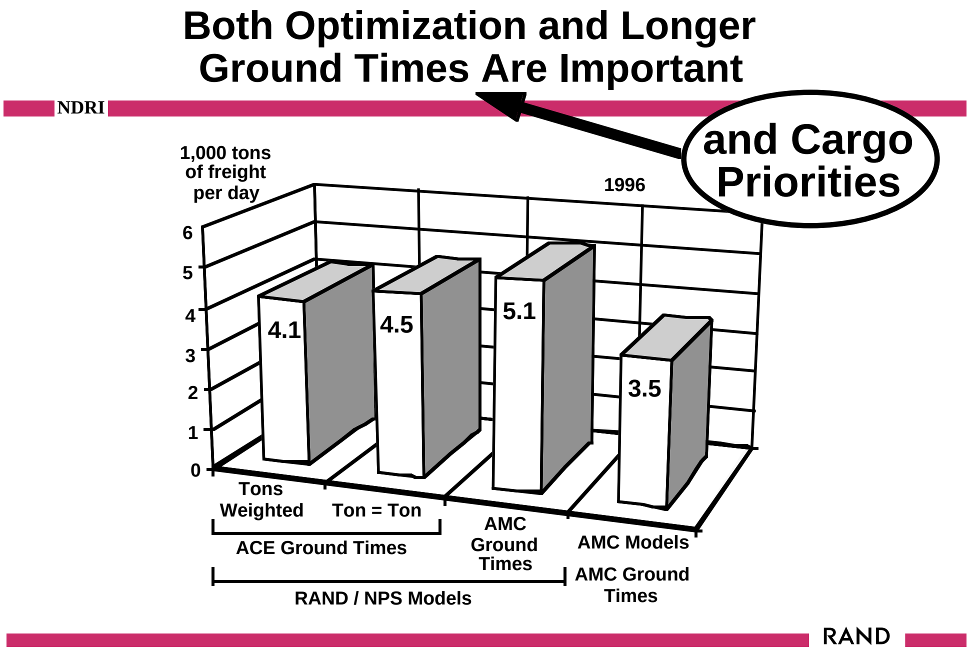
This graph depicts the delivery profile when we value a ton of outsized cargo twice as much as a ton of bulk and a third more than a ton of oversized cargo.

CRAF aircraft continue to carry all of the bulk. Because they are very inefficient at loading oversized and outsized cargo, transporting bulk cargo, even when it is valued less, remains their “best use.”

The C-141s and KC-10s, which can transport oversized but not outsized, continue to do so. But the C-5s and C-17s, which can transport outsized as well as oversized cargoes, now specialize in transporting outsized cargo. In this scenario, they transport all of the outsized cargoes. That is, with a weighting factor of 2, 1.5, and 1 on the outsized, oversized, and bulk cargoes, respectively, the 1996 airlift fleet delivers all the bulk cargo, all the outsized cargo, and much of the oversized cargo.

But note that this weighting scheme reduces the total deliveries over the 30-day period by 10,828 tons, or by an average of 0.36 thousand tons per day. Whereas it increases the deliveries of outsized cargo by 23,918 tons, it decreases the deliveries of oversized by 34,746 tons, a trade-off of about 1.45 to 1. This could be good if the outsized tons are in fact more important to the deployment than the oversized tons; or it could be bad if they are less or even equally important. The point here is that all weighting should be carefully considered, in simulations as well as in optimizations.



Before we go on, let's look at this result once more and put it into context with our earlier findings. Weighting the cargoes to represent additional information on priorities has reduced the deliveries to an average of 4.1 thousand tons per day. That amount is still significantly larger than the AMC estimate of 3.5 thousand tons per day, but it is significantly reduced from our estimate of 4.5 thousand tons per day. If the object of our exercise is to replicate the AMC estimate, we could proceed further down this road: observing which cargoes the AMC model carries and weighting our inputs to prioritize those; observing which aircraft are assigned which routes by the AMC model, and tweaking our inputs accordingly. We believe, however, that simply following the TPFDL listings produces the preferred delivery profile.

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Allocating Aircraft to Routes

Now let's look at the way NRMO assigns aircraft to routes.

And then we'll finish up by demonstrating how NRMO can efficiently allocate a limited resource like ramp or fuel among the several airfields in ways that improve the overall flow of the airlift system.

