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SEP 80 W T MIKOLOWSKY, H J ABBEY, L A ADKINS F33615-78-C-0122
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ACMA	Transport Aircraft Design Features

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Advanced Civil/Military Aircraft (ACMA) is envisioned as an advanced-technology cargo aircraft with the potential for fulfilling the needs of both military airlift and commercial air freight in the 1990s and beyond. The ultimate goal of the Design Options Study is the development of fundamental information regarding both the military and commercial cost and effectiveness implications of the most significant transport aircraft functional design features. This volume, the Qualitative Assessment of the Design Options Study
(Cont'd)

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Final Report, qualitatively assesses all functional design features and associated options that have a potential impact on military/commercial commonality of the ACMA and recommends which should be subjected to more detailed analysis. Functional areas considered in the assessment include basic aircraft performance, ground interface, airfield compatibility, cargo compartment, inflight refueling, personnel accommodations, and military/civil design criteria. Based on this assessment, the following features are recommended for more detailed analysis: design payload, loading/unloading apertures, planform shape of cargo compartment, floor height, takeoff distance/gear flotation, noise characteristics/engine-out climb gradient, cargo-envelope maximum height, passenger provisions, maximum structural payload, service-life specification, cargo compartment pressurization, and cargo accommodation provisions.

DESIGN OPTIONS STUDY

Volume III: Qualitative Assessment

LG80ER0008

September 1980

APPROVED BY: R. H. Lange

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FOREWORD

The Design Options Study was performed by Lockheed-Georgia for the Air Force Aeronautical Systems Division, Deputy for Development Planning, under Contract F33615-78-C-0122. This final report for the effort is presented in four volumes:

Volume I	Executive Summary
Volume II	Approach and Summary Results
Volume III	Qualitative Assessment
Volume IV	Detailed-Analysis Supporting Appendices

A fifth volume, describing the privately-developed analytical techniques used in this study has been documented as Lockheed Engineering Report LG80ER0015. This volume, which contains Lockheed Proprietary Data, will be furnished to the Government upon written request for the limited purpose of evaluating the other four volumes.

The Air Force program manager for this effort was Dr. L. W. Noggle; Dr. W. T. Mikolowsky was the Lockheed-Georgia study manager. Lockheed-Georgia personnel who participated in the Design Options Study include:

H. J. Abbey	Configuration Development
L. A. Adkins	Avionics
H. A. Bricker	Cost Analysis
E. W. Caldwell	Configuration Development
W. A. French	Propulsion and Noise Analysis
J. C. Hedstrom	Mission Analysis
J. F. Honrath	Aerodynamics
R. C. LeCroy	Mission Analysis
E. E. McBride	Stability and Control
A. McLean	Reliability
T. H. Neighbors	Maintainability
J. M. Norman	Commercial Systems Analysis
J. R. Peele	Mission Analysis
A. P. Pennock	Noise Analysis
C. E. Phillips	Maintainability
R. L. Rodgers	Mission Analysis
R. E. Stephens	Structures and Weights
R. L. Stowell	Mission Analysis
S. G. Thompson	Cost Analysis and Configuration Development
R. M. Thornton	Mission Analysis

Program management of the Design Options Study was the responsibility of the Advanced Concepts Department (R. H. Lange, manager) of the Advanced Design Division of Lockheed-Georgia.

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GLOSSARY

AAFIF	-	Automated Air Facility Information File
A/C	-	Aircraft
ACMA	-	Advanced Civil Military Aircraft
ADS	-	Aerial Delivery System
AEEC	-	Airline Electronic Engineering Committee
AFB	-	Air Force Base
ALICE	-	Aircraft Life Cycle Cost Evaluation
ANSER	-	Analytical Services, Inc.
APOD	-	Aerial Port of Debarkation
APOE	-	Aerial Port of Embarkation
ARINC	-	Aeronautical Radio, Inc.
ATA	-	Air Transport Association
¢/ATNM	-	Cents per Available Ton-Nautical Mile
CLASS	-	Cargo/Logistics Airlift Systems Study
combi	-	Combination Cargo/Passenger Aircraft
COMPASS	-	Computerized Movement Planning and Status System
CONUS	-	Continental United States
CRAF	-	Civil Reserve Air Fleet
DADS	-	Deterministic Airlift Development Simulation
DOC	-	Direct Operating Cost
E^3	-	Energy Efficient Engine
EPA	-	Environmental Protection Agency
FAA	-	Federal Aviation Administration
FAR	-	Federal Air Regulations
GRADE	-	GRaphics for Advanced Design Engineers
GASP	-	Generalized Aircraft Sizing and Performance

GLOSSARY (Cont'd)

GSPS	-	Global Satellite Positioning System
GSE	-	Ground Support Equipment
IADS	-	Innovative Aircraft Design Study
IFF/SIF	-	Identification: Friend or Foe/Selected Identification: Friend
IFR	-	Inflight Refueling
IOC	-	Initial Operational Capability
LCC	-	Life Cycle Costs
LCG	-	Load Classification Group
LCN	-	Load Classification Number
LD	-	Lower Deck
LIN	-	Line Item Number
L/D	-	Lift-to-Drag Ratio
LRU	-	Line Replaceable Unit
MAC	-	Military Airlift Command
NATO	-	North Atlantic Treaty Organization
NSN	-	National Stock Number
OR	-	Operational Readiness
O&S	-	Operation and Support
PAX	-	Passenger
POL	-	Petroleum, Oil, and Other Lubricants
RDT&E	-	Research, Development, Test and Evaluation
ROI	-	Return on Investment
RTCA	-	Radio Technical Commission
SAE	-	Society of Automotive Engineers
SFC	-	Specific Fuel Consumption
SKE	-	Station Keeping Equipment

GLOSSARY (Cont'd)

SRC	-	Standard Requirements Code (Army)
TACAN	-	Tactical Air Navigation
TOE	-	Tables of Organization and Equipment
UE	-	Unit Equipment
ULD	-	Unit Load device
UTC	-	Unit Type Code
ZFW	-	Zero Fuel Weight

I. INTRODUCTION

This volume of the Design Options Study Final Report describes the qualitative assessment of ACMA design options which was performed at the outset of the study effort. As such, it presents a qualitative examination, in the context of a conventional aircraft of all functional design features that have a potential impact on military/commercial commonality. The principal objective is to identify those features for which design options can be developed that could significantly enhance the prospects for military/commercial commonality by improving commercial economics and/or military cost effectiveness. This detailed examination of these options is described in Volume II.

The Air Force requested that the following items be specifically included in the assessment:

- Truck-bed deck height
- Drive-thru loading
- Reinforced floor
- Outsize/oversize cargo cross-section
- Navigation aids
- 463L pallet loading equipment
- Aerial refueling receptable
- Takeoff distance
- High-wing vs low-wing
- Engine noise specification
- High flotation landing systems
- Airport compatibility
- Maintenance/support concepts
- Range

For some of these items, the prospects for commonality can be improved by considering CRAF modification kits (e.g., reinforced flooring), while other items suggest the possibility of abandoning the militarily desirable feature entirely (e.g., deletion of the rear cargo door, thus eliminating drive-thru loading and air-drop capability). Still others (e.g., oversize versus an outsize cross section) imply a fundamental change in the aircraft's design and military utility.

The qualitative assessment presented in this report attempts to identify which features and associated design options, including those listed above, have the greatest potential effects on commercial economics, on military cost-effectiveness, and ultimately, on the prospects for commonality. Section II of the report develops a contextual framework for use in the assessment. Individual features and option are then examined by functional design groupings in Sections III through X. The final ranking and recommendations for detailed analyses are presented in Section XI.

The baseline aircraft configuration used in this assessment is described in Appendix A, Volume IV.

II. CONTEXTUAL FRAMEWORK

Subsequent sections of this report will show that the potential number of aircraft configurations, representing various combinations of plausible design options, makes it impossible to examine each possibile configuration. Consequently, any qualitative assessment that aims to identify the most appropriate options for further detailed analysis, or to establish a logical order for that analysis, must be carefully structured to ensure that adequate consideration has been given to all pertinent features and that significant interdependencies have been taken into account.

Thus, this section presents a simplified overview of the aircraft system design process and examines the relationship of the design options to this process.

THE AIRCRAFT SYSTEM DESIGN PROCESS

Figure 1 is a simplified representation of the design process that is intended to highlight the initialization parameters which ultimately determine the characteristics of the system. Note that all of the steps usually associated with system design have been collapsed into a single block labeled "synthesis and optimization." As illustrated in Figure 1, three types of initialization parameters, usually specified by the customer, are required. These parameters are: the required system capabilities; the assumptions regarding the environment in which the aircraft will ultimately operate (e.g., the technology level established for the time frame of interest, fuel cost, etc.); and the objective function (e.g., minimum cost, minimum gross weight, etc) that forms the basis of system optimization. Given that all three types of parameters are wholly specified, the design process can, conceptually at least, generate the optimum system.

For example, the required capabilities and optimization basis could be simply stated as the minimum life-cycle cost system for airlifting a specified mix of Army equipment from base A to base B in some fixed time period. Such a statement of the required capability would probably be only partially satisfactory, however, since the main purpose of strategic mobility forces is

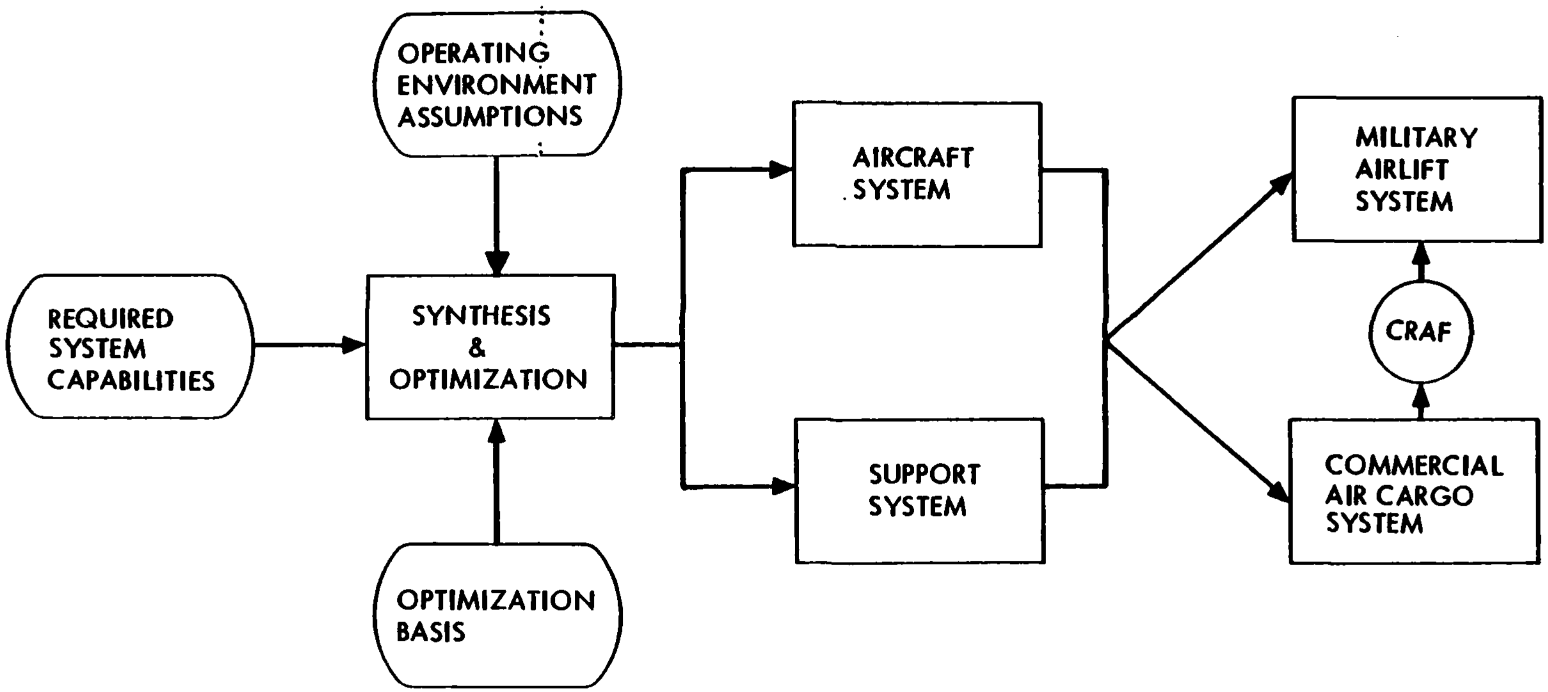

Figure 1. Simplified Overview of the Aircraft System Design Process

to provide flexibility. A system optimized under such very specific conditions could not be expected to provide much flexibility, since the airlift system design features would be established solely on the characteristics of bases A and B and the specified mix of Army equipment.

In practice, therefore, required system capabilities are more likely to be expressed in terms of the functional capabilities desired of the system. Figure 2 illustrates how the required capabilities can be expressed in terms of eight functional groupings. Two or more design features characterize each functional grouping. For example, as shown in Figure 2, takeoff distance, landing gear flotation, runway width for a 180° turn, and noise characteristics are the design features associated with the airfield-compatibility functional group. In this context, various design options are available for each feature as illustrated for the takeoff distance feature in Figure 2. (Throughout this report, the preceding distinction between "design feature" and "design option" will be consistently used.)

Once a set of design options is specified by the customer, iteration in the design process will ultimately yield the optimum system subject to other specified constraints. Note, however, that the synthesis and optimization process is by no means straightforward. Rather, the process is cyclic in nature, often relying as much on past experience and intuition as on precise analytical methods.

Note that some design options are likely to affect the eventual configuration of the support system as well as the aircraft system itself. Features belonging to the ground interface, inflight refueling, and personnel accommodations functional groupings will be revealed later in this report as particularly significant in this respect.

A comment is also in order regarding the inclusion of what is termed in Figure 2 "Military/Civil Design Criteria" as one of the functional groupings. Because of the different specifications, procedures, etc. that apply to military and civil aircraft, conflicts arise regarding which should be applicable to the ACMA. One could assume that resolution of these conflicts should be included as part of the operating environment assumptions. However,

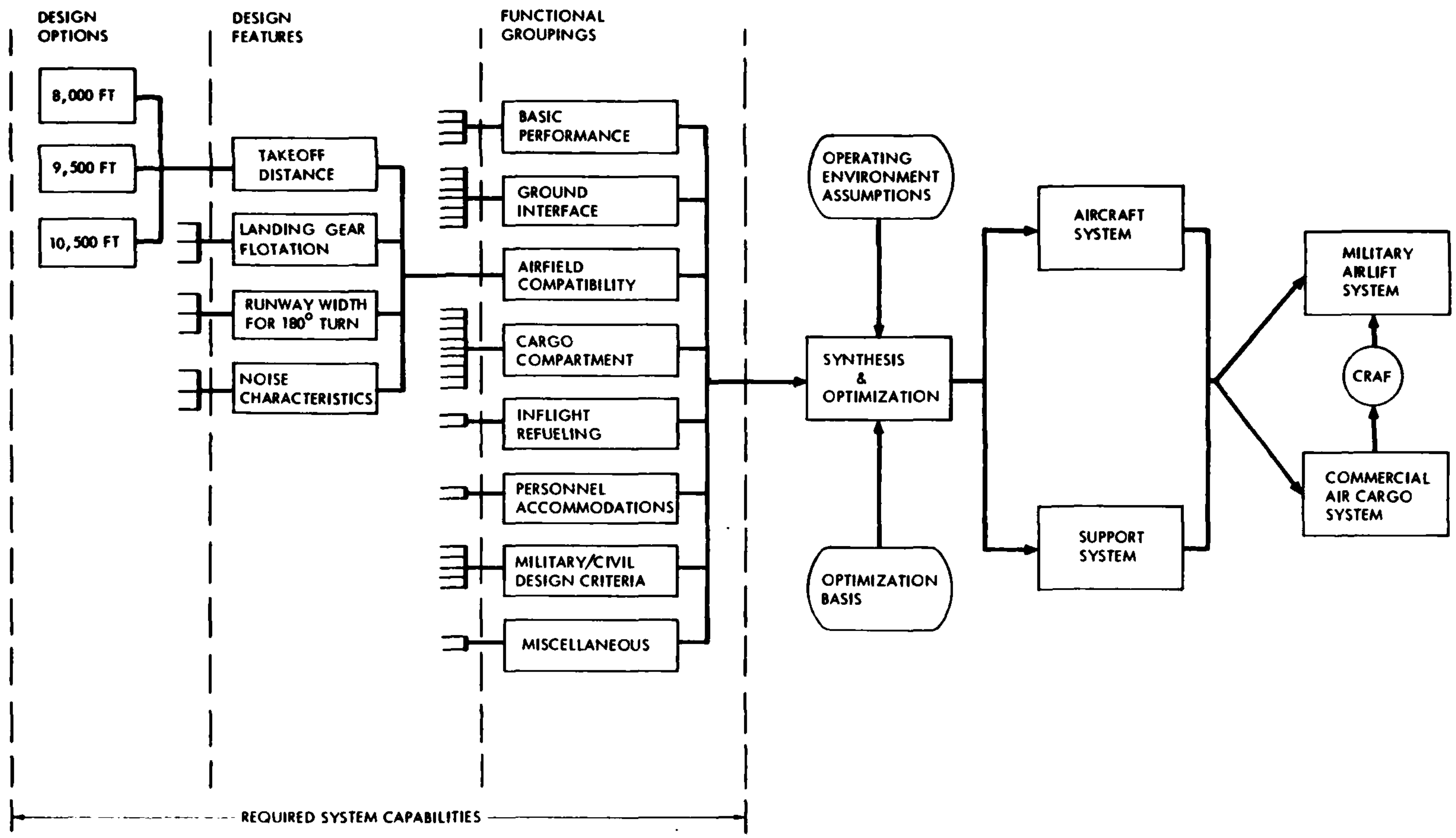

Figure 2. Relationship of Design Options, Design Features, and Functional Groupings to the Aircraft Design Process

thinking of them as design features and associated options introduces the possibility of improving the prospects for commonality by considering the waiver of a particularly restrictive specification (which may be either military or civil) in favor of its less demanding counterpart.

This volume describes the examination of the available design options for a military/commercial airlifter in the context described above and identifies those which were subjected to the detailed analysis reported in Volume II. In that analysis, a conceptual design incorporating each selected option was generated, and the resulting system cost and effectiveness in a military environment as well as the commercial economics was carefully examined. The analysis produced aircraft configurations that are optimum on the basis of the specified design option set. Which combination of options ultimately proves to be optimal for either the military or commercial role or both, will inevitably require a subjective judgment by the customer with regard to the various aspects of cost, effectiveness, flexibility, etc.

PERTINENT DESIGN FEATURES

The design features that have been identified as having a potential impact on military/commercial commonality are listed in Table 1 in terms of the functional groupings introduced in Figure 2. Note that, if only two options exist for each of these design features, then over 100 billion combinations would be possible. Of course, for some features, three or more potentially attractive options exist causing further complications. Thus, the importance of the present qualitative assessment should be clear.

Table 2 relates the items specified by the Air Force for inclusion in this analysis to the list of pertinent design features. All of the requested items except one correspond to one or more design features--thus ensuring their inclusion in the subsequent qualitative assessment. The one exception is "high-wing versus low-wing." In the present formulation, all features pertaining to the aircraft general arrangement can be thought of as outcomes of the synthesis and optimization process. That is, selection of certain combinations of design options could result in a low-wing configuration being

TABLE 1

DESIGN FEATURES AND ASSOCIATED OPTIONS

BASIC PERFORMANCE
- DESIGN RANGE
- DESIGN PAYLOAD
- MAXIMUM STRUCTURAL PAYLOAD
- CRUISE MACH NUMBER

GROUND INTERFACE
- CARGO-COMPARTMENT FLOOR HEIGHT
- LOADING/UNLOADING APERTURES
- VEHICLE LOADING/UNLOADING MECHANISM
- CONTAINER/PALLET LOADING/UNLOADING SYSTEM
- AIR DROP PROVISIONS
- LOADING STABILIZER STRUTS
- GROUND REFUELING PROVISIONS

AIRFIELD COMPATIBILITY
- TAKEOFF DISTANCE
- LANDING GEAR FLOTATION
- RUNWAY WIDTH FOR 180° TURN
- NOISE CHARACTERISTICS

CARGO COMPARTMENT
- CARGO COMPARTMENT PLANFORM SHAPE
- CARGO ENVELOPE
- FLOOR STRENGTH
- SUB-FLOOR STRENGTH
- VEHICLE TIEDOWNS
- CONTAINER/PALLET HANDLING/RESTRAINT SYSTEM
- PRESSURIZATION
- CARGO-STICK WIDTH
- CARGO-COMPARTMENT LENGTH

INFLIGHT REFUELING
- INFLIGHT REFUELING TECHNIQUE
- TANKER KIT PROVISIONS

PERSONNEL ACCOMMODATIONS
- RELIEF-CREW PROVISIONS
- PASSENGER PROVISIONS

MISCELLANEOUS
- MAINTENANCE/SUPPORT CONCEPT
- AVIONICS
- SUBSYSTEM MOTIVE POWER

MILITARY/CIVIL DESIGN CRITERIA
- NOISE REGULATIONS
- ENGINE EMISSIONS REGULATIONS
- PERFORMANCE SPECIFICATIONS
- CERTIFICATION PROCEDURE
- DESIGN LIMIT-LOAD FACTOR
- SERVICE-LIFE SPECIFICATION

TABLE 2

CORRESPONDENCE BETWEEN USAF SPECIFIED ITEMS AND FUNCTIONAL DESIGN FEATURES

USAF SPECIFIED ITEM	FUNCTIONAL GROUPING	ASSOCIATED DESIGN FEATURES
Truck-bed deck height	Ground Interface	Cargo compartment floor height
Drive-thru loading	Ground Interface	Loading/unloading apertures
Reinforced floor	Cargo Compartment	Floor strength, Sub-floor strength
Outsize/oversize cargo cross-section	Cargo Compartment	Cargo envelope
Navigation aids	Miscellaneous	Avionics
463L pallet loading equipment	Ground Interface	Container/pallet loading/unloading system
	Cargo Compartment	Container/pallet handling/restraint system
Aerial refueling receptacle	Inflight Refueling	Inflight refueling techniques
Takeoff distance	Airfield Compatibility	Takeoff distance
Engine noise specification	Military/Civil Design Criteria	Noise characteristics
	Airfield Compatibility	Noise characteristics
High-flotation landing system	Airfield Compatibility	Landing gear flotation
Airport compatibility	Airfield Compatibility	Takeoff distance, Landing gear flotation, Runway width for 180° turn, Noise characteristics
Maintenance/support concept	Miscellaneous	Maintenance/support concept
Range	Basic Performance	Design range

superior to a high-wing. Such combinations are discussed in Section IV as an element of the ground-interface functional grouping.

The following paragraphs describe how the qualitative assessment was performed for each functional grouping of design features within the context of the system development framework presented above.

QUALITATIVE ASSESSMENT: GENERAL APPROACH

Each of the following sections assesses the design features and associated options within one of the functional groupings defined above. In each instance, the section begins with a listing of the design features under consideration and any required clarifying definitions.

The design options available for the first feature are then discussed. The design option thought most desirable from a military viewpoint is examined first in terms of its primary and secondary functions and the military objective it facilitates. Quite frequently, the principal function of an option is simply to further the goal of moving the greatest tonnage for a given system cost or, alternatively, minimizing the cost to provide a given capability. The associated military objective is to satisfy the military airlift requirement in the most cost-effective manner. Rather than repetitively belaboring the obvious, the discussion in the following section implicitly incorporates these considerations.

Alternatives to the militarily desirable design option are then explored. Of primary interest among the alternatives is the design option thought most desirable from a commercial viewpoint, or, if possible, one that can provide the desirable military feature by means of the CRAF modification kit. Other potentially interesting design options representing a compromise position may also be considered. A qualitative assessment of design-option substitution (relative to the option incorporated in the baseline, as described in Appendix A, Volume IV) on mission effectiveness and military/commercial commonality is then made. These assessments are predicated on the assumption that the ACMA (CRAF as well as organic) is the only aircraft availble for military deployments. This assumption appears sensible inasmuch as the ACMA will eventually have to operate in an environment in which current organic airlifters will have been retired.

The above process is repeated for the remaining design features within the functional grouping. After this point, all of the options within the functional grouping are considered in terms of possible mutual interactions. Inconsistent combinations of options as well as potentially synergistic combinations are identified. (Interactions among features from different functional groupings are addressed in Section XI.)

Each functional-grouping section concludes with a recommended disposition of the candidate design options. The principal criteria for eliminating design options from further consideration in the present study are:

1. At least one option has been identified that is thought to be substantially superior in terms of system cost and effectiveness for both military and commercial purposes than the *eliminated* design option.

2. Selection of the most desirable option can be more appropriately resolved at a later stage of the concept definition process. (In this instance, all of the options associated with the design feature are eliminated, and the design option incorporated in the baseline aircraft is held invariant for the remainder of this study.)

To eliminate design options using the latter criterion also requires that the relative attractiveness of options associated with other design features be essentially independent of the options associated with the eliminated design feature. A further requirement is that design-option selection can be straightforwardly incorporated in the system optimization as discussed earlier in this section.

All of the remaining options are retained for further consideration and ultimately ranked in Section XI in the order recommended for the detailed analysis. At the conclusion of each section, the relative potential of each surviving design feature is subjectively scored. The scoring is in terms of the attractiveness of the identified design options for each feature relative to the design option incorporated in the baseline. These subjective judgments are intended to provide further insights into which options display the greatest promise for improving military cost-effectiveness or commercial economics and, ultimately, for enhancing the prospects of military/commercial commonality.

Before proceeding, the reader may wish to at least familiarize himself with the contents of Appendix A, located in Volume IV, since as noted above, all assessments in the following sections are made relative to the baseline aircraft.

III. BASIC PERFORMANCE FUNCTIONAL GROUPING

The pertinent basic-performance design features are:

- Design range
- Design payload
- Maximum structural payload
- Cruise Mach number

For purposes of the present study, design payload refers to the payload used to geometrically size the fuselage. Design range is the maximum range of the aircraft when carrying the design payload. In the current work, aircraft sizing is performed on the basis of this design-point mission.

Maximum structural payload is determined by the design zero fuel weight (ZFW) less operating empty weight. Increasing the design zero fuel weight permits payloads greater than the design payload to be carried distances less than the design range. An increase in design ZFW, of course, results in an increased structural weight and maximum gross weight.

DESIGN RANGE

The candidate design options are:

- 6500 nm (CONUS - Middle East)
- 5500 nm (transpacific)
- 4000 nm (transpolar)
- 3500 nm (transatlantic)
- 2500 nm (transcontinental)

Obviously, the candidates listed above are not the only possibilities. The intent here, however, is to envelop the range spectrum of interest as well as to highlight some of the more prominent intermediate possibilities.

Militarily Desirable Design Option

Which of the candidate ranges is most desirable from a military viewpoint is uncertain at this time. Some insight may be gained through examination of the conceptual aircraft designs developed in References 5 through 8.

Present concerns regarding overseas bases and overflight rights, however, tend to suggest the desirability of a 6500 nm design range. The primary function of a 6500 nm design range is to provide a deployment capability to any place in the world using only US owned bases. References 3 and 9 demonstrate that 6500 nm is the minimum range that would provide this capability without inflight refueling, including allowances for overflight restrictions. Secondarily, such a range would also provide the capability to deliver the design payload from CONUS to Europe and return empty without a ground refueling at the APOD (Aerial Port of Debarkation) or elsewhere in Europe.

The military objective facilitated by this design option is that of maintaining a remote presence worldwide, independent of third-party geopolitical constraints. By using inflight refueling when required on the longer missions, this range capability would also satisfy the objective of minimizing in-theater POL demands if necessary by enabling the airlifters to fly radius missions.

Alternative Design Options

The best design range from a commercial viewpoint is equally difficult to specify. However, the results of the recent CLASS study (Cargo/Logistics Airlift Systems Study), performed by Lockheed-Georgia for NASA Langley Research center under Contract NAS 1-14967, provide some guidance.

Lockheed's CLASS results suggest that the primary market for the ACMA aircraft is likely to be international air freight rather than US domestic. Thus, primary interest should probably be focused on design ranges between 3500 and 5500 nm.

Forecasts made as part of the CLASS effort indicate the top three markets in the 1990s will be:

1. US — Europe
2. Europe — Far East
3. US — Far East

Range requirements for each of these markets are discussed below.

Table 3 presents great circle and wind adjusted flight distances for some prominent US-Europe city pairs. The minimum acceptable range appears to be about 3400 nm based on the London-to-New York flight. Alternatively, a range of 4200 nm permits direct flights from Rome to New York or from Frankfurt to Chicago.

Similar flight distance data are shown in Table 4 for the Europe-Far East market. Because of the extreme distances involved, most flights require two enroute stops, such as Bahrein and Singapore. This routing scheme requires a minimum range of 3800 nm based on the Bahrein-to-Singapore segment. Note, however, that substantial flight distance and one en-route stop can be eliminated on Europe-to-Japan flights if they are routed thorugh Anchorage. For example, the total great circle distance from London to Tokyo via Anchorage is more than 2000 nm shorter than that via Bahrein and Singapore. routing through Anchorage suggests a design range approaching 4200 nm.

Finally, the flight distances associated with the US-Japan market are presented in Table 5. Observe that non-stop flights from Tokyo to the US West Coast require ranges approaching 5500 nm. The alternative is to stage through Anchorage. Interestingly, for flights originating in the US interior north of an imaginary line between Seattle and Dallas-Fort Worth, the total flight distance is less if Anchorage is used as the en-route stop rather than one of the West Coast points. Other areas of the Far East can be reached by staging through Tokyo. Perhaps a better alternative that eliminates one en route stop is to stage these flights through Wake Island. This requires a minimum range of 4000 nm. Such a design range would also permit non-stop Honolulu-to-Tokyo flights as well as one-stop flights from the United States to Australia,

TABLE 3
U.S. - EUROPE MARKET: FLIGHT DISTANCES OF PRIMARY INTEREST

(NM)

CITY PAIR			GREAT CIRCLE	WIND ADJUSTED[a] OUTBOUND	WIND ADJUSTED[a] INBOUND
New York	-	Paris	3150	2970	3550
	-	Rome	3720	3520	4170
	-	London	2990	2820	3380
	-	Frankfurt	3340	3160	3760
Chicago	-	Frankfurt	3760	3600	4150
	-	London	3420	3200	3800

[a] 75 percent reliability

TABLE 4
EUROPE - FAR EAST MARKET: FLIGHT DISTANCES OF PRIMARY INTEREST

(NM)

CITY PAIR		GREAT CIRCLE	WIND ADJUSTED[a] OUTBOUND	WIND ADJUSTED[a] INBOUND
London	- Bahrein	2750	2650	3010
Bahrein	- Singapore	3420	3440	3710
Singapore	- Sydney	3400	3310	3660
	- Hong Kong	1390	1430	1430
	- Taipei	1750	1790	1810
	- Manila	1280	1350	1280
	- Tokyo	2860	3850	3080
Anchorage	- London	3890	3890	4000
	- Tokyo	3000	3280	2910
	- Frankfurt	4050	4060	4160

[a]75 percent reliability

TABLE 5
U.S. - FAR EAST MARKET: FLIGHT DISTANCES OF PRIMARY INTEREST

(NM)

CITY PAIR		GREAT CIRCLE	WIND ADJUSTED[a] OUTBOUND	WIND ADJUSTED[a] INBOUND
Tokyo	- Seattle	4160	3940	4650
	- San Francisco	4470	4160	5120
	- Los Angeles	4760	4420	5450
Anchorage	- Tokyo	3000	3280	2910
	- Seattle	1260	1240	1370
	- New York	2930	2830	3180
	- Dallas - Ft. Worth	2640	2570	2860
Honolulu	- Los Angeles	2220	2130	2430
	- Chicago	3680	3490	4080
	- Tokyo	3340	3990	3120
Tokyo	- Hong Kong	1550	1820	1480
	- Taipei	1130	1340	1070
	- Singapore	2860	3080	2850
	- Manila	1620	1800	1580
Wake Island	- San Francisco	3810	-	-
	- Hong Kong	3000	-	-
	- Singapore	3840	-	-
Tahiti	- Sydney	3300	3860	3790
	- San Francisco	3650	3630	3790

[a]75 percent reliabilities

staging through Tahiti. Thus, 4000 nm appears to be the preferable minimum range.

