NASA Contractor Report 158914 Volume 3

Cargo Logistics Airlift Systems Study (CLASS)

Volume 3. Cross Impact Between the 1990 Market and the Air Physical Distribution Systems

Book 1

R. J. Burby
W. H. Kuhlman
McDonnell Douglas Corporation
Douglas Aircraft Company
Long Beach, California 90846

Contract NAS1-14948
October 1978

National Aeronautics and Space Administration

Langley Research Center
Hampton, Virginia 23665

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

N79-27112-27115

CARGO LOGISTICS AIRLIFT SYSTEMS STUDY (CLASS) VOLUME 3. CROSS IMPACT BETWEEN THE 1990 MARKET AND THE AIR PHYSICAL DISTRIBUTION SYSTEMS BOOK 1

R.J. Burby, et al

McDonnell Douglas Corporation
Long Beach, California

October 1978

386

CARGO/LOGISTICS AIRLIFT SYSTEMS STUDY (CLASS)

VOLUME III – CROSS IMPACT BETWEEN THE 1990 MARKET AND THE AIR PHYSICAL DISTRIBUTION SYSTEMS
BOOK 1

JUNE 1978

By R. J. Burby, Program Manager
W. H. Kuhlman, Principal Investigator
Flying Tiger Line, Subcontractor

Prepared under Contract No. NAS1-14948 by
McDonnell Douglas Corporation
Douglas Aircraft Company
Long Beach, California 90846

for

Langley Research Center
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

i-a

PREFACE

In June 1977, the Douglas Aircraft Company (DAC)was awarded Contract No. NAS1-14948 for the Advanced System Division (ASD) of NASA/Langley Research Center, Langley Field, Virginia, to perform a Cargo/Logistics Airlift System Study (CLASS). The scope of this study as defined by the NASA Work Statement was as follows:

- Characterize current air cargo operations
- Survey shippers to determine nature of demand
- Develop commodity characteristics leading to high elegibility for air transport
- Determine sensitivity of demand to improved efficiency
- Identify research and technology requirements

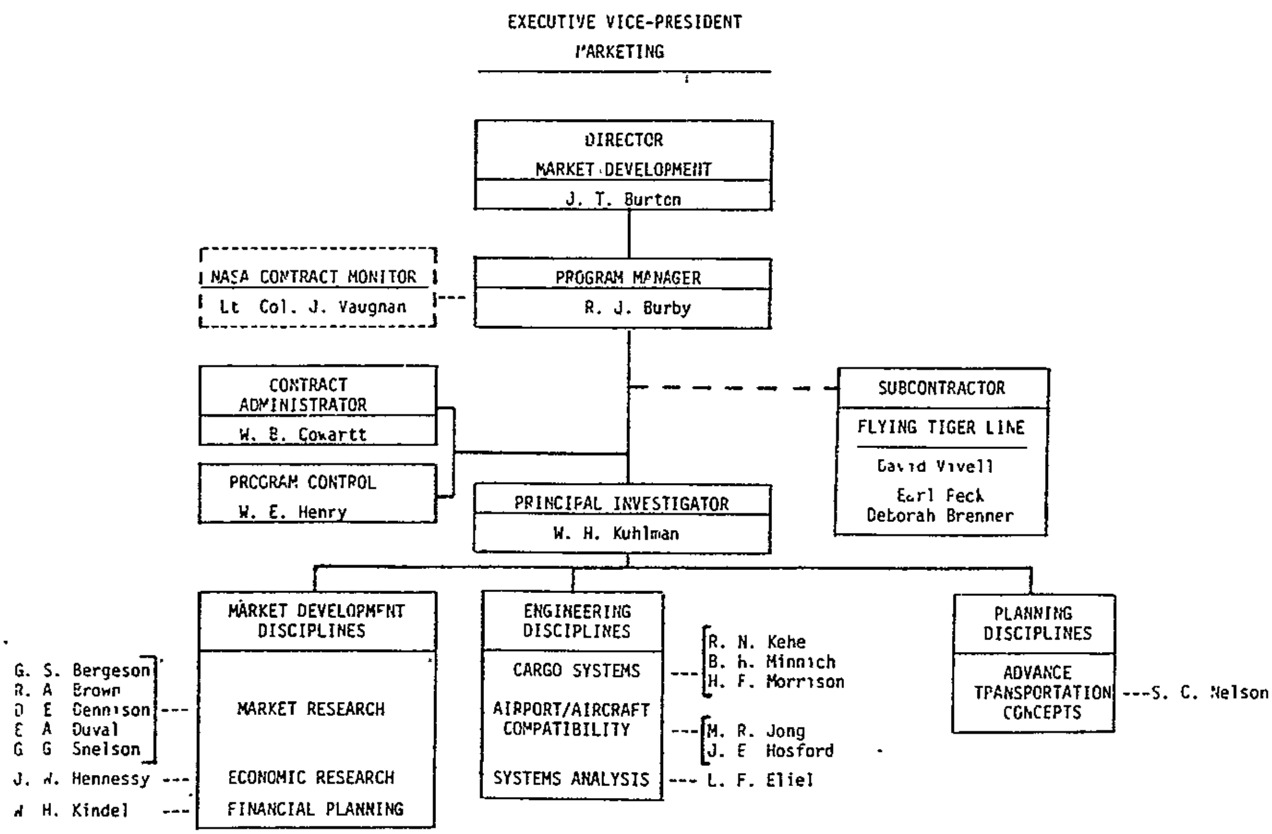
To comply with the scope of the study, the effort was segregated into five discrete tasks.

Task 1 was the analysis of the current air cargo system with the objective of clearly understanding what the air cargo operation is today and how prevailing conditions might impact on the 1990 time period. It can be noted here that during the preparation of the Task 1 report deregulation of the air cargo industry was signed into law. The affects of this legislation are not reported and the discussion is maintained as originally written prior to the legislation. This approach was taken in consideration for the short term during which any observation would be presumptuous.

Task 2 was to perform case studies with the objective of determing current distribution characteristics, total distribution cost concepts and their application, and the factors the consignor or consignee considered in their transport mode selection. Concurrent with the case studies was the development of a 1990 scenario designed to provide a framework for the total future environment, within which a 1990 market forecast and the 1990 system characteristics are postulated.

The findings of Tasks 1 and 2 provided the basic information necessary to accomplish Task 3, which was to define the characteristics and requirements for the 1990 system. In this task, the market and system growth factors were identified followed by a domestic and international forecast of the 1990 freight market.

The objective of Task 4 was to explain the cross impacts that exist between the air cargo market, technology development and implementation, and the operation of the air physical distribution system. Emphasis was placed upon identifying the factors which had to be considered to measure the possibility of achieving the NASA-defined goals of a 30-percent reduction in aircraft direct operation costs, a 40-percent reduction in indirect operating costs, and a 45-percent reduction in total operating costs. Task 5 identified future system and technology studies and was conducted as an integral effort within all tasks.



The Douglas CLASS study organization is shown above. Douglas is pleased

to acknowledge the excellent contribution made to the project by personnel of the Flying Tiger Line and, in particular, David Vivell, Director of Marketing Research; Earl Peck, Senior Economic Analyst; and Deborah Brenner, Director Advertising. It should be noted that the Flying Tiger team had prime responsibility for Sections 2, 4 and 5 of Volume I; Case Study Approach and Results, Volume II; and Section 6 of Volume III. In addition, they contributed to Section 5 and assisted in the analysis encompassed by Section 2 of Volume I. Douglas appreciates the keen interest and support provided by the NASA contract monitor Lt. Col. John Vaughan.

The study results comprise five volumes:

- Volume I - Analysis of Current Air Cargo Systems, NASA CR158912
- Volume II - Case Study Approach and Results, NASA CR158913
- Volume III - Cross Impact Between the 1990 Market and the Air Physical Distribution Systems
- Volume IV - Future Requirements of Dedicated Freighter Aircraft to Year 2008, NASA CR158950
- Volume V - Summary, NASA CR158951

CONTENTS
BOOK 1

PRECEDING PAGE BLANK NOT FILMED

Page

PRECEDING PAGE BLANK NOT FILMED

BOOK 2

LIST OF FIGURES

BOOK 1

Page

Page

Page

Page

BOOK 2

LIST OF TABLES
BOOK 1

BOOK 2

Page

Page

ABBREVIATIONS

AADA	Airport and Airway Development Act
ATA	Air Transport Association
ATC	Air Transport Corporation
AWB	Airway Bill (airbill)
CAB	Civil Aviation Board
CAN	Committee on Aircraft Noise
CFR	Code of Federal Regulations
CLC	Consignor-Loaded Container
COFC	Container on Flatcar
COMAT	Airline Company Materials
CRAF	Civil Reserve Air Fleet
DAFRI	Domestic Air Freight Rate Investigation
DOC	Direct Operating Costs
DOD	Department of Defense
DOT	Department of Transportation
DWT	Dead Weight Tons
ETV	Elevating Transfer Vehicles
FAA	Federal Aeronautics Act
FAR	Federal Aeronautics Regulations
FMC	Federal Maritime Commission
GNP	Gross National Product
GRP	Gross Regional Product
HBR	High By-pass Ratio
IATA	International Air Transport Association
ICAO	International Civil Air Organization
ICC	Interstate Commerce Commission
IOC	Indirect Operating Costs
LASH	Lighter Aboard Ship
LCL	Less Than Carload (rail)
LD	Less Developed
LDC	Lower Deck Container Series
LTL	Less Than Truckload
MAC	Mean Aerodynamic Chord
MTOGW	Maximum Takeoff Gross Weight

OAG	Official Airline Guide
O-D	Origin-Destination
OECD	Organization for Economic Cooperation and Development
OPEC	Organization of Petroleum Export Countries
PU&D	Pickup and Delivery
ROA	Return on Assets
ROI	Return on Investment
RRRR(4R)	Railroad Revitalization and Regulatory Reform Act
RTKM	Revenue Tonne-Kilometers
SAF	Society of American Florists
SFAR	Special Federal Aeronautics Regulations
SITC	Standard Industrial Transportation Code
TAA	Transportation Association of America
TDC	Total Distribution Concept
TEU	Twenty-foot-Equivalent Unit
TOC	Total Operating Costs
TOFC	Trailer on Flatcar
TOGW	Takeoff Gross Weight
UD	Underdeveloped
ULD	Unit Load Device
UPS	United Parcel Service
WPL	Weight of Payload

2.4-x 2.4-x 6-meter - metric definition of current 8-x 8-x 20-foot container

SUMMARY

This volume of the CLASS report presents the results of the efforts to Define Characteristics/Requirements for 1990 System, Analyze Cross Impact Between Market and Air Physical Distribution Systems and to define Future Study Requirements. Among the items discussed are the interrelations between the infrastructure and the forecast future market with potential corrective action defined for deficient areas and the associated reductions in indirect operating cost defined. Potential reductions in aircraft direct operating cost are estimated and related to future total revenue along with the indirect operating cost and profit potential. In addition, service and cost elasticities are established and utilized to estimate future potential tariff reductions that may be realized through cost reductions and economies of scale. The potential of representative derivative and new larger dedicated cargo aircraft concepts are evaluated in the future market in competition with each other and with contemporary aircraft. The most promising concept is then considered for its ability to lower tariffs, and the resulting market stimulation is estimated.

The results presented herein identify issues and orient them to aircraft design and establish the relative importance of the infrastructure and the aircraft to future market growth. Forecasts of market growth provide a base for the evaluation of future aircraft concepts, and the suggested infrastructure changes and elasticities provide a guide for the air cargo airline industry to reduce their indirect operating costs and to plan their future revenue and profit posture. Furthermore, the economic and aircraft analyses combine to provide a guide to the NASA and aircraft industry on the importance of advanced technology and large aircraft by defining their potential contribution to reducing direct operating costs and their indirect stimulation of the air cargo market.

This summary is limited to brief comments on a broad range of interrelated subjects that are presented under six headings considered to best outline the overall results.

Market Growth (1978-1990)

Based upon U.S. and world conditions, growth rates of 9.5 percent, 8.3 percent and 14.3 percent are forecast for the U.S. domestic, U.S. international, and foreign markets respectively. The primary impetus for this growth is the annual relative increase in real gross national product (GNP) between trading countries. As an example, every 1 percent growth in real GNP has resulted in 2.2 percent increase in the domestic cargo market. Domestically, the larger portion of this growth will occur in the South and Southwest. Internationally, the higher rates of growth will be in South America, West Central and North West Africa, Mid-East and the Far East.

Improvements in service and reductions in tariffs can stimulate additional market growth defined by the following air transport related elasticities:

- Reduction of air cargo tariffs of 10 percent will increase demand 13 percent.
- Decreasing delivery time by 10 percent will increase demand 3 percent.
- Increasing the number of cities served by 10 percent will increase demand 1-1/2 percent.

In addition to the preceeding, the competitive mode investigations indicated that a 10-percent increase in truck tariffs will increase the air cargo demand by 1 percent. It must be pointed out that these and other analysis of the CLASS study are based upon data that originated under regulated conditons and, hence, may not be totally indicative of the future domestic scene.

A comprehensive survey of transport modes was conducted to evaluate future technologies, vehicle operations, support, and institutional operations for their effect on cost and time of transit, equipment and facilities, environment, personnel and procedures, and the cargo market. The objective of this analysis was to define the future competitiveness of the surface modes. It was generally concluded that changes to vehicles and infrastructure will be evolutionary, directed to the improvement of operating efficiences and reductions in costs and transit times. The integrated result of these applications of new technology combined with the future impact of labor and fuel costs as determined by the compartive cost analysis, will lead to reduced truck and increased rail competition. However, the latter, handicapped by institutional barriers, will be small until the late 1980s. Competition by the sea mode will show a small increase.

There will be very little change in commodities making up the future air cargo markets. There will be some shifts into and out of the top 20 commodities with a continual increase in the percentage of manufactured goods. Any new products that enter or leave the market will not be visible at the five-digit SITC code level and there will be a continuing trend toward miniaturization and compactness of the more complicated fabricated items. On the whole there will be little change in the average warehouse density of air cargo high-value bulk or processed goods. Future commodity patterns for developing regions will be a function of their state of development and must, therefore,be established at the time of concern. Periodically,refined minerals will become eligible back-haul cargo from select, developing regions. Once again, the economic feasibility will be a function of the world's mineral markets and the current environmental situation within the originating region.

Air Cargo System

Both the analysis and case study results pointed to the need for reduced transportation cost and improved service with the latter encompassing door-to-door delivery. These needs cannot be met without the implementation of an integrated, or at a minimum a coordinated and cooperative, intermodal approach. Analysis of the interrelations existing within such an integrated system identified the environment, containerization,and commodity characteristics as the top three most affecting factors and delivery time, total transport cost, and indirect operating cost as the three most affected factors. The importance of these and other identified factors to the shipper as well as to the transport operator point to the necessity for considering air transport problems and developments in the context of the total system.

Deregulation which occurred during the course of this study will have a pronounced affect on the domestic air cargo system. Modifications to shipper-airline relations will occur in combination with network changes including the number of cities served. The latter will lead to an increase in the quantity of cargo flowing over stage lengths less than 3000 kilometers.

Changes will also occur in international routes, although in this case the changes in controlling regulations will be minor prior to 1990. In this regard, various new network concepts were investigated including the hub-spoke arrangement. Evaluated relative to flows between the U.S. and Europe, South America, and the Far East, the hub-spoke concept shows promise of eliminating, or at least alleviating, the current back-haul problem that exists with many regions of the world. However, in the current international environment there are institutional road blocks, such as multilaterial agreements, that place restrictions on this type of operation.

Infrastructure

Airports. - Analyses of the airport survey results provided insight into scope and depth of airport development prior to 1990. It is unlikely that any new airport construction will occur during the 1980s. However, cargo terminal expansions at Atlanta, Chicago O'Hare, and Los Angeles International are anticipated. While these actions are favorable to air cargo operations the anticipated increases in aircraft flow control and curfews represent a growing handicap. By the mid-1980s most worldwide airports will prohibit aircraft that do not meet current ICAO, Annex 16, or the FAA Part 36 noise regulations. It is anticipated that such noise regulations will be made even more strict for future aircraft.

Current airports also place restrictions on aircraft size. Runway, taxiway, and apron area dimensions are such that they will seriously handicap the efficient operation and productivity of aircraft significantly larger than the B747. Considering the magnitude of the modifications, it is unlikely that current major airports will be changed to accommodate these larger aircraft should they materialize. Possible solutions to this problem may rest in new aircraft configurations or in the implementation of all-cargo airports. The former solution must consider the impact on aircraft performance and cost; while the latter must consider the revenue potential, interline cargo transfer, and ground access. In any case, the planning of changes to or the design of new airports must be closely coordinated with the aircraft industries design efforts on future derivative and new aircraft.

Cargo terminals and ground handling summary. - Airline cargo terminal operations have been compromised by less-than-desirable circumstances ranging from severe surges in activity level to extreme variations in manpower productivity. This has been compounded by other problems such as low priority in airline resource allocations; airport site constraints; and most recently, environmental impact restrictions and operational curfews. Even with such adversities, the demand placed on cargo terminals continues to grow as the air cargo market expands.

Results of the terminal analysis revealed that most present-day terminals handling ULDs up to the 3.0-meter M1 container size cannot meet 1990 flow levels without substantial changes in level of mechanization, reduced import storage time, and/or handling of increasing levels of shipper-loaded containers rather than bulk cargo. The latter of the three will derive the greatest relative benefits in terms of reduced terminal handling equipment costs and reduced manpower levels. Processed flow can be improved through the application of automated data management which can eliminate or reduce manpower, procedural and maintenance inefficiencies and improve load planning and aircraft utilization. Based upon the terminal changes that are implemented, the handling equipment costs per ULD handled can range at 60 to 80 percent of present levels, and cargo handling personnel per ULD handled can range at 30 to 50 percent of present levels. These reduced levels of equipment investment and manpower levels per ULD handled clearly indicate a strong potential for significant cost reductions. Since shipper-loaded containers are the major benefactor in meeting 1990 flow levels and in reducing costs, it is essential that this aspect continue to be encouraged and fostered through appropriate tariff incentives.

Increases in cargo flow beyond 1990 may entail development of new and/or alternative terminals, particularly with the quantity of 6.0-meter M2 containers reaching large proportions. Even though the cost per ULD handled will be significantly greater, the M2 container terminals will be highly competitive based on cost per kilogram handled. Conversely, if ULD buildup and breakdown of bulk cargo is still a large activity of the airport terminal, a large part of the growth could be accommodated by increasing utilization of the available volume (cube utilization) in the ULD. Unless this potential is exploited, the aircraft cargo ramp capacity may become a limiting factor since greater numbers of freighters are required to sustain a given flow.

Containerization summary. - Containerization and palletization have both made significant contributions to the reduction of cargo handling costs. However, the full benefit of either is,today,compromised by insufficient air cargo flow based on available airlift capacity and by certain counter productive operational practices. Therefore, the containerization analysis centered on the improved utilization that is possible if circumstances are bettered and if larger ULDs such as the 2.4- x 2.4- x 6-meter containers are employed.

From existing levels of 54 percent, improvements up to 85 and 90 percent cube utilization in ULDs are held possible. Such improvements in cube utilization will be further reflected in higher loaded densities and cargo revenues. Understandably, an impact on basic aircraft design and performance may also be felt. The effects include potentially higher aircraft design densities; increased cargo floor, fuselage shell, wing, and landing gear loads; lower tare weight/cargo weight ratios; and improved DOCs per revenue tonne-kilometer.

A preliminary analysis of maritime containers revealed that the mean value of DOD gross weights in direct supply support (DSS) channels made them eligible for airlift through airworthiness gross load derating. Conversely, the same analysis revealed that the mean gross weight of commercial export containers out of Baltimore was so high as to preclude most as candidates for airlift gross load derating. However, historical data show that higher value goods will have lower densities. Thus, it is quite possible that a pairing of higher-value goods that are economically air eligible would occur with the lower weight range of Baltimore containerloads and be acceptable for airworthiness gross load derating and airlift. Design technology studies in process are aimed at developing new methods for loading and handling the beam-bottom maritime containers in aircraft without the tare weight penalty of heavy flat-bottom slave adapter pallets. This would enable the routine acceptance of maritime containers,when air eligible,along with flat-bottom air containers.

Advances in materials and manufacturing technology will make tare weight and cost reductions of 30 percent or more possible for intermodal containers. When coupled with other marginal benefits associated with containers as compared with palletized loads, the role of the 6.0-meter container in airlift will assume added importance. Analysis shows containers to have an economic advantage out to ranges of 6000 kilometers and more. At greater ranges, pallets enjoy the advantage although the use of one or the other is subject to operator preference depending upon his route structure and methods of operation. Shipper preference for containers and the marketability of air cargo based on containerization will be strong influences tending to enhance future air cargo containerization and market growth. Based on air cargo growth projections exclusive of mail and parcel post, a $100 million, 20 000 fleet of 6.0-meter air containers will be in use in 1990.

Cost, Tariffs, and Profit

Despite the growth of the air cargo market and a cost structure that has exhibited increasing returns to scale, cargo carriers have not been able to achieve consistant profits. Future profit levels will have to increase to induce the capital investments required to serve a greatly expanded air cargo market. The trend to the mid-1980s will be toward increased profits with a proliferation of incentive tariffs directed to increasing customer-loaded containers, productivity, container volumetric utilization, and aircraft load factors. Such incentive tariffs will be stimulated by the innovative challenges of the new domestic entrants under deregulation. However, in spite of this competition,the relationships between price elasticity, as seen by the airlines, and the marginal to average cost ratios will provide little incentive for industry members to reduce tariffs to increase market shares.

Prior to the advent of derivative,more-efficient cargo aircraft around 1985 the airlines could increase profits by reducing their indirect operating costs (IOC). These improvements can be achieved with today's technology but will require determined efforts on the part of management and sales personnel. Transition to shipper-loaded containers (CLC) could substantially reduce cargo handling attaining a 23 percent reduction in IOC with 90 percent CLCs. Parallel improvements in terminal productivity through the application of vertical storage, the reduction of import storage time, and the utilization of additional economically viable mechanization could provide an additional 6-percent reduction in IOC. It is probable that not all these improvements, such as the conversion to 90 percent CLC, can be accomplished by 1985; however, the level of saving that is achieved will contribute to an improved profit picture. This picture will be improved even more by the reduction in general administrative and sales costs due to the economies of scale which can amount to a 15-percent reduction for the anticipated U.S. domestic and international market growths between now and 1990. Parallel improvements in airport/aircraft compatibility stemming from coordinated efforts by the FAA, airport authorities, and the airlines could provide an additional 4-percent reduction in IOC. The combined effect of all these changes/improvements could result in a 48 percent reduction in IOC by 1990 and a comparable reduction of 19 percent in total operating cost.

Reductions in IOC will place greater emphasis on direct operating cost (DOC) as a percent of the total revenue increasing from the current level of 50 to 57 percent to nearly 70 percent by 1990. Of the elements making up DOC, namely crew, maintenance, insurance, depreciation, and fuel, the last three are the more important. Analysis shows that the cost of insurance and depreciation for a new aircraft can substantially reduce, and in some cases negate, the reductions achieved by improved fuel consumption. Since insurance and depreciation are both functions of the aircraft purchase price, the importance of reducing development and production costs and increasing the production run cannot be overemphasized. The depreciation component can also be reduced by increasing aircraft utilization, useful life, and operational load factor. Regarding the last, the DOC can be reduced 7 percent by increasing the load factor of all-cargo aircraft from the 60 to 65 percent prevelant in today's operations to 70 percent.

The increased size, payload around 154 000 kilograms, and improved technology of a future (post-1990) dedicated cargo aircraft could decrease direct operating costs by 13 to 23 percent based on a production run of 200 aircraft. Combining this cost saving with that due to improved load factor results in a 20 to 30 percent reduction in DOC with a comparable reduction in total operating cost of 11 to 16 percent. Comparing the latter to the comparable reduction due to IOC, it is seen that the proposed changes in the infrastructure, obtainable with current technology, are as important to improving the airlines financial picture as the anticipated large dedicated cargo aircraft utilizing 1990 technology.

- Of the advanced conceptual aircraft generally considered as candidates for a joint civil-military concept, only the 59 000 kilogram payload aircraft appears in the resulting fleet. It would not compete with derivative aircraft until 1991, and even then its potential to capture a portion is extremely low.

- The low-pressure 154 000 kilogram aircraft, designed solely as a commercial cargo transport, does appear in the three fleets and displaces some derivatives in the United States markets. In the foreign market, there is a lesser demand for this aircraft than for the derivatives. The real-world demand for this size cargo aircraft will not occur until the post-1990 time period.

- The spanloader concepts with payloads greater than 317 000 kilograms appear only when the market is large enough to require those sizes at the required flight frequencies. This would not occur until well after 1990 with the predicted and continued expansion of the cargo market.

Additional Macrolevel Findings

The Douglas CLASS study has identified many problems with an equal number of solutions or alternatives. In addition, there are a limited number of macrolevel findings deserving of particular emphasis having the potential to strongly influence the course of future development. The following are brief descriptions of these findings:

- The importance of reducing indirect operating cost with current technology is about equal to the anticipated future direct operating cost reduction with 1990 technology. As infrastructure improvements are introduced the relative importance of indirect operating cost will decrease while importance of direct operating cost increases.

- The depreciation and insurance costs associated with new aircraft tends to offset the cost reduction due to improved specific fuel consumption.

- Due to the wide variations in airline accounting methods, relatively large differences can occur between computed direct operating costs and values obtained from operational records.

- Emphasis must be placed on reducing the purchase price of new cargo aircraft through design, technology, and production technique.

Potential for Dedicated Cargo Aircraft

The combined econometric and performance results indicate that within the considered time period there is a good potential for a three-engine wide-body cargo aircraft with a payload of 82 000 kilograms. A lesser potential is indicated for a regional, two-engine, wide-body derivative aircraft having a payload capacity of 40 000 kilograms. In the post-1990 time period the market should be sufficient to accommodate a large cargo aircraft in the 154 000 kilogram payload class.

A review of the relative performance and economic potential of the considered aircraft in each of the fleet mixes provide these general comments:

- If only contemporary aircraft were to be used, an aircraft of the B747 class would carry the bulk of the traffic with a continuing demand for the DC-8, B707 narrow-body type of aircraft. This latter is most prominent in the foreign market.

- The addition of derivative aircraft forces a rapid replacement of contemporary types with the dominant configuration equivalent to a three-engined DC-10 type derivative. Of lesser, but significant importance would be a shorter-range, twin-engined, wide-body regional type aircraft.

- The current deregulation of cargo air carrier operations is anticipated to generate additional service to new cities at reduced stage lengths, less than 3000 kilometers. This factor combined with other qualitative study results including the case study findings will, if realized, increase the demand for the regional size aircraft.

- Very little demand exists for a derivative small, short-range, narrow-bodied cargo aircraft, of the 22 000 kilogram payload class.

- Within the ground rules and constraints of the operational simulation, the introduction of derivative aircraft generates a larger total fleet than would be generated by continued use of contemporary aircraft only. This might indicate that contemporary aircraft are not as well matched to the market as the derivatives would be. This is especially noted in the United States markets where the derivative cargo fleet is almost double the contemporary fleet. In the foreign market, the increase in fleet size is about 10 percent greater.

- The trend to 1985 will be toward the realization of increased airline profit with improved return on investment and price stability.

- The shipper/consignee is not interested in the cargo aircraft used to transport his freight, only the resulting service and price.

- The cost and performance penalties associated with military requirements can make the joint military/civil aircraft noncompetetive in the commercial market.

- Current institutional agreements and regulations are one of the more influential road blocks to large aircraft, new network and operational concepts, and improved customs operation.

- Design and planning of future airports must be coordinated with the aircraft industries definition of dedicated cargo aircraft.

- The future growth of the air cargo market and the development of a comparable air cargo system requires the coordinated initiative of government agencies, the airline and aircraft industries, and civil domestic and international air transport organizations.

N79-27113

Section 1

1990 SYSTEM CHARACTERISTICS AND REQUIREMENTS

Air cargo transport operating in combination with the other modes of transport make up the total transportation system of the United States. As one element in the total system, the past growth of the air cargo system has been, and its future growth will be, affected by developments in the remaining elements of the total system. This section, therefore, identifies potential future developments that may occur in the air, truck, rail and sea transportation industries. It also identifies the multiplicity of cross impacts that must be considered when viewing air cargo as an integrated transport system.

Technological and operational developments are qualitatively evaluated for their potential effect upon the vehicle and institutional characteristics of the respective modes. Although current data indicate that the considered developments are possible, not all will be pursued for a variety of reasons, many of which will be nontechnical. During the course of study, these results provided a framework within which to investigate the future of intermodal competitiveness and integration. On the other hand, the cross-impact results provided a guide to the relative importance of the many issues pertinent to establishing an effective, integrated air cargo system.

Evaluation of Impact of Technology and Institutional Changes on the Transport System

A qualitative exposition of the anticipated characteristics of the 1990 cargo transport infrastructure involved examination of expected technological and institutional changes from the 1977 time period. Different transport modes examined were air cargo, highway trucking, and railroad systems. These three transport media were analyzed in some detail. Technological and institutional changes in river, lake, and ocean transport did not appear very promising. Thus, water transport was reviewed in gross detail only.

A series of charts was prepared to show the interactive relationships between technological development, vehicle and supporting operations, and institutional operations with these terms as one side of a matrix. The other matrix dimension included vehicle characteristics, infrastructure (system) characteristics, and shipper desires. The last category was derived from surveys of freight forwarders, product manufacturers, and airlines. The matrix items are presented in three tables, each with several pages. They are Table 1-1, Air Cargo Systems; Table 1-2, Highway Cargo Systems; and Table 1-3, Rail Cargo Systems.

In the three series of tables, the horizontal listings are each sub-elements of the general categories of vehicle characteristics, infrastructure characteristics, and shipper requirements. Each vehicle characteristic refers to a physical parameter, a performance measure, or a cost factor. Infrastructure characteristics consist of the providers and users of transportation services, the physical entities within the system, and the functions and interfaces of various system elements.

In reviewing the interaction entries in each table, it should be remembered that the primary impact is indicated with a somewhat detailed discussion in each section following. Lesser relations are implied, but generally not stated.

Air cargo systems - technologies. - Current trends in commercial transport aircraft are to consider the major bulk of cargo and freight as moving in the belly pits of wide-bodied passenger aircraft. In addition, there are configurations of conventional, narrow-bodied and wide-bodied aircraft which are devoted solely to cargo operations. Three domestic cargo carriers offer a regular scheduled service. Other charter carriers offer specialized airlift to all areas of the world. With the apparent trend in passenger traffic, domestic carriers will expand their cargo capacity with each DC-10, B747, and L-1011 they acquire in the next decade. Some versions of these aircraft also are produced as cargo carriers.

TABLE 1-1
AIR CARGO SYSTEM
EVALUATION OF POTENTIAL DEVELOPMENTS

AIRCRAFT TECHNOLOGIES	AIRCRAFT CHARACTERISTICS											
	PAYLOAD	SPEED	RANGE	PRODUCTIVITY	MAINTAINABILITY	DOCKING, LOADING	INTERIOR, EXTERIOR CONFIGURATION	ENERGY CONSUMPTION	FABRICATION	ACQUISITION COST	FLIGHT OPERATIONS COSTS	NUMBER IN FLEET
LAMINAR FLOW, SUPERCRITICAL WING, DRAG REDUCTION	GREATER PAYLOAD FACTOR	HIGHER SPEED WITH SAME POWER	INCREASED RANGE/PAYLOAD FRACTION	POSSIBLE INCREASE WITH SPEED	POSSIBLE INCREASED MAINTENANCE			REDUCED POWER REQUIREMENTS	INCREASED COMPLEXITY	POSSIBLE INCREASE	POSSIBLE INCREASE OR DECREASE	REDUCED NUMBER FOR SAME TASK
ACTIVE, AUGMENTED FLIGHT CONTROL SYSTEMS		POTENTIAL INCREASE IN BLOCK SPEED		POTENTIAL INCREASE	INCREASE IN MAINTENANCE		ENLARGED LOADING ENVELOPE	POTENTIAL REDUCTION	INCREASED COMPLEXITY	INCREASE	POSSIBLE INCREASE	POTENTIAL REDUCTION
TURBOFAN ENGINE IMPROVEMENTS	RELATIVE INCREASE, TRADEOFF POTENTIAL	RELATIVE INCREASE, TRADEOFF POTENTIAL	POTENTIAL TRADEOFFS	POTENTIAL TRADEOFFS				RELATIVE REDUCTION - IMPROVED CYCLE EFFICIENCIES			RELATIVE REDUCTION	
TURBOPROP ENGINE IMPROVEMENTS	RELATIVE INCREASE, TRADEOFF POTENTIAL	RELATIVE INCREASE, TRADEOFF POTENTIAL	POTENTIAL TRADEOFFS	POTENTIAL TRADEOFFS				RELATIVE REDUCTION - IMPROVED CYCLE EFFICIENCIES			RELATIVE REDUCTION	
ADVANCED FUELS RESEARCH	POTENTIAL IMPROVEMENT										POSSIBLE INCREASE WITH OIL SCARCITY	
MATERIALS - COMPOSITES	GREATER PAYLOAD FACTOR			POTENTIAL INCREASE	IMPROVEMENT				AUTOCLAVE TECHNOLOGY	POSSIBLE INCREASE	RELATIVE REDUCTION	
- ADVANCED METALLICS	GREATER PAYLOAD FACTOR			POTENTIAL INCREASE	IMPROVEMENT				INCREASED COMPLEXITY	INCREASE	RELATIVE REDUCTION	
CONFIGURATION - EXTERIOR	INCREASE WITH LARGER AIRCRAFT			POTENTIAL INCREASE	DESIGN TRADEOFF	IMPROVED INTERFACE	POTENTIAL STOL OR VTOL			POSSIBLE INCREASE		
- INTERIORS				POTENTIAL INCREASE	SIMPLIFICATION	INCREASED AUTOMATION				POSSIBLE INCREASE		
DESIGN TECHNIQUES AND AUTOMATED DRAFTING									SIMPLIFICATION	RELATIVE REDUCTION		
FABRICATION TECHNIQUES. - ADHESIVE BONDING	GREATER PAYLOAD FACTOR				POTENTIAL SHIFT IN EQUIPMENT AND FIELD TECHNIQUES				INCREASED COMPLEXITY	RELATIVE DECREASE		
- ISOGRID STRUCTURES	INCREASED FACTOR				SIMPLIFICATION IMPROVEMENT		SIMPLIFIED INTERIORS		INCREASED COMPLEXITY	RELATIVE INCREASE		
LANDING GEAR, FLOTATION	POTENTIAL INCREASE IN LANDING WEIGHTS				POTENTIAL IMPROVEMENTS							POTENTIAL INCREASE AT SECONDARY AIRPORTS
LIGHTER-THAN-AIR	POTENTIAL CARGO LOADS OF 450 TONNE	<95 KM/HR	VARIABLE	LESS THAN CONVENTIONAL AIRCRAFT	POTENTIAL WEATHER DAMAGE	REQUIRES NEW EQUIPMENT		POTENTIAL SAVINGS	NEW FACILITIES REQUIRED	EXPENSIVE NEW SYSTEM	EXTENSIVE TRAINING PROGRAM	NEW PROCUREMENT

TABLE 1-1.- Continued
AIR CARGO SYSTEM
EVALUATION OF POTENTIAL DEVELOPMENTS

	AIRCRAFT CHARACTERISTICS											
	PAYLOAD	SPEED	RANGE	PRODUCTIVITY	MAINTAIN-ABILITY	DOCKING, LOADING	INTERIOR, EXTERIOR CONFIGURATION	ENERGY CONSUMPTION	FABRICATION	ACQUISITION COST	FLIGHT OPERATIONS COST	NUMBER IN FLEET
AIRCRAFT OPERATIONS. INTEGRATED DOOR-TO-DOOR SERVICE	POTENTIAL INCREASE	REDUCTION IN TOTAL TRANSIT TIME		INCREASE WITH HIGHER LOAD FACTORS		REQUIRED COMPATIBILITY, SURFACE, AIR	MODAL INTERFACE COMPATIBILITY	POTENTIAL RELATIVE REDUCTION				
MULTICARRIER DOOR-TO-DOOR SERVICE		REDUCTION IN TOTAL TRANSIT TIME		POTENTIAL INCREASE		REQUIRED COMPATIBILITY SURFACE, AIR	MODAL INTERFACE COMPATIBILITY					
PROLIFERATED HUB-SPOKE	POTENTIAL DECREASE	REDUCTION IN TOTAL TRANSIT TIME	SHORTER AVERAGE STAGE LENGTHS					INCREASED WITH SHORTER STAGE LENGTHS			POSSIBLE INCREASE WITH SHORTER STAGE LENGTHS	POTENTIAL INCREASE
MULTISTOP ITINERARY	MULTIPLE PICKUPS			PROBABLE DECREASE		INTERIOR FLEXIBILITY REQUIRED FOR MULTISTOP	INCREASE WITH SHORTER STAGE LENGTHS				POSSIBLE INCREASE WITH SHORTER STAGE LENGTHS	
REDUCED CRUISE SPEED		DECREASE		POTENTIAL DECREASE				POTENTIAL REDUCTIONS			POTENTIAL REDUCTIONS	TRADEOFF POTENTITAL SPEED, PAYLOAD FREQUENCY
GROUND SUPPORT OPERATIONS. REMOTE CARGO TERMINAL				INCREASED WITH LESS LOADING TIMES		OPTIMIZED CONFIGURATIONS		POTENTIAL DECREASE IN AIR - INCREASE ON GROUND			POTENTIAL REDUCTIONS	
DEDICATED CARGO AIRPORTS				INCREASED WITH LESS LOADING TIMES		OPTIMIZED CONFIGURATIONS		POTENTIAL DECREASE IN AIR - INCREASE ON GROUND			POSSIBLE DECREASE	
TERMINAL AUTOMATION				POTENTIAL INCREASE		FASTER LOAD-ING AND UNLOADING	AIRCRAFT AND TERMINAL COMPATIBILITY				POSSIBLE DECREASE	
IMPROVEMENTS IN JOINT CARGO AND PASSENGER LOADING				POTENTIAL INCREASE		OPTIMIZATION OF DOCKING CONFIGURATIONS		POTENTIAL REDUCTION				
AIRWAYS CONTROL AND DATA MANAGEMENT		POTENTIAL DECREASE IN BLOCK TIMES		POTENTIAL INCREASE				POTENTIAL REDUCTION			POSSIBLE DECREASE	

TABLE 1-1.- Continued
AIR CARGO SYSTEM
EVALUATION OF POTENTIAL DEVELOPMENTS

INSTITUTIONAL OPERATIONS	AIRCRAFT CHARACTERISTICS											
	PAYLOAD	SPEED	RANGE	PRODUCTIVITY	MAINTAIN-ABILITY	DOCKING, LOADING	INTERIOR, EXTERIOR CONFIGURATION	ENERGY CONSUMPTION	FABRICATION	ACQUISITION COST	FLIGHT OPERATIONS COST	NUMBER IN FLEET
JOINT AIR-SURFACE RATES FOR NEW MARKETS				POTENTIAL INCREASE				POTENTIAL RELATIVE REDUCTION				
CONTAINERS FOR INTERMODAL COMPATIBILITY	INCREASE IN TARE WEIGHT			POTENTIAL INCREASE IN FLIGHT HOURS		MODAL INTERFACE COMPATIBILITY	POTENTIAL INTERIORS MODIFICATION	RELATIVE INCREASE		POSSIBLE INCREASE FROM INTERIOR CHANGES		
PRE-SEALED, DOCUMENTED CONTAINERS FOR INTERNATIONAL OPERATIONS				POTENTIAL INCREASE IN FLIGHT HOURS		TIME SAVINGS AT CUSTOMS PORTS	POTENTIAL INTERIORS MODIFICATION	RELATIVE INCREASE				
AUTOMATED DOCUMENTATION, IDENTIFICATION, AND TRANSIT CONTROL FOR CARGO CONTAINERS				POTENTIAL INCREASE IN FLIGHT HOURS		TIME SAVINGS						
DEDICATED FLEETS FOR INTEGRATED OR INTERNATIONAL TRADING FIRMS	CONSISTENTLY HIGH LOAD FACTOR			POTENTIAL INCREASE	POTENTIAL IMPROVEMENTS		SIMPLIFIED INTERIORS	POTENTIAL RELATIVE REDUCTIONS		POSSIBLE DECREASE		POTENTIAL INCREASE
NEW MATERIALS AND DESIGNS FOR CONTAINERS	POTENTIAL DECREASE IN TARE WEIGHT			POTENTIAL INCREASE		SIMPLIFICATION OF INTERFACE	SIMPLIFIED INTERIORS	IMPROVED EFFICIENCY PER UNIT OF CARGO				
BLOCK CAPACITY RATES	POTENTIAL INCREASE			POTENTIAL REVENUE INCREASE								POTENTIAL INCREASE
JOINT DAY AND NIGHT USE OF CARGO TERMINAL FOR FORWARDERS AND CARRIERS												
CARRIER DEREGULATION				POTENTIAL DECREASE			POTENTIAL NEW CONFIGURATIONS	POTENTIAL INCREASE/UNIT CARGO			POTENTIAL INCREASE/UNIT CARGO	INCREASE

TABLE 1-1.- Continued
AIR CARGO SYSTEM
EVALUATION OF POTENTIAL DEVELOPMENTS

	INFRASTRUCTURE CHARACTERISTICS							SHIPPER REQUIREMENTS					
	AIRLINE OPERATOR	AIRPORT OPERATOR	AIRWAYS ENVIRONMENT	CARGO TERMINAL	FORWARDER	MODAL INTERFACE	MARKET STRUCTURE	TRANSPORT SECURITY	10- 20- 40-FT. CONTAINERS	SINGLE WAYBILL	MINIMUM TIME	MINIMUM COST	PROLIFERATED DISTRIBUTION
AIRCRAFT TECHNOLOGIES: LAMINAR FLOW, SUPERCRITICAL WING DRAG REDUCTION	INCREASED PRODUCTIVITY, LESS FUEL										DECREASED BLOCK TIMES		SPECIAL AIRCRAFT TO SMALLER AIRPORTS
ACTIVE, AUGMENTED FLIGHT CONTROL SYSTEMS	REDUCED BLOCK TIMES, STOL POTENTIAL								GREATER FLEXIBILITY IN LOADING ENVELOPE		DECREASED BLOCK TIMES		POTENTIAL SERVICE TO SMALLER AIRPORTS
TURBOFAN ENGINE IMPROVEMENTS	RELATIVE REDUCTION IN FUEL	NOISE AND POLLUTION REDUCED									POTENTIAL DECREASE IN BLOCK TIMES	POTENTIAL FOR LOWER RATES	POTENTIAL SERVICE TO SMALLER AIRPORTS
TURBOPROP ENGINE IMPROVEMENTS	RELATIVE REDUCTION IN FUEL	NOISE AND POLLUTION REDUCED	REDUCTION IN CONTROL AREA FLIGHT TIMES								POTENTIAL DECREASE IN BLOCK TIMES	POTENTIAL FOR LOWER RATES	
ADVANCED FUELS RESEARCH												POSSIBLE INCREASE IN CARGO RATES	
MATERIALS, COMPOSITES	INCREASED MAINTENANCE COMPLEXITY												
- ADVANCED METALLICS	REDUCED MAINTENANCE												
CONFIGURATION - EXTERIOR		POTENTIAL GROUND INTERFERENCES		DOCKING INTERFACE CHANGES		VEHICLE COMPATIBILITY REQUIREMENTS	POTENTIAL FOR NEW REGIONS						POTENTIAL SERVICE TO SMALL AIRPORTS
- INTERIORS	NEW OR DERIV. AIRCRAFT FOR >10' CONTAIN.			POSSIBLE CHANGES IN LOADING EQUIP					NEW OR DERIVED AIRCRAFT REQUIRED				
DESIGN TECHNIQUES AND AUTOMATED DRAFTING													
FABRICATION TECHNIQUES													
- ADHESIVE BONDING	INCREASED MAINTENANCE COMPLEXITY												
- ISOGRID STRUCTURES	REDUCED MAINTENANCE												
LANDING GEAR, FLOTATION		POTENTIAL FOR LOWER FOOT-PRINT PRESSURE					EXTENSION TO NEW MARKET REGIONS						EXPANSION TO SECONDARY AIRPORTS
LIGHTER-THAN-AIR	NEW VEHICLE SYSTEM	INCOMPATIBLE VEHICLES	INCOMPATIBLE FLIGHT PROFILE	NEW VEHICLE INTERFACE		VEHICLE COMPATIBILITY REQUIREMENTS	SERVICE TO NON-AIRPORT REGIONS		FLEXIBILITY IN LOADING		INCREASED BLOCK TIMES		POTENTIAL NEW ROUTES

TABLE 1-1.- Continued
AIR CARGO SYSTEM
EVALUATION OF POTENTIAL DEVELOPMENTS

	INFRASTRUCTURE CHARACTERISTICS												
								SHIPPER REQUIREMENTS					
	AIRLINE OPERATOR	AIRPORT OPERATOR	AIRWAYS ENVIRONMENT	CARGO TERMINAL	FORWARDER	MODAL INTERFACE	MARKET STRUCTURE	TRANSPORT SECURITY	10- 20- 40-FT CONTAINERS	SINGLE WAYBILL	MINIMUM TIME	MINIMUM COST	PROLIFERATED DISTRIBUTION
AIRCRAFT OPERATIONS:													
INTEGRATED DOOR-TO-DOOR SERVICE	SINGLE OR JOINT MODAL OPERATIONS			INTERMODAL COMPATIBILITY	FUNCTION MAY BE DONE BY AIRLINE	COORDINATED BY CARRIER	MERGED SERVICE WITH POTENTIAL EXPANSION	COORDINATOR RESPONSIBILITY	VARIABLE OWNERSHIP	COORDINATED RESPONSIBILITY	LESS INTERMODAL DELAY	POTENTIAL COST SAVINGS	EXPANSION OF AIR SERVICE
MULTI-CARRIER DOOR-TO-DOOR SERVICE	COOPERATION WITH SURFACE CARRIER			INTERMODAL COMPATIBILITY	COOPERATIVE FUNCTION	COOPERATIVE AMONG CARRIERS		COORDINATOR RESPONSIBILITY	VARIABLE OWNERSHIP	REQUIRES COORDINATION	POTENTIAL INTERMODAL DELAYS		
PROLIFERATED HUB-SPOKE	POTENTIAL EXPANSION OF NETWORK	INCREASED OPERATIONS	POTENTIAL INCREASED TRAFFIC	POSSIBLE INCREASE IN FACILITIES	GREATER CHOICE OF SHIPPER NETWORKS	GREATER CONTACT AND PROBLEMS	POTENTIAL EXPANSION WITH SMALLER AIRCRAFT	CARRIER RESPONSIBILITY INCREASED EXPOSURE		COORDINATED RESPONSIBILITY	POTENTIAL CHANGE PLUS OR MINUS		BETTER SERVICE POTENTIAL
MULTI-STOP ITINERARY	CHANGE IN NETWORK	INCREASED OPERATIONS	POTENTIAL INCREASED TRAFFIC	POSSIBLE INCREASE IN FACILITIES	POTENTIAL EXPANSION OF NETWORKS	GREATER CONTACT WITH SURFACE CARRIERS	TRADEOFF SERVICE WITH AIRCRAFT SIZE	INCREASED EXPOSURE			POTENTIAL INCREASE IN AIR TRANSIT TIME		EXPANSION OF AIR SERVICE
REDUCED CRUISE SPEED	SAVINGS IN FUEL		PATTERN TRAFFIC POTENTIAL PROBLEMS								POTENTIAL INCREASE		
GROUND SUPPORT OPERATIONS:													
REMOTE CARGO TERMINAL	INCREASED FACILITIES, LOSS OF CENTRAL CONVENIENCE	POTENTIAL REDUCTION OF AIRPORT OPERATIONS AND CONGESTION		BENEFITS OF SPECIALIZATION INTERLINE PROBLEMS	POSSIBLE INCREASED ACCESSIBILITY	POSSIBLE INCREASED ACCESSIBILITY		POSSIBLE INCREASED EXPOSURE	INCREASED EASE OF ACCESS AND HANDLING		REQUIRES TIGHT CONTROL OF TRANSFER FUNCTION TO/FROM AIRPORT	POTENTIAL COST SAVINGS	POTENTIAL DUPLICATION OF INTERFACES, SHIPPER AND CARRIER
DEDICATED CARGO AIRPORTS	BENEFIT ALL-CARGO - DETRIMENT TO PAX/BELLY-PIT	REQUIRES NEW OR ADDED FACILITIES	PROLIFERATION OF TRAFFIC PATTERNS	BENEFITS OF SPECIALIZATION, INTERLINE PROBLEMS	INCREASED ACCESSIBILITY	POSSIBLE INCREASED ACCESSIBILITY		BETTER CONTROL	INCREASED EASE OF ACCESS AND HANDLING		POSSIBLE IN INCREASE DUE TO EXTENDED GROUND TRAVEL	POTENTIAL INCREASE DUE TO EXTENDED GROUND TRAVEL	
TERMINAL AUTOMATION				POTENTIAL COST AND TIME SAVINGS				POTENTIALLY BETTER CONTROL		INCREASED EFFICIENCY	POTENTIAL TIME SAVINGS	POTENTIAL COST SAVINGS	
IMPROVEMENTS IN JOINT CARGO AND PASSENGER LOADING	REDUCED GROUND TIME FOR AIRCRAFT			INTERLINE TRANSFER PROBLEMS		REQUIRES CAREFUL COORDINATION		NEEDS IMPROVEMENT	INCOMPATIBLE WITH PAX AND BELLY PITS		POTENTIAL TIME SAVINGS	POTENTIAL TIME SAVINGS	
AIRWAYS CONTROL AND DATA MANAGEMENT	IMPROVED DATA TRANSMISSION TO ENROUTE AIRCRAFT	INCREASED OPERATING CAPACITIES	AUTOMATED ENROUTE AND TERMINAL AREA CONTROL										

TABLE 1-1.- Concluded
AIR CARGO SYSTEM
EVALUATION OF POTENTIAL DEVELOPMENTS

INSTITUTIONAL OPERATIONS	INFRASTRUCTURE CHARACTERISTICS													
								SHIPPER REQUIREMENTS						
	AIRLINE OPERATOR	AIRPORT OPERATOR	AIRWAYS ENVIRONMENT	CARGO TERMINAL	FORWARDER	MODAL INTERFACE	MARKET STRUCTURE	TRANSPORT SECURITY	10- 20- 40-FT CONTAINERS	SINGLE WAYBILL	MINIMUM TIME	MINIMUM COST	PROLIFERATED DISTRIBUTION
JOINT AIR-SURFACE RATES FOR NEW MARKETS	POTENTIAL INCREASE IN CARGO	INCREASED OPERATIONS	INCREASED TRAFFIC	INTERMODAL COMPATIBILITY FOR MINIMUM COST AND TIME	EXPAND TO NEW SHIPPERS	MINIMIZED INTERFERENCE	ATTRACT NEW COMMODITIES, IMPROVED SERVICE		PROMOTION OF COMPATIBLE CONTAINERS - AIR/TRUCK/RAIL	FORWARDER OR CARRIER RESPONSIBILITY		POTENTIAL SAVINGS	REQUIRES INTERNATIONAL COOPERATION
CONTAINERS FOR INTERMODAL COMPATIBILITY	REVISIONS TO AIRCRAFT FOR LOADING			INTERLINE TRANSFER COMPATIBILITY	EXPANDED HANDLING REQUIREMENTS	CONTAINER COMPATIBILITY	ATTRACT NEW COMMODITIES, IMPROVED SERVICE	IMPROVED SECURITY WITH PRELOADING	TARE WEIGHT PROBLEMS	UNITIZATION COST BORNE BY SHIPPER		SAVINGS IN CONSOLIDATION AND UNITIZATION	
PRE-SEALED, DOCUMENTED CONTAINERS FOR INTERNATIONAL OPERATIONS	SIMPLIFIED HANDLING			SIMPLIFIED HANDLING AND PROCESSING	FORWARDER CONTROLLED	AIR/SURFACE COMPATIBILITY	INCREASE DUE TO IMPROVED SERVICE	GOOD SECURITY		UNITIZATION COST BORNE BY SHIPPER	CONSIDERABLE SAVINGS IN CUSTOMS PROCESSING TIME	REDUCED CUSTOMS CHARGES	
AUTOMATED DOCUMENTATION, IDENTIFICATION, AND TRANSIT CONTROL FOR CARGO CONTAINERS	PASSIVE OR ACTIVE SIGNAL DETECTORS			SIGNAL IDENTIFIER AND DATA PROCESSERS	SIGNAL GENERATORS	COMPATIBLE RECOGNITION AND PROCESSING EQUIPMENT	INCREASE DUE TO IMPROVED SERVICE	TRANSIT MONITORING	IMPROVED CONTAINER UTILIZATION	INTEGRATED DOCUMENT SYSTEM		POTENTIAL SAVINGS	
DEDICATED FLEETS FOR INTEGRATED OR INTERNATIONAL TRADING FIRMS	COMPETITIVE OR LEASING POTENTIAL	POTENTIAL INCREASED OPERATIONS	POTENTIAL INCREASED TRAFFIC	MIGHT RESULT IN UNDER-UTILIZATION OF TERMINALS	SERVICE NOT USED		EXPANSION TO NEW MARKETS AND COMMODITIES	GOOD SECURITY	MAXIMUM UTILIZATION EFFICIENCY	NOT NEEDED		POTENTIAL SAVINGS	
NEW MATERIALS AND DESIGNS FOR CONTAINERS	POTENTIAL INCREASE IN PAYLOAD AND INTERIOR COMPATIBILITY			POTENTIAL FOR INCREASED EFFICIENCY		POTENTIAL FOR GREATER COMPATIBILITY		DESIGNED FOR SECURITY	LIGHTER WEIGHTS		REDUCTION IN HANDLING TIME	POTENTIAL SAVINGS IN RATES	
BLOCK CAPACITY RATES	POTENTIAL REVENUE GUARANTEES						POTENTIAL ATTRACTION OF NEW COMMODITIES		PROMOTION OF CONTAINERS				
JOINT DAY AND NIGHT USE OF CARGO TERMINAL FOR FORWARDERS AND CARRIERS	POTENTIAL COST SAVINGS			INCREASED UTILIZATION EFFICIENCY	POTENTIAL COST SAVINGS							POTENTIAL COST SAVINGS	
CARRIER DEREGULATION	EXPANSION OF ROUTE STRUCTURE	POTENTIAL SATURATION PLUS NEW ROUTES	PROLIFERATION OF TRAFFIC REDISTRIBUTION	POTENTIAL INCREASED UTILIZATION	GREATER ORIGIN AND DESTINATION POTENTIAL		INCREASE DUE TO IMPROVED SERVICE				POTENTIAL SAVINGS IN SWITCH TO AIR		EXPANSION OF SERVICE TO MORE CITIES

TABLE 1-2
HIGHWAY CARGO SYSTEM
EVALUATION OF POTENTIAL DEVELOPMENTS

	VEHICLE CHARACTERISTICS									
	PAYLOAD	SPEED	PRODUCTIVITY	MAINTAINABILITY	DOCKING, LOADING	INTERIOR, EXTERIOR CONFIGURATION	ENERGY CONSUMPTION	FABRICATION	ACQUISITION COST	LINE HAUL OPERATIONS COSTS/TON
TRUCK AND TRAILER TECHNOLOGIES OPTIMIZED DESIGN FOR. - LIGHT-WEIGHT VEHICLES (STRUCTURES AND MATERIALS)	INCREASED PAYLOAD FRACTION		INCREASED POTENTIAL	REVISED METHODS FOR NEW MATERIALS AND STRUCTURES			RELATIVE REDUCTION	POTENTIAL USE OF COMPOSITES AND ADVANCED METALLICS	POTENTIAL INCREASE	RELATIVE REDUCTION
- STREAMLINING							REDUCTION	ADDED COMPLEXITY	RELATIVE INCREASE	RELATIVE REDUCTION
- TANKERS AND SPECIAL-PURPOSE VEHICLES			POTENTIAL INCREASE	INCREASED SCOPE OF MAINTENANCE	POTENTIAL SIMPLIFICATION	DESIGNED FOR PURPOSE		POTENTIAL INCREASED COMPLEXITY	POTENTIAL INCREASE	RELATIVE SAVINGS IN SPECIALIZATION
IMPROVED SUSPENSION AND BRAKE SYSTEMS	POSSIBLE INCREASE ,	HIGHER BLOCK SPEED POTENTIAL		POTENTIAL IMPROVEMENT			POTENTIAL REDUCTION			POTENTIAL SAVINGS
LARGER, MORE EFFICIENT ENGINES	POSSIBLE INCREASE	HIGHER BLOCK SPEEDS	POTENTIAL INCREASE	POTENTIAL IMPROVEMENT			POTENTIAL REDUCTION		SLIGHT INCREASE	RELATIVE SAVINGS
TURBINE DEVELOPMENT	POTENTIAL INCREASE IN POWER/WEIGHT	HIGHER BLOCK SPEEDS	POTENTIAL INCREASE	INCREASED REQUIREMENT		POTENTIAL CHANGE	HIGHER THAN DIESEL		MODERATE INCREASE	INCREASED
MULTIMODE CONTAINER COMPATIBILITY	POTENTIAL INCREASE IN TARE WEIGHT		RELATIVE INCREASE	INCREASED REQUIREMENT	SIMPLIFICATION, COMPATIBILITY REQUIREMENT	JOINT REDESIGN INTERIORS AND CONTAINERS			SLIGHT INCREASE	POTENTIAL CHANGE
TRUCK SYSTEM OPERATIONS. LARGER TRUCKS, DUAL AND TRIPLE TRAILER TOWS	SIGNIFICANT INCREASE		SIGNIFICANT INCREASE		EXPANSION OF FACILITIES		RELATIVE SAVINGS		SOME INCREASE	RELATIVE SAVINGS
AUTOMATED DATA MANAGEMENT. - CARGO THROUGH-BILLING			POTENTIAL INCREASE							SLIGHT SAVINGS
- CARGO AND VEHICLE IDENTIFICATION FOR SCHEDULING AND CONTROL		POTENTIAL INCREASE IN BLOCK SPEED	POTENTIAL INCREASE				POTENTIAL SAVINGS		ADDED EQUIPMENT COSTS	POTENTIAL REDUCTION
- DISPATCH-CREW COMMUNICATIONS		POTENTIAL INCREASE IN BLOCK SPEEDS	POTENTIAL INCREASE				POTENTIAL SAVINGS		MODEST EQUIPMENT COSTS	POTENTIAL REDUCTION
- INTERLINE CARGO TRANSFERS					SIMPLIFICATION REQUIRED	INTERIOR COMPATIBILITY				POTENTIAL SAVINGS
HIGHWAY AND MARKER DESIGNS FOR GREATER SAFETY		POTENTIAL INCREASE IN BLOCK SPEEDS	POTENTIAL INCREASE THROUGH SAFER OPERATIONS				POTENTIAL SAVINGS			POTENTIAL SAVINGS
DEDICATED TRUCK LANES IN HIGH-DENSITY TRAFFIC AREAS		INCREASED AVERAGE BLOCK SPEEDS	INCREASE THROUGH TIME SAVINGS				MORE EFFICIENT CRUISE			POTENTIAL SAVINGS
INCREASED ROUTE AND BACKHAUL FLEXIBILITY	BETTER OVERALL PAYLOAD FRACTIONS		POTENTIAL INCREASE				GREATER SYSTEM EFFICIENCY			POTENTIAL INCREASE IN REVENUE
INTERLINE AND INTERMODAL TERMINALS			POTENTIAL INCREASE		REQUIRES COMPATIBLE CONFIGURATIONS					