Allocating Aircraft to Routes

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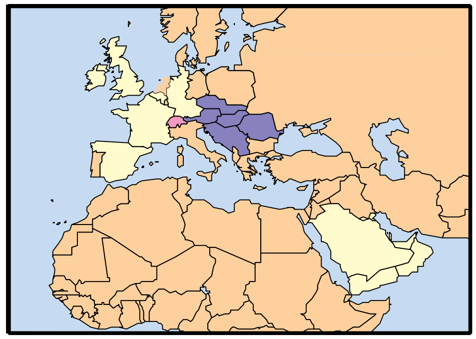

	From Dover	From Dhahran	Total
Mildenhall	**3,123**	**2,953**	**6,076**
Ramstein	**3,437**	**2,765**	**6,202**
Moron	**3,213**	**2,879**	**6,092**

RAND

We assume in this study that all of the military aircraft load and leave from a common location in the United States (Dover, Del.), fly to Europe where they refuel, fly to a common off-loading site in Southwest Asia (Dhahran), fly back to Europe for more fuel, and then return to the United States.

We identify en route airfields in England, Germany, and Spain for the military aircraft, so they have a choice of routes, both going and coming.[18]

The table shows the distances in nautical miles that the military aircraft travel when routed through the alternative en route airfields. Note that in each case the critical leg—the leg where the required fuel load limits the amount of cargo that can be carried—is the U.S.–Europe leg. Stopping over in England allows the most cargo to be transported and requires the least (total) fuel. Going through Spain increases the length of the critical leg by 3 percent and increases the total distance by about a quarter of 1 percent. Going through Germany increases the critical

[18]CRAF aircraft fly from Dover to an airfield in England (collocated with Mildenhall, but not competing with it for resources), then to Dhahran, and then back through England to the United States.

leg by 10 percent and increases the total distance by just over 2 percent.[19]

[19]Going through Mont de Marsan, France would increase the critical leg by 4.5 percent while *lowering* the total distance by about 3.5 percent.

The “Best” Route Depends on . . .

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- Geography
- Politics
- Weather
- Type of aircraft
- Type of cargo
- Airfield resources

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In addition to distance, selecting the “best” route depends on a number of factors, not all of which we can consider in this study.

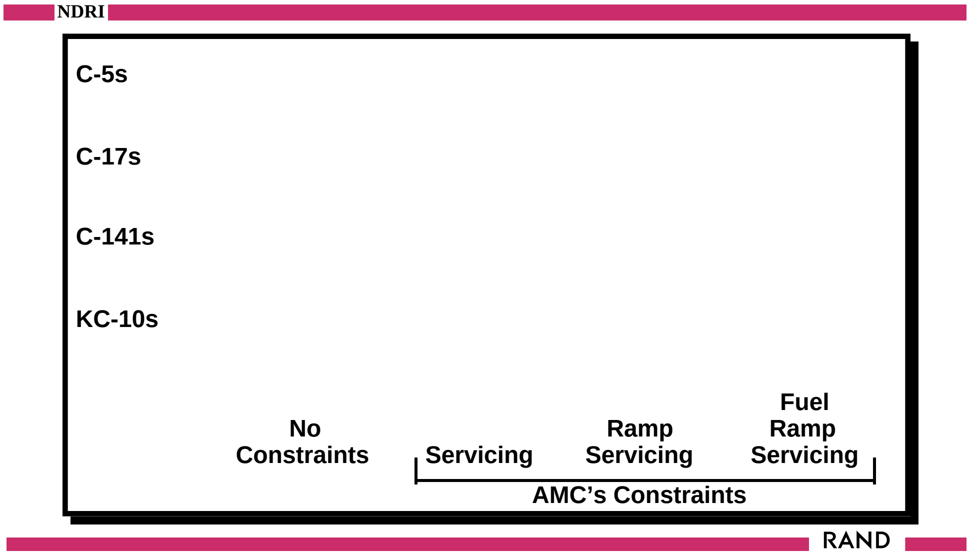
Geography is important because it determines the distances. We do account for that.

Politics is important because it can cause shutdowns at airfields. We do not account for that. Politics is also important because it may prevent us from flying over certain countries, and this we do account for. As shown in the previous chart, the routes through England and, especially, Germany must detour significantly to avoid flying over Italy and the nations of Eastern Europe.

Weather is important but we do not consider it.

Aircraft type, cargo type, and airfield resources are all important, and we do model them all.

The Best Routes (1)



Our analysis of the best routing of aircraft through the en route airfields consist of four cases:

- one with no constraints on any of the en route airfields;
- one with constraints on servicing, by aircraft type, which we explain;
- one with constraints on servicing and on the ramp space available at the individual airfields; and
- one with constraints on servicing, ramp space, and fuel.