The preceding observations are summarized in Table 6 which tends to suggest that a design range of about 4000 nm is most desirable from the viewpoint of international commercial air cargo operations in the 1990s. Obviously, a precise specification of the optimum design range would require a substantially more sophisticated analysis than that used here. The purpose here, however, has been merely to develop a respectable estimate. That is, we feel that the best design range for commercial applications appears to be closer to 4000 nm than 3000 or 5000 nm.

Assessment of Design-Option Substitution

The baseline aircraft for the study is sized to provide a design range of 4000 nm. For some scenarios, the military cost-effectiveness of the system would be enhanced if the design range were increased to 6500 nm. The shorter-range aircraft are at a particular disadvantage for scenarios requiring long-range non-stop flights (greater than 5000 nm) in which fuel unavailability requires the airlifter to fly radius missions. This assessment, of course, assumes the use of inflight refueling (IFR) when required by the military situation; without IFR, the advantage of the greater design range will grow markedly.

For deployment scenarios involving shorter critical legs (e.g., US-NATO), the advantage will accrue to the shorter-range aircraft, since the other incorportes a capability that will be substantially unused. Again, however, the availability of fuel at the destination is a primary factor to be considered.

From the viewpoint of commonality, the situation is much clearer. The preceding discussion has shown that commercial operations requiring flight segments longer than 5000 nm are likely to be rare. Furthermore, an aircraft with a 6500 nm design range would suffer a DOC disadvantage in the neighborhood of 10 percent relative to a 4000 nmi range aircraft when operating in the most promising commercial market (3000-4000 nm flight segments, Ref 8). This penalty is a result of the increases in structural

TABLE 6
DESIRABLE DESIGN RANGES FOR INTERNATIONAL AIR CARGO

(NM)

MARKET	DESIRABLE RANGE MINIMUM	DESIRABLE RANGE MAXIMUM
U.S. - Europe	3400	4200
Europe - Far East	3800	4200
U.S. - Far East	4000	5500

weight and engine size necessitated by the greater gross weight required to provide an increased range capability for a fixed design payload.

To summarize, unless the military advantages of a 6500 nm design range are shown to be very significant, a design range near 4000 nm appears to better serve the goal of commonality.

DESIGN PAYLOAD

Specification of design payload is to a certain extent arbitrary. The following candidate options will be considered in the present study:

- 495,000 lb
- 450,000 lb
- 405,000 lb
- 360,000 lb
- 315,000 lb

The reasoning behind this particular set of options will become apparent in the following discussion. For present purposes, these design payloads are assumed to correspond to a limit-load factor of 2.50g. Reduced limit-load factors are discussed in Section X.

Militarily Desirable Design Option

Often the militarily desirable design payload is expressed as an integral multiple of the heaviest item that must be airlifted in substantial numbers -- usually, the main battle tank. Results obtained using Lockheed's privately developed Aircraft Loading Model, however, suggest that this restriction is not particularly significant when deploying brigade-sized units or larger. That is, for the design payloads listed above and assuming that floor loading is held constant, average payload as a percent of design payload does not markedly worsen for design payloads that are non-integral multiples of main-battle-tank weight. Of course, if the ACMA were to operate in conjunction with other aircraft with an oversize-only capability, this observation could be substantially altered depending on the relative numbers of each aircraft type available.

Thus, from a military viewpoint, the only requirement imposed upon design payload is that it be greater than the heaviest item to be airlifted. For the XM-1 tank, 135,000 lb should be sufficient to achieve this objective. Furthermore, previous results suggest that payloads up to at least 600,000 lb yield slightly increased returns to scale from a military viewpoint. (Ref 10)

Alternative Design Options

Identifying the desirable design payload from a commercial viewpoint is even more difficult. Only two somewhat nebulous constraints are apparent. First, the payload must be large enough to permit improved economics relative to contemporary aircraft. The IADS-77 analysis indicated that an aircraft with a 200,000 lb design payload and which incorporated a very significant level of advanced technology would be only marginally competitive with existing commercial air freighters. (Ref 8) Since further DOC reductions of 10 percent or more are possible through increases in design payload, a minimum payload of 250,000 to 300,000 lb appears necessary for the ACMA.

The second constraint is that the payload should not be so large as to outstrip the potential market. Unfortunately, very little is known about this end of the payload spectrum. The CLASS results suggest that the commercial market could readily accommodate a 330,000 lb-payload aircraft in the 1990s. Whether similar results would be obtained for a 500,000 lb- or 600,000 lb-payload aircraft is uncertain.

Assessment of Design-Option Substitution

To summarize the preceding results, the desirable military payload must be greater than 120,000 lb and is probably less than 600,000 lb. Commercially, the market place will probably require a design payload of at least 300,000 lb but the maximum acceptable design payload cannot be readily identified. Most observers would agree, however, that it is probably less than 600,000 lb.

Using these bounds for guidance, the following paragraphs describe the process that identified the candidate design payloads presented earlier.

Section VI discusses the design options available for sizing the cargo compartment. For the baseline aircraft, a stick-width of 8.5 ft was used to determine the overall floor width. Floor length can then be determined on the basis of carrying an integral number of 20-ft long containers with an average gross weight of 15,000 lb per container. (See Section VI for the rationale associated with the 15,000 lb average gross weight assumption and the average cargo density that it implies.) Figure 3 illustrates the resulting cargo compartment length-to-width ratios under the preceding assumptions for one-, two-, three-, and four-stick configurations. The ratios for contemporary cargo aircraft are also depicted in Figure 3.

Figure 3 yields several important observation. First note that design payloads between about 100,000 lb and 150,000 lb are particularly troublesome because neither a one-stick nor a two-stick configuration is suitable. Fortunately, this dilemma is of little consequence to the present effort since 300,000 lb is the minimum design payload of interest as discussed above. Figure 2 indicates, however, that design payloads in the neighborhood of 300,000 lb may be awkward in the sense that a two-stick configuration would be excessively long and thus create structural problems related to fuselage bending or limit rotation on takeoff; conversely, a three-stick configuration may suffer from too small an overall fineness ratio. For payloads greater than 300,000 lb, the three-stick configuration would appear to be superior to the two-stick arrangement. Finally, the four-stick configuration does not appear particularly attractive unless the design payload is greater than about 500,000 lb.

These observations lead to the selection of a three-stick configuration for the baseline aircraft. Furthermore, a design payload of 495,000 lb was selected on the basis of carrying thirty-three 20-ft long containers with an average gross weight of 15,000 lb. Design payloads larger than 495,000 lb are thought to be of lesser commercial interest based on current perceptions of the future air cargo market; furthermore, this appears to be near the upper limit for a practical three-stick configuration.

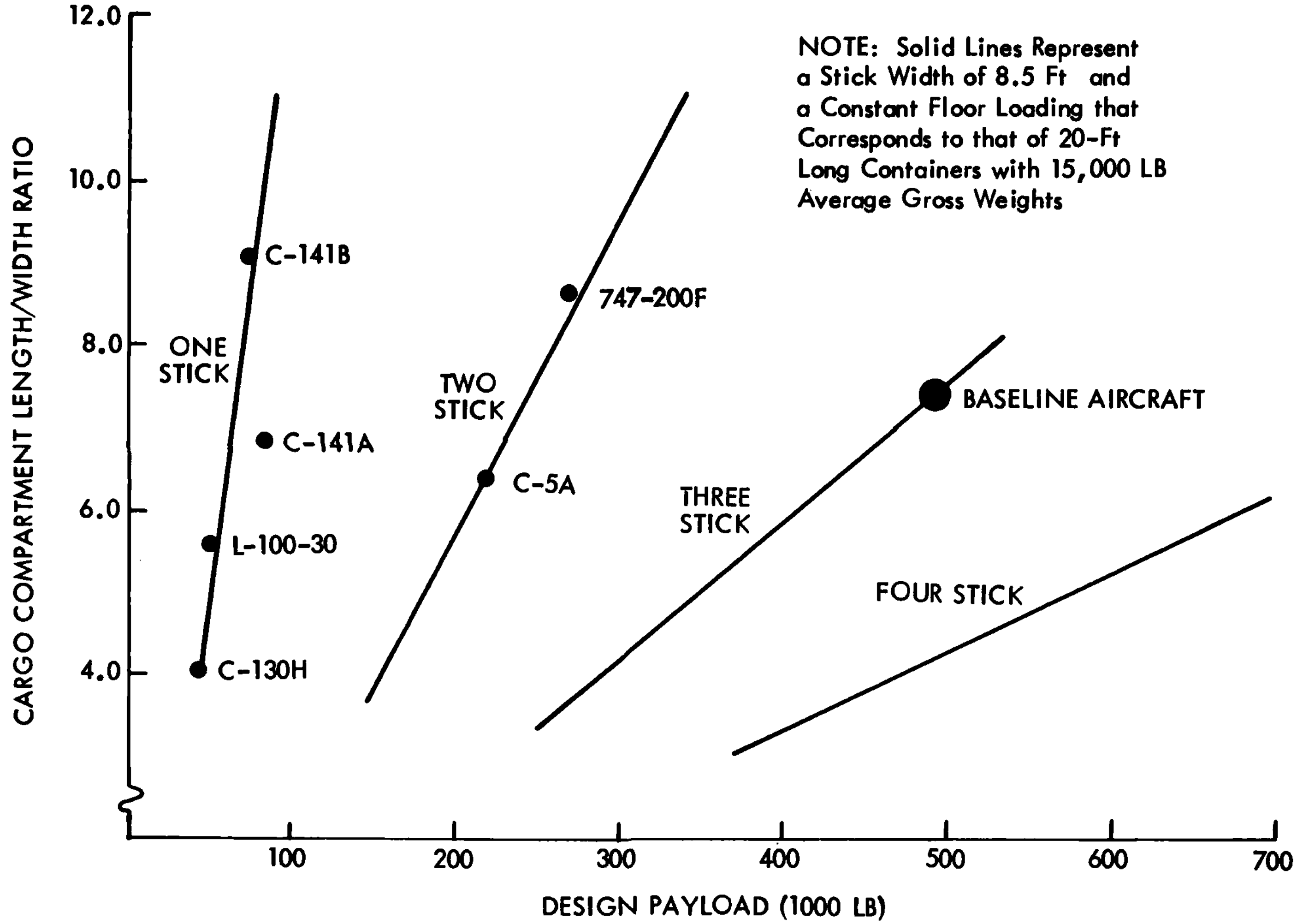

Figure 3. Cargo Compartment Length-to-Width Ratios in Terms of Design Payload

The design options presented earlier represent 45,000 lb decrements from the baseline design payload. That is, each row of three 20-ft containers represents 45,000 lb of payload. By stepping at this decrement and deleting 20 ft of fuselage length at each step, a constant floor loading (or payload density) is maintained for each design option. Note that the smallest design payload of 315,000 lb is near the apparent lower-limit for practical three-stick configurations as discussed above.

MAXIMUM STRUCTURAL PAYLOAD

The design zero fuel weight determines the maximum structural payload that can be carried, since this maximum payload is equal to the design ZFW less the aircraft operating empty weight. Frequently, design ZFW is based on the design payload. That is, for flights less than the design range, the payload cannot be increased beyond the design payload (i.e., fuel weight cannot simply be traded for additional payload weight). There are three candidate design options for maximum structural payload.

- o Corresponds to design range (i.e., the design payload).
- o Corresponds to a 3500 nm flight with takeoff at maximum gross weight.
- o Corresponds to a 2500 nm flight with takeoff at maximum gross weight.

Note that the maximum structural payload has no effect on design payload or design range as used in this report except that the latter two options obviously assume a design range greater than 3500 nm. Clearly, for the same design range and payload, an increased ZFW results in a greater structural weight and, hence, greater gross weight.

Militarily Desirable Design Option

Whether or not an increased ZFW is desirable from a military viewpoint depends on the frequency that the greater payload capability can be utilized. Consider Figure 4 which displays average payload functions for the baseline aircraft. Recall that the baseline aircraft has a design payload of 495,000

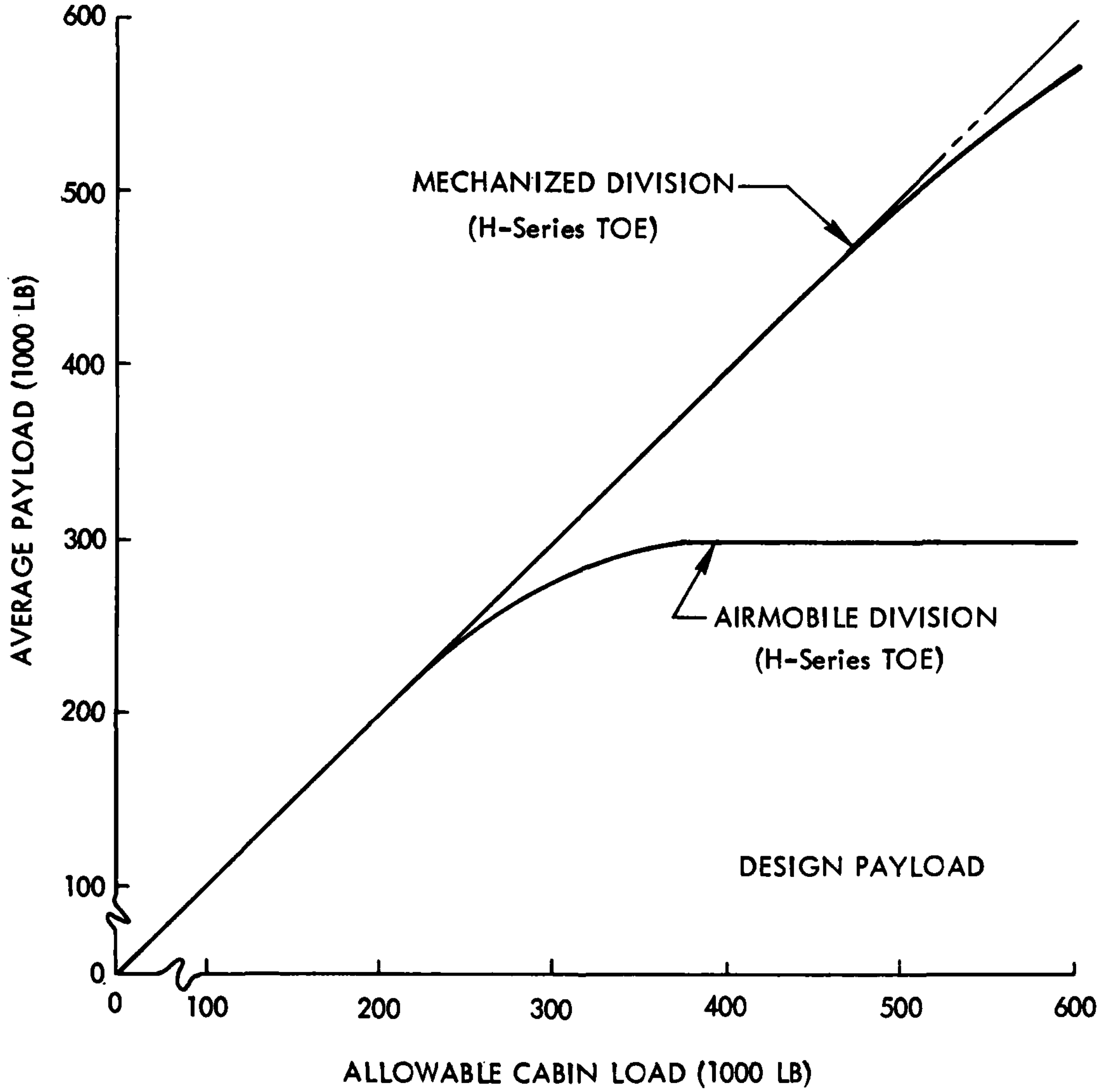

Figure 4. Average Payload for a Mechanized or an Airmobile Division in Terms of Allowable Cabin Load for the Baseline Aircraft

lb and a design range of 4000 nm. During a deployment to NATO critical legs less than 4000 nm are possible by staging through an East Coast base (e.g., Dover AFB). If, for example, the design ZFW permitted a maximum structural payload of 550,000 lb rather than 495,000 lb, then the average payload would increase from about 490,000 lb to 535,000 lb for the movement of a mechanized division. On the other hand, no improvement would be obtained in the case of an airmobile division.

For longer flights involving inflight refuelings, similar improvements in average payload might be possible.

Alternative Design Options

Greater maximum payloads may also be of interest in the commercial sector -- perhaps even as much as that corresponding to a 2500 nm transcontinental flight (yielding a maximum structural payload in the neighborhood of 600,000 lb for the baseline aircraft). Commercial operators might profit from the larger payload in two ways. One possibility is the potential accommodation of increased payload densities. Lockheed's CLASS results indicate that commercial densities may increase to over 12 lb/ft^3 as the freight market is further penetrated by air cargo. The design payload of the baseline aircraft corresponds to net payload densities between 8.2 and 11.1 lb/ft^3, depending on the container size used, as explained in Section VI.

The second approach to utilizing an increased payload capability while maintaining a constant density is to take advantage of otherwise unused volume within the fuselage. This includes the possibility of providing for LD (lower-deck) containers in underfloor compartments or hanging a floor from the cargo compartment ceiling using a truss arrangement. The latter configuration with 8 ft x 8 ft containers on the main deck and LD class containers overhead would yield net payload densities in the neighborhood of 9 lb/ft^3 for a 600,000 lb maximum payload. (See Sections VI and VIII for further discussions of this arrangement.)

Assessment of Design-Option Substitution

As mentioned earlier, the maximum structural payload of the baseline aircraft is the same as the design payload of 495,000 lb. From a military viewpoint, mission effectiveness and flexibility appear to be enhanced by increasing the maximum structural payload to correspond to at least that associated with a 3500 nm flight with takeoff at maximum gross weight.

Since commercial users may also be able to benefit from an increased maximum structural payload, these options appear compatible with the commonality goal. Whether the potential benefits of an increased ZFW are worth the increased costs associated with an increased structural weight can be determined only by more detailed analysis.

CRUISE MACH NUMBER

Cruise Mach number can be regarded as an independent design option specified by the customer or, as discussed in Section II, an outcome of the system optimization process. Taking the former view for the present, the following candidates are suggested:

- 0.70
- 0.78
- 0.85

Of course, other specific cruise Mach numbers between 0.70 and 0.85 (or even higher) could be considered as candidates. However, the listed values bracket the range thought to be of the greatest interest.

Militarily Desirable Design Option

As cruise Mach number is increased, both system cost and system effectiveness increase. IADS-77 results provide insights into the relative magnitude of the effects for military airlifters. That study indicated that the most cost-effective cruise Mach number is 0.85 where cost-effectiveness is defined as life-cycle cost divided by system productivity, and the aircraft is optimized on the basis of this parameter. (Ref 8)

However, the same study shows that system cost-effectiveness is relatively independent of cruise Mach numbers in the range of 0.78 to 0.85. For example, the cruise Mach number for an aircraft optimized on the basis of minimum gross weight was found to be 0.78. The cost-effectiveness of this aircraft, however, was only 1.2 percent less than the Mach 0.85 aircraft. Furthermore, optimizing on acquisition cost also yielded a 0.78 cruise Mach number; in this instance, the cost-effectiveness was identical to that of the 0.85 aircraft. Thus, any cruise Mach number between 0.78 and 0.85 appears to result in nearly constant cost-effectiveness.

At the other extreme, an IADS-77 aircraft optimized for minimum fuel consumption cruised at 0.70 Mach number. The corresponding cost-effectiveness was 19 percent poorer than the 0.85 Mach number configuration.

Thus, the militarily desirable cruise Mach number appears to be in the range of 0.78 to 0.85. Because of the relative insensitivity of cost-effectiveness, other considerations can be used to identify the most desirable value. One such consideration is compatibility with other air traffic. The lower end of the range appears preferrable since 0.78 is only slightly faster than the C-141A/B and the C-5A while being slightly slower than existing commercial airplanes which tend to cruise near 0.80 Mach number.

Alternative Design Options

IADS-77 also provides insights into the desirable cruise Mach number from a commercial viewpoint. For examples, an aircraft optimized on the basis of an equal compromise between unit flyaway cost and DOC resulted in a cruise Mach number of 0.78. Optimizing solely on the basis of minimum DOC would tend to drive the Mach number towards 0.85. However, increasing fuel costs will tend to reduce the Mach number from 0.85 for minimum DOC.

As discussed above, Mach numbers lower than 0.78 yield probably unacceptable penalties in DOC. Thus, 0.78 appears to be a reasonable minimum cruise Mach number for commercial purposes. Depending on the assumed unit fuel cost, increases in cruise Mach number will tend to yield slightly lower DOCs.

Assessment of Design-Option Substitution

The baseline aircraft configuration cruises at a 0.78 Mach number. Cruise speeds lower than this value appear to be generally unacceptable from both military and commercial viewpoints.

As noted, cruise Mach numbers between 0.78 and 0.85 result in essentially constant military cost-effectiveness. Military/commercial commonality can thus be readily achieved by selecting the most desirable Mach number from a commercial point of view.

ASSESSMENT OF DESIGN OPTION INTERACTION

The only potential inconsistency among the options within this functional grouping is specification of a maximum structural payload that is less than the design payload. That is, if the design range is 2500 nm, then a maximum structural payload that corresponds to a 3500 nm flight with takeoff at maximum gross weight is a contradiction.

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Synergistic combinations of options within this group can only be identified through more detailed analysis. For example, if the design range is fixed, then the most desirable design payload, maximum structural payload, and cruise Mach number could be identified for a given objective function by analyzing the options available for each feature in the order stated.

RECOMMENDED DISPOSITION OF CANDIDATE OPTIONS

We recommend retaining only the options pertaining to design payload and maximum structural payload for further consideration in the present analysis.

Rationale

Design range is of clear importance to military/commercial commonality. However, the 4000 nm design range of the baseline aircraft appears to be near optimum for the international air cargo market and, with aerial refueling, is likely to be acceptable for military purposes.

Cruise Mach number is also not recommended for further analysis at this time. The available evidence suggests that military cost-effectiveness is relatively constant between the 0.78 cruise Mach number of the baseline and 0.85. Furthermore, the optimum commercial aircraft is likely to cruise at a Mach number of 0.78 or more -- depending primarily on the assumed fuel costs.

Final resolution of cruise Mach number can, in our view, be more appropriately determined at a later stage of the system definition process (i.e, during final system optimization) when parameters such as fuel costs can be more confidently projected. Although the attractiveness of several options within other functional groups is somewhat dependent on cruise Mach number, the baseline value of 0.78 should be sufficiently close to the eventual optimum to minimize any undesirable masking of changes in cost and effectiveness associated with such options.

All of the candidate options within the design payload and maximum structural payload categories are recommended for further consideration.

Relative Potential

Table 7 displays the results of the subjective scoring of the relative potential of the two surviving design features.

TABLE 7
SUBJECTIVE ASSESSMENT RELATIVE TO BASELINE AIRCRAFT
OF BASIC PERFORMANCE DESIGN FEATURES

-3	-2	-1	0	1	2	3
Much Poorer			Neutral			Much Better

Military Considerations	Design Payload	Maximum Structural Payload
Life-Cycle Cost	2	0
Mission Effectiveness	0	1
Mission Flexibility	1	1
Subtotals	3	2
Commercial Considerations		
Direct Operating Cost	2	1
Indirect Operating Cost	0	0
Market Expansion Potential	1	0
Subtotals	3	1
Grand Totals	6	3

These subjective judgments should be interpreted as follows. Three features of merit are considered in a military context and three others in a commercial context. For each figure of merit, a positive score (corresponding to the scale presented in Table 7) reflects the opinion that at least one option for a particular design feature is likely to provide an improvement relative to the baseline aircraft. Conversely, a negative score indicates an anticipated degradation in the stated figure of merit for all candidate options relative to the design option incorporated in the baseline aircraft.

To illustrate further, consider the scoring of the design payload feature presented in Table 7. The results shown assume that the number of military aircraft procured for any of the design payload options is such that the same fleet capability is provided on the basis of the design-point mission. For example, 110 aircraft with a 405,000 lb design payload represent the same capability in this sense as 90 aircraft with a design payload of 495,000 lb. Throughout this report, the mission effectiveness category will be scored in terms of equal fleet productivity as illustrated above. Thus, the mission effectiveness category receives a score of zero (i.e. no change in fleet productivity relative to the baseline when performing the design point mission).

A potentially substantial improvement in life-cycle cost is indicated since the 495,000 lb payload incorporated in the baseline aircraft probably yields an undesirable fuselage fineness ratio as shown in Figure 3. That is, we anticipate that some design-payload option less than 495,000 lb. will be found to be less costly than the baseline when performing the same deployment task. Finally, a design payload less than 495,000 lb may also provide a modest improvement in mission flexibility. The rationale here is based on the belief that the flexibility provided by having a greater number of units in the organic fleet will outweigh problems such as an increased likelihood of queuing delays.

A similar logic is used in scoring the commercial figures of merit. The direct operating cost and indirect operating cost categories are self-explanatory. Market expansion potential, however, includes a consideration of return on investment. That is, any design option that offers either an increase in system flexibility or an improved return on investment has the potential for expanding the air-cargo share of the total freight market.

Note that the "Military Considerations" subtotal reflects the overall potential of the feature from a military viewpoint. The grand total is indicative of the prospects for enhancing military/commercial commonality. Table 7 reveals that both of the subject design features are quite promising in both regards. Of course, assigning such interpretations to the total assumes that each figure of merit has an equal weight. Observe that equal weighting implies that military capability as expressed in terms of mission effectiveness and flexibility is twice as significant as life-cycle cost. On the other hand, cost considerations dominate the commercial assessment. These assumptions appear acceptable for present purposes, since the objective is merely to provide some indication of the relative significance of the design options being considered for the more detailed analysis. (See also the discussion in Section XI.)

IV. GROUND INTERFACE FUNCTIONAL GROUPING

The ground interface functional grouping includes the following design features:

- Cargo-compartment floor height
- Loading/unloading apertures
- Vehicle loading/unloading mechanism
- Container/pallet loading/unloading system
- Air drop provisions
- Loading stabilizer struts
- Ground refueling provisions

Note that the first five features are likely to exhibit a fair degree of interdependency.

For each design feature in this functional grouping, the option that tends to minimize ground time generally will be most desirable from the viewpoint of military mission effectiveness. The reason, of course, is that a decreasing loading and/or off-loading time tends to further the military objective of maximizing aircraft unit productivity. Additionally, shorter ground times at the off-load base increase the survivability of the aircraft in the event of hostile action. Ultimately, however, these impacts on mission effectiveness must be considered in concert with system cost before the most cost-effective option for each feature can be identified.

CARGO-COMPARTMENT FLOOR HEIGHT

Three candidate options for this design feature are readily identifiable for the class of aircraft represented by the baseline configuration:

- 8 ft kneeled (level), 13 ft unkneeled
- 13 ft (no kneeling)
- 18 ft (no kneeling)

A floor height of 13 ft is compatible with the K-loaders used by civil narrow-body aircraft and is sufficient to provide acceptable underfloor depth and rotation angle for a three-stick aircraft configuration. Starting from this height, the aircraft can be kneeled to provide an 8 ft level floor height while maintaining adequate static ground clearance. By kneeling only the nose landing gear (or only the main landing gear for aircraft incorporating a rear aperture), a floor height at the aperture of about 6 ft can be achieved. (Lower floor heights could be achieved by reducing the fuselage underfloor depth at the expense of increased structural weight.) An 18-ft floor height would be compatible with existing civil wide-body loaders and also would permit a low-wing general arrangement.

If the baseline aircraft were another range/payload class, then the candidate floor heights would vary somewhat from those listed above. However, the rationale presented above should be generally invariant. That is, the three options of interest correspond to: high-wing with kneeling; high-wing, no kneeling; and low-wing, no kneeling.

Militarily Desirable Design Option

From a military viewpoint, the minimum possible floor height is thought to be most desirable. For this reason, the C-130, C-141, and C-5 aircraft were designed to provide truck-bed floor height (i.e., 4 to 5 ft). The primary function of the minimum possible floor height is to permit rapid loading and unloading of vehicles without reliance on specialized ground equipment or facilities. A low floor height minimizes the weight penalty of all candidate loading/unloading mechanisms -- particularly integral ramps having acceptable ramp angles. For example, the forward ramp angle is 14 degrees for the C-5A in the level-kneeled position with a corresponding floor height of 72 inches. In the fully-kneeled forward position, the ramp angle is 10 degrees, and the floor height is 58 inches. In the aft-kneeled position, the aft ramp angle is 12 degrees with a floor height of 62 inches. Vehicle loading operations are substantially easier when shallow ramp angles are maintained, both in terms of negotiating the ramp as well as minimizing overhead clearance problems associated with vehicle cresting at the ramp/cargo floor hinge line. (See, for example, Ref 13.)

secondary function of a minimum floor height is to simplify some ground maintenance activities. For example, since kneeling is required to achieve minimum floor height, tire changes on main landing gear bogies can be accomplished without jacking the airplane if the gear bogies can be kneeled independently.

A minimum floor height facilitates the military objective of minimizing ground-turnaround time, both for loading and unloading operations, as discussed at the outset of this section.

Alternative Design Options

From a commercial viewpoint, assuming operations are restricted to a relatively fixed route system, minimizing floor height is of considerably less concern. The reason, of course, is that any specialized ground equipment or docks for loading/unloading operations can be permanently positioned at each airport being served. This strategy largely negates the need for ramps (or other integral loading/unloading mechanisms), and hence, there is no corresponding aircraft weight penalty associated with higher floor heights. Note, however, that an integral loading/unloading mechanism could have commercial utility in special cases -- for example, the delivery of excavating or earth moving equipment as discussed in the paragraphs dealing with the vehicle loading/unloading design feature.

Thus, the kneeling feature is not thought to be desirable for a commercial airfreighter. Whether 13 ft or 18 ft is prefereable is somewhat more uncertain. The lower height would permit using a wider assortment of existing loading devices and any specialized facilities (e.g., fixed docks) would probably be less expensive. Alternatively, an 18 ft floor height would make a low-wing configuration possible. The principal benefits expected from a low-wing location are a potential reduction in afterbody drag and elimination of the penalties associated with the main landing gear pods since the gears could be stowed in the wing as well as the fuselage. Furthermore, LD container storage (if desired) could more readily be provided in the belly, rather than overhead in the cargo compartment, as discussed in Section III. The structural weight reduction made possible by having the landing gears tie directly to the inner-wing box should be largely balanced by the larger fuselage cross section required by the low-wing arrangement to provide the same cargo-compartment cross section.

Finally, the possibility exists of providing a 13-ft floor height (without any kneeling capability) on commercial aircraft but including modification kits to convert to a kneeling gear when the aircraft is activated in a CRAF capacity. Such an option has been examined recently and found feasible to a certain extent (Ref 8). The resulting commercial gear without the kneeling-kit installed is about 15 percent lighter than its kneeling counterpart. With the kneeling kit installed, the weights are comparable, but the flotation characteristics of the kitted gear are somewhat inferior to the kneeling military gear (LCN 80 versus LCN 60). Installation and checkout of the kneeling kit would considerably lengthen the CRAF conversion time to the military configuration.

Of course, a third possibility is to install a kneeling gear on only the military versions of the ACMA (and, if specific operators so desired, on some commercial aircraft) and accept the degradation in effectiveness in CRAF aircraft. Under these circumstances, the 13-ft basic floor height option would probably evolve as the best compromise. Note, however, that this option violates the ground rules of the present study since the CRAF aircraft would differ functionally from organic aircraft.

Assessment of Design-Option Substitution

The baseline aircraft incorporates a 13-ft floor height with the capability to kneel to 8 feet while maintaining a level floor.