TABLE 1-2 (CONCLUDED)
HIGHWAY CARGO SYSTEM
EVALUATION OF POTENTIAL DEVELOPMENTS

	INFRASTRUCTURE CHARACTERISTICS							SHIPPER REQUIREMENTS					
	TRUCK LINE OPERATOR	ROADWAYS	OPERATING ENVIRONMENT	CARGO TERMINAL	FORWARDER	MODAL INTERFACE	MARKET STRUCTURE	TRANSPORT SECURITY	10- 20- 40-FT CONTAINERS	SINGLE WAYBILL	MINIMUM TIME	MINIMUM COST	PROLIFERATED DISTRIBUTION
TRUCK AND TRAILER TECHNOLOGIES: OPTIMIZED DESIGN FOR - LIGHT-WEIGHT VEHICLES (STRUCTURES AND MATERIALS)	INCREASED REVENUE PAYLOAD											POTENTIAL SAVINGS	
- STREAMLINING	FUEL SAVINGS		POSSIBLE REDUCED NOISE	DOCKING, LOADING COMPATIBILITY					POTENTIAL REDUCTION IN COMPATIBILITY			POSSIBLE SAVINGS	
- TANKERS AND SPECIAL-PURPOSE VEHICLES	EFFICIENCIES OF SCALE			SPECIALIZED HANDLING AND LOADING EQUIPMENT			COMMODITY SPECIALIZATION	IMPROVEMENT	POTENTIALLY GREATER ACCOMMODATION				
IMPROVED SUSPENSION AND BRAKE SYSTEMS	REDUCED MAINTENANCE	POTENTIAL REDUCTION IN MAINTENANCE									POTENTIAL SAVINGS	POTENTIAL SAVINGS	
LARGER, MORE EFFICIENT ENGINES	UPGRADED EQUIPMENT		REDUCED NOISE AND POLLUTION								POTENTIAL SAVINGS	POTENTIAL SAVINGS	
TURBINE DEVELOPMENT	REEQUIPMENT PROBLEMS										POTENTIAL SAVINGS	POTENTIAL INCREASE	
MULTIMODE CONTAINER COMPATIBILITY	POSSIBLE EQUIPMENT CHANGES			REQUIRES HANDLING AND LOADING FLEXIBILITY	INCREASED LOADING POTENTIAL	SIMPLIFICATION OF CONTAINERS	EXPANSION WITH IMPROVED SERVICE	POTENTIAL IMPROVEMENTS	MODAL STANDARDIZATION	REQUIRES COOPERATION BETWEEN MODES	POTENTIAL TIME SAVINGS	POTENTIAL RATE REDUCTION	GREATER AVAILABILITY OF SERVICE
TRUCK SYSTEM OPERATIONS LARGER TRUCKS, DUAL AND TRIPLE TRAILER TOWS	INCREASED UNIT REVENUE POTENTIAL	INCREASED MAINTENANCE ON ROADBEDS	POSSIBLE INCREASED NOISE AND POLLUTION	ADAPTATION TO LARGER VEHICLES AND TOWS								POTENTIAL RATE REDUCTIONS	
AUTOMATED DATA MANAGEMENT. - CARGO THROUGH-BILLING	SIMPLIFIED PROCEDURES			AUTOMATED DATA PROCESSING	COMPATIBLE EQUIPMENT, PROCEDURES REQUIRED	COMPATIBILITY REQUIRED				FORWARDER RESPONSIBILITY	POTENTIAL TIME SAVINGS	POTENTIAL RATE REDUCTIONS	
- CARGO AND VEHICLE IDENTIFICATION FOR SCHEDULING AND CONTROL	PASSIVE/ACTIVE SIGNAL AND DETECTION SYSTEMS		REQUIREMENT FOR DETECTION AND REPORTING	SIMPLIFIED HANDLING	COMPATIBLE EQUIPMENT REQUIRED			POTENTIAL IMPROVEMENT	INCREASED UTILIZATION		POTENTIAL TIME SAVINGS	POTENTIAL SAVINGS	
- DISPATCH-CREW COMMUNICATIONS	INCREASED EFFICIENCY WITH ON-BOARD EQUIPMENT		REQUIREMENT FOR SIGNAL RELAY EQUIPMENT					POTENTIAL IMPROVEMENT			POTENTIAL TIME SAVINGS		
- INTERLINE CARGO TRANSFERS	COORDINATED INTERLINE EQUIPMENT							POTENTIAL IMPROVEMENT		FORWARDER RESPONSIBILITY	POTENTIAL REDUCTION	POTENTIAL SAVINGS	
HIGHWAY AND BARRIER DESIGNS FOR GREATER SAFETY	ACCIDENT REDUCTION, INCREASED BLOCK SPEEDS	INCREASED INVESTMENT	REDUCED DRIVER STRESS					REDUCTION IN LOSSES TO ACCIDENTS			POTENTIAL TIME SAVINGS	POSSIBLE CHANGE WITH TAX STRUCTURE	
DEDICATED TRUCK LANES IN HIGH-DENSITY TRAFFIC AREAS	TIME SAVINGS IN URBAN TRANSIT	INCREASED INVESTMENT	MORE ROAD RIGHT-OF-WAY REQUIRED					REDUCTION IN LOSSES TO ACCIDENTS			POTENTIAL TIME SAVINGS	POSSIBLE IN INCREASE WITH USER TAXES	
INCREASED ROUTE AND BACKHAUL FLEXIBILITY	INCREASED REVENUE POTENTIAL				GREATER AVAILABILITY OF SERVICE							POSSIBLE RATE REDUCTIONS	GREATER AVAILABILITY OF SERVICE
INTERLINE AND INTERMODAL TERMINALS	GREATER EFFICIENCY OF TRANSFER TO OTHER CARRIERS			INCREASED ECONOMIES OF SCALE		POTENTIAL EFFICIENCIES AT CONVENIENT TRANSFER MODES		GREATER EXPOSURE	COMPATIBLE EQUIPMENT REQUIRED	FORWARDER RESPONSIBILITY	POTENTIAL DECREASE		

TABLE 1-3
RAIL CARGO SYSTEMS
EVALUATION OF POTENTIAL DEVELOPMENTS

RAIL TECHNOLOGIES.	VEHICLE CHARACTERISTICS									
	PAYLOAD	SPEED	PRODUCTIVITY	MAINTAIN-ABILITY	DOCKING, LOADING	INTERIOR EXTERIOR CONFIGURATION	FUEL CONSUMPTION	FABRICATION	ACQUISITION COST	LINE-HAUL OPERATIONS COSTS/TON
RAIL LINE ELECTRIFICATION				NEW REQUIREMENTS, EQUIPMENT, PROCEDURES	MODIFICATION REQUIRED		REDUCTIONS IN FUEL		RAIL ELECTRIFICATION, NEW VEHICLES	POTENTIAL SAVINGS
OPTIMIZED DESIGN FOR - LIGHT-WEIGHT CARS	NET INCREASE IN PAYLOAD	POTENTIAL INCREASE	POTENTIAL INCREASE	POTENTIAL IMPROVEMENT	POTENTIALLY GREATER MOBILITY	POSSIBLE CHANGES	TRADEOFF WITH PAYLOAD	MODERN MATERIALS, METHODS	NEW INVESTMENT	POTENTIAL SAVINGS
- IMPROVED SUSPENSION SYSTEMS	POTENTIAL INCREASE	POTENTIAL INCREASE	POTENTIAL INCREASE	POTENTIAL IMPROVEMENT			POTENTIAL REDUCTION			POTENTIAL SAVINGS
- STREAMLINING CARS AND ENGINES		INCREASE	POTENTIAL INCREASE	POTENTIAL IMPROVEMENT		NEW DESIGNS	RELATIVE REDUCTION	MORE SOPHISTICATED	INCREASED INVESTMENT	SAVINGS IN FUEL COSTS
- ACCIDENT INTEGRITY			POTENTIAL INCREASE	POTENTIAL IMPROVEMENT		REDUCTION ON INTERVEHICLE CONFLICT			INCREASED INVESTMENT	
- DEDICATED CARGO (TANKS, BULK, CONTAINERS, ETC.)			POTENTIAL INCREASE		DEDICATED FACILITIES REQUIRED	NEW DESIGNS OR MODIFICATIONS			POTENTIAL INCREASES	
- LARGER FLAT AND BOX CARS	INCREASED PAYLOAD		INCREASE		COMPATIBILITY REQUIRED	GREATER FLEXIBILITY	POTENTIAL REDUCTION/TON OF CARGO		INCREASED UNIT COSTS	POTENTIAL SAVINGS
- DUAL-MODE RAIL-TRUCK TRAILERS	INCREASED PAYLOAD FACTOR		POTENTIAL INCREASE	POTENTIAL INCREASED MAINTENANCE	COMPATIBILITY WITH RAIL, TRUCK	COMPLETELY NEW DESIGN	POTENTIAL REDUCTION	INCREASED COMPLEXITY	NEW INVESTMENT	POTENTIAL SAVINGS
HIGHER CAPACITY TRACKAGE AND MARSHALLING YARDS			POTENTIAL INCREASE				POTENTIAL SAVINGS		INCREASED INVESTMENT	POTENTIAL SAVINGS
IMPROVED MULTIMODE CONTAINER COMPATIBILITY			POTENTIAL INCREASE		INCREASED COMPATIBILITY	POSSIBLE MODIFICATIONS			INCREASED OWNERSHIP COSTS	
IMPROVED TOFC, COFC INTERFACES			POTENTIAL INCREASE		IMPROVED EQUIPMENT, PROCEDURES REQUIRED				POSSIBLE INCREASE IN EQUIPMENT COSTS	POTENTIAL REDUCTION
TRAIN OPERATIONS: TRAIN COMPOSITION (SIZE VS FREQUENCY)	POTENTIAL INCREASE IN PAYLOAD FACTORS	POSSIBLE INCREASE	POTENTIAL INCREASE				POSSIBLE INCREASE		POSSIBLE INCREASE IN LOCOMOTIVES	INCREASED UNIT COSTS
AUTOMATED DATA MANAGEMENT		REDUCTION IN TIME AT TERMINALS, MARSHALLING YARDS AND ON MAIN LINES	POTENTIAL INCREASE		HANDLING PROBLEMS FOR INTERLINE TRANSFERS		POSSIBLE SAVINGS IN CAR HANDLING AND TRAIN CONTROL		ADDED EQUIPMENT	POTENTIAL SAVINGS
SPECIAL HANDLING OF EXPRESS	SMALL ITEMS ONLY FOR EXPEDITED DELIVERY		INDETERMINATE, NEW TYPE OF SERVICE		EXPRESS AND PASSENGER INTERFACE COMPATIBILITY	NEW EXPRESS CAR DESIGN		COMPATIBLE WITH PASSENGER CAR FACILITIES	NEW VEHICLE INVESTMENT	

TABLE 1-3 (CONCLUDED)
RAIL CARGO SYSTEMS
EVALUATION OF POTENTIAL DEVELOPMENTS

	INFRASTRUCTURE CHARACTERISTICS							SHIPPER REQUIREMENTS					
	RAIL LINE OPERATOR	TRACKAGE AND YARDS	OPERATING ENVIRONMENT	CARGO TERMINAL	FORWARDER	MODAL INTERFACE	MARKET STRUCTURE	TRANSPORT SECURITY	10- 20- 40-FT CONTAINERS	SINGLE WAYBILL	MINIMUM TIME	MINIMUM COST	PROLIFERATED DISTRIBUTION
RAIL TECHNOLOGIES: RAIL LINE ELECTRIFICATION	ACQUIRE NEW EQUIPMENT	EXTENSIVE MODIFICATION	LESS NOISE AND POLLUTION	ELECTRIFIED SIDINGS								POTENTIAL SAVINGS	
OPTIMIZED DESIGN FOR - LIGHTWEIGHT CARS	INCREASED NET PAYLOAD	POTENTIAL REDUCTION IN MAINTENANCE	POTENTIAL NOISE REDUCTION								POTENTIAL REDUCTION	RELATIVE TONNAGE COST SAVINGS	
- IMPROVED SUSPENSION SYSTEMS	SAFER OPERATIONS, REDUCED COSTS	REDUCED WEAR ON TRACKS	POTENTIAL NOISE REDUCTION					LOWERED ACCIDENT RISK			POTENTIAL REDUCTION		
- STREAMLINING CARS AND ENGINES	TRADEOFF FUEL AND SPEED		POTENTIAL NOISE REDUCTION								POSSIBLE SAVINGS		
- ACCIDENT INTEGRITY	REDUCED DAMAGE LOSSES		REDUCED SPILLAGE OR VENTING					POTENTIAL IMPROVEMENT				REDUCED CASUALTY CLAIMS	
- DEDICATED CARGO (TANKS, BULK, CONTAINERS, ETC.)	ECONOMIES OF SPECIALIZATION - BACKHAUL PROBLEMS			SPECIALIZED LOADING FACILITIES				POTENTIAL IMPROVEMENT				RELATIVE COST SAVINGS WITH UNIT TRAINS	
- LARGER FLAT AND BOX CARS	ECONOMIES OF SCALE							POTENTIAL DECREASE	GREATER ACCOMMODATION			POTENTIAL SAVINGS	
- DUAL-MODE RAIL-TRUCK TRAILERS	ADDED EQUIPMENT	YARD COMPATIBILITY REQUIRED		COMPATIBLE HANDLING, LOADING EQUIPMENT	DOOR-TO-DOOR CAPABILITY	INCREASED COMPATIBILITY	POTENTIAL EXPANSION OF SERVICE	REDUCED CARGO EXPOSURE	COMPATIBILITY REQUIRED		POTENTIAL SAVINGS	POTENTIAL SAVINGS	INCREASED ROUTING FLEXIBILITY
HIGHER CAPACITY TRACKAGE AND MARSHALLING YARDS	SAVINGS IN COST AND TIME	ECONOMIES, INCREASED INVESTMENT										POTENTIAL SAVINGS	POTENTIAL SAVINGS
IMPROVED MULTIMODE CONTAINER COMPATIBILITY	EQUIPMENT MODIFICATION			HANDLING, LOADING FLEXIBILITY	INCREASED LOADING POTENTIAL	SIMPLIFICATION OF CONTAINERS	POTENTIAL EXPANSION OF SERVICE	POTENTIAL IMPROVEMENTS	MODAL STANDARDIZATION		POTENTIAL SAVINGS		
IMPROVED TOFC, COFC INTERFACES	EQUIPMENT, PROCEDURES CHANGES			SIMPLIFIED LOADING REQUIRED	INCREASED DOOR-TO-DOOR CAPABILITY	SIMPLIFICATION OF INTERFACES	POTENTIAL EXPANSION OF SERVICE	REDUCED CARGO EXPOSURE	MODAL COMPATIBILITY		POTENTIAL SAVINGS	POTENTIAL SAVINGS	
TRAIN OPERATIONS. TRAIN COMPOSITION (SIZE VS FREQUENCY)	RELATIVE INCREASE IN CREW COSTS FOR SHORT TRAINS	INCREASED TRAIN ASSEMBLY OPERATIONS	POTENTIAL REDUCTION IN IMPACT	INCREASED TERMINAL UTILIZATION	INCREASED SCHEDULE POTENTIAL	INCREASED SCHEDULE POTENTIAL	POTENTIAL EXPANSION OF SERVICE, COMMODITIES	BETTER SURVEILLANCE			POTENTIAL TIME SAVINGS	POSSIBLE RATE INCREASE TRADEOFF WITH SERVICE	INCREASED FREQUENCY
AUTOMATED DATA MANAGEMENT	ACQUIRE NEW EQUIPMENT	SIGNAL GENERATING, DETECTION SYSTEMS		CAR, CARGO IDENTIFYING SYSTEMS	IMPROVED SERVICE AND CARGO IDENTIFICATION	EQUIPMENT COMPATIBILITY AND COORDINATED PROCESSING		BETTER SURVEILLANCE		FORWARDER PROCESSING	POTENTIAL TIME SAVINGS	POSSIBLE SAVINGS	
SPECIAL HANDLING OF EXPRESS	NEW SCHEDULE AND TRAIN ASSEMBLY, NEW EQUIPMENT COSTS	CAR COORDINATION BETWEEN TERMINALS		EXPEDITED PROCESSING	INCREASED SERVICE OPTIONS	INTERMODAL PROCESSING COMPATIBILITY	ATTRACTION FOR NEW SHIPPERS	POSSIBLE INCREASED EXPOSURE			EXPEDITED SERVICE	PREMIUM RATE	EXPANDED SERVICE

It is expected that new commercial transport aircraft purchased through 1990 will be those in current production, and advanced derivatives will incorporate some new technology but avoid the magnitude of cost associated with a new development program. Technology likely to be incorporated in modified or derivative aircraft will include engine and aircraft component improvements directed at reduced specific fuel consumption, reduced noise, reduced emissions, and increased propulsive and aerodynamic efficiency (Reference 1-1). To an airline operator, the prime objective in his business is to maximize the differential between revenue received and cost of operations. A positive differential is gross profit which enables the airline to continue operating in a viable fashion. Technological, operational, and institutional changes all may serve either to reduce cost or increase revenue. Thus, the following discussions of each entry in Table 1-1 are presented in terms of profit potential for the operator and lowered rates and/or better service to the shippers.

Aerodynamic improvements: Technologies in this general area are involved with aerodynamic design and performance, control system functions, and the general interaction between the aircraft and its operating environment. The development of the supercritical wing resulted in superior lift-to-drag ratios compared with previous wing configurations. The effect is to reduce drag forces and, hence, power requirements without loss of lift or speed. A secondary effect is to achieve a thicker wing section with attendant increases in structural efficiency. Both new aircraft and derivative or growth versions of existing aircraft are expected to incorporate supercritical wing technology. Another prominent development is the laminar-flow wing with the boundary layer sucked or blown to reduce drag with an increase in the lift-to-drag ratio.

The potential impact of laminar flow control is summarized in the following:

- Greater payload fraction with increased revenue
- Higher cruise speed with reduced flight costs
- Increased range with increased revenue
- A greater annual productivity with savings in block time and potential reduction in fleet size

- A possible increase in maintenance costs due to the complexity of the flow control systems
- A reduction in fuel burned without loss of performance
- Greater complexity of fabrication with increases in acquisition cost
- Possible savings in cost and time both to operators and shippers

The use of a supercritical wing and other drag reductions will have the same effects as above except for a lesser or no comparable effect on fabrication and acquisition costs.

Active, augmented flight control systems: Active control systems technology will be applied increasingly in derivative and future aircraft. Reduced static stability systems sense flight path perturbations and actuate control surfaces to make a stabilizing correction in the aircraft attitude. Other active controls alleviate gust and maneuver loadings and wing flutter. Net savings in all of these arise in lower structural weights and attendant power savings (Reference 1-2). The application of these systems also may allow aircraft operations at higher speeds in turbulent air as compared with current aircraft. The effect of these might be:

- Increase in effective block speeds with resultant savings in flight cost and possible increases in productivity and in aircraft maintenance
- A greater flexibility in the loading envelope with an increased aft range of the c.g., e.g., from 8 to 29 percent mean aerodynamic chord (MAC) with an increase from 8 to 37 percent MAC in the series 30 DC-10 type aircraft
- A potential reduction in energy consumption with smoother flight performance profiles and reduced trim drag with aft c.g. positions
- An increased complexity in fabrication from installation of added control systems (this also will add to acquisition and maintenance costs)
- The effect on flight operations cost is indeterminate without specific study
- Benefits to the airlines and shippers could consist of reduced costs and/or savings in block time plus greater flexibility in air accommodations of containers due to increased latitude in loading envelope

Engine improvements: The imposition of Federal Aviation Regulation (FAR) Part 36 will require new and existing aircraft to comply with lower engine noise levels which cannot be achieved by some of the current aircraft. By 1978, the United States Federal regulations will be consistent with ICAO Committee on Aircraft Noise (CAN) 5 Standards. In general, the new noise level will be equivalent to Part 36 minus 1 to 10 decibels (dB), depending on size, type, and number of engines on the aircraft. A major reduction in engine noise levels was achieved with the high bypass ratio engines (HBR-6). It is not expected that significant technology improvements in noise reduction will be achieved by 1990. Changes will be incremental in nature and will be applied to engines and nacelles as shown by the results of internal research and Reference 1-1.

The same situation is expected to prevail in fuel efficiency. Present technology will be applied as existing aircraft are updated with growth and derivative versions. Again, the HBR engines achieved significant improvements. New developments in turbuprop engines could achieve excellent fuel economies.

Improvements in both turbofan and turboprop engines may have the following form and impact:

- Better specifics and/or increased power to increase the payload fractions, increase cruise speeds and range, or to reduce fuel consumption and flight operations costs as compared with current operations
- Reduction in environmental noise and air pollution with noise treatment of engines and improved mixture/combustion controls
- Benefits to airlines and shippers would be noted in lower operations costs and/or savings in block times and possible service to new sites at secondary airports
- Possible benefit to shippers from reduced cost of operations if these savings are reflected in lower rate structures

In all of the above technology areas, improvements may result in an increased capability of aircraft to perform the transport function (payload, speed, range) or to perform the same function with less energy, cost, or aircraft. In addition, these developments on special aircraft may allow proliferation of service to small airports.

Advanced fuels research: With the increasing OPEC price for petroleum, new types of fuels and new sources of hydrocarbon fuels are being investigated. Hydrocarbon fuels may be synthesized from coal, tar sands oil, shale oil, and vegetable sources. Hydrogen and methane are being studied. However, the volumetric and cost efficiencies for hydrogen currently are expected to be much less than those for petroleum-based derivative fuels. Much public writing has been directed toward the future of petroleum fuels. Although the cost may continue to rise, availability seems certain through the present century. The impact of new fuels most likely would be to raise the level of operating costs to the airline operator. Other possible effects are:

- Requirement for added or different fuel storage systems at airports
- Potential reduction in pollution emissions
- Higher cargo rates if advanced fuel costs are passed on to cargo shippers

Composite materials: A great deal of research has been done on the use of composite materials for secondary structures. As more experience is gained, it is likely that primary structure also will incorporate composite materials. Another development in advanced metallics is the use of non-metallic or dissimilar fibers in a physical matrix with light metals. Superior strength-to-weight ratios result. Although both of these composite materials currently are expensive in comparison with conventional metals, it is expected that future materials will be competitive for both primary and secondary structures.

Development of fiber-reinforced plastics for primary structures is expected to have the following impacts:

- Increased payload fractions
- Some reduction in structural maintenance but requiring new maintenance equipment for airline operators
- A shift in fabrication technique to larger autoclave facilities

- A possible increase in acquisition costs of new or derivative aircraft potentially offset by increased productivity and revenue
- A potential reduction in flight operations costs if maintenance reductions are achieved

Exterior configurations: With larger aircraft, expected characteristics affected are:

- An increased payload fraction
- A relative, potential increase in productivity
- A possible increase in ground maintenance equipment to service larger aircraft but potentially offset with more efficient use of manpower
- The interface with cargo terminal docks and loading equipment requiring general compatibility
- Possible applications of STOL (or VTOL) configurations to extend cargo service to remote and relatively inaccessible areas throughout the world
- Increased acquisition cost as a function of size
- Potential increases in direct operating costs for STOL or VTOL operations into new areas, but with new airlift capability
- Potential reductions in cargo terminal costs if the docking and loading interface results in more efficient transfer of cargo to and from the aircraft
- With aircraft larger than a B747, ground clearance problems on taxiways, parking aprons, and cargo docks as presently configured
- New aircraft must be designed to be compatible with existing and near-term loading equipment and vehicles
- STOL capability assisting in exploiting new markets (products and regions) as well as existing airports currently without or limited to service by small aircraft.

Interior configurations: New cargo aircraft interiors may be designed to accommodate larger containers and containers designed for compatibility between both air and surface transports. Expected effects of improved interiors are:

- A potential increase in annual productivity due to more efficient loading
- Possible simplification in maintenance
- Increased automation in loading
- An increase in acquisition cost
- Improved, simplified interiors might lead to reductions in flight crew costs
- Potential reductions in cargo terminal costs with improved loading devices
- New aircraft to easily accommodate containers with lengths exceeding 6 meters

Design techniques and automated drafting: Potential savings in engineering time and costs may be realized with the trend toward design routines on mathematical computers. Graphic output also may be used to create drawings for release to tooling and fabrication departments. Expected results are simplification of fabrication and relative savings in new (or derivative) aircraft acquisition costs.

Fabrication technique - adhesive bonding: Chemical bonding on primary metallic structure can result in appreciable weight savings compared with mechanical fasteners. Expected effects are:

- Greater payload fractions
- Extension of maintenance equipment and techniques from secondary to primary aircraft structures with possible increase in size of autoclaves
- A shift to more complex fabrication equipment with larger autoclaves and pneumatic layup equipment offset by easier assembly because of greater flexibility and increased dimensional tolerances in assembled parts
- A significant decrease in the relative cost of production and acquisition costs

Fabrication technique - isogrid structure: This development was originally created for orbital launch vehicles. The isogrids are chemically milled to produce an integrally stiffened plate with a waffle-like raised grid on one side. Possible effects on aircraft are:

- Increased payload fraction
- Simplification of maintenance
- Increased cost and complexity of fabrication
- Relative increase in acquisition costs

Landing gear and flotation: The footprint pressures of very large aircraft cause serious design and maintenance problems for runways, taxiways, and parking aprons. Current aircraft, such as the DC-10 and B747, provide multiple-tire landing gear with attendant ground pressures compatible with current airports. Special-purpose aircraft, such as the advanced Military STOL Transport, achieve much lower ground pressures. For cargo purposes, civil derivatives of these aircraft will be operable on unimproved or graded dirt runways. This capability might expand greatly cargo service by air to small communities and remote areas of the world. Shippers could benefit from proliferated route structures to secondary airports. Design of gear with low footprint pressures could allow larger aircraft to be operated on existing runways without requirements for rebuilding or strengthening runways.

Lighter-than-air: Periodically, the use of helium-filled buoyant aircraft is suggested for passenger and cargo use. Potential effects of reintroducing this concept are:

- Payload capabilities up to 450 tonnes
- Cruise speeds of up to 160 km per hour
- A range dependent on winds and amount of fuel on board
- Productivity and maintainability less than conventional aircraft because of inclement or hazardous weather conditions
- Completely new docking and loading equipment at each cargo operations base
- Potential savings in energy per ton of payload carried due to the buoyant effect with great flexibility in accommodations of 2.4-x 2.4-x 6/12-meters.

- Development of new training facilities and procedures for air and ground crews and for maintenance and operations personnel
- New investment in cargo terminals and fabrication facilities for aircraft
- Total acquisition costs for new aircraft and supporting systems
- Reliance on noncombustible but expensive helium for buoyancy
- New airport sites to avoid interference with heavier-than-air traffic
- Revised air traffic control procedures to accommodate both buoyant airships and aircraft in joint use zones
- A potential for expanded service to areas and cities not currently served by cargo aircraft

Aircraft operations. - The way the aircraft is used in airline operations interacts with aircraft performance characteristics, the transport system infrastructure characteristics and shipper requirements. These interactions are discussed in sequence.

Integrated door-to-door service: There are three possible variations in this concept. In each, the item is picked up at the shipper point of origin and is transported and delivered directly to the user destination. Responsibility for safe transport is assumed by a single entity. In the first case, a shipper may assume responsibility for transport to the user. Arrangements would be made for local truck pickup, airline transport, and destination delivery by truck.

A forwarder (consolidator) could assume total door-to-door service in the second case. The forwarder would furnish his own truck pickup (and delivery) or use the services of local trucking operators. Air transport would be provided by a carrier with responsibility only for the airborne portion of the trip. The forwarder selects the airline, but retains original responsibility for the entire trip.

In the last example, an airline with its own cargo marketing and delivery system provides the total transport function from origin to destination.

Proliferation of the integrated function described above might have the following generalized effects if an air carrier were to provide the total service:

- Potential increase in aircraft payload with greater capture of traffic
- Possible increase in door-to-door speed through efficiencies of single carrier control
- Potential increase in the productivity of the aircraft
- Required compatibility between the truck, the cargo terminal, and the aircraft for docking and loading
- A potential for relative efficiency in the use of propulsive energy through achievement of greater payloads in both surface and air vehicles
- Relative reduction in terminal costs by higher utilization of terminal facilities
- Potential extension of the "draw-down" capture area for an air carrier by providing its own truck pickup and delivery in the area surrounding the airport
- Air carrier control or elimination of the freight forwarder function
- A single agency responsibility for the security of the cargo in transit
- Increased use of 3-, 6- or 12-meter containers provided by the airline operator, or leased from a container supplier
- A single waybill which includes a statement of shipping costs for convenience both of shipper and receiver of the cargo
- A potential time savings in transfer of cargo between surface and air
- Potential rate savings to shippers
- A possible increase in commodity types attracted by speed, security and competitive rates of air cargo service

Multicarrier door-to-door service: The impact of this function is the same as above with the following exceptions. The surface carrier may consist of one or more companies working cooperatively with the air carrier. Relative disadvantages compared with integrated service are:

- Inefficiencies at the interface between carriers, with cost penalties and loss of time

- Greater potential for loss of cargo at each interchange of responsibility
- Multiple ownership of containers
- Use of single waybill as created by initial carrier and accepted all through transit

Proliferated hub-spoke: In a single hub-spoke transit system, each origin and destination is connected radially with the hub cargo transits from an origin to the hub. There it is redistributed to an aircraft bound for the destination airport. In the United States, Federal Express provides a small-package service through a single-hub terminal at Memphis, Tennessee. By contrast, a proliferated network consists of two or more hubs interconnected by direct routes. From each hub, local routes radiate to origins and destinations. The interactive effects of this type of service are as follows:

- Potential decrease in payloads as routes are added, with gradual increase as demand grows
- Potential reduction in total freight transit time with shorter air itineraries
- Increases in energy consumption with more flight activity
- Possible increase in flight operations costs with more of the shorter stage lengths
- An increase in costs of ground facilities if more airports are used plus capital costs of new aircraft if existing fleet cannot provide satisfactory frequency of service
- Increased operations at airports as flights are added to both existing and new sites served
- Increased airways activities requiring air traffic control
- Potentially greater choice of origin/destination routes
- A possible increase in the sizes of aircraft used between hubs with more small aircraft used on the spokes
- Increased potential to alleviate back-haul imbalance at hub
- Increased intermodal contacts requiring coordination of loading and transfer facilities
- Increased exposure of freight to losses by virtue of increased transfer points
- Single waybill with forwarder responsibility

- Potential savings to shippers with shorter, more direct routes
- Proliferation of air service to more communities

Multistop itinerary: Multistop itineraries are those which include several intermediate stops on a one-way or a round trip. This type of route, compared to longer, nonstop itineraries, offers one way of proliferation of scheduled cargo service. Interactive effects of this type of operation are:

- A potential decrease in the size of the payload picked up at each stop, but a potentially larger payload average for the entire route
- A probable decrease in the aircraft productivity due to greater number of stages with attendant delays at each stop
- Redesign or modification of interior configurations to facilitate partial loading/offloading at itinerary stops
- A relative increase in energy consumption caused by shorter stage lengths which could result in more fuel burned per aircraft mile
- Potential to alleviate back-haul imbalance at hub
- A cost increase per flight hour commensurate with shorter stage lengths
- Addition of more airport and terminal facilities for cargo handling and administration plus possible modifications of runways, taxiways, and aprons
- Increases in number of aircraft enroute and terminal area control operations
- An expansion of origins and destinations available to freight forwarders with attendant potential increases in market share for air cargo
- A potential expansion of modal contacts with surface carriers
- An increase in the exposure of cargo to losses in transit
- A possible increase in air transit time if direct flights are fractionated into multiple stops

Reduced cruise speed: In the interest of achieving economy of fuel, a reduction of cruise speed has been suggested. The effects of this could be:

- An increase in block time for the aircraft
- A potential decrease in annual productivity
- Savings in fuel per aircraft mile

- Possible savings in flight operations if savings in fuel are greater than increases in costs due to increased block time
- A possible increase in numbers of aircraft required if annual aircraft productivity is reduced
- A cost advantage to shippers only if the rates can be reduced by cargo carriers

Ground Support Operations. - Ground support operations are those primarily oriented to cargo handling and processing, aircraft loading and unloading, and maintenance of the enroute control environment while the aircraft is airborne. A number of different operations are discussed in subsections which follow.

Remote cargo terminal: To achieve benefits of specialization in cargo handling and processing, suggestions have been made to locate the cargo terminal away from the airport. From this remote site, containerized/unitized cargo would be moved directly to the aircraft for loading. Anticipated effects of this practice are:

- A potential increase in the aircraft productivity from decreased ground loading/unloading times.
- Optimized configurations for docking the aircraft.
- Potential decreases in fuel required for ground taxi time since the aircraft would not be required to move back and forth between cargo and passenger terminal or the takeoff runway (this saving might be partially offset by increased truck or ground transit fuel to transfer cargo between remote terminal and the airport).
- Potential reductions in cargo terminal costs with less congestion from surface traffic and optimized configuration of the terminal. This may be offset by increased manpower and management requirements. For transfer shipments and some direct bulk delivery, airport cargo facilities will remain a requirement.
- The airline operator may benefit if increased cargo shipments add expensive congestion to airport terminal operations. Potential savings in containerization and unitized loads will be offset by increased facilities, manpower and management, and dilution of control. The airport terminal will remain to handle transfer loads,

and direct bulk or small unit loads submitted by forwarders and shippers. Transfer of all cargo operations to a remote site would result in some diversion of patronage to airlines which retain the airport location.

- Transfer of terminal operations to remote sites could possibly reduce airport facilities and services required if space were actually vacated or reduce the demand for expansion of facilities and services.
- A remote site cargo terminal potentially can benefit from reduced surface traffic and congestion and economies due to scale and mechanization. Against this are offset the relative increase in investment and manpower as compared with an airport location.
- An airfreight forwarder might benefit by easier access to the cargo terminal, but also might have to make a longer surface journey if his loads are destined for more than one airline.
- The cargo modal interface is shifted off the airport with possibly easier access, but the aircraft interface with loading equipment remains the same.
- A possible increase in the exposure of cargo to losses because of increased handling requirements. This potential is reduced if the cargo is placed in secure containers for transfer from the terminal to the aircraft.
- The use of 3-, 6- and 12-meter containers might be increased with remote terminals specially equipped.
- Efficiencies within the terminal must result in savings in time and cost to offset the terminal-to-airport transfer function.
- An extensive investment may be required for land, terminal buildings, equipment, and the transfer system from the remote terminal to the airport.
- A possible proliferation of sites to which a shipper has access.

Dedicated cargo airports: Relative ground separation of cargo and passenger aircraft operations could be accomplished by developing new airports for exclusive use of airfreight operations. In a few areas, this could be accomplished by fill sites in the Great Lakes or the oceans in coastal regions. For inland sites, new land areas would be required. The impacts of this type of development are:

- Potential increases in the productivity of all-cargo aircraft with increases in terminal, loading, and air control efficiencies, offset, however, by possible decreases in belly-pit cargo patronage.
- Optimized design for docking and loading interfaces between the surface, terminal and aircraft.
- With more efficient cargo aircraft operations, there may be some savings in aircraft fuel which could be offset by increases in surface fuel for trucks required to service both belly-pit and all-cargo operations.
- Flight operations costs might be reduced for all-cargo aircraft if flight profile efficiencies can be realized at dedicated airports.
- Time penalties and inconvenience in transferring cargo between the dedicated and combination carrier (belly pit) aircraft.
- With dedicated cargo airports, time saved in transferring cargo to and from the aircraft may reduce total ground time with attendant savings in aircraft operating costs, compared with contemporary practices.
- The all-cargo air carrier might obtain an operating time and cost advantage in comparison with carriers offering only belly-pit service at passenger terminals.
- Removal of all-cargo terminals and surface approaches should relieve landside congestion at existing passenger/cargo airports as well as reduce future expansion needs; however, new facilities must be constructed at the new airports.
- Airways terminal area traffic patterns would be enlarged to include the new sites with potential increases in the control facilities and functions.
- New terminal design could utilize an optimized layout and cargo handling equipment for cargo processing.
- Freight forwarders would have increased accessibility to carrier terminals but with potential need to split cargo loads between dedicated and combined carriers.
- Cargo security is enhanced by reducing the general accessibility and vulnerability to pilferage.

- Cargo containers may become increasingly attractive at dedicated airport operations because of specialized consolidating activity and good surface accessibility for delivery vehicles.
- Ground transportation time and cost could be adversely affected for shippers who are required to split loads between dedicated and conventional airport terminals.

Terminal automation: The present tenor of air cargo is highly labor-intensive. The nature of current shipments is a wide variety of shapes and sizes of packages. Consolidation into palletized, containerized shipments is primarily a manual function. Many observers note the best cargo terminal is a large space free of ports or room columns. This allows maximum freedom for manual sorting. Automation has been tried with more terminals in Europe than the United States, but success has not been marked or widespread. Some transport and loading functions have been mechanized with manual control predominating.

The major activities in cargo handling are transport, sorting, and storage. Mechanization is of benefit in the transport and storage functions. General effects of automation (mechanization) are noted as:

- A potential increase in aircraft productivity if loading, unloading times can be reduced, resulting from reduced times for the aircraft at the loading dock or area
- A requirement for the aircraft loading interface to achieve maximum compatibility with all loading equipment
- A potential decrease in aircraft operations costs with reduced loading times
- Potential savings in terminal manpower costs, but with additional capital costs for mechanization
- A possible reduction in security losses with less exposure of open cargo to pilferage
- Automated waybill issued and/or processed by terminal operator
- Potential savings in processing time and costs to shippers, if savings result in reduced transport rates

Improvements in joint cargo/passenger loading: Where cargo is carried in belly pits of passenger aircraft, loading must be provided at the passenger dock. This requires mobile equipment to bring cargo to the aircraft. Mechanized equipment reduces time and manpower requirements. Additional time savings might result if the cargo loading/unloading function were to be simplified and speeded up with more efficient dock design and equipment. Expected impacts are:

- Reduced loading time and increased productivity for the aircraft
- Increased expense in redesign and re-equipping of loading docks, with potential savings in aircraft ground time
- A possible reduction in energy expended by mobile ground equipment for loading cargo
- A continuing problem in interline transfer of cargo
- A continuing requirement for coordination of transfers from surface modes of transport
- No reduction in requirements for cargo security, unless access to loads is reduced
- Cargo containers remain generally incompatible with belly-pit loading in passenger aircraft
- Potential savings in time and costs to shippers

Airways control and data management: A proposed microwave terminal control system would allow curved approaches for aircraft on final approach. This would permit time savings in landings over the current control systems. Automated data storage and transmission may enable more efficient and time-saving, flight profile management. Other effects expected are:

- Potential savings in fuel with attendant savings in operations costs for the aircraft
- Possible increase in airport operating saturation levels without attendant delays to aircraft
- Use of active, augmented flight control systems may permit an increased rate of landings and takeoffs in all types of weather

Institutional operations. - There are a number of different changes in the way air cargo operations may be conducted. Some are policy changes and some involve physical equipment and materials. Changes in operations may affect the way aircraft are used. These changes are discussed in the following paragraphs.

Joint air-surface rates for new markets: A cooperative rate policy might have the effect of encouraging new types of commodities to be carried by air cargo carriers. Expected effects could be:

- An increase in the total quantity of cargo carried with better utilization of aircraft with higher load factors and increased fuel efficiency per ton of cargo carried
- Increases in aircraft flight operations for operators, airports, and control facilities
- An increased need for intermodal compatibility to assure minimum costs and time of transport
- Potentially expanded opportunities for forwarders in selection of carriers
- A need for greater cooperation in use of containers among surface and air carriers
- Facilitation of single responsibility for security and waybill documentation
- Potential savings to shippers through lower cargo rates

Containers for intermodal compatibility: The large 2.4- x 2.4- x 6-meter cargo containers for ocean shipping are constructed with heavy structure at the corners to facilitate six-high stacking. This same style is used on rail and truck. Restraints are designed primarily to resist horizontal movement both for containers and contents. The bottom surfaces are composed of structural beams and cross members similar to cargo pallets. When used on aircraft, the net cargo weight is reduced to match the requirements of gust uploads. An accommodation also is required to achieve equivalent tie-down latching, again for dynamic uploads. Containers built for air cargo, in contrast to surface carriage, are built for minimum tare weight. They are constructed generally of aluminum rather than steel. Internal restraint fittings permit strapping or netting for vertical gust loads. In general, such conditions are not serious and damage to cargo is a minimum. Air cargo containers may be stacked two high at cargo terminals or customs areas.

If containers in the future are designed for intermodal compatibility, the following effects are noted:

- Modification of surface containers to be compatible with aircraft cargo-floor tie-down latching and mechanized loading equipment, or redesign of aircraft restraints to accommodate surface type containers
- Lighter weight construction may reduce energy requirements on a cargo per net ton basis
- Extensive use of new containers requiring added capital investment in aircraft design and production
- A potential increase in aircraft ground time and expense if two or more types of containers are loaded/unloaded
- Possible increase in flight operations costs per unit of net cargo payload if the use of multimodal containers requires repositioning of empty containers
- Possible retrofitting of aircraft to achieve multimodal container flexibility
- Increased flexibility from the cargo terminal, forwarders, and carriers to acquire multimodal container handling capability
- Possible greater use of containers by shipper/originators with load unitization costs transferred from carrier to shipper/forwarder
- Enhanced load security with increased use of preloaded containers among surface and air carriers
- Wider use of 3-, 6- and 12-meter containers requiring careful control of tare weight for the air carriers picking up loads from surface carriers
- Minimization of consolidation and unitization expense at modal interfaces

Presealed, documented containers for international operations: If containerized loads can cross international boundaries and customs jurisdictions with minimum opening, inspection, and resealing of containers, both time in transit and transit costs can be minimized. Resultant effects of improvements in this area are:

- A potential increase in payloads and aircraft productivity from reduced ground time at customs inspections and greater packing efficiencies in the containers

- Potential ground time savings in simplified docking/loading interfaces with attendant cost savings in aircraft
- Potential reductions in fuel burned per unit of net cargo if containerized loads are packed more efficiently
- Potential simplification of handling procedures for the airline operator and the cargo terminal operator
- A requirement for certification procedures by the shipper or forwarder or agency packing, sealing, and documenting the containers
- Intermodal compatibility of containers required for simplified handling
- Potential attraction of new commodities for air transport in international trade
- Improved security for shipments due to minimum accessibility of container contents
- Increased use of 3-, 6- and 12-meter containers
- Use of single waybill is facilitated

Automated documentation, identification and transit control for cargo containers: A positive coding system which can be automatically read by sensors may save both time and money in transport. Contents, shipper, carrier, and consignee all may be identified automatically. Effects of this technique are expected to be:

- Potential increase of aircraft productivity through time savings in loading and operating cost reductions with less time on the ground or at terminal docks
- Savings in fuel per ton of cargo commensurate with increased aircraft productivity
- New equipment for producing the identification symbols or markers and sensing equipment will be required by shippers, forwarders, carriers, and terminal operators
- Reduced requirements for opening containers should increase security of cargo
- A potential increase in the use of 3-, 6- and 12-meter cargo containers
- Incorporation of waybill information into the markings on the containers

Dedicated fleets for integrated or international trading firms: A dedicated fleet is owned or leased and operated by or for a large manufacturer, distributor, or integrated international trading firm. This concept involves a large and continuous volume of cargo commodities to be moved. Cargo flights would be scheduled as needed. Against the advantages of management control of the transport function must be weighed the capitalized cost and operations cost of the aircraft. Another consideration is empty or lightly filled backhaul flights. Anticipated effects of this concept are:

- An aircraft might be selected to operate at a high payload fraction with the size and range selected to match distribution requirements
- Productivity might be increased if the cargo could be carried on both day and night flights, offset, however, by repositioning flights at very low load factors
- Maintainability might be simplified if aircraft configuration were oriented toward the cargo to be carried
- Increased acquisition costs of dedicated aircraft to a specific operator could reflect a special configuration, offset, however, by economies in flight operations and cargo terminal loading/unloading costs
- A potential increase in total number of aircraft including both public and private carrier fleets
- A possible shift from public carriers to private fleets resulting in increased competition
- Increased airport and airway operations commensurate with greater numbers of aircraft in both private and commercial fleets
- Possible duplication of cargo terminals if private fleets were to build their own or lease terminals
- Potential increase in types of commodities carried
- Maximum possible security for the cargo
- Maximum utilization of pre-loaded 3-, 6- and 12-meter cargo containers for outbound shipments but repositioning problems on return flights

In the case of leased service, the added effects could be:

- Leasing business for cargo aircraft owned by commercial operators
- Potential increase in networks and airport and airways operations

- Owner-operated cargo terminals at strategic worldwide locations plus purchased terminal service at other locations
- A minimization of the freight forwarder role or complete absorption of the function by the trading firm
- Potential increased networks and new commodities as volume and distribution expand
- Utilization of 3-, 6- and 12-meter containers with attendant packaging efficiency and cargo security in transit including single waybill documentation
- Minimum cost services compared with utilization of common carrier service

New materials and designs for cargo containers: Increasing shipment of cargo is leading toward greater use of containers in all modes. Larger aircraft will facilitate use of containers. The opportunity exists for emphasis on multimodal use and designs to reduce or eliminate intermodal problems of carriage and handling. Anticipated effects are:

- A lower tare weight resulting from improved design and lower weight materials, with attendant greater net cargo loads per container and per aircraft
- Specific designs for intermodality with consideration for interline transfer of less than the full container load
- Potentially simplified aircraft interiors if intermodal compatibility is inherent in the design
- Energy consumption per tonne of cargo may be reduced with lower container tare weights
- With simplified container design, terminal and loading times may result in reduced time and costs for the aircraft
- Cargo security provisions may be incorporated into new container designs
- Shippers may save both tare weight and handling time with new, lightweight containers

Block capacity rates: At various times in the past, some shippers have contracted with airlines to pay for a "block" space on certain flights. This permitted a shipper, such as Sears Roebuck, to have a guaranteed delivery of a specified amount of cargo on a regular flight. Expected effects of this practice are:

- A potential increase in revenue productivity and profit to the operators
- A possible increase in numbers of aircraft to provide scheduled block capacity
- A potential increase in types of perishable commodities which might be attracted to air shipment

Joint day and night use of cargo terminals by forwarders and carriers: In the United States, air carriers typically own and operate their own cargo terminals. Freight forwarders collect, consolidate, and pack cargo for shipment, generally in their own terminal areas. Thus, duplication of facilities exists, leading to underutilization, increased transit times, and costs for assembling and loading cargo into the aircraft. One way to save costs and increase terminal use would be to consolidate activities. Forwarders could assemble cargo in daylight hours with the carriers moving pallets, containers and other types of cargo through the terminals at night. With shared facilities, terminal costs for airline operators and forwarders both could be reduced. Benefits to shippers would be a greater acceptance and utilization of containers with potential cost savings arising from lower terminal costs.

Carrier deregulation: Air cargo carrier regulation has been reduced substantially. In 1978, carriers in operation in 1977 may apply for certification to serve any domestic route of their choice. The CAB retains regulatory rights over cargo rates to change those which are found to be predatory, prejudicial, preferential or discriminatory. By 1979, any carrier who can demonstrate air cargo capability will be permitted to operate all-cargo domestic air service. With proliferated service, aircraft payloads and productivity may decrease, fuel consumption per net ton of cargo may increase, and aircraft operations and terminal costs may rise in a similar manner. An increase in the number of all-cargo aircraft already has taken place, with Federal Express acquisition of several B727-100C aircraft.

Deregulation may be expected also to have the following impacts on the cargo system infrastructure:

- An expansion of routes to serve new cities, or more service to/from existing cities
- Potential saturation of operations capacities at current airports and increased flights to other airports
- Increased air traffic control operations in terminal and enroute airways
- Possible capital expenditures for expanded or new cargo terminals
- More choice of carriers, origins, and destinations for freight forwarders
- Aggressive exploitation of new commodities and market areas
- Benefits to shippers in terms of time savings, lower cargo rates, and air shipments to more areas in the United States domestic market.

Highway cargo systems - truck/trailer technologies. - There is a trend toward larger, heavier trucks and three-trailer tows on the United States interstate highway system. The Federal Highway Administration recommended changing the gross vehicle weight limitation from 32 065 kilograms to a flat maximum of 36 288 kilograms. An axle limitation also was set at 9070 kilograms for a single axle and 15 419 kilograms for a tandem axle (Reference 1-3, Part 2). These limits were recommended by Congress in 1976 for adoption on all interstate highways. All but 17 states (1977) have adopted these standards for their interstate and state and county roads (Reference 1-4, Part 2).

The interstate highway system provides a vast, high-speed transport network for automotive vehicles. The price rise and shortage of fuel after the autumn of 1973 prompted a federal speed limit of 88.5 kph. A return to higher speed limits does not appear in the near future. Thus, improvements in highway truck technologies will be geared to saving time and costs in areas other than speed. Various technological improvements and vehicle characteristics are interrelated as presented in Table 1-2 and discussed in the following paragraphs.

Optimized design for lightweight Vehicles: Use of lighter weight materials and structural design techniques may save many kilograms of weight in trucks and trailers. The effects of this on vehicle characteristics are:

- A greater payload fraction for loaded highway vehicles, with a potential for productivity as measured in net cargo tonne-kilometers per year
- Reductions in maintenance with both improved lightweight materials and designs keyed to maintainability
- Savings in fuel per ton of cargo carried corresponding to increased payload fractions
- Revised fabrication techniques to utilize composite or advanced metallics if cost savings are indicated
- A possible increase in acquisition costs offset by savings in operating line-haul costs
- Increased revenue potential for operators due to greater payload fractions and potentially lower operations costs

Vehicle streamlining: There are some improvements in the efficiency of truck energy consumption from aerodynamic streamlining of trucks, tractors and trailers. Wind deflectors on the cab and boat-tailing the trailer could reduce propulsive energy about 5 to 10 percent at speeds in excess of 88.5 kph (Reference 4, Page 146). Complete streamlining of highway trucks could reduce propulsive energy by 30 percent (Reference 4, Page 378). For present truck configurations, wind resistance is equal to rolling resistance at 113 kph. However, studies have shown that the added volume needed by streamlining is offset by reduced cargo capacity. Thus, the general trend is to apply only a minimum effort toward tractor or cab streamlining or air flow control. Current and future speed limits also make streamlining relatively unattractive. Effects which could occur in vehicle and infrastructure characteristics and shipper requirements are:

- A potential reduction in fuel per ton of cargo with cost savings to the operators
- Added complexity and increased cost of fabrication and acquisition that would require offsetting savings in line-haul costs
- Reduced aerodynamic noise

- Preservation of compatibility between trailer (or truck) and terminal loading docks and equipment
- Accommodation of 3-, 6-, and 12-meter cargo containers
- A potential for lower cargo rates if line-haul costs can be reduced

Tankers and special-purpose vehicles: There is a growing diversity of special types of highway trucks and trailers. As traffic demands increase, more special-purpose vehicles with capacity up to 36 288 kilograms are forecast. To be expected from these are:

- Increased productivity both from size and specialization, potentially offset by lack of backhaul loads
- Greater scope of maintenance
- Potential simplification of docking with specific designs
- Completely compatible configurations with types of cargo hauled
- Requirements for expansion of fabrication techniques
- A potential savings in line-haul costs with specialized, maximum weight vehicles, offset by possible empty backhauls
- Possible additions of specialized handling and loading equipment at cargo terminals
- Increasing numbers of vehicles dedicated to a specific market and commodity
- Improvement in transport security incorporated in the design of new vehicles
- An increased trend toward use of 3-, 6- and 12-meter cargo containers

General improvements in design: Among improvements currently being developed are improved suspension and brake systems for trucks and trailers, larger and more-efficient engines, and gas turbines for propulsive power. These improvements are intended generally to increase the net payload per pound of fuel used and/or decrease the time-in-transit or block speeds. Greater payload or reduced times translate to increased productivity. New vehicles with these design features may require new or improved maintenance practices. Gas turbines might be less fuel efficient than improved diesels but offer other savings in operations. Most design improvements should show a net result of cost savings per unit of cargo delivered on lower capital cost with increased capacity.

The general public which observes trucking operations expresses the opinion that intercity trucks are large, smelly, dirty and slow-moving highway menaces. With the trend toward larger truck trailers, the industry is developing more powerful engines. These will increase the accelerating and hill-climbing ability. The result is that future trucks will blend more equitably with other traffic. It is the nature of a diesel engine to burn fuel rich with changes in engine speed and load. Engine manufacturers are working on better mixture controls to reduce black smoke. They also are developing improved muffler systems to reduce exhaust noise levels.

There is no emerging fuel-engine combination which will displace the diesel as a prime power source. Some synthesized fuels may be developed from coal and oil shale as the price of crude petroleum continues to rise. These fuels, however, will continue to be used in diesel engines.

With more powerful engines, there should be a trend toward reductions in trucking accidents. This is a benefit, but it should be noted that interstate/intercity trucks already have a good safety record.

Multimode container compatibility: Containers developed for truck, rail, air, and ocean transport need to be designed for stacking, variable tie-down features, and horizontal and vertical internal restraints for cargo. If a truck trailer can accommodate several types of containers, it offers a potential increase in productivity. On the other hand, vehicle maintenance requirements may increase, and docking and loading equipment must be compatible with various container configurations to avoid increased time and cost at the terminal interface. With general compatibility, containers might be exchanged between various owners as rail cars are currently exchanged. Line-haul costs and cargo terminal costs per ton of cargo potentially may be reduced with the great flexibility of multimodal containers.

Forwarders would benefit also by greater choice both of mode and carrier. Both commodity types and market demand could proliferate with a more widely used container. With greater use of multimode containers, especially in the 3-, 6- and 12-meter lengths, increased security may be obtained and cargo might travel with fewer intermodal delays. Forwarders would retain responsibility for single waybill preparation. Shippers also might benefit from reductions in transit time, greater availability of intermodal service, and reduced rates.

Truck system operations. - There are a number of different operational modes which have been studied or proposed. These involve use of vehicles, management policies, and highway designs. General improvement objectives are to increase productivity and safety with attendant improvements in the revenue/cost ratio.

Larger trucks, dual- and triple-trailer tows: An experimental program in Oregon in 1968 demonstrated reduced fuel consumption per ton mile of freight by allowing a trucker to haul a triple-tandem trailer. A comparison of test results is reproduced in the following tabulation (converted from original English units, Reference 1-5).

8.23 m	Weights (kg)		Truck	Liters
Trailers	Gross Combined	Payload	(km/year)	(fuel/year)
2	29 471	15 869	160 900	89 704
3	41 033	23 804	107 320	70 780

These figures are for delivery of the same amount of tonnage in a year. Fuel savings are about 21 percent for the triple-trailer combinations.

12.2 m	Weights (kg)		Truck	Liters
Trailers	Gross Combined	Payload	(km/year)	(fuel/year)
1	33 225	18 227	160 900	93 868
2	51 008	32 191	109 412	79 485

Again, delivering an equivalent amount of freight tonnage, the savings in fuel are about 15 percent for the double trailer.

Dual trailers will become common in all states. As noted above, there have been demonstrated fuel savings in going to triple-trailer tows. Other effects from these changes will be:

- A significant increase in payloads
- A commensurate increase in unit productivity
- A modification of docks and loading facilities coordinated with truck/trailer design
- Savings in fuel per unit load of cargo
- Increased cost of larger vehicles
- Savings in line-haul and cargo terminal costs per unit of cargo
- A relative reduction in the number of vehicles needed to carry cargo in intercity transport
- An increased revenue potential for operators
- A potential increased in roadbed maintenance
- An increased in noise and exhaust emissions from larger units, offset by potential reductions in the number of vehicles needed in the total fleet for a given level of cargo

Automated data management: The tremendous increase in computer technology has made automated data management a valuable tool in rapid communications. Applications of data management techniques to truck transport are expected to facilitate cargo through billing, cargo and vehicle identification for scheduling and in-transit control, dispatch-to-crew communications, and interline cargo transfers. Expected results of these practices are:

- Potential increase in block speeds and hence productivity through reduction in communication delays
- Concommitant reductions in energy and line-haul costs per unit of cargo carried
- An increase in capital acquisition to add central and mobile data processing and transmission units
- Possible reductions in numbers of fleet vehicles required to satisfy total demand
- Routinized procedures for operators with passive/active central and mobile signal generators and detectors for all carriers including interline transfers

- A possible addition of signal detection, reporting, and delay equipment in the highway network to assure total continental coverage
- The addition of data processing and transmission equipment at cargo terminals
- Greater flexibility for freight forwarders with a requirement for extra equipment to ensure compatibility with all carriers
- A stronger competitive system for trucks with improvements in transport service which could increase both scope and quantity in the market
- Potential reduction in losses attributable to presealed loads and greater control of cargo and vehicle
- An increase in 3-, 6- and 12-meter container use with cargo identity coded on the exteriors
- Single waybill incorporated into identity markers at point of origin
- Potential savings in transit time and costs to shippers

Highway and marker designs for greater safety: Statistics for 1971 on all roads in the United States reveal that passenger cars experience the highest accident rate per million kilometers traveled. The rate was 15.75 accidents. For all trucks, a comparable level was 9.31. For intercity trucks, the accident rate was 1.66 per million kilometers traveled (Reference 1-5, Page 131).

Continual safety improvements are being studied and incorporated on United States, federal and state highways. Both the Federal Highway Administration and the National Highway Traffic Safety Administration are conducting studies in driver safety and reaction times to road hazards and tire safety and automotive electronic systems to develop a better data base for analysis of operations of trucks. In addition, the Office of the Assistant Secretary of Transportation for Environment, Safety, and Consumer Affairs is developing airborne and surface systems for interrogation and identification of trucks and electronic systems to improve terminal and cargo security against theft and pilferage. Also included are breakaway sign and luminaire supports, highway surfacing materials and application techniques, and increased safety measures for railroad grade crossings (Reference 3, Part 2).

With scarcity and high prices for fuel, a trend will accelerate to smaller passenger cars and larger trucks. This traffic mix is potentially more hazardous to cars involved in collisions with trucks. However, the peril is more psychological than real. To reduce the hazard and speed up truck flow in congested areas, dedicated truck lanes have been suggested to separate private traffic from heavy commercial vehicle traffic. These design features may affect vehicle and infrastructure characteristics in the following manner:

- Potential increases in block speeds and vehicle productivity at lowwered unit line-haul operations costs
- Reduced fuel consumption through reductiion of delays and higher block speeds
- Reduced losses of vehicle and cargo to accidents and reduction of driver stress
- Increased cost of providing new and modified highways necessitating increased highway user taxes
- A potential increase in right-of-way requirements for new or enlarged roadways
- Possible savings in shipping time with improved service

Increased route and back-haul flexibility: At the present time, the Interstate Commerce Commission limits carrier ability to choose freely where service will be provided and types of cargo to be carried. Permitting greater choice of routes and types of cargo carried might assist in scheduling and achievement of greater payloads on back-haul operations. In such cases, carriers might enjoy better payload fractions and increased revenues. Truck productivity could be increased with attendant cost savings in reduced fuel per unit of cargo carried. Forwarders and operators might enjoy an expanded service area with a system that can react quickly to changes in demand. The shipper might benefit if operator cost savings were reflected in lower cargo rates.