The Best Routes (2)

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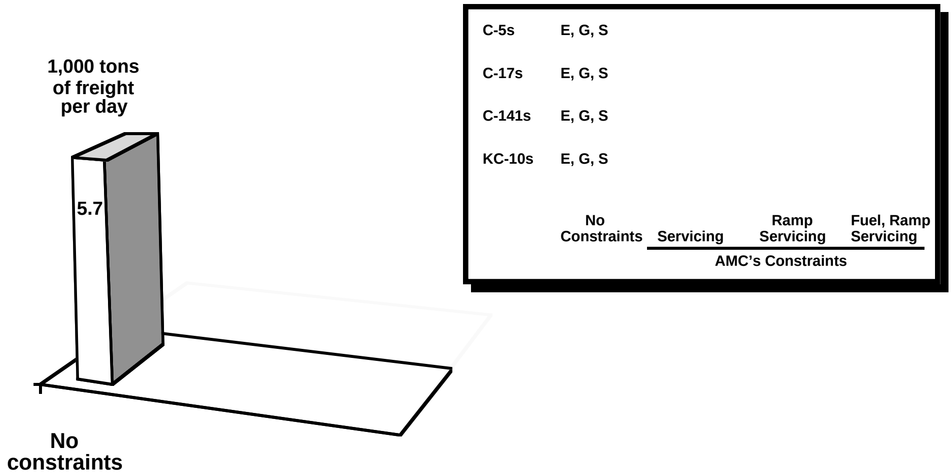

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NOTE: E = England; G = Germany; S = Spain.

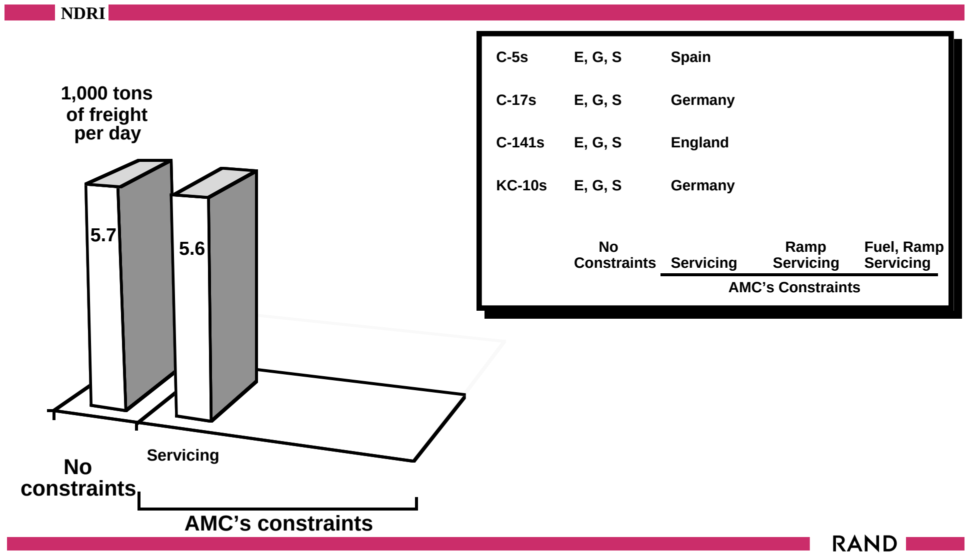
When we have no en route constraints, that is, when we allow the model to select the "best" en route airfield for each military aircraft on each trip it makes to and from Saudi Arabia, the model routes aircraft through all of the airfields. Every type of aircraft has most of its planes routed through England, but some of them go through Germany, and some of them go through Spain.

The TPFDL identifies 33 different categories of cargo. The AMC aircraft data specify "typical loads" of each cargo category for each aircraft type. And many of those loadings "bulk out" the aircraft before its lifting limit or maximum cabin load is reached, so marginally longer routes do not reduce the amount of those cargoes that can be carried.

Additionally, because we do not "charge" for fuel and the quantity of fuel available is not limited in this run, and because the differences in travel time and in cycle time resulting from using the alternative en route airfields are minor and are lost in the time-period structure used by the model, the model just doesn't care in this case which en route airfields are selected by the aircraft.

With no active airfield constraints, we estimate that in this case, the 1996 airlift fleet can deliver an average of 5.7 thousand tons per day over the first 30 days of the conflict.

The Best Routes (3)



When we impose the "servicing" or "service center" constraint, the profiles look like this.

This constraint recognizes that the supply of servicing personnel for each type of aircraft is limited and that a critical mass of correctly trained technicians is required to service and repair these complex, fragile aircraft.

This constraint requires that all of the C-5s route through the same country, that all of the C-17s route through a different (single) country, and that all the C-141s route through a different country. We allow the KC-10s, because so few of them are available as airlifters, to flow through any single airfield. We call this our "birds of a feather" constraint. That is, the model selects the "best" routing for each type of aircraft, given the set of cargoes, the characteristics of the routes, and the different capabilities of the aircraft.