A 13-feet floor height without any kneeling capability would degrade military effectiveness by increasing loading and unloading times even if integral ramps are retained. Although the costs (both acquisition and maintenance) associated with the more complex kneeling landing gear would be eliminated, this could be largely balanced by the increased costs associated with longer ramps. Elimination of the kneeling landing gear would tend to make the aircraft more attractive to commercial operators; thus, from the view of commonality, a 13-ft height without kneeling appears preferable.

A floor height of 18 ft would probably have a severely adverse impact on military effectiveness inasmuch as loading and unloading times would be greatly increased and the operations would be riskier. Since the commercial benefits are likely to be relatively small at best, the net benefit in terms of military/commercial commonality is likely to be negative (relative to the 13-ft height), thus not enhancing the goal of commonality. This last judgement is based on the observation that the weight and drag penalties associated with the main landing gear pods, as incorporated on the baseline, can be lessened if the kneeling design option is eliminated.

LOADING/UNLOADING APERTURES

The design options associated with this feature are:

- Front and rear
- Front only
- Rear only
- Front and side

In this case, only major apertures are being considered. Not included, for example, are smaller personnel access/egress doors. Note that a drive-on/drive-off capability requires the incorporation of both front and rear apertures in the aircraft design. With only one aperture, a more appropriate terminology would be back-on/drive-off. (Drive-on/back-off is not usually considered because it leads to a greater time requirement for the potentially critical off-load operation.)

Militarily Desirable Design Option

Since minimum ground time for unloading is achieved by having loaded the vehicles such that they can be driven off the aircraft, both front and rear apertures are most desirable for military purposes. If the aircraft incorporates only a single aperture, vehicles would be loaded facing the direction of the aperture; all vehicles would, therefore, be loaded by backing them into the cargo compartment. This procedure would be comparatively straightforward for tracked vehicles, since their maneuverability is good. Also, because of their high unit weights, relatively few of these vehicles are required to attain the maximum aircraft payload. However, loading wheeled vehicles, particularly those with trailers, presents a greater challenge, since maximum utilization of floor space is often mandatory for these less-dense vehicles (compared to tracked armored vehicles) in order to minimize the number of aircraft loads required. For example, in the baseline aircraft cargo compartment which is over 200 ft long, backing a semi-trailer up the forward ramp, and then down the entire length of the compartment into a space with small clearances would be a tedious and time-consuming operation. Inclusion of a rear aperture permits such vehicles to be driven on as well as off—thus reducing the time required for loading.

Furthermore, if absolute minimum off-load times are desirable, providing both front and rear apertures would permit unloading at both apertures simultaneously. Such a simultaneous operation can be performed in the drive-off mode at the expense of on-load time, as noted above.

Incorporating both front and rear apertures also provides cargo compartment ventilation as a secondary function. Without such flow-through ventilation, an auxiliary system would probably be required to remove vehicle exhaust emissions. An additional secondary function is the redundancy provided by having two apertures. That is, in the event of a failure of one of the doors, the aircraft can still be unloaded (or loaded) if the military situation so dictates.

Finally, an airdrop capability can be readily provided if the aircraft incorporates a rear aperture. Preliminary analysis for the class of aircraft represented by the baseline aircraft indicates that including the air drop capability can be accomplished at little additional cost if a rear aperture is specified for ground loading reasons.

Providing both front and rear apertures obviously furthers the objective of increasing unit productivity by reducing ground times. Additionally, the air drop capability makes possible the delivery of equipment and supplies in situations in which suitable airfields are unavailable.

Alternative Design Options

Since most commercial loads are anticipated to be made up of various sized containers and/or pallets, incorporating more than one loading/unloading aperture is thought to be superfluous, since the commercial loading/unloading operation is envisioned to take place normally at a dock specifically designed for this purpose. The speed of this automated operation is expected to be such that simultaneous use of two apertures is unnecessary. Although both front and rear doors would shorten loading/unloading time if mobile ground loaders were used, little commercial benefit is obtained even in this instance, since other routine ground operations (e.g., refueling and maintenance) are likely to be the pacing items when performed concurrently.

If given a choice between a front or rear aperture, providing only a front aperture would appear to be preferable for two reasons. First, eliminating the rear aperture yields benefits in terms of structures and aerodynamics that exceed any corresponding benefits from eliminating the front aperture, particularly if a full-width aperture is desired (see Section VI). Second, a front aperture facilitates mating the aircraft to loading dock in terms of aircraft ground operations, and it simplifies the design of the dock itself.

The final possibility is to equip the aircraft with both a front and a side aperture. Note that a side aperture alone cannot be considered because of the limitations it would impose on maximum cargo length -- at least, for reasonable door widths. The primary benefit of a side aperture (if located aft of the wing) is that it would permit loading items taller than the height limitations imposed by the front aperture or by the wing carry-through structure. As such, a side door facilitates use of fuselage volume that might otherwise be unused by unit load devices (ULDs) loaded through the front only.

Assessment of Design-Option Substitution

The baseline aircraft incorporates both front and rear apertures. Note, however, that although the cargo compartment is 328 inches wide, the width of the front aperture is but 234 inches wide (about the same as the C-5A) and the rear aperture is only 156 inches wide. (For additional detail, refer to the discussion on cargo compartment planform shape in Section VI.) The visor nose door permits straight-in loading of items 13.5 ft high while the aft door arrangement limits maximum height to 9.5 ft for straight-in loading or air drop. In the latter case, vehicles with heights approaching 13 ft can be accommodated in the drive-on mode, depending on vehicle length and wheel spacing. All wheeled vehicles in current Army divisional TOEs excluding helicopters, can be loaded in this fashion except possibly the 20-ton crane.

The commercially desirable design option of eliminating the rear aperture will have an adverse impact on military effectiveness since loading times would be increased. Elimination of the rear aperture will, however, result in lower acquisition and operating costs. Whether the cost savings outweigh the military effectiveness degradation requires more detailed analysis. As noted, providing some type of vehicle guide rails to ameliorate the back-on alignment problem could significantly lessen this degradation.

Assuming that deletion of the rear door does not have an overly adverse impact on military cost-effectiveness, then this design option would substantially benefit commonality since it provides lower acquisition cost and DOC without degrading the overall commercial system.

Replacing the rear aperture with a large side aperture would appear to offer little benefit compared with the associated structural weight penalty. From a military viewpoint, a side aperture is certainly the less preferable choice because of the added difficulty of maneuvering vehicles through a 90-degree turn during the loading process, assuming the existence of a device providing a drive-on capability. In terms of commercial operations, using ULDs with heights greater than 13.5 ft to fully utilize the available fuselage volume aft of the wing would appear less attractive than simply double-decking this area of the fuselage, as discussed in Sections VI and VIII. Of course, access to the upper deck may require a small side aperture and, in such cases, this should be provided in addition to front or front and rear apertures. An additional concern is the inherent safety problems associated with an outward-opening door for the side aperture compared with the door arrangements for the front and rear apertures described in Appendix A.

Finally, deleting the aft aperture or replacing it with a large side aperture does eliminate the airdrop capability. However, the advisability of using the ACMA class of aircraft in the air drop mode is uncertain. In addition, the absence of a rear aperture precludes off-loading palletized cargo while taxiing the aircraft, as might be desired under some high-threat circumstances.

VEHICLE LOADING/UNLOADING MECHANISM

Military requirements dictate that the aircraft be equipped with an integral mechanism for off-loading wheeled and tracked vehicles. Candidate options are:

- Partially removable ramps
- Fully removable ramps
- Elevator
- Crane

Before discussing these, two points are of particular importance. First, in configurations incorporating two apertures, only one needs to be equipped with an integral unloading mechanism assuming that appropriate ground handling equipment is made available at all on-load points. (As such, the possibility of simultaneously, off-loading at both apertures is foregone.) A second observation is that any of these options can be handily eliminated from commercial versions of the aircraft if CRAF kits were provided, although each implies a somewhat different scar weight. Temporary removal from organic military aircraft is also possible if desired, thus enhancing military flexibility.

Militarily Desirable Design Option

Integral ramps are the preferable option from a military view. Although any of the four could satisfy the military objective of being able to off-load vehicles without having prepositioned special ground-handling equipment, only ramps allow for the off-loading operation to proceed more or less continuously rather than on the basis of one vehicle at a time.

Given the choice between partially removable ramps (i.e., one in which at least one of the ramp segments serves as an extension of the cargo compartment floor) and fully removable ramps, the military preference is probably the former. Since the ramps would always be installed on organic aircraft, the partially removable option represents the least cost choice, since it requires the lesser structural weight.

Integral, partially-removable ramps facilitate the military objective of minimizing ground times during off-loading as well as loading operations in apparently the most cost-effective way.

Alternative Design Options

No firm commercial requirement exists for a capability that permits routine loading and unloading of vehicles without the use of specialized ground equipment. Consequently, if the vehicle loading/unloading mechanism is designed as a kit, it could be installed on commercial aircraft when activated as CRAF or on those expectedly infrequent occasions when vehicle loading/unloading is desirable in commercial operations. An example of the latter is airfreighting of earthmoving or excavating equipment or similar outsized equipment to airports with inadequate ground facilities.

This situation suggests that the commercially most desirable option is the one that minimizes scar weight on commercial versions of the aircraft. That is, the commercial aircraft must include some penalty for the fittings, etc. that accept the conversion kit. The partially removable ramps are probably inferior in this regard due to the scar weight associated with the ramp segments that cannot be deleted from the commercial aircraft. Fully-removable ramps would appear to be more desirable than either an elevator or a crane from a commercial viewpoint for similar reasons.

Assessment of Design Option Substitution

The baseline aircraft incorporates partially-removable ramps at both the front and rear apertures. Each ramp consists of three segments. The first essentially forms the extreme ends of the cargo compartment. When in the retracted and stowed position, these ramps are level with the compartment floor; they are an integral part of the fuselage and cannot be removed in the commercial version of the aircraft--although the floor space can be productively used. The remaining two segments of each ramp can be configured as a kit for CRAF aircraft. In both cases, straight-in loading of civil ULDs would still be possible with the two extreme ramp segments removed, assuming appropriate docks or mobile-loaders are available.

The fully-removable ramp design may be the most attractive option from the viewpoint of military/commercial commonality. The major penalty associated with this option is the greater ramp weight of the military configuration. On the other hand, the modest scar weight should yield the lowest commercial DOC of the available options.

The principal disadvantage of the elevator or crane option is that vehicles can only be accommodated on at a time (or perhaps by twos or threes for smaller vehicles) rather than more or less continuously. The increased loading/unloading times would cause a degradation in military mission effectiveness. Furthermore, maintenance of an elevator or crane is expected to be more costly due to the increased complexity of these devices compared to ramps.

An advantage of elevators or cranes is that their weight is much less sensitive to floor height than is the case with ramps. For example, a doubling of floor height is likely to require at least two additional ramp segments. The associated weight increase can be expected to be more than double that of the original middle and toe segments. Under similar circumstances, the total weight of the elevator would increase only fractionally, whereas that of the crane would increase by a slightly greater amount. Since integral carriage is a requirement, the crane would appear to rep·esent the less complex device and might be particularly attractive in conjunction with an 18-ft floor height. Furthermore, a loading/unloading crane is also compatible, at least conceptually, with using an overhead crane for on-board cargo handling. (See Section VI.)

CONTAINER/PALLET LOADING/UNLOADING SYSTEM

The purpose of this design feature is to provide a means of loading or unloading containers or pallets at airfields where loading docks are unavailable. The candidate options are:

- o Ground loader
- o Integral elevator
- o Integral crane

The ground loader would be similar to today's K-loaders or their equivalent used in conjunction with civil wide-body aircraft and the C-141A and C-5A military aircraft.

Note that these candidates closely correspond to the vehicle loading/unloading option discussed previously.

Militarily Desirable Design Option

Use of a ground loader should remain acceptable for military purposes. In the event that off-loading at fields without adequate prepositioned equipment is required, the ground loader can be transported aboard the airlifter and off-loaded first using the integral ramp.

Alternative Design Options

If either an elevator or crane were selected for vehicle/unloading, it should be configured to handle both pallets and containers. Because the vehicle loading/unloading feature is not a primary commercial requirement, however, the ground loader option is still probably preferable for commercial purposes, since it does not result in an increase in aircraft weight. As noted earlier, commercial loading/unloading will usually occur at a specialized dock.

Assessment of Design Option Substitution

The use of ground loaders for loading and unloading containers/pallets has been assumed for the baseline aircraft. Since all three candidates load/unload discretely (rather than continuously, as with vehicles in the case of ramps), the choice between them from a military viewpoint appears largely dependent on which is selected for vehicle loading and unloading.

Note, however, that the great majority of commercial operations will be into airports with specialized docks or with ground loaders available. Consequently, the ground-loader option is likely to prevail in the commercial case, regardless of the military's choice, since the vehicle loading/unloading mechanism will not normally be installed on the aircraft when in commercial operation.

AIR DROP PROVISIONS

Air drop capability is not of interest from a commercial viewpoint. As noted earlier, however, little penalty is associated with including the provisions for an Aerial Delivery System (ADS) assuming that the aircraft incorporates an aft aperture.

The existing system for use in C-141s and C-5s consists of a kit that can be rapidly installed in the aircraft. Almost no scar weight would be associated with the required non-removable provisions. The other major requirement is the capability to open the rear door in flight.

Because of the less-than-full-width aperture incorporated in the baseline aircraft, the one-piece aft door can also provide the required pressure seal. Thus, the only penalties associated with providing the capability to open this door inflight are the relatively modest increased structural weight of the door plus some minor design compromises that permit inflight deployment of the aft ramp to an position similar to that used for straight-in loading. For these reasons, we feel that any configuration that incorporates a rear aperture should also include provisions for an Aerial Delivery System (ADS).

Finally, a comment on the potential for an advanced ADS is in order. The current ADS kit would permit loading and air dropping only a single stick of cargo with a width of 9 ft. The possibility exists that the cargo handling system of the compartment floor could be configured to transfer cargo from either outside stick to the center stick in flight. If so, all three sticks could be airdropped, although three passes would probably be required. (See also the discussion in Section VI.) This option could be pursued in more detail if USAF interest in providing the ACMA with an airdrop capability increases.

LOADING STABILIZER STRUTS

Stabilizing struts must be deployed during cargo loading or unloading operations, probably both forward and aft. From a military viewpoint, these struts should be integral to the aircraft, thus providing minimum ground turnaround time and assuring the feasibility of deployments to airfields with inadequate ground facilities.

Commercial users probably prefer non-integral loading stabilizer struts, when such are required. This is an obvious kit situation. Thus, the baseline aircraft incorporates integral but removable stabilizer struts. The commercial version is stabilized at the same points using ground-based stands. Scar weight associated with this approach is minuscule.

GROUND REFUELING PROVISIONS

Two additional ground-interface features, relating to ground refueling, are of interest, although of considerable less significance than those discussed previously. The first pertains to configuring the aircraft so that refueling can proceed concurrently with other ground operations. The desirability of this feature for both military and commercial users should be evident.

Especially important is concurrent loading/unloading and refueling during military operations when the vehicular cargo lacks spark arrestors and other safety equipment.

The second aspect is whether aircraft should be equipped with single- or multiple-point ground refueling receptacles. Providing sufficient ground-refueling points to assure a refueling time within the cargo off-load/on-load cycle appears straightforward assuming that concurrent operations are possible. The specific number of refueling points required can more appropriately be resolved at a later stage of system definition.

ASSESSMENT OF DESIGN - OPTION INTERACTION

Figure 5 depicts the interactions among the features within this functional grouping. Shown are those combinations of options that are inconsistent or potentially synergistic. The Loading Stabilizer Strut and Ground Refueling Provisions have been excluded from Figure 5 for simplicity since neither of these features exhibit any significant interdependency with other design features.

Since the format of Figure 5 is used at several points in this report, an explanation of how to interpret it is worthwhile. Consider first the combinations of options that are inconsistent and denoted by an "X." Clearly, all design options for a particular feature are mutually inconsistent (i.e., one cannot combine an 18-ft floor height with a 13-ft floor height). Physically impossible combinations of options, such as providing an airdrop capability without having a rear aperture, are also easy to identify. Certain inconsistencies are sometimes less obvious. For example, we have indicated in Figure 5 that a floor height of 18 ft is inconsistent with providing an air drop capability. The rationale is that a low-wing configuration is the logical outcome of an 18-ft floor height, and because of the corresponding arrangement of the fuselage, the only practical way of providing a rear aperture is a swing-away tail section. That is, the most reasonable rear aperture for an 18-ft floor height could not be capable of opening in flight.

		ADS	No ADS	Crane	Elevator	Ground Loader	Crane	Elevator	Fully Rem. Ramps	Part. Rem. Ramps	Front & Side	Rear Only	Front Only	Front & Rear	18 ft	13 ft	8 ft
Floor Height	8 ft								S	S					X	X	
	13 ft														X		
	18 ft	X	S				S	S									
Loading Apertures	Front & Rear	S									X	X	X				
	Front Only	X							S		X	X					
	Rear Only	S									X						
	Front & Side	X															
Vehicle Loading Mechanism	Part. Rem. Ramps						X	X	X								
	Fully Rem. Ramps						X	X									
	Elevator				S		X										
	Crane			S													
ULD Loading Mechanism	Ground Loader			X	X												
	Elevator			X													
	Crane																
Air Drop	No ADS	X															
	ADS																

X Inconsistent Combination

S Potentially Synergistic Combination

Figure 5. Assessment of Interactions Among Ground-Interface Design Options

Potentially synergistic combination (i.e., design options that seem to fit together particularly well) are also indicated in Figure 5 and are denoted by an "S." To illustrate, the elevator and crane vehicle loading options appear to be most attractive in conjunction with an 18-ft cargo compartment floor height, as noted earlier.

This assessment of design-option interaction serves two purposes. First, as the following subsection shows, it provides insight into which features can be combined with some confidence in an attempt to reduce the total number of design options under consideration. Second, an awareness of the likely interdependencies provides useful insights regarding the most appropriate order for examining the design options in detail. This latter point is expanded upon in Section XI.

RECOMMENDED DISPOSITION OF CANDIDATE OPTIONS

Of the seven design features and associated options discussed in this section, only the following are recommended for further consideration.

- Cargo Compartment Floor Height
  - 8 ft kneeled and 13 ft unkneeled
  - 13 ft with no kneeling capability

- Loading/Unloading Apertures
  - Front and rear with ADS kit provisions
  - Front only with no air drop capability

- Cargo Loading/Unloading System
  - Partially removable ramp(s)
  - Fully removable ramp(s)

Note that the third feature above is a consequence of collapsing the vehicle and container/pallet loading/unloading features into a single design feature.

Rationale

An 18-ft floor height is not recommended for further consideration, since it would degrade system effectiveness in both military (substantially) and commercial (to some extent) contexts, while not offering commensurate savings in costs. This latter judgment is primarily based on the observation that any low-wing configuration with a flat cargo compartment floor and, with at least a partial outsize capability, is unlikely to result in a total structural weight less than that of a comparable high-wing aircraft. Any aerodynamic improvements attributable to a low-wing configuration are likely to be modest and, in the military case, would be unable to balance the penalties associated with the cargo loading/unloading mechanism.

As discussed earlier in this section, the integral crane and elevator options seem to be practical only in conjunction with the 18-ft floor height. Thus, these also are eliminated from further consideration.

Since air drop requires a rear door and implies little additional penalty if the rear door is specified for other reasons, the Air Drop and Loading/Unloading Apertures features will be collapsed into a single feature. As noted earlier, providing only a rear door does not seem to be a viable option relative to the other choices available. This judgment would change if air drop emerged as an absolute requirement. Additionally, providing a large side aperture rather than a rear aperture offers to apparent advantage in an overall sense.

The Vehicle Loading/Unloading Mechanism and Container/Pallet Loading/Unloading System features will be combined into a single feature termed Cargo Loading/Unloading System because of their parallel characteristics. Thus, with the elimination of the crane and elevator options, the mobile ground loader (or a specialized dock) emerges as the sole method of loading or unloading containers and pallets.

Finally, Loading Stabilizer Struts and Ground Refueling Provisions are also not recommended for further analysis in the present study. Neither appear to be very significant and, furthermore, the options incorporated in the baseline appear to be the preferable choices.

Relative Potential

Table 8 presents the results of a subjective ranking of the surviving features. Note that the Loading/Unloading apertures feature offers the greatest potential improvement, although the remaining two design features also show some promise — particularly from a commercial viewpoint.

TABLE 8
SUBJECTIVE ASSESSMENT RELATIVE TO BASELINE AIRCRAFT
OF GROUND INTERFACE DESIGN FEATURES

-3 (Much Poorer) · -2 · -1 · 0 (Neutral) · 1 · 2 · 3 (Much Better)

Military Considerations	Floor Height	Loading Apertures	Cargo Loading System
Life-Cycle Cost	1	2	-1
Mission Effectiveness	-1	-1	0
Mission Flexibility	-1	-1	0
Subtotals	-1	0	-1

Commercial Considerations	Floor Height	Loading Apertures	Cargo Loading System
Direct Operating Cost	2	2	1
Indirect Operating Cost	-1	0	0
Market Expansion Potential	1	2	0
Subtotals	2	4	1
Grand Totals	1	4	0

V. AIRFIELD COMPATIBILITY FUNCTIONAL GROUPING

This section discusses aircraft design features that impact airfield compatibility. The following features are of interest:

- Takeoff distance
- Landing gear flotation
- Runway width for 180^{o} turn
- Noise characteristics

The noise characteristics feature has been included in this grouping rather than the section dealing with military/civil design criteria for two reasons. First, noise regulations may be promulgated by local authorities (e.g., banning night-time operations) as well as by the Federal government. Thus, an aircraft meeting all applicable FARs (Federal Air Regulations) might still be restricted from using certain airfields. Such restrictions are one of the few examples in which local governments have pre-empted the Federal government in the regulation of air transportaion. Second, noise characteristics and takeoff distance are likely to exhibit strong interdependence, as discussed subsequently, and as such must be analyzed with care.

Before discussing each of these features, some background information will prove useful. First, consider takeoff distance. Any of three parameters could be used to describe takeoff field length characteristics--takeoff distance over 50 ft; critical field length (military); and FAR balanced field length (civil). Figure 6 displays these for a typical aircraft of the ACMA class as a function of gross weight. The perceived field performance of the aircraft used in this illustration is clearly dependent on which parameter is used. For example, at maximum gross weight the FAR balanced field length exceeds the critical field length by about 2000 ft. Since takeoff distance over 50 ft approximately splits the difference at the higher gross weights, it will be used for aircraft sizing purposes. Of course, both FAR-balanced and critical-field lengths will be estimated for all aircraft developed in the subsequent detailed analyses. Interestingly, if balanced field length and critical field length are used as the primary civil and military criteria for

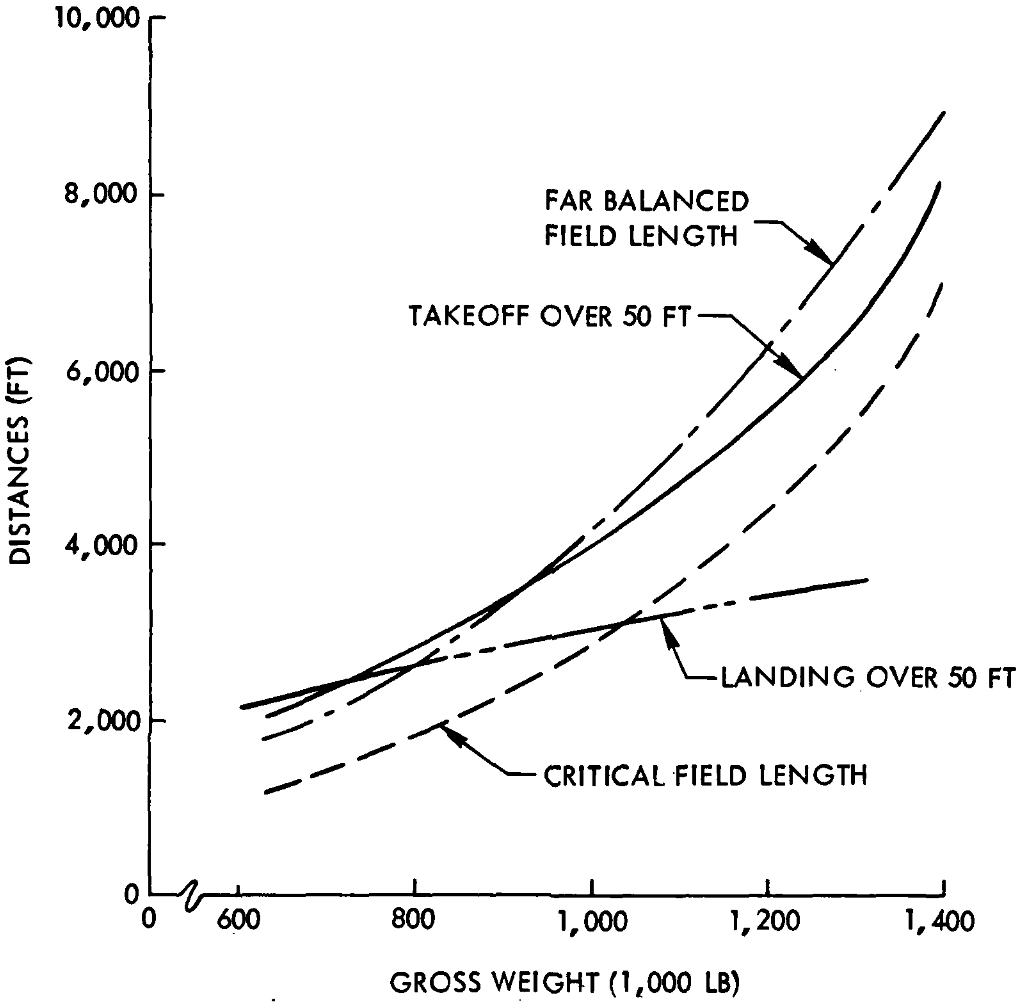

Figure 6. Field Length Characteristics of an Aircraft with a Design Takeoff Distance Over 50 Ft of 8,000 Ft

determining airfield availability, respectively, then the fact that the first is generally greater can be thought of as benefitting commonality since the military is likely to desire a much shorter takeoff distance, as discussed subsequently.

Landing gear flotation is even more troublesome. The LCN (load classification number) concept will be used for the purpose of determining the number of airfields suitable for use by a given aircraft. Conceptually, if the LCN of the airfield is greater than that of the aircraft, that airfield can be regarded as suitable for unlimited use. However, several factors complicate this concept considerably.

First, for a given aircraft with multi-wheel bogies, the aircraft LCN is dependent on both the characteristics of the airfield subgrade and pavement thickness as well as aircraft gross weight and then compared with published airfield LCNs, since the first is dependent on the same parameters that strongly influence the second. Figure 7 illustrates these effects for the baseline aircraft by presenting calculated LCNs for two gross weights as a function of pavement thickness. The higher gross weight corresponds approximately to the maximum takeoff value and the lower to the landing weight. Results for two different values of the subgrade modulus, K, are shown for each gross weight. (Values of K range from 50 to 500 lbs per cu in, corresponding to very poor to excellent subgrades.) Also displayed in Figure 7 is the Defense Mapping Agency's recommended estimate of airfield LCN in terms of pavement thickness for poor and good subgrades. Based on these data, the aircraft LCN can be estimated as 82 for a good subgrade and 98 for a poor subgrade at the takeoff gross weight of 1,350,000 lb. Note that Figure 7 is for use with rigid pavement (concrete) only. Corresponding characteristics could be developed for flexible pavement (asphalt).

The second complication concerns the frequency of use of a given airfield by a particular aircraft type. The accepted groundrules (Ref 14) are as follows:

- If the LCN requirement of the aircraft is not more than 10 percent greater than the LCN rating of the pavement, the strength of the runway is considered adequate for unlimited use by the aircraft.

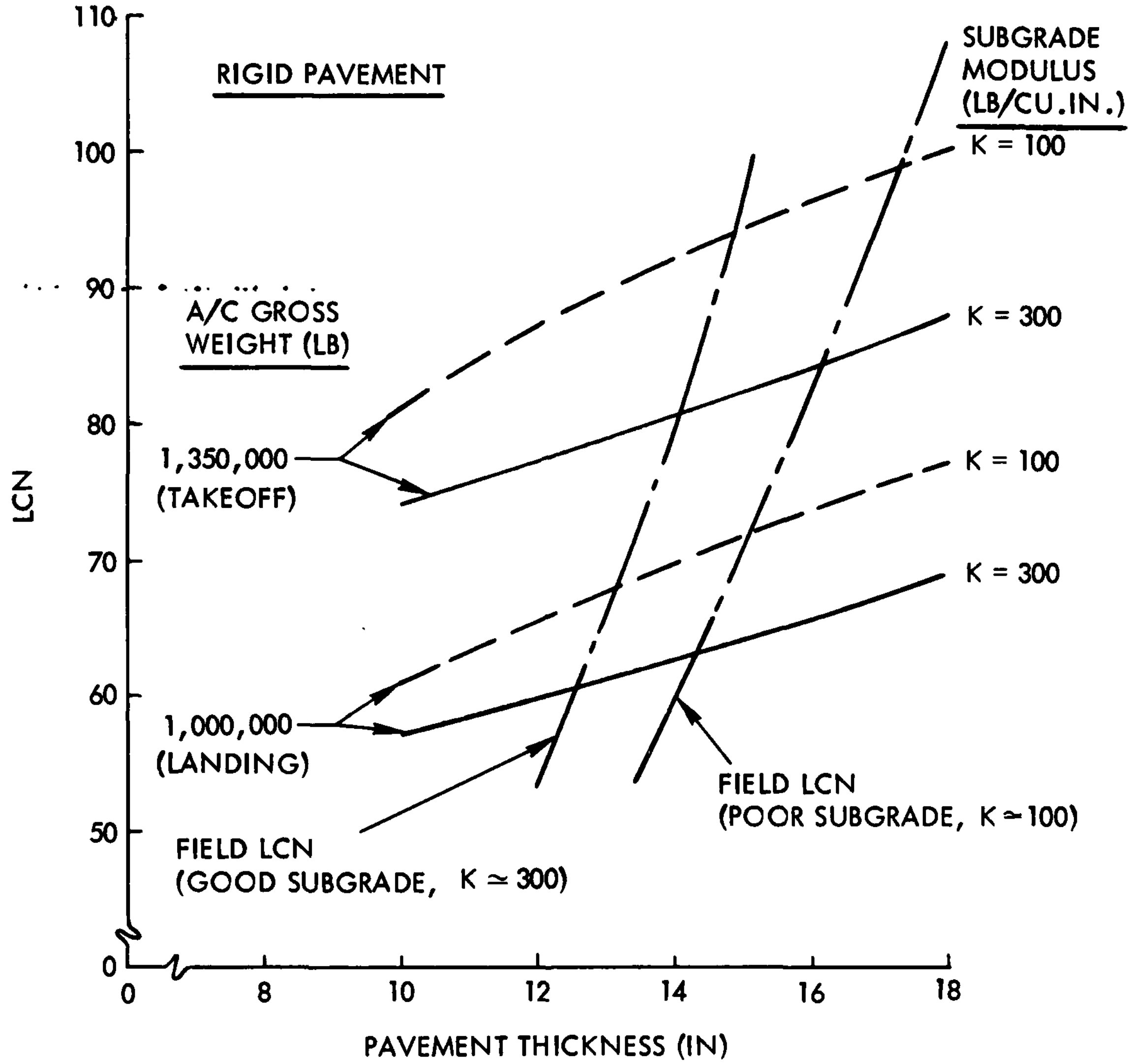

Figure 7. LCN Characteristics of the Baseline Aircraft for Rigid Pavement

Normal maintenance of the runway is understood to be performed during this usage.

- If the LCN requirement of the aircraft is between 10 percent and 25 percent greater than the LCN of the pavement, up to 3000 movements may be planned with some degree of confidence. This usage entails acceptance of greater than normal maintenance on the runway, including the repair of some minor failures.