Interline and intermodal terminals: Greater cooperation among like and unlike carriers may be expressed at terminals where cargo loads are interchanged for trans-shipment. Such practices, if permitted by the ICC, could result in greater productivity of vehicles with higher average payloads. All vehicles must be designed not only for multimodal container but also for cargo terminal docking/loading equipment compatibility. This could result in some added capital costs for new vehicle design and acquisition. Joint terminal activities could simplify truck operators cargo transfer procedures and achieve economies of scale with operating cost and time savings. Some adaptation of terminal equipment might be required to transfer 3-, 6- and 12-meter containers between trucks and other carrier vehicles. Some savings in total transit time should be realized with terminal cost savings in handling of cargo.

Rail cargo systems - rail technologies. - A number of different agencies are working to improve freight transportation in many areas. The Federal Department of Transportation and its subagencies are engaged in railroad research. Among these are Amtrak (National Railroad Passenger Corporation); the Federal Railroad Administration; The Transportation Test Center at Pueblo, Colorado; the Transportation Systems Center at Cambridge, Massachusetts; and various offices in the Secretariat. Institutional agencies are the Association of America Railroads (AAR) and the Rail Progress Institute (RPI). They represent the operations and the suppliers of equipment. In addition, a limited effort is mounted by the railroads themselves. The interrelations among technologies, vehicles, systems, and operations are presented in Table 1-3 and are discussed below.

Rail line electrification: Prior to 1930, the United States was the world leader in railroad electrification. At the present time, Switzerland leads with 99 percent electrified trackage, Italy with 47 percent, and the Soviet Union (USSR) with 25 percent. The United States has only about 1 percent of its trackage electrified. Studies show that if 35 400 kilometers of track (10 percent) were to be electrified in the most heavily traveled core, some 50 percent of United States gross cargo/freight tonnage would be carried. Such electrification would reduce diesel fuel consumption by 5.678 billion liters annually. In addition, improved rail service might draw traffic away from trucks for an added saving in fuel. Research scheduled by the Federal Railroad Administration for 1977 (and on) includes the following (Reference 1-4, Part 3):

- Wayside distribution and catenary systems for power distribution to electromotive units
- Establishment of a basis of design for rotary motors with better adhesion and dynamic characteristics
- Regenerative braking systems for recovery of power
- Flywheel energy storage systems, primarily for switch engines in yard operation
- The feasibility and costs of conversion of existing diesel-electric locomotives to all-electric locomotives
- Improvements in traction
- Advanced concepts for transfer of power through pickup systems for high vehicle speeds

Although the potential savings in electrification are great, the capital requirements for complete conversion are beyond the present capability of United States rail lines. Anticipated effects of rail line electrication are:

- Changes in line maintenance in the power distribution systems
- Modification of the power systems interface at loading docks
- Reductions in fuel per unit of cargo moved at cost savings to carrier operators
- A substantial investment in traction vehicles and electrified rights of way, power-generating stations and distribution substations
- Potential reductions in locomotive line-haul costs
- Displacement of diesel-electric locomotives with all-electric locomotives, probably on a one-for-one ratio
- Conversion of trackage and yards to accommodate both diesel-electric and electric locomotives
- Reduction in noise and exhaust gas pollution of the operating environment
- Potential savings in freight rates if relative fuel savings are passed on to shippers

Optimized design of rail vehicles: A number of areas of research in rail vehicle design are being pursued to improve freight transport. One is the analysis of rail-wheel dynamics and the physical characteristics of rail and car-train interactions. Various college transportation laboratories and institutions are engaged in railroad components research. Included in these efforts are improved methods of suspension to reduce wheelset hunting or lateral oscillation of wheels. At high speeds, in excess of 160 kph, wheelset hunting could cause catastrophic derailment. Elimination or reduction of wheelset hunting will benefit both freight and passenger trains in reduced flange-rail friction and safety (Reference 1-6). Along with improved suspension system is a trend toward more efficient design with lightweight materials. Train safety research includes a general program to reduce train accidents (and casualty loss expense). Vehicle research is concentrated on improved flaw-detection devices for both track and train components. Research also is being conducted on tank cars in the areas of reduction in tank rupture from adjoining car attachments such as in coupling in classification yards, improved thermal shielding for heat and fire resistance, and improved safety relief venting and valves for voiding or relief of tank pressure during accidental fires.

Academic and institutional studies have been conducted to evaluate energy savings arising from vehicle streamlining. For example, streamlining of diesel-electric locomotives could reduce power requirements from 3 to 10 percent at speeds from 65 to 133 kph. These savings are in comparison with the power requirements for contemporary diesel-electric locomotives. Streamlining of freight cards coupled with use of lighter weight designs could generate savings approaching 20 percent in tractive power requirements (Reference 1-5).

Among the railroad operators and equipment manufacturers, typical developments include more powerful diesel-electric locomotives, all-electric locomotives, and gas turbine locomotives. The first two are of prime interest in freight operations. There is also a trend toward larger, dedicated or special-purpose freight cars.. These will lower the relative costs of transport as more cars come into use. The trend toward special-purpose freight cars results in more frequent empty trips for repositioning. This tends to offset loaded cost savings compared to smaller, less-efficient cars that move frequently carry loads in both directions (Reference 1-7).

One item of specialized development is a dual-mode truck trailer with both pneumatic rubber tires and a steel-wheel deployable bogie. For rail use, the bogie is deployed to fit a standard track; the tires clear the rail. The truck coupling is designed to fit both a tractor-truck and a coupling device on the rear of the trailer. Thus, a series of trailers may be coupled to form a train for rail use. The advantages of this concept are to be dual mode plus eliminating the need for a flat car as a trailer carrier.

Anticipated effects of all of these trends are:

- Increased net cargo capacity as a function of vehicle function, weight, and size
- A potential increase in annual productivity due to lower weight coupled with increased speed, reduced accidental loss, specialized vehicles, or larger capacity cars
- Increased or decreased vehicle maintenance as a function of design complexity or simplification of design and rugged construction
- Assurance of dynamic and static compatibility with docking and loading facilities
- Possible changes in configuration to ensure intervehicle integrity and acceptability of a greater variety of cargo and container types
- Potential savings in fuel per net unit of cargo carried
- Application of numerically controlled automated fabrication techniques
- Inflated costs of new equipment offset partly by potential savings in line-haul and cargo terminal loading costs
- Improved operating loads, revenues, and profits to rail carriers
- Reduced wear and maintenance requirements on yard and line trackage plus greater efficiencies from larger yards
- A reduction of car and engine noises because of better power systems, improved suspension and trackage, and less spillage or venting in case of accidents of gas or liquid tank cars or other hazardous material carriers

- Revision or modification of terminal loading facilities to accommodate new car and engine configurations
- A greater choice of routing and an increased potential for door-to-door service available to freight forwarders through use of multimode containers, intermodal transfers, and dual-mode trailers with concommitant access to an expanded market for commodities
- A potential increase in cargo security from accidental damage because of accident resistant cars
- A continuing need for security monitoring with large flat or boxcars
- A potential for accommodation of 3-, 6- and 12-meter containers with larger flatcars
- Potential savings in time to shippers with increased train speed and quicker movements through marshalling yards
- A potential for freight rate reduction if carrier cost savings are passed on to the shipper

Higher capacity trackage and marshalling yards: The Federal Railroad Administration is concerned both with increasing intercity track capacity and flow of rail cars through marshalling yards. The FRA is conducting research on train classification yard management and automated control systems and components. Another project is research and development of motor-driven flywheel energy storage and recovery systems for propulsion of classification yard locomotives. Yard layouts are made to save time in assembling trains. Maximum advantage is taken of gravity to save energy in moving cars through the yards to be train assembly station. The expected impacts of these developments are:

- A potential increase in railcar annual productivity coupled with savings in fuel
- Need for substantial capital investment to preserve and improve line and yard trackage
- Lowered car-handling and operating costs with higher speeds, less delay time, and better roadbeds for smoother transit
- Savings in cost and time to rail line operators with higher block speeds and efficient car processing in larger yards

Improved multimode container compatibility: The same qualifications for multimode cargo containers apply to rail as to air, highway, and ocean transport. Benefits are generally the same with forecasted effects as follows:

- A potential increase in railcar productivity with greater loading capability
- Car configuration compatibility both with the containers and the loading docks for each transport system
- Some increase in the costs of new cars and railroad loading equipment to accommodate multimode containers
- Increased container business for the railway operators
- Increased loading flexibility for all cargo terminals which interface with the railroads
- A wider choice for container forwarders in using more than one transit mode
- Some simplification of containers with adoption of multimode standards
- A potential expansion of commodities shipped because of greater flexibility in route choices
- Greater security with a container sealed from origin to destination
- Increasing adoption of 3-, 6- and 12-meter containers with wide-spread acceptance of commonality standards
- Potential time savings to shippers with reduced intermodal handling

Improved trailer-on-flatcar and container-on-flatcar interfaces: There is a project sponsored by the FRA with rail carriers and through the AAR in which the viability of carrying truck trailers in selected freight markets will be examined over an extended time period. Research emphasis will be concentrated on system line-haul concepts, systems engineering, carrier operating practices and systems management, information management and control systems, and terminal operating concepts. The objective is to create an improved trailer-on-flatcar (TOFC) service and network designed to respond to and exploit an intermodal traffic potential. Predicted effects of this trend are:

- A modification and improvement of loading docks and equipment and of procedures for handling trailers and containers
- An increase in capital investment both for railcars and for terminal equipment

- Reduction of line-haul operating costs with increased usage of containers and trailers
- Potential decrease in unit cargo processing and handling costs in the terminals
- Simplified loading procedures at cargo terminals
- Increased potential for door-to-door delivery of containerized or unit-loaded cargo
- Simplified procedures at modal interfaces for handling of containers and trailers
- A possible expansion to new commodities traditionally carried in a single mode
- Increased use of mode-compatible 3-, 6- and 12-meter containers
- Savings in time and costs to shippers
- A proliferation of routes available to shippers

Train operations. - A considerable amount of research activity has been conducted by various governmental and industrial groups. These areas have included train operations and the design of supporting equipment. The areas of research presented below include changes in train composition, automated data management including marshalling yard operations, and special handling of express. Each topic is discussed qualitatively to reveal the expected impacts on vehicles and the infrastructure of rail systems.

Train composition: For bulk commodities, trains have consisted of large numbers of cars where traffic demands have been high. Long-haul trains also have contained large numbers of cars of mixed composition. These have included flatcars, hopper cars, boxcars, refrigerated cars, tankers, and other types of rail cars. A suggestion has been made to decrease the number of cars in a freight train and increase the frequency of service. By providing more trains during the week (or day), it is expected that the railroads would be more competitive with other transport modes. The impact of shorter trains and increased frequency of service is expected to be:

- A potential increase in payload fraction per car or an increase in train speed
- A possible increase in productivity per year as a result either of payload gains per car or speed gain per train

- Increased fuel consumption rates per train unit due to diseconomies of reduced scale of locomotives and drawbar pull required for lower-power units
- A possible increase in the number of engines and a decrease in the size of each engine used for shorter trains resulting in a total increase in acquisition costs
- Increased line-haul operations costs per car because of increase in ratio of crew, fuel consumption, and locomotive costs per car unit
- Increased management control if more trains are operated in a given time period
- Greater train makeup activities in classification and marshalling yards
- A relative reduction in the noise and possibly exhaust pollution impact upon the environment from each train
- Accelerated use of cargo terminals with greater numbers of trains
- Proliferation of schedules for freight forwarders
- Improvement of scheduling availability for intermodal transfer of cargo
- Potential attraction of new commodities with improved schedules or frequencies
- Possible reduction in loss of cargo with more frequent or direct service and less time in transit
- Some possibility of increased freight rates with increased frequency and higher unit costs of service as well as a potential for an enlarged route structure

Automated data management: The application of computer technology to transportation has enabled rapid ticketing of passengers, instant information on capacity, identification and monitoring of vehicle progress, and many other activities to accelerate and increase the reliability of transport. Opportunities exist in rail freight transport to improve many activities. These include cargo through billing, cargo and car identification, dispatch-crew communications, interline transfers, and automated marshalling yards. The future impact of these various developments are expected to be:

- Savings in time at terminals and classification yards because of more rapid handling of cars and cargo and reduction of line-haul delays caused by weather, breakdown of equipment, or other factors

- Increase in train annual productivity with reductions in block time
- Required compatibility between carriers to expedite interline transfers
- Savings in energy consumption through reduction of standby operations
- Investment in automated processing and signal generation and detection equipment for operators, terminals, and marshalling yards
- Potential savings in line-haul and marshalling yard costs
- A relative reduction in fleet size to reflect increased productivity
- Adoption of equipment and procedures by rail carriers and cargo terminals with interline coordination
- More rapid and greater accessibility of routes and schedules availability to freight forwarders
- Expedited intermodal transfer of cargo and containers
- Increased use of sealed containers with external identification coding to improve cargo security and provide single and complete waybill data
- Potential savings in time and cost to shippers if carrier savings are passed on as rate reductions

Special handling of express: In the heyday of passenger train operations, the now-extinct Railway Express Agency provided a special service for individual shipments of cargo. Each passenger train included an express car for special shipments. Shipping time was markedly less than by freight. Truck delivery or pickup provided door-to-door service. The rapid growth of air and truck cargo service, coupled with the decline of rail passenger service, displaced rail express as a viable concept. The federally sponsored Amtrak passenger service opens the opportunity to resumption of express cars on passenger trains. If an express service were to be reinstituted along with terminal processing of packages, the following effects might be expected to occur:

- Increased competition with intercity buses and express truckers for over-night service
- Lowered transit time for door-to-door service
- Added productivity of passenger trains with incremental express cargo service

- Provision of specialized terminal processing and loading service and equipment
- Potentially new designs for express cars both to accommodate express cargo and to be compatible with passenger train configurations
- Additional capital investment for modern express cars with an absolute increase in the total rail cargo fleet
- Added scheduling and train assembly problems for carriers
- Integration of passenger baggage and express handling procedures and equipment
- Potential increase of market by penetration into truck and bus service
- Problems in both interline and intermode transfer without increasing line-haul costs
- A net increase in exposure of cargo to pilferage opportunities
- Potential need to accommodate small aircraft-type cargo containers and other surface containers
- Potentially faster service to shippers and proliferation of cities served with express service.

General Surface Transportation Technology

The Office of the Assistant Secretary of Transportation for Systems Development and Technology has a number of research study areas which are expected to improve transportation systems in general. These various areas are (References 1-8, 1-9):

- Transportation noise abatement - Research on general methods of noise reduction from highway and guideway vehicles and the lateral propagation of noise from highway and guideway vehicle systems.
- Technology for environmental analysis - Development of a unified technology base to aid in the definition, analysis assessment, and control of the environmental impact of transportation systems and facilities.
- Climatic impact assessment program - Technical support of research programs in engine emissions; atmospheric monitoring and experimentation; atmospheric chemical dynamics; and information analysis; integration, and assessment. This is an ongoing program which has been referred to as CIAP.

- Ride quality of transportation systems - Development of an accurate, statistically reliable set of ride-quality criteria for various types of surface transportation systems and in terms of the item or product being transported.
- Cargo data interchange system (CARDIS) - Cooperative participation in a government/industry effort to reduce delays and costs in cargo movement created by inefficiencies or short comings in the transfer of cargo documentation. In plain words, simplify and speed up "paper shuffling."
- Inland waterway and coastal shipping - Improvements in these two modes of surface transport are insignificant in terms of savings in time or cost.

In addition to these areas of general research, the Federal Railroad Administration has two projects under way at the Pueblo, Colorado, test facility (Reference 9, Part 4). The first is to develop and test a vehicle and a track for a linear induction motor-drive unit. Another interest in the concept of tracked air cushion vehicles is being restricted to monitoring of systems being developed in foreign nations.

Ocean Transportation Technology

The United States Coast Guard has a research effort in using orbiting satellites in data transmission. The task is to more quickly and cheaply relay ship-to-shore voice, technical, and navigational data (Reference 1-8).

Other areas of research and expected developments are in liquid tankers at ambient and cryogenic temperature levels and dry-bulk carriers. With a major interest in oil in the Arctic regions, new super-icebreakers have been developed by the Russians and may be developed by other nations. Nuclear-powered submarines designed as tanks and submersible tanker tows have been suggested for research activity.

Although the USS Savannah has been deactivated, its nuclear powerplant provided much data on propulsion and operations. Foreign opposition to nuclear-powered commercial vessels appears to be waning, raising the good possibility of future developments in this area. Increasing fuel costs for diesel and bunker oil also make nuclear power more attractive.

By the year 2000, it is expected that tankers for feeder operation will approach 55 000 to 65 000 dead-weight tonnes (DWT) with a draft of 12 to 13 meters. Supertankers for long ocean voyages will approach 315 000 to 360 000 DWT in common usage. Dry-bulk carriers of 115 000 DWT will need new types of dockside loading/unloading devices such as self-contained pumping units for dry or slurry operations (Reference 1-10).

Use of computers is expected to result in automated operations with reductions in manpower needs, automatic fault finding systems to monitor operating systems, and automated command and control systems linked to satellite relay stations in orbit around the earth.

General Impressions of Technology Impact Upon Future Transport Developments

A general impression to be drawn from the technology impact survey is that transport systems for cargo and freight will incorporate evolutionary changes in hardware and physical components. A basic factor affecting both surface and air cargo systems is the inflationary rise in petroleum fuel costs. Thus, systems dependent on petroleum distillates will be driven toward fuel efficiencies in order to keep costs down. As coal becomes a prime fuel for nontransportation use, a greater fraction of oil fuels will be used for transportation. Fuels derived from processing of oil shale and possible liquified coal products will also be used for internal combustion engines. Although research will continue on liquid hydrogen for high-speed aircraft, cargo and freight systems will continue to be operated at medium to high subsonic speeds. For these speeds, oil fuels will continue to be used.

In the simplest of analyses, freight and cargo will continue to move in those systems which offer cost and speed compatible with the market sensitivity of the product in the transfer from producer to consumer. Thus coal, a large bulk, low unit-value commodity, is transported in large amounts and has no storage perishability or environmental requirements. At the other extreme, strawberries and flowers have high unit values in the market place, critical transit time, and storage requirements due to perishability. They cannot be stockpiled in their natural state for future use. Other commodities between these extremes of value and physical characteristics will be carried by transport systems offering various combinations of transit speed with delivery cost and flexibility of service.

In cargo aircraft transport, technologies which could make aircraft more competitive with truck transport are those which will lower the cost of air transport. Speed and range already are adequate for domestic and international traffic. Size and payload increases will provide economies of scale, provided that the larger aircraft achieve compatibility with airports and contemporary terminals and ground support equipment. Along with increased size of aircraft, supporting technologies will consist of engine improvements; cargo loading and unloading equipment; advances in fabrication techniques which will use improved metals, structure, and composite materials; and developments in flight sciences. A large size of aircraft is the only potential factor which is expected to lead to a new development program. By the year 1990, a new program with a total payload of 154 000 kilograms might be put into development. This aircraft most likely will be developed with a main deck for large bulk or containerized cargo. A lower cargo hold would accommodate small bulk and containers similar to the current LD- series. The economic viability will be closely tied to price and an adequate production base.

The aircraft will be a conventional land-based configuration. Ground effects vehicles, seaplanes, or buoyant airships cannot compete on a direct operating cost basis with the same speeds and/or ranges.

With the current military interest in a medium-sized (90 000 to 135 000 kilogram gross takeoff weight) STOL transport, a civil derivative promises benefits of air transport to emerging nations and remote undeveloped regions. The technologies applied for this concept are flight sciences (lift and control) and low flotation landing gear design.

Evaluation of the competition of other surface transport systems leads to the same general conclusions. Evolutionary developments will continue to supply the competitive capability of various transport systems.

In aircraft technologies, composite materials are being developed for both civil and military applications. Advanced metallics include powder technology for aluminum and titanium and metal and fiber physical alloys. Integrated structure refers to fabrication techniques such as formed waffle structure and adhesive bonded primary structure. Automated design and drawings are considered as improvements in fabrication, design, and manufacturing. Note that all of these are expected to be used in derivative configurations. The 154 000-kilogram payload transport aircraft is a possibility in the early 1990s. The other technological improvements are expected to be evolutionary on derivative aircraft as shown.

With the adoption of a 36 300-kilogram truck gross weight, new designs are expected to be on the highways by 1979 or 1980; other changes will be gradual.

Rail improvements are not expected to be very dramatic because of the financially precarious position of the railroads and institutional road blocks. A consolidation/merger phase is underway, as evidenced by Conrail (merger of six bankrupt lines by the U.S. Railway Association, a federally chartered corporation). Until the railroads themselves become more profitable, new equipment and developments will be gradual. Rail cars with reasonable maintenance have about 20 to 25 years of useful life so replacement is slow.

The use of the dual-mode road-rail trailer is a possible development in the next 10 years. A fully streamlined freight train is not indicated before 1991 because of financing problems and present equipment longevity.

In ocean transport, new tankers with cryogenic capabilities will continue to be built. A nuclear-powered submerged tanker and very large surface tankers are not expected before 1990. A nuclear-powered surface transport could be introduced by 1991. The initiation of automated navigation systems is uncertain but a guess would be in the middle to late 1980s.

Integrated Transport System

During the first half of this study, efforts were directed to defining the characteristics of the current air cargo system and to the identification of issues and requirements pertinent to developing an effective 1990 system. In this second half of the study, these issues and requirements were oriented to aircraft design and the relative importance of the infrastructure and aircraft to air cargo market growth established. In performing these investigations and analyses, air cargo operations were viewed from the total system point of view. In this approach, the interrelating infrastructure includes not only the direct supporting airport and terminal elements but also the market, shipper and consignee, and surface transport elements of a total transport system. Each of these elements encompasses a multiplicity of issues that influence and/or is influenced by other issues on an intra- and interelement basis. This section identifies the more prominent of these cross impacts and qualitatively discusses their importance to the aircraft and to the relations between the aircraft, infrastructure, and the air cargo market.

System cross impacts. - A qualitative cross-impact analysis of the many system factors (issues) was performed with the results provided in Table 1-4. For clarity, the prime factors considered are segregated under the seven system elements and are listed both vertically and horizontally in the table. Reading horizontally, opposite a particular considered factor, identifies all the factors impacted by that considered factor. On the other hand, reading vertically, below an impacted factor, identifies all of the considered factors having the potential to effect that specific impacted factor. Interrelations between the factors within a given system element, such as for the market or airport elements, are shown adjacent to the diagonal. The data of Table 1-4 provide a visual orientation of issues in a manner that facilitates the qualitative evaluation of their relative importance in the development of the future air cargo systems.

In order to keep the table to a reasonable size, some groupings were utilized along with descriptive terms, each of which encompasses two or more specific factors. To avoid duplicate listing, the factors included under the shipper element are considered equally applicable for the consignee.

Similarly, the factors considered under the surface transport element are viewed as being equally applicable in the case of a forwarder. In addition, the following descriptions identify specific factors included under the respective descriptive terms.

- Commodity - Characteristics of the commodity including density, volume, weight, value, perishability
- Environment - Encompasses considerations in the social, political, physical, technical, and economic arenas
- Delivery Time - Total delivery time including such requirements as next-day delivery
- Security - Includes considerations related to theft, damage, and other losses
- Accessibility - Availability of considered installation or service to users both surface and air
- Adaptability - Ability to accommodate changes in the market and in air and surface equipment and their operation
- Regulations - Those discussed in Section 5, Political and Economic Factors, of Volume I
- Capacity - The level of surface and air activity that a given airport can accommodate
- Responsibility - Operations and functions taken on by the management of the shipper and/or consignee, surface transport, and airline (For airlines this responsibility has been identified under the air cargo terminal element of the system.)
- Productivity - Encompasses the functions related to the aircraft, truck, and rail docks and to freight flow within the terminal

Of prime concern to the development of an effective air cargo system is the assignment and/or assumption of responsibility for fulfilling the shipper and/or consignees desires including those related to surface transport. Three views of responsibility are illustrated in Table 1-4, being identified by the cross-hatched squares on the diagonal. In the first approach, the shipper or consignee assumes the responsibility of coordinating the total transport operation from origin to destination in a manner similar to that of a forwarder. In the second approach, these functions are performed by the surface

TABLE 1-4. CROSS IMPACTS IN AN INTEGRATED TRANSPORT SYSTEM

FACTORS (ISSUES) IMPACTED →

FACTORS (ISSUES) CONSIDERED ↓

Column factors (issues impacted):

- MARKET: LOCATION, COMMODITY, ENVIRONMENT, QUANTITY
- SHIPPER & …: LOCATION, PACKAGING, HANDLING EQUIP. AVAILABLE, SHIPPING COSTS, DELIVERY TIMES, CONTAINERIZATION, DOOR/DOOR DELIVERY CAP., TRACEABILITY/DOCUMENTATION, SECURITY, CLAIMS, RESPONSIBILITY
- & AND/OR CONSIGNEE
- SURFACE TRANSPORT*: NETWORK, ACCESSIBILITY, TERMINAL, HANDLING EQUIPMENT, VEHICLES, SCHEDULING, CONSOLIDATION, UNITIZATION, DOCUMENTATION, ADAPTABILITY, RESPONSIBILITY, TARIFF, REGULATIONS
- *AND/OR FORWARDER
- AIRPORT: LOCATION, ACCESSIBILITY, CAPACITY, LAYOUT, RUNWAYS, TAXIWAYS, CARGO AREA, ADAPTABILITY, FEES, REGULATIONS, LANDSIDE CONGESTION
- AIR CARGO TERMINAL: LOCATION, ACCESSIBILITY, LAND AVAILABLE, APRON, BUILDING, HANDLING EQUIPMENT, ROAD VEHICLES, CAPACITY, CONSOLIDATION, UNITIZATION, CUSTOMS, PRODUCTIVITY, ADAPTABILITY, DOCUMENTATION, REGULATIONS, RESPONSIBILITY
- AIRCRAFT: PAYLOAD, RANGE, SPEED, LOADING, INTERIOR CONFIGURATION, EXTERIOR CONFIGURATION, ENERGY CONSUMPTION, PRODUCTIVITY, DOC, IOC, FABRICATION, ACQUISITION COST, REGULATION
- AIR NETWORK: POINTS SERVED, SCHEDULING, NUMBER OF AIRCRAFT, TARIFF

Row factors (issues considered):

- MARKET: LOCATION, COMMODITY, ENVIRONMENT, QUANTITY
- SHIPPER & …: LOCATION, PACKAGING, HANDLING EQUIP. AVAILABLE, SHIPPING COSTS, DELIVERY TIMES, CONTAINERIZATION, DOOR/DOOR DELIVERY CAP., TRACEABILITY/DOCUMENTATION, SECURITY, CLAIMS, RESPONSIBILITY
- & AND/OR CONSIGNEE
- SURFACE TRANSPORT*: NETWORK, ACCESSIBILITY, TERMINAL, HANDLING EQUIPMENT, VEHICLES, SCHEDULING, CONSOLIDATION, UNITIZATION, DOCUMENTATION, ADAPTABILITY, RESPONSIBILITY, TARIFF, REGULATIONS
- *AND/OR FORWARDER
- AIRPORT: LOCATION, ACCESSIBILITY, CAPACITY, LAYOUT, RUNWAYS, TAXIWAYS, CARGO AREA, ADAPTABILITY, FEES, REGULATIONS, LANDSIDE CONGESTION
- AIR CARGO TERMINAL: LOCATION, ACCESSIBILITY, LAND AVAILABLE, APRON, BUILDING, HANDLING EQUIPMENT, ROAD VEHICLES, CAPACITY, CONSOLIDATION, UNITIZATION, CUSTOMS, PRODUCTIVITY, ADAPTABILITY, DOCUMENTATION, REGULATIONS, RESPONSIBILITY
- AIRCRAFT: PAYLOAD, RANGE, SPEED, LOADING, INTERIOR CONFIGURATION, EXTERIOR CONFIGURATION, ENERGY CONSUMPTION, PRODUCTIVITY, DOC, IOC, FABRICATION, ACQUISITION COST, REGULATION
- AIR NETWORK: POINTS SERVED, SCHEDULING, NUMBER OF AIRCRAFT, TARIFF

[illegible]

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

2 FOLDOUT FRAME

1 FOLDOUT FRAME

transport or forward management. In the third, by airline management. The purpose here is not to evaluate these or other approaches to operational responsibility but to identify the many factors that can be effected by the choice.. Considerations pertinent to the placing of responsibility are discussed in other more appropriate sections of this report.

Relative importance of system factors. - A prime concern in any system's study, such as CLASS, is to establish bounds on the scope and depth of the investigations that are compatible with available resources yet provide viable results that meet the study objectives. While it was mandatory that the seven system elements be included, there was the question of which of the many identified factors should be viewed in more detail. This question was answered by first reviewing all the factors (issues) identified through experience and from the investigations of the current system conducted during the first half of the study. The latter included results from the case interviews of air cargo users and potential users. The list so developed was reduced to the more pertinent factors delineated in Table 1-4. Using these cross-impact data, the relative importance of the considered factors was developed utilizing impact counts, ratios, and qualitative judgment.

The semiquantitative analysis used in deriving the following results is by no means rigorous, many of the points of judgment could be extensively debated. However, the development of Table 1-4 serves the purpose of providing an insight into the detailed interrelations that can occur between elements and requirements existing within the total air cargo transport system. The relative importance of the various factors derived are compatible with the views and concerns which the case studies indicate to be prevalent within the industry today.

Affecting factors: The considered factors listed in Table 1-4 were each considered for their potential to affect change in the total system. The importance of each considered factor is based upon this change potential as indicated by the importance and number of other factors impacted. As an example, the implementation of containerization and/or changes in the container system used has the potential to affect 38 of the remaining system factors. Nine of these affected factors, 24 percent, are included in the list of 10 judged to be most susceptible to possible changes that could originate within the total of seven system elements. The identification of the latter most susceptible (affected) factors will be discussed in the section that follows.

Within the total system the following 10 factors are those estimated to have the most effect on system development. An attempt was made to order the list; however, small variations in value judgment can make the relative positions debatable.

Environment
Containerization
Commodity
Terminal adaptability
Aircraft exterior configuration
Aircraft payload
Road vehicles
Handling equipment
Aircraft loading
Responsibility

In any case, it is definite that containerization must be high on the list of considerations pertinent to system design and development. This point is emphasized by the fact that, with the exception of the environment and commodities, all the remaining factors on the foregoing list are directly affected by container characteristics.

Affected factors: In order to understand and evaluate future system developments, it is necessary to be aware of those factors (issues) most susceptible to changes within that system. The impacted factors of Table 1-4 were examined in a manner similar to that discussed above. The following 10 factors are identified as those most susceptible to changes in the total system.

Delivery time
Transportation cost

Indirect operating cost
Security
Commodity
Road vehicles
Terminal productivity and adaptability
Scheduling
Handling equipment
Unitization

Seven of these factors, namely delivery time, transportation cost, security, commodities, road vehicles, scheduling and unitization, are issues of prime concern to the users of air cargo transportation. On the other hand, the airlines have special interest in reducing indirect operating costs that are strongly impacted by terminal productivity, which in turn is directly affected by the handling equipment utilized therein.

Interrelations between system elements: The data of Table 1-4 also provide a qualitative view of interelement change. The ratio of the number of potential impacts identified within a considered element to the total number of possible impacts that could occur from the considered element was used to establish a basic measure of the importance of element interactions. These results were then tempered by the application of value judgments to provide the qualitative ranking of potential cross-element impacts shown below.

- Market interactions
  - with air and surface networks
  - with shippers and/or consignees
  - with the air cargo terminal
  - with the aircraft
- Shipper/consignee interactions
  - with surface transport
  - with aircraft
  - with air cargo terminal
- Air cargo terminal interactions
  - with surface transport
  - with aircraft

Once again, the specific ordering of these issues can be debated on the basis of value judgment. However, the importance of the market characteristics and customer desires to the development of a desirable transportation cannot be over stated. As in any commercial enterprise, one must first understand the business to be conducted, then develop operations in a manner that will best serve the customer needs from the standpoints of service and cost.

Relative to the transport system, the characteristics of the terminal are a prime consideration because it provides the interface between the air and surface modes. It also relates to the market and to the shipper/ consignee requirements and desires through such functions as consolidation, unitizations, customs, security, and documentation.

D2

N79-27114

SECTION 2

AIRFREIGHT FORECASTING METHODOLOGY AND RESULTS

This report documents results of an econometric study on the long-term prospects for airfreight traffic demand to the year 1990. A series of econometric behavioral equations was developed to explain and forecast the evolution of airfreight traffic demand for the total U.S. domestic airfreight system, the total U.S. international airfreight system, and the total scheduled international cargo traffic carried by the top 44 foreign airlines. The basic explanatory variables used in these macromodels are the real gross national products of the countries involved and a measure of relative transportation costs (i.e., yield deflated by a composite price deflator for GNP reflecting both inflation rates and variations in exchange rates). The results of the econometric analysis reveal that the models explain more than 99 percent of the historical evolution of freight traffic. The long-term traffic forecasts generated with these models are based on scenarios of the likely economic outlook in the United States and 31 major foreign countries.

A more fundamental methodology was then developed to translate these aggregate freight traffic forecasts in terms of origin-destination traffic demand forecasts. A separate method was devised for the top 10 United States domestic city-pairs which will be discussed later.

The following airfreight markets were analyzed for this study.

- Subsystem Industry Markets
  - U.S. certificated carriers' scheduled domestic operations
  - U.S. certificated carriers' scheduled international operations
  - Top 44 foreign (non-U.S.) carriers' scheduled international operations
- Directional U.S. Domestic Origin-Destination Markets
  - Los Angeles-New York-Los Angeles
  - Los Angeles-Chicago-Los Angeles
  - Chicago-New York-Chicago

- Chicago-San Francisco-Chicago
- New York-San Francisco-New York

- Directional International Origin-Destination Markets
  - U.S.-Germany-U.S.
  - U.S.-UK-U.S.
  - U.S.-Japan-U.S.
  - U.S.-Indonesia-U.S.
  - U.S.-Brazil-U.S.
  - Germany-Japan-Germany
  - Germany-UK-Germany

Annual traffic and revenue statistics for the U.S. industry subsystem models were obtained from the U.S. Civil Aeronautics Board traffic and financial publications. These pertain to the U.S. total domestic and total international airfreight networks. Sources for the top 44 foreign carriers were the International Air Transport Association and the Association of European Airlines traffic and revenue publications. Table 2-1 shows the foreign carriers aggregated for this subsystem and the 1975 freight traffic by airline.

Statistical summaries by year are compiled from CAB Form 41 submitted to the CAB by each United States carrier. The domestic freight subsystem model also includes statistics on the major domestic airfreight forwarding companies which were obtained from CAB Form 244. This provided forwarder's revenues, expenses paid to the airlines, and traffic statistics which were used to construct a component of the U.S. domestic airfreight yield.

Historical data for traffic volumes for the United States domestic city-pairs were based upon the Douglas Aircraft domestic shared airfreight industry statistics published to participating carriers since 1968. Airfreight volume history for the United States international O/D markets came from the U.S. Department of Commerce publications. Traffic for the foreign markets were from German government statistical reports for total airfreight to and from Germany.

TABLE 2-1

TOP 44 FOREIGN CARRIERS.
INTERNATIONAL OPERATIONS

Carrier	1975 Scheduled Intn'l. Freight Tonne-Kilometers (Millions)	Percent of Total 44
Aer Lingus	67.5	0.8
Aerolineas	52.3	0.7
Aeromexico	30.2	0.4
Air Afrique	132.6	1.7
Air Canada	205.0	2.6
Air France	644.1	8.0
Air India	192.5	2.4
Air New Zealand	88.6	1.1
Air Zaire	35.4	0.4
Alitalia	368.4	4.6
Avianca	38.4	0.5
British Airways	669.3	8.3
British Caledonian	40.5	0.5
Canadian Pacific	83.0	1.0
Cruzeiro de Sol	3.1	(Nil)
East African Airways	24.9	0.3
Egypt Air	20.5	0.3
El Al	130.9	1.6
Ethiopian Airlines	15.5	0.2
Finnair	26.9	0.3
Garuda	26.5	0.3
Iberia	167.7	2.1
Iran Air	31.2	0.4
Japan Air Lines	766.8	9.5
KLM	585.2	7.3
Lan-Chile	45.0	0.6
Lufthansa	903.0	11.2
Mexicana	12.4	0.2
Middle East Airlines	47.8	0.6
Olympic Airways	29.1	0.4
Pakistan International	114.6	1.4
Philippine Airlines	78.7	1.0
Quantas	224.0	2.8
Sabena	281.2	3.5
Saudi Arabian Airlines	42.4	0.5
Scandinavian Airlines	300.3	3.7
S. African Airways	115.7	1.4
Swissair	281.5	3.5
TAP	30.9	0.4
Trans-Mediterranean	435.9	5.4
UTA	237.0	2.9
Varig	328.2	4.1
Viasa	67.9	0.8
Zambia	24.8	0.3
Total	8047.5	100.0%

Subsystem Forecasting Models

Methodology. - The method of forecasting used for the three subsystem markets (U.S. domestic, U.S. International, and top 44 foreign) was econometric in nature. Econometric analysis incorporates a combination of economics, mathematics, and statistics disciplines. The initial phase of this type of procedure is the preselection of the potential explanatory economic factors. The second step in the development of the econometric model consists of specifying the form of the mathematical equation which relates the various explanatory or independent variables to the dependent variable, airfreight traffic. The third step of the analysis consists in performing a series of statistical tests designed to assess the significance and the reliability of each independent variable and the overall goodness of fit of the model. Once the behavioral equation is established and tested, the final step is to apply forecasts for the independent variables in the equation, thereby forecasting the dependent factor.

Further detail of econometric model building is offered by Figure 2-1.

Potential economic explanatory variables: According to accepted economic theory, consumption of any good or service is dependent upon the level of real income and the relative price of the good or service as compared to other prices in the marketplace. A random disturbance variable was used in the three models and will be explained later.

Income effect - The level of real income can be expected to greatly influence the demand for airfreight. Several measures of real income were investigated; the one found most highly related, statistically, to traffic was real gross national product (GNP), that is GNP measured in constant dollars.

The permanent income hypothesis was also tested. This theory, whose leading proponents include Milton Friedman (Reference 2-1), states that consumption in time t depends not only upon real income in time t but also is affected by past and expected future levels of income. For example, if an individual undergoes a drop in income level, the theory states that his

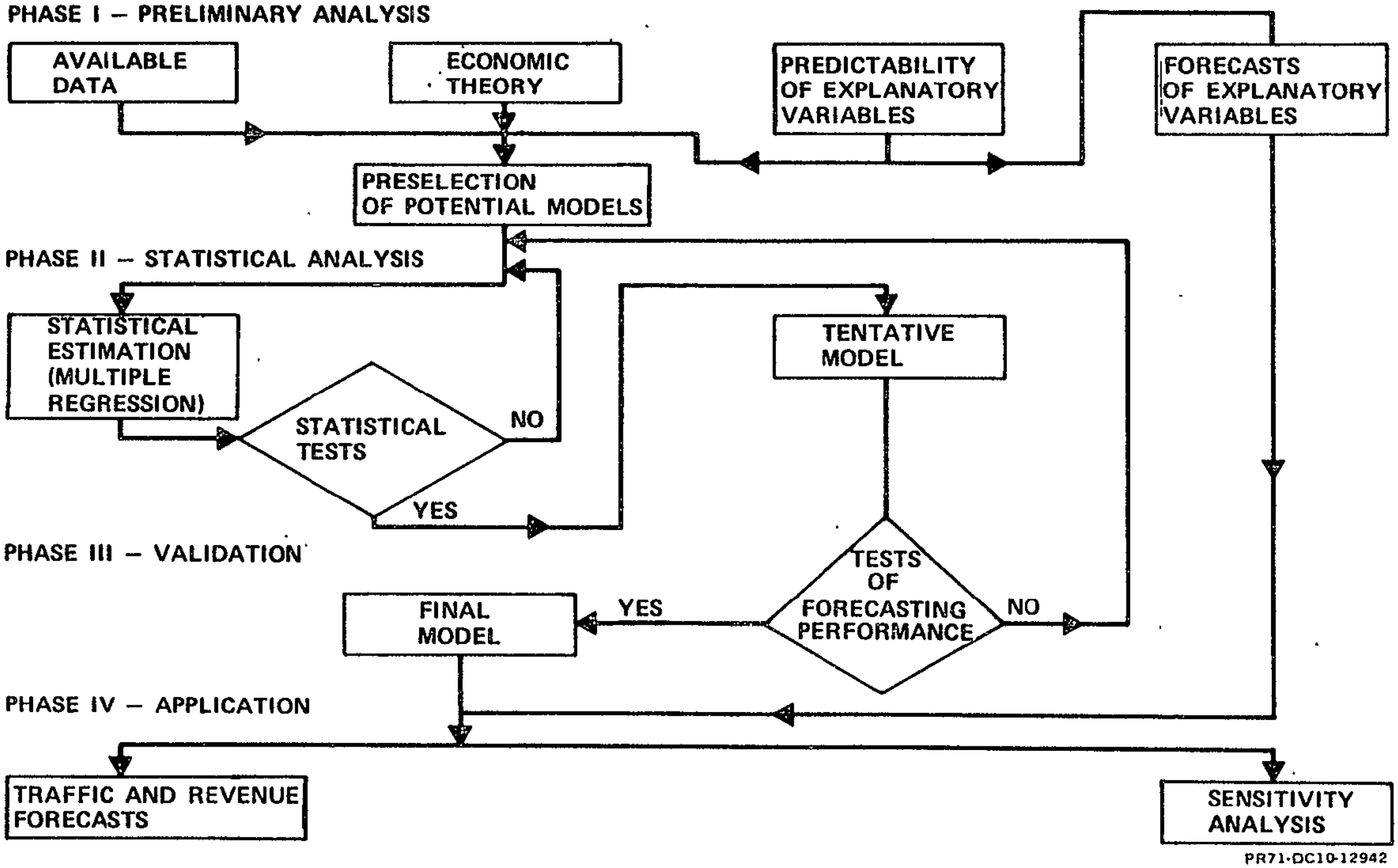


Figure 2-1. Econometric Model Building

consumption expenditures will also decline but at a slower rate, and his total consumption is likely to be greater than his income. This is accomplished by the reduction of liquid or real assets as well as borrowing. This occurs because of his desire to maintain past levels of consumption regardless of present income. A second interpretation of the theory is that consumption in time t is dependent upon expected future income, which, in turn, is estimated on the basis of a distributed lag function of present and past incomes. If an individual believes his income will increase in the future, he is likely to dis-save at the present and replenish his reduced assets from the higher levels of future income.

A final interpretation relates to the lag time between consumption and the flow of goods for restocking. The producer will not always be able to estimate accurately the demand for his products. So when a drop in sales occurs, it takes some amount of time to slow the flow of goods to the marketplace.

The measurement of this phenomenon for this study was accomplished by transforming real income into permanent income using distributed lag coefficients to lag real GNP. The formulation for this distributed lag in calculating permanent income is shown below.

$$GNP_t^* = \sum_{\theta=0}^{3} \omega_\Theta \; GNP_{t-\theta}$$

where

t = time in years

GNP_t^* = Permanent income measure of gross national product in constant 1972 dollars

ω_Θ = Coefficients applied to lag values of GNP

$GNP_{t-\Theta}$ = Lagged values of GNP in constant 1972 dollars

The decision whether or not to use the permanent income hypothesis in a specific model was made by examining its effect on the overall goodness of fit and its improvement in the significance of the income variable to traffic.

Specifically, the coefficients of the lag distribution were assumed to decrease according to the following truncated geometric progression:

$$\omega_\Theta = K\rho^\Theta \qquad \text{with} \qquad 0 < \rho < 1$$

The constant K thus being interpreted in such a fashion that

$$\sum_{\Theta=0}^{3} \omega_\Theta = 1$$

In practice, the actual lag time is not known, so a search procedure was performed to determine that value of ρ which maximized the overall goodness of fit of the model. By varying the value of ρ in increments of 0.1 and using each transformed income with the other independent variables, the optimal lag structure was estimated.

Price substitution effect - The price substitution effect measures the relative price of airfreight service compared to prices of other items faced by the shipper. It was felt that a variable characterizing the price of airfreight compared to other goods and services, as well as prices of competing substitute modes, should be included in each model. The specification of this variable for each model is discussed in later sections.

Random disturbance variable - Some events which affect traffic cannot be quantified and separated from the dependent variable. They are random disturbances that can cause large fluctuations in freight volume. These can be strikes, business mergers, wars, etc. They have the common characteristic of being either "on" or "off."

When these occur, it is necessary to assign a value which differentiates the duration of the event. Event "on" = 1; event "off" = 0. For this reason, the variable is sometimes called a "dummy" variable.

On January 1, 1970, the Civil Aeronautics Board announced a new definition for domestic and international market areas. Although Alaska and Hawaii gained statehood in 1960, the CAB continued to classify traffic between these and the 48 contiguous states as international airfreight. The national income accounts, such as gross national product, began to include Alaska and Hawaii in 1960. Due to the fact that the CAB as yet has not published historical traffic and revenue data on a 50-state basis prior to 1960, there remains an inconsistency in these data.

In the absence of appropriate series to account for this difference in definition, a dummy variable was used in the U.S. domestic and international freight subsystem models having values of zero for 1955-1968 and values of one for 1969 onwards.

The mathematical form: Once the set of potential explanatory variables was selected based upon economic theory, as well as availability and predictability criteria, the proper mathematical form was considered. The logarithmic or multiplicative form was selected because of its special qualities. Those qualities are (1) once the logarithms are computed for the dependent and independent variables, linear ordinary least squares (OLS) estimating procedures can be employed to determine the unknown coefficients; (2) the log form tends to reduce the residual error terms between the actual and estimated values in the later historical years, thus minimizing the effects of one form of heteroscedasticity; and (3) the coefficients estimated by OLS which apply to each independent variable can be directly interpreted as the constant partial percent elasticity of traffic with respect to that variable.

Mathematically, the general form of the equation can be expressed as follows:

$$Y_t = B_o \prod_{i=1}^{m} X_{i,t}^{B_i}$$

or

$$\text{Log}_{10}\ (Y_t) = B_o' + \sum_{i=1}^{m} B_i\ \text{Log}_{10}\ (X_{i,t})$$

where

Log_{10} = Base 10 logarithm

Y_t = Traffic measured in revenue tonne-kilometers

t = Time in years

B_o' = A constant (y intercept)

m = Number of independent variables

B_i = Coefficient of the ith variable

$X_{i,t}$ = ith independent variable

Statistical analysis: A vital step of the methodology involves statistical inference and testing. The method of statistical inference selected to estimate the structural parameters of the model and to select the best model (within the class of log-linear models) is the ordinary least-squares method of multiple regression. This method consists of linearizing the model by performing logarithmic transformations on the original variables and then fitting a hyperplane to the sample points associated with the historical observations in the (m + 1) dimensional space generated by m independent variables and the dependent variable. This hyperplane minimizes the sum of the squares of the residuals, (measured parallel to the dependent variable axis between the actual points and the estimated hyperplane). The estimators of the structural coefficients are then parameters describing the hyperplane.

Once this hyperplane is fitted to the actual data, a series of statistics are computed to determine the best subset of explanatory variables which most accurately estimate the historical evolution of the dependent variable. The statistical results associated with the fit comprise the following statistics.

Numerical estimates of the structural parameters of the model - Since the true values of these structural coefficients are not known and since the model involves a random element, the coefficients can only be determined in probability. It can be shown that, given the hypothesis that the random element is normally distributed, the estimates of the structural coefficients follow a student t probability distribution (the number of degrees of freedom is equal to the number of observations available in the sample minus the total number of coefficients estimated). These probability distributions can be characterized by their mean and their standard deviation. The mean will represent the numerical estimate of the structural coefficient and the corresponding standard deviation a measure of the degree of uncertainty attached to this estimate.

These coefficients, with the exception of the constant, have no dimension and represent the elasticities of traffic with respect to the corresponding independent variable.

Student's t statistic - This is a measure of the significance of a particular variable and its contribution to the explanation of the total variation in the dependent variable. It is the ratio of the value of the coefficient divided by the standard deviation of this coefficient. These t ratios, which follow a student distribution with a unitary standard deviation, are tabulated in conventional statistical tables. A test can, therefore, be made on whether the individual coefficient is significantly different from zero (or equivalently whether the corresponding explanatory variable is significant). The empirical t value is then compared with the theoretical value obtained from the standardized student table, with the appropriate degrees of freedom and the arbitrarily selected confidence level. Given the number of degrees of freedom available in this study, if the absolute value of the t statistic exceeds roughly 2.00, then the corresponding coefficient is significantly different from zero and the corresponding variable is significant at a 95 percent confidence level.

R^2 - coefficient of determination - This statistic measures the overall goodness of fit of the estimated hyperplane. More specifically, R^2 is the amount of variance of the dependent variable that is explained by the regression equation.

$$R^2 = \frac{\text{amount of variance explained by the regression}}{\text{total variance of the dependent variable}}$$

The values for R^2 range between 0 and 1, and the larger the R^2, the better the overall goodness of fit. An R^2 of 0.9972 means that the estimated equation explains 99.72 percent of the variance of the dependent variable.

This coefficient of determination is also the square of the coefficient of correlation between the actual time series of the dependent variable and the estimated series obtained by substituting the values of the explanatory variables into the estimated equation. A coefficient of determination of 0.9972 therefore implies a coefficient of correlation between the actual and the estimated sums in the order of 99.86 percent.

Standard error (SE) of estimate - This statistic measures the errors associated with the estimated equation. It is defined as the square root of the sum of squares of the deviations between the actual and estimated values corrected for the appropriate degrees of freedom.

Durbin-Watson statistic and test - A measure for the existence or absence of autocorrelation of the residuals. Autocorrelation of residuals denotes that the residual difference between the estimated and actual value for a period is correlated with the residual(s) of the previous period(s). The statistic is defined in such a manner that a value of 2.00 would ideally imply no autocorrelation of residuals.

F-statistic - Fisher-Snedecor statistic - This is a measure for the significance of the goodness of fit for the overall model. It is the ratio of the variance of the dependent variable divided by the variance of the residuals. Therefore, the smaller the residuals, the larger the F-value.

U.S. domestic airfreight market - historical review. - It is somewhat difficult to identify the cause of annual fluctuations in total domestic airfreight traffic because of the many overlapping and counteracting factors taking place each year. For example, in 1970 the United States experienced a recession which depressed airfreight. At the same time, introduction of widebody aircraft would have tended to stimulate demand with increasing productivity and lower prices charged to the shipper. These problems are compounded by the fact that airfreight does not react instantaneously with market influences.

There are definite lead and lag periods between the cause and the effect on traffic level. We have seen in the past that airfreight is late to respond to an economic downturn and early to respond to an upswing because it is sensitive to stocking levels.

To get a better feel for the primary determinants on the airfreight market in the past 15 years, Figure 2-2 shows the relationship of airfreight traffic with United States real GNP and real yield from 1960 to 1976. The plotted values are annual percent changes for each series and illustrate the close relationship between traffic, the economy, and prices.

Chronological highlights of some of the more important economic and airline operational elements which affected domestic airfreight development are described below.

1960: There was an economic downturn in the United States as measured by gross national product in constant 1972 dollars. The recession lasted almost four quarters from April 1960 to February 1961. Real growth for the year 1960 amounted to only 2.4 percent over the previous year.

Operations by Flying Tigers and Eastern were curtailed for a total of 37 days due to management-labor disputes.

Increasing utilization of more-efficient jet aircraft starting in 1958 and 1959 with expanded lower-hold cargo capacity.

1961: U.S. economic recovery started at the end of the first quarter. A dramatic expansion in industrial output and business inventories supplied growing consumer demand in the last three quarters.

There was a significant decline in real domestic freight yields of nearly 4 percent with the GNP price deflator growing by only 0.9 percent

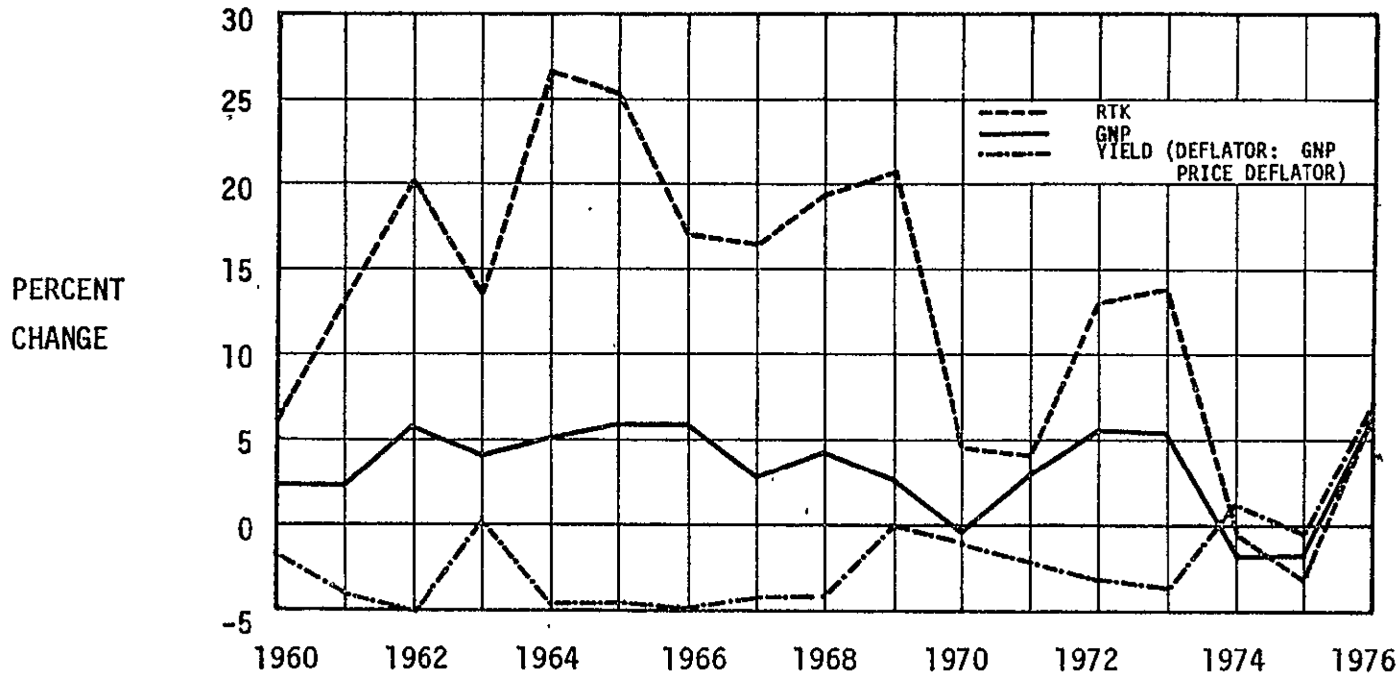


Figure 2-2. Comparison of Annual Change in U.S. Scheduled Domestic Traffic, Real Gross National Product and Real Yield

in the year. This was possibly due to improving productivity as new jet aircraft were deployed.

Operations were suspended due to strikes for American, Eastern, TWA and curtailed service for Flying Tigers, National and Pan American. The duration of these stoppages was 1 week.

1962-1963: Real economic growth of 5.8 and 4.0 percent for the 2 years provided stimulation to airfreight traffic.

1962 produced only one major airline strike. This was a 30-day suspended operations for National through most of July.

In 1963, the first Douglas and Boeing convertible configurations of the DC-8 and B707 were delivered. The effect upon total domestic cargo capacity was nil at this early stage but provided a significant impact upon cargo services later in the decade.

In 1963, average freight yields increased almost 2 percent in current dollar terms and by 0.4 percent in real terms. This was the only real yield increase for the 1960 to 1968 period.

1964: Economic growth continued to strengthen for the U.S. with real GNP registering a 5.3 percent gain. This increase in volume was accompanied by a moderate 1.6 percent inflation rate measured by the GNP price deflator.

U.S. domestic scheduled airfreight revenue per tonne-kilometer yield dropped by more than 3 percent in current dollar terms and by 4.7 percent in real terms.

The first DC-8-50 all-freighters were delivered, providing additional domestic capacity.

1965-1966: Rapid real growth in the economy in 1965 and 1966 of 5.9 percent each year provided additional increases in airfreight demand. Domestic freight expanded by 25 and 18 percent for the 2 years as a result.

Improvements in service and capacity affected constant dollar freight yields by a decline of 4.5 percent for each of the 2 years.

1966 produced a relative tightness in the short-term money markets driving the prime commercial paper interest rate up to 5.6 percent. The effect upon airfreight demand due to higher interest rates would have had a stimulus effect initially. In the end, however, business investment slowed along with consumer goods demand, causing a depressant effect on traffic.

1967: The economy suffered a minor slowdown in 1967, registering only a 2.7 percent real gain in output. Real yield continued to drop, however, as more efficient aircraft and expanded schedules were implemented.

1968-1970: The slowdown of 1967 was corrected in 1968 with a 4.4 percent real gain in GNP. But this was followed by another slowdown in 1969 and recession in 1970 with rates of change of 2.6 percent and -0.3 percent respectively. This was due to several factors, not the least important was the slowdown in military ordnance production as the United States began withdrawing from the Vietnam conflict.

Inflation in 1968 and 1969 was running 2 to 3 percent higher than in previous periods as output began to fall short of meeting domestic demand. As a result, the decline in real domestic freight yields in 1969 was arrested.

By the end of 1970, United States carriers had received a total of 222 Douglas DC-8 and Boeing 707 convertible and all-freighter aircraft.

1971-1973: Economic recovery ensued from December of 1970 through 1971, 1972, and 1973 with the last two of these years growing by 5.7 percent and 5.5 percent.

Inflation continued to persist even though an incomes policy was attempted by the Nixon administration in the fall of 1971.

Capacity was significantly increased with the advent of wide-body aircraft into many domestic markets. Probably as a result of this additional cargo volume, increases in tariffs were dampened. The years 1972 and 1973 witnessed more than a 3 percent decline in real freight yields further stimulating domestic demand.

Starting at the end of 1973, world crude oil prices exploded due to OPEC causing not only higher United States inflation rates but for most of the international community as well.

1974-1975: The United States economy for this period experienced the worst recession since the 1930s partly due to higher energy costs, interest rates, and a diminution in business and consumer confidence and spending patterns. The recession years had a tremendous impact on cargo traffic with the only two declines in domestic volume for the 1960 through 1976 period. The declines in real GNP for these years were nearly 2 percent per year.

Inflation (GNP price deflator) grew by 10.0 and 9.3 percent for 1974 and 1975. When compared to freight yields, an increase in real yield of 1.0 percent was witnessed for 1974.

Because of extremely high fuel costs to the airlines, many cut back on scheduled services and cargo capacity as well as increasing prices to shippers. These actions were taken also because of the heavy losses accumulating from the decline in United States economic activity.

1976: This year can be considered as a banner year in terms of economic recovery in the United States with a real growth in GNP of 6.1 percent.