With this constraint imposed, our model routes the C-5s through Spain, the C-17s and the KC-10s through Germany, and the C-141s through England. But, again, the routings appear not to be critical: Little difference in the total number of tons delivered, which we estimate here as 5.6 thousand tons per day, would result if other routings were chosen or imposed.

The Best Routes (4)

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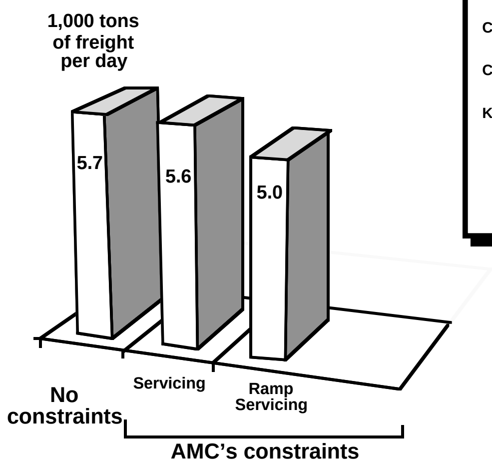

	No Constraints	Servicing	Ramp Servicing	Fuel, Ramp Servicing
		AMC's Constraints		
C-5s	E, G, S	Spain	Spain	
C-17s	E, G, S	Germany	England	
C-141s	E, G, S	England	Germany	
KC-10s	E, G, S	Germany	England	

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Introducing the servicing constraint reduced deliveries by about 100 tons per day. Now we see that introducing the set of ramp constraints imposed by AMC reduces deliveries by another 500 tons per day, down to an average of 5.0 thousand tons per day.

These constraints hurt. The C-5s going through Spain saturate its airfield every day from the 2nd day through the 30th day. The C-17s and KC-10s going through England fill its airfield every other day and keep it at over 90 percent of capacity on the odd days. The C-141s keep the German airfield at over 90 percent of capacity every day.

Table 5 below shows the resources available at the individual en route airfields in 1996.

Table 5

Resources Available at the En Route Airfields in 1996

Airfield	Ramp (narrow-body-equivalent hours per day)	Fuel (million gallons per day)
England	240	1.61
Germany	336	1.57
Spain	168	0.82

NOTE: MRC-E scenario for 1996.

The Best Routes (5)

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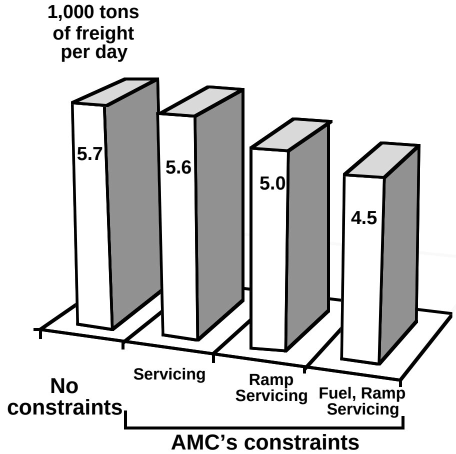

	No Constraints	Servicing	Ramp Servicing	Fuel, Ramp Servicing
C-5s	E, G, S	Spain	Spain	Germany
C-17s	E, G, S	Germany	England	Spain
C-141s	E, G, S	England	Germany	England
KC-10s	E, G, S	Germany	England	Spain

AMC's Constraints (Servicing; Ramp Servicing; Fuel, Ramp Servicing)

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Finally, imposing the set of fuel constraints used by AMC reduces deliveries by another 500 tons per day. This duplicates our base case and our base-case deliveries of 4.5 thousand tons per day. This estimate is based on AMC's estimates of the currently available ramp and fuel at each airfield and on the requirement that all aircraft of the same type make their en route stopovers in the same country.

The ramp, or parking-space, constraint limits the C-5s in Germany and the C-141s in England. But both those fleets consume substantially more fuel in those countries, respectively, than they would have been able to, had they been routed through Spain. The C-17 and KC-10 fleets, with substantially fewer aircraft, exhaust the limited supplies of fuel in Spain, but do not stress the ramp there.

Now, as a first check on its robustness, we compute these runs again using the Air Force standard ground times.