- If the LCN requirement of the aircraft is between 25 and 50 percent greater than the LCN of the pavement, up to about 300 movements may be planned. This limit is based on the assumption that the movements are spread over "some months" time period and that normal pavement maintenance is increased. Concrete pavements may crack and there may be some local failures in flexible surfaces.

- If the calculated LCN of the aircraft is between 50 and 100 percent greater than the published LCN of the pavement, very limited use is advisable. In the United Kingdom, permission for operation would be given only after an engineer's evaluation of the pavement strength, aircraft data, and planned operational usage.

- If the LCN requirement of the aircraft is greater than 100 percent more than the LCN rating of the pavement, the aircrat should not use the pavement except in emergency. Significant damage to the pavement may result from even a single operation.

Commercial operation will generally fall in the unrestricted use category, thus limiting the aircraft LCN to be no more than 10 percent greater than that of the runway. From a military viewpoint, however, the requirements of some contingencies could be met by 3000 or even 300 movements. Consequently, military operations are possible even if the LCN of the aircraft is 25 percent greater than that of the runway.

Finally, there are questions regarding the validity of the available airfield LCN data. The Airfield Intelligence Data File maintained by the Defense

Mapping Agency has been used for this purpose in the present effort. A cursory examination of the LCN information contained in this file suggests that it may not be wholly accurate. For example, an LCN of 72 is listed for the best runway at the new Dallas/Ft Worth Airport. Our suspicion is that much of LCN data, particularly for US airfields, is conservative since the LCNs are apparently not derived from direct measurements of the pavement/subgrade combination. Rather, many of the listed LCNs appear to be based on the published LCN values (see Table 9) of the aircraft with the poorest flotation characteristics that have used the airfields at least once. Thus, for many airfields, the actual LCN could be substantially greater than that listed in the file. In other instances, the LCN information is absent from the data file.

Given the uncertainties associated with use of the LCN concept, we recommend that aircraft flotation characteristics be thought of in terms of load classification groups (LCGs) rather than LCNs. The relationship between the two is presented below for the LCN range of present interest.

LCG	LCN Range	Representative Aircraft
I	101 - 120	B-52
II	76 - 100	L-1011, DC-8
III	51 - 75	C-141A, 707, Dc-10, 747
IV	31 - 50	C-5A, C-130

The Defense Mapping Agency recommends that an LCG number be assigned to an aircraft based on its estimated LCN characteristics. For example, Figure 6 suggests that an LCG of II for the baseline aircraft at maximum gross weight is appropriate. An aircraft LCG of II, in turn, allows unlimited use of any runway with an LCN in either LCG I or II, again following the recommendation of the Defense Mapping Agency.

Note also that Figure 7 reveals that, at its landing weight (with design payload), the baseline aircraft can be assigned to LCG III. Such behavior should be typical for the aircraft size class represented by the baseline aircraft.

TABLE 9
AIRFIELD COMPATIBILITY CHARACTERISTICS OF CONTEMPORARY AIRCRAFT

Aircraft	TAKEOFF CONDITIONS				LANDING CONDITIONS				Runway Width for 180° Turn (Ft)
	Gross Wt (Lb)	Distance (Ft)		LCN	Gross Wt (Lb)	Distance (Ft)		LCN	
		Ground	To 50 Ft			Ground	From 50 Ft		
C-5A	732,500	8,150	11,200	37	635,850	2,300	3,740	33	143
C-141A	323,100	5,350	6,950	72	257,500	1,900	3,700	57	127
B-52G/H	488,000	7,400	11,100	114	270,000	4,700	8,000	63	456
707-320C	333,600	7,060	10,450	67	247,000	4,870	6,330	50	123
DC-8-63F	350,000	9,200	11,500	77	245,000	3,550	5,910	54	210
L-1011-200	466,000	6,420	8,350	84	368,000	3,840	6,400	64	140
DC-10-30CF	555,000	10,220	11,750	66	403,000	3,570	5,950	55	170
747-200B	775,000	7,430	9,300	70	564,000	2,750	3,970	53	170
747-200F	820,000	8,480	10,730	75	630,000	4,110	6,850	60	170

Source: Defense Mapping Agency, Aircraft Characteristics, DMAAC Forms 8210/ADP-2

Using LCGs rather than LCNs for purposes of this report is a straight-forward way of recognizing the imprecision associated with estimates of LCN for both aircraft or airfields. For example, if an aircraft LCN were estimated as 90, its use of an airfield with a published LCN of 80 would be disallowed. The proceeding discussion suggests that neither estimate is likely to be within 10 percent (at best) of the actual values. Thus, use of the airfield by the aircraft in question is probably justifiable. The point of this example is that the same conclusion is reached if the aircraft and airfield are thought of in terms of LCGs.

To conclude this background discussion, Table 9 presents data published by the Defense Mapping Agency on takeoff and landing distances, LCNs, and minimum runway width for a 180° turn for several contemporary aircraft. As noted, the listed LCNs are valid (in a strict sense) only for some particular combination of pavement thickness and subgrade characteristics. The specific combination used in Table 9 is not given in the referenced source.

TAKEOFF DISTANCE

The following options are recommended for consideration as design takeoff distances over 50 ft at maximum gross weight:

- o 8000 ft
- o 9500 ft
- o 10,500 ft

The rationale for selecting these particular values should become clear in subsequent paragraphs. The following discussion is couched in terms of LCGs of I, II, or III at maximum takeoff gross weight--these being the LCG design options that are examined in the next subsection.

Militarily Desirable Design Option

From a military viewpoint, a takeoff distance less than that of typical commercial aircraft (see Table 9) is generally thought to be attractive.

The primary function of a relatively short field-length capability is to provide operational flexibility in the choice of an APOD. In this instance, landing distance must also be taken into consideration. As a secondary function, the takeoff characteristics influence operational flexibility regarding the number of bases available to serve as Aerial Ports of Embarkation (APOEs) or as en route stops.

No firm guidance for takeoff distance is provided by Table 9 since the characteristics of the C-5A and C-141A differ markedly. However, we have assumed that 8000 ft is the minimum takeoff distance of interest (at maximum gross weight). The following discussion explores what other options might be attractive to the military.

__APOE Flexibility__ - Consider first the situation at the APOE. In this instance, the aircraft will be operating at or near maximum gross weight and the question is, for a given Army post, how many airfields are available to serve as APOEs? Figure 8 provides insights for the nine posts in CONUS that are home to at least one active Army division. For each post, the characteristics of all airfields within 250 nm (air distance) having the principal runway with adjusted length greater than 7500 ft and LCN greater than 35 are presented. (Here, and throughout this section, all runway lengths have been adjusted to approximately account for the airfield's altitude above sea level.) Interestingly, all posts have at least one potential APOE (i.e., an airfield within 250 nm of the post) with an LCN greater than 100 and an adjusted field length greater than 11,000 ft. Also indicated in Figure 8 is the airfield closest to each post (often located on the post).

These data are presented in Figure 9 in terms of the number of airfields (both military and civil) available to aircraft with different characteristics. The following observations are pertinent.

- For an LCG of II, reducing the takeoff distance to less than 9500 ft offers no additional benefit.

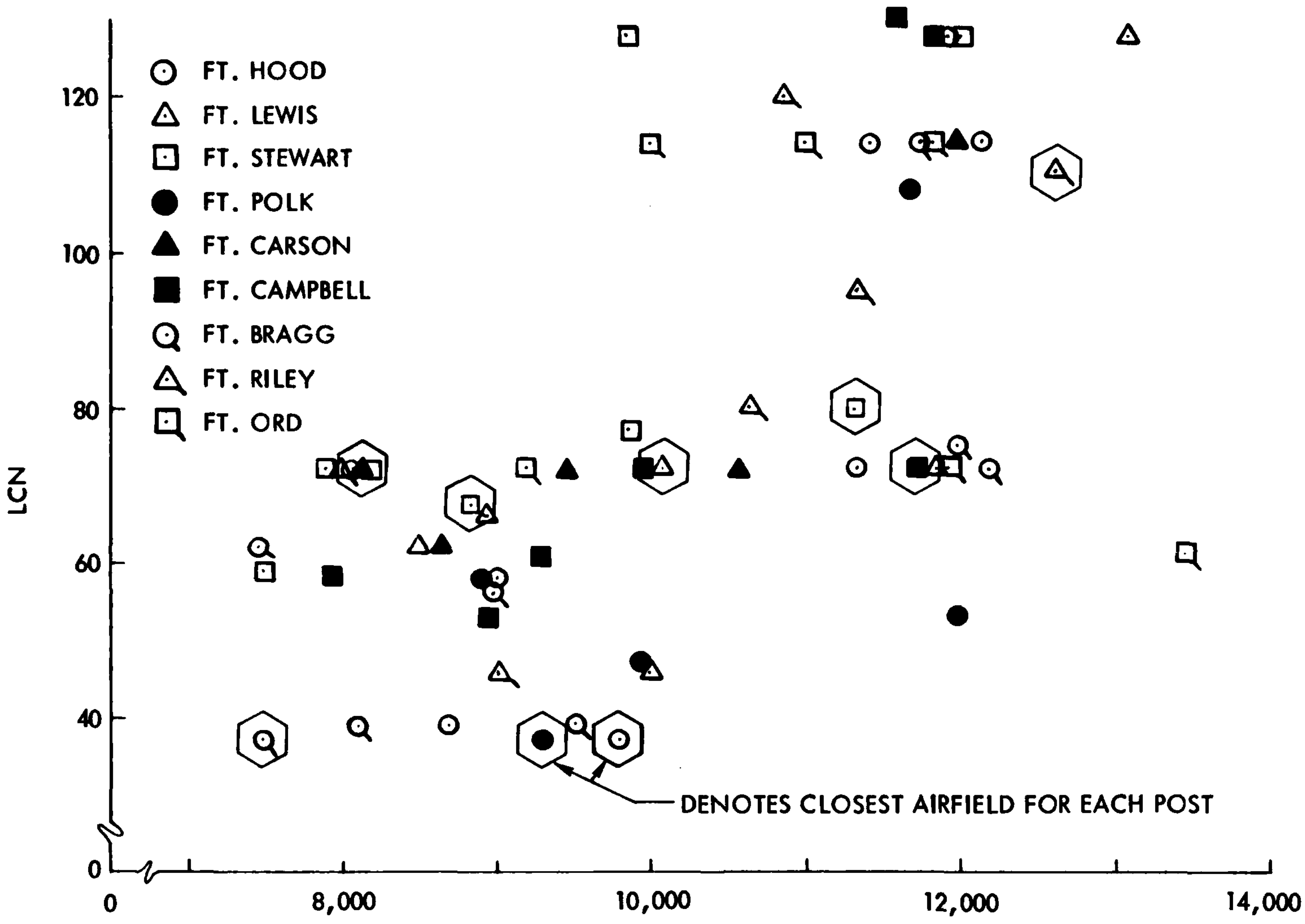

Figure 8. Characteristics of Airfields Potentially Suitable as APOEs

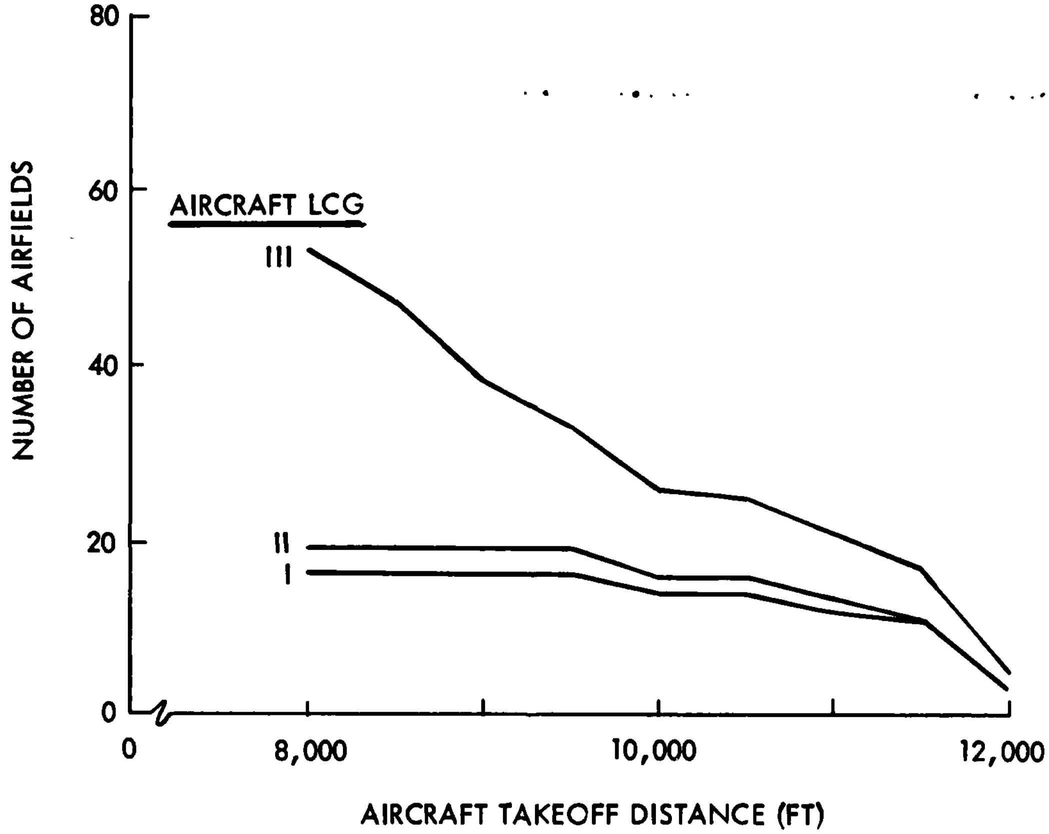

Figure 9. Number of APOE s Available in CONUS in Terms of Aircraft LCG and Takeoff Distance

- For an LCG III aircraft, reducing the takeoff distance from 9500 ft to 8000 ft results in a substantial increase in the number of airfields available.

- A takeoff distance of 10,500 ft appears to be a convenient break point for all three LCGs.

The information presented in Figures 8 and 9 is only intended to be used for identifying design takeoff distance options. Whether the additional military flexibility provided by shorter field lengths merits the associated costs requires subjective judgments that are well beyond the scope of the present effort. Rather the intent here is to ensure that the design options investigated are sensible. These comments also apply to much of the following discussion.

The Air Force bases most likely to be used as home stations and/or for en route stops are listed in Table 10. Of these, the bases that would tend to limit the aircraft's field characteristics are Dover, McChord, and McGuire -- any of which could play a prominent role in any major deployment. These three bases suggest that the takeoff distance should be no more than 9500 ft with an LCG of III. Note, however, that improving these fields (or more carefully determining their LCN characteristics, if necessary) should be considered as a possible alternative to their defining minimum acceptable aircraft takeoff and flotation characteristics.

APOD Flexibility - Consideration of flexibility in the choice of an APOD is greatly complicated by the fact that the set of countries of interest as potential deployment destinations cannot be precisely defined. For present purposes, 11 representative countries are selected under the assumption that they are characteristic of this undefined set. The selection of these countries is not entirely arbitrary, however, since several are of obvious importance.

Figure 10 depicts typical results of this analysis for West Germany. Recall that, for each field, the principal runway is represented in the compilation. Two aircraft gross weight conditions are of interest. First, landing can be

TABLE 10
CHARACTERISTICS OF POTENTIAL HOME STATION AND/OR
EN ROUTE AIR FORCE BASES

AIR BASE	LOCATION	FIELD LENGTH (FT)	LCN
ANDERSEN AFB	GUAM	11,100	114
DOVER AFB	DELAWARE	9,600	72
EIELSON AFB	ALASKA	14,400	128
ELEMENDORF AFB	ALASKA	9,900	128
HICKAM AFB	HAWAII	12,300	114
MCCHORD AFB	WASHINGTON	10,000	72
MCGUIRE AFB	NEW JERSEY	9,900	72
TRAVIS AFB	CALIFORNIA	11,000	114
LAJES (PORTUGAL)	AZORES	10,750	72
DIEGO GARCIA (UK)	CHAGOS ARCH.	8,000	-

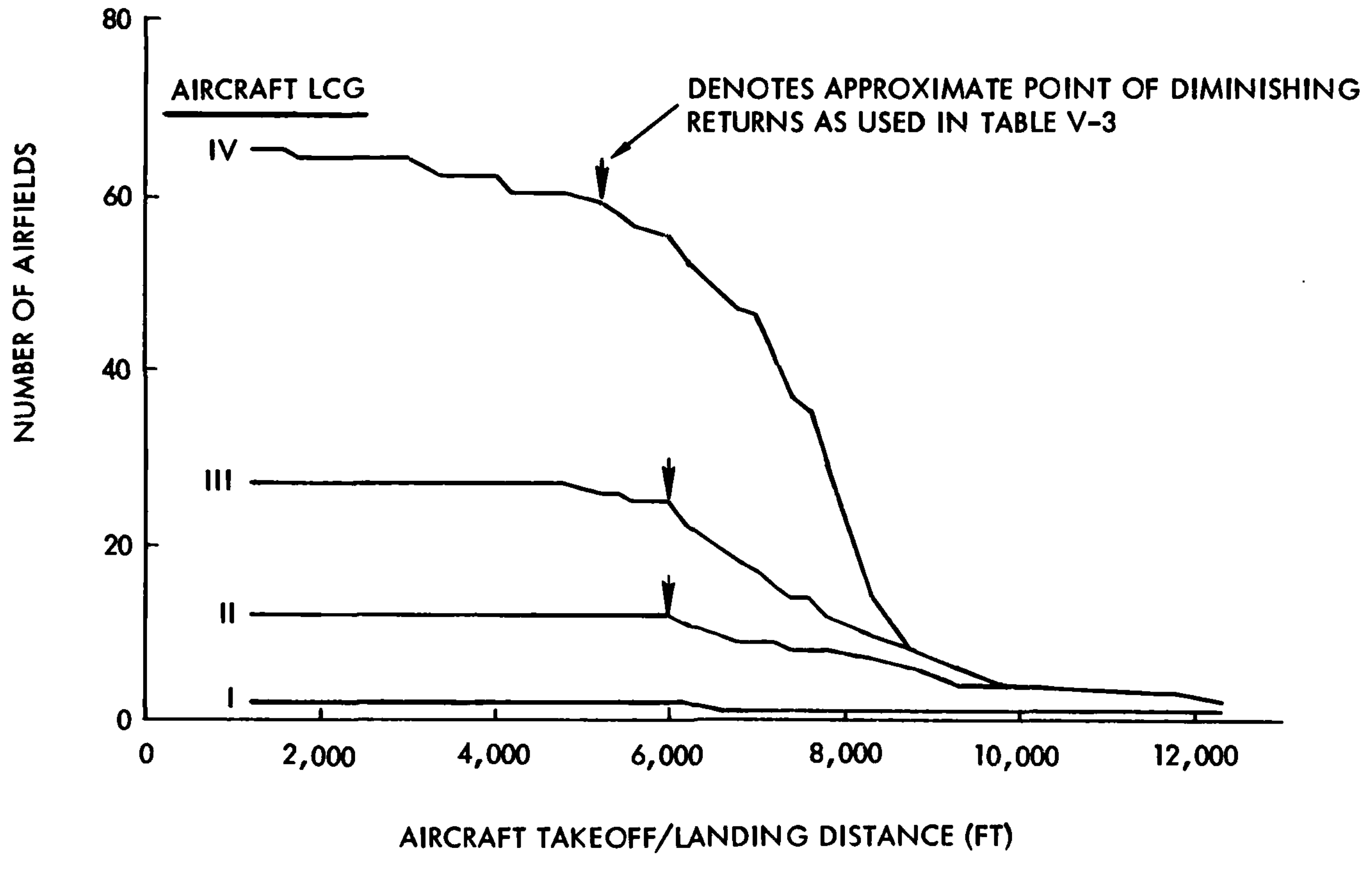

Figure 10. Number of Airfields in West Germany Available as Potential APODs

assumed to occur with maximum payload (or less) but with all mission fuel consumed. Takeoff from the APOD involves zero, or very much reduced, payload with a fuel load that is likely to be less than the maximum payload. Thus, in both cases, the gross weight is likely to be significantly less than maximum. As illustrated in Figure 7, a reasonable first approximation is to assume that the LCG at the APOD is one step better than the maximum gross weight LCG. In other words, takeoff LCGs of I, II, and III are assumed to translate to LCG II, III, and IV, respectively, for purposes of identifying suitable APODs.

One application of Figure 10 is to identify, for each LCG, the distance in which the aircraft should be capable of landing and, after off-loading the payload, taking off. For West Germany, these distances are about 6000 ft for LCGs II and III and 5200 ft for LCG IV, as indicated in Figure 10. Note that specifying the "knee" for LCG IV is somewhat arbitrary.

Table 11 tabulates corresponding distances for the 11 selected countries. On this basis, a landing/takeoff distance of 6000 ft for LCGs II and III and of 5000 ft for LCG IV appears appropriate. The field-length characteristics presented in Figure 6 suggest that these constraints will not strongly influence aircraft design, at least for the 8000-ft takeoff-distance option. However, these constraints must be taken into account when considering the longer takeoff-distance options.

To summarize, a takeoff distance over 50 ft of 8000 ft at maximum gross weight assures excellent flexibility in the choice of APOEs and APODs. Increasing takeoff distance to 9500 ft appears acceptable, however, particularly for LCGs I and II.

Alternative Design Options

Table 5 suggests that a takeoff distance substantially greater than 8000 ft would be more appropriate for commercial purposes. For example, cargo versions of both the DC-10 and 747 require more than 11,000 ft to takeoff over 50 ft at maximum gross weight.

TABLE 11
AIRCRAFT LANDING/TAKEOFF DISTANCES PROVIDING MAXIMUM FLEXIBILITY FOR DEPLOYMENTS TO SELECTED COUNTRIES

	AIRCRAFT LCG		
COUNTRY	II	III	IV
GERMANY	6,000	6,000	5,200
BENELUX	-	7,800	7,600
FRANCE	6,000	6,000	5,000
UNITED KINGDOM	8,800	7,000	6,000
GREECE	9,800	7,800	5,200
TURKEY	9,800	7,800	6,600
ISRAEL	11,900	11,900	6,200
SAUDI ARABIA	8,800	8,800	6,000
IRAN	10,800	7,000	5,000
EGYPT	8,800	8,300	8,300
SOUTH KOREA	8,800	7,800	5,000

[a] For each country and LCG combination, the distance shown corresponds to an approximate point of diminishing returns in the sense that a further reduction in aircraft landing distance would provide only a modest increase (or none) in the number of airfields available. See, for example, Figure 9.

To provide insights into appropriate takeoff distance options for commercial purposes, the characteristics of the world's airports that are anticipated to be the most prominent cargo airports in the future should be examined. Of course, the difficulty is in deciding which airports such a definition includes. Figure 11 displays the location of 95 airports that have been selected for this purpose on the basis of discussion with participants in the CLASS study. Although arguments can be easily made for adding or deleting airports to this set, we believe that it is representative of the airports that might be served in the 1990s by an advanced air cargo system. Note that the principal markets discussed in Section III (i.e., United States, Europe, and the Far East) are particularly well-represented. Interestingly, of the 111 cities originally identified for this exercise, the airports of six were disqualified because the LCG was IV or worse, five because the adjusted field length was less than 8000 ft, and two for both reasons. LCN data was unavailable for the other three airports.

The number of these airports available in terms of aircraft takeoff distance is presented in Figure 12. Note that for all three LCGs, distinct knees exist at 9500 ft and 10,000 ft. Thus, the appropriateness of 8000 ft, 9500 ft, and 10,500 ft as takeoff distance design options appears to be confirmed.

Whether a takeoff distance of 9500 ft or 10,500 ft is more appropriate for commercial purposes is another question that is beyond the scope of the present effort. To illustrate the point, however, Figure 13 shows the distribution of airports within the set that have at least one runway with an adjusted length of 10,500 ft or greater. Observe that there appear to be enough such airfields for a 10,500 ft takeoff distance to be viable for an international cargo aircraft, particularly if it has an LCG III capability. Realize also that no US military airfields are included in Figure 13 and, for that matter, several potentially prominent commercial airports may not be included in the set. Such fields could play an important role in an advanced air cargo system and thus, their inclusion in Figure 13 might add significantly to the number of airports available.

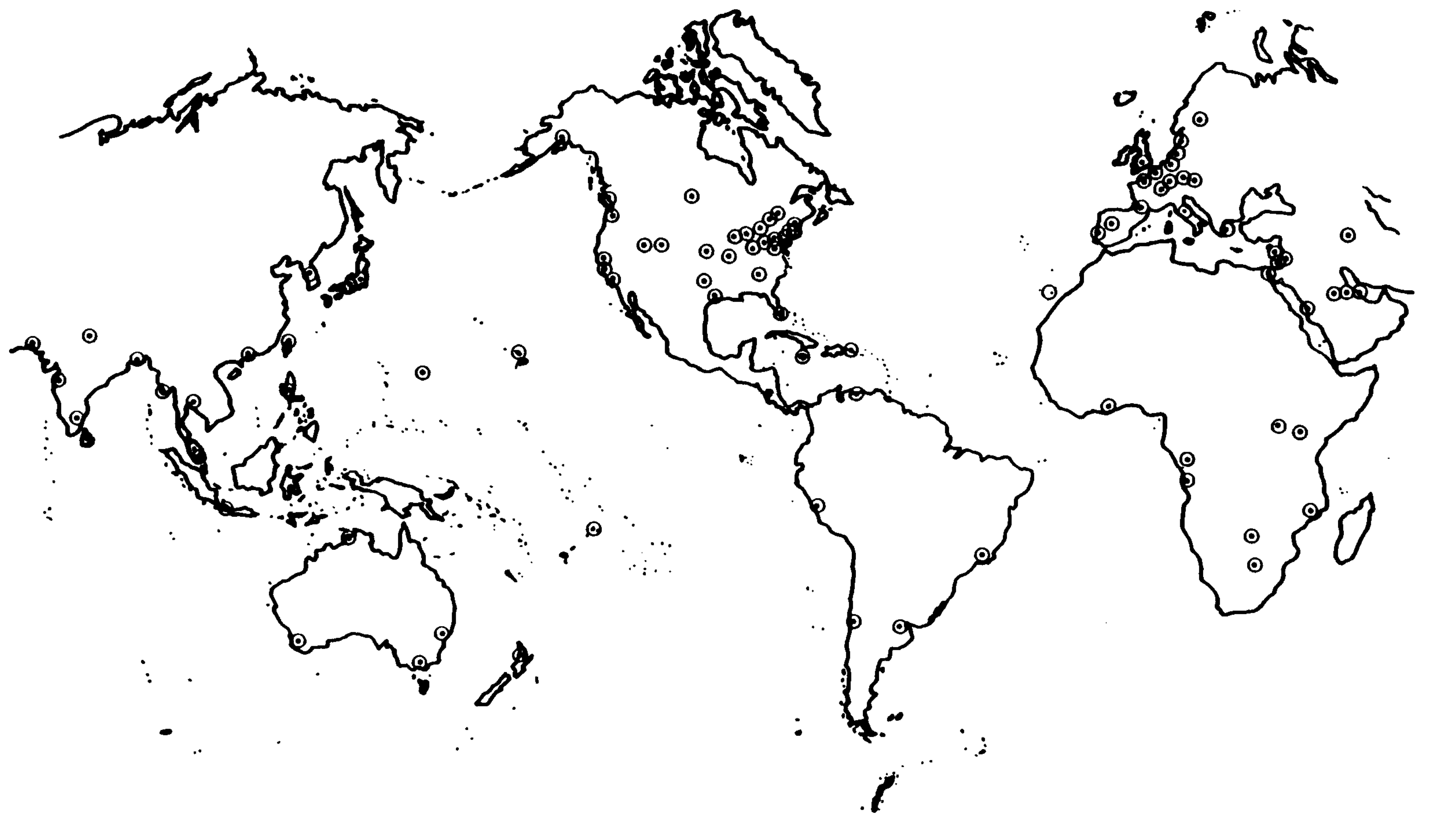

Figure 11. Distribution of Commercial Airfields Under Consideration

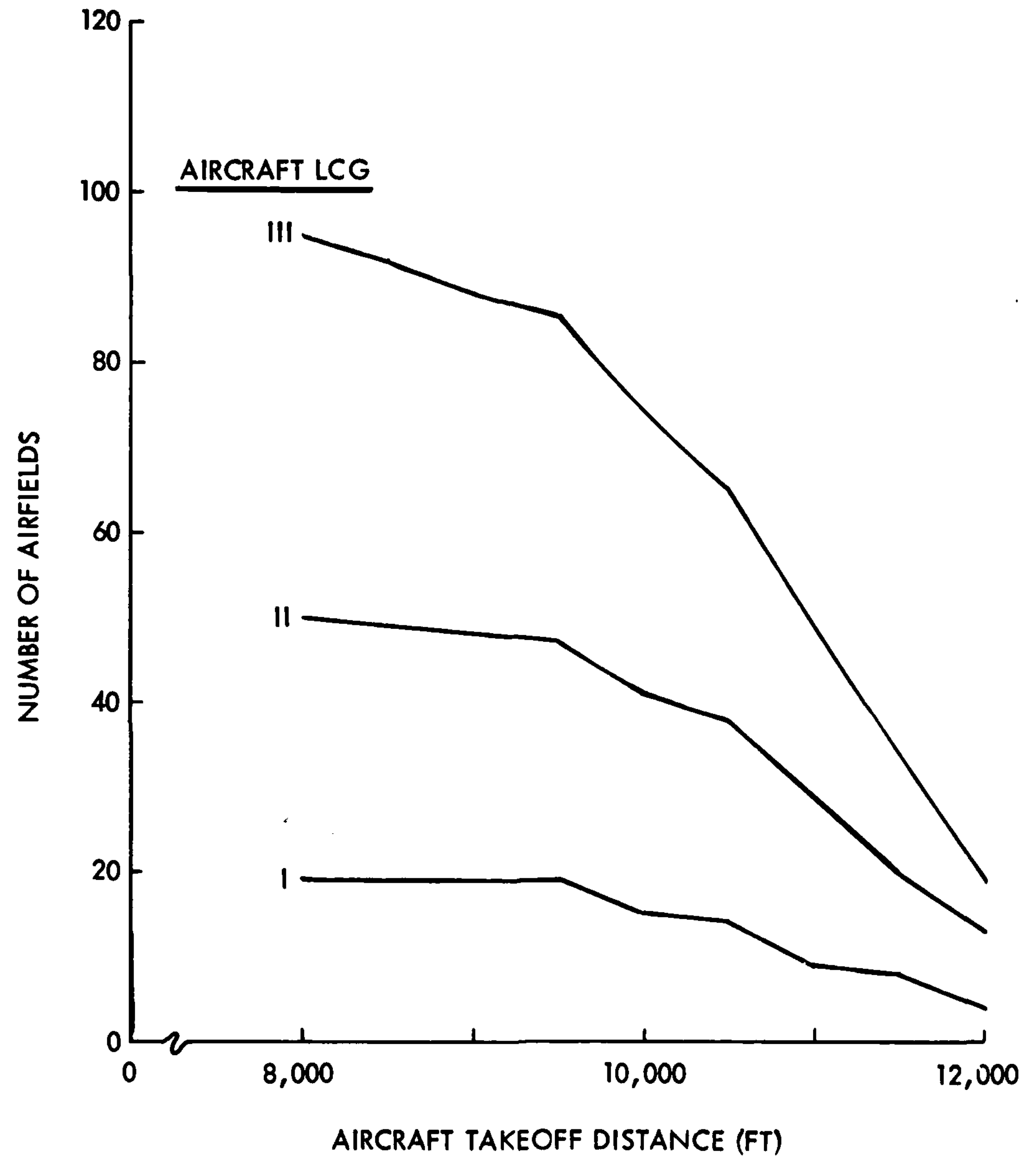

Figure 12. Number of Commercial Airports Available from Worldwide Sample In Terms of Aircraft LCG and Takeoff Distance

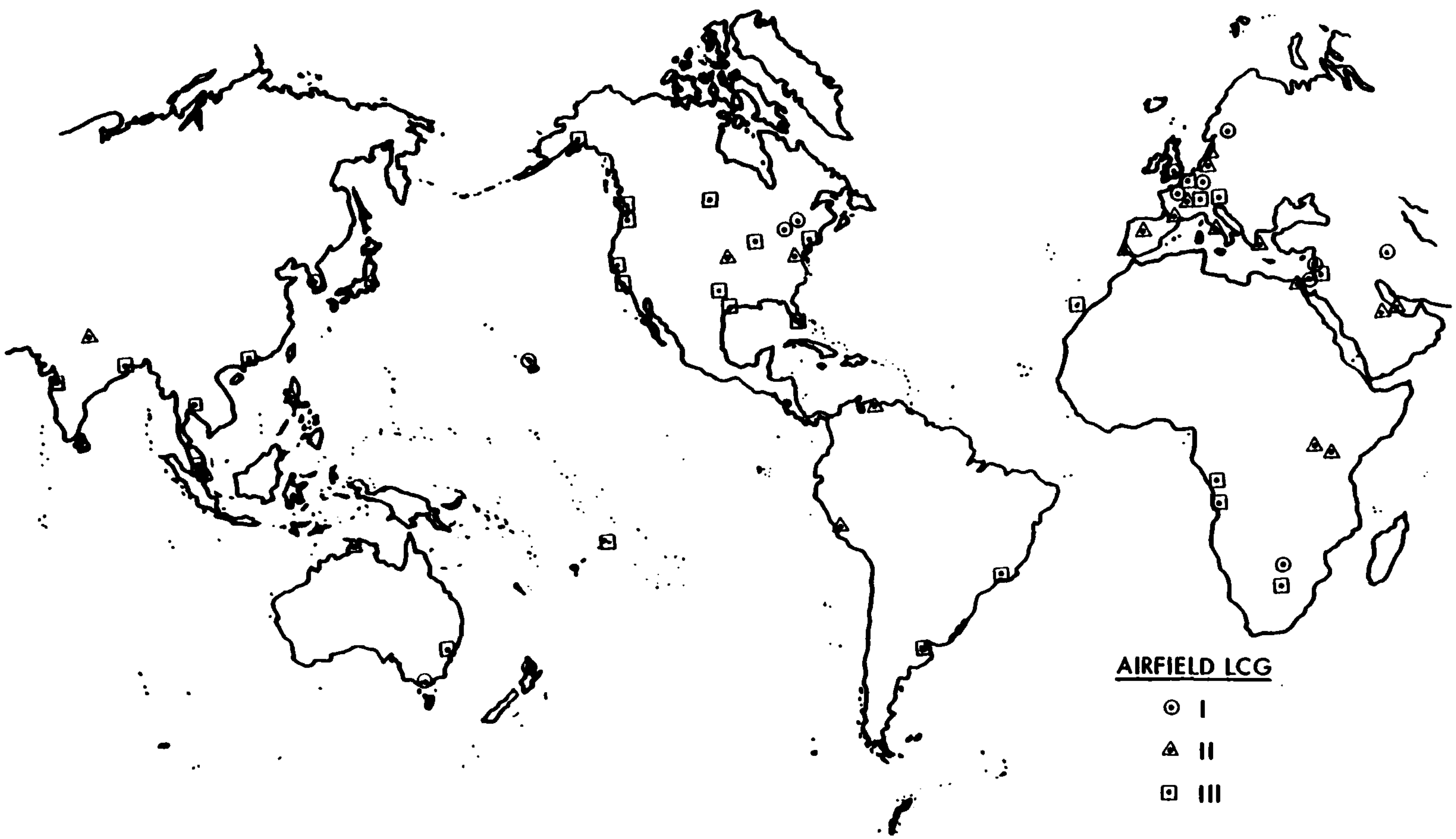

Figure 13. Distribution of Commercial Airfields Having at Least One Runway With an Adjusted Length of 10,500 Ft. or Greater

Assessment of Design-Option Substitution

The baseline aircraft was sized to achieve a takeoff distance (over 50 ft) of 9500 ft at maximum takeoff gross weight. The corresponding critical field length is 8600 ft, and the FAR balanced field length is 10,800 ft.