A significant decline in the rate of inflation also took place as further oil price increases slowed relative to past years. The year did mark a period for airline revenues to catch up with costs as the current dollar domestic freight yield increased by almost 13 percent. This amounted to 7.0 percent in constant dollar terms.

<u>Economic scenarios</u>. - The following subsections discuss the economic scenarios for the United States, international, U.S. International, and the top 44 foreign airlines.

United States: The economic forecasts for the United States were obtained from Wharton Econometric Forecasting Associates which is affiliated with the Wharton School of Business, University of Pennsylvania. Two macro-economic indicators were used for the three subsystem models, U.S. gross national product in constant 1972 dollars and the implicit price deflator for GNP (1972 = 100). The June 1977 Wharton scenario ends in 1985. To extend the forecasts to 1990, the Economic Research Department of Douglas Aircraft Co. has input the exogenous assumptions of the model from 1986-1990 without altering the simultaneous solution of the behavioral equations. Table 2-2 presents the Wharton and Douglas extended United States economic forecasts to 1990.

International: Macroeconomic indicators for the foreign nations were obtained from the International Financial Statistics, IMF; Agency for International Development, U.S. Department of State; and the National Accounts Statistics of the United Nations. Forecast scenarios for real GNP and the GNP price deflator by country are from OECD short-term forecasts, Wharton's Project LINK, and projections made by the Economic Research Department, Douglas Aircraft Company.

U.S. international: The top 20 foreign nations were combined, based upon 1973 United States air exports plus imports in tonne-kilometers. The distances for tonne-kilometers were estimated using the most likely United States city of origin and destination to/from the largest foreign city within each country.

The foreign nations are shown in Table 2-3 along with 1973 tonne-kilometers and percent of the total 20 countries. The rationale for combining these economies and the specific equation is discussed later.

Real GNP for each of these nations was indexed into the 1970 base year for use in the U.S. international model. Table 2-4 illustrates this combined real GNP index for the 20 countries. The procedure to combine these economies was to use the 1973 percent of total for each nation times the annual GNP index.

TABLE 2-2

UNITED STATES ECONOMIC OUTLOOK

(JUNE 1977 WHARTON SOLUTION)

Year	Gross National Product Constant 1972 Dollars (Billions)	Percent Change		Implicit Price Deflator for GNP (1972=100)		Percent Change
1970	1075.3	-		91.4		-
1971	1107.5	3.0	Avg. Comp.	96.0	Avg. Comp.	5.0
1972	1171.1	5.7	Growth Rate	100.0	Growth Rate	4.2
1973	1235.0	5.5	1970-1976	105.8	1970-1976	5.8
1974	1214.0	-1.7	= 2.7%	116.4	= 6.5%	10.0
1975	1191.7	-1.8		127.3		9.4
1976	1264.5	6.1		133.7		5.0
1977	1335.4	5.6		141.4		5.6
1978	1409.4	5.5		150.2		6.2
1979	1452.8	3.1		159.7		6.3
1980	1487.1	2.4		171.1		7.1
1981	1528.7	2.8		181.1		5.8
1982	1575.2	3.0	Avg. Comp.	191.2	Avg. Comp.	5.6
1983	1615.8	2.6	Growth Rate	201.9	Growth Rate	5.6
1984	1668.5	3.3	1976-1990	211.7	1976-1990	4.9
1985	1721.6	3.2	= 3.5%	221.3	= 5.1%	4.5
1986	1778.4	3.3		230.4		4.1
1987	1838.9	3.4		238.9		3.7
1988	1903.2	3.5		245.8		2.9
1989	1969.9	3.5		253.9		3.3
1990	2040.8	3.6		266.9		5.1

TABLE 2-3

U.S. INTERNATIONAL MODEL

TOP 20 FOREIGN NATIONS
RANKED BY U.S. AIR EXPORTS + IMPORTS

Nation	1973 Tonne-Kilometers (millions)	Percent of Total 20 Nations
1. Japan	774.0	16.2
2. United Kingdom	629.2	13.2
3. Germany	544.4	11.4
4. Italy	406.9	8.5
5. France	375.3	7.9
6. Hong Kong	327.5	6.9
7. China-Taiwan	231.8	4.9
8. Brazil	225.4	4.7
9. Belgium	154.4	3.2
10. Switzerland	144.5	3.0
11. South Korea	134.0	2.8
12. Netherlands	132.4	2.8
13. Singapore	131.6	2.8
14. Venezuela	126.6	2.7
15. Spain	124.9	2.6
16. Sweden	77.4	1.6
17. Ireland	72.9	1.5
18. Colombia	65.1	1.4
19. Mexico	57.5	1.2
20. Canada	31.7	0.7
Total	4767.5	100.0%

TABLE 2-4

U.S. INTERNATIONAL MODEL

COMBINED REAL GNP INDEX

Year	Top 20 Nations Real GNP Index (1970 = 100)	Percent Change	
1970	100.0	-	
1971	105.1	5.1	
1972	111.6	6.2	Average Growth Rate = 4.7%
1973	120.7	8.2	
1974	123.4	2.2	
1975	124.0	0.5	
1976	131.8	6.3	
1977	138.1	4.8	
1978	145.4	5.4	
1979	151.0	3.8	
1980	159.2	5.5	
1981	168.4	5.8	
1982	177.2	5.3	
1983	186.2	5.0	Average Growth Rate = 5.1%
1984	195.6	5.1	
1985	205.6	5.1	
1986	216.2	5.1	
1987	227.4	5.2	
1988	239.0	5.1	
1989	251.2	5.1	
1990	264.0	5.1	

the 20 countries. The procedure to combine these economies was to use the 1973 percent of total for each nation times the annual GNP index.

$$GNPI_{Top\ 20,t} = \sum_{i=1}^{n} W_{t_o,i} \quad GNPI_{i,t}$$

where:

$GNPI_{Top\ 20}$ = Composite GNP index (1970=100) from constant 1970 U.S. dollars

t = Time t

t_o = 1973

n = 20 countries

W_i = 1973 tonne-kilometers for country i percent of total 20 countries' tonne-kilometers

$GNPI_i$ = Country i GNP index (1970=100) from constant 1970 U.S. dollars

Top 44 foreign airlines: The nations aggregated for the top 44 foreign airlines' scheduled international model were the 24 OECD countries plus eight others representing emerging industrial economies. Country-pair airfreight statistics are not available for many foreign countries, so it was felt that the "OECD plus eight" definition would be appropriate in describing the world market.

The procedure for combining these 32 economies was more simple than for the U. S. international model. Since it was difficult to obtain origin-destination airfreight traffic to act as weights against the individual economies, GNP in constant 1970 U.S. dollars were accumulated over the 32 countries by year without taking indices. Each nation's GNP magnitude then becomes the implicit weight for each in the total world GNP aggregate.

Table 2-5 shows the 1976 gross national product in constant 1970 dollars by country and their respective weights as a percent of the total 32 nations. Historical and forecast values for the combined world GNP is presented in Table 2-6.

TABLE 2-5

TOP 44 FOREIGN AIRLINES MODEL

OECD-PLUS-8 1976 GROSS NATIONAL PRODUCT IN CONSTANT 1970 U.S. DOLLARS (BILLIONS)

OECD	1976 GNP	Percent Of Total For 32 Countries
Australia	38.5	1.3
Austria	17.9	0.7
Belgium	31.8	1.2
Canada	107.4	4.0
Denmark	18.0	0.7
Finland	12.6	0.5
France	183.6	6.9
Germany	215.4	8.1
Greece	12.9	0.5
Iceland	0.6	(NIL)
Ireland	4.7	0.2
Italy	108.1	4.0
Japan	271.3	10.1
Luxembourg	1.3	0.1
Netherlands	37.8	1.4
New Zealand*	6.8	0.3
Norway	14.7	0.6
Portugal	6.7	0.2
Spain	42.4	1.6
Sweden	36.0	1.3
Switzerland	22.4	0.8
Turkey	20.1	0.8
United Kingdom	137.0	5.1
United States	1155.3	43.2
Non-OECD		
Argentina	25.8	1.0
Brazil	65.0	2.4
China-Taiwan	9.1	0.3
Colombia*	10.3	0.4
Nigeria*	11.6	0.4
South Africa	21.2	0.8
South Korea	15.5	0.6
Venezuela	13.5	0.5
TOTAL	2675.3	100.0%

* GROSS DOMESTIC PRODUCT

TABLE 2-6

TOP 44 FOREIGN AIRLINES MODEL

COMBINED OECD-PLUS-8 NATIONS REAL GNP

Year	GNP Constant 1970 $ (Billions)	Percent Change	
1970	2196.1	-	
1971	2281.9	3.9	
1972	2409.2	5.6	Average Growth
1973	2558.1	6.2	Rate = 3.3%
1974	2572.2	0.6	
1975	2546.4	-1.0	
1976	2675.3	5.1	
1977	2792.7	4.4	
1978	2922.2	4.6	
1979	3011.9	3.1	
1980	3135.9	4.1	Average Growth
1981	3270.9	4.3	Rate = 3.8%
1982	3406.6	4.2	
1983	3528.1	3.6	
1984	3654.9	3.6	
1985	3792.7	3.8	
1986	3929.2	3.6	
1987	4066.7	3.5	
1988	4209.1	3.5	
1989	4356.4	3.5	
1990	4508.8	3.5	

Table 2-7 presents the individual country GNP forecasts in annual percent change for all nations included in the U.S. International and top 44 foreign airlines' models.

Econometric models and traffic forecasts. - The following subsections describe the econometric models and traffic forecasts.

U.S. domestic model: The econometric model for the United States carriers' scheduled domestic operations is presented in Figure 2-3. A comparison of the historical estimates from the model and actual traffic is shown in Figure 2-4.

Independent variables - The distributed lag which optimizes the effect of permanent income upon traffic was found to be $GNPL1_t = 0.90009\ (GNP_t) + 0.09001\ (GNP_{t-1}) + 0.00900\ (GNP_{t-2}) + 0.00090\ (GNP_{t-3})$. The average lag is 7.4 percent a year, or approximately 1 month.

Since airfreight forwarders are responsible for a large portion of domestic volume, the prices they pay to the airlines must be included in the price variable. A time series was developed for the top 15 domestic air forwarders, ranked by 1976 revenues, taking the ratio of expenses paid to the airlines over the traffic tendered. This was mixed as an index with the index of total United States domestic airline revenue per revenue tonne-kilometers yield to quantify the price for airfreight.

The precise weights for forwarders' shipments and direct shippers' consignments were not known, so the weights were varied until the overall goodness of fit was maximized. Weights of 20 percent on the price index paid by forwarders and 80 percent on total airline yield index were found to be the optimum combination for 1963-1976.

The final step in the specification of the price variable was to compare surface mode prices to air. This was accomplished by comparing the mixed price of air to the price index of intercity motor freight. The latter was obtained from the American Trucking Association statistics of Class I, II, and III intercity motor carriers' total revenue and revenue tonne-kilometers.

TABLE 2-7

REAL GROSS NATIONAL PRODUCT

ANNUAL PERCENT CHANGE

Average Compound	Argentina	Australia	Austria	Belgium	Brazil	Canada	China (Tai)	Colombia*	Denmark	Finland
Growth Rate 1970-1976	2.5	2.6	3.2	3.0	7.8	3.9	8.3	6.4	2.5	2.5
-77	4.0	4.8	4.5	2.5	6.6	3.1	9.0	6.5	2.0	4.0
-78	4.5	4.0	3.2	3.2	5.5	4.1	6.9	5.5	4.5	4.9
-79	3.5	4.0	2.6	3.2	4.9	4.8	5.1	3.5	2.5	3.5
-80	3.2	4.0	4.5	3.2	7.0	4.4	8.4	4.4	3.0	4.0
-81	3.2	4.0	2.9	3.2	7.1	5.2	7.5	4.9	3.5	3.9
-82	3.2	4.0	3.3	3.2	6.9	5.6	7.5	4.7	3.5	4.1
-83	3.5	4.0	2.7	3.2	7.0	4.5	7.0	4.8	3.5	4.0
-84	3.5	4.0	3.1	3.2	6.5	4.5	7.0	4.8	3.5	4.0
-85	3.5	4.0	3.0	3.2	6.5	4.5	7.0	4.8	3.5	4.0
-86	3.5	3.5	2.9	3.2	6.5	4.4	7.0	4.8	3.5	4.0
-87	3.5	3.9	3.2	3.2	6.5	4.5	7.0	4.8	3.5	4.0
-88	3.5	3.9	3.2	3.2	6.5	4.5	7.0	4.8	3.5	4.0
-89	3.5	3.9	3.2	3.2	6.5	4.5	7.0	4.8	3.5	4.0
-90	3.5	3.9	3.2	3.2	6.5	4.5	7.0	4.8	3.5	4.0

*Gross Domestic Product

TABLE 2-7. - Continued

REAL GROSS NATIONAL PRODUCT

ANNUAL PERCENT CHANGE

Average Compound	France	W.Germany	Greece	Hong Kong	Iceland	Ireland	Italy	Japan	Luxemborg	Mexico
Growth Rate 1970-1976	4.0	2.4	5.0	6.9	4.1	2.8	2.5	6.7	4.3	5.1
-77	4.0	4.4	5.0	7.9	1.9	2.5	2.5	4.7	2.5	2.4
-78	3.7	3.5	5.5	7.6	2.5	3.5	4.5	7.4	3.5	5.8
-79	3.0	2.5	4.0	5.5	2.5	4.0	1.5	4.5	3.0	6.5
-80	4.6	4.9	4.0	7.6	2.6	2.5	4.5	6.0	3.0	5.6
-81	5.3	4.0	4.0	8.5	2.5	3.5	5.5	6.0	3.0	4.7
-82	4.5	3.5	4.0	6.0	2.6	3.5	3.5	6.0	3.0	4.9
-83	4.5	3.5	4.0	5.5	2.4	3.5	3.5	6.0	3.0	4.8
-84	4.5	3.5	4.0	6.5	2.6	3.5	3.5	6.0	3.0	4.7
-85	4.5	3.5	4.0	6.5	2.5	3.5	3.5	6.0	3.0	4.7
-86	4.5	3.5	4.0	6.4	2.5	3.5	3.5	6.0	3.0	4.9
-87	4.5	3.5	4.0	6.5	2.5	3.5	3.5	6.0	3.0	4.8
-88	4.5	3.5	4.0	6.5	2.5	3.5	3.5	6.0	3.0	4.8
-89	4.5	3.5	4.0	6.5	2.5	3.5	3.5	6.0	3.0	4.8
-90	4.5	3.5	4.0	6.5	2.5	3.5	3.5	6.0	3.0	4.8

TABLE 2-7. - Continued
REAL GROSS NATIONAL PRODUCT
ANNUAL PERCENT CHANGE

Average Compound	Netherlands	New Zealand	Nigeria*	Norway	Portugal	So. Africa	Singapore	Spain	So. Korea
Growth Rate 1970-1976	3.0	1.6	6.4	4.6	1.3	4.0	9.0	4.6	10.9
-77	3.5	(0.4)	8.8	6.5	1.0	4.0	7.5	2.0	5.0
-78	2.6	4.7	10.6	7.0	4.0	4.2	7.9	5.9	5.0
-79	2.8	4.8	9.0	4.9	5.5	4.2	6.5	4.8	5.0
-80	3.6	3.5	4.0	7.0	3.5	4.2	7.4	2.5	5.0
-81	3.0	2.6	6.0	7.0	4.0	4.2	8.1	4.2	5.0
-82	3.0	2.5	8.0	7.0	5.0	4.2	8.6	5.0	5.0
-83	3.0	3.7	7.0	7.0	5.0	4.2	7.5	5.0	5.0
-84	3.0	2.4	7.0	7.0	5.0	4.2	7.5	5.0	5.0
-85	3.0	3.5	7.0	7.0	5.0	4.2	7.5	5.0	5.0
-86	3.0	3.4	6.0	7.0	5.0	4.0	7.5	5.0	5.0
-87	3.0	2.2	6.0	7.0	5.0	4.0	7.6	5.0	5.0
-88	3.0	2.2	6.0	7.0	5.0	4.0	7.6	5.0	5.0
-89	3.0	2.2	6.0	7.0	5.0	4.0	7.6	5.0	5.0
-90	3.0	2.2	6.0	7.0	5.0	4.0	7.6	5.0	5.0

*Gross Domestic Product

TABLE 2-7. - Concluded
REAL GROSS NATIONAL PRODUCT
ANNUAL PERCENT CHANGE

Average Compound Growth Rate	Sweden	Switzerland	Turkey	United Kingdom	Venezuela* 1970-1975
1970-1976	1.9	0.8	7.8	1.8	4.9
-77	2.0	1.5	5.5	2.0	7.5
-78	4.0	3.0	6.0	2.0	8.0
-79	3.0	2.0	6.5	0.5	7.0
-80	3.0	2.5	6.0	2.3	7.5
-81	3.0	3.0	5.0	3.8	7.0
-82	3.0	3.0	5.0	3.1	7.0
-83	3.0	3.0	5.0	2.4	7.0
-84	3.0	3.0	5.0	2.1	6.5
-85	3.0	3.0	5.0	2.5	6.5
-86	3.0	3.0	5.0	2.5	6.5
-87	3.0	3.0	5.0	2.5	6.5
-88	3.0	3.0	5.0	2.5	6.5
-89	3.0	3.0	5.0	2.5	6.5
-99	3.0	3.0	5.0	2.5	6.5

*Gross Domestic Product

L DOMRTK = - 4.2209 + 2.8697 (LGNPL1) - 1.0365 (L FFALYLD2) + 0.0618 (L 50 STATE)
(T = 18.861) (T = -5.441) (T = 4.193)

R^2 = 0.9972 DURBIN-WATSON = 1.6707

S.E. = 0.0148 F (3,10) = 904.1702

WHERE:

L = BASE 10 LOGARITHM

DOMRTK = U.S. DOMESTIC SCHEDULED FREIGHT REVENUE TONNE-KILOMETERS

GNPL1 = A PERMANENT INCOME MEASURE OF U.S. GROSS NATIONAL PRODUCT IN CONSTANT 1972$

FFALYLD2 = $\frac{0.20 \text{ FFYLDI} + 0.80 \text{ ALYLDI}}{\text{TRYLDI}}$

WITH: FFYLDI = EXPENSES OF TOP 15 U.S. FREIGHT FORWARDERS PAID FOR AIR TRANSPORTATION PER POUND. (1972 = 100)

ALYLDI = U.S. DOMESTIC FREIGHT REVENUE PER RTK (1972 = 100)

TRYLDI = U.S. INTERCITY MOTOR FREIGHT REVENUE PER RTK (1972 = 100)

50 STATE = DUMMY VARIABLE TO ACCOUNT FOR A CHANGE IN CAB DEFINITION OF DOMESTIC TRAFFIC STARTING IN 1969.

Figure 2-3. U.S. Scheduled Domestic Freight Traffic Behavioral Relationship, 1963-1976

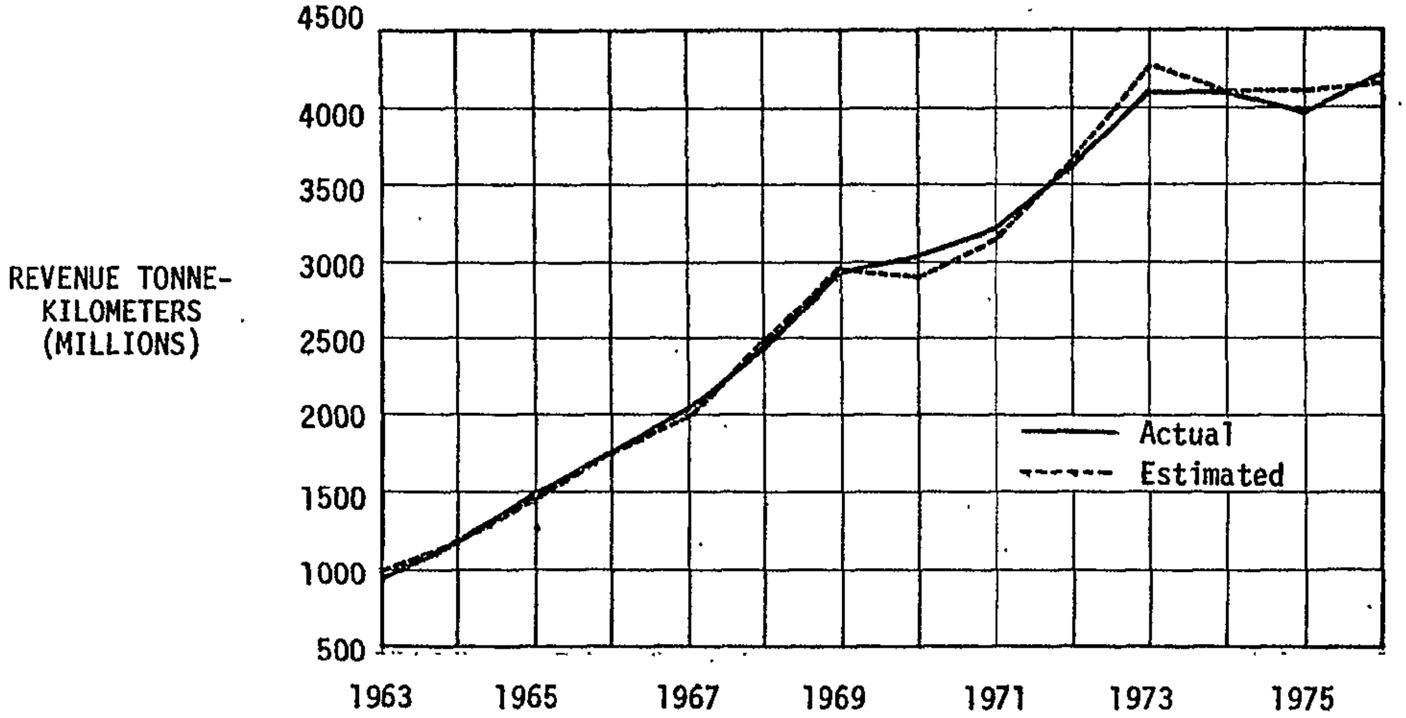


Figure 2-4. U.S. Domestic Scheduled Freight Model - Goodness of Fit Comparison

The resulting relative price variable measures changes in the prices charged by the airlines compared to changes in the prices charged by motor carriers. With the price elasticity estimated by the model at -1.0365, the following statement can be made: If the price of airfreight rises 1 percent over and above a change in the price for motor freight, all other things remaining equal, then air traffic will decline by 1.0365 percent.

Similarly, with an increase in permanent income of 1 percent, traffic will increase by approximately 2.9 percent, all other things remaining equal.

Traffic forecasts - As mentioned before, once the behavioral equation is estimated, forecasts are applied to the independent agents to determine the forecast for dependent variable - traffic. Three different traffic forecasts were generated by using three scenarios for the relative price variable. This was done to better illustrate the sensitivity of traffic level to changes in relative prices. Instead of attempting to project each of the three elements comprising the price variable, it was assumed that the ratio would drop 2 percent per year, remain constant from 1976, and increase 2 percent per year. Figure 2-5 shows the graph of this variable from 1965-1990. With these three yield scenarios, the resulting traffic forecasts were calculated and are shown in Table 2-8.

The 1977 forecast is the same for all three yield scenarios because it is an estimate based upon 12 months ending September 1977 over the same period for 1976. The partial year growth rate of 6.4 percent was then applied to the base year 1976 shown in the table.

U. S. international model: The model developed for the United States carriers' scheduled international airfreight subsystem, along with attendant statistical tests, is presented in Figure 2-6. A goodness-of-fit graph is also shown in Figure 2-7 between the actual and estimated historical values.

Independent variables - International freight traffic carried by United States flag airlines is of course two-way flow between mostly the United States and foreign points. In order to determine real income for this market before permanent income is found, a combination of the United States and

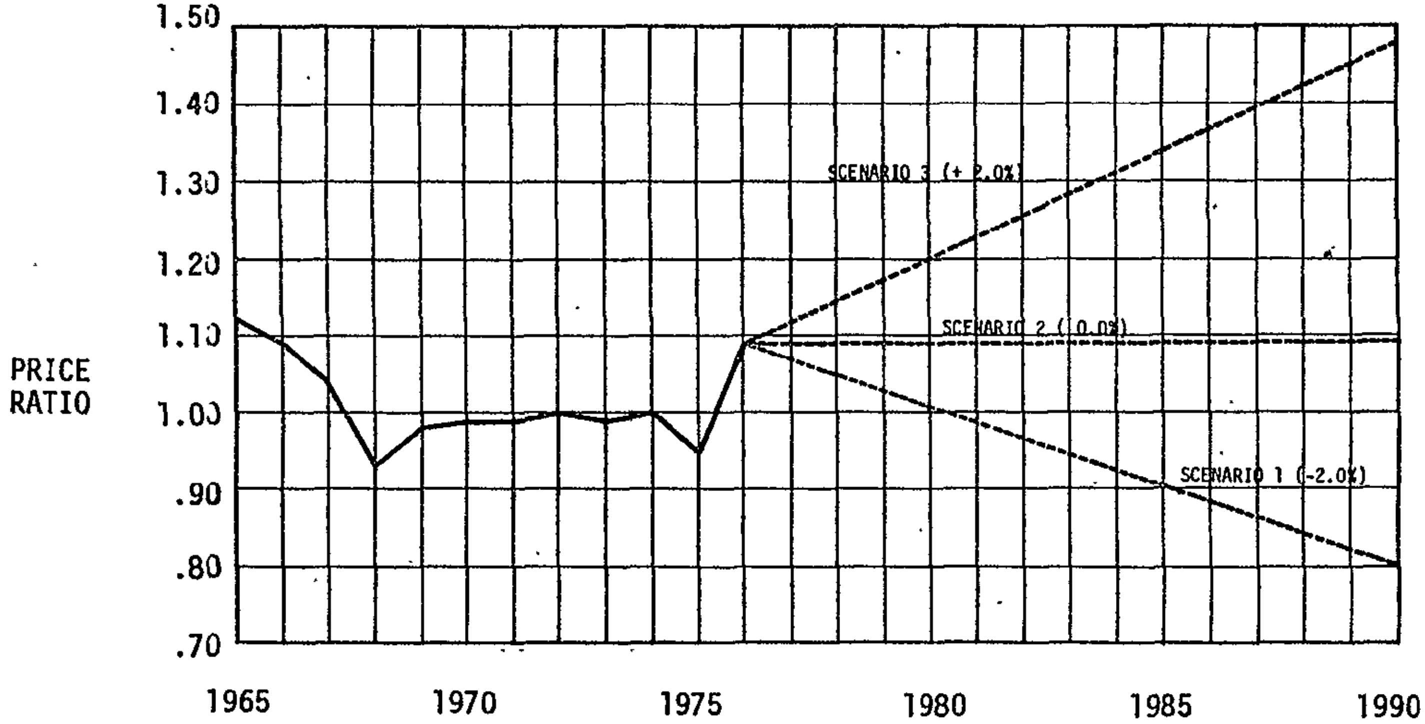


Figure 2-5. U.S. Domestic Model - Relative Price Ratio of Air to Motor Freight from Base Year 1972

TABLE 2-8

CLASS U.S. SCHEDULED DOMESTIC AIRFREIGHT FORECAST

Year	Revenue Tonne-Kilometers (Millions)	Percent Change
1970	3079.9	-
1971	3205.2	4.1
1972	3620.9	13.0
1973	4120.0	13.8
1974	4100.3	-0.5
1975	3968.4	-3.2
1976	4216.1	5.8

Avg. Compound Growth Rate 1963-1976 = 12.2 percent

Year	Scenario 1	Percent Change	Baseline Scenario 2	Percent Change	Scenario 3	Percent Change
est 1977	4485.9	6.4	4485.9	6.4	4485.9	6.4
1978	5348.3	19.2	5237.5	16.8	5131.1	14.4
1979	5997.1	12.1	5751.2	9.8	5519.9	7.6
1980	6565.3	9.5	6165.6	7.2	5797.4	5.1
1981	7250.1	10.4	6667.6	8.1	6142.1	5.9
1982	8061.2	11.2	7259.9	8.9	6551.8	6.7
1983	8866.9	10.0	7820.0	7.7	6913.9	5.5
1984	9910.3	11.8	8559.2	9.5	7413.7	7.2
1985	11072.0	11.7	9364.3	9.4	7946.3	7.2
1986	12389.6	11.9	10263.2	9.6	8534.3	7.4
1987	13888.7	12.1	11279.2	9.9	9182.9	7.6
1988	15597.0	12.3	12418.4	10.1	9899.2	7.8
1989	17531.0	12.4	13672.7	10.1	10681.2	7.9
1990	19740.0	12.6	15081.0	10.3	11557.1	8.2
Avg. Compound Growth Rate 1976-1990 =		11.7		9.5		7.5

Scenario 1: -2.0 Percent Real Yield; Scenario 2: 0.0 Percent Real Yield; Scenario 3: +2.0 Percent Real Yield

LINTRTK = 0.2181 + 2.2834 (L.8WGNPL5) - 1.2740 (LYLD.9) - 0.0617 (L 50 STATE)

T = 7.997   T = -7.495   T = -3.826

R^2 = 0.9986   DURBIN-WATSON = 1.7316

S.E. = 0.0188   F STATISTIC (3,18) = 3808.24

WHERE:

L = BASE 10 LOGARITHM

INTRTK = SCHEDULED FREIGHT TONNE-KILOMETERS CARRIED ON INTERNATIONAL OPERATIONS BY U.S. AIRLINES

0.8WGNPL5 = A PERMANENT INCOME MEASURE OF UNITED STATES AND 20 TOP FOREIGN COUNTRIES

YLD.9 = U.S. SCHEDULED INTERNATIONAL FREIGHT YIELD IN CONSTANT 1970 ¢/RTK

50 STATE = DUMMY VARIABLE WITH VALUES OF 0 FROM 1955-1968 AND 1 FROM 1969-1990 FOR A CHANGE IN TRAFFIC BASE TO 50 STATES IN 1969

Figure 2-6. United States Scheduled International Freight Traffic Behavioral Relationship, 1955-1976

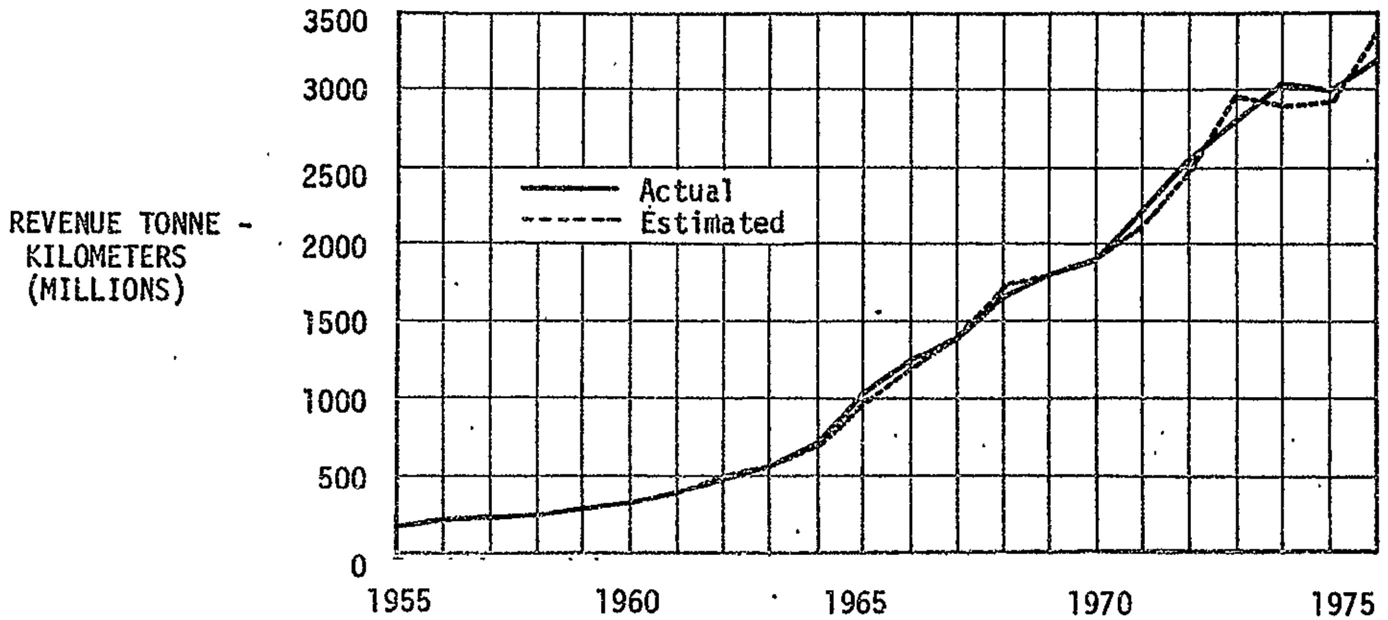


Figure 2-7. U.S. Scheduled International Freight Model - Goodness-of-Fit Comparison

foreign real GNPs had to be combined. The following calculation was used to accomplish this task.

$$WGNP.\alpha = \alpha \; GNPI_{US} + (1-\alpha) \sum_{i=1}^{n} w_i \; GNPI_i$$

Where

$WGNP.\alpha$ = Composite GNP index from constant 1970 dollars for the United States and foreign economies

GNPI = GNP index (1970=100) from constant 1970 dollars

n = 20 major foreign countries

w_i = Percent of total 20 countries 1973 TKMs for country i

α = Varies for 0.0 ... 1.0

In practice, (α) alpha was varied in increments of 0.1 from 0.0 to 1.0 and the optimum was selected using the goodness-of-fit criteria. The value of alpha resulting from this search was 0.80 or 80 percent of the United States GNP index and 20 percent of the foreign.

The distributed lag procedure was then applied resulting in the following estimation of permanent, composite income:

$$0.8WGNPL5_t = 0.53333 \; (WGNP.8_t) + 0.26667 \; (WGNP.8_{t-1}) + 0.13333 \; (WGNP.8_{t-2}) + 0.06667 \; (WGNP.8_{t-3})$$

An average lag of 18.3 percent of the year, about 9½ weeks, is the outcome from this distributed lag scheme.

The price variable for this model was quantified by the following equation:

$$YLD.\alpha = \frac{\dfrac{INTYIELD}{0.90\ (GNP\$_{US}) + 0.10\ (GNP\$_{TOP20})}}{0.90\ (GNP_{US}) + 0.10\ (GNP_{TOP20})}$$

WITH:

YLD.α = International scheduled yield in constant 1970 dollars

INTYIELD = U.S. international scheduled freight revenue per RTK

GNP\$ = Gross national product in current \$

GNP = Gross national product in constant 1970 \$

The price variable compares the price of airfreight to the overall price level of goods and services. As the current dollar yield increases by 1 percent over and above inflation, the estimated price elasticity suggests that international traffic will drop by 1.274 percent. This elasticity should not be confused with the price elasticity of the market today. It is the average elasticity over the period 1955 to 1976. It is also the best estimate for the price affect upon demand for previous years and, therefore, should be used for forecasting purposes.

Traffic forecasts - Again, three traffic scenarios were generated, based on as many real yield scenarios. Estimated growth for the 12 months ending September 1977 was 2.3 percent higher than the corresponding 12-month period ending September 197 .

A graph of historical real yield and the three scenarios are shown in Figure 2-8. The traffic forecasts are presented in Table 2-9.

Top 44 foreign airlines model: Figure 2-9 presents the top foreign airlines' traffic model for the total scheduled international freight system. The goodness-of-fit comparison between the model's estimates and actual traffic is shown in Figure 2-10.

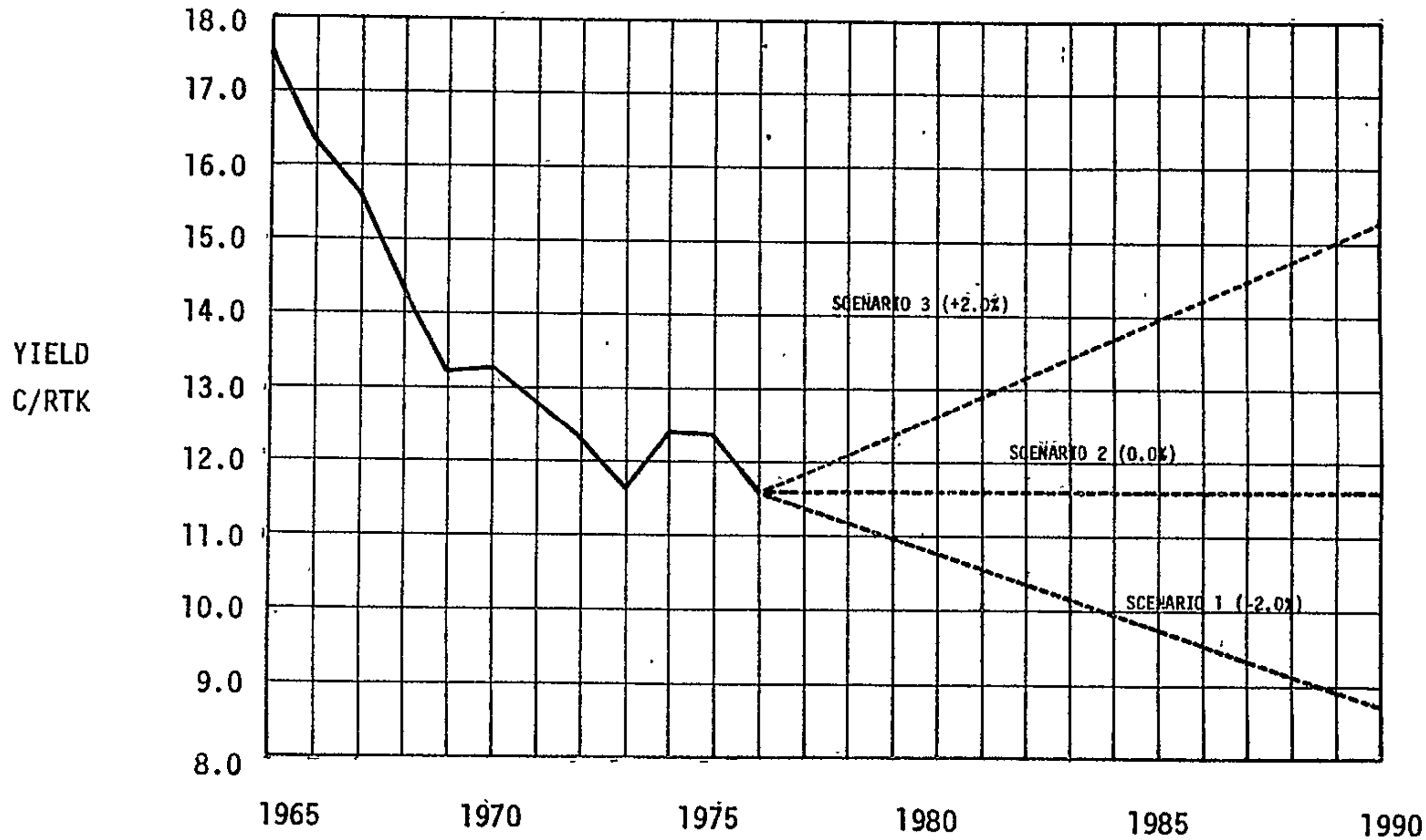


Figure 2-8. U.S. International Model Freight Yield in Constant 1970 U.S. Dollars

TABLE 2-9

CLASS U.S. SCHEDULED INTERNATIONAL AIRFREIGHT FORECAST

Year	Revenue Tonne-Kilometers (Millions)	Percent Change	
1970	1895.2	-	Avg. Compound Growth Rate 1955-1976 = 15.0 percent
1971	2214.8	16.9	
1972	2536.5	14.5	
1973	2795.6	10.2	
1974	3039.2	8.7	
1975	2990.1	-1.6	
1976	3192.2	6.8	

Year	Scenario 1	Percent Change	Baseline Scenario 2	Percent Change	Scenario 3	Percent Change
1977 est	3265.6	2.3	3265.6	2.3	3265.6	2.3
1978	3759.7	15.1	3664.2	12.2	3572.9	9.4
1979	4248.6	13.0	4035.4	10.1	3836.9	7.4
1980	4716.7	11.0	4366.2	8.2	4047.9	5.5
1981	5229.8	10.9	4718.2	8.1	4265.2	5.4
1982	5797.6	10.9	5097.5	8.0	4493.4	5.3
1983	6406.9	10.5	5490.1	7.7	4718.9	5.0
1984	7116.9	11.1	5943.5	8.3	4981.3	5.6
1985	7916.8	11.2	6443.6	8.4	5265.9	5.7
1986	8815.1	11.2	6992.3	8.5	5572.0	5.8
1987	9826.5	11.5	7596.6	8.6	5902.6	5.9
1988	10907.4	11.0	8242.3	8.5	6260.6	6.0
1989	12107.2	11.0	8943.9	8.5	6636.2	6.0
1990	13439.0	11.0	9703.1	8.5	7034.4	6.0
Avg. Compound Growth Rate 1976-1990 =		10.8		8.3		5.8

Scenario 1: -2.0 Percent Real Yield; Scenario 2: 0.0 Percent Real Yield; Scenario 3: +2.0 Percent Real Yield

$$L\ WORRTK = -7.0205 + 3.3345\ (L3WGNPM2) - 0.2560\ (LYLD.GN) + 0.0449\ (L\ STRIKE\ 69)$$

$$\qquad\qquad (T = 19.623) \qquad\qquad (T = -1.854) \qquad\qquad (T = 2.589)$$

$R^2 = 0.9992$ DURBIN-WATSON = 1.1686

S.E. = 0.0165 $F_{(3,15)} = 4776.6732$

WHERE

L	=	BASE 10 LOGARITHM
WORRTK	=	TOP 44 FOREIGN AIRLINES INTERNATIONAL SCHEDULED FREIGHT REVENUE TONNE KILOMETERS
3WGNPM2	=	COMBINED GROSS NATIONAL PRODUCT IN CONSTANT 1970 $ for the OECD NATIONS PLUS 8 DEVELOPING COUNTRIES
YLD.GN	=	REVENUE PER RTK FOR THE MAJOR EUROPEAN AIRLINES DEFLATED BY THE OECD PLUS 8 GNP PRICE DEFLATOR
STRIKE 69	=	DUMMY VARIABLE FOR U.S. DOCK WORKERS' STRIKE IN 1969

Figure 2-9. Top 44 Foreign Airlines Scheduled International Freight Traffic Behavioral Relationship, 1958-1976

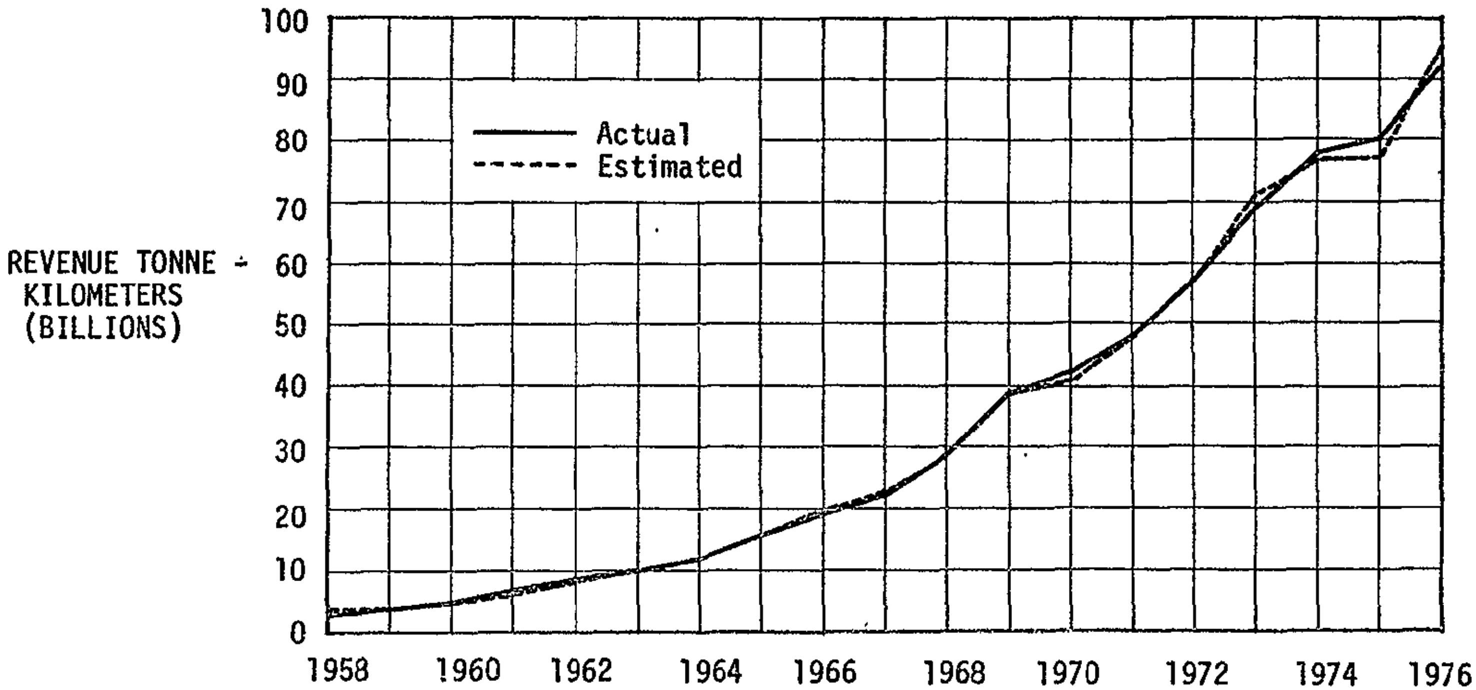


Figure 2-10. Top 44 Foreign Airlines Scheduled International Freight Model — Goodness-of-Fit Comparison

Independent variables - Development of the final income variable started from the world composition (OECD + 8) of GNP in constant 1970 dollars. The procedure was followed to transform this real income into permanent income as previously discussed. With the application of the distributed lag coefficients came the 10 distinct measures of permanent income, and none of these improved the statistical fit over the original real GNP time series.

A second transformation was tested using the composite income which improved the R^2 and significance of the income effect with respect to traffic. It is named the "theta transformation" for the purpose of discussion and it accounts for two phenomena: An apparent declining elasticity of traffic with respect to income as a market matures, and a theoretical minimum threshold traffic generating level of income below which no airfreight takes place. Since this threshold income is not known, it is estimated through an iterative procedure which quantifies threshold income as a constant fraction of income for the first year of the same period. Constant threshold income is subtracted from each value of the income time series to yield theta income. This can be illustrated mathematically by the following equation:

$$WGNPM\Theta_t = WGNP_t - \Theta\ (WGNP_{1958})$$

Where

$WGNPM\Theta_t$ = Weighted real GNP in time t exceeding the threshold level

$WGNP_t$ = Weighted real GNP of the OECD + 8 nations in time t

$\Theta(WGNP_{1958})$ = Threshold level of GNP at which airfreight traffic started

The general form of the equation is now:

$$\log_{10} Y = b_o + b_1 \log_{10} (X_1 - X_o) + b_2 \log_{10} X_2 + \ldots + b_m \log_{10} X_m$$

Where

X_o is a constant

The elasticity of traffic with respect to the income variable X_1 is computed as follows: We first differentiate $\log_{10} Y$ with respect to X_1.

$$\frac{\partial Y}{\partial X_1} \cdot \frac{1}{Y} = \frac{b_1}{X_1 - X_0}$$

Multiplying by X_1, we find the elasticity e_{Y/X_1}

$$e_{Y/X_1} = \frac{\partial Y/Y}{\partial X_1/X_1} = \frac{b_1 X_1}{X_1 - X_0}$$

As X_1 increases over time, $e_{Y/X}$ decreases asymptotically toward b_1.

The price variable was quantified from statistics for European airlines reporting to the Association of European Airlines (AEA). Freight revenue per revenue tonne-kilometers yield was then deflated by the composite "OECD + 8" implicit price deflator for GNP.

Historical values for the real freight yield as well as the three forecast scenarios are shown in Figure 2-11.

A dummy variable was also used in the model to account for the United States dock worker's strike in 1969.

Traffic forecasts - The resulting traffic forecasts based upon the econometric model and alternative real yield assumptions are presented in Table 2-10.

U.S. Domestic Origin-Destination Forecasts

The approach used to forecast the top 10 United States domestic city-pair markets was to compare the historical development of each market to their total. Industry freight revenue tonne-kilometers (RTK), for the 10 markets were first summed by year and then forecast using the total

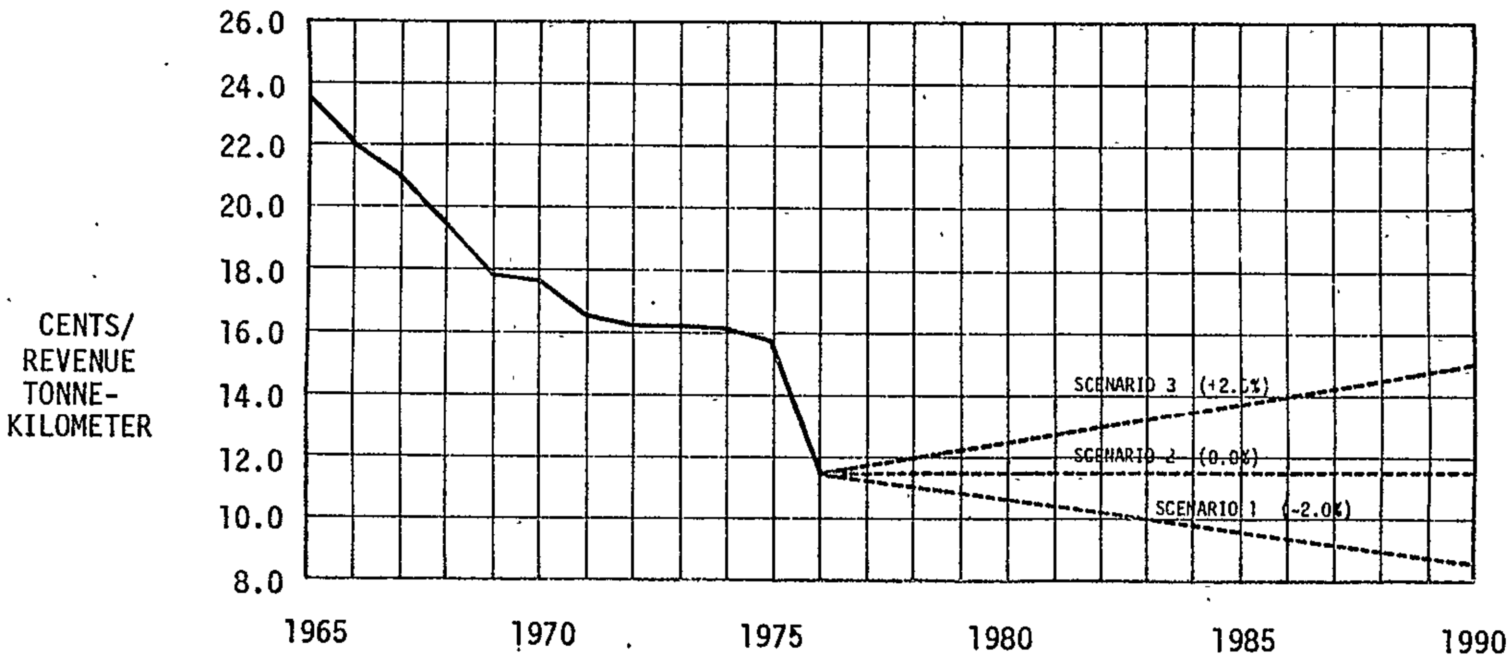


Figure 2-11. Top 44 Foreign Airlines Freight Yield in Constant 1970 U.S. Dollars

TABLE 2-10

CLASS TOP 44 FOREIGN AIRLINES SCHEDULED INTERNATIONAL AIRFREIGHT FORECAST

Year	Revenue Tonne-Kilometers (Millions)	Percent Change
1970	4248.6	-
1971	4766.9	12.2
1972	5656.0	18.7
1973	6907.3	22.1
1974	7752.6	12.2
1975	8047.5	3.8
1976	9246.6	14.9

Avg. Compound Growth Rate 1958-1976 = 20.2 Percent

Year	Scenario 1	Percent Change	Baseline Scenario 2	Percent Change	Scenario 3	Percent Change
1977	10744.8	16.2	10689.4	15.6	10635.3	15.0
1978	12678.1	18.0	12547.6	17.4	12420.9	16.8
1979	14442.9	13.9	14220.5	13.3	14005.8	12.8
1980	16699.5	15.6	16357.5	15.0	16029.0	14.4
1981	19478.9	16.6	18981.6	16.0	18506.4	15.5
1982	22679.6	16.4	21986.5	15.8	21327.6	15.2
1983	26011.6	14.7	25086.6	14.1	24211.7	13.5
1984	29715.5	14.2	28510.9	13.7	27377.4	13.1
1985	34044.4	14.6	32495.8	14.0	31046.1	13.4
1986	38810.6	14.0	36882.7	13.5	35082.1	13.0
1987	44050.0	13.5	41677.5	13.0	39467.4	12.5
1988	49996.8	13.5	47095.6	13.0	44400.8	12.5
1989	56746.4	13.5	53218.0	13.0	49950.9	12.5
1990	64407.1	13.5	60136.3	13.0	56194.7	12.5
Avg. Compound Growth Rate 1976-1990 =		14.9		14.3		13.8

Scenario 1: -2.0% Real Yield; Scenario 2: 0.0% Real Yield; Scenario 3: +2.0% Real Yield

United States domestic freight subsystem as the independent variable. This was done because the top markets are more mature and have grown at a slower average rate than the total system. The following relationship will illustrate the procedure more clearly.

Step 1:

$$SOD_t = \sum_{i=1}^{10} RTK_{i,t}$$

with:

SOD_t = RTK total of the top 10 markets in year t

$RTK_{i,t}$ = RTK scheduled industry freight for city pair i in year t

Step 2: Behavioral Relationships 1968 - 1976

$$L\ SOD = 6.892 + 0.8178\ (L\ DOMRTK)$$
$$(T = 7.201)$$

$$R^2 = 0.8811$$

Where:

L = Natural logarithm

SOD = Defined in Step 1

DOMRTK = U.S. domestic scheduled freight revenue tonne-kilometers

Once the relationship was estimated between the sum of the markets and the total domestic subsystem, the three forecasts scenarios of the subsystem were applied to the equation for the scenarios of the 10 markets total. Table 2-11 presents the historical traffic along with these three scenarios.

Each individual market forecast was derived in a similar manner by estimating the relationship between its historical traffic and that of the

TABLE 2-11

SUMMARY OF TOP 10 U.S. DOMESTIC CITY-PAIR MARKETS

Year	Revenue Tonne Kilometers (Millions)	Percent Change	
1968	598.9	-	
1969	654.9	9.3	
1970	671.9	2.6	
1971	716.5	6.6	
1972	845.2	18.0	Average Compound
1973	970.2	14.8	Growth Rate
1974	910.6	-6.1	1968-1976 = 4.0
1975	854.5	-6.2	Percent
1976	818.1	-4.3	

	Scenario 1	Percent Change	Scenario 2	Percent Change	Scenario 3	Percent Change
1977 est	896.6	9.6	896.6	9.6	896.6	9.6
1978	1035.6	15.5	1017.7	13.5	1006.6	11.6
1979	1137.1	9.8	1099.1	8.0	1062.6	6.2
1980	1224.6	7.7	1163.9	5.9	1106.2	4.1
1981	1328.7	8.5	1240.8	6.6	1159.3	4.8
1982	1449.6	9.1	1330.1	7.2	1221.9	5.4
1983	1567.0	8.1	1413.9	6.3	1276.9	4.5
1984	1715.9	9.5	1522.8	7.7	1352.2	5.9
1985	1878.9	9.5	1638.5	7.6	1430.1	5.8
1986	2064.3	9.9	1769.8	8.0	1519.2	6.2
1987	2271.9	10.0	1917.8	8.4	1616.2	6.4
1988	2504.2	10.2	2078.5	8.4	1720.9	6.5
1989	2760.2	10.2	2252.5	8.4	1833.9	6.6
1990	3047.1	10.4	2442.4	8.4	1959.1	6.0
Average Compound Growth Rate 1976-1990		9.8		8.1		6.4

Scenarios 1, 2 and 3 based upon corresponding scenarios for the U. S. total domestic system total 10 markets. This is illustrated by the following equation representing Step 3.

Step 3: $L\ RTK_i = A + B\ (L\ SOD)$

Where:

L = Natural logarithm

RTK_i = City pair i revenue tonne-kilometers

SOD = Revenue tonne-kilometers total of top 10 markets

After each market relationship was determined, three city-pair forecasts were produced from the application of as many scenarios for the total 10. In three of the markets, Chicago-New York, New York-Chicago, and San Francisco-New York, the relationship with the total was unsatisfactory statistically. Therefore, the scenarios for these markets were applied externally using 1 percent per year growth rate for the Chicago markets and 6.2 percent for San Francisco-New York.

Tables 2-12, 2-13, and 2-14 contain the three forecast scenarios for each of the top 10 domestic markets.

International Country-Pair Forecasts

Total scheduled and nonscheduled airfreight volume was forecast for 14 representative world markets. The method was to extend the historical trend into the future, tempered subjectively by current and expected developments in the partner economies. Real national economic growth, relative inflation rates and trends in currency conversion rates affecting the terms of trade were all taken into account.

Results of this analysis are displayed in Table 2-15 and plotted in Figures 2-12 through 2-25.