The Best Routes with ACE Times and with Standard Times

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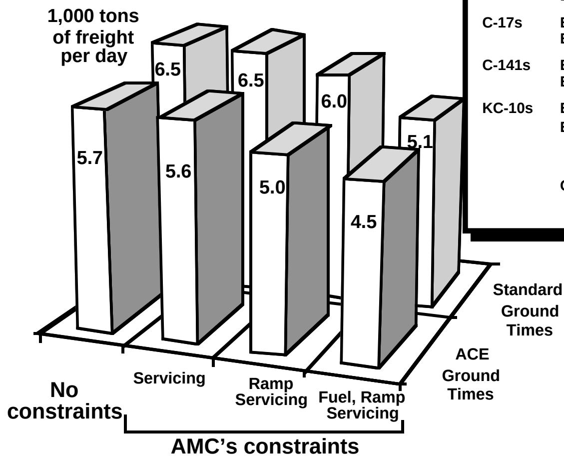


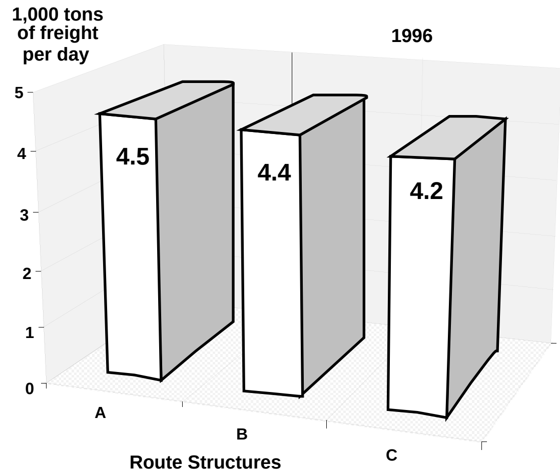
	No Constraints	Servicing	Ramp Servicing	Fuel, Ramp Servicing
		AMC's Constraints		
C-5s	E, G, S England	Spain Spain	Spain Spain	Germany Germany
C-17s	E, G, S E, G, S	Germany Germany	England England	Spain Spain
C-141s	E, G, S England	England England	Germany Germany	England England
KC-10s	E, G, S E, G, S	Germany Spain	England England	Spain Spain

RAND

The standard times (second line in columns 2–5) do not change the profiles. Deliveries increase because of the short ground times, but the routings remain the same. In the fully constrained case, the C-5s still stop over in Germany, the C-17s and the KC-10s in Spain, and the C-141s in England.

As a second check, we will look at these routes from a different angle to see what happens if the aircraft are systematically misrouted.

Improper Routing Reduces Deliveries



	Routing Profile A	B	C
C-141s	E	G	S
C-5s	G	S	E
C-17s	S	E	G
KC-10s	S	E	G

NOTE: E = England; G = Germany; S = Spain.

The graphic shows deliveries for runs including the three constraints (service centers, ramp, and fuel), but routing the aircraft through different countries.

The best routing of aircraft through airfields—Profile A here, with the C-5s going through Germany, the C-17s through Spain, and the C-141s through England—delivers an average of 4.5 thousand tons of cargo per day.

Profile B—with the C-5s routing through Spain, the C-17s through England, and the C-141s through Germany—delivers an average of more than 4.4 thousand tons per day. This is approximately a 2 percent reduction in deliveries.

Profile C—with the C-5s routing through England, the C-17s through Germany, and the C-141s Spain—delivers an average of more than 4.2 thousand tons per day, or nearly a 7 percent reduction in deliveries.

In summary, when resources are limited, the routes chosen for (or allocated to) the several types of aircraft can significantly affect the total tons of cargo that are delivered.

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Allocating Ramp and Fuel to Airfields

In addition to optimally allocating cargoes to a fixed fleet of aircraft and optimally allocating those aircraft to a fixed set of routes, optimization models like NRMO can also estimate the "best" fleet (mix) of aircraft and the best specification of the routes. In this scenario, MRC-East, where the en route airfields are all large international airports and where the portion of the airfield and its fuel resources made available to U.S. airlift is determined at least as much by negotiation as by physical constraints, we also can use the model to suggest better distributions of ramp and fuel among the airfields. We could attach costs to those resources at each location and solve for the least-cost distribution that supports delivery of all or some prestated portion of the cargoes. For this demonstration, however, we will assume that the total ramp and fuel for the set of en route airfields remains as specified by AMC but that negotiations with our European allies can alter the amount used by U.S. airlift in each nation.

This process will complement the preceding analysis in which we showed how the existing allocations of ramp and fuel constrained our estimates of cargo deliveries.