Increasing the design takeoff distance to 10,500 ft can be expected to have at least some adverse impact on mission flexibility and on mission effectiveness. As noted in the preceding discussion, the number and distribution of airfields appear to be such that most military objectives can be accomplished with the longer design takeoff distance, particularly if landing distance can be held to 6000 ft or less. We again emphasize, however, that final judgments regarding the best airfield compatibility design options for military purposes can only be made by the appropriate USAF and DOD organizations.

Reducing the takeoff distance to 8000 ft would increase flexibility in the choice of APOE as well as en-route stops. The latter point may be *particularly important* since it could reduce potential queuing delays and hence increase mission effectiveness.

In terms of military/commercial commonality, a takeoff distance of 9500 ft appears to be the most appropriate compromise. The possibility of designing to 10,500-ft cannot, however, be entirely discarded. Whether or not the decreased flexibility associated with a 10,500 ft takeoff distance is sufficiently compensated by the corresponding reduction in costs also required judgments that are beyond the scope of the present effort.

LANDING GEAR FLOTATION

The design options under consideration for this feature in terms of load classification group (LCG) at maximum-gross-weight are:

- LCG I (LCNs greater than 100)
- LCG II (LCNs between 76 and 100)
- LCG III (LCNs between 51 and 75)

As noted earlier, for the purposes of this discussion, the LCG at landing is assumed to be one step better than the maximum gross weight LCG.

In terms of functions, landing gear flotation is similar to takeoff distance; hence, the discussion of military objectives facilitated, etc., will not be repeated in the following paragraphs.

Militarily Desirable Design Option

As in the case of takeoff distance, landing gear flotation should be examined in the context of both the APOE and APOD situations. Consider first the APOE case. Figure 9 suggests that very little benefit is obtained from increasing the flotation from LCG I to LCG II regardless of aircraft takeoff distance. However, going from LCG II to LCG III results in almost a doubling of the number of airfields available. Thus, to ensure flexibility in choice of APOE, an LCG of III would appear to be prefereable. Given a choice between LCG II or LCG I, the latter may be regarded as a better choice particularly if LCG I aircraft prove to be significantly less costly than aircraft with LCG II capability.

Table 12 provides information useful for examining the situation at the APOD. Observe that for most of the selected countries, improving the LCG by one step results in at least doubling the number of airfields available as APODs. Once again, the value of this increased flexibility is a subjective judgment well beyond the scope of this analysis. However, LCG III (at maximum gross weight) would seem to be most desirable from a military viewpoint, although LCG II or perhaps even LCG I may be acceptable.

Of possible significance is the observation that LCG II (at maximum gross weight) does not appear to be very beneficial in the case of the APOE but, as shown in Table 12, is much more important when though of in terms of the number of potential APODs available. Because of this dichotomy, LCG III appears to us to be the most desirable military design option, since the military objective of flexibility in the choice of both APOE and APOD is assured.

TABLE 12
NUMBER OF AIRFIELDS POTENTIALLY AVAILABLE TO SERVE AS APODS IN SELECTED COUNTRIES

	AIRCRAFT LCG AT LANDING			
COUNTRY	II [a]	III [a]	IV [a]	IV [b]
GERMANY	12	25	55	59
BENELUX	0	6	27	29
FRANCE	11	38	82	91
UNITED KINGDOM	21	55	99	110
GREECE	6	10	27	32
TURKEY	2	10	19	21
ISRAEL	1	1	4	4
SAUDI ARABIA	6	12	18	18
IRAN	6	21	28	34
EGYPT	4	15	41	47
SOUTH KOREA	2	6	19	20

[a] Based on airfields with adjusted lengths of 6000 ft or greater, see Table 10.

[b] Based on airfields with adjusted lengths of 5000 ft or greater, see Table 10.

Alternative Design Option

Military airlifters generally have flotation characteristics superior to commercial cargo aircraft. The reason, of course, is that commercial carriers tend to operate over a fixed route structure that mainly consists of the most prominent commercial airports. Table 9 suggests that LCG II would likely be the commercial choice. Note, however, that successful commercial utilization of an LCG III aircraft cannot be discounted, since both the 747 and DC-10 are in this category.

To provide further insight into the commercially-desirable LCG, consider Figure 12. Observe that a one step improvement in LCG either from I to II or II to III) results in a substantial increase in the number of airports that can be served, regardless of the design takeoff distance. Indeed, the number of available airports is about doubled in most instances.

A question of further interest is whether an aircraft with an LCG I capability is practical from a commercial viewpoint. Figure 14 indicates which airports of those shown in Figure 11 have LCNs of 100 or better. Although definitive conclusions cannot be drawn from Figure 14, the airports shown might be sufficient to form an air cargo route system, particularly when thought of in terms of a hub-spoke concept (i.e., one in which the ACMA is assumed to operate only between major airports, with smaller aircraft being used for local collection and delivery.) Two other points merit reiteration. First, many military airfields with LCNs greater than 100 exist in the United States and elsewhere; these are not shown in Figure 14. Second, the lack of confidence in the available LCN data suggests that several more commercial airports may fall in LCG I. For example, Dallas/Ft. Worth and the new Tokyo airport (Narita) are likely to have LCG I runways although the data file lists LCNs of 72 and 77 (LCG III and II), respectively.

Assessment of Design-Option Substitution

The landing gear design of the baseline aircraft yields an LCG II capability at maximum gross weight as shown in Figure 7. However, work in the early part of the present study may result in a substantial reduction of the maximum

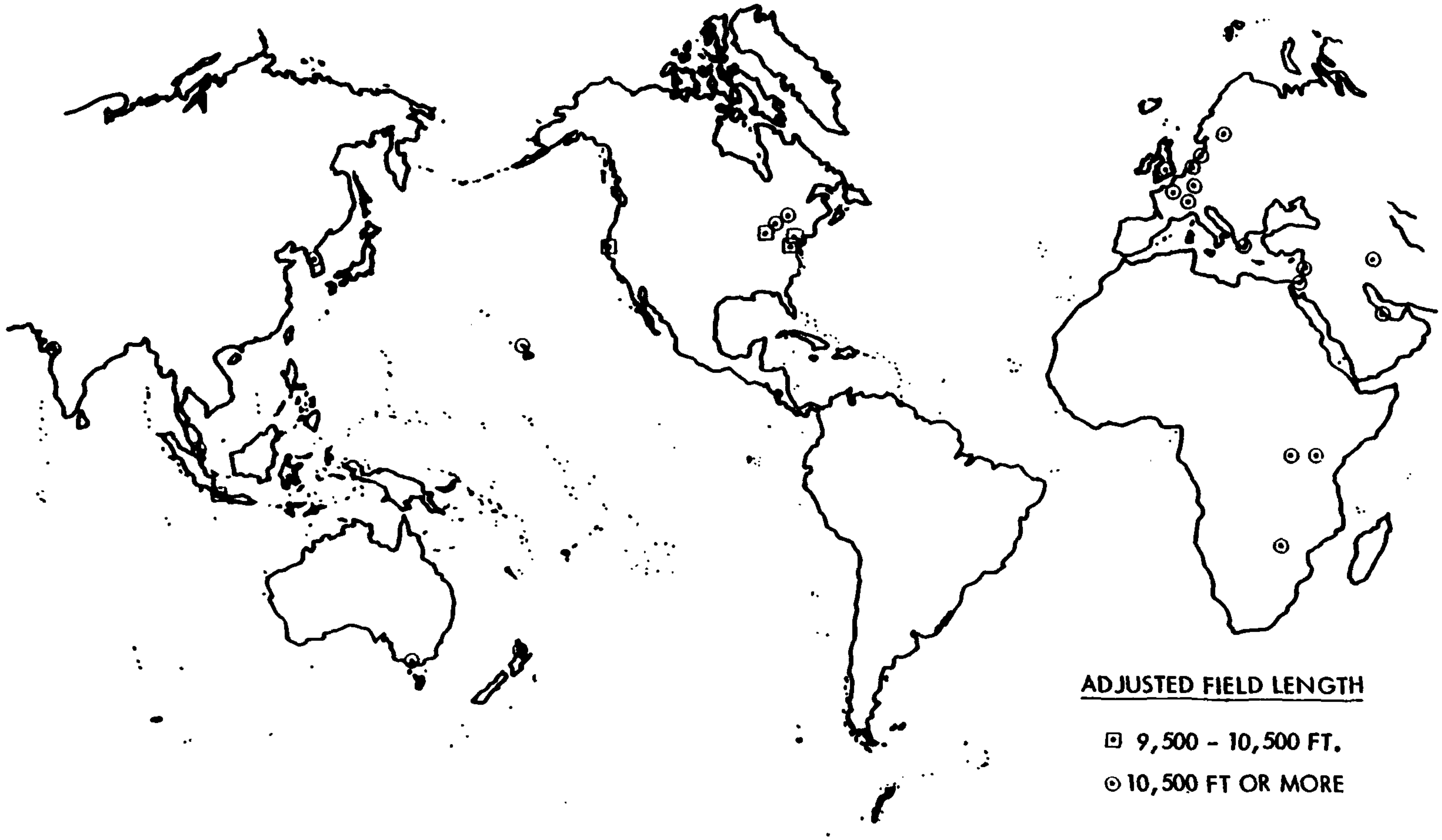

Figure 14. Distribution of Commercial Airfields Having at Least One Runway With an LCN of 100 or Better

gross weight of the baseline aircraft. For example, recall from Section III that a design feature recommended for early investigation is design payload. If this analysis reveals that the design payload should be reduced by 90,000 lb or more (as discussed in Section III) and the landing gear design is held constant, an LCG III capability is likely to result.

As illustrated above, an LCG I or II capability will result in a clear loss of mission flexibility from a military viewpoint. Whether this degradation in system capability is balanced by the resulting cost savings could only be determined by appropriate USAF and/or DOD personnel. To make such judgments, reliable estimates of system costs for the various options will be required and these will require more detailed analysis.

From the viewpoint of commonality, LCG III ensures military acceptability and may also be desirable for commercial purposes. However, both LCG I and II may be viable in a commercial environment and, hence, either may be preferred by commercial operators because of the associated reduction in costs. Once estimates are made of these costs, such judgments can be made by the cognizant organizations. Finally, the possibility exists of designing the gear to provide an LCG III (or LCG II) capability; commercial users may then be able to substantially reduce tire and associated costs by operating at a higher tire pressure corresponding to LCG II (or LCG I).

RUNWAY WIDTH FOR 180° TURN

Although of considerably lesser importance than the preceding features, the runway width required by the aircraft to negotiate a 180° turn is likely to impact its compatibility with existing airfields. Options of interest are:

- 150 ft
- 200 ft
- 300 ft

For the class of aircraft represented by the baseline (i.e. cargo compartment floor length of 120 ft or more), a turning width less than 150 ft is essentially not possible.

Militarily Desirable Design Option

The shortest possible turning width is preferable for military purposes. The primary function of a short turning width is to permit continued use of a given airfield as an APOD even if taxiways are damaged or otherwise unavailable. As a secondary function, a short turning width will tend to minimize ground-handling problems and space requirements associated with maneuvering the aircraft into a loading/unloading position.

Thus, providing the ACMA with the shortest possible turning width furthers the military objectives of flexibility in the choice of APOD and minimal ground turn-around time (and hence maximal unit productivity.)

Alternative Design Options

Commercial operators also prefer that the aircraft turning width be as short as practical. The motivation here is primarily associated with minimizing the space required in the terminal area for ground maneuvers.

The fact that the 747-200F is equipped with steerable main landing gears and has a turning width of 170 ft (Table 9) illustrates the extent of commercial desires in this regard.

Assessment of Design-Option Substitution

The baseline aircraft should be capable of making a 180^o turn on a 200-ft-wide runway. The length of the fuselage of the baseline aircraft precludes a turning width of 150 ft.

The preceding discussion suggests that the minimum possible turning width is most desirable from both military and commercial viewpoints. Thus, a turning width greater than the minimum practical adversely affects mission effectiveness and commercial commonality. However, the desire to be able to make a 180^o turn on a 150 ft wide runway is probably not sufficiently significant to dictate the maximum length of the fuselage, particularly if the turn can be made within 200 ft. Note also that inability of the aircraft to negotiate a 180° turn within the available runway width does not preclude the aircraft's using the runway, assuming that adequate taxiways or turnaround areas are available.

Observe that a minimum turning width inevitably implies castoring or steerable main landing gears. As such, a crosswind landing gear can readily be provided if deemed desirable or found necessary on the basis of flight tests.

NOISE CHARACTERISTICS

Three levels of acoustic treatment can be readily identified to define design options relative to aircraft emitted noise characteristics:

- o No special acoustic treatment.
- o Treatment for aircraft to conform to FAR 36 Stage 3 limits.
- o Treatment and engine cycle selection for even lower noise levels to permit "curfew free" operations.

The first alternative would require a waiver of FAR 36 limits (unless some technology breakthrough occurs to reduce inherent engine and airplane noise). In the second option, the aircraft and engine would be designed to conform to FAR 36, and certification of the civil version would pose no problem. For the third option, the aircraft would be made sufficiently quiet, by a combination of acoustic treatment and selection of an engine cycle with a low inherent noise level, to permit night-time operations at airports where local authorities impose a curfew that forbids takeoffs or landings by turbine-powered aircraft even though they might satisfy FAR 36 limits.

Militarily Desirable Design Option

Air Force Regulation 80-36 provides the policy and procedures to assure that USAF transport aircraft meet civil airworthiness standards, including FAR 36 noise standards, when "intended usage is generally consistent with civil operations." A large strategic airlifter, such as the ACMA, is likely to be operated this way, especially in peacetime. On the other hand, a military intra-theater transport is less likely to have a commercial counterpart and, therefore, might be more likely to be allowed waivers of FAA standards, especially if any commercial use were limited to only occasional operations at major airports. Such deviations from FAA standards are permitted by AFR 80-36 when it is "essential for the aircraft to serve a military role under its intended operating condition."

While no special acoustic treatment might be the operationally preferred military option to ensure maximum performance of the aircraft, AFR 80-36 directs conformance with FAR standards. The no-treatment option, therefore, would be based on aircraft mission performance considerations and whether or not wartime capability might be compromised for environmentally more acceptable peacetime operations.

Military air bases are not typically located within large urban areas whereas civil airports are usually near population centers. Thus, the additional weight and cost of "curfew free" noise level treatment and the most noise-advantageous engine cycle (e.g., high bypass ratio, low fan pressure ratio, low tip-speed fan) might not provide the ACMA with any useful increase in operational flexibility. Further, considering that night-time restrictions are imposed by local authorities and that military transport operations from civil airports are relatively infrequent (especially when compared with total commercial operations), negotiation on an instance-by-instance basis is probably the preferred strategy when such operations are necessary.

Even though it might not satisfy the full intent of Air Force regulations, deleting special acoustic treatment will provide the desired performance capabilities for the least system cost. Thus, the most appropriate option should ultimately be based on the noise characteristics of the selected powerplant, aircraft performance in the noise-measuring regime, and the compromise in capabilities resulting from acoustic treatment.

Alternative Design Options

Regardless of the preferences of commercial operators, civil versions of the ACMA will have to comply with FAR 36 noise standards unless a specific waiver can be obtained. Such waivers for continuing commercial operations may be

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extremely difficult to obtain or even impossible for operations not in direct support of military transport activities. Thus, for commercial operations, noise treatment to comply with FAR 36 will probably be required.

Conformance may be particularly difficult for the class of aircraft represented by the baseline since allowable noise levels are flat-lined for gross weights in excess of 850,000 lb. Consider the takeoff flyover noise limit, for example. For an aircraft of 500,000 lb gross weight, the limit is presently set at 103 EPNdB. At 850,000 lb, the limit is 106 EPNdB, but there are no further increases for greater gross weights. In addition, little inherent engine noise reduction is anticipated between the present and the 1990s IOC of the ACMA. Perhaps a 2 to 5dB decrease in engine noise can be obtained, but more will require a presently unpredictable technical breakthrough.

No nationally applicable criteria exist for defining "curfew-free" operation. Night-time restrictions are imposed by local airport authorities and they tend simply to ban operations of an entire class of aircraft (e.g., turbine-powered). Work sponsored by Lockheed-Georgia, however, suggests that noise levels would have to be substantially reduced from FAR 36 levels. For example, a current four-engined turboprop, medium transport could be expected to generate an undesirable night-time ground-noise level on takeoff at points ten miles or more from the end of the runway. Designing the ACMA to such stringent, curfew-free requirements without undesirable performance penalties is probably impossible. However, since only a relatively few major airports in the world presently restrict night-time operations and, hopefully, reasonable noise limits will be imposed in the future, inability to achieve curfew-free noise characteristics may not seriously inhibit the commercial utility of the ACMA.

Assessment of Design-Option Substitution

The baseline aircraft incorporates no special acoustic treatment or other considerations pertaining to noise characteristics beyond that inherent in the STF477 study engine. No special cycle characteristics are yet incorporated in the STF477 to help attain the low noise levels likely to be required for curfew-free operations. Since conforming to FAR 36 noise levels is expected to increase both acquisition and operating costs, it will adversely affect military cost effectiveness. The only potential benefit that can be identified from a military viewpoint is a lessening of the ACMA's possible adverse environmental impact and eliminating the potential program delays associated with such impacts.

Conforming to FAR 36 will increase the prospects for a common military/commercial aircraft. Indeed, without such conformance, even assuming a waiver could be obtained from the FAA, local authorities might act to restrict all operations of the civil variant, thus threatening its commercial viability.

ASSESSMENT OF DESIGN-OPTION INTERACTION

Figure 15 summarizes our assessment of the interactions among the options in this functional grouping. Note that the combination of Load Classification Group I and a takeoff distance of 8000 ft has been shown to be inconsistent, since it offers no benefits when compared to LCG I and 9500 ft.

Six of the LCG/takeoff distance combinations are shown as potentially synergistic. Of the two remaining combinations, LCG II and 8000 ft offers only modest benefits compared with 9500 ft. On the other hand, LCG I and 10,500 ft is thought to result in too few airports being available for a viable commercial system.

Also indicated in Figure 15 is the interdependency between design takeoff distance and ability to conform with noise regulations. Generally, but not always, increasing the design takeoff distance will result in takeoff noise regulations being more difficult to achieve because altitude over the measuring point is likely to have a greater influence than the decreased thrust permitted by the longer takeoff distance. Stated another way, more thrust results in a shorter takeoff and, at the same time, probably less measured noise even though engine noise is likely to be greater. Approach noise must also be considered, however, to establish the acoustic treatment necessary.

		Curfew-Free	FAR 36	None	300 ft	200 ft	150 ft	LCG III	LCG II	LCG I	10,500 ft	9,500 ft	8,000 ft
Takeoff Distance	8,000 ft	S	S					S		X	X	X	
	9,500 ft							S	S	S	X		
	10,500 ft							S	S				
Landing Gear Flotation	LCG I							X	X				
	LCG II							X					
	LCG III												
Turning Width	150 ft				X	X							
	200 ft				X								
	300 ft												
Noise Characteristics	None	X	X										
	FAR 36	X											
	Curfew-Free												

X (crossed box) Denotes Inconsistent Combination

S (boxed) Denotes Potentially Synergistic Combination

Figure 15. Assessment of Interactions Among Airfield Compatibility Design Options

RECOMMENDED DISPOSITION OF CANDIDATE OPTIONS

All of the options discussed in this section are recommended for more detailed analysis except those associated with the turning-width feature and the curfew-free option for noise characteritics. Because of the interdependency exhibited by the takeoff distance and landing gear flotation features, they will be combined into a single feature.

Rationale

The preceding discussion suggests that both military and commercial interests are best served by providing the ACMA with the capability to negotiate a 180^{o} turn on as narrow a runway as practical. The baseline aircraft, because of its fuselage length, requires a 200 ft wide runway for this maneuver. Since the baseline represents the longest fuselage length that will be investigated in the present effort (Section III), all subsequent aircraft examined will be capable of making a 180^{o} turn within 200 ft or less. A turning width of 150 ft will serve as a design goal.

Of the three noise-characteristics features discussed, designing to the curfew-free criterion appears to be technically unattainable for the ACMA class of aircraft. Thus, no further consideration of this option is recommended.

Finally, only those combinations of options for takeoff distance and landing gear flotation shown as potentially synergistic in Figure 15 are recommended for the more detailed analysis. The reasoning here should be clear from the preceding subsection.

Relative Potential

The design options within this functional grouping that are recommended for more detailed analysis are summarized below.

- o Takeoff distance/gear flotation
  - 8000 ft/LCG III
  - 9500 ft/LCG III
  - 10,500 ft/LCG III
  - 9500 ft/LCG II
  - 10,500 ft/LCG II
  - 9500 ft/LCG I

- o Noise Characteristics
  - No special acoustic treatment
  - Conform to FAR 36, Stage 3 limits

A qualitative assessment of the relative potential of these options is presented in Table 13.

Note that the regulatory aspects of the noise characteristics feature reduces the meaningfulness of this assessment. That is, conformance with FAR 36 must be examined in detail since it can be regarded as an externally imposed constraint. Furthermore, because of the interdependency of conformance to FAR 36 and takeoff distance, analysis of the noise characteristics feature should be conducted for all of the takeoff-distance options under consideration.

TABLE 13
SUBJECTIVE ASSESSMENT RELATIVE TO BASELINE AIRCRAFT OF AIRFIELD COMPATIBILITY DESIGN FEATURES

-3	-2	-1	0	1	2	3
Much Poorer			Neutral			Much Better

Military Considerations	Takeoff Dist./Gear Flotation	Noise Characteristics
Life-Cycle Cost	1	-1
Mission Effectiveness	0	0
Mission Flexibility	2	0
Subtotals	3	-1

Commercial Considerations	Takeoff Dist./Gear Flotation	Noise Characteristics
Direct Operating Cost	1	-1
Indirect Operating Cost	0	0
Market Expansion Potential	1	3
Subtotals	2	2
Grand Totals	5	1

VI. CARGO COMPARTMENT FUNCTIONAL GROUPING

Nine design features have been identified that define the functional characteristics of the cargo compartment:

- o Cargo-compartment planform shape
- o Cargo envelope
- o Floor strength
- o Sub-floor strength
- o Vehicle tiedowns
- o Container/pallet handling/restraint system
- o Pressurization
- o Cargo-stick width
- o Cargo-compartment length

Note that several of these features are interdependent--particularly floor strength, sub-floor strength, vehicle tiedowns, and container/pallet handling/restraint system. Furthermore, significant interdependencies exist between features in this grouping and those in the ground interface grouping. (See Section XI.)

CARGO-COMPARTMENT PLANFORM SHAPE

A generally rectangular planform is of principal interest in the ACMA class of aircraft. That is, the outboard edges of the cargo floor should be parallel straight lines for a substantial portion of the compartment length. However, the forward and/or aft ends of the cargo floor can be tapered, thus providing floor sections of less than full width in these areas.

The following candidate options are suggested, assuming a three-stick wide cargo compartment:

- o Tapered forward (19 ft width) and aft (13 ft width)
- o Full width (27.3 ft) forward and aft
- o Full width (27.3 ft) forward and tapered aft (13 ft width)

As illustrated in Appendix A, the tapered portion of the floor can also serve as the first ramp segment (i.e., the segment integral to the aircraft) when partially removable ramps are used. The tapered portions of the floor should be sized such that at least one 20-ft-long container can be accommodated on the aft segment and at least two 20-ft containers on the forward segment. Apertures of less than full width are one consequence of tapered floors.

Militarily Desirable Design Options

Full-width floor sections, both forward and aft, are thought to be most desirable for military purposes. The primary functions of the full-width floor, when provided in conjunction with a cargo aperture and ramp, is to facilitate the loading and unloading of wheeled and tracked vehicles during drive-on/drive-off and back-on/drive-off operations and to permit ground loader offloading of pallets/containers simultaneously from all sticks. Secondarily, in terms of military loadability, a fully rectangular cargo compartment invariably yields the maximum utilization of floor space.

Thus, a full-width cargo floor for the entire compartment length appears most compatible with the military objective of minimizing ground time, particularly at the APOD, with the attendant benefits regarding productivity and survivability as discussed in Section IV.

Finally, full-width openings enhance military flexibility in as much as the possibility of airlifting items wider than 19 ft is not foregone. Although little interest exists at present in the capability to airlift 27-ft-wide items (or 27-ft-long items loaded sideways), future developments might alter this perception.

Alternative Design Options

Commercial operators, being less interested in achieving absolute minimum ground time, would probably not object to tapers at both ends of the cargo compartment. Such an arrangement requires a relatively more complex on-board cargo handling system, since straight-in loading of ULDs is not possible.

However, tapering the cargo compartment results in improved aerodynamic and structural characteristics. These, in turn, yield acquisition and operating cost benefits that are thought to outweigh the disadvantages associated with the loading/unloading operation. To assure outside capability, the degree of taper should be such that at least one aperture is a minimum of two-sticks in width.

A potential compromise option is to maintain the full-width cargo floor forward but to taper the aft portion. This offers the potential for minimizing ground-time at the APOD, simplifying commercial loading or unloading of ULDs, and still providing the benefits associated with eliminating the aft full-width floor. Tapering only the forward segment of the floor appears considerably less attractive, since most of the benefits attributable to a tapered-floor arise in conjunction with the arrangement of the aft fuselage.

Assessment of Design-Option Substitution

The baseline aircraft incorporates tapers at both the fore and aft ends of the cargo compartment, as described in Appendix A. Note that the dimensions of the baseline's forward aperture are almost identical to that of the C-5A. (See also Section IV.)

A fully rectangular cargo compartment would reduce military loading and unloading times, improve floor-space utilization, and increase flexibility. These benefits could be largely obtained by maintaining a full-width only at the forward end of the cargo compartment, since ground time at the APOD is substantially more critical.

From the viewpoint of commonality, a full-width cargo floor at the forward end only may prove to be the most attractive compromise. As noted, it would provide most of the desirable military capabilities. Furthermore, a forward full-width opening would greatly simplify the on-board cargo handling system as well as reduce commercial turnaround times. A full-width front aperture also provides commercial operators the ability to take advantage of unforseeable future opportunities.

Whether these anticipated benefits to system effectiveness and flexibility are sufficient to outweigh the associated costs requires detailed analyses.

CARGO ENVELOPE

Figure 16 sets forth the dimensions that must be specified in order to define the cargo envelope for the ACMA class of aircraft. Maximum width, W_1, is determined by the desired number of sticks, the width of each stick, and clearance requirements, as discussed later in this section. W_2, the width that the maximum height is maintained, is based on the widths associated with maximum height items. An alternative approach is to require W_2 to be at least 13 ft, which corresponds to that of the C-5A. Geometric considerations will invariably permit a value for W_2 greater than 13 ft for three-stick configurations.

The sidewall (or shoulder) height, H_2, must be sufficient to accommodate the tallest items that are to be loaded three abreast. For the ACMA, we suggest a minimum value of 10.5 ft which will permit the loading of 10 ft high containers. (Refs 12, 15, and 16)

The remaining dimension, H_1, is determined by the height of the largest item to be transported. This is the parameter of principal concern in the present effort. Candidate options for H_1 are:

- o 13.5 ft for entire compartment length
- o 11 ft for entire compartment length
- o 13.5 ft forward of wing carry-through, 11 ft aft

The first of these provides full outsize capability, whereas the second is the minimum height for accommodating main battle tanks. Note that H_1 limits the height of the tallest item that can be loaded straight in (e.g., from a dock, ground loader, etc.). Determining the tallest vehicle that can be loaded utilizing a ramp is much more complicated, since the maximum "crest" height depends on the ramp angle and length as well as vehicle geometry (e.g., length, wheel spacing, etc.).