TABLE 2-12

U.S. DOMESTIC
-2.0 REAL YIELD SCENARIO
REVENUE TONNE-KILOMETERS
(MILLICNS)

	CHI-LAX	LAX-CHI	CHI-NYC	NYC-CHI	CHI-SFO	SFO-CHI	LAX-NYC	NYC-LAX	NYC-SFO	SFO-NYC
1976	51.6	86.8	25.2	29.5	34.1	52.6	202.9	120.4	75.0	140.0
1977[est]	61.2	96.7	24.3	28.7	37.3	44.8	232.5	136.5	94.6	140.0
1978	78.1	136.1	24.5	29.0	47.4	52.9	270.4	144.1	104.5	148.7
1979	89.5	168.5	24.8	29.3	54.1	58.1	296.4	148.2	110.3	157.9
1980	98.5	198.6	25.0	29.6	59.4	62.3	318.3	150.6	114.5	167.7
1985	154.2	495.1	26.3	31.1	89.8	89.9	468.7	159.9	137.3	226.5
1990	225.8	1216.7	27.7	32.7	126.0	122.1	650.8	187.2	152.2	306.0
Average Compound Growth Rate 1976-1990 =	11.1	20.8	0.7	0.7	9.8	6.2	8.7	3.2	5.2	5.7

est: 1977 estimated based upon 3/4 year-to-date

TABLE 2-13

U.S. DOMESTIC
0.0 REAL YIELD SCENARIO
REVENUE TONNE-KILOMETERS
(MILLIONS)

	CHI-LAX	LAX-CHI	CHI-NYC	NYC-CHI	CHI-SFO	SFO-CHI	LAX-NYC	NYC-LAX	NYC-SFO	SFO-NYC
1976	51.6	86.8	25.2	29.5	34.1	52.6	202.9	120.4	75.0	140.0
1977est	61.2	96.7	24.3	28.7	37.3	44.8	232.5	136.5	94.6	140.0
1978	76.3	130.4	24.5	29.0	46.3	51.8	264.6	142.9	103.1	148.7
1979	85.7	155.1	24.8	29.3	52.0	55.9	284.7	146.1	107.6	157.9
1980	92.3	175.9	25.0	29.6	55.9	58.9	300.2	147.7	110.7	167.7
1985	132.8	378.9	26.3	31.1	78.2	78.8	408.7	151.3	126.0	226.5
1990	187.0	815.9	27.7	32.7	106.1	104.0	550.0	171.8	141.2	306.0
Average Compound Growth Rate 1976-1990 =	9.6	17.4	0.7	0.7	8.4	5.0	7.4	2.6	4.6	5.7

est: 1977 estimated based upon 3/4 year-to-date

TABLE 2-14

U.S. DOMESTIC
+2.0 REAL YIELD SCENARIO
REVENUE TONNE-KILOMETERS
(MILLIONS)

	CHI-LAX	LAX-CHI	CHI-NYC	NYC-CHI	CHI-SFO	SFO-CHI	LAX-NYC	NYC-LAX	NYC-SFO	SFO-NYC
1976	51.6	86.8	25.2	29.5	34.1	52.6	202.9	120.4	75.0	140.0
1977[est]	61.2	96.7	24.3	28.7	37.3	44.8	232.5	136.5	94.6	140.0
1978	75.2	126.0	24.5	29.0	45.7	51.1	261.1	142.8	102.5	148.7
1979	82.0	142.9	24.8	29.3	49.8	53.7	273.3	144.0	105.0	157.9
1980	86.4	155.6	25.0	29.6	52.6	55.6	282.5	144.5	106.7	167.7
1985	113.8	269.6	26.3	31.1	67.8	69.4	356.6	149.9	119.1	226.5
1990	152.5	501.7	27.7	32.7	88.2	88.1	459.9	169.3	133.1	306.0
Average Compound Growth Rate 1970-1990 =	8.1	13.4	0.7	0.7	7.0	3.8	6.0	2.5	4.2	5.7

est: 1977 estimated based upon 3/4 year-to-date

TABLE 2-15

INTERNATIONAL COUNTRY-PAIR FORECASTS
AIRFREIGHT - ALL SERVICES
REVENUE TONNE-KILOMETERS
(MILLIONS)

Year	U.S. - U.K.	Percent Change	U.S. - GERMANY	Percent Change	U.S.- JAPAN	Percent Change	U.S. - INDONESIA	Percent Change	U.S. - BRAZIL	Percent Change
1976	321.9	-	291.7	-	316.0	-	22.3	-	120.7	-
1977 est.	379.9	18.0	360.0	23.4	385.5	22.0	21.9	-2.0	118.3	-2.0
1978	416.8	9.7	399.6	11.0	457.6	18.7	24.2	10.5	127.7	8.0
1979	426.3	2.3	429.1	7.4	502.0	9.7	26.5	9.7	137.2	7.4
1980	473.7	11.1	486.6	13.4	572.3	14.0	28.9	9.0	146.8	7.0
1981	536.7	13.3	540.2	11.0	655.8	14.6	32.1	11.0	160.0	9.0
1982	615.0	14.6	543.9	9.7	750.9	14.5	35.6	11.0	179.2	12.0
1983	682.0	10.9	595.1	9.4	859.0	14.4	39.5	11.0	200.7	12.0
1984	748.2	9.7	652.2	9.6	978.4	13.9	43.9	11.0	224.8	12.0
1985	833.5	11.4	713.5	9.4	1123.3	14.8	48.7	11.0	227.0	12.0
1986	927.7	11.3	780.6	9.4	1280.5	14.0	53.1	9.0	249.7	10.0
1987	1030.7	11.1	853.2	9.3	1447.0	13.0	57.9	9.0	274.7	10.0
1988	1123.4	9.0	929.9	9.0	1620.6	12.0	63.1	9.0	302.2	10.0
1989	1224.5	9.0	1013.6	9.0	1798.9	11.0	68.8	9.0	332.4	10.0
1990	1334.8	9.0	1104.9	9.0	1996.8	11.0	75.0	9.0	365.6	10.0
Distance:	5536 km		6185 km		8808 km		13937 km		7725 km	

est: 1977 estimated based upon 1/2 year-to-date

TABLE 2-15.- Continued

INTERNATIONAL COUNTRY-PAIR FORECASTS
AIRFREIGHT - ALL SERVICES
REVENUE TONNE-KILOMETERS
(MILLIONS)

Year	GERMANY - JAPAN	Percent Change	JAPAN - GERMANY	Percent Change	GERMANY U.K.	Percent Change	U.K. - GERMANY	Percent Change
1976	38.8	-	50.3	-	9.7	-	10.6	-
1977 est.	41.3	6.5	55.0	9.2	9.9	2.0	10.8	2.0
1978	43.9	6.1	59.6	8.4	10.1	2.0	11.0	2.0
1979	46.4	5.8	64.2	7.7	10.3	2.0	11.2	2.0
1980	49.0	5.5	68.8	7.2	10.5	2.0	11.5	2.0
1981	51.5	5.2	73.4	6.7	10.8	2.0	11.7	2.0
1982	54.0	4.9	78.0	6.3	11.0	2.0	11.9	2.0
1983	56.7	5.0	82.6	5.9	11.2	2.0	12.2	2.0
1984	59.6	5.0	87.6	6.0	11.4	2.0	12.4	2.0
1985	62.6	5.0	92.8	6.0	11.6	2.0	12.7	2.0
1986	65.7	5.0	98.4	6.0	11.9	2.0	12.9	2.0
1987	69.0	5.0	104.3	6.0	12.1	2.0	13.2	2.0
1988	72.4	5.0	110.6	6.0	12.3	2.0	13.4	2.0
1989	76.0	5.0	117.2	6.0	12.6	2.0	13.7	2.0
1990	79.8	5.0	124.2	6.0	12.8	2.0	14.0	2.0
Distance:	9360 km		9360 km		654 km		654 km	

Est: 1977 estimated based upon 1/2 year-to-date

TABLE 2-15.- Concluded

INTERNATIONAL COUNTRY-PAIR FORECASTS AIRFREIGHT — ALL SERVICES REVENUE TONNE-KILOMETERS (MILLIONS)

Year	U.K.-U.S.	Percent Change	GERMANY-U.S.	Percent Change	JAPAN - U.S.	Percent Change	INDONESIA-U.S.	Percent Change	BRAZIL-U.S.	Percent Change
1976	229.6	-	256.4	-	703.9	-	7.3	-	102.4	-
1977 est.	245.0	6.7	280.0	9.2	537.8	-23.6	8.1	45.8	112.9	-20.8
1978	275.1	12.3	311.9	11.4	577.6	7.4	8.9	13.4	130.6	15.6
1979	296.6	7.8	331.2	6.2	616.9	6.8	9.9	12.3	149.4	14.4
1980	313.2	5.6	346.5	4.6	655.7	6.3	11.0	11.4	169.2	13.3
1981	335.1	7.0	365.9	5.6	694.4	5.9	12.2	10.7	190.2	12.4
1982	361.3	7.8	388.6	6.2	743.0	7.0	13.5	10.0	212.3	11.6
1983	384.8	6.5	408.8	5.2	795.0	7.0	15.0	9.4	235.4	10.9
1984	416.7	8.3	435.7	6.6	850.7	7.0	16.5	8.9	259.6	10.3
1985	450.0	8.0	463.6	6.4	910.2	7.0	18.3	8.4	284.8	9.7
1986	486.0	8.0	493.3	6.4	973.9	7.0	20.1	8.0	311.0	9.2
1987	524.9	8.0	524.9	6.4	1042.1	7.0	22.1	8.0	338.4	8.8
1988	566.9	8.0	558.5	6.4	1115.0	7.0	24.3	8.0	368.2	8.8
1989	612.2	8.0	594.2	6.4	1193.1	7.0	26.6	8.0	400.6	8.8
1990	661.2	8.0	632.2	6.4	1276.6	7.0	29.1	8.0	435.8	8.8
Distance:	5536 km		6185 km		8808 km		13937 km		7725 km	

est: 1977 estimated based upon 1/2 year-to-date

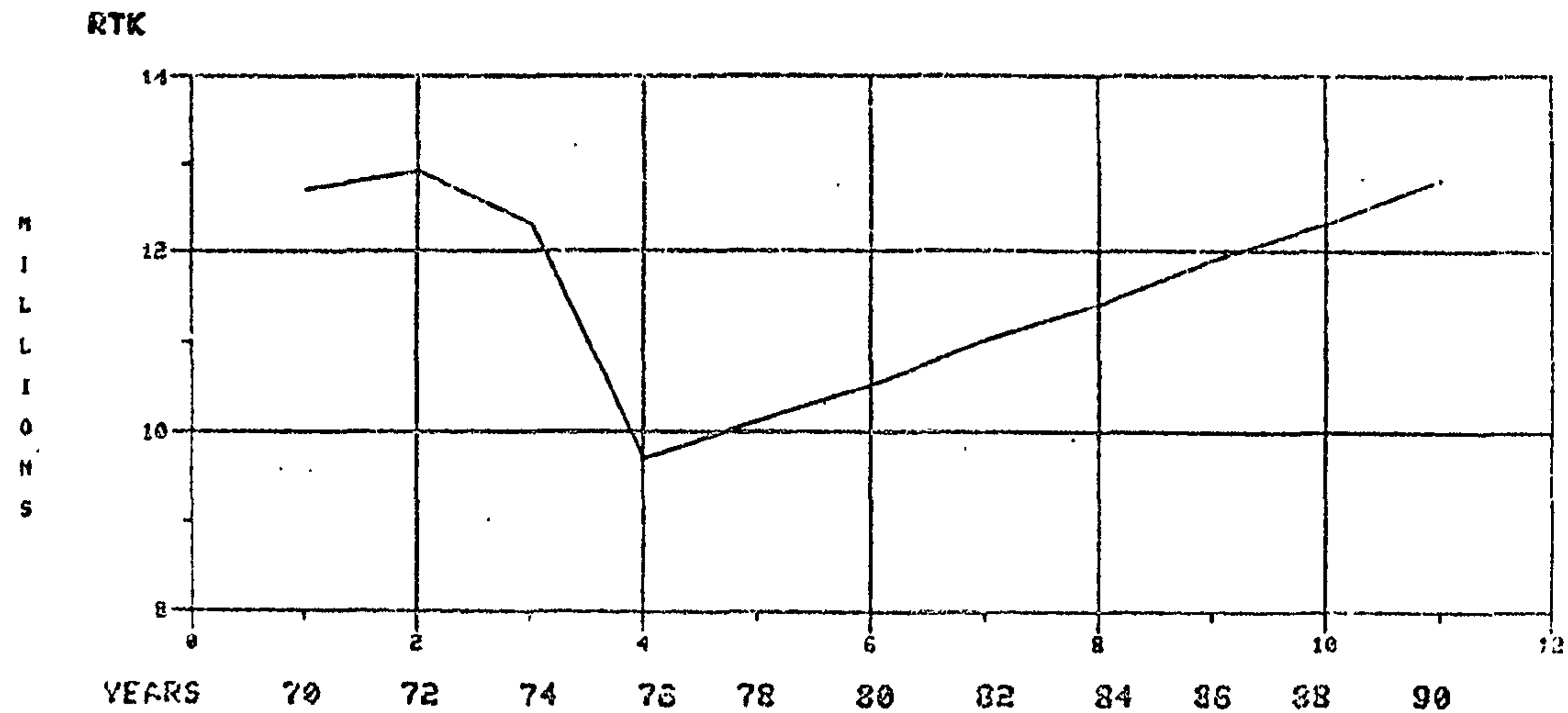


Figure 2-12. Germany - United Kingdom Revenue Tonne-Kilometers

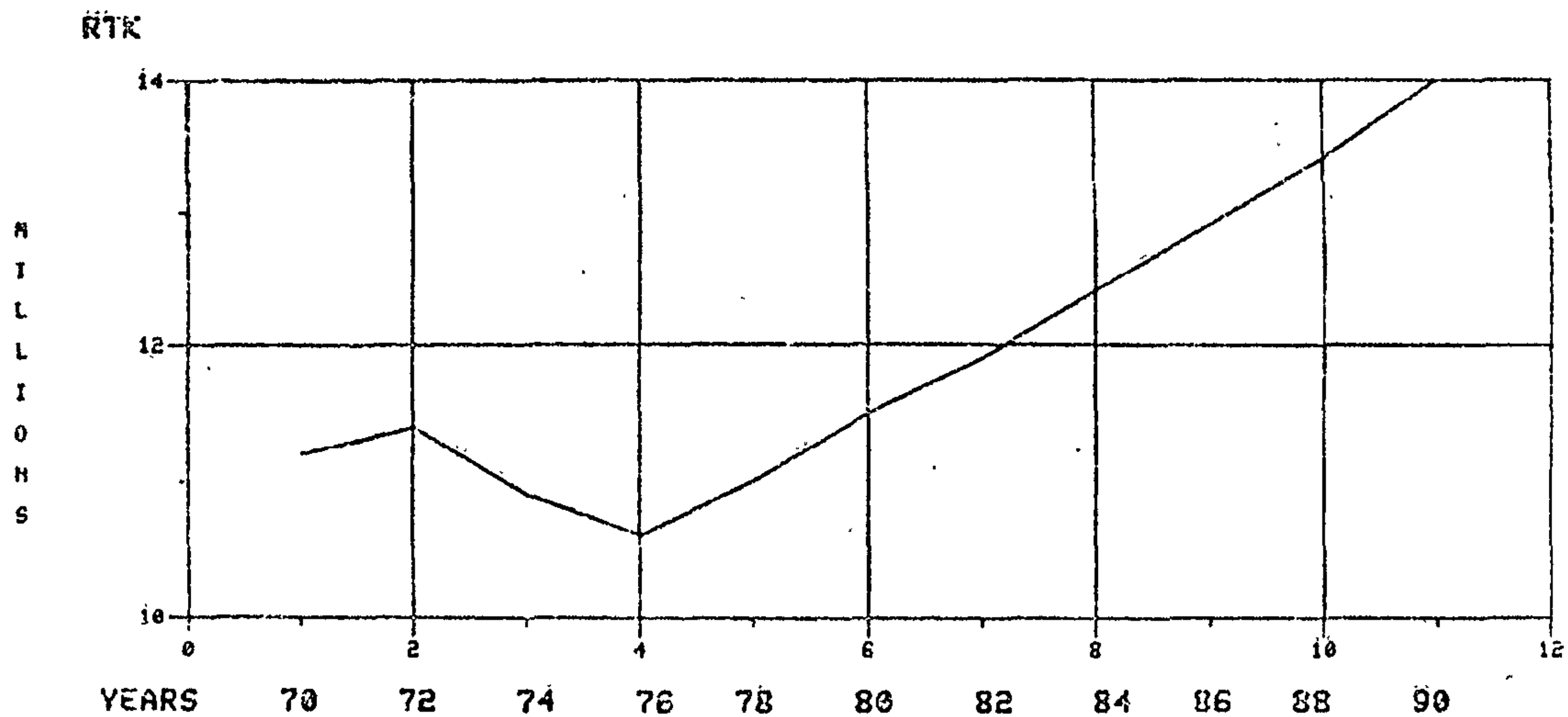


Figure 2-13. United Kingdom - Germany Revenue Tonne-Kilometers

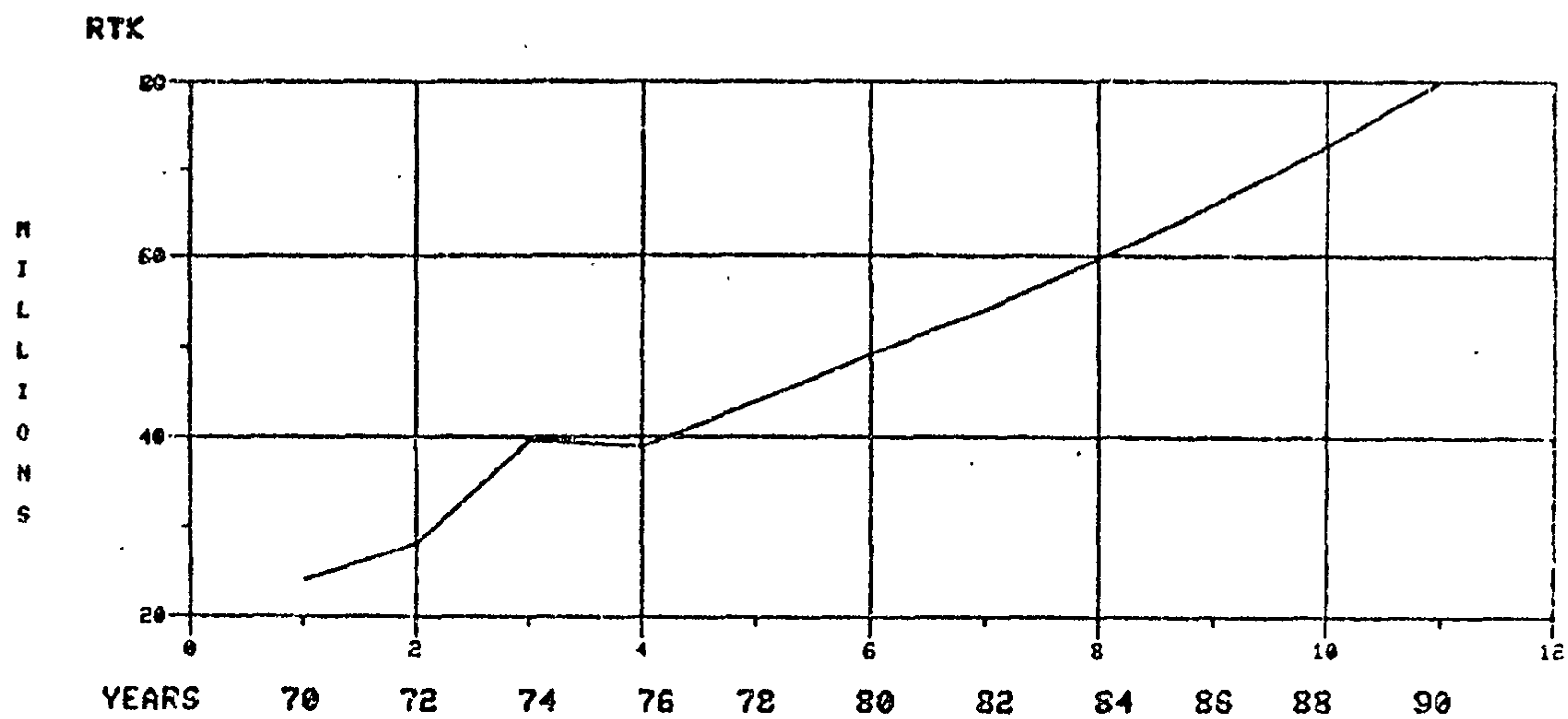


Figure 2-14. Germany - Japan Revenue Tonne-Kilometers

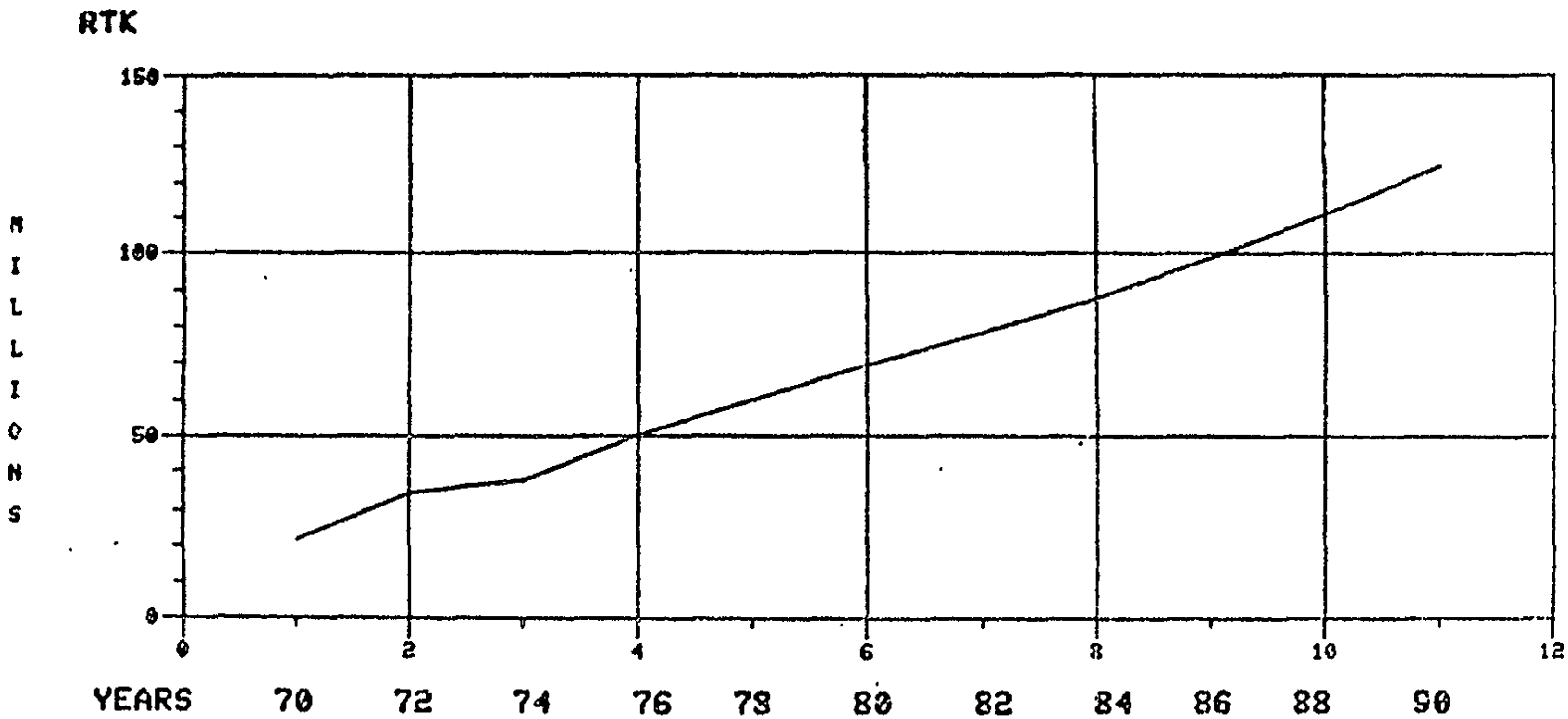


Figure 2-15. Japan - Germany Revenue Tonne-Kilometers

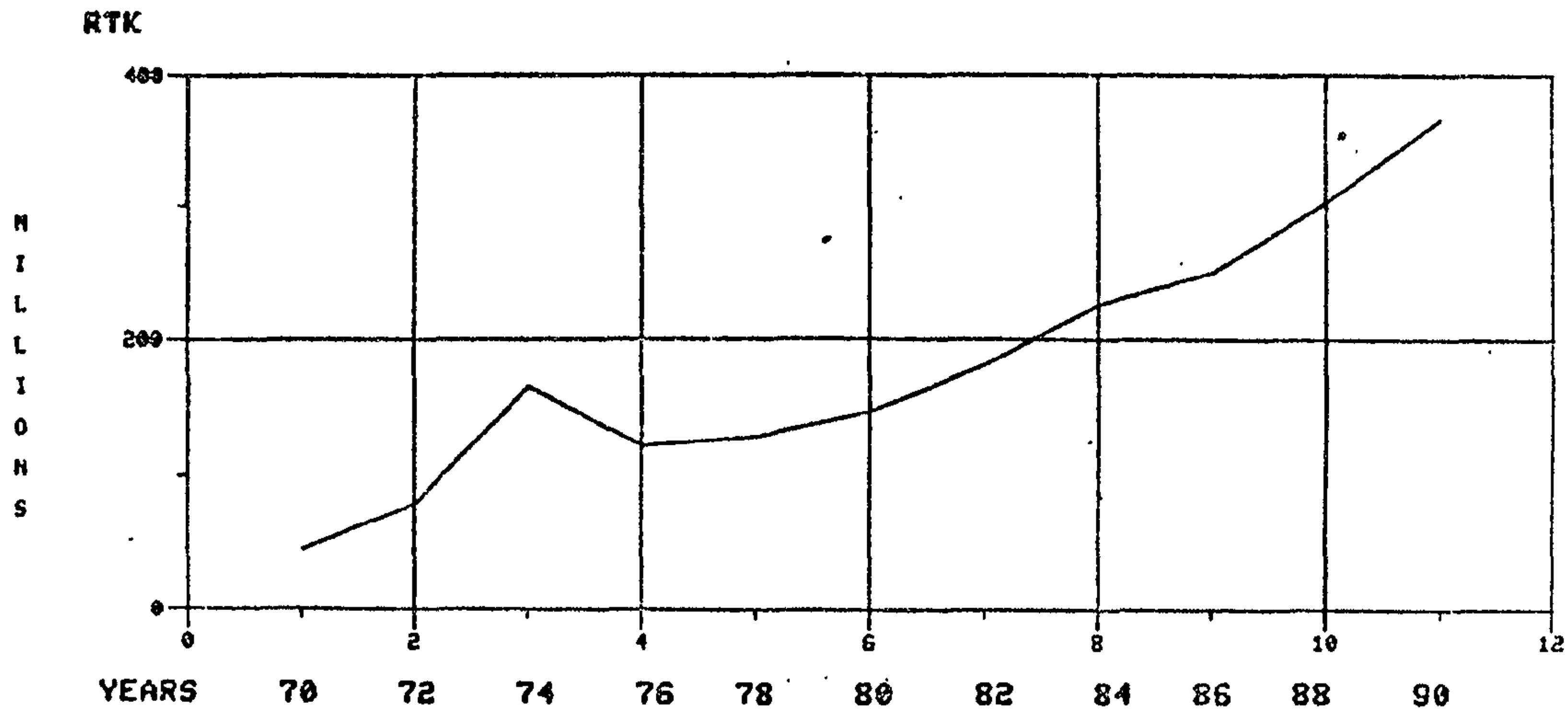


Figure 2-16. United States - Brazil Revenue Tonne-Kilometers

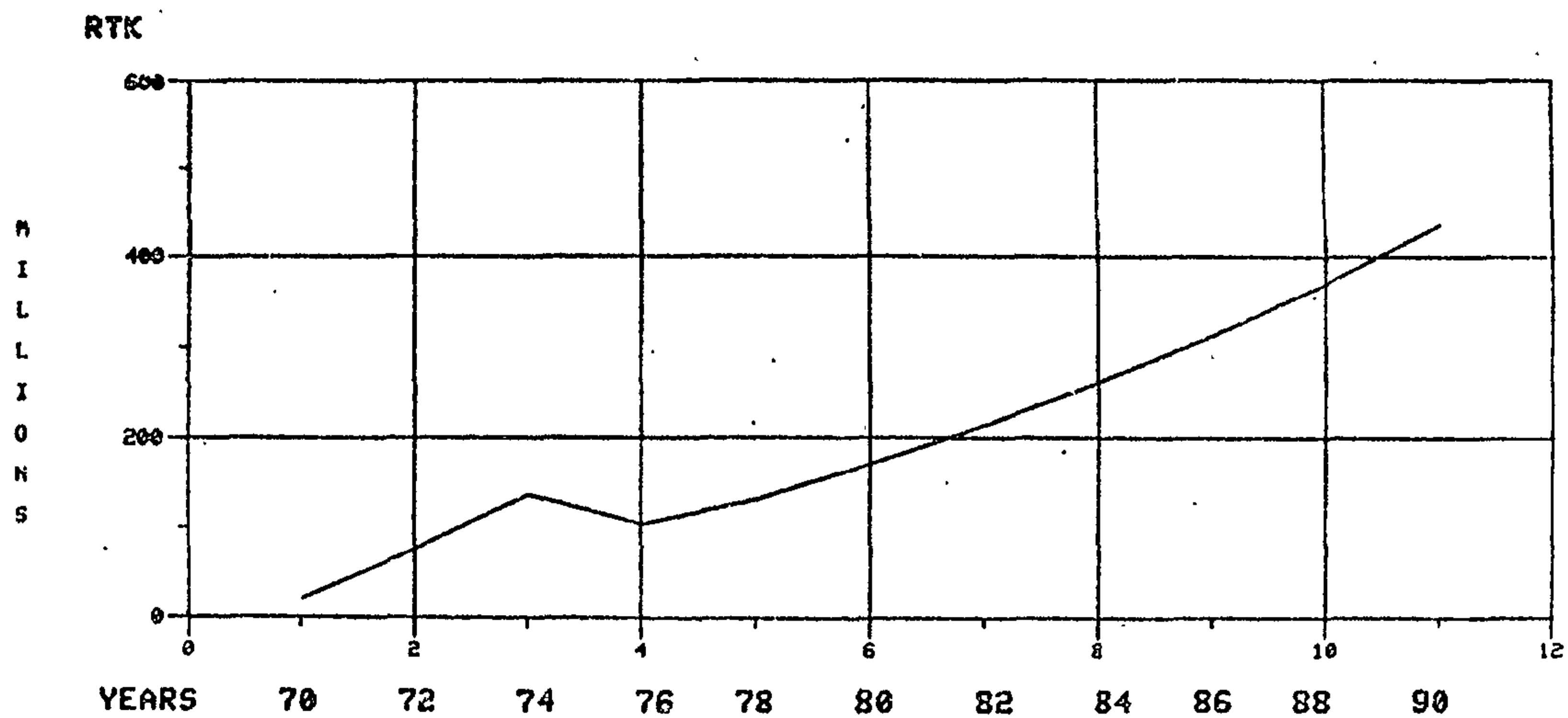


FIGURE 2-17. Brazil - United States Revenue Tonne-Kilometers

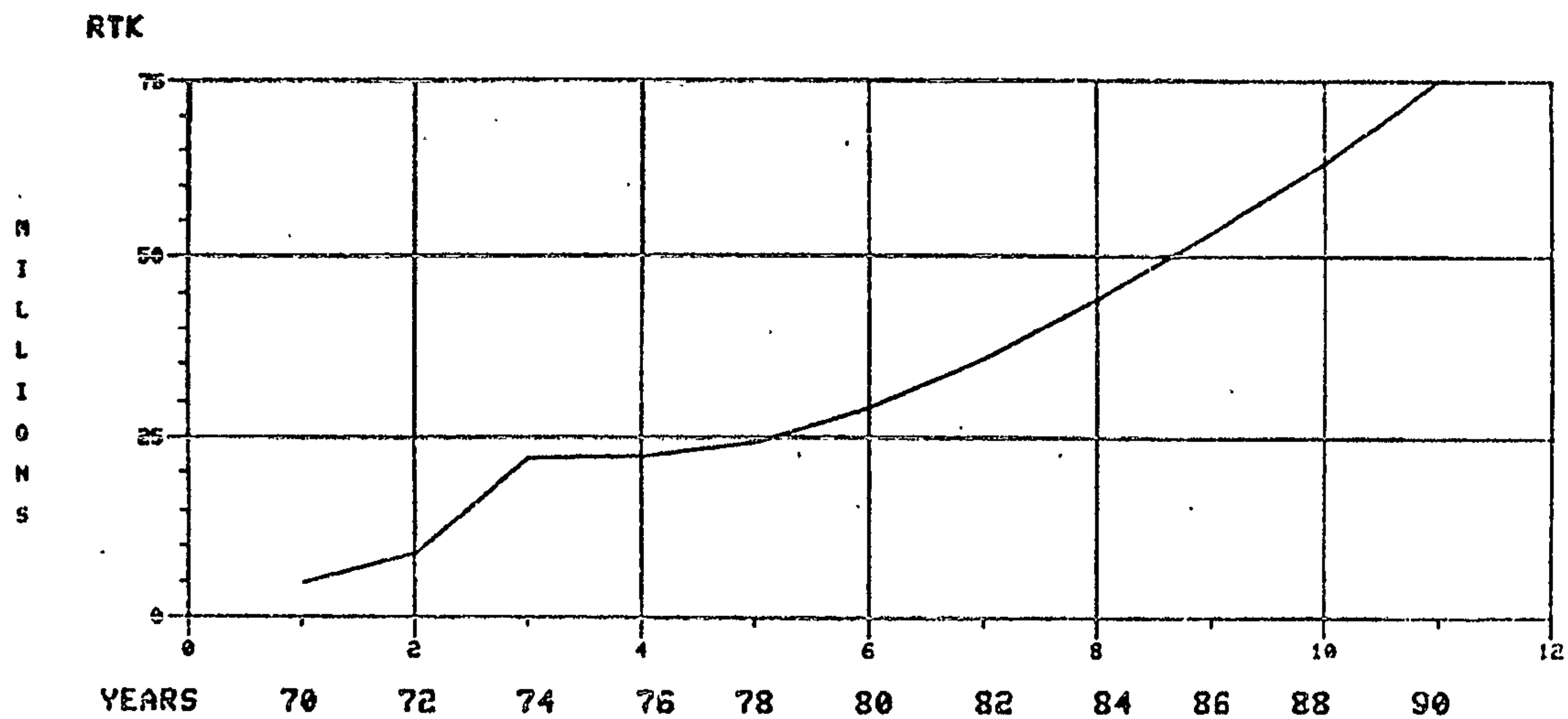


Figure 2-18. United States - Indonesia Revenue Tonne-Kilometers

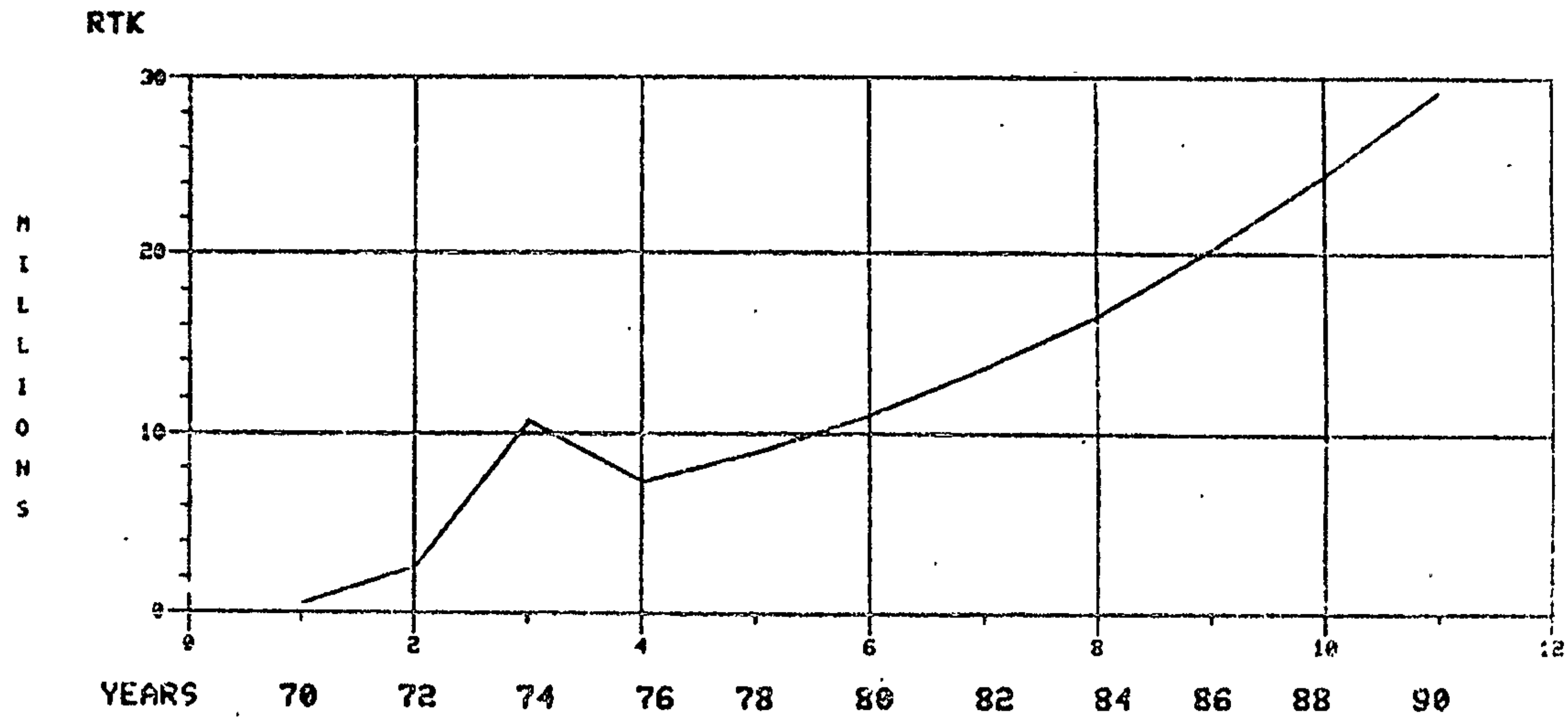


Figure 2-19. Indonesia - United States Revenue Tonne-Kilometers

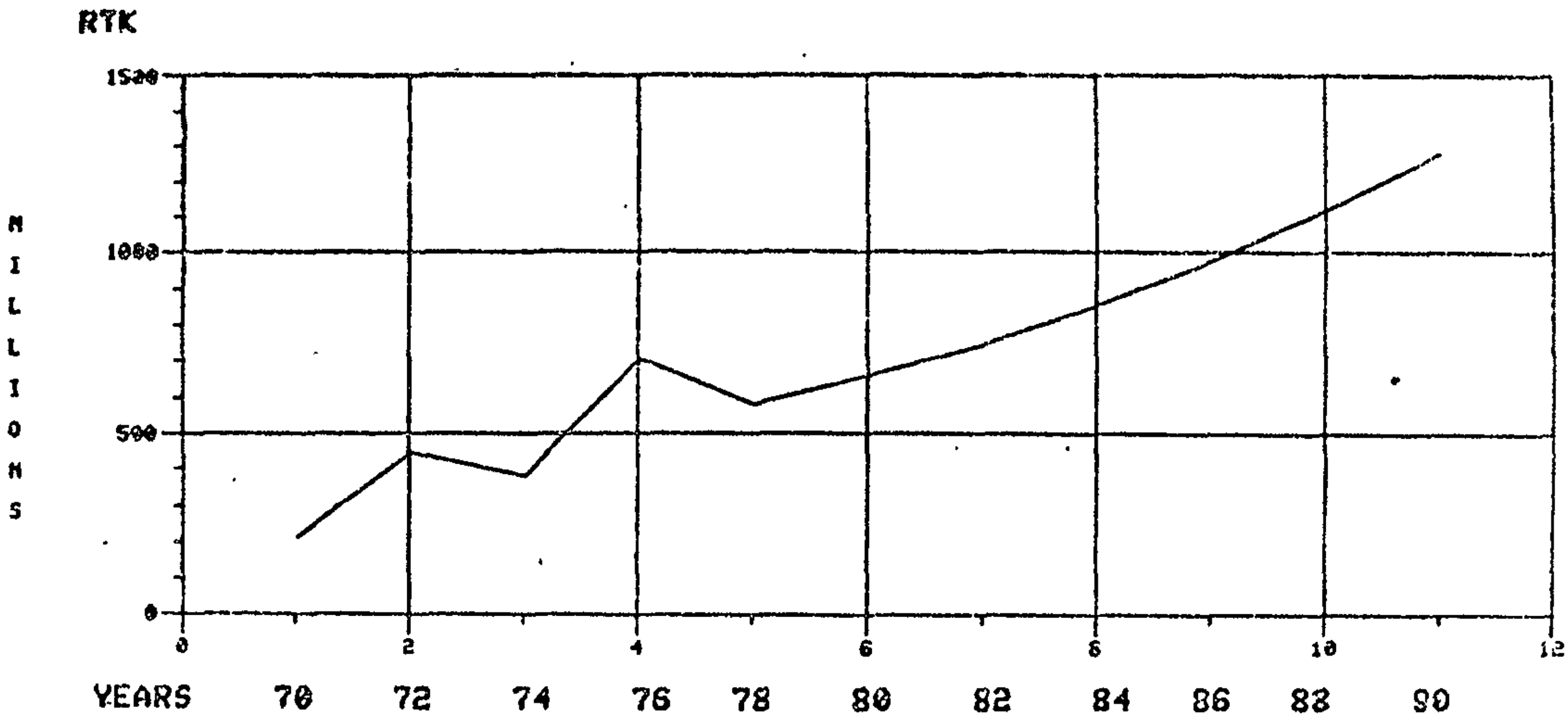


Figure 2-20. Japan - United States Revenue Tonne-Kilometers

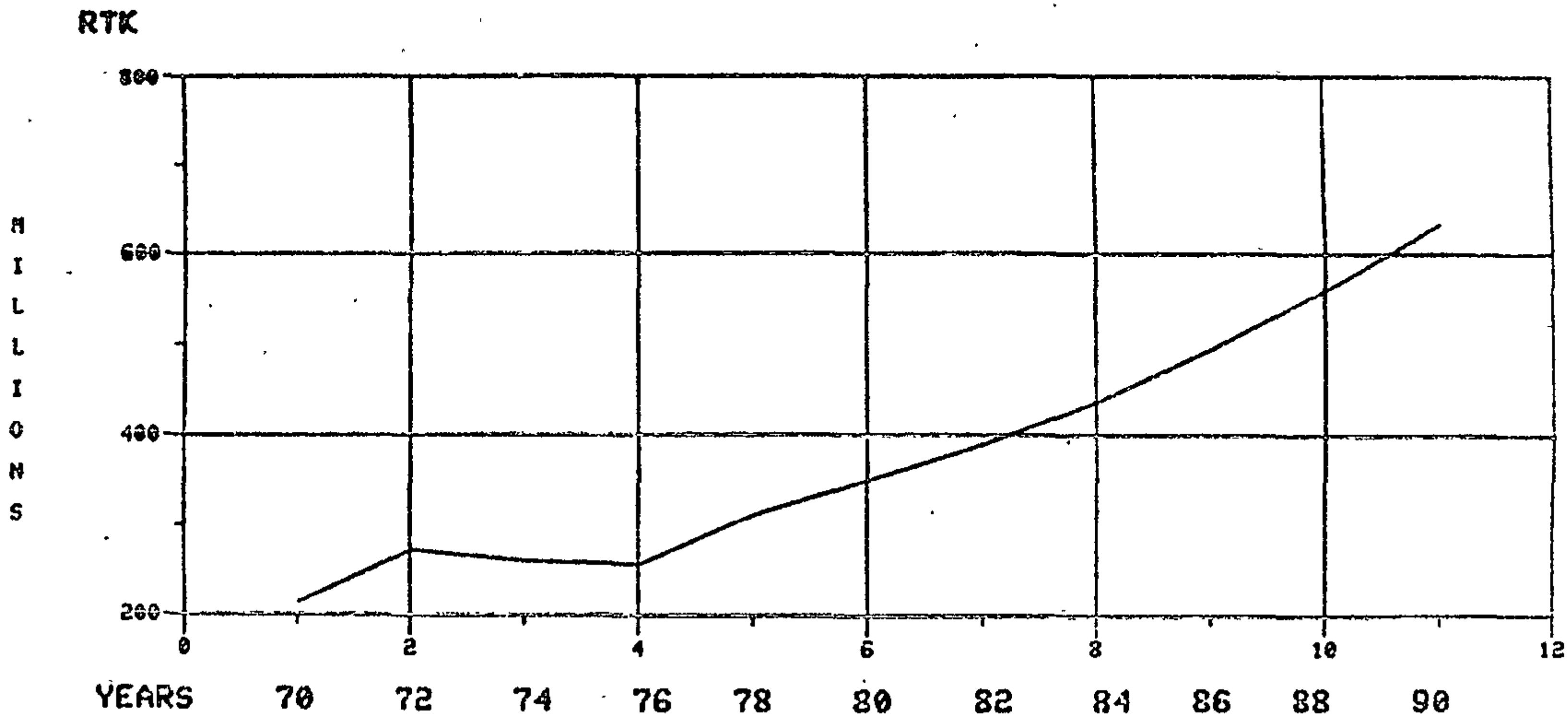


Figure 2-21. Germany - United States Revenue Tonne-Kilometers

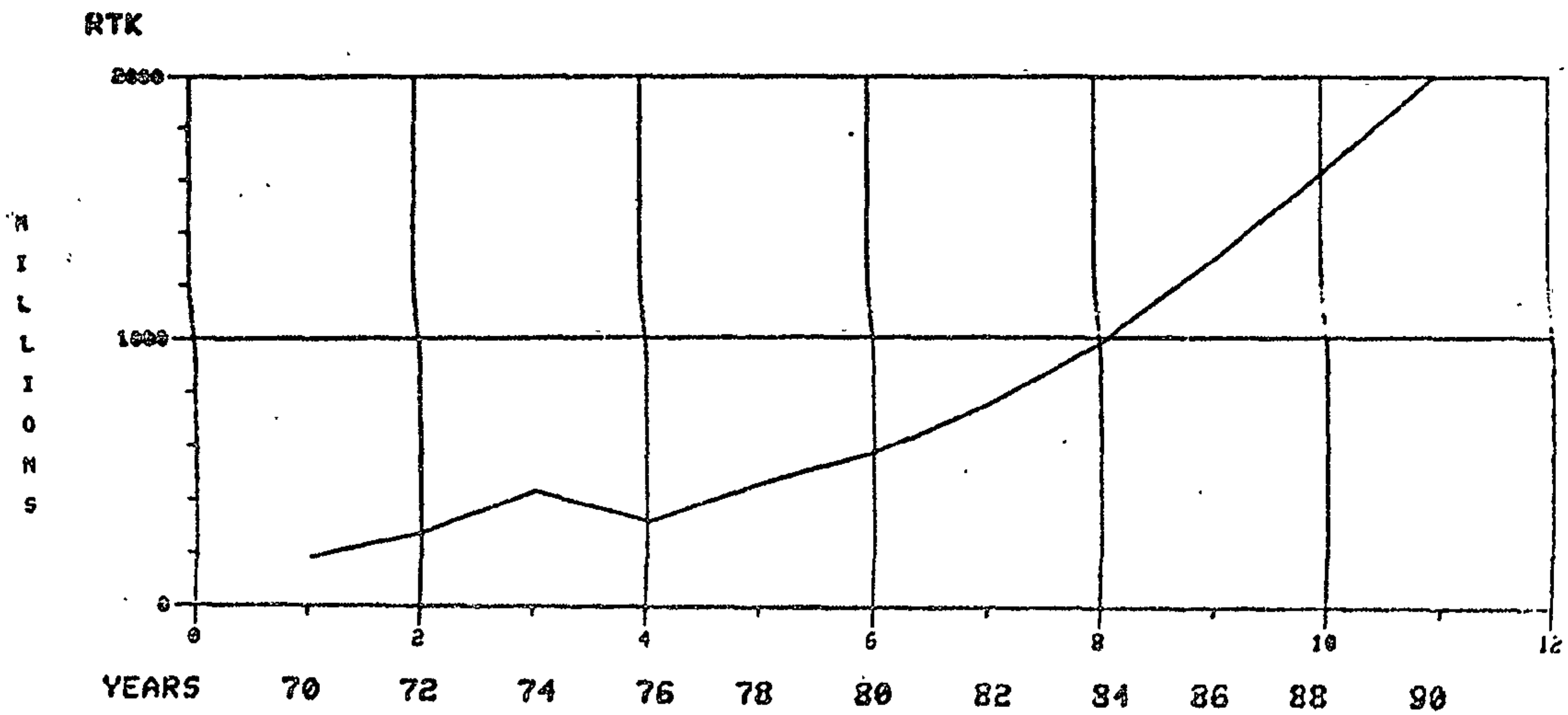


Figure 2-22. United States - Japan Revenue Tonne-Kilometers

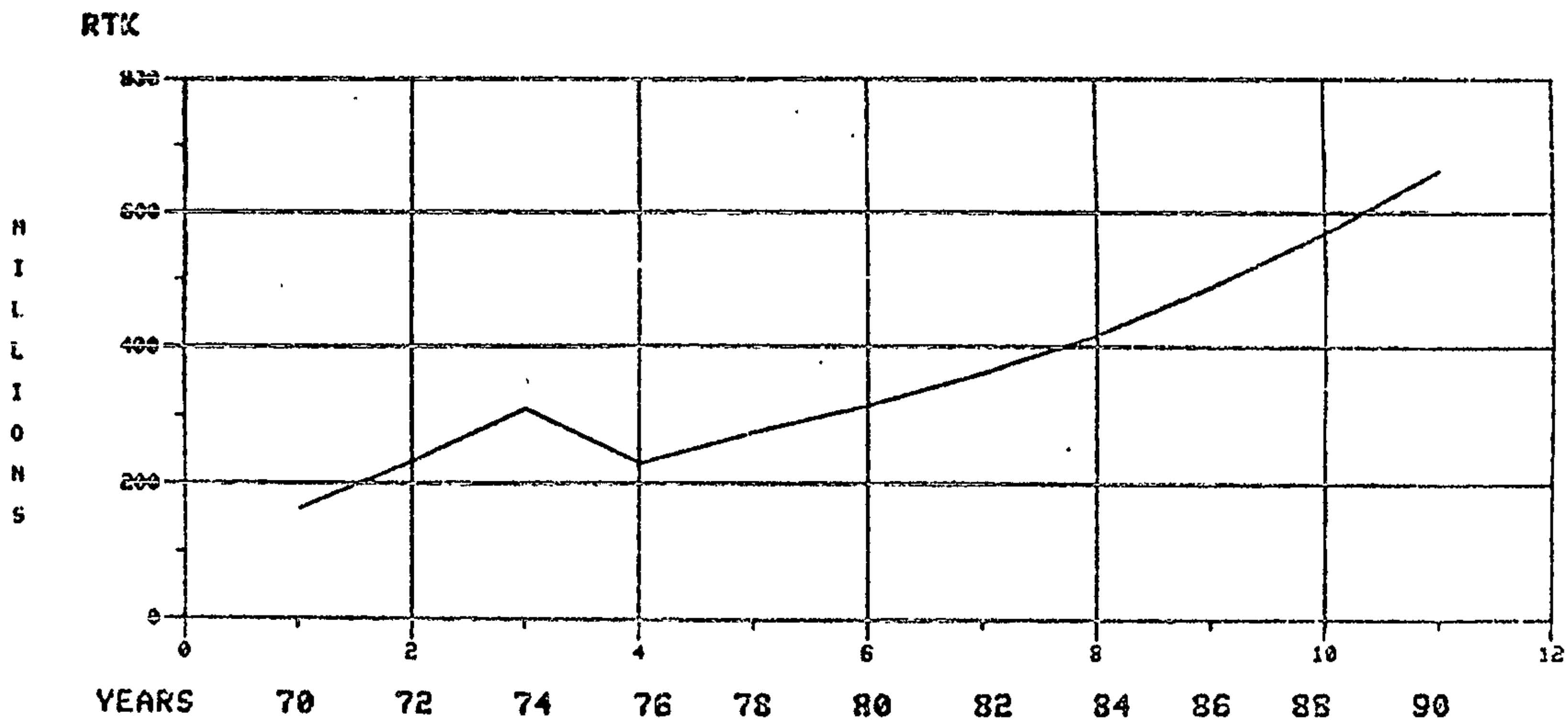


Figure 2-23. United Kingdom - United States Revenue Tonne-Kilometers

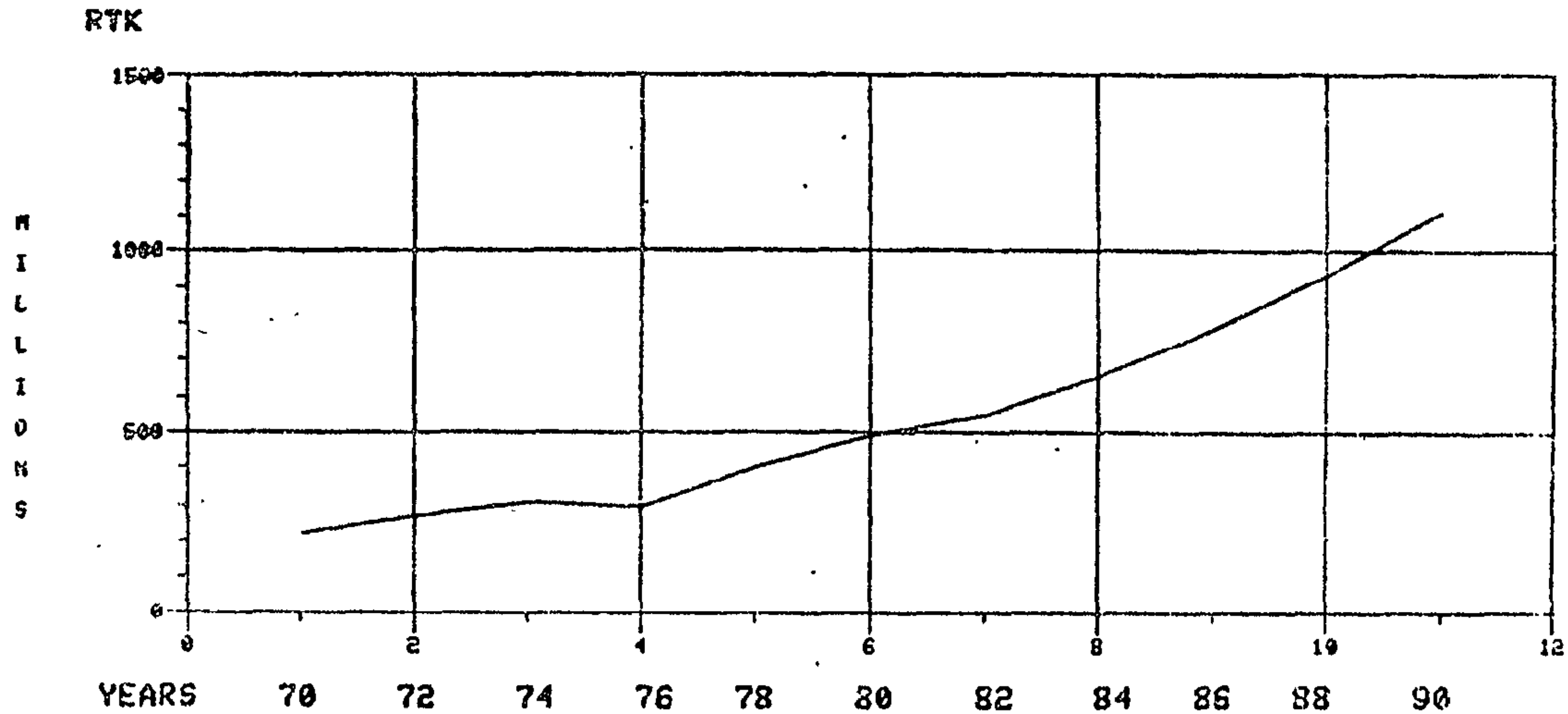


Figure 2-24. United States - Germany Revenue Tonne-Kilometers

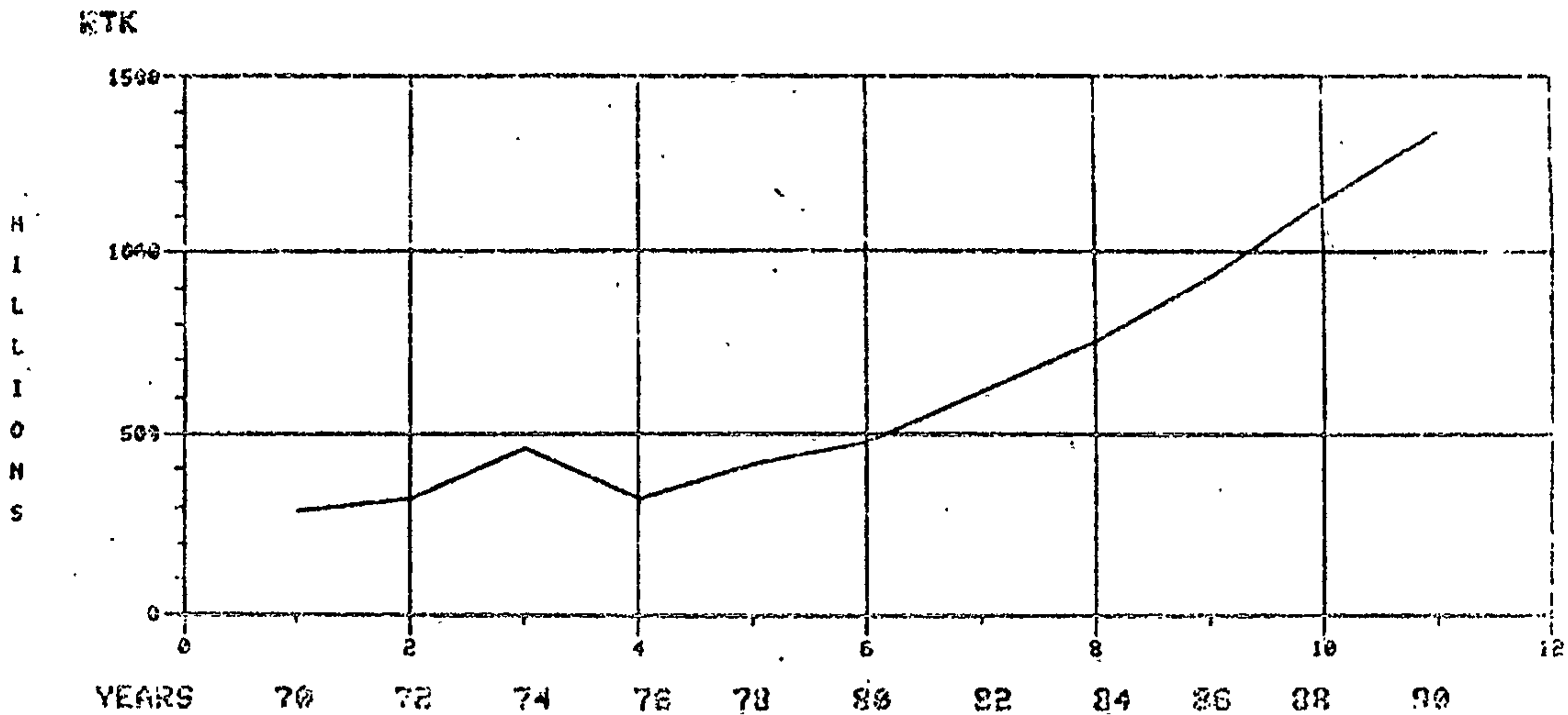


Figure 2-25. United States - United Kingdom Revenue Tonne-Kilometers

D3

N79-27115 351

Section 3

1990 DIRECT SUPPORT INFRASTRUCTURE

In recent years, air cargo has emerged as a significant factor in airline operations. In its infancy it had little impact and received only minimum consideration in the way of direct support. Being a byproduct of passenger-oriented service placed it in a low-priority status with airline corporate hierarchies. Except for cargo airlines, air cargo is still plagued with this role. The aircraft manufacturers, airport planners, and regulatory agencies, understandably, without intending to have also fostered this second-class status. The net result has been an inclination to ignore the needs of air cargo and, except for those directly involved, to forget that it too needs a complementary and supportive infrastructure if its benefits are to be fully developed.

In this section, the airport and cargo terminal are individually considered in depth as the principal direct infrastructure components having cross-impacts with aircraft carrying cargo. Containerization is also addressed in depth as an infrastructure component since it categorically is linked with and cross impacted by the aircraft, the cargo terminal, the surface transport system, the shipper and consignee, and the actual cargo being moved.

In the analyses and discussions following, the importance of the direct-support infrastructure will become increasingly evident. Unless given equal consideration in advance planning and resource allocation, it may curtail future air cargo growth. If this pronouncement sounds harsh, it is intended to because it is a very real concern. Regardless of the potential benefits of containerization, the most efficient air freighter in the world will be rendered ineffective if it cannot land or move on an airport or if the cargo terminal cannot handle the flow.