En Route Constraints Reduce Throughput

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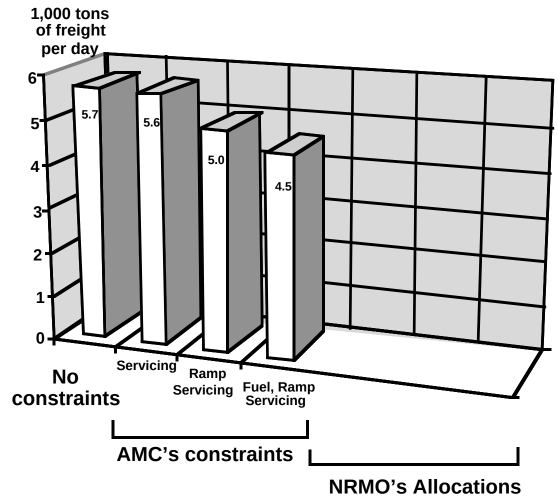

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The graphic again shows the deliveries for the cases we have just discussed—culminating in our estimate of an average 4.5 thousand tons of cargo being delivered per day for the first 30 days of the conflict. These estimates are based on AMC's estimates of the current distributions of ramp and fuel among the airfields.

En Route Constraints Reduce Throughput, Improved Allocations Increase Throughput (1)

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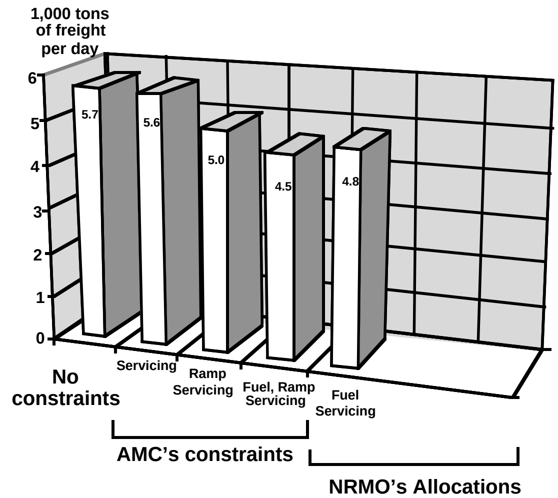

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Assuming that the same total amount of fuel is available for airlift operations, but that we can reallocate that total among the airfields, and that we choose to reallocate according to NRMO's optimal assignments, we can deliver more cargo. We estimate that reallocating that fuel among the airfields can increase deliveries by an average of 300 tons of cargo per day. This raises deliveries to an average of 4.8 thousand tons per day.

Given the existing distribution of ramp and the requirement that all aircraft of a type flow through the same airfields, then it would pay to take 600,000 gallons of fuel per day from England and ship about 400,000 gallons of it to Germany and about 200,000 gallons to Spain. Table 6 below shows the details.

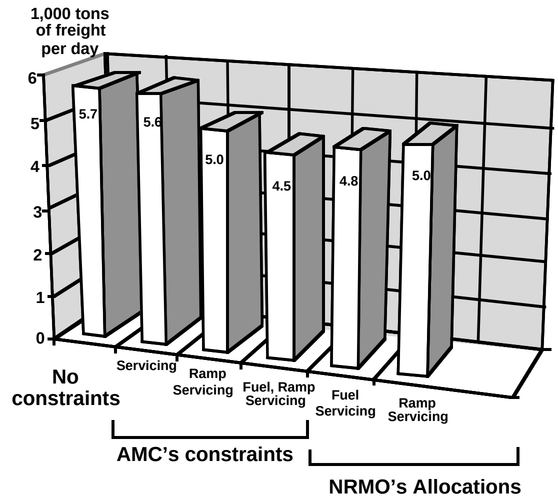
Table 6

Fuel Available at the En Route Airfields in 1996

Airfield	Fuel (million gallons per day) Existing	Preferred	Aircraft
England	1.61	1.01	C-5
Germany	1.57	1.98	C-141
Spain	0.82	1.01	C-17, KC-10
Totals	4.00	4.00	

En Route Constraints Reduce Throughput, Improved Allocations Increase Throughput (2)

NDRI



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If we go back to the predetermined allocation of fuel for a moment, but allow the optimization model to reallocate the ramp space among the airfields in the most efficient manner it can determine, we can increase deliveries even more than by reallocating fuel. Reallocating ramp space increases deliveries to an average level of 5,000 tons of cargo per day.

In summary, given the existing distribution of fuel, it would pay, if it were possible, to take some 90 parking-hours from Germany and some 50 parking-hours from Spain, and exchange them for about 143 more parking hours in England. Table 7 shows the details.