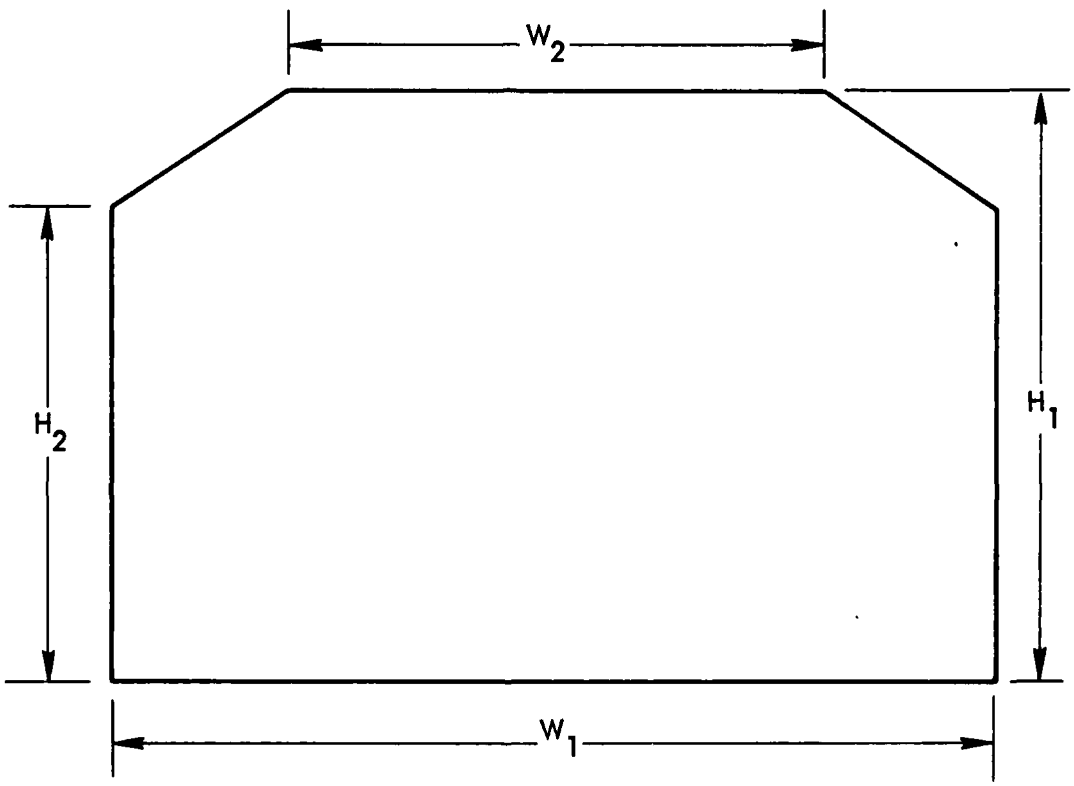

Figure 16. Dimensions Required to Specify the Cargo Envelope

Militarily Desirable Design Option

A full outsize height of 13.5 ft is desired by the military. This permits the airlifting of essentially all road vehicles inasmuch as these are generally constrained by the 13.5 ft minimum clearance on the US Interstate Highway system. Furthermore, all Army helicopters can be accommodated within the 13.5-ft height limitation if reduced from their operational configuration. (Ref 17) As noted, however, straight-in loading may be required in some instances.

A full outsize capability satisfies the military objective of being able to deploy fully-equipped combat units without dependency on pre-positioning or sealift.

Alternative Design Options

A reduced maximum height is thought to be preferable for commercial purposes. Indeed, if commercial loads were limited to ULDs of 10 ft or less in height, the sidewall height of 10.5 ft would be acceptable. Increasing this maximum height slightly to 11 ft permits carrying the M-60 or XM-1 tanks as well as most other Army vehicles. Note that the ability to airlift main battle tanks has been designated essential for the ACMA by the Military Airlift Command. (Ref 4)

A potentially interesting compromise design option, at least for high-wing configurations, is to provide a maximum compartment height of 13.5 ft forward of the wing carry-through structure but 11 ft aft of this point. All outsize vehicles could still be accommodated, but the penalty associated with the capability might be substantially reduced.

Assessment of Design Option Substitution

The cargo compartment of the baseline aircraft has a maximum height of 13.5 ft. Were this reduced to 11 ft, several Army vehicles could no longer be airlifted, as shown in Table 14. Note that, if transporting vehicles in a non-operational configuration is acceptable, only 13 types of vehicles would

TABLE 14
U.S. ARMY VEHICLES WITH HEIGHTS EXCEEDING 11 FT - OPERATIONAL CONFIGURATION

LINE ITEM NO.	DESCRIPTION	HEIGHT (IN)	HEIGHT (FT)
S73531	6-ton Semi-Trailer, M119A1	134	11.2
X49051	5-ton Fork Lift	135*	11.3*
X60696	5-ton Wrecker	136*	11.3*
S74490	6-ton Semi-Trailer, M313	136	11.3
K29660	Attack Helicopter, AH-1G	150*	12.5*
K31795	Utility Helicopter, UH-1H	200*	16.7*
K31804	Utility Helicopter, UH-1M	226*	18.8*
K30449	Cargo Helicopter, CH-47C	224**	18.7**
S74832	Repair Van, M750	132	11.0
T21646	Aircraft Shop Set, B-2	134	11.2
T21509	Aircraft Shop Set, B-1	134	11.2
T22057	Aircraft Shop Set, B-5	134	11.2
T21920	Aircraft Shop Set, B-4	134	11.2
T21783	Aircraft Shop Set, B-3	134	11.2
F39241	5-ton Crane	135	11.3
X58093	2500-gal Tank Truck	135*	11.3*
X41653	8-ton Cargo Truck	135*	11.3*
X62237	5-ton Truck	138	11.5
X63436	10-ton Wrecker	142*	11.8*
S74079	12-ton Semi-Trailer	146	12.2
L45534	762 mm Rocket Launcher	148*	12.3*
F39378	20-ton Rough Terrain Crane	149	12.4
L43664	Bridge Launcher, M60	156***	13.0***

* Reducible to a height less than 11 ft
** Reducible to a height less than 13.5 ft but greater than 11 ft
*** Height of 121 in (10.1 ft) with bridge removed

be excluded by an 11-ft maximum height limitation. Table 14 is based on current divisional TOEs (H-series) and as such excludes vehicles unique to support units (e.g., the Rock-Crushing Plant).

Limiting the cargo compartment height to 11 ft would presumably result in a less costly system, both in terms of acquisition and operating costs. Thus, system cost-effectiveness, when deploying the items that can be accommodated, should be improved relative to the baseline aircraft with its 13.5 ft maximum ceiling height.

Reducing the cargo compartment height to 11 ft may enhance the prospects for commonality. However, the reduced height does preclude the possibility of overhead container carriage, as discussed in Sections III and IV. Furthermore, potential new business opportunities may be limited by the restricted maximum height.

The compromise option seems ideal operationally. Whether the extra cost of a partial 13.5-ft height compared with that of a constant 11-ft height is worthwhile requires more detailed analyses.

FLOOR STRENGTH

The cargo loading limits of an airlifter are defined by two parameters. The first is the maximum running load capability and the second is the maximum axle load. The former can be thought of as the distributed load that must be supported by the sub-floor structure, described subsequently. Axle loads, on the other hand, are concentrated loads that must be distributed to the subfloor structure by the floor itself.

The desired military capability is to provide for a maximum axle load of 25,000 lb. (Ref 4) This capability would accommodate the heaviest wheeled vehicle in the Army inventory (the 20-ton Rough Terrain Crane). The candidate design options that will provide a floor capable of distributing such loads are:

- Integral hard floor
- Commercial floor with hard-floor kit
- Commercial floor with slave pallets

As will become clear in the discussion of subsequent design features in this section, each of these options is particularly compatible with certain combinations of other options.

Militarily Desirable Design Option

An integral hard floor is preferable from a military viewpoint since the primary function of a military airlifter is the deployment of wheeled and tracked vehicles. Any other option requires greater weight and hence increased cost to provide the same capability.

Thus, an integral hard floor facilitates the military objective of providing a deployment capability for wheeled and tracked vehicles at minimum cost.

Alternative Design Options

If all commercial cargo is containerized or palletized then no corresponding commercial requirement for a hard floor exists. That is, use of flat-bottom containers or pallets results in a distribution of loads by the ULDs themselves. On the other hand, if carriage of beam-bottom containers up to 40 ft in length (i.e., similar to today's sea-land container) is desired, then some means of distributing the load must be devised. Candidates include loading the beam-bottom container on a slave pallet or, in the absence of a rail-roller cargo handling system, specifically configuring the floor to prevent these containers from resting solely on their corner fittings.

Thus, the commercially preferable option is dependent on the types of containers to be carried an on the type of container/pallet handling/restraint system selected, as discussed in a following subsection.

Assessment of Design-Option Substitution

The baseline aircraft incorporates an integral, hard floor capable of handling wheeled and tracked vehicles in the same fashion as the C-5A. As noted earlier, both non-integral hard floor design options can be expected to have an adverse effect on military cost-effectiveness. However, either would likely result in reduced commercial acquisition and operating costs, and may therefore be preferable for encouraging commonality.

SUB-FLOOR STRENGTH

The military requirement, based on the need to carry main battle tanks, is a running load capability of 5000 lb/ft. The corresponding commercial requirement is 3750 lb/ft based on a 25,000 lb maximum gross weight for 20-ft-long containers loaded three abreast. Thus, the obvious design options are:

- o Integral for military loading
- o Integral for commercial loading with military beef-up kit.

An interesting possibility for the second option is to provide the required commercial strength solely with underfloor beams, thus providing underfloor cargo volume for the LD class of containers. The military kit could then consist of underfloor stanchions as discussed in Reference 8.

The discussion of costs, mission effectiveness, and commonality for this feature parallels that of the previous features and is therefore not repeated.

VEHICLE TIEDOWNS

To accommodate wheeled and tracked vehicles, 25,000-lb tiedown points are required. These should be capable of accepting a single 25,000-lb tiedown device or two 10,000-lb devices. The candidate options are:

- o Integral tiedowns rings
- o Kitted tiedowns rings

In either case, the rings should be stowable below floor level when not in use.

Once again, the discussion of the relative merits of these options parallels that presented previously.

CONTAINER/PALLET HANDLING/RESTRAINT SYSTEM

Candidate options for providing on-board container/pallet handling and in-flight restraint are:

- o Flip-Flop rollers, stowable and adjustable lateral restraint rails/locks, stowable and adjustable fore/aft locks, and stowable powered-drive units.

- o Fixed rollers, laterally adjustable restraint rails/locks, stowable and adjustable fore/aft locks, and fixed powered-drive units.

- o Overhead crane with corner-lock restraints.

- o Externally-powered shuttle loader with corner-lock restraints.

A cargo which is assumed to be provided in military versions of the aircraft for the first two options as a back-up system. Note that the cargo handling and restraint systems have been combined in a single feature because of the dual function of the lateral restraint rails/locks in the first two options.

Several ground rules were adhered to in developing these designs options. In the case of the first two options, the outside sticks were to be adjustable to widths of 88, 96, and 102 inches and the center stick to 96, 102, or 198 inches. This arrangement permits the loading of several combinations of pallets and containers up to 40 ft in length, as discussed subsequently in conjunction with the cargo-stick width feature. The lateral restraint rails/locks are used in conjunction with the side-lock points on flat-bottom containers. Pallets require these lateral locks as well as the fore/aft locks. The adjustable feature of the latter permits loading of different sized pallets as well as the intermixing of containers and pallets; these locks are adjustable in two-inch increments.

Ground rules for the last two options are somewhat different, as they have been conceived on the basis of accommodating beam-bottom containers equipped with corner fittings (i.e., similar to the current standardized sea-land intermodal container) as a primary function. In both cases, stick-widths are adjustable only to 8.0 ft and 8.5 ft; corner-locking devices are provided to accept mix of 10-ft, 20-ft, or 40-ft-long containers.

Finally, all options had to be convertible to a flat floor suitable for loading military vehicles.

Military Desirable Design Option

Although airlifting wheeled and tracked vehicles is the primary military function of the ACMA, the ability to accommodate pallets and/or containers for resupply missions is a significant secondary function. For this reason, the first of the aforementioned design options can be regarded as most attractive since it converts rapidly from the vehicle to the pallet/container configuration and permits continuous loading/unloading in both cases.

As noted earlier, this option was conceived primarily on the basis of accommodating flat-bottom containers or pallets. However, beam-bottom containers can be handled by loading them on appropriately designed slave pallets.

The military objective facilitated by this option is that of providing increased unit productivity by minimizing ground times; furthermore, flexibility in converting between vehicle loads and container/pallet loads is assured.

Alternative Design Options

The second design option is functionally identical in the ULD mode to the first. The only difference is that all floor-hardware items are not readily removable. The expected consequence is that the resulting system should be lighter and less complex, thus reducing both acquisition costs and operating costs. For these reasons, the second option is thought to be preferable for commercial purposes, particularly if commercial loads are exclusively palletized and/or containerized.

The third and fourth options represent an entirely different approach to onboard cargo handling and restraint. Both are predicated on restraining the containers using a locking device at the four lower corner-fittings of the standardized intermodal container. The overhead crane provides on-board cargo-handling by attaching to the upper four corner fittings of the container. Flat-bottom containers could be handled by this system by equipping them with corner fittings. Pallets, however, would have to be enclosed in some type of a cage equipped with appropriate corner fittings. For a 463L pallet, an 8-ft-wide by 10-ft-long cage would be needed.

The last design option envisions an externally powered shuttle for positioning cargo in the cargo compartment. Such a shuttle was developed as part of the Project INTACT demonstration. (Ref 11) The shuttle uses guide rails in the middle of each stick to assure proper alignment of the container with the locking devices. When properly aligned, the shuttle lowers the containers onto the locking mechanism and is then withdrawn. Project INTACT tested both a wheeled shuttle and one operating on the air-bearing principle; tentative conclusions suggested that the latter was the superior device. Note that the motive power can be integral to the shuttle device or provided by a separate tug, the latter probably being the preferable choice.

The shuttle system can also accommodate flat-bottom containers by fitting corner-locks to the lower four corners of the containers. Pallets would be placed on a frame incorporating corner locks. Again, an 8-ft-wide by 10-ft-long frame would be required to accept the standard 463L pallet.

Assessment of Design Option Substitution

The cargo compartment of the baseline aircraft incorporates flip-flop rollers, stowable lateral restraint rails/locks, stowable and adjustable fore/aft locks, and stowable powered-drive units in conjunction with a military hard floor (25,000-lb axle loads), sub-floor strength capable of 5000 lb/ft and kitted tiedown rings. Since the system is capable of readily meeting all military and commercial requirements, it can be thought of as a dual-purpose system. However, because it is quickly convertible to several configurations, it is expected to be heavier and hence more costly than some of the alternatives.

Of the first two systems, the second would probably yield lower commercial DOCs at the expense of military cost-effectiveness. A drive-on/drive-off capability with adequate floor strength for vehicles could be provided by loading specifically configured pallets on the fixed handling/restraint system. Thus, this option is likely to be compatible with a commercial-strength floor, a sub-floor requiring a beef-up kit, and kitted tiedown rings. (Depending on the final configuration, some tiedown rings might have to be incorporated in the special pallets.) The resulting military system would undoubtedly be significantly heavier than the first design option and would require substantial time to install. Because of its commercial attractiveness, however, this second option may provide the greater boost to the goal of commonality. Only a detailed analysis could provide insights into the relative magnitude of these anticipated efforts.

The overhead crane option eliminates the need for floor panels on the cargo floor. Hence, a military floor kit with tiedown rings, coupled with an underfloor beef-up kit, appears to be the best combination for this option. The shuttle-loader system, on the other hand, requires a commercial strength floor. Hence, it can be most logically combined with the slave-pallet or the military hard-floor kit options, underfloor beef-up kit, and kitted tie-down rings. Note that the slave pallet in this instance would differ substantially from that discussed in conjunction with the second option because of the wholly different restraint systems involved.

An overhead crane or shuttle system would have several benefits relative to the first two options. First, both are substantially less complex and hence could be expected to reduce maintenance costs. Furthermore, ULDs would suffer less wear than is the case with a roller system. Note, however, that both probably require a full-width aperture to be wholly effective.

Thus, from a commercial viewpoint, either the third or fourth option is likely to be preferred because of the expectedly lower DOCs, particularly if routine carriage of beam-bottom containers is desired. For military purposes, however, both would probably be less attractive in terms of system effectiveness than the first option for several reasons. First, in both instances, the floor cannot rapidly be reconfigured to handle containers rather than vehicles. In addition, carriage of 463L pallets would be inefficient in the sense that the 88-in. by 108-in. pallet would be loaded on a cage/frame with dimensions of 96 in. by 120 in., thereby, wasting considerable floor space. Finally, providing the same maximum height for vehicles in the cargo compartment may result in a larger fuselage cross-section than that of the first option due to the clearance requirements of the cargo handling system, particularly the overhead crane. As before, only a more detailed analysis can provide the information necessary to clarify this situation.

Given a choice between the last two options, the shuttle-loader system appears to be the better alternative for the following reasons.

1. The overhead crane system requires a constant maximum height, thus limiting possible system improvements related to a reduced maximum height aft of the wing as discussed earlier in this section.

2. The overhead crane is expected to result in a somewhat greater aircraft structural weight compared to the shuttle-loader system.

3. Simultaneous loading of multiple containers is possible by ganging shuttles.

4. The shuttle system is the less complex system and should have the lower maintenance costs.

We, therefore, recommend that only the shuttle system be considered for more detailed analysis. Note, however, that if a crane system were reconsidered as a loading/unloading option (Section IV), then the overhead crane cargo handling system should also be reconsidered since the possibility exists, at least conceptually, of synergistically combining the two systems.

PRESSURIZATION

Three candidate design options can be identified for the cargo compartment pressurization feature. Expressed in terms of equivalent cabin altitude at a flight altitude of 40,000 ft, these are:

- 8000 ft (8.2 psi pressure differential)
- 18,000 ft (4.6 psi pressure differential)
- Unpressurized (zero pressure differential)

In all cases, the flight deck and relief crew compartment area would be maintained as a "shirt sleeve" environment with a cabin altitude of 8000 ft.

Militarily Desirable Design Option

A cabin altitude of 8000 ft is generally considered to be preferable from a military viewpoint. This level of pressurization assures that vehicles can be airlifted in their operational configuration. As a secondary function, an 8000-ft cabin altitude permits carriage of troops (e.g., vehicle drivers) in the main compartment without undue discomfort.

Thus, the 8000-ft option is compatible with the military objective of reducing ground time at the APOD, since vehicles would be operational upon offloading and drivers would be already matched with their vehicles. Furthermore, on-loading operations would be simplified because of the minimum required preparation of vehicles.

Alternative Design Options

The available evidence suggests that an 18,000-ft cabin altitude is the minimum pressurization compatible with vehicle fuel, oil, and hydraulic systems. (Ref 4) Substantial reductions in fuselage weight may be possible through reduced pressurization, thus reducing both acquisition and operating costs.

Corresponding reductions in DOC would be of clear benefit to commercial operators. However, an 18,000 ft cabin altitude clearly restricts the number of items eligible for air freight. (Ref 12) Items that may be so affected include electronic components (particularly items that include cathode-ray tubes), live animals, hazardous chemicals, pharmaceuticals, and items packaged in sealed containers. Whether reduced DOCs could increase the market share for eligible items sufficiently to offset the losses associated with reduced pressurization requires more detailed analysis.

The remaining option, no pressurization, essentially translates to restricting maximum flight altitude to no more than 18,000 ft, at least when vehicles are being transported. The resulting overall impact on aircraft performance can be expected to outweight any benefits attributable to an unpressurized fuselage.

Assessment of Design-Option Substitution

An 8000-ft cabin altitude is provided in the baseline aircraft. Reducing the pressurization to an 18,000-ft cabin altitude could prove detrimental to military operations. For example, the higher cabin altitude probably precludes carrying troops in the cargo compartment. If troop carriage is desired, it could still be provided through the use of special pressurized containers serving as cabin modules. These containers, of course, decrease the floor space available for vehicular cargo. Furthermore, access to the cargo compartment by crew memebers from the flight deck would necessitate either depressurization of the flight station area or incorporation of an airlock.

In terms of military/commercial commonality, reduced pressurization would probably be acceptable for military purposes if it proved to be attractive to commercial users. However, the ultimate commercial attractiveness of an 18,000-ft cabin altitude remains to be validated.

CARGO-STICK WIDTH

The next design feature considered for the cargo compartment functional grouping is the width of each cargo stick. The principal candidate options are:

- o 8.0 ft (96 in)
- o 8.5 ft (102 in)
- o 9.0 ft (108 in)

In conjunction with the number of sticks, as discussed in Section III, the stick width plus allowances for clearance determines the cargo compartment width. Note that for most three-stick configurations, walkways and/or fold-down seats can easily be provided in the fuselage cheek (i.e., outboard of the cargo sticks).

Militarily-Desirable Design Options

Cargo-stick width for military purposes should be compatible with both vehicular and palletized loads. Tables 15 and 16 provide some insights into the impact of stick-width on vehicle loadability. Table 15 indicates a slight advantage of about five percent for the airmobile division in the case of a three-stick configuration for widths greater than 8.0 ft. Note that an 8.5-ft or 9.0-ft width is markedly superior for the two-stick case.

Table 15 more closely compares the implications of an 8.5-ft width versus 8.0-ft. For all division types, a significantly greater percentage of vehicles can be accommodated side-by-side with an 8.5-ft stick width. Although limitations in allowable cabin load may prevent taking full advantage of the 8.5-ft stick width in some cases, the increased flexibility it provides the loadmaster should still prove valuable. Both Tables 15 and 16 are based on current Army divisional TOEs, (H-Series). The 1990 Mechanized Division data in Table 16 was developed from Reference 18.

Turning now to palletized military loads, the 463L pallet has dimensions of 88 in. by 108 in. Thus, a 9.0-ft stick width would permit three-abreast loading

TABLE 15
AIRCRAFT LOADS REQUIRED TO DEPLOY ARMY DIVISIONS

CARGO COMPARTMENT WIDTH ENVELOPE	MECH INF DIVISION	AIRMOBILE DIVISION
2 - 8.0 FT STICKS	248	183
2 - 8.5 FT STICKS	247	96
2 - 9.0 FT STICKS	249	98
3 - 8.0 FT STICKS	245	97
3 - 8.5 FT STICKS	244	92
3 - 9.0 FT STICKS	245	92

[a] BASED ON A MAXIMUM ALLOWABLE CABIN LOAD OF 400,000 LB AND ASSUMING A CONSTANT FLOOR AREA OF 5 480 SQ FT

TABLE 16
PERCENTAGE OF DIVISION EQUIPMENT THAT CAN BE ACCOMMODATED SIDE-BY-SIDE

DIVISION TYPE	WIDTH OF STICK 8.0 FT	WIDTH OF STICK 8.5 FT	PERCENTAGE INCREASE
AIRBORNE	94.5	96.7	2.3
AIRMOBILE	89.6	92.6	3.3
INFANTRY	82.6	93.2	12.8
MECHANIZED	67.0	85.2	27.2
ARMORED	66.3	83.4	25.8
1990 MECHANIZED	52.5	67.8	29.1
		AVERAGE	16.8

with the 108-in dimension. An 8.5-ft stick-width requires that two of the pallets (possibly only one, depending on the clearance requirement) be loaded with the 88-in dimension transverse.

Based on the preceding discussion, the only motivation for selecting a 9.0-ft stick width is compatibility with the 463L system. In anticipation of the eventual demise of the 463L in favor of containers, we believe the 9.0-ft stick-width can be eliminated from further consideration. Thus, the 8.5-ft width appears preferable to the 8.0 ft width from a military viewpoint because of its somewhat superior flexibility in vehicle loading.

Alternative Design Options

The most desirable stick width for commercial purposes should be based on container width. Today's sea/land and air/surface intermodal containers are 8 ft wide with heights varying between 8 and 10 ft, as noted earlier. In the future, however, shippers may push to increase the standard container width to 8.5-ft.

Thus, the commercially desirable stick width depends on the eventual evolution of the intermodal container system.

Assessment of Design-Option Substitution

The baseline aircraft provides an 8.5-ft cargo stick width. Allowing for clearances, the resulting floor width is 328 inches from one fixed side constraint to the other. Table 17 displays the possible combinations of ULDs that can be loaded three-abreast with this width. The floor of the baseline aircraft (e.g., powered-drive units, restraints, rollers, etc.) has been designed so that all combinations shown can be accommodated by simple adjustments of the locking/restraint mechanisms located in the two aisles. Note also that the curvature of the fuselage readily permits an elevated walkway to be located outside the outboard sticks in the fuselage cheek.

In terms of commonality, the 8.5-ft stick width would appear to be the best choice if the evolution of an 8.5-ft-wide container is assumed. However, if

TABLE 17
POSSIBLE COMBINATIONS OF THREE-ABREAST UNIT LOAD DEVICES
IN THE BASELINE AIRCRAFT BASED ON AN 8.5 FT STICK WIDTH

LOAD TYPE	OUTBOARD STICK (IN)	AISLE CLEARANCE (IN)	CENTER STICK (IN)	AISLE CLEARANCE (IN)	OUTBOARD STICK (IN)	TOTAL WIDTH (IN)
463L	88	22	108	22	88	328
8 FT WIDE	96	20	96	20	96	328
8.5 FT WIDE	102	11	102	11	102	328
MIXED	96	17	102	17	96	328
MIXED	102	14	96	14	102	328
MIXED	96	14 [a]	108	14	96	328
MIXED	102	8 [b]	108	8	102	328

[a] Military aisle width requirement is presently 14 inches. This combination of 8 ft wide containers in the outboard sticks and a 463L pallet in the center stick thus sized the total floor width inasmuch as both types of ULDs are expected to coexist in military inventories for the foreseeable future.

[b] Minimum clearance requirement for laterally adjustable locking mechanism.

container widths are assumed to remain at 8 ft, then the 8.0 ft stick width would be the commercial choice and would have only a minor impact of military effectiveness.

Note that the preceding situation presents an analytical dilemma. That is, if one assumes that 8.5 ft wide containers come into widespread use, then the 8.5 ft stick width is required to provide the desired capability—providing lower DOCs as well. Without this assumption, a stick width of 8.5 ft might be substantially inferior to 8.0 ft. Simply stated, the width of the cargo stick should be compatible with whatever commercial container eventually evolves.

CARGO COMPARTMENT LENGTH

The length of the cargo compartment can be based on either of two criteria:

- Based on military-unit loadability
- Based on commercial containerized payload density

Military-unit loadability implies basing the length of the cargo compartment, given that the maximum payload and fleet size are fixed, on minimizing the product of system life-cycle cost and the number of aircraft loads required to deploy a specified mix of US Army equipment.

The discussion that follows assumes that the number of sticks in the cargo compartment and the width of each stick is specified, as discussed in Section III and the preceding subsection, respectively.

Militarily Desirable Design Option

The obvious military preference is to base fuselage length on combat-unit loadability. Conceptually, such an analysis is straightforward once the mix of Army equipment to be moved is specified along with the level of unit integrity to be maintained. For example, Figure 17 depicts the loading characteristics of three-stick cargo compartments with lengths of 203 ft and 162 ft for both mechanized and airmobile divisions. By generating comparable information for each unit type of interest and at several specific lengths,

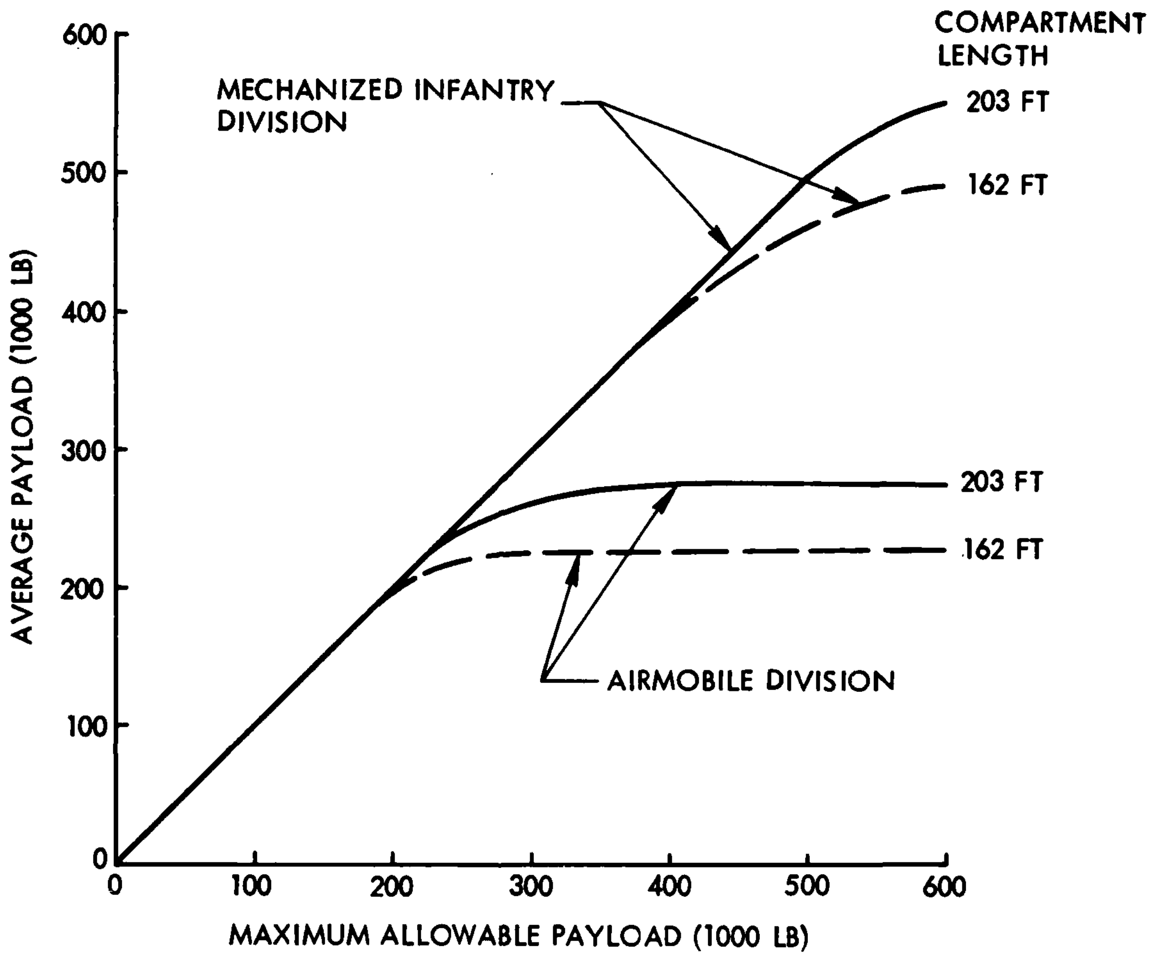

Figure 17. Loading Characteristics for a Three-Stick Aircraft Configuration

the length that minimizes system life-cycle cost multiplied by the number of aircraft loads required to move the specified mix of units can be readily determined. Figure 17 demonstrates that the resulting length is likely to be quite sensitive to the mix of lightweight versus heavyweight unit types.

The strategy outlined above works toward the military objective of providing the most cost-effective airlift force.

Alternative Design Option

The equally obvious alternative is to base the cargo compartment length on the average payload density anticipated during commercial use. Unfortunately, suggested values of air cargo densities for operations in the 1990s range between 7 and 12 lb/ft^3 or even higher. A further complication is that container cross-sections could vary from the 8 ft by 8 ft in use today up to 8.5 ft (or even 9 ft) wide by 10 ft high.

Rather than select a specific average payload density and container type, we have assumed an average gross weight of 15,000 lb per 20 ft long container. (Such containers have a maximum gross weight of 25,000 lb). The resulting net densities for a variety of container cross-sections are presented in Table 18. Observe that the densities vary from about 8 to 11 lb/ft^3, thus capturing the range of greatest interest.

Assessment of Design-Option Substitution

The baseline aircraft is sized to accommodate 33 containers with a 15,000 lb average gross weight. The 203-ft cargo compartment accepts 30 of these 20-ft containers, allowing for adequate fore/aft clearance. Two containers can be positioned on the first segment of the forward ramp and one on the aft ramp.