1990 Impact of Airports Upon Air Cargo

The first-generation jet aircraft were enthusiastically received throughout the world. Citizens eagerly supported airport expansion so their community could have the most modern air service. The economic stimulation provided by jet air travel was sought by all. The adverse effects of noise and pollution were not initially recognized.

Today, the emphasis is on environmental protection instead of economic stimulation. The aerospace manufacturers must design aircraft which can operate from existing airports, and they must significantly reduce noise and air pollution. Airport expansion has nearly come to a halt at the large air carrier airports, and these are the airports which are experiencing congestion. During the 1970s, the U.S. airlines could have more than doubled their earnings if they did not incur the additional operating cost due to landing and takeoff delays. Dallas/Fort Worth and Kansas City are the only two major U.S. airports built in the 1970s. The FAA has identified 10 metropolitan areas having a potential need for a new airport. It is likely that there will not be any new major U.S. airports opened in the 1980s.

Los Angeles International Airport (LAX) has been trying since 1969 to strengthen the Sepulveda tunnel under the south runways. New York City's John F. Kennedy International Airport (JFK) dropped plans to extend runway 4L into Jamaica Bay due to environmental impact. These examples are extreme, but almost every air carrier airport has experienced delay or cancellation on some airport expansion project during the 1970s. Environmental and economic constraints will cause the 1990 U.S. airport facilities to be very similar to today's U.S. airports facilities.

The airports are the air transportation system's interface with ground transportation. Airport constraints impact ground transportation, passengers, cargo, and air transportation systems. The airports impact the cost of operating the air transportation system and impose limits on the:

- Number of passengers, ground vehicles, and aircraft at congested airports

- Size of aircraft that can be processed at selected airports
- Noise and pollution permitted at airports
- Hours of operations permitted at noise-sensitive airports

The following defines the current and forecasted 1990 congestion status of U.S. commercial airports, how airport constraints impact aircraft design and operation, and the feasibility of having commercial air cargo operations from airports which do not currently have commercial air service.

U.S. airport congestion in 1990. - The FAA recently published a report (Reference 3-1) on future airport requirements. The report stated that up to 10 new airports will be needed in the U.S. before the year 2000. It is important to note that 10 times as many new airports are required for high growth as for low growth. This range in new airport requirements illustrates the importance of the growth rate used in the forecast. The following discussion of airport congestion is based on annual growth of revenue passenger-kilometers of 5 to 6 percent per year and 8 to 10 percent for cargo. A higher growth rate would significantly increase 1990 airport congestion.

Runway congestion: Runway congestion costs the airlines more than congestion due to the other airport components. The FAA is currently developing a standard airport delay-reporting procedure. There is a shortage of consistent historical airport delay data. The FAA has reported (Reference 3-2) that airport delays (landing and takeoff delays) cost the airlines $118 million in 1968, $157 million in 1969, and $195 million in 1973 (Figure 3-1). These delay costs only include additional direct operating cost (DOC).

The average delay cost from 1968 through 1973 was over $170 million per year. The average earnings of U.S. scheduled airlines from 1968 through 1973 were less than $85 million per year (per CAB form 41s). Hence, the airlines could have tripled their earnings from 1968 through 1973 if they did not incur the additional operating cost caused by airport delays. These additional earnings would greatly improve the airlines' ability to finance new aircraft.

The two largest U.S. air carrier airports, Chicago O'Hare (ORD) and Atlanta Hartsfield (ATL), also have the greatest delay costs. A recently

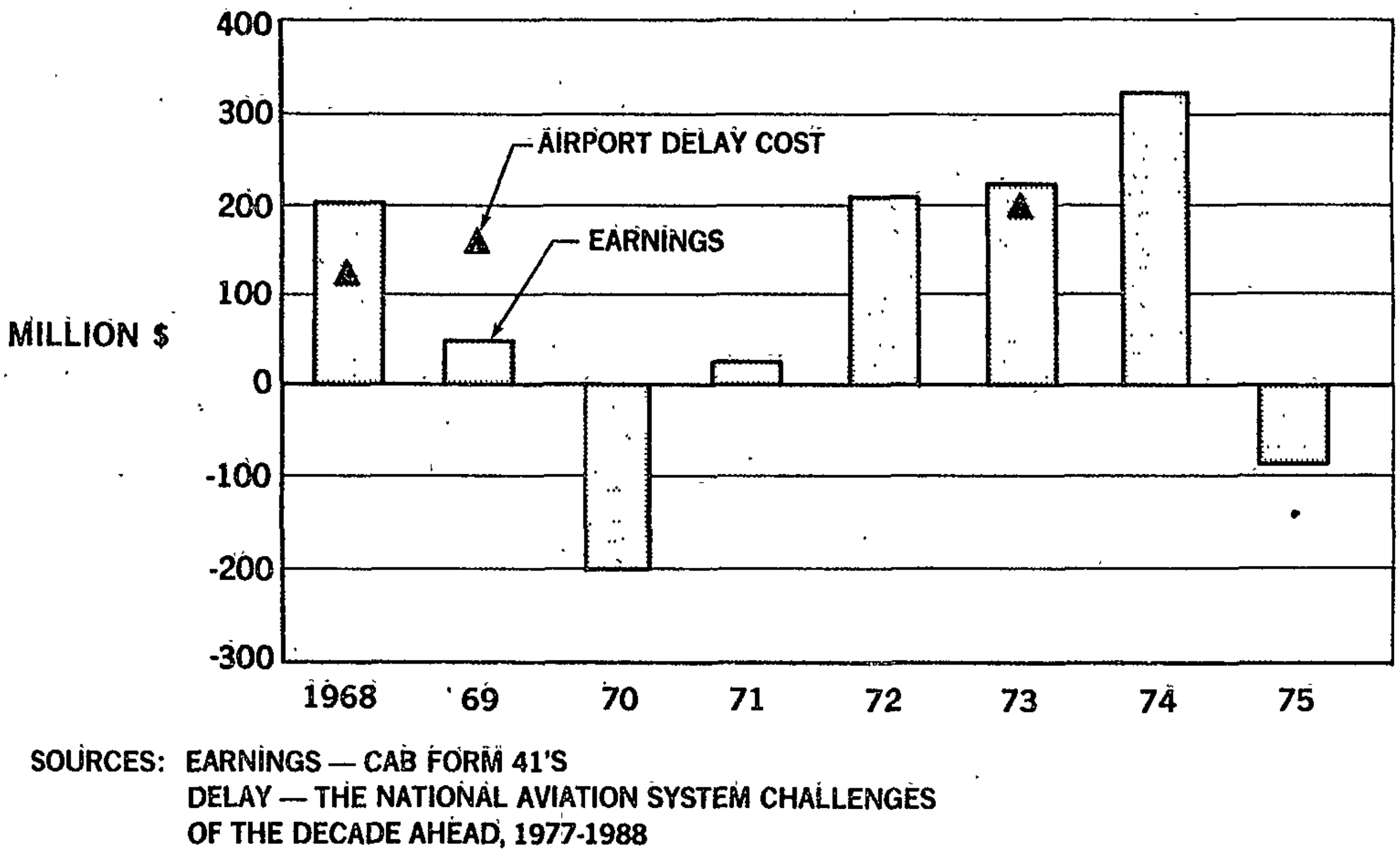


Figure 3-1. U.S. Scheduled Airlines Delay Costs

completed delay study at O'Hare (Reference 3-3) stated that the 1975 delays at ORD

- Cost the airlines $44.3 million in increased direct operating cost.
- Cost 4.6 million hours of passenger delay.
- Wasted 67 million gallons of fuel. This is enough fuel for 10 round trips per day for the entire year between Chicago and Los Angeles with a fully loaded DC-10.

Delay data from Eastern Air Lines (Reference 3-4) state that their system-wide delay cost exceeded $62 million for the 12 months ending June 1977. Their average airborne arrival delay was 4.58 minutes and cost $15.98/minute. Their average taxi-out delay was 3.99 minutes and cost $7.98/minute. (They also averaged 1.09 minutes of taxi-in delay at $7.98/minute). Their average delay per operation at major airports is shown below.

July 1976 Through June 1977
Average Delay/Operation (Minutes)

Airport Code	Airport Arrival	Taxi In	Taxi Out
ATL	7.87	2.57	7.47
BOX	4.99	1.67	5.55
DCA	5.64	0.80	4.00
EWR	5.82	0.71	3.68
JFK	6.97	1.70	8.82
LGA	5.62	0.99	7.63
MIA	3.03	0.60	3.14
ORD	6.05	1.36	6.23

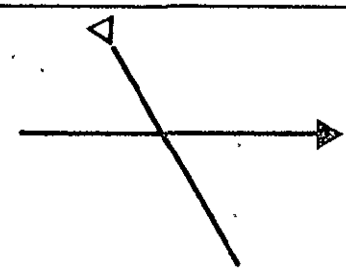
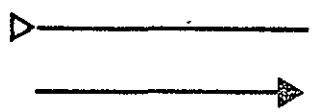
The FAA currently limits the number of operations which can be scheduled during congested hours at ORD, JFK, LGA, and DCA. These flow control constraints are among the main reasons that airport congestion has not returned to the levels experienced in the late 1960s. It is possible that flow control limits will exist at the following airports by 1990:

ORD*	BOS
JFK*	PHL
LGA*	ATL
DCA*	SFO

(*Currently flow controlled)

The FAA is currently performing research on new air traffic control (ATC) systems. These new ATC systems include wake vortex avoidance, metering and spacing, and discrete address beacon system which are expected to become operational in the late 1980s. These ATC systems reduce the entrail separation behind a heavy aircraft whenever the meteorological conditions permit. (There is currently a wake vortex separation behind aircraft with a maximum allowable gross weight over 136 054 kg). The benefit of these new ATC systems depends upon the runway configuration and the aircraft mix. For intersecting runways, the IFR capacity will be increased by 13 to 17 percent. The capacity will be increased from 25 to 35 percent at airports with parallel landing and takeoff runways (Figure 3-2). In both cases, the larger capacity increase is for a large percent of heavy aircraft. The intersecting runway configuration has a lower capacity increase than the parallel runway configuration because a departure occurs between consecutive arrivals, which makes it impossible to operate the arrival stream at minimum entrail separation.

A new runway will result in aircraft flights over land which currently does not have flights. These new flights will have an environmental impact. Hence, it is very difficult to get environmental approval to build a new runway. The environmental impact of a runway which is a close parallel to an existing runway is less than for an independent runway because a close parallel only shifts operations by 300 meters. However, it is difficult to get environmental approval for a close parallel runway. The only known planned new runways at congested airports are one close parallel runway at both ATL

FUTURE ATC / RUNWAY CONFIGURATION	1982 WAKE VORTEX ADVISORY	1987 WAKE VORTEX AVOIDANCE ADV METERING AND SPACING DESCRETE ADDRESS BEACON SYSTEM (DABS)
	0—5%	13—17%
	0—7%	25—35%

LOWER CAPACITY INCREASE IS WITH 0% HEAVIES

HIGHER CAPACITY INCREASE IS WITH 50% HEAVIES

Figure 3-2. Planned Air Traffic Control Improvements Capacity Increase Over Current Operations and ORD. The only new airports being actively discussed are for St. Louis and Los Angeles (Palmdale); it is likely that neither one will be operational by 1990 and it is possible that they will never be built.

As air carrier airports become congested, there is a sequence of changes that usually occur. First, there is a reduction in the number of general aviation aircraft. This is usually accomplished by charging a fee that encourages general aviation to use another airport. The second step is to reduce growth in air carrier aircraft operations. This is performed by diverting part of the transfer traffic to another airport or offering direct flights instead of transferring at the congested airport. This, of course, reduces growth in enplanements. The growth at the airport is handled more by larger aircraft than by increased frequency. The third and final step is FAA-imposed quotas which stop growth in aircraft operations during the peak hours. There is more diversion of transfer traffic, and any growth in demand will result in larger aircraft or a higher load factor.

Airport runway congestion is basically dependent upon the ratio of demand divided by capacity. Runway delays are not significant during low-demand time periods. Figure 3-3 illustrates the total scheduled air carrier demand per hour for the top 100 U.S. airports. The hourly demand from 2200 until 0700 hours is less than half of the average hourly demand from 0700 to 2200 hours. Runways delays during these nighttime hours are not significant. Figure 3-4 presents the total scheduled all-cargo operations at the 25 largest U.S. airports. The all-cargo operations peak during the hours when total operations are lowest. Therefore, the majority of the all-cargo flights will not be significantly delayed on landing or takeoff. However, a large share of air cargo is carried on passenger aircraft which will experience landing and takeoff delays.

Apron/gate and terminal congestion: The airlines cannot park any additional aircraft at gate positions during peak hours at Atlanta, O'Hare, LaGuardia, and Washington National. The airlines could not expand operations at these airports if the operations quota was removed. Other airports with very serious apron/gate or terminal congestion are Las Vegas, Cleveland, and San Francisco. All large hub airports experience some problems due to limited apron/gate and terminal facilities.

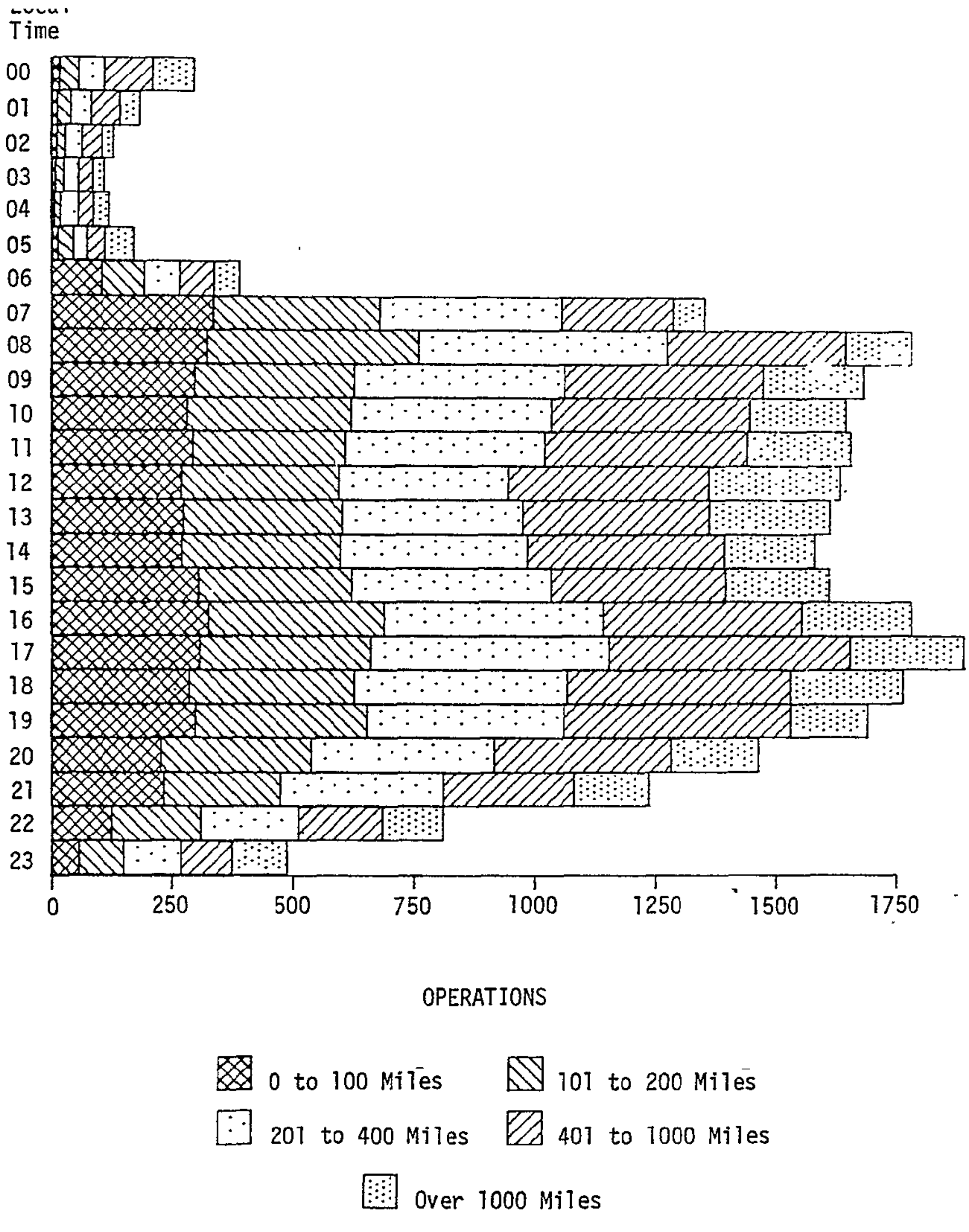


Figure 3-3. U.S. Total Top 100 Airports Scheduled Operations by Hour — Friday, August 6, 1976

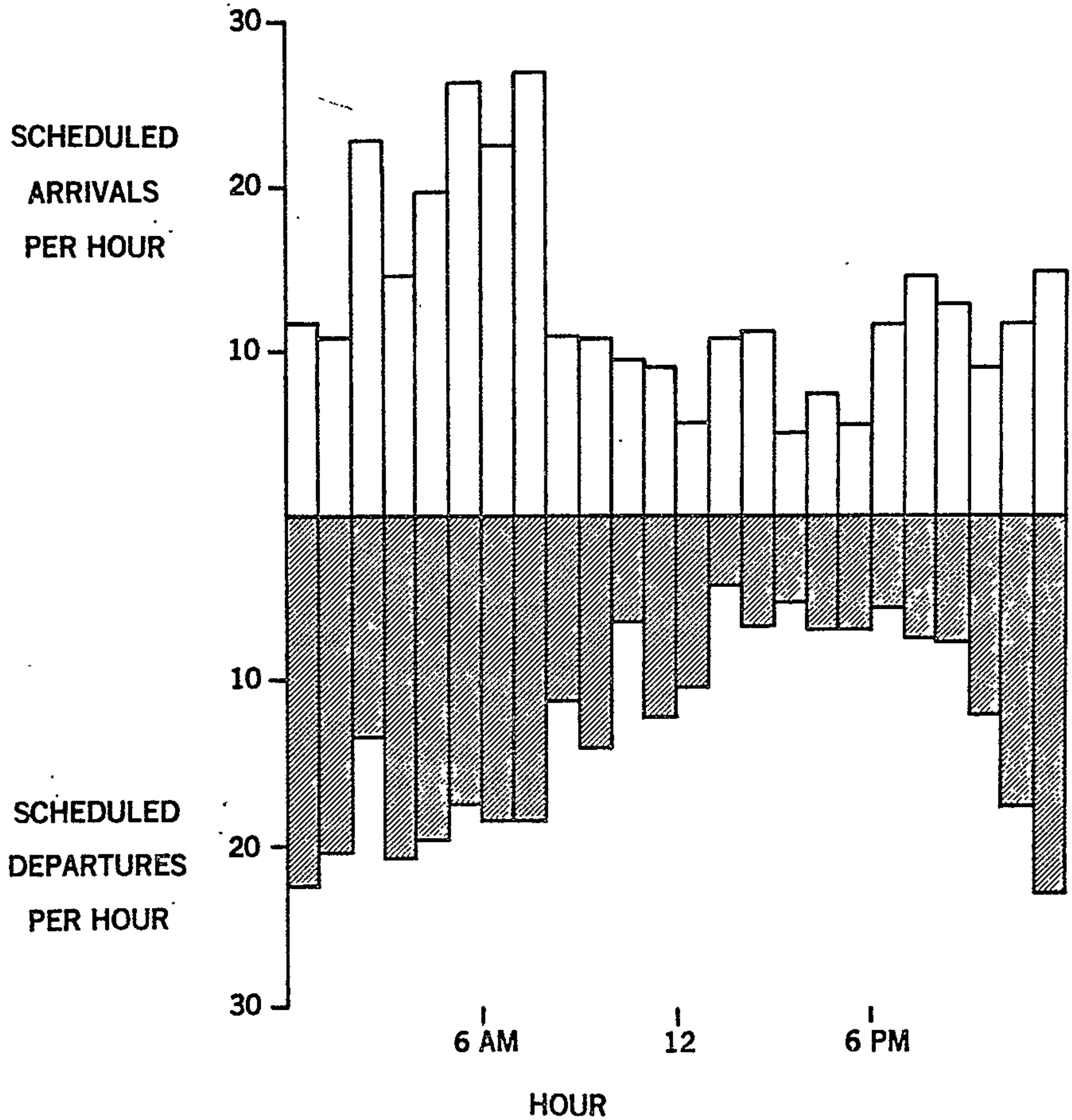


Figure 3-4. Total Scheduled All-Cargo Operations
at 25 Largest United States Airports

The wide-body tri-jets were designed to operate from LaGuardia Airport. However, there are currently only a few wide-body tri-jets per day at La Guardia because there is not adequate apron/gate area to handle their larger wing span and length. The airlines are currently seriously considering the purchase of aircraft with approximately 200 seats (e.g., the B7X7, DC-X-200, A300). The airlines have emphasized that they do not want too big a wing span or length because that will make it difficult or impossible to operate at existing airports.

It is easier to get environmental approval to expand the apron/gate area or terminal than it is to expand the runway system. Atlanta and San Francisco are currently building new passenger and/or cargo terminals. St. Louis, O'Hare, Los Angeles, and others have preliminary designs for expanding passenger or cargo terminals; and many airports have decided where additional passenger and/or cargo apron/gate areas and terminals should be built. However, under current legislation it is possible to receive federal financial aid (ADAP) for 75 percent of the expense of runways, taxiways, and aprons; the rate is 18 percent for passenger terminals and zero percent for cargo terminals. There is also a problem at some airports due to a lack of room for terminal expansion.

The apron/gate and terminal congestion at Atlanta should be relieved before 1990. However, it will probably be worse at La Guardia, O'Hare, and Washington National. There will be a new cargo terminal at Atlanta, and possibly a new one at O'Hare and Los Angeles. Cargo terminals will be expanded at many airports but it is unlikely that any congested airport will build cargo apron/gate and terminal facilities which are designed for an aircraft significantly larger than the current Boeing 747.

Ground access congestion: Many experts believe that Los Angeles International Airport will become capacity constrained by ground-access congestion in the 1980s. The ground-access constraint is one of the major reasons that the new airport at Palmdale is planned. There is reason to believe that the ground-access capacity at LAX can be significantly increased by additional remote parking (particularly if the remote parking lots have an exclusive right-of-way transit system to the terminals) and by additional freeways and/or freeway interchanges.

Ground-access congestion is serious at Boston, Kennedy, La Guardia, Miami, San Francisco, Denver, O'Hare, and Ft. Lauderdale. The ultimate capacity of several of these airports may be limited by ground access.

The peak hours for all-cargo aircraft operations are at night. However, the peak hours for trucking cargo to the airport is during the evening rush hour when ground access is highly congested. Similarly, a sizable percent of the cargo is trucked from the airport during the morning rush hours. The cargo terminals at most of the larger airports are at least a kilometer from the passenger terminals. At many large airports, passenger and cargo traffic use the same freeway interchange and then separate on the surface streets. The separation of ground passenger and cargo traffic is a major factor in selecting the site for the cargo terminal.

Airport congestion summary: Table 3-1 presents a summary of airport age, size, location, and daily scheduled arrivals for passenger and all-cargo aircraft. The airport size is basically dependent upon the size of the metropolitan area, the year the airport began operations (newer airports are larger), and the distance from the central business district (CBD) (the close-in airports are smaller). La Guardia (LGA) is one of the smallest airports (only 2.6 km^2), yet there are only five airports with more scheduled aircraft.

The following listing summarizes the 10 most congested U.S. airports for 1990 according to runway congestion, apron/gate congestion, and ground-access congestion.

Runway Congestion	Apron/Gate Congestion	Ground Access Congestion
ORD	LGA	LAX
LGA	DCA	JFK
JFK	ORD	LGA
DCA	BOS	BOS
BOS	SFO	SFO
SFO	JFK	MIA
PHL	LAX	ORD
DEN	CLE	CLE
ATL	PHL	PHL
LAX	DEN	DTW

TABLE 3-1.

U.S. AIRPORT SIZE, LOCATION, AND DAILY ARRIVALS

City Name	Airport Code	Approximate Year Comm. Service Began	Size in 1977 (km^2)	Distance From Central Business District (km)	Scheduled Aircraft Arrivals Per Day - August 1977	
					Passenger	All-Cargo
Atlanta	ATL	1930	15.2	13	623	14
Boston	BOS	1933	9.3	5	398	12
Chicago	ORD	1959	28.3	30	917	51
Cleveland	CLE	1925	6.5	19	179	11
Dallas	DFW	1973	72.8	27	614	13
Denver	DEN	1929	18.8	11	428	8
Detroit	DTW	1955	15.0	24	234	14
Honolulu	HNL	1927	19.5	16	205	11
Houston	IAH	1969	32.4	27	248	2
Kansas City	MCI	1972	20.2	24	193	4
Las Vegas	LAS	1948	6.9	11	156	0
Los Angeles	LAX	1928	14.2	27	568	26
Miami	MIA	1929	13.1	8	309	14
Minneapolis	MSP	1920	12.1	16	203	9
New Orleans	MSY	1946	6.9	19	166	2
New York	JFK	1948	20.0	24	368	42
New York	LGA	1939	2.6	13	410	5
New York	EWR	1928	9.3	23	217	9
Philadelphia	PHL	1940	10.1	11	310	18
Pittsburgh	PIT	1952	40.5	27	332	--
St. Louis	STL	1942	8.1	16	290	2
San Diego	SAN	1928	2.0	3	121	1
San Francisco	SFO	1926	21.1	24	382	22
Seattle	SEA	1942	8.9	24	220	6
Tampa	TPA	1927	13.4	10	189	3
Washington	DCA	1941	3.4	5	341	5

The top airports for scheduled all-cargo flights are listed below.

Airport	Daily All-Cargo Arrivals	Remarks
ORD	51	The world's busiest airport
JFK	42	About 60% overseas
LAX	26	Several to JFK, SFO, and Asia
SFO	22	Several to ORD and Asia
PHL	18	Mostly small propeller aircraft

All-cargo operations at other airports are significantly less than at these five airports. These five airports have half of the all-cargo flights to the 26 airports listed in Table 3-1.

ORD is the major transfer hub for U.S. domestic flights. ORD has extreme runway congestion (the FAA legislates how many flights per hour are allowed between 1500 and 2000 hours). ORD has severe passenger apron/gate and terminal congestion; the congestion at the cargo terminal is not quite as severe. ORD has ground-access congestion. The airlines cannot increase aircraft frequency into ORD. United is establishing minihubs in Cleveland and Denver while American and Trans World are increasing transfer service at St. Louis. It is expected that ORD will have a below-average growth in passenger and cargo enplanements, almost no growth in aircraft operations, and a higher-than-average growth in aircraft size. Only half of the passenger enplanements at ORD are originations. This will increase slightly as the airlines establish new transfer hubs and increase service without the en route stop at ORD.

JFK has many of the characteristics that ORD has; however, JFK is the transfer hub to Europe. JFK has extreme runway congestion (it also has FAA-established flow control), some apron/gate and terminal congestion, and ground-access congestion. The airlines can not increase flights during the afternoon, and there has been a significant increase in the number of U.S. airports which have been authorized service to Europe. Hence, JFK (like ORD) will have a lower-than-average growth in passenger and cargo demand, almost no growth in aircraft operations, and will further increase the already large average aircraft size. Most major European airports have restrictions on night operations which will keep the morning arrivals or departures at JFK from growing significantly.

LAX and SFO are the two major west coast airports, and most of the flights to Asia or Australia go through one or both airports. LAX and SFO also have many nonstop flights to the east coast. There is only moderate runway congestion at LAX; SFO has significant runway congestion. SFO currently has worse apron/gate and terminal congestion, but construction is being performed to relieve this congestion. LAX has very severe ground-access congestion, and SFO has serious ground-access congestion. The City of Los Angeles is planning a new airport at Palmdale, but the site is too hot and high for international flights and too far from population centers for short-haul flights. LAX and SFO will probably be improved in the apron/gate and terminal areas and in ground access. Demand and operations at the two airports will probably grow near the national average until the late 1980s when airport congestion will decrease the number of new flights added to these two airports.

Growth in passenger or cargo air travel demand results in

- Increased service frequency on existing routes
- New service between airports which did not have nonstop service
- Use of larger aircraft on existing routes.

As airports become congested, the only way to handle increased demand is to use larger aircraft or to divert part of the through or transfer traffic by increasing frequency and the number of routes at uncongested airports. The currently congested airports are ATL, ORD, JFK, LGA, and DCA. The other airports most likely to become congested by 1990 are BOS, CLE, DEN, LAX, MIA, MSP, PHL, and SFO.

Impact of airport constraints upon aircraft design and operation. - There will probably not be any new major air carrier airports built before 1990. Atlanta will open new passenger and cargo terminals in the early 1980s and may add a fourth runway before 1990. San Francisco will complete a major expansion to the terminal and parking facilities. Los Angeles may improve ground access before 1990. The above summarizes the airport improvements expected during the 1980s. These improvements are very small compared to the rate at which improvements were completed during the 1960s and early 1970s.

The air transportation system must operate during the next decade with an airport system which is not significantly improved over today's airports. During the 1960s, aircraft design and operations impacted airport design. During the 1980s, airports will impact aircraft design and operations.

The 1990 air transportation system will either have aircraft and operational constraints imposed by the airport system or the airport system will be significantly changed by building new airports or having commercial operations at existing airports currently not used for commercial operations. The first alternative is most likely, but there is a possibility that commercial operations can be strated at a new airport or an existing military air base. The following defines the aircraft and operational constraints imposed by the airport system. A later part of this report defines the feasibility, advantages, and disadvantages of significantly changing the airport system so these constraints are minimized.

Airport impact on aircraft design: Today's wide-body tri-jets (DC-10, L-1011) are the first aircraft where the design was impacted by airport constraints. These aircraft were designed to comply with the FAR Part 36 noise limits, and planned operations from La Guardia airport impacted aerodynamic performance (takeoff runway requirement) and spacing of the landing gear (to spread the load on the pier). The takeoff performance and landing gear were designed for La Guardia; however, only a very few wide-body tri-jets currently operate at La Guardia because there are operational problems with these large aircraft at the congested apron/gate area.

Future aircraft design will be more impacted by airport constraints than the wide-body tri-jets were. The impact is primarily upon the large aircraft and will impact wingspan, landing gear, length, noise, and other features.

Wingspan - The world's busiest airport, Chicago O'Hare, has an inner and an outer taxiway for aircraft movements between the runways and gates. One taxiway is used for inbound aircraft and one for outbound. However, the separation between taxiways does not allow two Boeing 747s to meet. There are many other smaller airports where it is difficult or impossible to maneuver aircraft with a large wingspan.

There are many airports where aircraft with large wingspan cannot park at the terminal unless the adjacent gate positions are empty or have a small aircraft. This is part of the previously mentioned problem with wide-body tri-jets at La Guardia and is a very serious problem at O'Hare, Atlanta, and many other airports.

However, the ultimate constraint on airplane wingspan is the separation standards used for airport design. The FAA has established airport design standards; these are presented in Advisory Circulars 150/5335-1, 150/5335-1A, 150/5335-1A Chg. 1, 150/5335-1A Chg. 2, and the proposed 150/5335-1A Chg. 3. These define the standard separations and clearances. The maximum wingspan is readily computed from these. The following illustrates the maximum allowable wingspan calculation based on 150/5335-1A Chg. 1.

Item	Separation or Obstacle Free Width (Meters)	Clearance (Meters)	Max Wing Span (Meters)
Parallel Taxiways	91	24	67
Terminal Taxi lane	90	11 x 2	68
Taxiway Obstacle Free Area	111	21 x 2	68
Apron Taxiway Obstacle-Free Area	111	21 x 2	68

Therefore, the maximum allowable wingspan for an airport built to these FAA standards is 67 meters (220 ft). The maximum wingspan for an airport built to AC No. 150/5335-1A Chg. 2 (the current standards) is 61 meters (200 ft). These wingspan limits restrict aircraft design on NASA's energy-efficient design research as well as the future large all-cargo aircraft.

It is possible to operate an aircraft with too large a wingspan. However, it is necessary to ensure that

- There are no aircraft on parallel taxiways when the airplane is landing or taking off
- There are no aircraft parked in positions near the taxiway
- There are no aircraft parked in adjacent gate positions

Such restrictions could possibly be met for one or two aircraft per day if the airport was not busy at the time. However, it is doubtful that a busy airport, (e.g., ORD, JFK, LAX, SFO, BOS, ATL) would permit an oversized aircraft to operate during the busy hours (see Figure 3-3) or to operate in any quantity in low-demand periods. Unfortunately, the demand for an oversized aircraft would be at the busy airports which are already overloaded and can not disrupt operations for the special handling required for this aircraft.

Landing gear - The DC-10 and L-1011 were designed with a large spacing between the landing gear to permit them to operate at La Guardia. The A300 did not consider the La Guardia pier in landing gear design and Eastern Airlines is having trouble getting approval to operate at La Guardia even though the A300 is lighter than the DC-10 or L-1011.

The B747 has 16 tires on the main gears, the DC-10-30/40 has 10, and the DC-10-10 and L-1011 have 8. These new aircraft need this number of tires because the runway strength of air carrier airports was designed to be adequate for the B707 and DC-8. All subsequent aircraft have had to design the landing gear to be adequate for the existing pavements.

There are a few special cases where operations of large aircraft are restricted due to the total weight on an overpass. The classic overpass problem is at Los Angeles International. Sepulveda Boulevard goes under the south runways (25L and 25R) and has a weight limit of approximately 147 400 kilograms (325,000 lb) depending upon the gear design. This means that all B747 operations must be on the north runways, and DC-10 and L-1011 takeoffs must be on the north runways. The longest runway at LAX is 25R which is 3685 meters

(12 090 ft). The overpass restriction requires aircraft to use 24L, which is only 2720 meters (8925 ft). O'Hare has a taxiway over the airport access highway; the B747 is not allowed to stop on the overpass. Several other airports have weight-restricted overpasses.

FAA Advisory Circular 150/5335-1A Chg. 2, defines the required taxiway width to be 23 meters (75 ft). Allowing a 5.2-meter (17-ft) dispersion on both sides, the maximum allowable tread width is 12.5 meters (41 ft).

Length - There are no advisory circulars which restrict aircraft length. However, too long an airplane will cause the following operational problems:

- The time to taxi across an active runway is increased.
- Many airports have close parallel runways. It is possible that the aircraft will be so long that it can not cross one active runway and hold for clearance to cross the other active runway.
- Almost every terminal gate position has a maximum allowable length so the aircraft will not violate the clear area for other aircraft to taxi behind the parked aircraft. A very long aircraft will have to be remotely parked and the cargo (or passengers) transported to the aircraft.
- It is likely that a very long aircraft will have a long wheelbase. The long wheelbase will cause taxiing problems because it will require additional fillets at all turns, and will probably taxi slower than aircraft with shorter wheelbase.

These operating problems for long aircraft, like the problems with large wingspan aircraft, can be occasionally tolerated during low-demand periods. However, it is doubtful that a busy airport would allow a very long aircraft to disrupt operations during high-demand time periods. The advanced supersonic aircraft and very large cargo or passenger aircraft will be classified as very long aircraft.

Noise: The following is a chronology of the major legislation related to aircraft noise.

- 1969 - The FAA promulgated Federal Aviation Regulation Part 36 (FAR 36) which established noise standards for new design aircraft. Similar international standards were established in ICAO Annex 16.

- 1973 - FAR Part 36 became applicable to all manufactured aircraft.
- 1977 - All aircraft in the fleet must meet FAR Part 36 by 1985.
- 1977 - FAR Part 36 and ICAO Annex 16 limits were modified and became more stringent for new design aircraft.
- 1978 - The British and French propose the new limits become applicable to all aircraft manufactured after 1983.

The new aircraft noise standards limits the allowable noise level (measured in EPNdB) for approach, sideline, and takeoff as illustrated in Figures 3-5, 3-6, and 3-7 respectively. The allowable noise limit depends upon the takeoff weight and aircraft type. The aircraft types are:

- Derived versions, bypass ratio less than 2.
- Derived versions, bypass ratio 2 or greater. For takeoff noise, different limits are given for two, three, and four engines.
- New propeller aircraft
- New jet aircraft. For takeoff noise, different limits are given for two, three, and four engines.

Other impacts on aircraft design - There will not be any new major airports built in the U.S. before 1990. It is doubtful if there will be any runway extensions at major airports used for long-haul flights. Therefore, aircraft design must allow operations from existing runways. This requirement impacts aerodynamic design and power plant requirements.

The airlines and airports had to make significant investments to service the wide-body aircraft. The airlines needed new ground support equipment, and the airports needed passenger-loading bridges for the higher door sills. This investment in ground facilities significantly reduced the benefits of the lower DOC of the wide-body aircraft. This additional investment will not prevent the airlines from purchasing a new larger aircraft with a lower DOC; however, it is a serious deterrent today due to the airlines' economic condition.

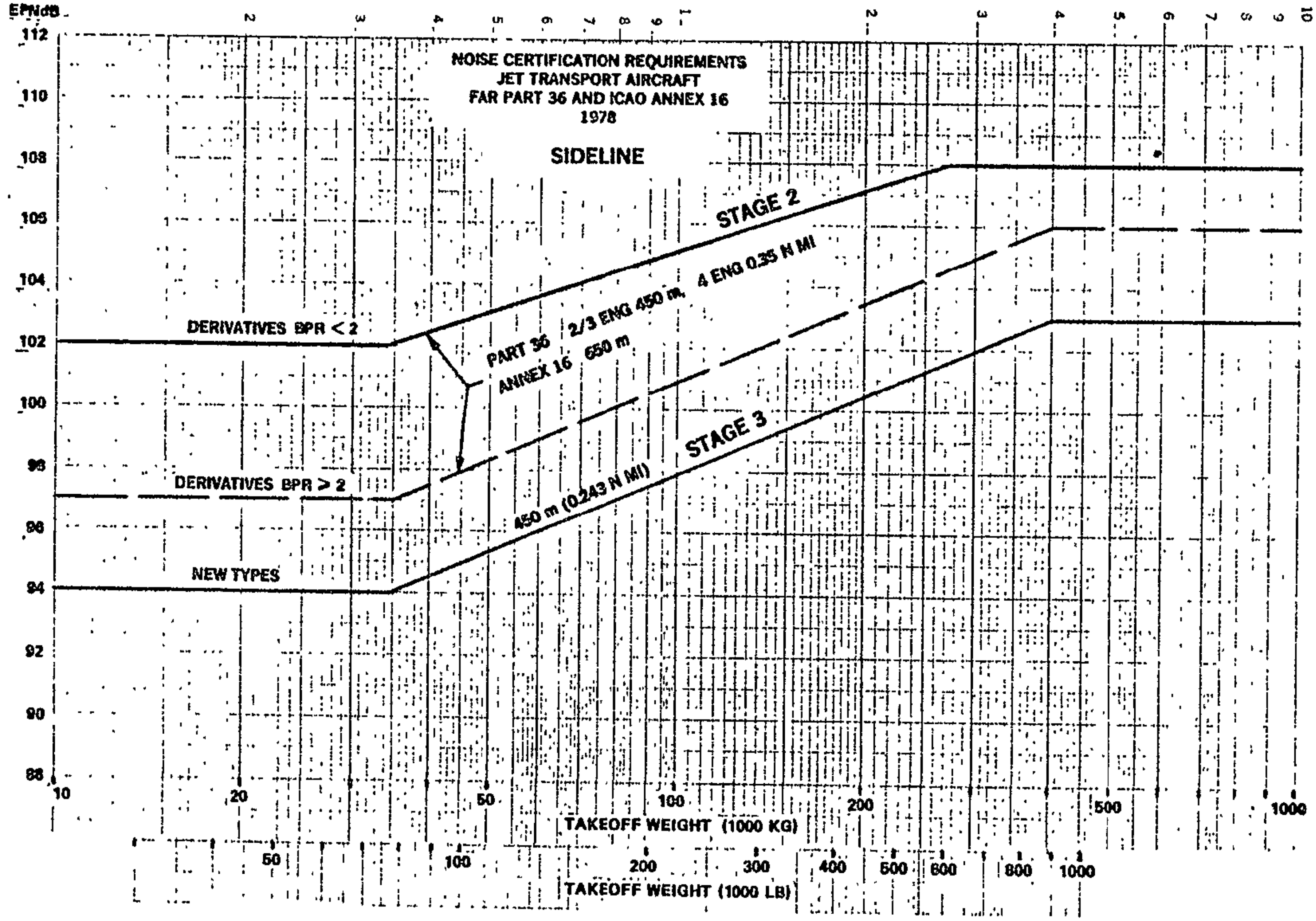


Figure 3-5. Allowable Noise for Approach

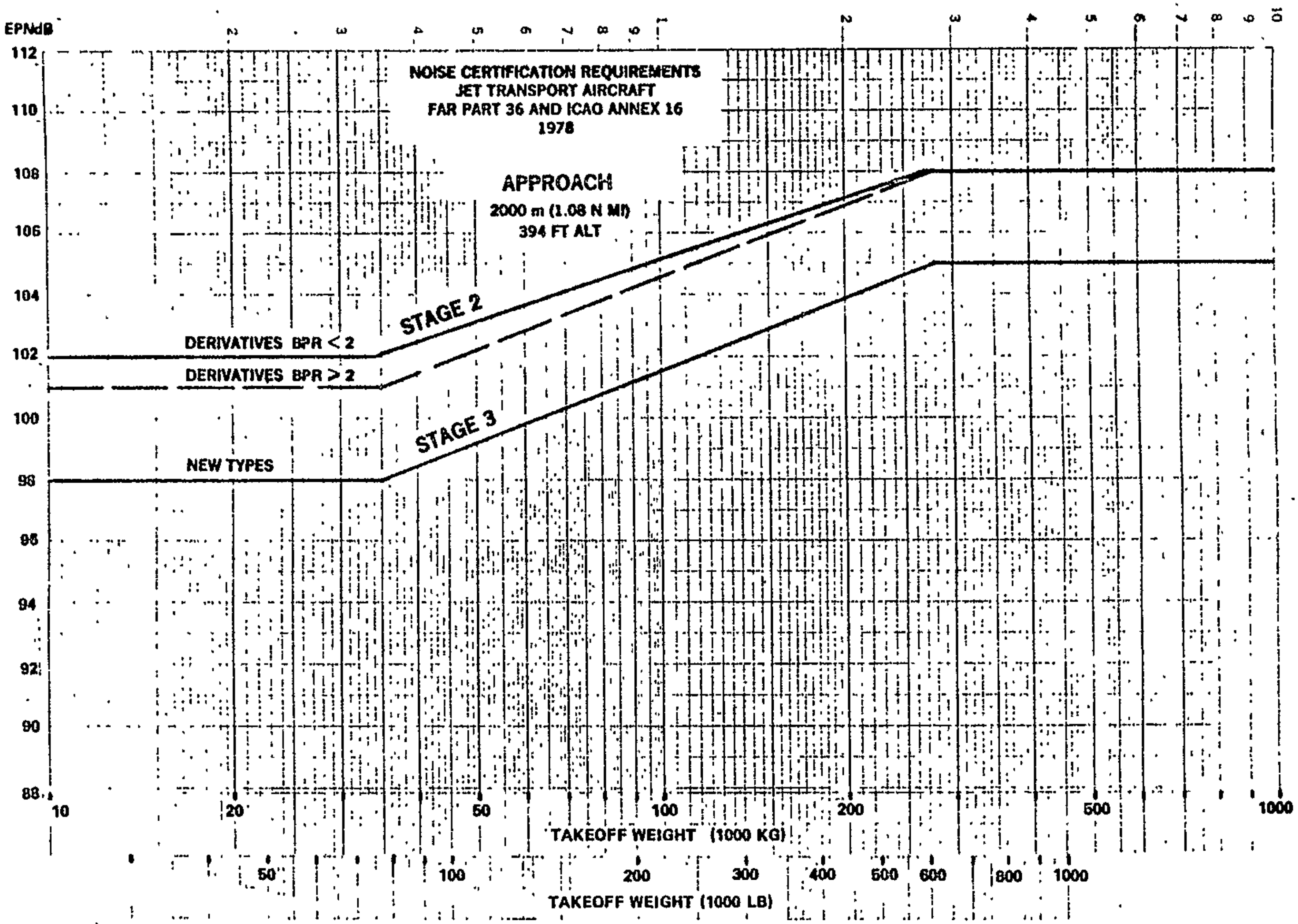


Figure 3-6. Allowable Noise for Sideline

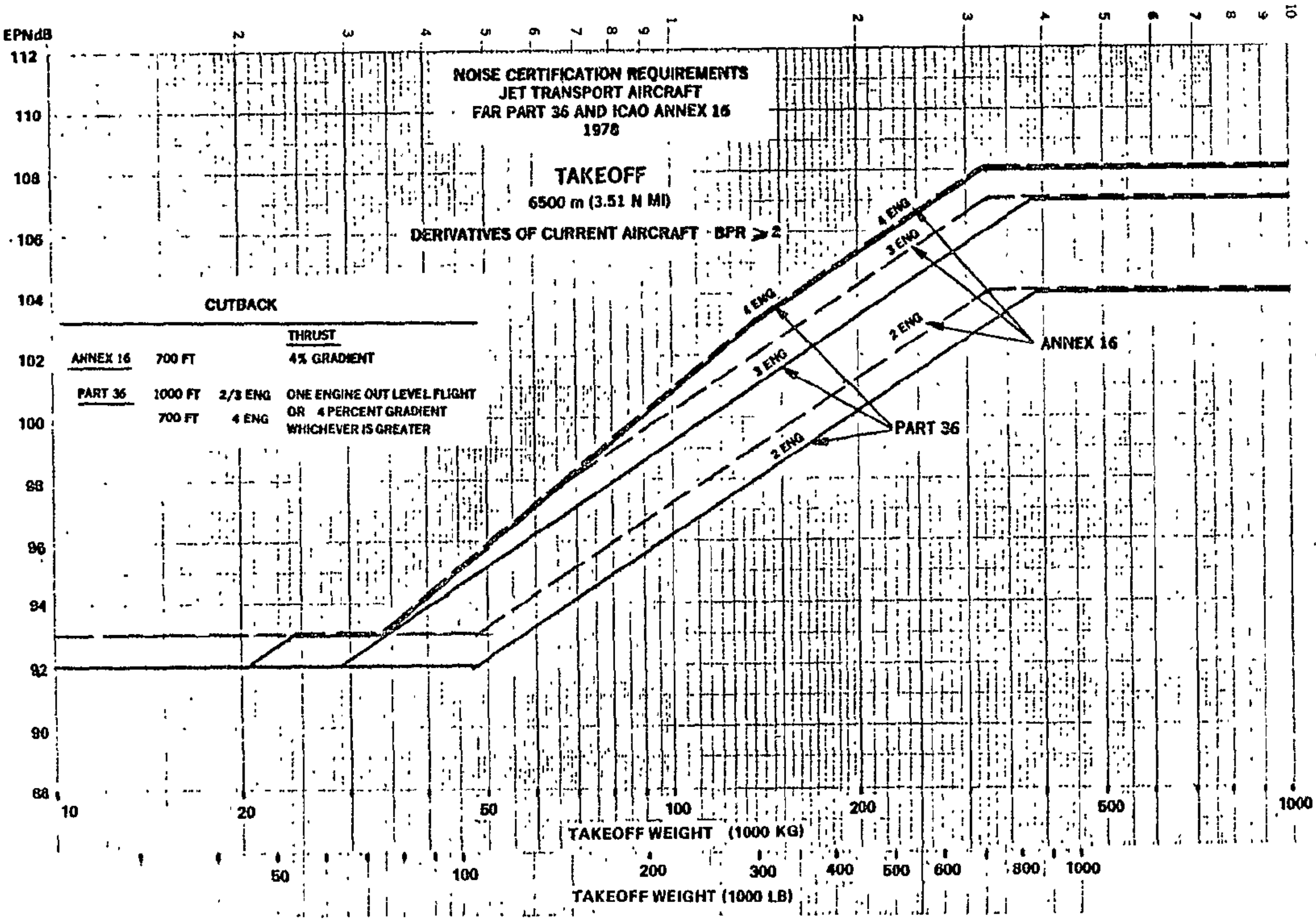


Figure 3-7. Allowable Noise for Takeoff

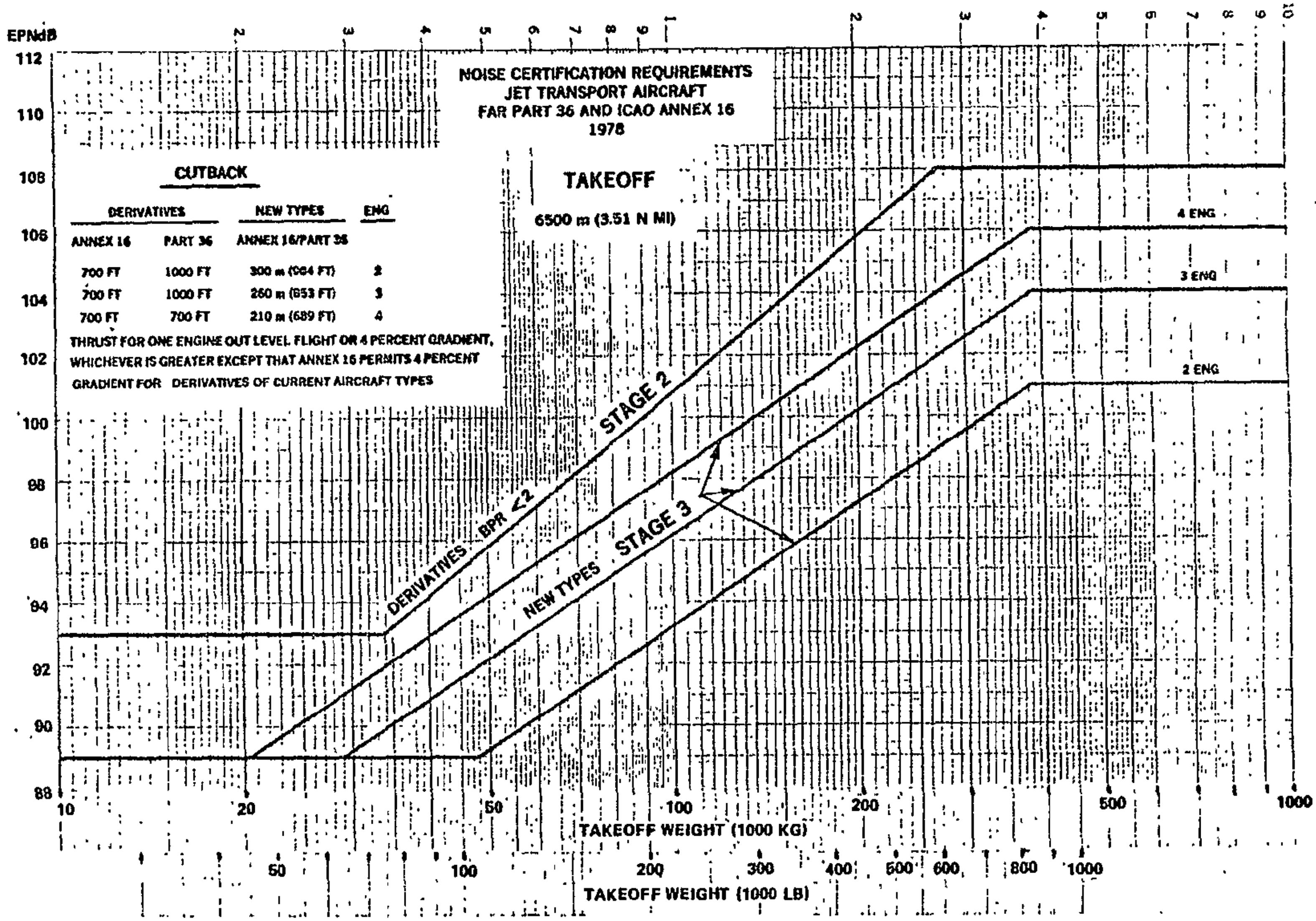


Figure 3-7. Allowable Noise for Takeoff (Concluded)

Impact of airport constraints upon airline operations: Airport constraints impact on how the aircraft operate as well as the type of aircraft allowed to operate at airports. These constraints will become significantly more common before 1990. The following subsections summarize the major constraints upon airline operations.

Curfews - Today there are many restrictions on night aircraft operations throughout the world. The most severe constraints are in Japan, Australia, and Europe. These nighttime restrictions vary considerably in aircraft, type of restriction, and hours. Table 3-2 is a brief summary of some of the major international restrictions. The detailed definition of the restrictions is quite involved and is subject to frequent changes, and almost every airport has exceptions.

While current restrictions on night aircraft operations are limited, the influence being exerted by special interest groups is proliferating this practice in many regions of the U.S. Major U.S. night operation restrictions are summarized below.

- No night jet operations are scheduled at LaGuardia and Washington National.
- Night jet operations are not allowed at Orange County, California, and several other airports which are primarily general aviation airports.
- All jet operations are prohibited at Santa Monica, California, and Watertown, Wisconsin.
- There is a limit on the number of nighttime operations at Minneapolis and San Diego.
- Noise is a consideration in assigning runways at most major airports.
- Excessively noisy aircraft must make nighttime operations over the ocean at Los Angeles; aircraft which meet FAR Part 36 can operate over land if required by weather conditions.
- Nighttime engine run up is prohibited at many airports. Several restrict use of reverse thrust, and Boston is considering a ban on taxiing to noise-sensitive areas.

TABLE 3-2

CURFEW SUMMARY

City	Hours	Restrictions
Adelaide, Australia	2300 - 0630	No jet operations
Brisbane, Australia	2300 - 0600	No jet operations
Sydney, Australia	2300 - 0600	No jet operations
Montreal, Canada	0000 - 0700	No jet operations
Toronto, Canada	0100 - 0700 2300 - 0700	No new scheduled jets No charter jets
Nice, France	2200 - 0500	No jet operations
Paris, France (Le Bourget)	2115 - 0500	No jet takeoffs
(Orly)	2230 - 0515 2215 - 0500	No jet landings No jet takeoffs
Dusseldorf, Germany	2200 - 0500 2100 - 0500	No jet landings No jet takeoffs
Frankfurt, Germany	2200 - 0500 2300 - 0400	No charter jets No scheduled passenger jets
Hamburg, Germany	2200 - 0500	No jet operations
Munich, Germany	2100 - 0500	No charter jets
Stuttgart, Germany	2100 - 0500	No jet departures
Hong Kong, B.B.C	2330 - 0630	No operations scheduled
Reykjavik, Iceland	2330 - 0730	No jet operations
Osaka, Japan	2200 - 0700	No jet operations
Tokyo, Japan	2300 - 0600	No jet operations
Rotterdam, Netherlands	2230 - 0500	No jets without noise certification
Oslo, Norway	2230 - 0600	No operations
Geneva, Switzerland	2300 - 0400 2300 - 0500	No jet landings No jet takeoffs
Zurich, Switzerland	2300 - 0400 2300 - 0500	No jet landings No jet takeoffs
Jersey, United Kingdom	2230 - 0730	No jet operations
Gatwick, United Kingdom	2330 - 0600	Jet quotas
Orange County, Cal., USA	2300 - 0700	No jet operations

C-3

U.S. airport proprietors can control what types of aircraft can use its airports, can impose curfews and other use restrictions, and can regulate runway use and flight paths subject to FAA approval related to safety. They may not impose an undue burden on interstate or foreign commerce, and they cannot unjustly discriminate between different categories of airport users.

The number of U.S. airports which restrict nighttime operations will undoubtedly increase before 1990. The FAA recently approved an airport development grant for Kalamazoo, Michigan, conditioned on a night jet-operating restriction. U.S. airports have spent $272 million on noise-related costs and will probably increase operating restrictions to slow the rate this cost is increasing.

Curfews have a far-reaching impact on long-haul air travel. Forty percent of the jet all-cargo aircraft departures at Los Angeles and San Francisco occur between 2300 to 0600 hours curfew. Approximately 64 percent of the jet all-cargo departures at LAX and SFO occur between 1515 and 0600 hours. Approximately 38 percent of the all-cargo arrivals or departures occur between 2300 and 0600 hours at major U.S. airports. Hence, well over 40 percent of the all-cargo flights would be impacted at the arrival and/or departure airport if there was a nationwide curfew between 2300 and 0600 hours.

The impact of curfews on international flights is very severe. For example, it is very difficult to add another flight from New York City to London (JFK to LHR). The aircraft cannot depart between 1500 and 2000 hours because JFK is flow controlled. The aircraft cannot depart between 0930 and 1600 hours because LHR has nighttime quotas which they are constantly reducing. If JFK added a 2300 to 0600 hours curfew, the only hours available for the flight departure would be between 0600 and 0930 hours and between 2000 and 2300 hours. Curfews throughout the world make it nearly impossible to schedule an eastbound multistop around the world flight itinerary.

Transfer operations - Most of the congested airports are transfer hubs, and the airlines radiate service from them as the center of a hub-spoke service. These airports differ considerably in the stage length they serve, but almost all of the major hub airports have a high passenger-transfer percentage as illustrated in Table 3-3. Data on cargo-transfer percentage are not readily available, but they should be comparable to the passenger-transfer percentages.

The hub-spoke service allows the airlines to consolidate passenger and cargo demand between many cities and use significantly larger aircraft than would be practical if they provided nonstop service instead of connecting service. For example, there are 123 airports which have daily nonstop flights to and from Chicago O'Hare. It would require over 15 000 flights per day to provide nonstop service between all of these airport pairs.

Three of the most severely congested airports (ORD, JFK, and ATL) are transfer hubs. This congestion will nearly stop any increase in service frequency throughout the day at ORD and during the afternoon and evening at JFK. It will be possible to expand operations at ATL after the midfield terminal is completed in the early 1980s. These airports will experience a below-average growth in enplanements and cargo tonnes because they will have a significantly below-average growth in service. The demand growth at these airports will be primarily passengers or cargo with an origin or destination in the metropolitan area served by the airport. Transfer traffic will only have a minimal growth at these congested airports. Transfer traffic might decline if alternative transfer airports are established or if there is an increase in direct service to the smaller communities. The congestion at ORD is one reason for increased transfer service at Denver, Cleveland, and St. Louis. The transfer demand at JFK will diminish because there have recently been many other cities receiving authority for nonstop flights to Europe. The transfer traffic at ATL is primarily Delta and Eastern Airlines. They will increase direct service in the southeast if required for competitive reasons or if ATL congestion costs increase significantly over the current $60 million per year.