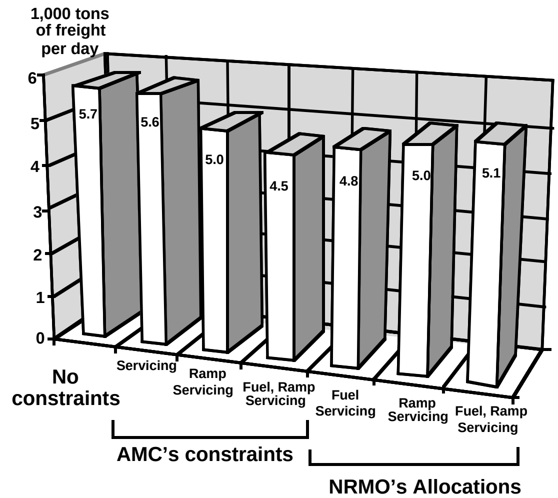
Table 7

Ramp Space Available at the En Route Airfields in 1996

Airfield	Ramp (narrow-body-equivalent hours per day) Existing	Preferred	Aircraft
England	240	383	C-5
Germany	336	243	C-141
Spain	168	118	C-17, KC-10
Totals	744	744	

En Route Constraints Reduce Throughput, Improved Allocations Increase Throughput (3)

NDRI



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Finally, if we allow the optimization model to reallocate both the fuel and the ramp space in the most efficient manner it can determine, we estimate that average daily deliveries over the first 30 days of the conflict would increase to 5.1 thousand tons of cargo per day.

This reallocation would return the level of average deliveries halfway to its unconstrained (by en route airfields) value: Our unconstrained estimate is 5.7 thousand tons per day; our fully constrained estimate is 4.5 thousand tons per day; and this estimate is 5.1 thousand tons per day.

Table 8 shows the details. When we can reallocate both ramp and fuel at the same time, in effect remaining tied only to the location of the three airfields, our model recommends that we increase the parking resources at the Spanish airfield by 117 narrow-body-equivalent hours per day, that we increase the fuel there by 1.18 million gallons per day, and that we then flow the C-5s—the largest, most cargo-carrying, and most fuel-consuming aircraft—through that airfield.

The model recommends that we flow the C-17s and KC-10s through England, the least-distance route, that we enable that flow by increasing

Table 8

Resources Available at the En Route Airfields in 1996

Airfield	Ramp Space (narrow-body-equivalent hours per day) Existing	Ramp Space Preferred	Fuel (million gallons per day) Existing	Fuel Preferred	Aircraft
England	240	281	1.61	0.99	C-17, KC-10
Germany	336	178	1.57	1.01	C-141
Spain	168	285	0.82	2.00	C-5
Totals	744	744	4.00	4.00	

NOTE: MRC-E scenario for 1996.

the parking resources there by 41 narrow-body-equivalent hours per day, and that we transfer more than 600,000 gallons of fuel per day from England to Spain.

And the analysis shows that we can slash Germany's ramp and fuel resources—moving 41 ramp-hours per day to England and 117 ramp-hours along with 560,000 gallons of fuel per day to Spain—while still supporting an average of 82 C-141s per day.

This Briefing

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Objectives:

Demonstrate use of ACE and NRMO in estimating the capacities of airlift resources

Plan:

- **I. Introduction**
- **II. Recent airlift studies**
- **III. The RAND study**
  - – **Approach**
  - – **Findings**
- **IV. Concluding remarks**

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CONCLUDING REMARKS

Now let's review our findings.

It's always a challenge to allocate resources wisely. As mobility dollars, like all military dollars, become scarcer and scarcer, the importance of properly allocating resources becomes greater and greater.

This research project was designed to expand OSD's capability for conducting, understanding, and using mobility analyses.

The research objectives for RAND were to find ways to use ACE and NRMO together to link airfield resources with airfield capacity.

The objective of this briefing was to demonstrate how the two models can be used to estimate the affects of airfield resources on the capacity of a specific airlift system.

Summary of Findings

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For MRC-E, 1996 scenario:

- **CRAF aircraft can deliver all passengers**
- **Freight deliveries are constrained by aircraft and airfields**
- **Optimization models show more deliveries than does simulation**
- **Longer ground times can reduce deliveries substantially**
- **When deliveries are constrained**
  - **Allocation of cargoes to aircraft is important**
    - **Cargoes selected on effectiveness of transport**
    - **Or can use priorities and examine trade-offs**
  - **Allocation of aircraft to routes is important**
  - **Allocation of resources to airfields is important**

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At the initiation of this study, AMC analysts were briefing the findings of their study of the en route airfields needed to successfully execute the MRC-East deployment. Our sponsor asked that we use that same scenario to demonstrate how our models and methods could complement AMC's models and analyses, and how our estimates might expand or validate theirs.

Our analyses did both. We validated AMC's findings that for the 1996 scenario the current European en route infrastructure would significantly constrain deliveries of military cargoes during a major deployment to Southwest Asia. Both we and the AMC analysis estimated that current en route resource shortages would reduce cargo deliveries by roughly 20 percent from what they could be if those shortages did not exist.