The principal difficulty in determining the length using the militarily-desirable design option is specifying the most appropriate mix of Army vehicles and resupply cargo (pallets and/or containers). First, the vehicle types within each unit are continually changing as modernization proceeds. Predicting the likely composition of combat units for the mid-1990s is,

TABLE 18
AVERAGE COMMERCIAL PAYLOAD DENSITIES FOR 20-FOOT CONTAINER LENGTHS

CONTAINER SIZE (WxHxL, FT)	TARE WEIGHT (LB)	USABLE VOLUME (FT^3)	NET PAYLOAD DENSITY [a] (LB/FT)
8 x 8 x 20	2250	1150	11.1
8 x 8.5 x 20	2300	1225	10.4
8 x 9 x 20	2350	1300	9.7
8 x 9.5 x 20	2400	1375	9.2
8 x 10 x 20	2450	1450	8.7
8.5 x 10 x 20	2500	1525	8.2

[a] Based on 15,000 lb average container gross weight

therefore, not straightforward. The second difficulty is that the mix of unit types (i.e., light versus heavy units), as well as the amount of resupply required, is dependent both on the scenario of interest as well as future doctrine. Given these uncertainties, determining compartment length on the basis of military loadability seems inadvisable, at least in the absence of specific high-level guidance.

In any event, in terms of military/commercial commonality, basing the length on average commercial payload density may be more appropriate. Basing the length solely on the characteristics of a mechanized division would result in a somewhat shorter compartment than that of the baseline (223-ft equivalent length and 495,000-lb design payload) since a reduction in cargo compartment length should provide a reduction in system life-cycle cost that is greater on a percentage basis than the corresponding increase in the number of aircraft loads required. Conversely, the airmobile division would probably yield a longer compartment because of the loading characteristics demonstrated in Figure 17. Thus, the commercial technique may well provide an adequate compromise.

ASSESSMENT OF DESIGN-OPTION INTERACTION

Figure 18 summarizes the results of our qualitative assessment of the interactions among the cargo-compartment options. Aside from the already emphasized interdependency exhibited between the floor strength, sub-floor strength, vehicle tiedowns, and the container/pallet handling/restraint system features, remarkably little interaction is apparent among the other options.

Note that a stick-width of 9.0 ft (for compatibility with 463L system) coupled with using commercial containerized density as the basis of compartment length is shown as logically inconsistent. The reason, is that a 9.0 ft stick width is though to be of little or no commercial interest. Of course, the eventual evolution of 9.0 ft-wide containers could invalidate this judgment.

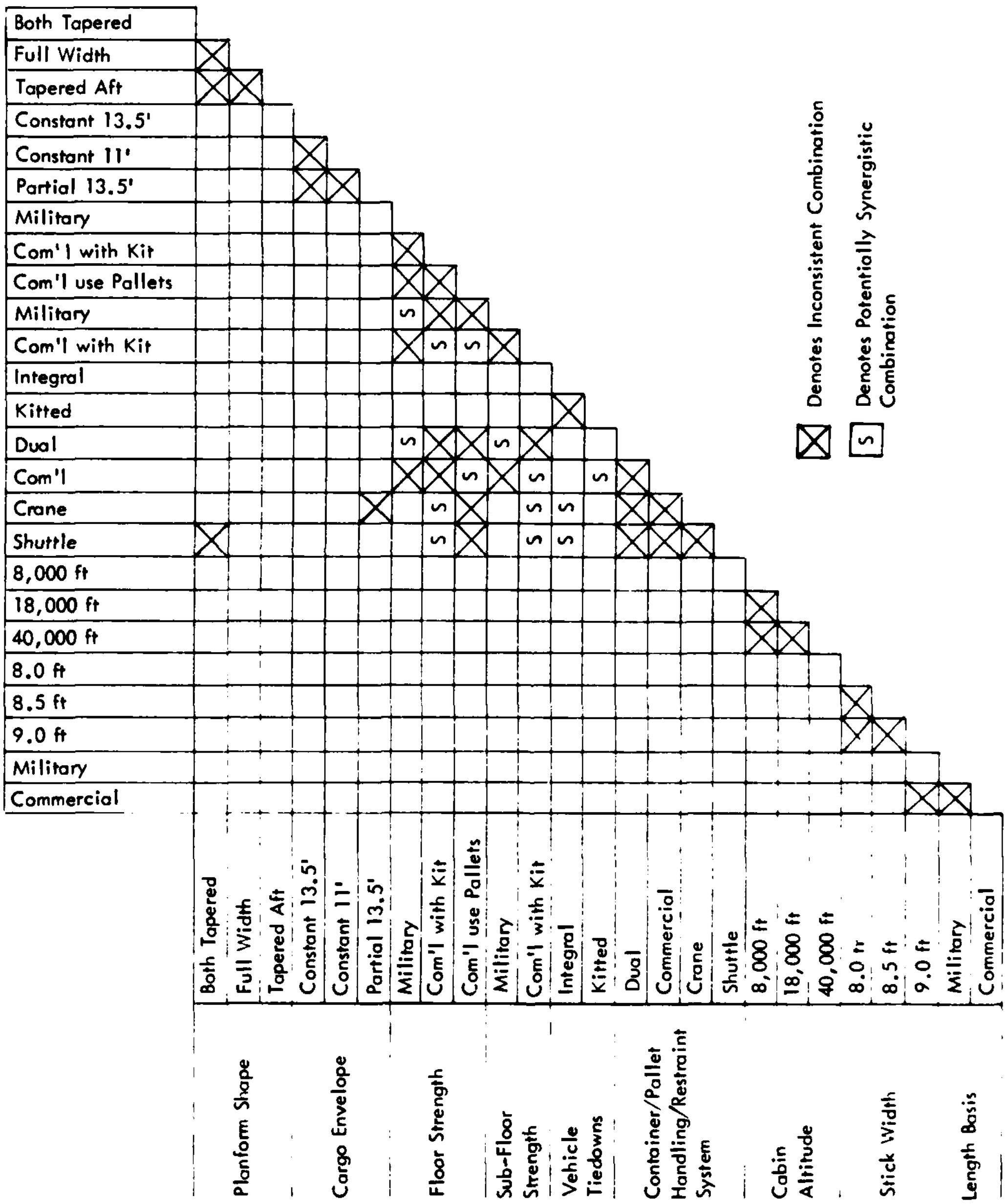

Figure 18. Assessment of Interactions Among Cargo Compartment Design Options

RECOMMENDED DISPOSITION OF CANDIDATE OPTIONS

We recommend retaining all of the options discussed in this section for further consideration with the following exceptions:

1. Delete the overhead crane cargo handling system option.

2. Delete the 40,000-ft cabin altitude as a pressurization option.

3. Base cargo compartment length solely on commercial containerized densities.

Furthermore, the four particularly interdependent features should be collapsed into a single feature with three design options.

Rationale

Cabin altitudes greater than 18,000 ft are though to be wholly incompatible with vehicular cargo. Since cruising at 18,000 ft entails significant performance penalties and precludes overflight of adverse weather, a zero pressure differential for the cargo compartment is probably impractical. Furthermore, most of the structural benefits attainable through reduced pressurization should be available with the 4.6-psi pressure differential that corresponds to an 18,000-ft cabin altitude at a 40,000-ft flight altitude. (Ref 12)

For the cargo compartment length basis, the absence of specific guidance regarding Army unit composition appears to result in the militarily-desirable option being inapplicable for present purposes. However, this feature can be conveniently pursued at a later stage of system definition if necessary.

The four interdependent features have been collapsed into a single feature termed Cargo Accommodation Provisions. The consolidation is based on the observation that only a few (relatively) combinations of these options are consistent whereas certain others appear to be synergistic, as shown in Figure 18. The specifics of the resulting three options are presented below.

- o Dual-Purpose System

  - Integral hard floor (military)
  - Integral military-capable sub-floor
  - Kitted tiedown rings
  - Flip-flop rollers, stowable and adjustable lateral restraint rails/locks, stowable and adjustable fore/aft locks, and stowable powered-drive units

- o Commercial System
  - Commercial floor with vehicles requiring slave pallets
  - Commecial sub-floor with beef-up kit
  - Kitted tiedown rings (in conjunction with pallets if required)
  - Fixed rollers, laterally adjustable restraint rails/locks, stowable and adjustable fore/aft locks, and fixed powered-drive units

- o Shuttle-Loader System
  - Commercial Floor with hard-floor kit (or slave pallets with corner fittings)
  - Commercial sub-floor with beef-up kit
  - Kitted tiedown rings
  - Externally-powered shuttle loader with corner-lock restraints

Recall that the third option requires a full-width opening.

Relative Potential

The design features and associated options that have survived this initial qualitative assessment are summarized below:

- o Planform Shape
  - Tapered forward and aft
  - Full width forward and aft
  - Full width forward and tapered aft

- o Cargo Envelope (maximum height)
  - Constant 13.5 ft
  - Constant 11.0 ft
  - 13.5 ft forward of wing, 11.0 ft aft

- o Cargo Accommodation Provisions
  - Dual-purpose system
  - Commercial system
  - Shuttle-loader system

- o Pressurization (cabin altitude at 40,000 ft flight altitude)
  - 8000 ft
  - 18,000 ft

- o Cargo-Stick Width
  - 8.0 ft
  - 8.5 ft

Table 19 present our qualitative assessment of the relative potential of these design features.

Observe that only the planform shape feature displays any significant potential for providing a net benefit in terms of military system cost, effectiveness, and flexibility. However, all of the features except cargo-stick width appear to possess options that might enhance the prospects for military/commercial commonality.

TABLE 19
SUBJECTIVE ASSESSMENT RELATIVE TO BASELINE AIRCRAFT
OF CARGO COMPARTMENT DESIGN FEATURES

-3	-2	-1	0	1	2	3
Much Poorer			Neutral			Much Better

	Planform Shape	Cargo Envelope	Cargo Accommodations	Pressurization	Cargo Stick Width
Military Considerations					
Life-Cycle Cost	-1	2	-1	2	1
Mission Effectiveness	2	0	0	-1	-1
Mission Flexibility	1	-2	-1	-1	-1
Subtotals	2	0	-2	0	-1
Commercial Considerations					
Direct Operating Cost	-1	2	1	3	1
Indirect Operating Cost	1	0	1	-1	0
Market Expansion Potential	1	0	1	-1	-1
Subtotals	1	2	3	1	0
Grand Totals	3	2	1	1	-1

VII. INFLIGHT REFUELING FUNCTIONAL GROUPING

Two design features pertaining to inflight refueling (IFR) are of interest.

- o Inflight refueling technique
- o Tanker kit provisions

The first refers to the method used to refuel the aircraft inflight, and the second concerns the possibility of using the ACMA as a tanker.

INFLIGHT REFUELING TECHNIQUE

Two options are available for providing the ACMA with an inflight refueling capability:

- o Receptacle kit
- o Probe kit

The first requires the tanker to be equipped with a refueling boom, and the second assumes the use of a refueling drogue.

Militarily Desirable Design Option

USAF bomber and transport-category, turbine-powered aircraft have usually employed the IFR receptacle option in conjunction with a flying-boom on the tanker. The receptacle is likely to be the preferable choice for the ACMA also, primarily because greater fuel transfer rates are possible with this option, thus minimizing the total time that the aircraft must remain coupled.

The primary function of an IFR capability is to extend the range of the receiver aircraft. In the case of the baseline with its 4000 nm range, missions in excess of 6500 nm with the design payload could be flown by employing inflight refueling. Alternatively, radius missions of 3500 nm or more with the design payload are possible. Were versions of the ACMA to evolve for other military missions that require extended station keeping, IFR would provide for increased maximum endurance as a secondary function.

Inflight refueling, therefore, furthers the military objective of providing a world-wide deployment capability at the least cost. That is, rather than design the aircraft for extreme range with the resulting penalty of unusable capability on shorter-range missions, the more cost-effective approach is to provide the extreme range capability by employing IFR. The latter approach is also much more flexible in terms of adapting to changes in the geopolitical environment with regards to basing and/or overflight rights. (How these assertions can be verified is discussed at the end of this section.)

Alternative Design Options

The desirable commercial option is not to include any IFR provisions since no commercial applications exist for this feature.

The other technique for providing inflight refueling is to equip the receiver aircraft with a probe. Such a probe could be mounted on either the forward fuselage or on an outboard wing section. Both the receptacle and the probe schemes are readily adaptable to the kit concept for commercial aircraft.

Assessment of Design-Option Substitution

The baseline aircraft incorporates an IFR receptacle. Commercial versions of the aircraft are convertible to the military configuration by use of a receptacle kit.

In choosing between the receptacle kit and probe kit options, the primary factor appears to be the greater transfer rate capability of the receptacle system. Both systems are likely to result in comparable scar weight on commercial versions. Kit installation time is also comparable with perhaps a slight edge for the probe system.

Not including any IFR provisions would, in our view, be exceedingly detrimental to military effectiveness. Without inflight refueling, extreme range missions could only be performed, if at all, with reduced payloads. Since the scar weight is small, the receptacle-kit option appears to be the most reasonable compromise from the viewpoint of military/commercial commonality.

TANKER KIT PROVISIONS

The following tanker capabilities could be provided in the ACMA:

- Boom only
- Drogue only
- Boom and Drogues
- None

Again because of commercial disinterest in this feature, only design concepts capable of being kitted will be considered.

Militarily Desirable Design Option

The option yielding the greatest military flexibility is a kit that provides both a refueling boom and a refueling drogue. The primary function of a tanker-capable ACMA is to enable it to serve in a tanker/cargo role. As such, tanker-capable versions could provide the inflight refueling needs of other ACMA performing in the cargo role, as dictated by the mission situation. Furthermore, as a tanker/cargo aircraft, the ACMA would be capable of the simultaneous deployment of tactical-air squadrons and their associated unit equipment.

As a secondary function, tanker versions of the ACMA could support the myriad of other missions that rely on inflight refueling, were the military situation to so dictate.

Thus, providing the ACMA with a tanker capability using the kit concept facilitates the military objective of increasing system flexibility in regard to the airlift mission as well as a host of other missions.

Alternative Design Options

Commercial operators would prefer that no tanker kit option be incorporated in the basic aircraft design because of the relatively substantial scar weight associated with the kit provisions, particularly those involving the refueling boom technique. Interestingly, not allowing for the tanker kit installation in commercial versions of the aircraft is an apparently viable alternative since it is unlikely that all aircraft (both organic military and CRAF commercial) would ever be required to be simultaneously configured as tankers. Thus, the option of principal interest reduces to incorporating kit provisions in military versions of the aircraft only. The reasonableness of this approach ultimately depends on the relative numbers of military and commercial aircraft in service.

The remaining options are to provide either a boom-only or drogue-only capability. The drogue-only may be of particular interest if all commercial aircraft must be tanker-capable when functioning in a CRAF role.

Assessment of Design-Option Substitution

The military version of the baseline aircraft is assumed to incorporate provisions for a boom and drogue tanker kit. The concept selected for providing this capability is based on replacing the aircraft tailcone with an operator's station capsule. It is similar to that proposed for providing the C-5 with a tanker capability. (Ref 19) One of the notable aspects of this approach is that it does not in any way interfere with the operation of the aft aperture or affect the aircraft's rotation angle.

The weight penalties associated with this tanker kit are presented in Table 20. Note that the scar weight (i.e., the additional weight that must be included in the basic airframe to make it capable of accepting the kit) is in excess of 1400 lb. For this reason, we have assumed that commercial versions of the ACMA will not be capable of being converted to a tanker configuration. All organic military aircraft, however, are assumed to include the stated scar weight.

TABLE 20
TANKER KIT WEIGHT PENALTIES (REF 19)

ITEM	SCAR WT (LB)	KIT WT (LB)	TOTAL WT (LB)
BOOM OPERATOR STATION CAPSULE	-	1,880	1,880
BOOM OPERATOR STATION STRUCTURE	620	-	620
BOOM	-	2,120	2,120
BOOM SUPPORT	390	-	390
CONTROLS FOR OPERATOR STATION	-	380	380
HOSE/DROGUE, ETC.	-	520	520
HOSE/DROGUE STRUCTURE	200	-	200
LINE AND PUMP FOR OFF-LOADING	-	200	200
AVIONICS AND LIGHTING	260	260	520
TOTALS	1,470	5,360	6,830

The boom-only and drogue-only options represent inherently less flexible choices. Clearly, the tanker-aircraft kit should be compatible with the IFR receiver option discussed earlier. As shown in Table 20, also including provisions for the drogue system causes only a fractional increase in cost.

Providing a drogue-only system could reduce the weight penalty substantially. However, as noted earlier, most USAF aircraft are equipped with a receptacle and, therefore, the drogue-only option would represent a considerable loss of flexibility.

The baseline aircraft configuration, which assumes that commercial version of the aircraft will not be capable of accepting the tanker kit, appears to be the most acceptable compromise in terms of military/commercial commonality.

ASSESSMENT OF DESIGN-OPTION INTERACTIONS

The only interaction among the options discussed in this section is that coupling a receptacle for the IFR provisions feature with a boom only for the tanker-kit feature, or vice-versa, is logically inconsistent.

RECOMMENDED DISPOSITION OF CANDIDATE OPTIONS

None of the alternative options discussed above are recommended for further analysis. That is, the option incorporated in the baseline should be retained for both features, but for different reasons.

In the case of the refueling receptacle, not including an IFR provision would result in an unacceptable degradation in military mission effectiveness as well as flexibility. Furthermore, abandoning the receptacle in favor of the probe and drogue system appears to offer little.

The tanker-kit feature is more troublesome. Clearly, if sufficient tanker capacity were available, providing a tanker kit for organic military airlifters would be less attractive. In other words, employing some fraction of the organic ACMA force in a tanker role only makes sense if no other tanker assets are available for supporting ACMAs performing as airlifters or if additional tanker capacity is desired for other reasons. Given this situation, retention of the tanker-kit option is essentially arbitrary inasmuch as the decision hinges on force-sizing questions well beyond the scope of the present analysis.

Incorporating a tanker-kit provision in the military versions of the ACMA does, however, have a notable benefit in terms of the usefulness of the subsequent analysis. In those situations requiring tanker support, diverting a part of the organic ACMA force to serve as tankers explicitly recognizes the cost of the tanker resource. Including the cost of tankers, if for example KC-135As were assumed available, would be exceedingly complicated if not impossible. Since in practice more cost-effective tankers could probably be found than an ACMA equipped with a kit, an analysis that presumes the use of the latter represents an upper-bound in terms of system cost for a given level of deployment capability when employing inflight refueling.

The principal basis of the preceding assertion is that outsize capability penalizes the aircraft when functioning as a tanker since the substantial cargo volume available (which has been achieved at considerable cost) goes largely unused. Thus, any smaller aircraft, incuding derivatives of passenger aircraft, would make a better pure tanker than an outsize-capable ACMA equipped with a kit. Note, however, that the above logic does not apply in the case of tanker/cargo missions (e.g., fighter squadron deployment) or if pure tankers are not needed for other purposes in those situations in which the ACMA fleet does not require tanker support (e.g., during shorter-range deployments).

To summarize, a decision regarding the advisability of incorporating a tanker-kit provision in the ACMA is strongly dependent on future force structure. Consideration of this feature can be appropriately deferred to a later stage of system definition. In any event, converting some fraction of ACMAs to tanker/cargo aircraft would be relatively straightforward after they entered the organic force, even if such was not intended at the outset of the program.

VIII. PERSONNEL ACCOMMODATIONS FUNCTIONAL GROUPING

Two functional design features relating to transport of personnel are of interest:

- o Relief-crew provisions
- o Passenger provisions

The latter feature should provide accommodations for vehicle drivers in the aircraft's military configuration, at a minimum.

RELIEF-CREW PROVISIONS

As noted in Section III, the design range of the baseline aircraft is 4000 nm. Thus, with inflight refueling, flight legs of 6000 nm or more are possible. The corresponding 14-hour flight time suggests that facilities for crew rest and/or a relief crew be considered. Design options that provide these accommodations are:

- o Integral relief-crew compartment
- o Containerized relief-crew compartment

For the second option, no specific provisions for a relief crew or crew rest are incorporated in the basic aircraft design. Rather, relief crew accommodations are provided, when required, by loading an appropriately appointed container as part of the cargo load.

Militarily Desirable Design Option

An integral relief crew compartment is more desirable from a military viewpoint. Its primary function would be to assure the availability of crew-rest and relief-crew facilities during long-duration mission.

Furthermore, during contingency operations, crew rest facilities and relief crew quarters may be unavailable or at a premium at the APOD. An integral relief-crew compartment, therefore, alleviates crew-related turnaround problems as a secondary function.

An integral relief-crew compartment is compatible with the military objectives of providing a world-wide deployment capability and of minimizing required ground-facilities at the APOD, which in turn, reduces the potential vulnerability of the airlift system.

Alternative Design Options

As discussed in Section III, few commercial operations with flight legs greater than 5000 nm are anticipated. At a cruising speed of 450 knots, the 12-hour limit on flight crew on-duty time specified by FAR Part 121.483 permits flight distances greater than 5000 nm. Therefore, no apparent commercial requirement exists for a relief crew compartment, and the desirable option would be to provide the military capability with the aforementioned containers.

Note, however, that if an integral relief-crew compartment were provided to satisfy military needs, much of the associated penalties could be eliminated by removing most of the compartment furnishings in commercial versions of the aircraft. For CRAF operations, these items could be installed as a kit. This concept permits, on a customer-specified basis, those features such as crew-rest facilities that might be viewed as desirable by some commercial operators.

Assessment of Design-Option Substitution

The baseline aircraft incorporates an integral relief-crew compartment located aft of the flight station. Provisions include six bunks, eight reclining seats, two tables, galley, lavatory, and a baggage-storage area. Bunks, seats, and tables are easily removable from commercial versions of the aircraft if the operator so desires.

For the non-integral relief-crew compartment option, the galley and lavatory would be relocated in the area occupied by the bunks in the baseline aircraft. All other relief-crew accommodations plus an additional lavatory and galley would be incorporated in containers that would be loaded when mission requirements so dictate.

The major impact of the containerized-compartment concept on mission effectiveness would be the loss of floor area that could otherwise be used for cargo and the increased complexity of the loading process. To assure that it does not interfere with the drive-off capability, the logical location for the container is as far aft as possible. If a rear aperture is incoporated in the design, the container must be positioned in an outboard stick to avoid interfering with vehicles driving on. In either event, the aft location of the relief-crew compartment is inconvenient relative to the flight station. The total weight penalty associated with the containerized concept is expected to be greater than that of an integral compartment, thus resulting in greater system cost. These costs can be reduced, however, by installing the compartment containers only when necessary.

In terms of commonality, the non-integral option might at first appear to be preferable. However, the integral relief crew compartment could be used by the commercials for crew-rest and transport of dead-heading crews or VIPs. Thus, retention of the integral relief-crew compartment is likely to depend on costs, which can be determined only by more detailed analysis.

PASSENGER PROVISIONS

During contingency operations, the capability to transport troops, particularly vehicle drivers, is generally regarded as a necessity. Four options are available for providing these accommodations:

- Integral troop compartment
- Containerized troop compartment
- Integral passenger/troop compartment
- None (except cargo-compartment bench seats for vehicle drivers).

The first two options presume such accommodations will only be required by the military for troop transport. The third envisions their use by commercial operators providing some type of passenger service—the first mention of the ACMA as a potential "combi" aircraft in this volume.

Militarily Desirable Design Option

The majority of loads during a combat unit deployment is made up of vehicles, which in turn, require drivers. Thus, the desirable option from a military viewpoint is an integral troop compartment, although any of the options may be acceptable. Note, however, that carriage of other vehicle crew members or troops is desirable since it results in increased combat readiness at the off-load point.

The primary function of an integral troop compartment is to provide accommodations for vehicle drivers that do not interfere with aircraft loadability. As a secondary function, an integral troop compartment is likely to be utilized in peacetime for routine passenger transport on a military space-available basis.

Carriage of drivers along with their vehicles will tend to minimize offloading time since clearing vehicles from the aircraft will be independent of ground support. Such capability is commensurate with the military objectives of maximizing productivity while minimizing potential vulnerability at the APOD. Furthermore, the objective of deploying equipment as combat-ready as possible is also achieved, particularly if other crew members (besides drivers) are transported.

Alternative Design Options

From a commercial viewpoint, no permanent provisions for passengers are necessary as long as the ACMA is though of as a pure freighter. However, we believe that consideration should be given to commercial operation of the ACMA as a combination passenger/freighter aircraft.

The combi concept would appear to have merit for several reasons--all of which ultimately relate to profitability and hence an increase in the commercial attractiveness of the aircraft. Consider the following hypothetical situation. Suppose, as a pure freighter, an aircraft with a 200-ton maximum payload had a DOC of $0.06 per available ton-nm on a 3500 nm flight (e.g., New York-to-Frankfort) with a resulting direct trip cost of $42,000.

If this aircraft carried 150 passengers at $100 per head, $15,000 of the trip cost would be covered. Allowing 300 lb per passenger, the DOC for cargo could then be thought of as equivalent to about $0.044 per available ton-nm, a reduction of more than 25 percent.

The basic tourist fare from New York-to-Frankfurt in July 1978 was $439 oneway and $878 round trip, with round-trip excursion fares (with restrictions on length-of-stay and so on) that varied from $358 to $725. Even if the $100 assumed in the preceding example were increased to $150 to cover the indirect costs of providing passenger service, it would represent only a fraction of the present fare structure. As an additional point of reference, Laker Airways charges $138 one-way for their first-come, first-served New York-to-London service. Given the success of discount and standby fares in the summer of 1978, as illustrated in Figure 19, the assumption that passengers will accept considerable inconvenience in return for substantially reduced fares appears wholly justifiable. In the case of the ACMA, such inconveniences are likely to include the relatively unattractive departure times associated with cargo shipments.

In terms of aircraft design, passenger accommodations can result in the utilization of otherwise useless fuselage volume, particularly for high-wing configurations. Thus, the associated penalties are likely to be quite small.

If the possibility of a combi ACMA is discounted, then commercial operators will undoubtedly prefer that the military provide troop accommodations by loading special passenger-carrying containers similar to that described for relief-crew facilities. If use of such a container is rejected, vehicle drivers would have to be accommodated on bench-seats located in the fuselage cheek.

Assessment of Design-Option Substitution

The baseline aircraft does not include any specific integral provisions for accommodating troops or passengers. Vehicle drivers and troops are assumed to use containerized troop compartments if troop-transport is desired. If only vehicle drivers are carried, they are assumed to use cargo-compartment bench seats.

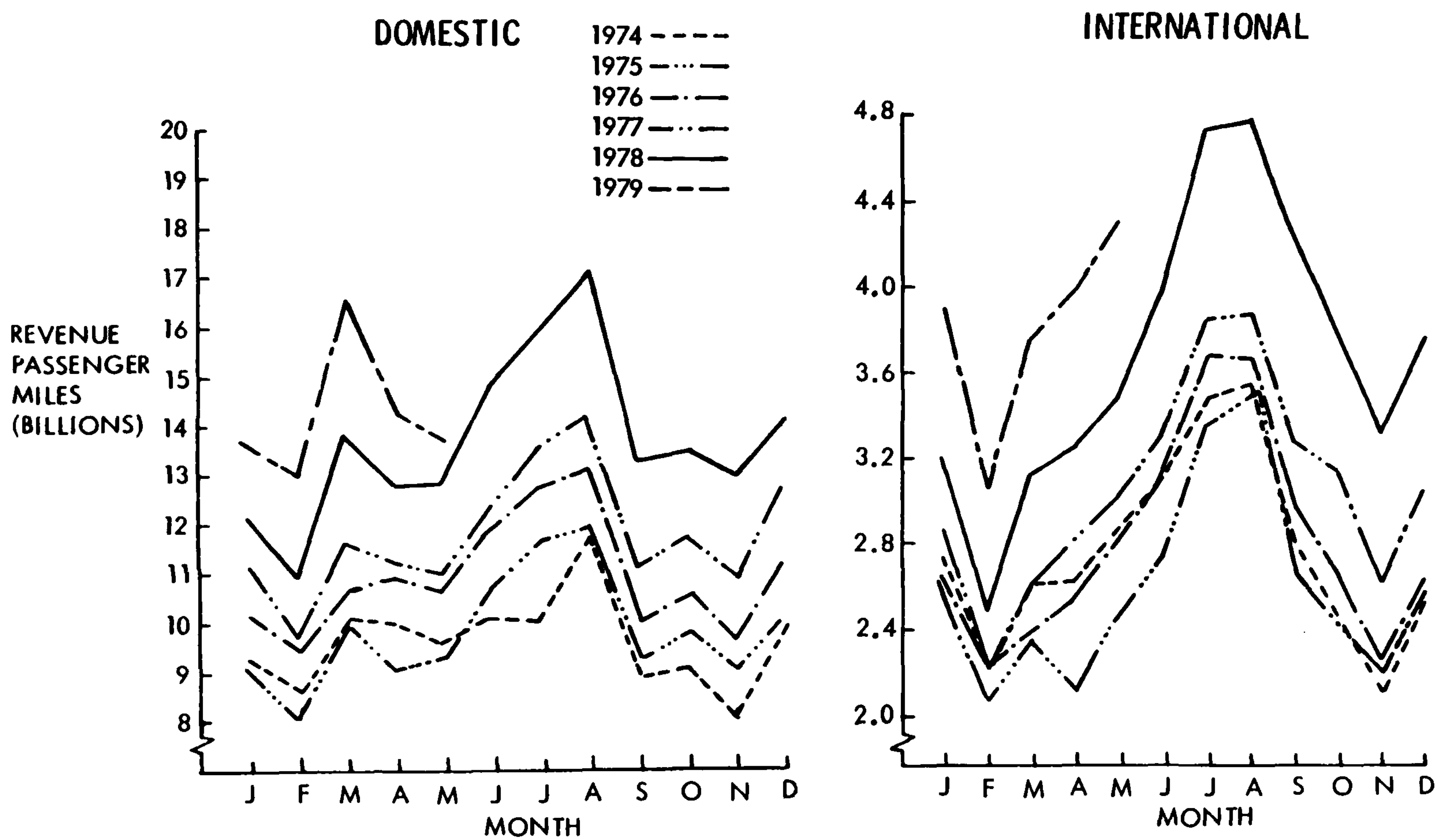

Figure 19. Passenger Traffic Trends of U.S. Domestic Trunk Airlines

An integral troop compartment aft of the wing and above the cargo compartment would require increasing the radius of the fuselage by about 4 in. The overall height of the fuselage would increase correspondingly by about 13 in., thus poviding sufficient clearance for six-abreast seating in the troop compartment while maintaining a 13.5 ft clearance in the cargo compartment. Since the baseline aircraft could accept about 30 rows of seats with a 34-in. pitch, a maximum of 180 troop seats could be provided.

Mission effectiveness would be enhanced with the integral troop compartment since available cargo floor area would be increased by eliminating the need for special containers. Such an arrangement may be undesirable from the viewpoint of commonality, however, since the troop compartment as configured above may be unacceptable for civilian passenger service. For example, the maximum ceiling height in the troop compartment is only 6.5 ft. Thus, the increased cargo compartment height might simply result in further useless volume for commercial purposes.

Interestingly, if drivers are carried in the cargo compartment using bench seats, then a 9.0g restraint is required on all cargo. If all personnel are accommodated above or behind the cargo, the restraint criterion is only 1.5g. Although the 9.0g restraint can easily be achieved with the tiedown pattern incorporated in the baseline aircraft, doing so increases the weight of the tiedown equipment required and the complexity of the loading process.

Acceptable passenger accommodations can be made available without a further increase in fuselage radius by lowering the ceiling height of the main cargo compartment from 13.5 ft to about 11 ft. The resulting passenger compartment could be configured with two aisles and seating of eight or nine abreast with clearances comparable with those of a wide-body passenger aircraft. The resulting maximum capacity would be 240 to 270 passengers. Since the maximum cargo compartment height has been reduced only aft of the wing carry-through structure, the partial 11-ft ceiling height would have only a minor impact on mission effectiveness, as discussed in Section VI. Note also that the size of the passenger compartment is such that it could be utilized for carriage of LD class containers in lieu of passengers, hence further increasing commercial flexibility.