Airport congestion will cause the airlines to have several transfer hubs rather than consolidate transfer operations at a few superhubs. This spreading of transfer traffic will reduce the need for a superlarge aircraft and will increase the need for slightly above average aircraft size. This impact on aircraft size will be more significant for passenger aircraft than for all-

TABLE 3-3

TRANSFER PERCENTAGE AND STAGE LENGTH OF MAJOR HUB

City Name	Airport Code	Scheduled Arrivals Per Day	Passenger Transfer Percentage	% of Flights		
				Under 400 mi	400 to 1000 mi	Over 1000 mi
Chicago	ORD	1947	52	47	36	17
Atlanta	ATL	1233	73	48	50	3
Los Angeles	LAX	1218	32	55	10	34
Dallas/Ft. Worth	DFW	991	53	47	34	19
San Francisco	SFO	828	30	55	20	25
NYC LaGuardia	LGA	838	28	53	34	12
NYC Kennedy	JFK	806	48	39	12	49
Boston	BOS	791	26	73	15	12
Denver	DEN	721	49	35	55	10
Washington National	DCA	697	31	70	30	0
Philadelphia	PHL	675	22	71	20	9
Pittsburgh	PIT	658	44	86	11	3
Miami	MIA	610	25	35	23	42
St. Louis	STL	574	41	65	27	9
Detroit	DTW	515	25	61	31	8
Houston	IAH	497	25	68	21	11
Newark	EWR	452	16	57	26	17
Seattle	SEA	451	32	60	15	25
Minneapolis	MSP	427	32	62	21	17
Kansas City	MCI	403	32	66	26	8
Cleveland	CLE	375	29	65	25	10
Tampa	TPA	339	24	52	32	15
Honolulu	HNL	329	53	62	0	38
New Orleans	MSY	322	37	54	34	12
Las Vegas	LAS	313	30	64	16	20

cargo aircraft. The economic viability of a new aircraft is dependent upon total sales; therefore, it is desirable to have considerable commonality between passenger, military, and cargo versions of a new aircraft.

The average aircraft size at the superhubs will grow at nearly the demand growth rate because that is the only way to increase the congested airports passenger/cargo capacity. However, most of the superhubs are transfer hubs, and they will experience below average growth in enplaned passengers and cargo.

Other operational impacts - Airports will impose operational constraints to reduce the impact of aircraft noise. Curfews were discussed in a previous section. Additional constraints include special approach and departure procedures, reduced use of reverse thrust, no engine run up, and taxiing restrictions. These constraints will be more restrictive during the night than during the day. The approach and departure procedures include noise-abatement descent path, reduce power on approach, power cutback soon after liftoff, and might include a curved approach when MLS is operational. These additional procedures have a limited impact on aircraft design and economic operations.

There might be a significant impact on airline operations caused by deregulation. However, deregulation and the airline economic conditions are not specifically airport problems and will not be discussed here. (Note that airline deregulation will have only a minimal impact at the busy airports.) Several airports (ORD, LGA, JFK, and DCA) are flow controlled during peak hours, and no airline can add flights during these hours. Similarly, almost all airports sign long-term leases with the airlines to rent terminal, operational, and maintenance facilities. There is a shortage of these facilities at nearly every major hub airport, and it would be very difficult and time consuming for an airline to initiate service at an airport they do not presently serve. Hence, airport congestion will prevent or retard the addition of new cargo flights to the congested airports even though cargo service has been significantly deregulated.

New airports. - Previous sections defined the problems with the present airport system and how these problems will impact aircraft design and airline operations. These airport constraints are a major deterrent for any aircraft which is significantly larger than a Boeing 747. Additionally, there is a possibility that curfews will become common throughout the U.S. by 1990. Curfews could create havoc with the air cargo transportation system.

These airport constraints can be eliminated by changing the airports. However, the only expected significant changes at the major hub airports will be the new terminal at Atlanta and possibly cargo terminals at Chicago O'Hare and Los Angeles. Therefore, it will be necessary to develop new airports to overcome the constraints imposed by the current airport system. The following discusses the site availability, economics, and operational advantages and disadvantages of new airports.

Site availability: A new air-carrier airport can be constructed on a site where there is currently no airport. It can be a joint use of a military airport or exclusive use of a surplus military base, or it can be the start or significant increase of commercial operations at an airport which basically serves general aviation. This does not include the availability of airports for general aviation aircraft which currently use major air-carrier airports. These general aviation airports exist; the problem is to motivate the pilots to use an airport which may be farther away, has poorer facilities, and does not allow transfer to commercial operations.

New airport sites - Land has been acquired for new major airports in Los Angeles and Atlanta. Site selection studies have been completed in Miami, Minneapolis, New Orleans, St. Louis, and San Diego. Site selection studies are in progress at Cleveland, Los Angeles, New York City, and San Francisco. In spite of this large number of studies, it is unlikely that a major air carrier will be built in the 1980s, and it is possible that there will not be any built this century. The land acquired for a new Los Angeles airport is at Palmdale. almost 60 km from downtown L.A. The site is too far from large population centers to be attractive as a short-haul airport and too high (approximately 750 meters) and hot (temperatures over 40°C are very common) to be attractive for a long-haul airport. Atlanta is currently undergoing a major expansion of Hartsfield airport, and there has been a reduction in discussions of building a new airport.

The size of the site required is a serious problem in locating a new major air-carrier airport. The site must be large enough for the noise buffer as well as for the airport facilities. The minimum site size has the following approximate requirements:

- 3000 hectares for a single-runway airport
- 4000 hectares for two intersecting runways
- 5000 hectares for two independent parallel runways

It is extremely difficult to find a site this size near a large metropolitan area. This is one of the primary reasons that new airports are far from the population centers.

Nine of the 12 largest U.S. airports are in communities near large bodies of water. It is possible that off-shore airports will be built at some of these cities during the first part of the next century. The primary benefits of off-shore airports are minimal noise impact and the potential for combining with a nuclear or other power generation facility. This would be very desirable for hydrogen fuel aircraft.

Military Airports: There are currently several surplus military airports which are being used as civil airports; similarly, there are several airports which are being used for both military and civil operations. Many of these military bases have facilities which are more spacious than civil airports; runway widths of 61 meters or 91 meters are common. There have been several studies of using military airports (References 3-5, 3-6, and 3-7) which have analyzed their availability, desirability, and defined the major issued which must be resolved. Table 3-4 is a summary of tables in References 3-5 and 3-6. There are instances where one study will state that a particular airport (e.g., Glenview NAS) has potential for joint use and the other report will state it is not available due to military mission.

TABLE 3-4

CIVIL USE OF MILITARY AIRPORTS

State	Military Airport	Not Usable: Not Avail Due to Military Mission	Not Usable: Unaccess. or no Civil Demand	Potentially Usable: General Aviation Reliever	Potentially Usable: Air Carrier: Non-Congested	Potentially Usable: Air Carrier: Congested Hub
AL	Craig AFB		X			
	Cairns AAB		X			
	Maxwell AFB		X			
	Redstone AAF		X			
AK	Adak NAS		X			
	Allen AAF			X		
	Bryant AAF			X		
	Eilson AFB		X			
	Elmerdorf AFB		X			
	Wainwright AAF		X			
AZ	Davis-Monthan AFB		X			
	Libby AAF		X			
	Luke AFB	X				
	Williams AFB	X				
AR	Blytheville AFB		X			
	Little Rock AFB			X		
CA	Alameda NAS	X				
	Beale AFB		X			
	Camp Pendleton MCAS		X			
	Castle AFB		X			
	China Lake NAF		X			
	Edwards AFB		X			
	El Centro NAF		X			
	El Toro MCAS	X				
	Fritzche AAF		X			
	George AFB		X			
	Hamilton AFB					(1)
	Imperial Beach NAS	X				
	Lemoore NAS	X				
	Los Alamitos NAS	X				
	March AFB			X		(2)
	Mather AFB			X		
	McClellan AFB			X		
	Miramar NAS	X				
	Moffett NAS	X				
	North Island NAS					X
	Norton AFB			X		
	Palmdale Plant					X
	Travis MCAS					(1)
	Vandenberg AFB		X			

TABLE 3-4 .- Continued

CIVIL USE OF MILITARY AIRPORTS

State	Military Airport	Not Usable		Potentially Usable		
					Air Carrier	
		Not Avail Due to Military Mission	Unaccess. or no Civil Demand	General Aviation Reliever	Non-Congested	Congested Hub
CO	Buckley ANGB	X				
	Butts AAF			X		
	Glasgow AFB		X			
DE	Dover AFB				X	
FL	Cecil Field NAS		X			
	Elgin AFB				(1)	
	Ellyson NAS		X			
	Homestead AFB	X				
	Jacksonville NAS		X			
	Key West NAS				X	
	Mac Dill AFB		X			
	Mayport NAS		X			
	New River MCAS		X			
	Patrick AFB		X			
	Pensacola		X			
	Saufley Field NAS		X			
	Tyndall AFB				X	
	Whiting Field NAS	X				
GA	Dobbins AFB					X
	Hunter AAF		X			
	Lawson AAF				X	
	Moody AFB		X			
	Robins AFB		X			
	Wright AAF		X			
HI	Barbers Point NAS			X		
	Bellows AFS			X		
	Bradshaw AAF		X			
	Dillingham AFB				(1)	
	Hickam AFB					(1)
	Kaneohe MCAS			X		
	Wheeler AAF			X		
ID	Mt. Home AFB		X			
IL	Glenview NAS	X				
	Haley AAF	X				
	Scot AFB	X				

TABLE 3-4.- Continued

CIVIL USE OF MILITARY AIRPORTS

State	Military Airport	Not Usable		Potentially Usable		
		Not Avail Due to Military Mission	Unaccess. or no Civil Demand	General Aviation Reliever	Air Carrier	
					Non-Congested	Congested Hub
IN	Grisson AFB		X			
KS	Marshall AAF		X			
	McConnell AFB				X	
KY	Campbell AFB		X			
	Godman AAF		X			
LA	Barksdale AFB		X			
	England AFB		X			
	Leesville AAF		X			
	New Orleans NAS			X		
ME	Brunswick NAS				X	
	Loving AFB		X			
MD	Andrews AFB	X				
	Patuxent River NAS	X				
	Phillips AAF		X			
	Tipton AAF	X				
MA	Devens AAF				X	
	Otis ANG					X
	South Weymouth NAS					(2)
	Westover AFB				(2)	
MI	Grayling AAF				(1)	
	Kincheloe AFB				X	
	K.I. Sawyer AFB		X			
	Miller AAF		X			
	Selfridge ANGB	X				
	Wurtsmith AF		X			
MS	Columbus AFB	X				
	Keesler AFB		X			
	Meridian NAS		X			
MO	Forney AAF		X			
	Richards - Gebaur AFB			(1)		
	Whiteman AFB			X		
MT	Malstrom AFB		X			

TABLE 3-4.- Continued

CIVIL USE OF MILITARY AIRPORTS

State	Military Airport	Not Usable		Potentially Usable		
		Not Avail Due to Military Mission	Unaccess. or no Civil Demand	General Aviation Reliever	Air Carrier	
					Non-Congested	Congested Hub
NE	Offutt AFB				X	
	Sherman AAF				(1)	
NV	Fallon NAS		X			
	Nellis AFB	X				
NH	Pease AFB			X		
NJ	Lakehurst NAS		X			
	McGuire AFB	X				
NM	Cannon AFB				X	
	Halloman AFB				X	
NY	Griffis AFB		X			
	Plattsburgh AFB	X				
	Seneca AAF		X			
	Wheeler-Sack AAF		X			
NC	Cherry Point MCAS		X			
	Pope AFB		X			
	Seymour Johnson AFB		X			
	Simmons AAF		X			
ND	Grand Forks			X		
	Minot AFB		X			
OH	Rickenbacker AFB		X			
	Wright-Patterson AFB		X			
OK	Altus AFB		X			
	Henry Post AAF		X			
	Tinker AFB		X			
	Vanee AFB		X			
PA	Warminster NAF	X				
	Willow Grove NAS			X	X	
SC	Beaufort MCAS				X	
	Charleston AFB				(1)	
	McEntire ANG		X			
	Myrtle Beach AFB				(1)	
	Shaw AFB		X			
SD	Ellsworth AFB			X		
TN	Arnold AFS			X		
	Memphis NAS				X	

Table 3-4.- Concluded

Civil Use of Military Airports

State	Military Airport	Not Usable: Not Avail Due to Military Mission	Not Usable: Unaccess. or no Civil Demand	Potentially Usable: General Aviation Reliever	Potentially Usable: Air Carrier: Non-Congested	Potentially Usable: Air Carrier: Congested Hub
TX	Bergstrom AFB				X	
	Biggs AAF				X	
	Carswell AFB	X				
	Chase Field		X			
	Corpus Christi NAS			X		
	Dallas Hensley NAS	X				
	Dyess AFB		X			
	Ellington AFB		X			
	Hood AAF		X			
	Kelly AFB				X	
	Kingsville NAS		X			
	Laughlin AFB				X	
	Randolf AFB	X				
	Reese AFB		X			
	Robert Gray AAF		X			
	Sheppard AFB				(1)	
	Webb AFB		X			
UT	Hill AFB				X	
	Michael AAF		X			
VA	A.P. Hill AAF		X			
	Blackstone AAF				(1)	
	Camp Peary AAF				X	
	Davison AAF	X				
	Felker AAF		X			
	Langley AFB	X				
	Norfolk NAS	X				
	Oceana NAS	X				
	Quantico MCAS				X	
WA	Fairchild AFB		X			
	Gray AAF		X			
	McChord AFB				X	
	Port Angeles CGAS		X			
	Whidbey Island NAS				X	
WI	McCoy AAF		X			
	Volk Field		X			

(1) Already open to civil operations
(2) Strong local opposition to civil use

The military airports are usually farther from population centers than civil airports; however, suburban growth has surrounded several military airports and these people are fighting the increased noise that would accompany civil use of the airport. The military airports that have the greatest potential to relieve demand at congested hubs are

- Dobbins AFB near Atlanta
- Hamilton AFB near San Francisco
- March AFB near Los Angeles
- North Island NAS near San Diego
- Otis ANG near Boston

Most of the other military airports are either not available or not in a metropolitan area with a congested civil airport. The only obvious cargo benefit of using a military airport in an uncongested area is that it might be possible to operate a larger aircraft at the military airport than at the civil airport.

Reference 3-7 defines major issues that must be resolved to have civil operations at an active military airport. Most of the same issues are applicable to a surplus military airport. These issues should be studied in more detail if there is a serious interest in designing an all-cargo aircraft which is significantly larger than the Boeing 747.

Existing nonmilitary airports - There are several airports in major metropolitan areas which only have a few air-carrier operations or are strictly general aviation airports. Some of these airports can be expanded to handle sizable air-carrier traffic. However, these airports are often limited in demand due to environmental or economic reasons.

Orange County, Long Beach, and San Jose, California, have airports which have a limited number of air-carrier operations. These airports have a large number of aircraft operations, but these are mostly single-engine propeller aircraft performing touch-and-go operations. These airports do not experience significant runway delays except in a few isolated instances. They have the runway capacity for additional air-carrier operations, and they are located in population centers that would support additional air-carrier traffic. However, it is unlikely that the communities will permit any additional air-carrier operations due to the additional noise that this would create. The new quieter aircraft will reduce the noise impact rather than increase frequency. These three airports have quotas on the allowable number of air-carrier operations per airline, and they will not permit additional airlines to initiate service even though the airlines have CAB authorization. Orange County has a curfew, Long Beach is considering one, and there are no scheduled flights at San Jose from 2330 to 0700 hours.

Midway Airport in Chicago is the other extreme for a satellite airport in a major metropolitan area. Unlike the three California airports discussed in the previous paragraph, the citizens around Midway are more interested in the economic benefits of air-carrier operations than in the environmental impact. The City of Chicago successfully encouraged the airlines to divert part of their flights from O'Hare to Midway. However, as soon as the energy crises occurred, the airlines quit Midway operations again. Many reasons have been given for why the airlines quit operations at Midway. The two most often stated reasons were (1) Chicago is a transfer hub and it is very impractical to transfer passengers or cargo arriving one airport and departing the other, and Midway did not have over 10 percent as many flights as O'Hare; (2) the airlines had significantly increased station costs by operating two airports rather than consolidating all of their demand at O'Hare. It is possible that flights will begin again at Midway within a few years. However, any new flights would be short-haul low-fare service for passenger and freight to and from Chicago, not transfer traffic.

The cargo capacity of existing airports can be significantly expanded with the use of combination passenger/cargo aircraft. This added cargo does create some congestion in the apron/gate area and on the airport road system between the passenger and cargo terminals. However, these problems can usually be solved with minimal investment.

Airport economics: Major air-carrier airports are owned by the local community and are financed by revenue bonds. The revenue at airports over two million annual enplanements is adequate for all expenses including debt payments on a major airport development. Airports under 275 000 annual enplanements cannot support moderate capital improvements.

Construction costs - Airport construction costs are summarized in Table 3-5, which is taken directly from Reference 3-1. The construction cost of an airport is approximately:

- $200 million for a single-runway airport. The federal share is approximately $80 million.
- $320 million for an airport with independent parallel runways. The federal share is approximately $125 million.

Federal participation is limited to $10 million per year for an airport, and it is unlikely that the full federal share can be obtained because that would require the maximum annual funding for 8 to 12 consecutive years.

In addition to the federal contribution costs, it is possible to obtain 75 percent funding for land acquisition. Assuming that land costs $20 000 per hectare, the following table summarizes the cost of a new airport:

Runways	Maximum Federal Share	Minimum Local Cost	Total Cost
Single	$125 million	$135 million	$260 million
Parallel	$200 million	$220 million	$420 million

Airport financing - The firm of Howard, Needles, Tammen and Bergendoff developed an equation to estimate airport operating surplus (S) as a function of annual enplanement (E). Their equation, converted to 1976 dollars is

$$S = \$2.209E - \$134\ 423$$

TABLE 3-5

DESIGN AIRPORT BUILDING AND CONSTRUCTION COSTS - 1976 DOLLARS

Construction	Cost per Unit	Cost, thousands: Single Runway	Cost, thousands: Double Runway	Federal Participation: Eligible Portion, Percent	Rate, Percent: Of Eligible Portion	Rate, Percent: Of Total	Amount, thousands: Single Runway	Amount, thousands: Double Runway
Runway	$50.83/sq m	$ 9 500	$ 19 000	100	75	75	$ 7 125	$ 14 250
Runway shoulder	14.98/sq m	700	1 400	100	75	75	525	1 050
Taxiway	50.83/sq m	6 175	12 350	100	75	75	4 631	9 262
Taxiway shoulder	14.98/sq m	1 400	2 800	100	75	75	1 050	2 100
Connecting taxiway	50.83/sq m	475	2 850	100	75	75	356	2,138
Connecting taxiway shoulder	14.98/sq m	126	700	100	75	75	94	525
Terminal apron	50.83/sq m	14 250	28 500	100	75	75	10 688	21 375
Terminal apron shoulder	14.98/sq m	280	560	100	75	75	210	420
Cargo apron	50.83/sq m	712	1 425	100	75	75	534	1 069
Cargo apron shoulder	14.98/sq m	42	84	100	75	75	32	63
Airfield lighting		3 000	5 000	100	75	75	2 250	3 750
Navaids and communications		4 000	4 500	100	75	75	3 000	3 375
Aircraft fuel system		1 720	1 900	0		0	0	0
Access road (4 lanes)	$1 500 000/km	24 000	24 000	100	75	75	18 000	18 000
Public road (4 lanes)	1 000 000/km	1 600	2 400	100	75	75	1 200	1 800
Service road (2 lanes)	620 000/km	6 000	8 000	100	75	75	4 500	6 000
Automobile parking	33.71/sq m	12 600	25 200	0		0	0	0
Landscaping and fencing		3 000	4 000	100	75	75	2 250	3 000
Power distribution		2 500	4 000	36	75	27	675	1 080
Water distribution		4 500	5 500	8	75	6	270	330
Sanitary collection		4 000	4 500	36	75	27	1 080	1 215
Telephone distribution		1 500	1 800	36	75	27	405	486
Total Construction		$102 080	$160 469				$58 875	$ 91 288
Buildings								
Control tower		4 000	4 000	100	100	100	4 000	4 000
Passenger terminal	$1177/sq m	77 000	132 000	36	50	18	13 860	23 760
Cargo terminal	642/sq m	6 000	12 000	0		0	0	0
Operation	642/sq m	2 400	3 600	8	75	6	144	216
Fire, crash, and rescue	535/sq m	1 000	1 000	100	75	75	750	750
Total Buildings		$ 90 400	$152 600				$18 754	$ 28 726
Total		$192 480	$313 069				$77 629	$120 014

This equation states that the operating surplus is zero at approximately 61 000 annual enplanements and increases at $2.209 per enplanement thereafter. The major hub airports have operating surpluses equal to approximately twice the bond payment. However, most of these bond payments are for construction performed several years ago when prices were considerably below today's rates. It would be necessary to have approximately 4 300 000 annual enplanements for the annual principal and interest payments for a new single-runway airport. (This is based on the minimum local cost for a 6-percent, 30-year bond).

Airport revenue bonds are tax-exempt municipal bonds, and they pay a lower interest rate. They are limited by the airlines' ability to guarantee revenues for payment. The airlines are currently in a very poor economic position and do not want to guarantee airport revenue bonds unless they anticipate a significant economic advantage. The airlines' current economic posture may make it necessary to find a new source of airport financing.

Airport revenues and expenses - The primary sources of airport revenues are landing fees, rentals, and concessions. Landing fees are approximately half of revenues at medium-sized airports and only about one-fourth at large airports. In general, the airlines negotiate the rate for rentals and concessions and then the airport authority determines landing fees to meet expenses. The following table summarizes the revenue sources for different size airports.

	Annual Passenger Enplanements		
Revenue Source	Under 500 000	500 000 to 2 000 000	Over 2 000 000
Landing area	44.6%	42.5%	29.5%
Terminal concessions	28.7%	45.2%	57.3%
Airline leased areas	9.0%	7.4%	8.5%
Other leased areas	10.8%	3.7%	2.7%
Other operating areas	6.9%	1.2%	2.0%
Total:	100.0%	100.0%	100.0%

The largest part of the airline rental and concession revenue is passenger related. The larger airports average over $0.50 income per passenger with the parking lot representing 40 percent of this income. The lack of this income at an all-cargo airport may make it necessary to increase other charges such as landing fees.

Fortunately, all-cargo airports would also have significantly reduced operating expense because they do not have terminal concessions. The percentage of airport operating expense per element (e.g., landing area, terminal concession, etc.) is very similar to the percentage of income per element. The operating expenses are about 87 percent of total expenses, payments on the debt being the other 13 percent.

Kennedy International Airport (JFK) processed approximately 1 100 000 metric tonnes of cargo during 1977. There were approximately 30 000 cargo aircraft operations which transported approximately two thirds (or 700 000 metric tonnes) of this cargo. For comparison, other U.S. airports with approximately 30 000 total air-carrier aircraft operations per year include Birmingham, Alabama; Des Moines, Iowa; Jacksonville, Florida; Kahului, Hawaii; Norfolk, Virginia; Raleigh/Durham, North Carolina; Spokane, Washington; Syracuse, New York; and West Palm Beach, Florida. The only one of these airports with over 1 000 000 annual enplanements is Kuhului, Hawaii. Landing fees are usually based on aircraft landing weight. The average weight of all-cargo aircraft at JFK is significantly higher than at the mentioned passenger airports so the landing fee revenue would be higher. However, the required runway dimensions for JFK are also significantly larger and the runway costs would be higher. Therefore, the landing fee would be comparable. An all-cargo airport would have more terminal buildings, but the rent should more than pay expenses. The all-cargo airport would not have passenger terminal expenses or income; the passenger terminal income usually exceeds expense.

The economic viability of an all-cargo airport with the cargo traffic currently transported by all-cargo airplanes at Kennedy International Airport (JFK) would be comparable to a passenger airport with 1 000 000 to 2 000 000 annual enplanements. Such an airport would

- Have operating income in excess of operating expenses.
- Be able to finance a moderate airport improvement program, but a major program would be marginal.
- Not be able to pay the debt that would be incurred if the airport was built today unless the landing fees and rentals are higher than current rates.
- Would have rentals and landing fees that could be slightly below the U.S. averages if the cargo operations were added to an existing airport with adequate facilities that is used for military or civil passenger operations.
- Would have approximately average rentals and landing fees if the cargo operations were performed at a surplus military airport. The fee level would be highly dependent upon the existing facilities and the cost charged for the surplus military airport.

Operations: There are several large metropolitan areas in the U.S. which have more than one air-carrier airport. In almost every case, these airports differ significantly in the type of flights. For example, in the New York City area, La Guardia is almost exclusively for short- and medium-stage length domestic flights; Kennedy has nearly half of its flights over 1600 km, and many of these are international. In the San Francisco area, most of the charter flights operate from Oakland, and the San Jose airport has a significantly higher percentage of its flights under 800 km than the other two airports. In the Los Angeles area, Burbank, Orange County, and Long Beach airports are exclusively short haul with well over half of their flights to the San Francisco area. In Washington, D.C., the majority of the short-haul service is from National airport.

The following defines the operational advantages and disadvantages of an all-cargo airport.

Economy of Size - An air-carrier airport must maintain a certain size in order to be economically viable. For passenger airports, it is necessary to have the following:

- Over 61 000 enplanements per year for operating revenue to exceed operating expenses.
- Over 2 000 000 enplanements per year to be able to pay for a major airport improvement.
- Over 4 300 000 enplanements per year to pay for a new single-runway airport, and this assumes $135,000,000 federal support.

Similarly, the airlines have economy of scale in order to keep operating costs down. The added expense of operations at two airports is one reason the airlines quit Midway operations. The airlines' cost of cargo handling is discussed elsewhere in this report.

Ground Traffic - One of the main advantages of air cargo shipment is overnight service. Cargo leaving the shipper at the end of a working day is usually at its destination at the start of the next working day. Many of the firms which make extensive use of air cargo shipments are located in the general airport area. However, if the airport were 150 kilometers farther away (Palmdale is approximately 100 kilometers from Los Angeles International), it would require 2 additional hours for ground travel. It would be very difficult to still provide overnight air cargo service if both airports were 150 kilometers farther than the existing airports. This is a serious deterrent to having more than one large cargo airport where each airport serves all cities within a wide radius.

There is a ground transportation advantage to having multiple cargo airports. The multiple airports disperse the trucks to several sites, and this offers relief to the ground congestion that often occurs near the airport during the afternoon rush hour.

Transfer cargo - Table 3-3 gives the percentage of the passenger enplanements which are transfers at the large hub airports. There are not readily available data on the percent of the enplaned cargo which is transferred at all of the large hub airports. It is likely that the cargo-transfer percentages are similar to the passenger-transfer percentages because both are correlated to population centers and available air service.

Approximately half of the air cargo is transported on passenger aircraft. The increased usage of wide-body aircraft significantly increases the availability of cargo space on passenger aircraft. A significant fraction of the cargo shipped on all-cargo aircraft is transferred from and/or to passenger aircraft. The need for large all-cargo aircraft is partially dependent upon cargo which completes part of its trip on a passenger aircraft.

A paradox in the operation of future very large all-cargo aircraft is that the very large all-cargo aircraft are physically too large for existing airports and that the existing airports are the main place where the capacity of very large aircraft will be needed.

Summary. - The following summarizes the 1990 U.S. airport system, how it impacts aircraft design and operations, and the research to minimize the constraints the airport system imposes on the 1990 air cargo system.

1990 airport system: Very limited expansion of congested airports. It is likely that there will not be any new major U.S. air-carrier airports built during the 1980s. The major expansion will probably be limited to passenger terminal, cargo terminal, and runway at Atlanta; cargo terminal at Chicago O'Hare; and cargo terminal at Los Angeles International.

More airports will be flow controlled. The government will restrict the maximum allowable arrivals and departures at more U.S. airports. There is currently flow control at Chicago O'Hare, New York City's Kennedy and La Guardia, and Washington National.

An all-cargo airport could be economically viable at a surplus or joint-use military airport. The revenue from an all-cargo airport would probably not be adequate to pay operating expenses plus debt retirement for an all-new airport.

Airport impact on 1990 aircraft: An aircraft can not efficiently operate at civil airports if it has a wingspan or length significantly larger than the Boeing 747. These dimension parameters are important on the runways, taxiways, and apron/gate area. It is very unlikely the airports will change to accommodate larger aircraft.

Future aircraft must be significantly quieter than today's aircraft. Most major worldwide airports will prohibit aircraft which do not meet today's ICAO Annex 16, or the FAR Part 36. These regulations will become more strict for future aircraft.

Airport impact on 1990 cargo operations: More U.S. airports will have curfews which prohibit or restrict nighttime landings or takeoffs.

The superhub airports have a high percentage of passengers and cargo enplanements transferred from another flight. This high transfer rate reduces the desirability of an all-cargo airport because it is necessary to have frequent service to many destinations to attract the transfer traffic.

An all-cargo airport should not require over 2 hours ground access time or it will become very difficult to provide overnight freight service.

Recommended airport research: The development of a system of surplus or joint-use military airports is the most economically feasible procedure to handle aircraft which are significantly larger than the Boeing 747. If a large all-cargo aircraft is seriously considered, research should be performed to answer the following:

- Which civil airports can handle the proposed large cargo aircraft?
- Which large hubs have nearby available surplus or joint-use military airports which can handle the proposed large cargo aircraft?
- What are the impacts upon operation and cargo demand resulting from all-cargo operations at an airfield which is at a different location and does not have passenger flights for transferring cargo?
- What are the legal, management, environmental, ground access, security, and economic factors associated with using a surplus or joint tenancy military airport?

Long-range research should be performed on off-shore airports with an electric power generating facility if it appears likely that future all-cargo or passenger aircraft will use hydrogen fuel.

Cargo Terminals and Ground Handling

The cargo terminals of today may curtail system flow and market growth of the future. A projected market expansion of 8 percent per year in cargo traffic will soon saturate many of the less-efficient terminals presently functioning at 80 percent capacity. Without expansions in size, mechanization, and increased efficiency, ground handling will retard the need for larger more-economical freighter aircraft and will provide serious handicaps to realizing of growths to levels greater than 1 to 2 percent of the total cargo market.

The prevailing pattern of congestion is chronic throughout the airfreight system affecting the cargo airlines as severely as it affects the passenger belly freight and combination operators. To economically accommodate the expected rate of growth, reverse the debilitating mode, and retain a competitive posture through 1990, either a major change in the labor-intensive portion (involving large capital investments) must be accomplished or increased adherence to the airfreight premise of "transporting cargo and letting others do the handling" must occur. Directions now being taken are near term and not sufficient to increase facility capacities to levels capable of handling 1990 projected increases in freight. As a result of the recent negative growth rates in the mid-1970s, terminal labor operations have been pared to functional minimums within individual cargo operations. Not only have these reductions achieved the object of reducing indirect operating expenses but they have correspondingly reduced productivity.

The rationale behind reduction in expenses by reduction in manpower is correct, but maintenance of higher levels of productivity require implementation of procedural changes that are compensatory. A great diversity exists between terminal personnel levels and productivity. Productivity for domestic carriers varied from as low as 70 kg/man-hour to as high as 325 kg/man-hour. Productivity varies between union and nonunion shops, geographical locations, training, and operational procedures, each of which is influenced by the cargo aggregate. Also the disparity between operational procedures from operator to operator reduces commonality and requires additional or special-handling techniques. Increasing air cargo terminal automation (mechanization) is also directly related to reduction in expenses. However, the financial positions imposed upon airlines with the acquisition of new wide-body aircraft as replacement for less-economical narrow-body and the increasing cost of operations imposed by energy and environmental factors aircraft has reduced cash outlays for terminals to a minimum.

Processed flow can be improved through the application of automated data management which can eliminate or reduce manpower, procedural, and maintenance inefficiencies. The most accelerated movement in this area is directed toward the documentation and control functions of the operations with implementation of varying computerized control networks. More than 61 airlines are now using computer systems with an industry-wide use seen by 1990. Advancement has been stimulated by passenger growth with application to enhance cargo movement being realized as a derivative. Not only will the carriers see cost benefits from the computerized documentation and control but the improved tracking will provide greater customer satisfaction and motivation.

By 1990, more than 75 percent of the cargo carried by airlines can be in shipper-loaded containers which is the most direct step towards reduction in costs. This will eliminate the piece handling of cargo by the carriers. Airlines are, and function best as, transporters similar to the trucking industry. Reduction in small-piece sortation and load buildup and breakdown can directly diminish the labor-sensitive expenses while at the same time providing for increased levels of flow. The shift toward containers, especially those of 2.4-x 2.4-x 6-meters gives an added benefit through realization of a greater stacking efficiency (cube utilization) and an internal shape more compatible with piece cargo. The trend from small piece to larger piece (containerization) speeds processing and results in reduced handling for equal cargo flow. This refinement of piece-handling techniques, when phased with a greater queue, can increase stacking efficiency and onboard loaded density. In-terminal storage and layover will therefore be less, freeing valuable real estate for use in additional container processing. Increased levels of international import operations will be assumed at the forwarders offsite locations resulting in a vast reduction of unproductive terminal area. By 1990, minor international accord will be reached upholding respective participating countries' laws and enforcement, allowing for preclearance of shipments to be imported. This measure will reduce terminal-area saturation caused by warehousing of import cargo, thus bringing it more in line with domestic cargo.

Other solutions to the certain probability of constrained terminals and choked cargo flow are present. Joint tenancy as well as off-site cargo facilities have been suggested as alternatives. Currently, these solutions are viewed with trepidation by operating carriers for many and varied reasons.

For joint tenancy there exist high-wing/low-wing design incompatibilities, overcapacity during normal operations, a lack of freight commonality, a dissociation from present cargo supply centers, and the need to handle transfer freight between operators. Combination carriers would also have the problem of separating passenger and freight traffic. On the other hand, some of the advantages which joint tenancy provides are cost sharing in cargo terminal operations, immediate transition to CRAF operation when needed, and reduction in land-traffic and airway congestion. Joint tenancy operations offer many positive and negative features, but a thorough and comprehensive study needs to be accomplished before any conclusive direction on this issue can be given.

Offsite airline cargo terminals, although offering lower-cost land and less traffic congestion, present an increased manpower burden and duplication of facilities equipment. They do provide warehousing for short-term storage freight, such as international imports, but do not eliminate the necessity to handle transfer cargo. Transfer cargo would have to be transported to the offsite terminal and back, creating time delays.

Decisions made and directions taken by airlines regarding offsite terminals will vary as the future flow composition changes from less bulk to more containerization. Forwarders are essentially offsite terminal operators. If the anticipated increase in freight is to be accommodated between now and 1990, some combination of new terminals, increased mechanization, procedural changes, and containerization must be actualized.

Terminal mechanization. - Existing cargo terminals vary in levels of mechanization, productivity, and operating capacity. The CLASS onsite surveys and questionnaires indicate these terminals to be operating at 80 percent capacity levels regardless of level of mechanization. However, productivity varies considerably among facilities of equivalent mechanization indicating varying levels of efficiency. The differences in flow per man-hour are of magnitudes sufficient to show the effect of individual procedural practices, wage variations, and philosophies.

Like cargo terminals have current manpower productivity levels ranging from a low of 70 kilograms per man-hour to a high of 200 kilograms per man-hour. This large variation in productivity is only partly due to the disparity in monetary rates. The greater influence is derived from cargo handling philosophies. When bulk loads should be built up and broken down, where, what, and how much loose-piece freight should be amassed before undertaking each function are among decisions which strongly affect the output per man-hour. Benefits can be gained by mechanization but proper utilization thereof is equally important. Existing terminals are nearly at maximum levels of mechanization relative to current handling procedures. Automation in a true sense is not likely to be achieved by the airlines due to shipments handled. The types of freight tendered by a carrier vary considerably in size and weight:

Shipment Weights

Seventy-five percent of total shipments weigh less than 90 kg.
Five percent of total shipments weigh more than 450 kg.
Three percent of total shipments weigh more than 900 kg.

Piece Weights

Eighty-five percent of total pieces handled weigh less than 25 kg.
Five percent of total pieces handled weigh more than 150 kg.
Three percent of total pieces handled weigh more than 300 kg.

Piece Size

Fifty percent of the total pieces handled are smaller than 0.5- x 0.4-x 0.5-meters.

Seventy-five percent of the total pieces handled are smaller than 0.6-x 0.5-x 0.4-meters.

Ten percent of the total pieces handled are larger than 1.0-x 0.6- x 0.5-meters.

The first two piece size items combined represent only 35 percent of the total weight handled by a carrier. Fifty percent of the total weight handled is of pieces 0.8-x 0.6-x 0.5-meters or less in size. Due to the importance of value and the necessity in selecting the air transport mode, it is probable these piece weight/size relationships will change little during the considered time period. Without standardization in size, it is unlikely that advanced mechanization of equipment, such as sorters and conveyors, will be adopted.

Pieces too large to be accommodated by sorters are routinely handled now. Since the amount of this type cargo is not expected to diminish, it could result in the need for dual-processing systems in the case of a highly sophisticated sorting system. It must also be kept in view that sorters do not lessen the manpower required for the ULD buildup functions but only speed the flow of pieces to the respective buildup locations. Since maximum density is a prime objective in ULD buildup or packing, a minimum of two base loads should be staged to provide an adequate piece queue relative to selecting piece, size, shape, and weight. The automated sorting system has lessened the congestion by separating the large queue into small queues by destination.

High-mechanization terminals are tailored for the types of operation and freight being handled. Elevating transfer vehicles (ETV), Figure 3-8, and stacker systems are adaptable to buildup, breakdown, stage, and storing operations. They are area efficient, allowing multilevel storage/staging of ULDs where vertical space is not a restriction. Narrow-aisle forklift stacker systems are also area productive in providing needed temporary storage for international import shipments.

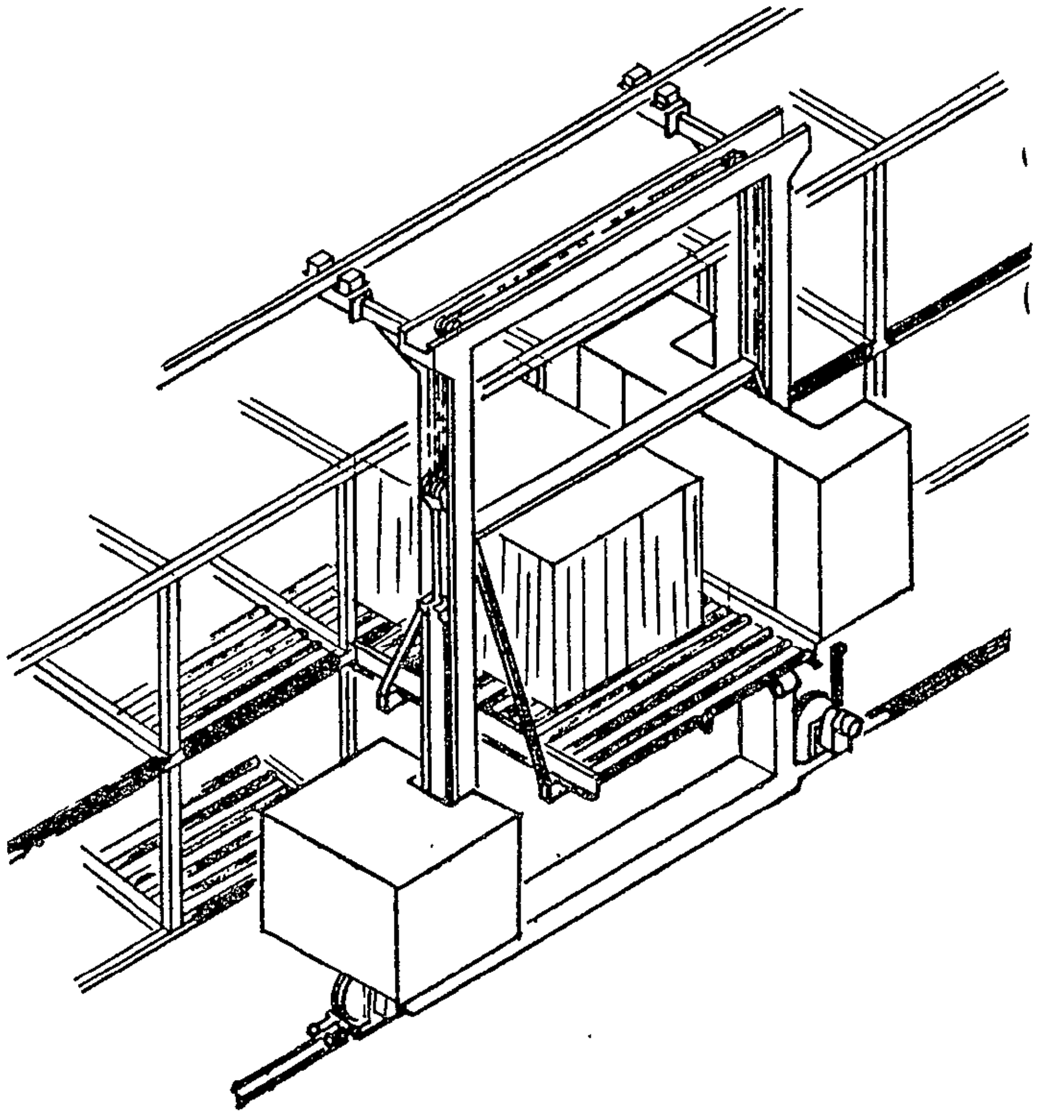


Figure 3-8. High Mechanization Elevating Transfer Vehicle

On a shipment-per-shipment basis, imports are stored for a period 24 times that of domestic. This imbalance in storage cannot be offset by mechanization but can be softened by use of vertical storage. As flow increases, a greater number of shipments must be handled, requiring more processing area. Vertical expansion does have limits, a restriction which many terminals have already reached. Approach glide path violations or massive investments to modify leased buildings are generally the curbing influences.

Bypass systems consisting of elevating transporting vehicles equipped for servicing mobile units, such as trailers, transporters, and dollies, are widely used. Increasing numbers of shipper-loaded ULDs and interline transfers are most effectively processed on these systems.

Other sophisticated equipment is common in low-, medium-, and high-mechanization terminals. Much of this hardware will be the mainstay of terminals through 1990. This material consists of pallet container transporters, dollies, tugs, straddle lifts (Figure 3-9), forklifts, main deck loaders, lower compartment loaders, mobile conveyors, and pallet container racks. More of one than the other may be employed depending upon facility layout and need. As the cargo composition changes form through increased containerization and decreased bulk, this machinery will change in size and weight-handling characteristics but will remain a necessity because of its flexibility. Simple sorting, transporting, staging, and storage will continue to be accomplished by use of handcart, forklift, tow truck, and conveyors. Handcarts are the more area-efficient of these methods, but forklifts will continue to be used for the heavy shipments. Warehouse pallets will continue to be the standard shipment base for bulk cargo because of commonality and widespread use in the surface modes of transport.

There are a few airlines that have made a transitional step toward the future. This transitional approach utilizes fixed or mobile docks which allow direct loading of the aircraft to and from the terminal. These systems interface with nose-loading wide-body aircraft and eliminate much of the main deck ground handling equipment. The need for the auxiliary service vehicles is

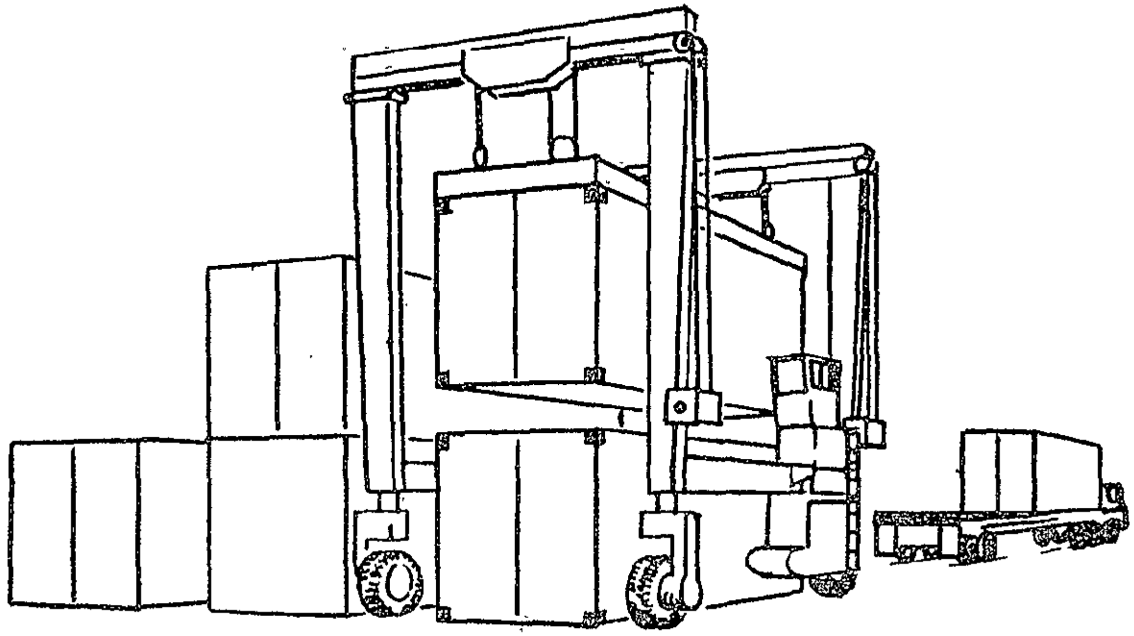


Figure 3-9. Straddle Lift - 6-Meter or Larger Container

prevalent since aircraft lower compartments are not compatible with fixed docks and because of the side main-deck cargo door situated aft of the wing on some cargo aircraft. Many operators, although utilizing nose-loading aircraft in their fleet, prefer the side door. As explained by most, the fixed dock is not as reliable or adaptable and does not eliminate the need for mobile servicing equipment. Loss of cube is another important aspect related to nose versus side loading. Existing wide-body nose-loaded aircraft cannot accept the high stack ULDs that can be loaded through a side door. Since more flights are grossed out by cube than by weight, this represents added direct operating cost (DOC).

Another labor-saving, cost-reducing approach is the application of computerization to the terminal documentation and control functions. In 1976, 61 airlines were already using computer systems. Most of these, however, were passenger carriers who utilize the reservations, billing, and tracking features. The larger all-freight, combination, and belly-freight carriers are already in various stages of computer use. Many of the smaller carriers are using TWX systems. The TWX systems are better than none but fall very short of the computers and cannot greatly affect the labor-intensive functions.

By 1990, computerized systems will furnish more than 25 functions having direct application to those now mechanically processed. Functions initiated before the cargo is physically received, such as cargo scheduling and routing, will be routinely dispatched. Inventory space availability will be more accurately controlled, allowing more efficient load planning, ground facility scheduling, interline accounting and air waybill auditing. With the greater data capture, management information, marketing information, and training can be provided. The better accumulation of cost data and documentation of accounts receivable, credit control, and nonair transportation charges will allow station cash control to be closely monitored. This information collection will deliver market patterns and projections helping to automate rating and miscellaneous storage and other change calculations. Cargo flow processing will be expedited by up-to-date document issuance, system integration, and terminal and unit-load device control. Under the documentation and control functions, a customs interface will be established, tying with international preclearance to eliminate need for storage of inbound international freight. Other functions which will help to stimulate and placate customer relations are cargo message processing and status tracing and customer invoicing. Prorating and routing are also among the useful duties.

Even though air waybills, customer invoicing, and cargo status can be maintained, much of the documentation and control work will need to be continued as is. Shipment status will still rely upon information manually fed for implementation. With continued bulk handling, duplicate paper must be transmitted along with the shipment. After all piece and shipment loading or unloading and storage procedures have been completed, the manual accounting can be input. There are intermediate points when additional computer inputs could be accomplished. Without this elementary accounting and tracking, the computer tracking system may lose the shipment location. Reliance on the computer alone is unrealistic.

The impetus which computerization will produce in reduction of overhead expenses and direct operating costs will come from more efficient load planning and aircraft utilization as well as expediting cargo movement. Processing times related to location and retrieval for outbound buildup or transfer, and inbound routing or customer pickup will be less. These improvements and others will either decrease the manpower or increase the processable flow.

Terminal Processing. - Parametric evaluation of present terminals with varying levels of mechanization over a spectrum of operation types indicates that increased flow will saturate the overall terminal operations well before 1990. A function-by-function examination of terminal operations shows the effect of interrelationships and mechanization on increasing flow or lowering expenses. The diagram shown in Figure 3-10 illustrates the top-level flow model that is representative of the more-advanced present-day terminals handling both bulk and containerized loads as well as domestic and international imports. Outbound flow moves from left to right, and inbound flow from right to left in this flow model. Each type of carrier, all freight, combination, and belly freight only, were evaluated by use of Figure 3-10 with appropriate delineations in functions according to their level of mechanization. Also, the documentation

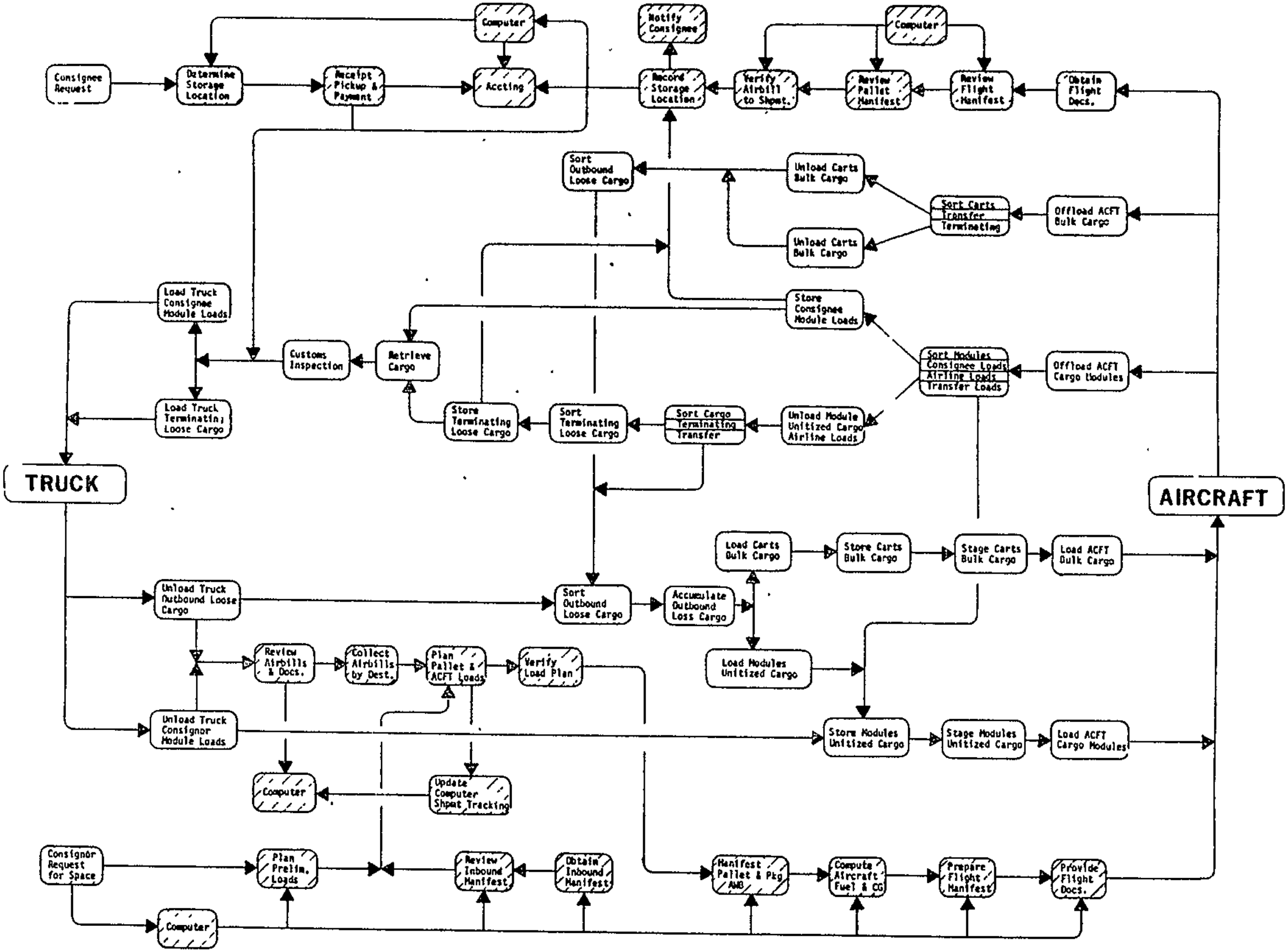


Figure 3-10. Maximum Mechanization Cargo Terminal Processing and Management System Functions Top Level Flow Model

and control functions which parallel those of processing were varied by complexity for the same terminal evaluations.

Figures 3-11, 3-12, and 3-13 show the mechanization and handling relationships with respect to functional processing times and amounts processed. The pallet transporter/ramp tug and walk movement times were generated from Reference 3-8 with a 15 percent allowance for manpower fatigue and time delay. The warehouse tug and dolly times do not include the loading and offloading of the unit but are representative of traveling times for empty or loaded units. The powered ULD movement conveyors and the elevating transfer vehicle (ETV) times were established from studies conducted by the Douglas Aircraft Company.

Tracing the processing times associated with the respective mechanization elements shown in Figure 3-11 indicates that powered ULD movement conveyors could be the pacing equipment. The equipment that is most productive from the standpoint of distance covered per unit time are the pallet container transporters and the ramp tugs. The next most productive element is the manpower obstructed or unobstructed walk while carrying cargo; all other types of cargo movement require more time per meter traveled.

The number of ULDs which can be handled in the terminal by use of different components of the system is shown in Figures 3-12 and 3-13. Figure 3-12 depicts the floor area requirements for narrow-aisle multilevel racks and floor-level storage accessible by either handcarts or forklift trucks. The functions shown are bulk oriented and are depicted in terms of equivalent ULD loads with areas determined for standard shipment sizes (Reference 3-1). These data show that a 77.6 percent reduction in utilized floor area can be achieved by shifting from floor storage accessible by forklift to a five-level narrow-aisle rack system serviced by narrow-aisle high-reach forklifts. Such multilevel systems will be required to handle the level of import flow forecast for the future. The point in time at which multilevel racks become mandatory will depend upon the terminal and the length of time that the current practices of bulk handling and delayed inbound pickup persist.