Moreover, we expanded AMC's findings (a) by demonstrating the sensitivity of deliveries to assumptions concerning aircraft ground times at the on-load, en route, and off-load airfields and (b) by demonstrating how a better distribution of existing en route resources could significantly increase the amount of cargo delivered during the first 30 days of the conflict.

In a previous study for OSD and the Air Staff, RAND analysts demonstrated that many of the standard ground times then used in airlift studies were not long enough to allow necessary inspection and servicing of airlift aircraft.[20] In this study, we have estimated specific ground times for on-load, en route, and off-load stopovers by each type of airlift aircraft and then compared estimates of airlift deliveries based on those times as inputs with estimates of deliveries based on the current or most recent Air Force–standard ground times. We found that use of the previous standard times overestimated deliveries by 12 to 13 percent.

Airlift simulation models use prespecified "rules" to allocate cargoes to aircraft and aircraft to routes. Similarly, the ground resources available at each airfield must be specified before each run. The models then estimate the flows and deliveries resulting from the use of those resources and the application of those rules. Airlift optimizations, on the other hand, can search for the best allocations of cargoes to aircraft and aircraft to routes. They can also, as we have demonstrated, search for the best allocation of ground resources to en route airfields. The resulting analyses can be quite useful to decisionmakers looking for ways to expand airlift capacity when resources are limited.

For such a scenario, we estimate that negotiating with our European allies to redistribute the ramp apace and fuel currently available to U.S. airlift operations, without increasing the total of either, could increase deliveries over the first 30 days of the 1996 scenario by 12 to 13 percent. For other scenarios and other baselines, the estimates will differ, but the relative strengths of the analyses and findings should remain the same.

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[20]See Stucker, Berg, et al., *Airfield Capacity for Airlift Operations*, Santa Monica, Calif.: RAND, MR-700-AF/OSD, 1998.

Conclusions

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ACE & NRMO useful tools in airlift analysis

- **Provide insights into ground times & resource capacities**
- **Suggest methods for allocating resources more effectively**

For MRC-E:

- **Allocating aircraft to routes of minor importance**
- **Aircraft ground times significantly affect deliveries**
- **Allocating ramp and fuel significantly affects deliveries**
- **Allocating and prioritizing cargoes quite important**

Other analyses of other airlift scenarios might provide different findings and insights

Detailed, responsive, timely analyses now feasible

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We have demonstrated that tools are now available for analyzing in detail the operations of airfields and the operations of complex airlift systems. And desktop computing power has increased to the point where detailed and iterative analyses of airlift performance are feasible. Analysts can now respond in a timely fashion to requests from decisionmakers, using optimization models to complement and expand their simulations. Decisionmakers should demand that they do so.

REFERENCES

Goggins, D. A., *Stochastic Modeling for Aircraft Mobility*, Master's Thesis, Monterey, Calif.: Naval Postgraduate School, 1995.

Killingsworth, P., and L. Melody, *Should C-17s Be Used to Carry In-Theater Cargo During Major Deployments?"* Santa Monica, Calif.: RAND, DB-171-AF/OSD, 1997.

Killingsworth, P., and L. Melody, unpublished RAND research on "Tankers: Air Mobility Roles for the 1990s."

Melody, L., S. Baker, R. E. Rosenthal, D. P. Morton, and P. Killingsworth, unpublished RAND research on "NPS/RAND Mobility Optimization (NRMO): A New Model for Air Mobility Analysis."

Morton, D. P., R. E. Rosenthal, and T. W. Lim, "Optimization Modeling for Airlift Mobility," *Operations Research,* Vol. 1, No. 3, 1995. (Available as NPS-OR-95-007, Naval Postgraduate School, Monterey, Calif.)

Schank, J., M. Mattock, G. Sumner, I. Greenberg, J. Rothenberg, and J. P. Stucker, *A Review of Strategic Mobility Models and Analysis*, Santa Monica, Calif.: RAND, R-3926-JS, 1991.

Stucker, J. P., and R. Berg, with A. Gerner, A. Giarla, W. Spencer, L. Arghavan, and R. Gates, *Understanding Airfield Capacity for Airlift Operations,* Santa Monica, Calif.: RAND, MR-700-AF/OSD, 1998.

Wing, V. F., R. E. Rice, R. W. Sherwood, and R. E. Rosenthal, *Determining the Optimal Mobility Mix,* Washington, D.C.: JS/J8, Force Design Division, October 1, 1991.

Yost, K. A., *The THRUPUT Strategic Airlift Flow Optimization Model,* Air Force Studies and Analyses Agency, June 30, 1994.