Given these observations, an integral passenger/troop compartment as described above may represent the ideal commonality compromise.

ASSESSMENT OF DESIGN-OPTION INTERACTION

None of the options associated with the design features discussed in this section exhibit any significant degree of interdependency. One exception is the possibility of configuring the relief crew compartment as a first-class section in the combi version of the aircraft. For the current baseline configuration, 16 first-class seats could easily be provided.

RECOMMENDED DISPOSITION OF CANDIDATE OPTIONS

We recommended that both design features discussed in this section be considered for more detailed analysis.

Table 21 presents the results of our qualitative assessment of the potential of the available options. Note that the inclusion of passenger accommodations in commercial versions of the aircraft is shown to be a most promising option in terms of commercial potential.

TABLE 21

SUBJECTIVE ASSESSMENT OF PERSONNEL ACCOMMODATIONS DESIGN FEATURES

-3	-2	-1	0	1	2	3
Much Poorer			Neutral			Much Better

Military Considerations	Relief-Crew Provisions	Passenger Provisions
Life-Cycle Cost	1	-1
Mission Effectiveness	-1	1
Mission Flexibility	-1	1
Subtotals	-1	1
Commercial Considerations		
Direct Operating Cost	1	3
Indirect Operating Cost	0	-1
Market Expansion Potential	0	3
Subtotals	1	5
Grand Totals	0	6

IX. MISCELLANEOUS DESIGN FEATURES

This section discusses several design features that cannot be readily classified in specific functional groupings. These features are:

- o Maintenance/support concept
- o Avionics
- o Subsystem motive power

These items are expected to have less influence on the eventual configuration of the ACMA than most previously discussed design features, although the first will certainly impact overall system design in a major way. Consequently, the following discussion is somewhat abbreviated.

MAINTENANCE/SUPPORT CONCEPT

This item refers to how maintenance and support services are provided for organic Air Force aircraft. The available options are:

- o All organic
- o All contractor
- o Hybrid organic/contractor

The third option recognizes the possibility of having contractors provide only depot-level, depot- and intermediate-level, etc., maintenance with organic personnel performing the remainder of the support functions.

Militarily Desirable Design Option

The primary military function of any maintenance/support system is to assure the highest possible operational readiness rate and the shortest possible cycle time in contingency situations. Military airlift forces present a particular difficulty in this regard because of the great disparity between peacetime and wartime utilization rates. The traditional approach has been to provide an organic maintenance/support organization that is capable of sustaining a surge utilization of 10 to 12 flying hours per day or greater.

Peacetime flying rates of two to four hours per day obviously represent a substantial under-utilization of the system.

The desirable option for military purposes is the one that satisfies the objective of providing the necessary wartime capability for the least cost in peacetime. Without doubt, some contractor maintenance is desirable since, at the very least, the concept eliminates some training costs associated with the normal functioning of the enlistment system. Because of the peacetime/wartime disparity in utilization rates, however, an all-contractor maintenance/support system may be more costly than a hybrid system. The most desirable level of contractor maintenance and support can be determined only by detailed analysis of a firm aircraft configuration and operational concept.

Alternative Design Options

Commercial operators will, of course, perform their own maintenance during normal operations or have it performed under contract with other airlines operating the same equipment. When operating as part of CRAF, the same maintenance structure should probably be utilized.

Contractor maintenance of organic military aircraft would benefit the commercial operators, since common spares inventories and so on could be shared. Thus, from the viewpoint of commonality, contractor maintenance can be viewed as a definite plus.

Assessment of Design-Option Substitution

As noted earlier, the choice of the maintenance/support concept does not impact the aircraft design, at least at the conceptual design level. For preliminary life-cycle costing purposes, the maintenance and support of military airlifters is assumed to be performed solely by organic personnel.

The preceding discussion suggests that some type of hybrid maintenance/support concept can be defined that provides the same wartime capability at least cost than the all organic concept. Furthermore, the hybrid concept is also likely to reduce operating costs for commercial operations.

AVIONICS

Two options are available for the avionics suite of the ACMA:

- o Common military/commercial suite
- o Commercial suite with hard points and permanently installed wiring for military peculiar avionics.

Note that both options presume the extensive use of commecial avionics in military versions of the ACMA as discussed in detail in the following paragraphs.

Militarily Desirable Design Option

Prior to the 1970s, very little commonality existed between military and commercial avionics. As the percent of avionics cost as a function of aircraft cost has increased, and as the avionics maintenance cost have escalated with each year, interest in striving for some level of system commonality has increased.

For many years, military requirements dominated all aspects of avionics, from development to production. As a result, commercial systems were lower-cost adaptations of the military systems. Two requirements generally imposed on military equipment frequently precluded adaptation to commercial applications. These were special military mission performance features, and the very stringent MIL SPEC design, fabrication, and qualification test requirements.

During the late 1950s and 1960s, the divergence between military and commercial avionics increased to a level where there was very little commonality. Wherein the military enlarged on the MIL SPEC requirement on every element of the system from materials, piece parts, and test requirements up to an all encompassing LRU (line replaceable unit) specification, the diverse commercial operators took a different approach.

In general, the commercial approach was simply to require the equipment to work in the specific airborne application. An organization was established under ARINC (Aeronautical Radio Inc.) which became known as the AEEC (Airline Electronic Engineering Committee). Other than cost and reliability, interchangeability is of paramount importance to commercial users. Over the years the AEEC has issued a number of rather loose standards that outline general system requirements but specify very precise constraints on envelope size, connector type, and pin assignments to insure interchangeability of various avionic systems regardless of the manufacturer. The requirements for environmental testing are generally much less stringent than the military as are the requirements defined by various SAE (Society of Automotive Engineers) advisories and RTCA (Radio Technical Commission) directives. Over the past 20 years approximately 100 of those AEEC standards have been released on topics from installation guidelines to area navigation systems and VHF communications to various air data systems. The results of these activities have been a high degree of standardization by the commercial users, rapid adaptation of substantially higher reliability than that being achieved by similar military equipment with, in many cases, a lower initial cost than the military equipment.

For many years, there was little utilization of commercial equipment and standards by the military. However, in the 1960s the relative success of commercial users with electronic system cost and reliability resulted in increasing attention by the military on commercial systems. It was also noted that on a worldwide basis the environments experienced by commercial equipment are generally no different than for military equipment.

One of the first major applications of commercial equipment to military aircraft was the FD-109 flight director and associated equipment which was retrofitted on the KC-135 aircraft in the late 1960s. Since then, there have been ever increasing attempts to enlarge the commonality of commercial and military avionics systems. For example, a major step in military utilization of commercial equipment is the program to install dual Carousel IV inertial systems in the C-141 and triple systems in the C-5. The Carousel IV has been in commercial service for over 10 years and complies with ARINC standards.

Finally, recent studies and assessments have indicated that life-cycle cost savings in the $100 million range can be realized by making more extensive use of commercial avionics in military aircraft. Specific comparative analysis studies on selected equipment and aircraft need to be conducted. But independent of such studies, cursory examination of the overall problem provides strong indication that major cost advantages can be realized by making maximum utilization of commercial avionics wherever possible in military application. Although there are a number of driving factors in support of this usage, the large commercial production quantities, compared with most recent military procurements, provide in themselves a significant cost advantage.

To summarize, the following advantages of maximizing military use of commercial avionics can be enumerated:

- Large production runs of commercial equipment result in reduced unit acquisition cost.
- Adherence to system interchangeability.
- Use of commercial supplies in event of national emergency.
- Ready availability of piece parts used in repair.
- Multiple sources of equipment repair when required.
- Higher realized reliability.
- Advantage of commercial-user pressure to correct system problems and deficiencies.

However, military requirements are unique for several systems, and thus no commercial counterpart exists. Examples are SKE (station-keeping equipment), Military IFF/SIF, TACAN, and various special-purpose radars such as that used for terrain-following.

Given the situation described above, the militarily desirable option is a common military/commercial avionics suite. That is, commercial components would be used wherever possible, but all military-required items would also be installed on the aircraft. This approach should satisfy the objective of providing the required capabilities in the organic fleet at minimum cost.

Alternative Design Options

From a commercial viewpoint, the preferable option is a commercial avionics suite. Military requirements would be met by providing hardpoints, necessary wiring, etc. so that the military-peculiar items can be installed when the aircraft is activated in a CRAF role.

Assessment of Design Option Substitution

The baseline aircraft incorporates the second design option described above. This approach appears wholly compatible with the goal of commonality while not adversely affecting military system effectiveness. Furthermore, such an approach could provide additional advantages, since the military-peculiar items may benefit from adopting some of the packaging and standardization techniques perfected by the manufacturers and implemented in ARINC standards.

A common military/commercial suite would almost certainly be unacceptable to civil users, since it entails at least some cost penalties but yields no corresponding advantages in a commercial environment.

SUBSYSTEM MOTIVE POWER

Modern transport-category aircraft use both hydraulic and electrical power to drive subsystems. The possibility exists of replacing all hydraulic subsystems with electrical counterparts, thus resulting in an "all-electrical" aircraft. The latter concept has potential for reducing both acquisition and operating costs.

In most respects, the subsystem motive power choice can be regarded as an element of the aircraft general arrangement, and can be considered an outcome of the system synthesis and optimization as discussed in Section II. However, the choice of motive power may have at least one important functional effective on certain design features--their rate of operation. That is, the time required to kneel the aircraft may be different if electrical rather than hydraulic power were used.

In terms of commonality, a change in the rate of subsystem operation is likely to be of far greater importance to the military, particularly if ground time at the offload point is significantly impacted as discussed in previous sections. The relative magnitude of these possible differences in ground times and potential cost savings can be determined only by more detailed analysis. The baseline aircraft includes conventional hydraulic-powered and electric-powered subsystems.

ASSESSMENT OF DESIGN-OPTION INTERACTION

No apparent interdependencies exist for the items discussed in this section. Note, however, that the eventual construct of a hybrid maintenance/support concept is likely to depend on the degree of functional commonality between military and commercial aircraft. That is, extensive use of CRAF kits could result in a commercial ACMA being substantially different from its organic military counterpart.

RECOMMENDED DISPOSITION OF CANDIDATE OPTIONS

All of the design features discussed in this section merit more detailed consideration. In our view, however, such analysis should be deferred until the other desirable features in the ACMA are more clearly defined.

The desirable level of contractor maintenance of organic military aircraft depends on the relative sizes of the military and commercial fleets as well as on the other points discussed above. Since the hybrid concept will result in lower costs for both military and commercial users, the preliminary cost estimates generated in the subsequent detailed analyses should be regarded as upper-bounds. That is, once the ACMA is better defined, the detailed development of a hybrid maintenance/support concept will result in lowering the estimates of both life-cycle cost and DOC relative to these preliminary estimates.

Note, however, that how an aircraft and its subsystems are configured directly affects the costliness of maintenance and support. Each design option under consideration in the present effort has an impact in this regard. Therefore, the detailed evaluation of the design options will explicitly incorporate maintenance and support considerations.

In the case of avionics, a commercial suite with hardpoints and wiring for military-unique equipment is clearly the preferable option. In addition, the rapid advance of electronic technology mitigates against fine-tuning system capabilities and user requirements at this point in the evolution of the ACMA.

Finally, the subsystem motive power option can also be deferred, since it is essentially a tertiary question. That is, whether or not a particular subsystem (e.g., kneeling landing gear) uses electrical or hydraulic power must be subordinate to analysis regarding the desirability of the subsystem itself.

X. MILITARY/CIVIL DESIGN CRITERIA

A comparison of military and civil regulations and specifications pertaining to aircraft certification and operation reveals numerous conflicts. Although not necessarily affecting the functional features of the aircraft, the ultimate resolution of the conflicts certainly impinges on aircraft design.

The following items relating to this aspect of the design process have been identified:

- Noise regulations
- Engine emissions regulations
- Performance specifications
- Certification procedures
- Design limit-load factor
- Service-life specification

Recall that noise regulations have been previously discussed in Section V as an element of airfield compatibility.

The discussion of the following items is abbreviated since, in the event of separate programs, the military or commercial option (whether or not desirable) would correspond to the appropriate military or civil regulation as a matter of course. For a common military/commercial program, the obvious solution is to conform to both sets of regulations, which in many cases, translates to achieving the more stringent or restrictive standard. Thus, the "conform to both" strategy may not be best in terms of commonality, and waiver applications for certain military or civil specifications/regulations should be considered.

ENGINE EMISSIONS

Civil regulations have been proposed by the EPA to control maximum allowable emissions of carbon monoxide (CO), unburned hydrocarbons (HC), and oxides of nitrogen (NO_x) from aircraft engines. An interim rule has been issued requiring implementation of certain standards in 1981, and new proposals have been issued for comment, with significant changes in applicability, emissions standards, and implementation date. The latest EPA proposals have not been finalized and adopted by the FAA for regulation. In addition, existing EPA/FAA regulations set limits for engine exhaust smoke and prohibit fuel venting to the atmosphere.

In accordance with AFR 80-36, as discussed previously in conjunction with the noise characteristics feature, whatever civil standards are in effect at the time of ACMA development would apply to the military version except as waivered. There are no corresponding specific limitations in Air Force regulations, although goals for USAF aircraft have been defined by the AF Aero Propulsion Laboratory in terms of combustor efficiency, specific NO_x values, and specific levels of visible smoke. In the most recent EPA proposals, emission standards are defined to apply only to "commercial aircraft engines;" that is, "only those aircraft engines which have been determined to be the major cause of air pollution at high-activity major air terminals." Thus, compliance with all applicable class standards will be required of commercial versions of the ACMA, whether an in-use or newly certified engine is eventually selected, unless specifically waived. The civil regulations have tended toward lower, increasingly stringent, and more explicity restrictive definitions related to available technology. So far, the military goals relate to reduce pollution, but with cost and mission capability compromises considered equally with technological capabilities. In both civil and military cases, safety of operation is a paramount consideration in establishing realistic emission limits.

In the most recent EPA-planned amendments to standards, delays have been proposed in implementation dates previously defined. Now the new standards for HC and CO are proposed to take effect on 1 Jan 1981, and the new standards for NO_x are to take effect on 1 Jan 1984. Existing standards for smoke and fuel venting will remain in effect without change.

There is no indication that changes are planned to make the military goals more severe. Any further reduction in emissions is likely to result in at least a modest penalty in engine performance with attendant increases in acquisition and operation costs. The only apparent direct military benefit is the increased survivability associated with low-smoke levels. However, reduced visible emissions may be of little significance to the ACMA, unless it is operated in a hostile environment within range of anti-aircraft weapons which use the smoke trail to locate the aircraft.

Precisely what engine emissions will be acceptable in the time of the ACMA cannot be predicted with confidence at this time. However, efforts to reduce engine pollutants will probably continue, and the engines of the 1990s will be an improvement over those of today. The performance of the STF477 engine, a late-1990s IOC Pratt & Whitney study engine, is based on meeting applicable EPA/FAA standards in effect at the time of its development. Relaxing these standards would presumably result in a reduction in weight and cost, and less internal engine complexity, and therefore, is attractive to both the military and commercial operators. We recommend, however, that consideration of this option be deferred until a later stage of system definition because of the uncertainties associated with predicting both standards and capabilities for the 1990s.

PERFORMANCE SPECIFICATIONS

Table 22 presents a comparison of military and civil performance specifications. The first three items refer to the rules used to calculate aircraft performance. In the present work, military rules are used for the purpose of aircraft sizing. Commercial performance of the aircraft is then calculated using the civil rules. Given that the aircraft is sized on the basis of its military configuration (e.g., with integral ramps installed), the described approach is a logical consequence.

An equally logical approach is to base the sizing of the aircraft on its commercial configuration using civil performance rules. Performance of the military configuration would be calculated using military rules. Which of the two approaches is preferable is inevitably intertwined with the figure of merit used in the aircraft optimization process. Since the current work used minimum gross weight (rather than cost-effectiveness or direct operating cost, for example), logical selection of the appropriate parameter for sizing/optimization is essentially arbitrary. However, care must be taken in developing

TABLE 22
COMPARISON OF MILITARY AND CIVIL PERFORMANCE SPECIFICATIONS

Performance Item	Military		Civil	
	Spec	Source	Spec	Source
Takeoff Rules	Critical Field Length	MIL-C-5011B (Para. 3.4.5.4)	Balanced Field Length	FAR 121.189
Reserve Fuel Rules	Flexible	MIL-C-5011B (Para. 3.5.3.6)	Flexible	FAR 121.645
Cruise Profile	Cruise-Climb	MIL-C-5011B (Para. 3.5.3.3)	Step Climb	FAR 91
Engine-Out Second Segment Climb Gradient	2.5%	MIL-C-5011B (Para. 3.4.2.5)	3.0% (4 Engine A/C)	FAR 25.121
Handling Qualities	Numerical	MIL-F-8785B	Qualitative	FAR 25

both military and commercial measures of merit for the detailed analysis to assure that important implications are not masked by the choice of performance rules.

From the viewpoint of commonality, an important issue that remains to be resolved is whether the aircraft should be optimized on the basis of military or commercial criteria or some compromise between them. The available evidence suggests that using minimum gross weight may be an acceptable compromise for this purpose (Ref 8). Since the focus of the current effort is on the relative effects of various design options, selection of criteria tends to become a moot point that can be more appropriately resolved at a later time.

The remaining items in Table 22 cannot be dealt with as described above, since they inherently influence the aircraft design. Of particular significance is the engine-out, second-segment climb gradient specification (i.e., with gear retracted and flaps in takeoff position). Although this specification does not affect functional characteristics of the aircraft, it can strongly influence engine selection as well as noise characteristics. The baseline aircraft has been sized on the basis of the less stringent 2.5 percent gradient. This military specification represents the preferable design option, since it is likely to provide a notable cost reduction relative to a 3.0 percent gradient; however, a waiver of existing civil regulations would be required before the aircraft could enter commercial service.

Handling qualities specifications, although important to the final aircraft configuration, represent parameters that are difficult to include in the conceptual design process. Thus, we recommend that their ultimate resolution also be deferred.

CERTIFICATION PROCEDURE

Also of relatively minor concern at the present time (but not necessarily later) is the procedure used to certify the aircraft commercially. At least two options are available. One is to run the civil certification concurrently with the military development and qualification as was done with the

C-141A/L-300. Initiating the certification procedure after military acceptance of the aircraft, as was planned for the C-5A/L-500, is the second approach. Of the two, the former appears to better serve the goal of military/commercial commonality. Furthermore, concurrent certification assures that the hazard analyses associated with civil safety regulations are performed in a timely fashion.

Lockheed experience with the C-141A/L-300 program suggests that concurrent certification poses no problems that cannot be overcome by appropriate program planning.

DESIGN LIMIT-LOAD FACTOR

The design limit-load factor of the aircraft can be based any of three operating conditions:

- Commercial
- Military peacetime
- Military contingency

The specification for the first two conditions is identical at 2.50g. This value consequently becomes a clearly desirable choice from the viewpoint of commonality.

For military airlift operations, a limit-load factor 2.25g is generally allowed for contingency situations. The aircraft could thus be sized on the basis of performing the design-point mission at a 2.25g load factor; under these circumstances, commercial and military-peacetime range-payload performance would still be based on a 2.50g load factor. Such an approach would be particularly appropriate if the military-contingency mission of greatest interest were well defined and if the corresponding design point or average payload densities were of little commercial interest. In the present case, as discussed in Sections III and VI, the preceding conditions do not appear to exist. However, if a design range of 6500 nm emerged as a firm military requirement, sizing the aircraft to perform the 6500 nm mission at a 2.25g load factor would be an option of primary interest.

To summarize, for the design-points and average payload densities of interest in the present effort, a design load factor of 2.50g, which is compatible with both commercial and military-peacetime operating limitations, is most appropriate. The baseline aircraft has, therefore, been sized on this basis.

SERVICE-LIFE SPECIFICATION

Two aspects of service-life specification are of interest. One is the design service life expressed in terms of flight hours. Because of the traditionally low military utilization rates in peacetime of about 1000 hours per year per UE (unit equipment), a service life of 30,000 hours is probably the maximum of practical interest. This provides a service life of more than 20 years, even including a substantial flight hour allowance for two or more contingencies during the aircraft life cycle. Commercial operators, on the other hand, are likely to demand a service life of at least 60,000 hours, since commercial unit utilization rates can approach 4000 or more hours per year.

The second aspect is that of the mission profiles used to determine the service life. In the military case, these should be representative of peacetime operations and thus include a primary emphasis on short-duration, low-payload missions which may result in a substantial fraction of total flight time being at relatively low altitudes. Representative commercial mission profiles tend to have higher payloads and longer flight times.

Coupling the respective desired service lives and representative mission profiles for military and commercial purposes may yield service-life specifications that are not necessarily incompatible. That is, the military profiles which contain a greater number of landing-takeoff cycles per flight hours and perhaps a greater fraction of total flight time at low altitude could be significantly more damaging per flight hour (in a fatigue sense) than the commercial profiles. Furthermore, representative military profiles could include a contingency allowance that assumes a fraction of the lifetime flight hours are flown at a 2.25g limit-load factor rather that 2.50g. Under these circumstances, a 30,000-hour lifetime based on military mission profiles may well be compatible with 60,000 hours based on representative commercial use. If true, then the goal of military/commercial commonality will be served.

The baseline aircraft, having originated as a military airlifter, is predicated on a 30,000-hour service life based on military profiles. Detailed analysis is required to validate the impact of requiring at least 60,000 hours of airframe life based on typical commercial operations.

RECOMMENDED DISPOSITION OF CANDIDATE OPTIONS

Of the potentially conflicting military/civil regulations or specifications, only two appear appropriate for further consideration in the present effort. These are:

- o Engine-out climb gradient
  - 2.5 percent (military)
  - 3.0 percent (commercial)

- o Service-life specification
  - 30,000 hours, military mission profiles
  - 60,000 hours, commercial operational profiles

The remaining items, as discussed in this section, can more appropriately be examined at a later stage of system definition and/or are dependent on the outcome of other ongoing research.

Eventual selection of the military specification for engine-out climb gradient will require a waiver of existing civil certification regulations. Thus, the purpose of including this option in the present effort is to illustrate the potential cost reductions that may be posible by adopting the military specification. As such, the relative potential of this feature receives the same qualitative scoring in Table 23 as the noise characteristics feature discussed in Section V. The service-life specification options are a somewhat different matter. In this case a 60,000-hour commercial life may be an economic requirement. Thus, should the two options prove incompatible, several alternatives in addition to designing to the 60,000-hour goal should be considered. These include the possibility of refurbishing or replacing fatigue-susceptible structure at some point in the life-cycle, and the possibility of exchanging commercial aircraft for organic military aircraft in

TABLE 23
SUBJECTIVE ASSESSMENT RELATIVE TO BASELINE AIRCRAFT OF MILITARY/CIVIL REGULATORY DESIGN FEATURES

-3	-2	-1	0	1	2	3
Much Poorer			Neutral			Much Better

	Engine-Out Climb Gradient	Service-Life Specification
Military Considerations		
Life-Cycle Cost	-1	-2
Mission Effectiveness	0	0
Mission Flexibility	0	0
Subtotals	-1	-2
Commercial Considerations		
Direct Operating Cost	-1	1
Indirect Operating Cost	0	0
Market Expansion Potential	3	3
Subtotals	2	4
Grand Totals	1	2

an attempt to equalize the service life of both fleets. A third possibility is to provide different structure in the commercial and military versions of the aircraft as required.

Finally, note that service life is an extremely difficult problem to deal with at the conceptual-design level. Indeed, an adequate treatment may require greater resources than are presently available.

XI. CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the design features and associated options that have been recommended for further consideration on the basis of the assessments contained in the preceding sections. Interdependencies among these features are discussed with the intent of providing further insights into the most appropriate ranking of the features for more detailed analysis (i.e., the order in which the most promising design options should be examined). Finally, recommendations for the detailed analysis are presented.

SUMMARY OF FEATURES UNDER CONSIDERATION

Table 24 lists the design features being considered for more detailed analysis in the order in which they are discussed in the preceding sections. Also shown for each feature is the scoring of its relative potential. Recall from Section III that these scores reflect subjective judgments regarding the potential of the design options considered for a given feature relative to the option incorporated in the baseline aircraft. The first column relates to military considerations and the second to commercial considerations. Thus, the total of these two can be thought of in terms of the net impact on military/commercial commonality. Recall also from Section III that the higher the numerical score in each category, the greater the possibility that at least one of the substitute design options (i.e., an option other than that incorporated in the baseline) will prove attractive.

Only three of the 16 features listed in Table 24 have total scores less than or equal to zero; these three appear to offer little or no potential for enhancing military/commercial commonality based on the subjective assessments.

ASSESSMENT OF DESIGN FEATURE INTERDEPENDENCEY

Despite the fact that many design features and options have been eliminated in the qualitative assessments presented in Sections III through X, those still under consideration represent a formidable list. To illustrate, if only two options existed for each of the 16 features listed in Table 24, over 65,000 combinations of design options are possible. Although significantly less than

TABLE 24
DESIGN FEATURES UNDER CONSIDERATION AND THEIR RELATIVE POTENTIAL BASED ON SUBJECTIVE ASSESSMENTS

Feature	Relative Potential: Military Considerations	Commercial Considerations	Total
Design Payload	3	3	6
Maximum Structural Payload	2	1	3
Floor Height	-1	2	1
Loading/Unloading Apertures	0	4	4
Cargo Loading/Unloading System	-1	1	0
Takeoff Distance/Gear Flotation	3	2	5
Noise Characteristics	-1	2	1
Planform Shape of Cargo Compartment	2	1	3
Cargo Envelope	0	2	2
Cargo Accommodation Provisions	-2	3	1
Pressurization	0	1	1
Cargo Stick Width	-1	0	-1
Relief-Crew Provisions	-1	1	0
Passenger Provisions	1	5	6
Engine-Out Climb Gradient	-1	2	1
Service-Life Specification	-2	4	2

the 100 billion possible combinations estimated in Section II, performing a detailed analysis of 65,000 configurations is still a practical impossibility.

Assessment Focus

One method of further reducing the total number of configurations to be examined is to idenfiy which design features are likely to be interdependent in terms of their relative attractiveness. That is, the relative attractiveness of the design options for some features is likely to be dependent on the specific combination of options incorporated in the baseline aircraft. This problem can be circumvented to some extent by first identifying which features exhibit such an interdependency. Once known, the most significant features (based on their relative potential) can be analyzed first and depending on the outcome of this analysis, the baseline aircraft can be modified to incorporate the best option for the design feature under consideration. Subsequent features will thus be analyzed in the context of what appears to be the most attractive aircraft configuration based on the analysis up to that point. Note that this technique does not entirely eliminate the interdependency problem but simply assures that all features are examined in the context of the most reasonable configuration for the ACMA based on the information available at that time.

Figure 20 presents our assessment of the likely interdependencies among the design features under consideration. Note that many of the features are dependent (in the sense described above) on design payload. The other major groupings reflect the interdependencies that exit between the loading apertures, floor height, cargo loading system, and cargo-compartment planform shape features and between the takeoff distance, noise characteristics, and climb gradient features.

Realize, of course, that Figure 20 has been developed on the basis of the design options for each feature that were developed in the preceding sections. If other options are added to any of the features, revision of the assessment presented in Figure 20 would be mandatory.

	Service Life Spec.	Climb Gradient	Passenger Prov.	Relief-Crew Prov.	Stick Width	Pressurization	Cargo Accom.	Cargo Envelope	Compartment Plan.	Noise Char.	T.O. Dist./Gear	Cargo Loading Sys.	Floor Height	Loading Apertures	Max. Structural Wt.	Design Payload
Design Payload		●	●				●		●	●	●		●	●		
Max. Structural Wt.													●	●		
Loading Apertures									●			●	●			
Floor Height												●				
Cargo Loading S.									●							
T.O. Dist./Gear		●								●						
Noise Char.		●														
Compartment Plan.																
Cargo Envelope			●													
Cargo Accom.					●											
Pressurization																
Stick Width																
Relief-Crew Prov.																
Passenger Prov.																
Climb Gradient																
Service-Life Spec.																

● Potentially Significant Interdependency Between Features

Figure 20. Assessment of Interdependencies Among the Design Features Under Consideration

Illustrative Example

A specific example should help to clarify the preceding discussion. Figure 20 indicates that the outcome of a quantitative assessment of the cargo loading system feature is likely to depend on which options are selected for the following design features: loading apertures, floor height, and cargo-compartment planform shape. That is, the choice between a partially removable ramp (as incorporated in the baseline) and a fully removable ramp is very much dependent on the number of apertures, the length of the ramp(s), floor height , and the width of the apertures (planform shape). Table 23 reveals, however, that the cargo loading system is expected to be the least significant of the four features being discussed. Thus, consideration of design options for the cargo loading system feature should be deferred until the most attractive combination of options for the other three features is identified.

RECOMMENDATIONS FOR DETAILED ANALYSIS

The rationale described above was employed to develop recommendations regarding which design options should be analyzed in detail. Table 25 lists these design options in the order recommended for performing these analyses.

Of the design features presented in Table 24, the cargo loading/unloading system, cargo-stick width, and relief-crew provisions features are not recommended for further analysis because of their relatively poor potential in the context of enhancing military/commercial commonality. This is not to say that these features have no impact on commonality, but rather that the baseline aircraft incorporates the best apparent choice and that further detailed analyses of them should be deferred until the other, more significant, design features are resolved.

The noise characteristics and engine-out (second-segment) climb gradient features have been combined in a single feature. This appears appropriate, since achievement of the FAR 36 Stage 3 noise limits will almost certainly require a three-percent engine-out climb gradient capability. On the other hand, waiver of FAR 36 but retention of the commercial climb-gradient requirement seems to us to be an unlikely possibility.

TABLE 25
DESIGN OPTIONS RECOMMENDED FOR DETAILED ANALYSIS

GROUP	DESIGN FEATURES	DESIGN OPTIONS
I	Design Payload	495,000 lb* 450,000 lb 405,000 lb 360,000 lb 315,000 lb
II	Loading/Unloading Apertures	Front & rear with ADS kit provisions* Front only with no air drop capability
	Planform Shape of Cargo Compartment	Tapered forward and aft* Full width forward and aft Full width forward and tapered aft
	Floor Height	8 ft kneeled and 13 ft unkneeled* 13 ft, no kneeling capability
III	Takeoff Distance/ Gear Flotation	8,000 ft/LCG III 9,500 ft/LCG III 10,500 ft/LCG III 9,500 ft/LCG II* 10,500 ft/LCG II 9,500 ft/LCG I
	Noise Characteristics/ Engine-Out Climb Gradient	No special acoustic treatment/2.5 percent* Conform to FAR 36/3.0 percent

*Incorporated in baseline aircraft (Model LGA-144-100)

TABLE 25 (CONT)

DESIGN OPTIONS RECOMMENDED FOR DETAILED ANALYSIS

GROUP	DESIGN	DESIGN OPTIONS
IV	Cargo Envelope (Maximum Height)	Constant 13.5 ft* Constant 11 ft 13.5 forward of wing, 11.0 ft aft
	Passenger Provisions	Integral troop compartment Containerized troop compartment Integral passenger/troop compartment None (except bench seats in cheek)*
	Maximum Structural Payload	Corresponds to design range* (i.e., the design payload) Corresponds to 3,500 n mi flight with takeoff at maximum gross weight Corresponds to 2,500 n mi flight with takeoff at maximum gross weight
	Service-Life Specification	30,000 hrs, military mission profiles* 60,000 hrs, commercial operational profiles
	Pressurization	8,000 ft (at 40,000 ft flight altitude)* 18,000 ft (at 40,000 ft flight altitude)
	Cargo Accommodation Provisions	Dual purpose system* Commercial system Shuttle-loader system

*Incorporated in baseline aircraft (Model LGA-144-100)

Table 25 separates the design features and associated options into four groups. These groupings are necessitated by the fact that, during the analysis of a series of features, efficient use of study resources requires that the analysis of options for the third feature must be initiated before the first two features are completed.

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