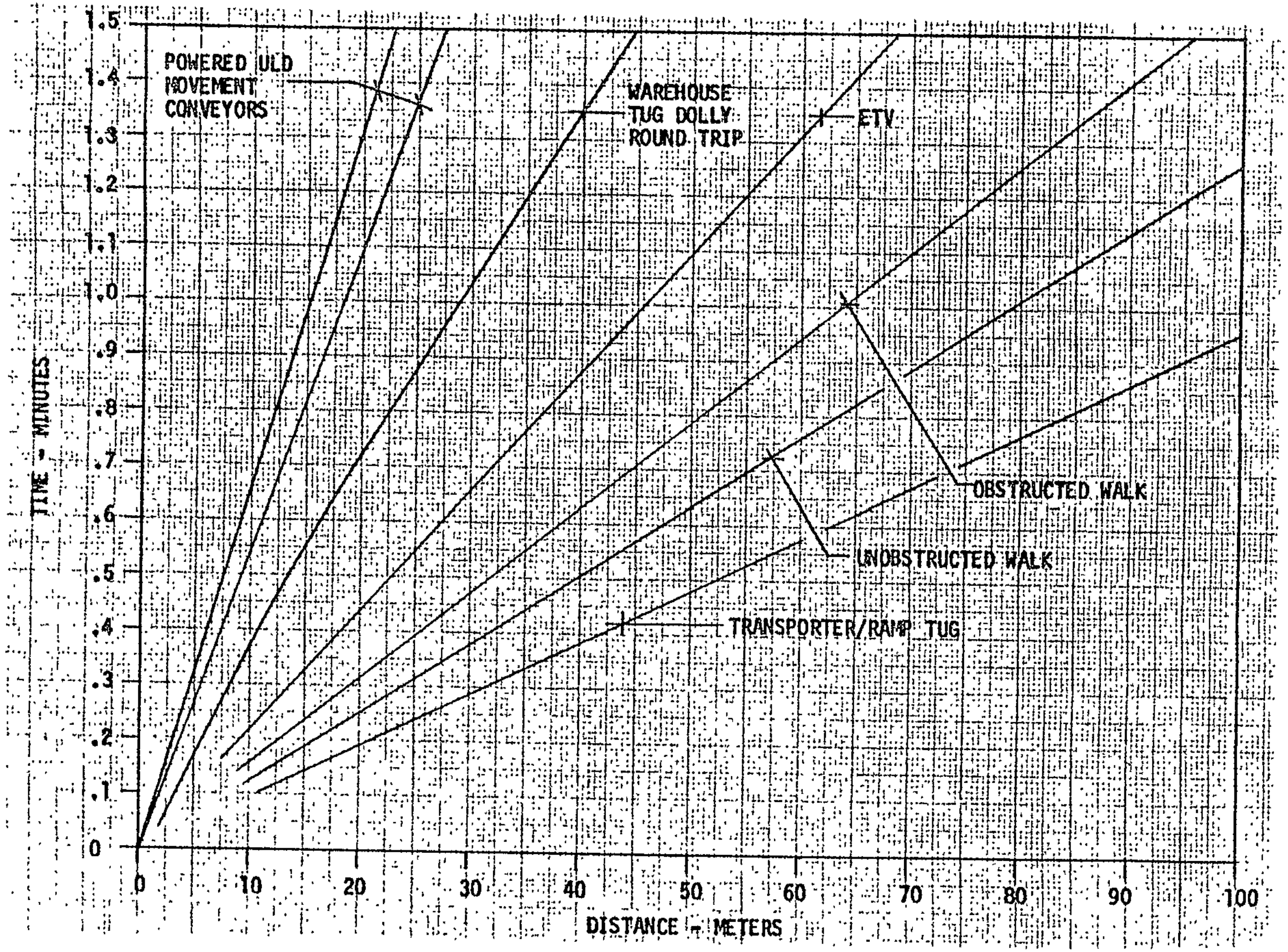


Figure 3-11. Movement Times

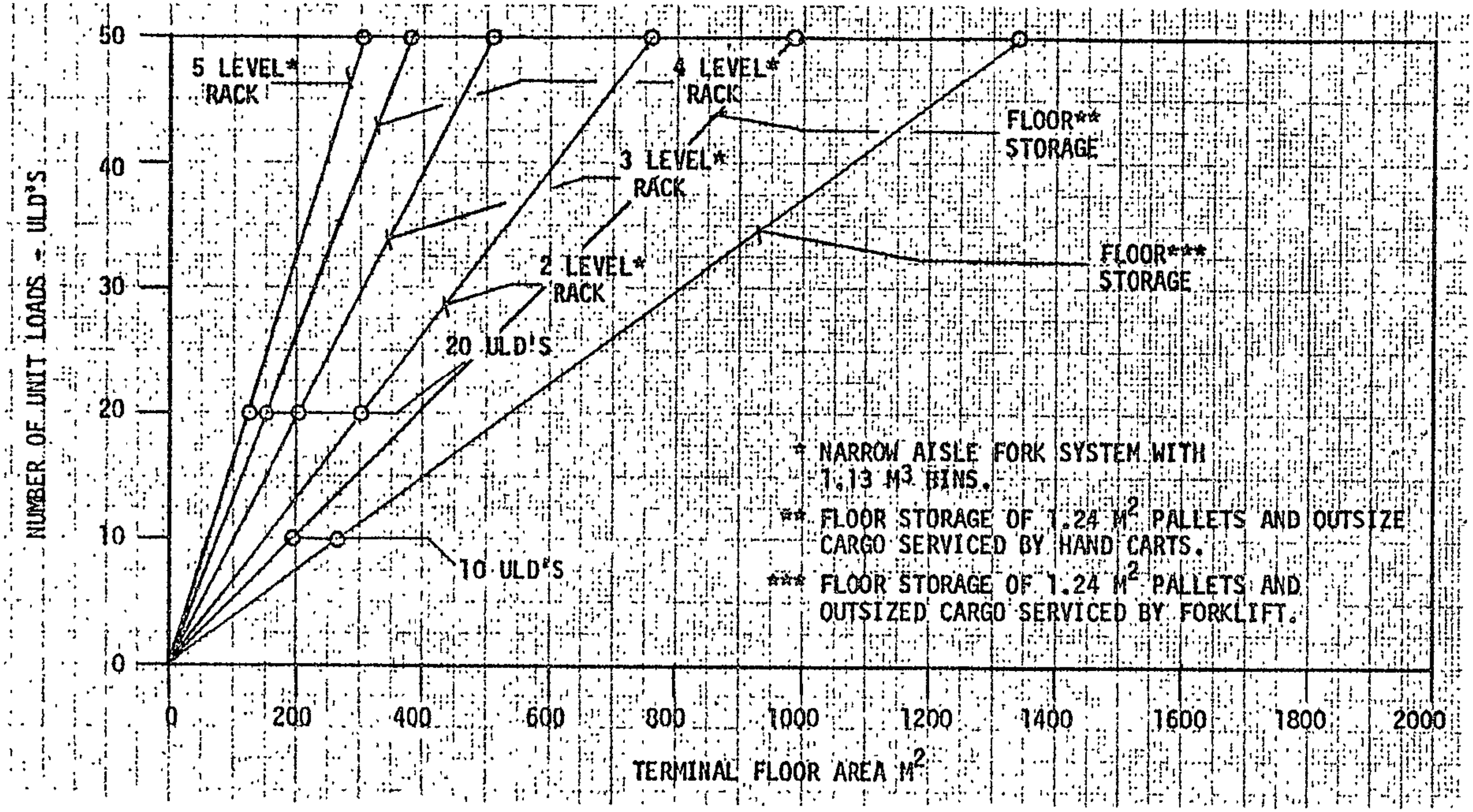


Figure 3-12. Area Requirements for Storage and Movement

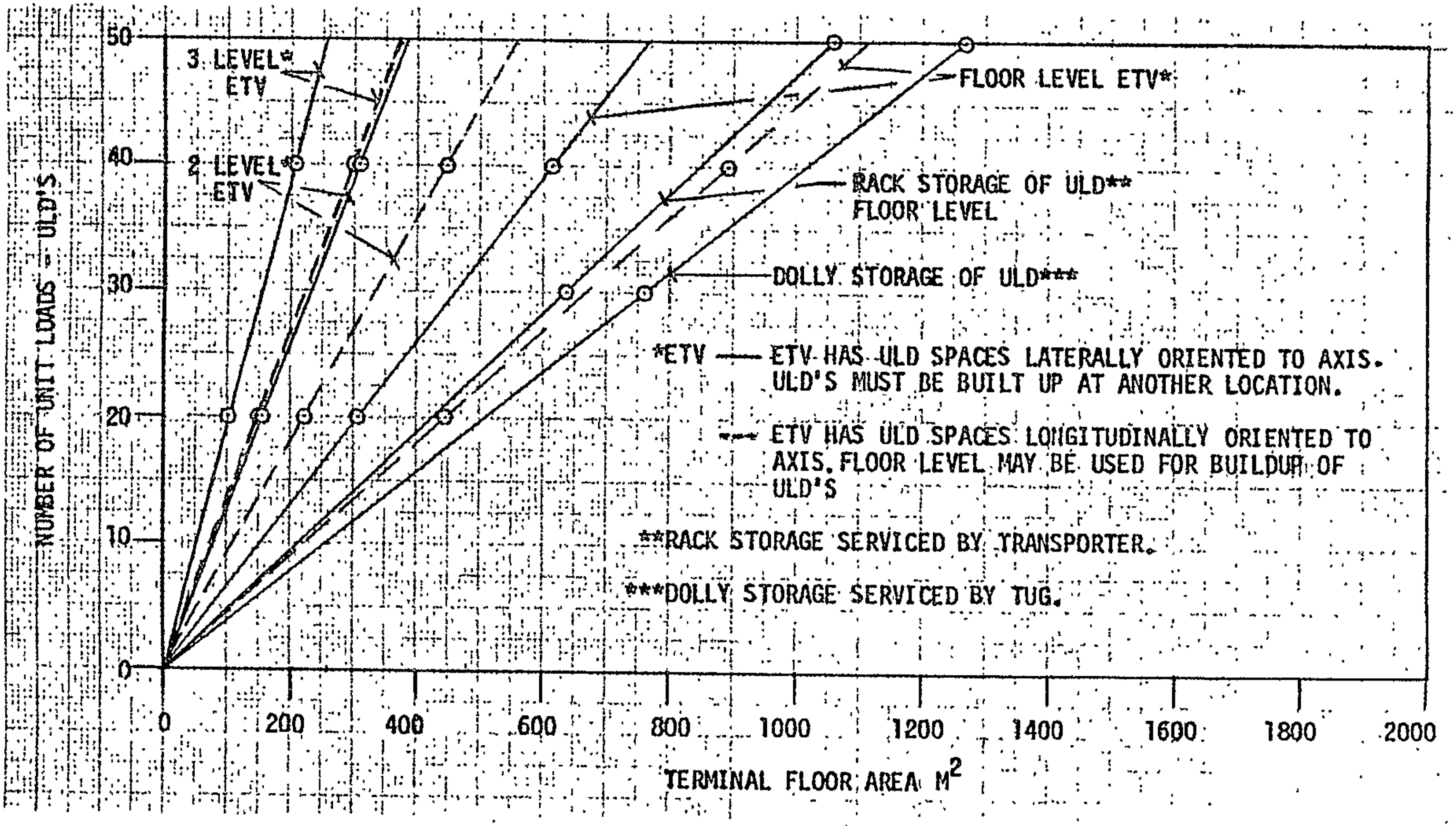


Figure 3-13. Area Requirements for Buildup, Breakdown and Staging

Since terminal area is at a premium and the volume of cargo handled is certain to increase, existing facilities caught in the area crunch must increase their effective floor processing area or stagnate. For airlines that are now using forklift floor storage and are unable to expand vertically, 25 percent of the floor area can be reclaimed for expansion by converting a portion of the operation to a handcart system. However, the total elimination of forklift storage areas is not possible as long as bulk cargo is processed. Such processing requires the handling of shipments and pieces of cargo that exceed warehouse pallet size (1.0-x 1.2-meters) or weight more than a man can lift unassisted. Even where vertical space is available, racks are not the total answer since all sizes and shapes cannot be stored on racks that usually have discrete bins 1.0-x 1.2-x 0.8-meters in size. Shipments consisting of more pieces than one or two bins can hold can be stored within or on the transporting ULD, thus relieving some of the floor congestion.

Figure 3-13 shows the handling capabilities and floor area requirements associated with those mechanized functions generally exercised in buildup, breakdown, temporary storage, and staging of ULDs. These data are representative of ULDs no larger than 2.4-x 2.4-x 3.2-meters (type M1). The larger containers which are forecast for wide use by 1990 cannot be handled on these dolly, rack, or ETV systems. The area usage for type M2 containers is equivalent to twice that shown in Figure 3-13 for any system when comparing equal numbers of ULDs. As mechanization increases, so does the productivity, resulting in reduced floor area being required and/or an increase in number of ULDs handled. These data also illustrate the fact that multilevel ETV systems (Figure 3-8) are more productive than dolly storage systems due to a reduction in maneuvering space required. Triple-level elevating transporter stacking systems with longitudinally oriented storage spaces for ULD's buildup or breakdown occupy 70 percent less area than the counterpart dolly system. With full containerization, no buildup and breakdown by the airline, an additional 30 percent reduction in this area can be achieved. ETVs stationary in-terminal racks and ramp racks can be serviced by transporters or dollies whereas dolly storage is serviced by tug.

As previously noted, many of the present terminals will not be able to handle the forecast cargo growth anticipated between now and 1990. Corrective action will probably be achieved by increasing the efficiency of existing mechanization and procedures combined with the increased use of shipper-/forwarder-loaded containers. As an example, the current generation of equipment widely used in terminals is readily adaptable to handling 3-meter containers with a modest capital investment. By using 1976 technology to extend present equipment and by processing only shipper-forwarder-loaded containers of 3-meter length or less, and resulting terminal capital investment per ULD throughout could be reduced 72 percent over the current level. The return on this minimal investment will be a 428 percent growth in the terminal processing capability.

The adoption of highly mechanized terminals will be achieved progressively with the increased use of shipper-/forwarder-loaded 6-meter containers and the attendant decrease in bulk handling. An interim but relatively advanced terminal capable of handling the 6-meter containers can be achieved with current technology. Such concepts have low commonality with current equipment, and their implementation will entail revisions to and/or replacement of approximately 90 percent of the current mechanization elements. This relatively large change in terminal elements is due to the current lack of equipment required to handle the 6-meter containers. These interim advanced terminals could increase the ULD throughout by 922 percent relative to current processing levels and will result in an 80 percent (additional 8 percent over preceding systems) reduction in the current level of capital investment per ULD processed.

Toward the end of the considered time period, some terminals will have implemented even more advanced systems capable of handling longer and heavier containers. The proprietary concept shown in Figure 3-14 and the spanloader-oriented system of Figure 3-15 illustrate two of the many such advanced terminals studied by the Douglas Aircraft Company. With this type of installation, the ULD throughput could be increased 1937 percent over today's level with an additional (relative to the interim advanced concept) 4 percent reduction in capital investment per ULD processed. It should be noted that the preceding growth levels are not predicted operating levels but are the maximum output levels possible with the respective levels of mechanization. These increases

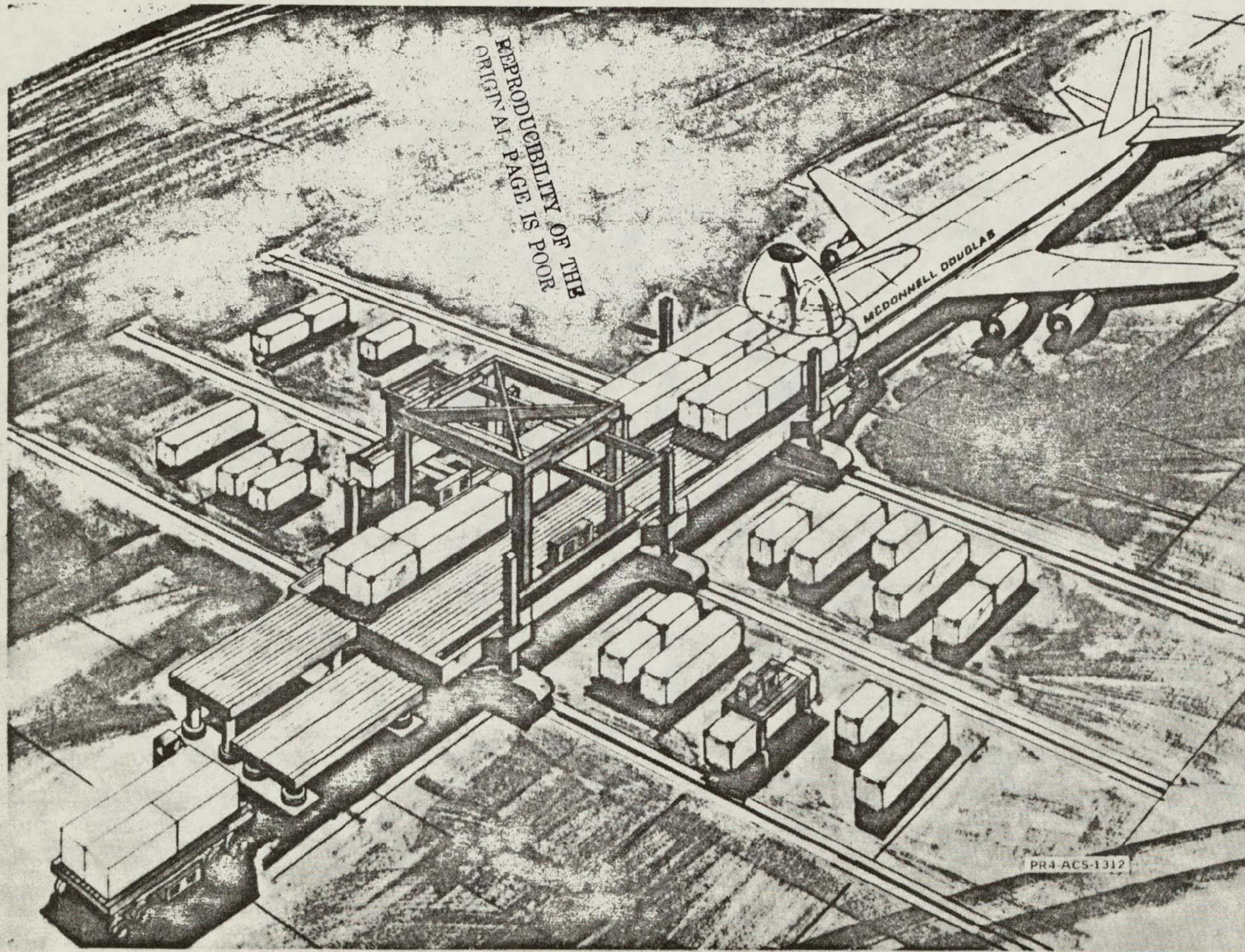


Figure 3-14. Future Air Cargo Ground System

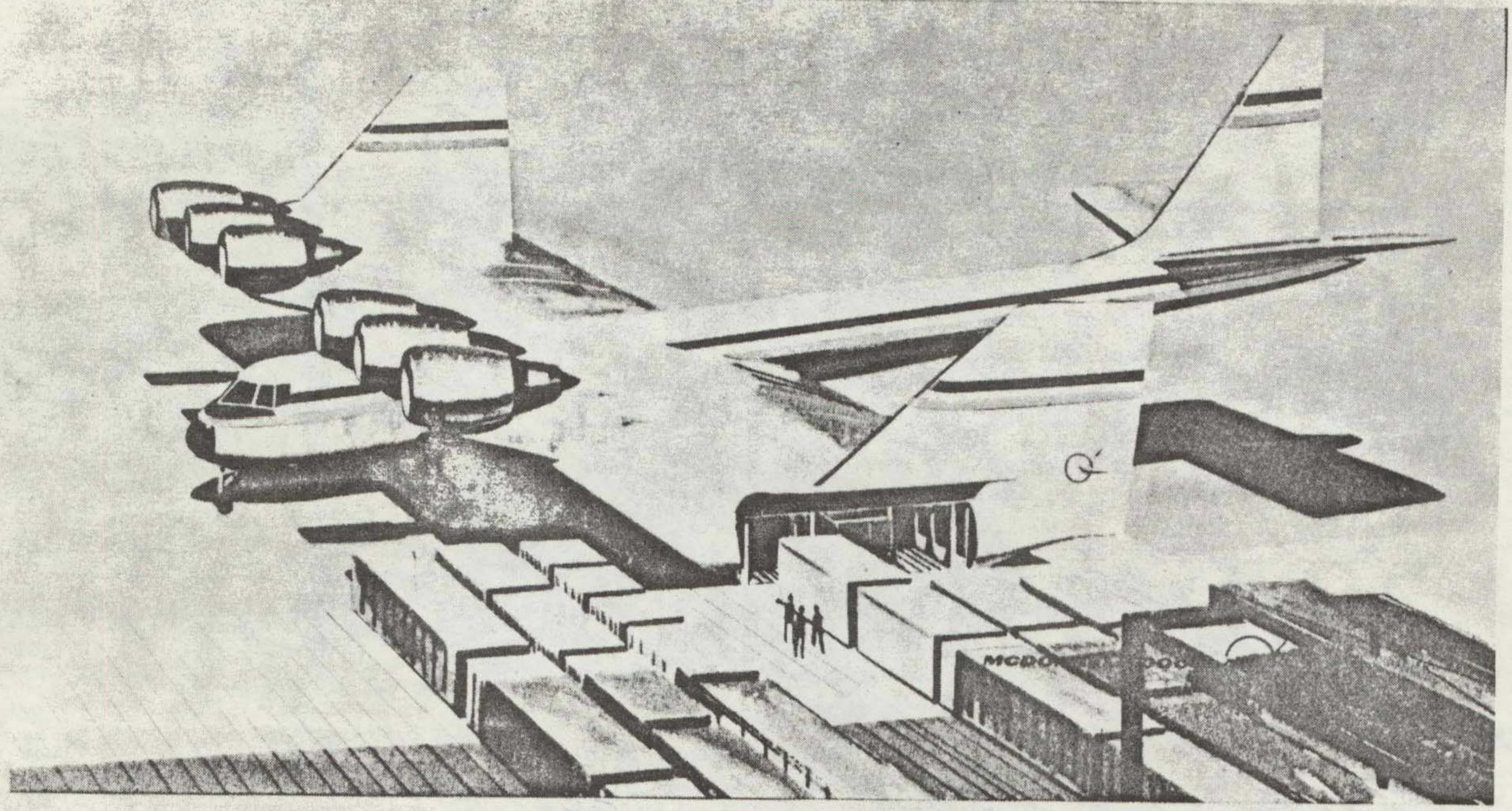


Figure 3-15. Advanced Airfreighter and Cargo Handling System Concept

can only be achieved if the interfacing modes can be sustained and the market can provide a comparable demand.

The processing of bulk cargo and international imports requires relatively large working areas and is, therefore, a likely source for congestion relief. As an example, any reduction in import customs processing times will reduce the necessity for the associated large storage areas. Until such times as reductions in processing are realized, vertical expansion can provide a short-term relief. Vertical expansion could probably increase usable area by 337 percent in maximum application situations and by 40 percent in minimum applications. It is equally important to implement efficient handling procedures when this recovered area is converted to processing. A point to consider in revamping procedures is the fact that peak-flow periods and trends in freight movement are not likely to change for some years to come. The resulting unsteady work load can contribute to the area congestion since the timing of container buildup is important. Results of the terminal surveys show that most airlines throttle their own system by overstaging. With the increased use of computers and advanced booking of space, load planning and buildup does not need to be delayed until the last minute, and much of the current terminal congestion can be avoided.

Terminal Manpower. - Today's airfreight terminals vary in levels of personnel as well as mechanization. Evaluation of the Task I terminal surveys showed the inefficient use of personnel. This is an area where large gains in either productivity or reduction in expenses are possible. Most facilities, although having reduced personnel levels in the mid-1970s, are not operating at capable production levels. This is evident in the fact that the productivity of like terminals, with comparable levels of mechanization, varied between 70 kilograms per man-hour and 200 kilograms per man-hour. This is not saying that other factors are not contributing to this disparity, because they do. Among these contributors are the environmental requirements, prevailing labor rates, lack of personnel, and motivational management.

With highly labor-intensive air cargo terminals, increases in indirect operating cost can be reduced effectively by making the facilities less labor intensive. From the Ralph M. Parsons "Air Cargo Terminal Handling Costs" 1973 report, 94 percent of the total terminal costs were directly related to labor. A further breakdown of these costs indicates that 54 percent of the handling costs are attributed to bulk and only 2 percent to shipper-loaded containers. This 47:1 ratio of bulk costs over container handling costs is comparable to a weight ratio of only 8:1 in favor of bulk. These ratios indicate the importance of the trend toward full containerization.

Although not contributing as much toward reduction of expenses as the shift in types of cargo handled, increased mechanization will reduce the labor force while increasing the flow. Without exception, the terminal survey results showed the conveyor system within the aircraft to be the determining factor in reducing loading time. Manual systems are capable of reducing the loading time relative to current powered systems but contribute to the manpower problems. Future aircraft powered systems, such as the proprietary concepts shown in Figures 3-16 and 3-17, will not only reduce the time but the manpower as well. Converting from a powered aircraft system with manual restraints to one with automatic latching can reduce the manpower by 500 percent (Reference 3-2).

Figure 3-18 shows the productivity per man for various types of cargo terminal processing equipment and operations. These data are based upon the currently operating powered aircraft systems with manual latching. These data show the least productive terminal functions are buildup/breakdown, while the most productive are the transit and aircraft loading systems. The equipment handling more than 40 ULDs per hour per three men are the epitome of greater mechanization and represent the dividing line between the high- and low-mechanization terminals. The close proximity of the upper bands in Figure 3-18 shows that the level of diminishing returns in manpower reduction has been reached once the terminals' functional operations are mechanized. Improvements in mechanization beyond currently operational powered main deck loading equipment have not been shown. Benefits in this area can be derived from fixed and mobile loading docks and the future aircraft powered loading systems discussed above. However, it must be recognized that there are physical limiters to manpower reduction. Items such as the unit sizes of pieces handled, complexity and maintenance of equipment, safety, and land and air side interfaces are examples of such limiters.

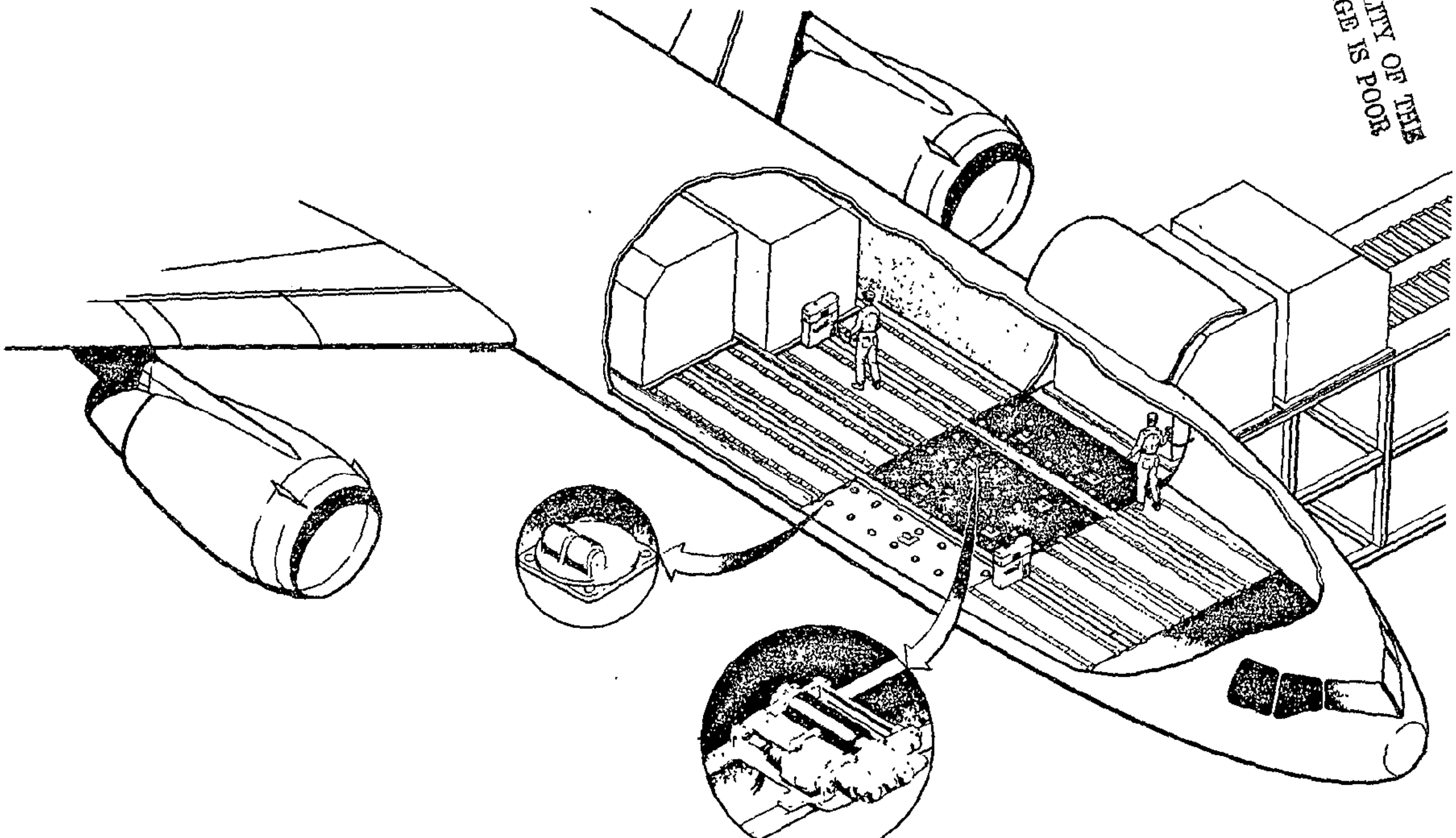


Figure 3-16. Main Deck Power Pack Shuttle
Container Handling System

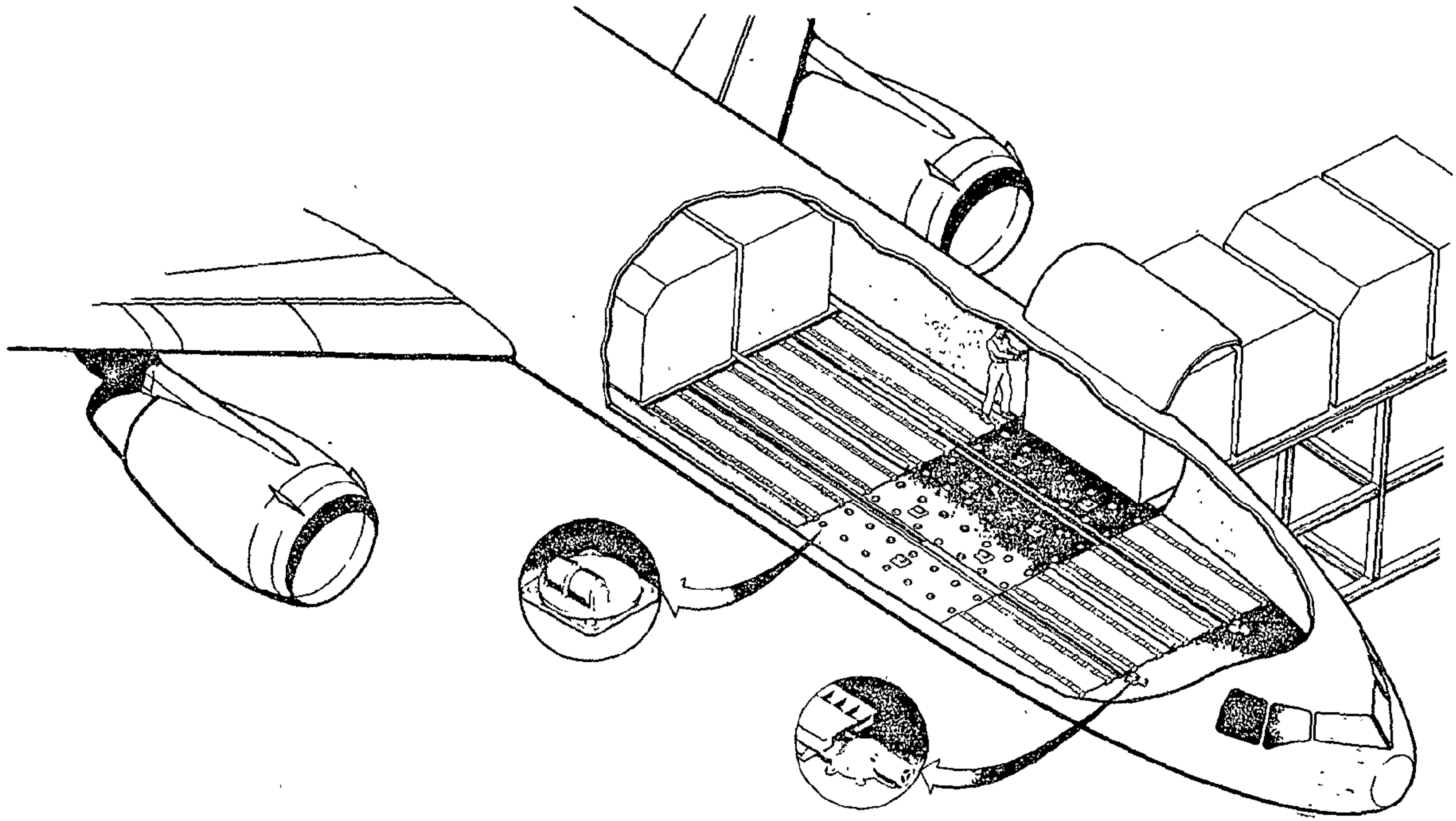


Figure 3-17. Main Deck Integrated Power Shuttle Container Handling System

PR2-DP-7151

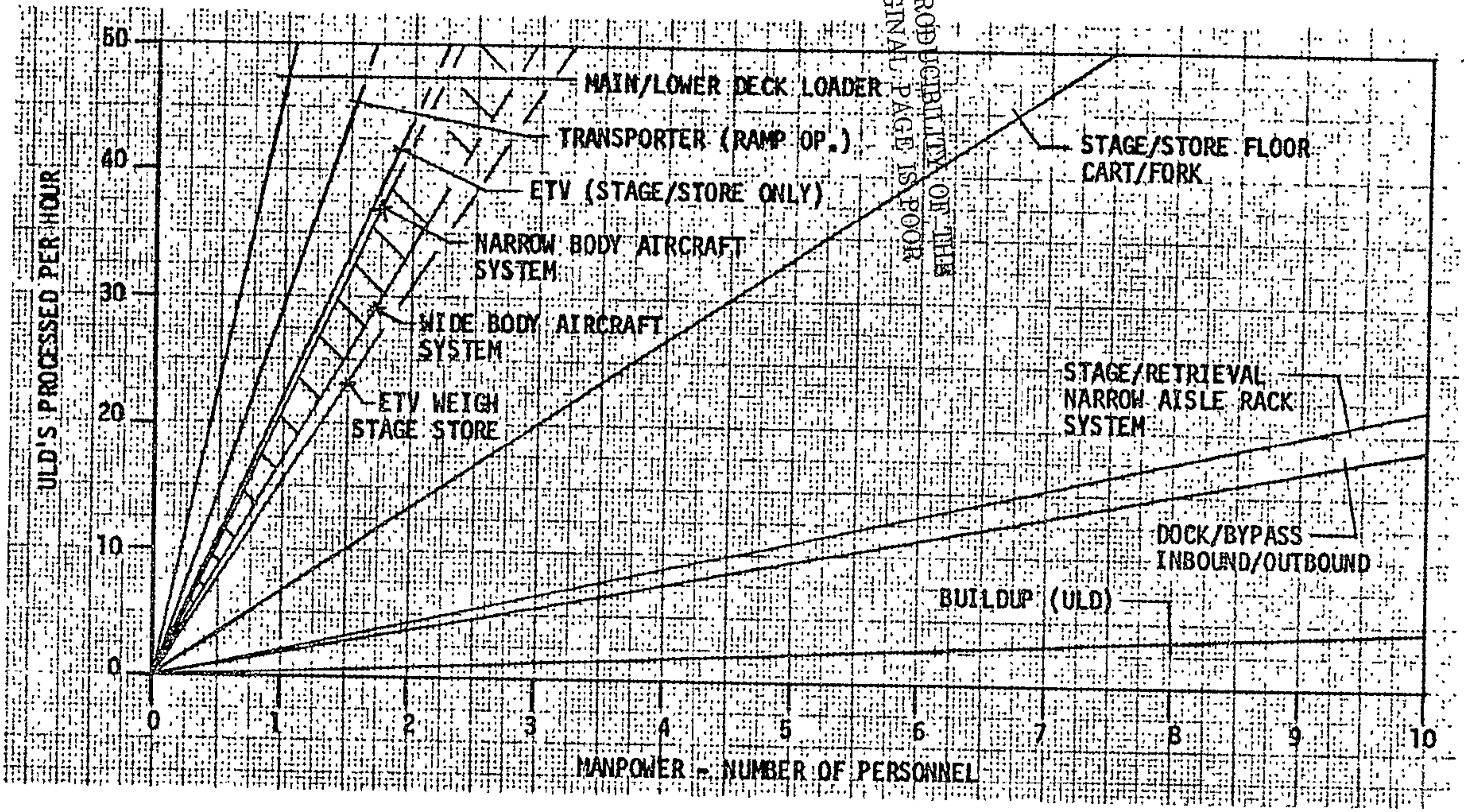


Figure 3-18. Manpower Required Per ULDs Handled

Functional productivity per man is shown for the various operations and/or associated equipment in Figure 3-19. Here the number of ULDs that can be expeditiously yet carefully handled per man-hour are given. These rates are maximums achievable and were used only for evaluation of types and classes of air cargo terminals. Actual realized rates vary from facility to facility and are influenced by complex causal relationships. The data of Figure 3-19 correlate with those of Figure 3-18 showing that high productivity is associated with high mechanization, thus reinforcing the postulate that expenses can be reduced by the use of labor-saving, highly mechanized equipment.

Larger, more-mechanized aircraft help to increase flow and reduce ground service handling. With the increased payload, fewer aircraft are needed for a given flow, thereby eliminating the offload and onload operations for each flight eliminated. This may either decrease the necessary aircraft service crew or allow their use in another critical flow area. The larger freighters will contribute to flow growth while maintaining the number of concurrent operations, thus reducing expenses in relation to static labor levels and boosted cargo outputs.

The bulk which is difficult to load and maneuver in lower bulk holds of aircraft can be efficiently containerized within the airline or forwarder terminal. This containerization of lower compartment cargo reduces the related handling and loading times and servicing crew sizes. The resulting shorter, more expeditious loading cycles can reduce turnaround times and passenger handling problems for belly-freight carriers. For combination and all-freight carriers, reduced servicing times can be realized by standardizing lower compartment containers or ULDs with an attendant reduction of the break and build operations necessary to accommodate varying aircraft. Such standardization could substantially reduce the cost of interline transfer.

The preceding discussions and data substantiate the fact that the labor-intensive situation can be ameliorated through mechanization and containerization. Reduction in piece handling can greatly decrease labor requirements for the airlines by shifting the essential buildup and breakdown functions to

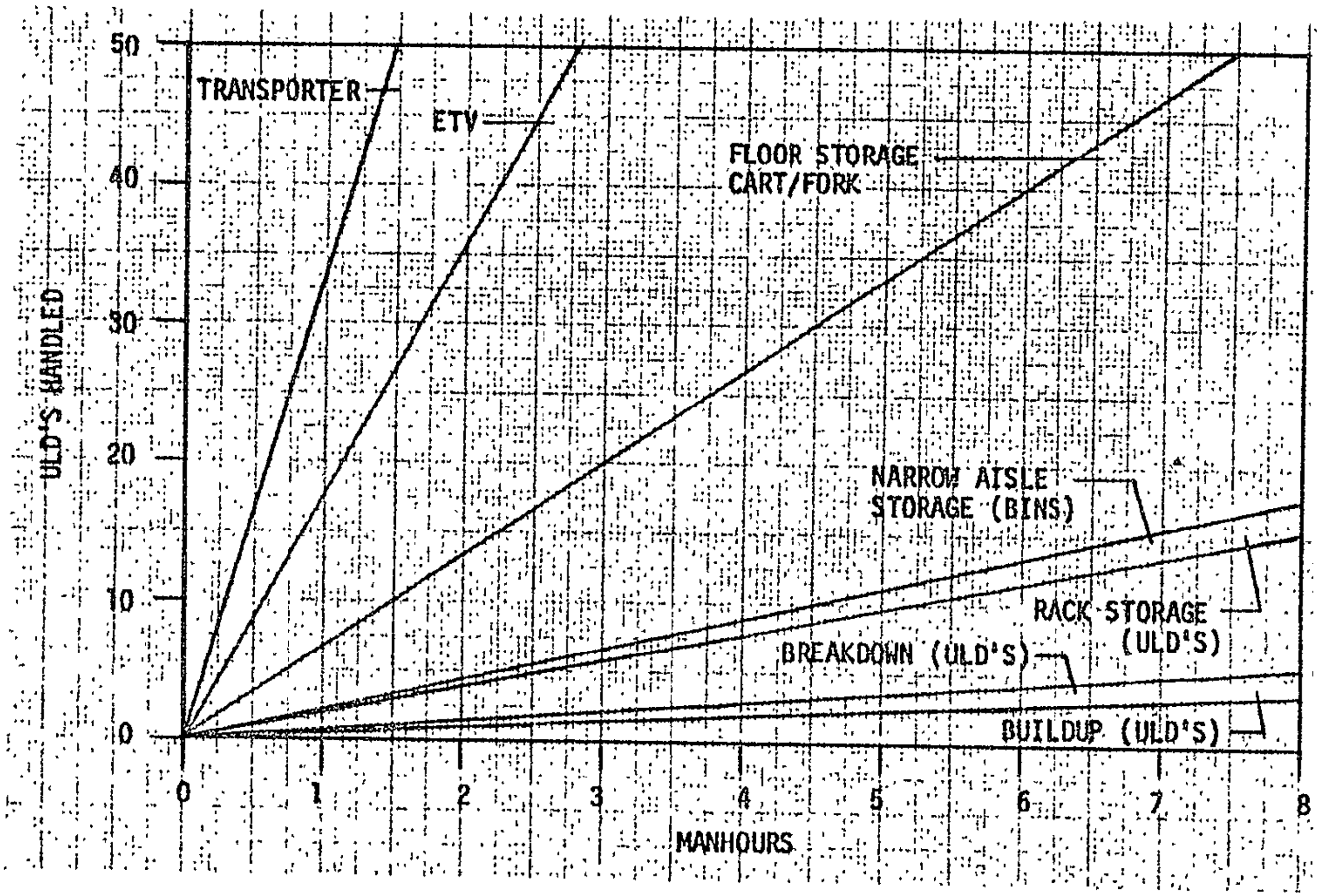


Figure 3-19. Functional Productivity Per Man

the forwarders/shippers. This shift, which is compensated for by incentive tariffs to the forwarders/shippers, is already in progress and may be complete within the 1990-2000 framework. Forwarders can more economically handle the build and break functions. They can, through specialization in piece or shipment size, realize higher ULD stacking efficiencies than can the airlines who are tendered freight having an extremely broad range of characteristics.

Terminal Analysis. - Having established the relationship of mechanization, labor levels, and productivity, evaluation of present and projected terminals in the following analysis indicates the following.

- Present terminals will need to expand in size unless more efficient use of available resources is implemented.
- Depending upon the present capacity and utilization, projected increases in cargo flow may be accommodated by area expansion and/or increases in mechanization.
- Increased shipper containerization alone can help the terminals to accommodate the 2.94 fold growth by 1990.
- Existing high-mechanization terminals hold more promise for meeting the projected growths than do the less-mechanized systems.
- Combination carriers presently operating at 50 percent or more of medium-mechanization terminal capacity will require increased terminal area to meet projected growths.
- Belly-freight carriers can operate at lower levels of mechanization than all-freight carriers and still accommodate 1990 projected flows.
- An increase in stacking efficiency (container cube utilization) can result in a 50 percent increase in weight flow processed through a bulk-handling terminal.
- For a fixed amount of weight flow processed, an increase in stacking efficiency can result in a 40 percent reduction in the number of containers handled in an all-container terminal.
- For a fixed number of containers handled, an increased stacking efficiency can result in a 67 percent increase in weight flow processed.

- For bulk-handling terminals, a greater cargo stacking efficiency in containers will result in an increase of 10 percent in the cost per ULD processed which is attributable to the 7 percent increase in the buildup labor required per ULD handled.
- Increased stacking efficiencies can prolong the life of existing terminals for as long as half a decade if the rate of flow increase does not exceed 8 percent per annum.
- Existing air cargo terminals, on the average, can handle only one wide-body cargo aircraft on their cargo terminal ramps.
- The phasing out of narrow-body cargo aircraft and increased use of more efficient and productive wide-body cargo aircraft will require either upgrading of cargo terminal ramps, establishment of remote facilities, revamping of existing cargo terminals, or all of these.

The emphasis on greater percentages of container handling in this study is well founded as evidenced by the increasing incidence of consignor-loaded container cargo. This now averages 40 percent among all surveyed carriers and reaches peak levels of 78 percent. The transfer of unitizing activity and costs to the shipper is conducive to increased terminal flow levels and lower air terminal operating costs. To compensate for this cost transfer, the shipper is offered incentive tariff reductions greater than his additional costs. Other compensating considerations include the following:

- More positive in-transit control and assurance of damage-free/loss-free delivery to consignee
- Limited availability and high cost of land at airport which limits cargo terminal expansion
- Extreme surface congestion at airports during prime time freight arrival/departure which can be reduced by handling container loads rather than individual pieces and shipments

The analysis herein spans the range of operation from the present 40 percent average consignor-loaded container handling done by the airline to 70 percent and 90 percent projected levels. These are also paralleled by different degrees of mechanization. Other considerations are international import processing, hazardous and high-value cargo, company-owned materials, perishables, and interline and intraline cargo.

Approach to Cargo Terminal Analysis: The conditions and assumptions outlined below define the basic framework within which analyses and the effects of terminal mechanization and productivity were conducted. Various sizing parameters were used to effectively describe flow growth levels for all-freight carriers, combination carriers, and belly-freight-only carriers. Where applicable, the considered parameters were projected into the 1990 framework to allow a subjective view of the effectiveness of present terminals operating into that time period and of the progressive developments that must occur during the interim.

System processing requirements were evaluated on the basis of three representative terminal and aircraft utilization concepts.

- All-freight operator using both wide- and narrow-body aircraft with terminal capability to concurrently service five aircraft. The ramp is established as being capable of handling no more than two wide-body aircraft at a time. The cargo terminal is considered to have a high level of mechanization.
- Combination operator using both wide- and narrow-body aircraft with terminal capability to concurrently handle three aircraft but no more than one wide-body at a time. A medium level of mechanization is assumed for the cargo terminal.
- All-belly freight operators using wide-body aircraft without the ability to service any at the cargo terminal site. With these operators, the service is accomplished with dolly trains moving the containerized cargo between the terminal and the aircraft loading/unloading site at the passenger ramp. Mechanization of the cargo terminal is assumed at medium level.

Each of these terminal utilization concepts is examined by varying the flow composition to determine the effect of increased forwarder involvement in bulk buildup, breakdown, and containerization. In this analysis, three levels of consignor-loaded (shipper-loaded) containers (CLCs) are considered.

- Forty percent of the total flow both in and outbound are CLCs. Fifty percent of the total inbound/outbound flow is bulk freight delivered and picked up by forwarders or individual shippers. Ten percent of the total inbound/outbound flow is interline and intraline transfer consisting of both bulk and full-container shipments.
- Seventy percent of the total flow inbound and outbound are CLCs. Twenty percent of the total flow inbound and outbound is bulk. Ten percent of the total flow is transfer cargo of the same mix as mentioned above.
- Ninety percent of the total flow processed through the terminal are CLCs and is, therefore, representative of an all-container operation. In other words, this system does not process or handle an appreciable or noticeable amount of bulk cargo within the terminal. All buildup and breakdown is performed by the forwarder at his facility. In this case, the airlines' cargo-handling function is reduced to a minimum with only the breakdown/buildup operations associated with interline and intraline remaining. The latter 10-percent increment completes the total flow through the terminal.

Export/import cargo will comprise 27 percent of the total terminal flow in 1990. This portion of the air cargo movement was projected to remain essentially a constant percentage of the total flow between now and 1990.

All three terminal utilization concepts were varied by area-related flows: CLC, imports, and bulk inbound and outbound.

All forwarder pickup and delivery times were assumed to remain equivalent to the following 1976 trends:

- For all-freight operators, the pickup peak period and delivery peak period are 0500-1100 hours and 2000-0200 hours respectively.
- For combination operators, the peak scheduling is 0800-1400 hours for pickup and 1800-2200 hours for delivery.
- For all-belly freight operators, the peak scheduling is 0730-1100 hours for pickup and 0330-0730 and 1800-2100 hours for delivery.

In a similar manner, the dock times required to service these forwarders were projected to be equivalent to the following values determined to be the best achievable in 1976.

- Forwarder transfer of bulk at the terminal dock pickup or delivery consumes 20 minutes.
- Pickup or delivery of CLC unit load devices (ULDs) requires 7 minutes.
- Dock operations require one man per customer serviced.
- The bypass processing of CLC ULDs requires only one man per customer.

Although results of the terminal surveys show that bulk buildup and breakdown of pallets and containers required three men per each ULD processed, the time required for these two operations varied. As a result, the following incremental times are used in the analysis.

- At an operating efficiency of 20 percent, the buildup of a ULD by an optimum of three men requires 54 minutes.
- Comparably, the breakdown of a ULD by three men requires 36 minutes with the same 20-percent assumed efficiency.

Due to the nature of air cargo flow, terminal space and operations must meet varying storage requirements dictated by the types of cargo movement being handled. The analysis considers the effect of these requirements in terms of representative values and procedures. For instance, all international import cargo is stored under bond within the various terminals except for the all-container terminal where customs clearance procedures are shifted to the forwarder. The following incremental times are utilized as representative of this function.

- 1976 average import storage of 3 days provides the comparative base.
- One and one-half days import storage is considered as an optimum achievable storage time, the best that can be achieved without customs preclearance.

Terminating domestic bulk is stored within the terminals for an average time of 2.5 hours. On the other hand, outbound bulk is stored for only 1.5 hours. Outbound domestic CLC units are stored an average of 0.5 hour, while outbound international CLC requires a 2-hour storage time due to the additional handling and air waybill documentation. For the high-mechanization computerized terminal, international outbound requires no more time than does the domestic, 1.5 hours. In addition, there are certain special requirements that are considered to be accommodated as follows:

- Transfer cargo both intraline and interline are stored for 6 hours.
- Perishables are stored in refrigeration units.
- Security cages are used for storage of valuables.
- High-risk and restricted articles are stored in separate areas.
- The optimum preflight cutoff times used for acceptance of the various types of cargo are 1.5 hours for bulk domestic cargo, 3 hours for bulk international cargo, 2 hours for international CLC ULDs, and 1 hour for domestic CLC ULDs.

In order to analyze terminal operations, it is necessary to establish representative values that define the characteristics of the shipments flowing through the terminals. These defining characteristics include the average net weight per cargo module ULD, weight per shipment delivered by the forwarder, and the number of pieces per shipment. The necessary representative values were derived from Reference 9. Results of the CLASS terminal surveys indicate little or no change in these data since 1974, and it is anticipated that this trend will continue over the considered time period. The values used are as follows:

- Average weight for all ULDs carried, Type A and others, is 1565 kg per unit.
- The average number of shipments per ULD is 7.05 for all-freight and combination carriers.
- The average shipment consists of 6.5 pieces and weighs 222 kg for all-freight and combination carriers.
- The stacking efficiency is 53.7 percent for current operations. The achievable maximum stacking efficiency attainable is 87.4 percent for Type A and smaller ULDs.
- The average weight of Type A and other ULDs at the 87.4 percent achievable maximum stacking efficiency is 2624 kg.
- The average weight for 6 meter M2-type containers stacked at a 90 percent maximum practical efficiency is 6760 kg.

- The average number of pieces per shipment for belly-freight carriers is 3.2, and the average shipment weight is 59 kg.
- The average number of shipments delivered and picked up per forwarder is four.

Combining the cargo flow forecasts of Section 2, Volume 3, with the airport growth forecasts acquired during the terminal surveys indicated an 8-percent-per-annum growth rate to be a representative value for terminals during the 14 year period from 1976 to 1990. This amounts to a 2.94 increase in flow level by 1990.

The preceding data comprise the constants and variables considered representative for the evaluation of the present state of air cargo terminals with respect to 1990 requirements. In summary, the variables used which most diversely affect the terminal flow are

- Terminal mechanization - heavy, moderate, minimal
- Terminal type - all freight, combination, belly freight
- Percent consignor-loaded containers handled - 40 percent (existing), 70 percent, 90 percent of total flow
- Aircraft type - narrow body, wide body, CXX.

Freighter Terminal 1990 Assessment: Terminals operated by all-freighter carriers have a high degree of mechanization which enables high numbers of ULDs to be processed. The study surveys indicated that these terminals appear to be operating at or near 70 percent capacity with little chance for accommodating increased flow levels without physical changes to their facilities. Using maximum functional capabilities from Figures 3-11, 3-12, 3-13, 3-18, and 3-19 and evaluations of model terminals at flows short of saturation indicates that many of these existing terminals are processing flows at 30 percent to 50 percent of their theoretical capacities. Although operation at these levels is not economically realistic, a 50-percent improvement is feasible and within reason. This improvement can be arrived at through procedural changes and use of state-of-the-art equipment.

Figure 3-20 depicts the relationship between increasing mechanization,

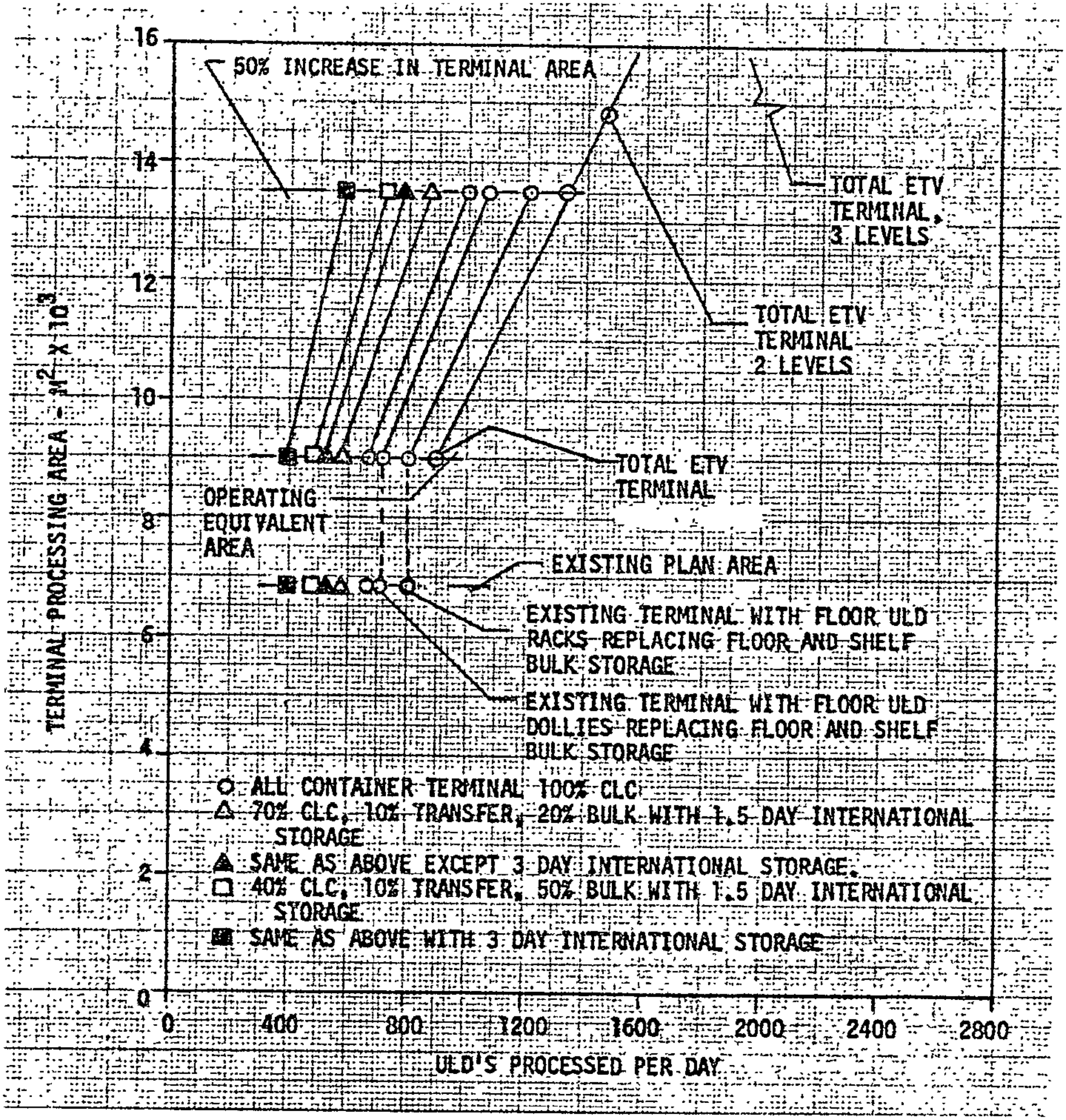


Figure 3-20. Maximum Mechanization Terminal All-Cargo Flow Area Relations

decreasing bulk handling, and facility area requirement for an all-freight carrier. The difference between the operating equivalent area and the existing plan area is a normalization adjustment to account for areas not included in the basic plan area. The more complex systems possess high-productivity, area-conservative apparatus. This model employes a multilevel ETV stacker, and a four-level narrow-aisle forklift system. The use of vertical storage results in the additional ULD capability. The horizontal movement, as indicated, is a measure of productivity increase. The far left side plot is representative of 1976 operations which consisted of 40 percent CLC (customer/shipper-loaded containers), 50 percent bulk cargo, 10 percent transfer cargo, and 3 day international import inbond clearance. By reducing the inbond clearance time to 1-1/2 days, which is exceptional by today's averages (but nonetheless possible), a 22 percent increase in processable flow could be generated. This is illustrated by the second plot from the left. Further, by decreasing the amount of bulk handled and varying the inbond clearance time between 3 and 1-1/2 days, 32 percent and 45 percent increases in flow could be achieved.

Finally, by converting to complete containerization and the most productive level of mechanization, an increase of 127 percent could be realized. Although these levels are based upon highly efficient, well-maintained and disciplined operations, the relative productivity increase with an existing system should be achievable unless other adverse conditions arise.

Taking a further step with this terminal and its future operation, Figure 3-21 presents a larger reproduction of the area of interest from Figure 3-20 with the addition of projected 1990 flow levels. The base represents the present operating equivalent terminal area and any horizontal movements are indicative of no change in processing area. The diagonal or plot lines represent the result of either increased flow or area for the specific processing conditions. The vertical lines are key indicators. Each vertical line represents the operating level of a terminal today projected at a rate of 8 percent per annum to its 1990 level. For example, assume that the terminal has the same level of mechanization, bulk/CLC processing, and the same types of ULDs which are no greater in size than an M1 (3 meter

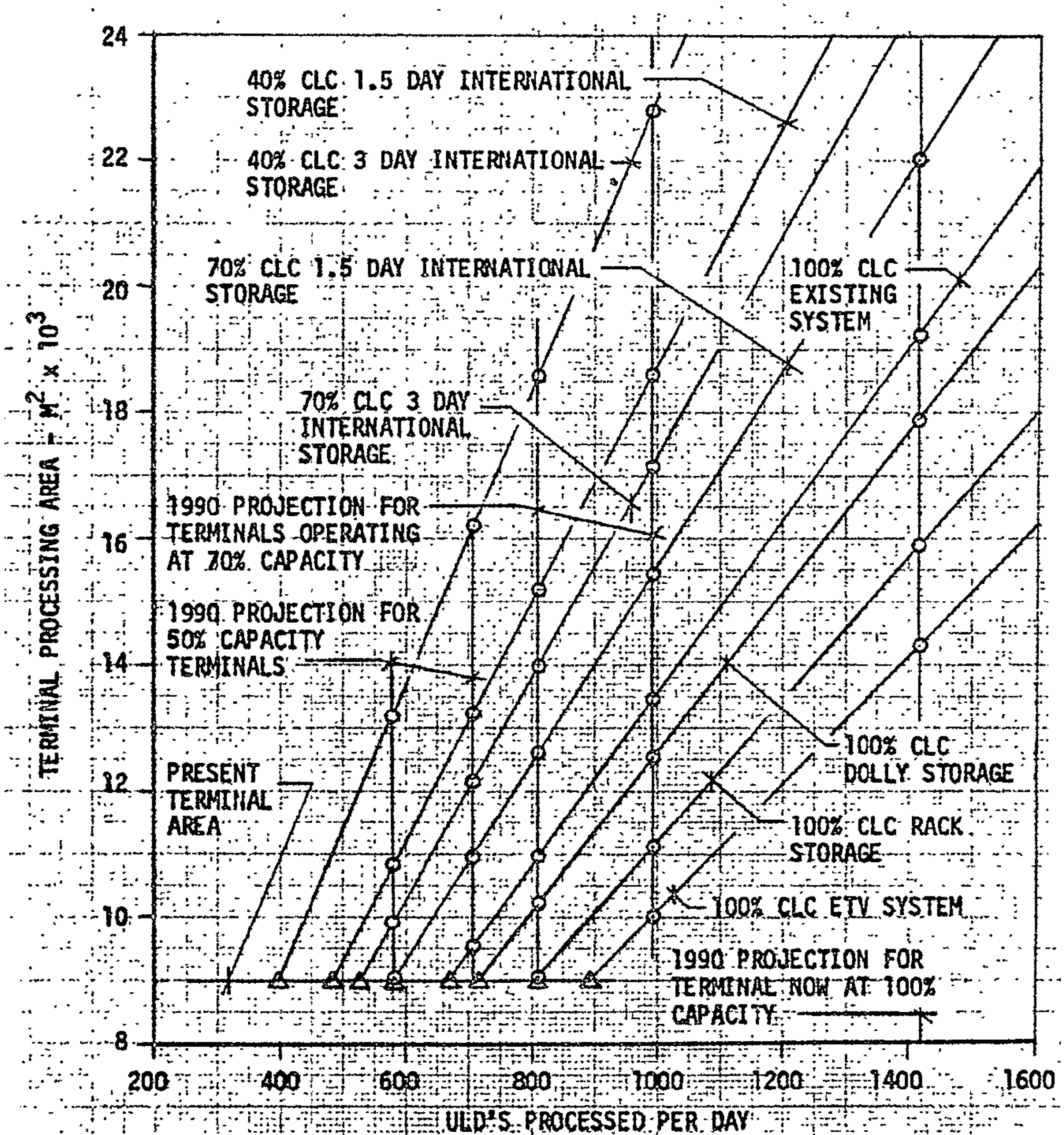


Figure 3-21. 1990 Terminal Comparison, All Freight

length) container. If this terminal is currently operating at 50 percent of its capacity processing 198 ULDs now and the expected growth rate of 8 percent per annum is to be realized, it would be processing 579 ULDs in 1990. This 1990 level is represented by the left-most vertical line. Each diagonal line it crosses above the base line represents the change in terminal area required to operate under those particular CLC and storage time performance levels. The system to the right of where the vertical line crosses the base terminal area horizontal line represents the required CLC/storage time if there is to be no change in the existing terminal area. Figures 3-22 and 3-23 separate the 3 and the 1-1/2-day international import variation in the systems respectively. Also, the 1976 operating percent projected at 8 percent per annum to 1990 is shown along the terminal base lines. In both of these figures it should be noted that any system operating at 34 percent or less capacity today will not require a change in terminal philosophy. This is assuming that 3-day import storage is not exceeded nor less than 40 percent consignor-loaded containers are handled.

By inspection, a terminal meeting the base requirements and operating at 70 percent capacity today will be unable to absorb the expected growth if it is now clearing imports within 1-1/2 days. An 11-percent increase in processing area would be needed if the 1990 flow make-up was 100 percent containerization and a full ETV system were incorporated. To operate this same system at 70 percent CLC, a 71 percent increase in processing area would be required. The only system which will accommodate this high flow level without a growth in processing area is an all-container ETV operation with more than one stacking level. Tables 3-6 and 3-7 list area requirements for 3 and 1-1/2 day import storage times for the various types of all-freight carrier systems studied. Both indicate the relative importance of mechanization as correlated with the increases in processing area for different flow mixes. A present air cargo terminal operating at 50 percent of maximum processable volume could accommodate the projected flow if it consisted of 70 percent consignor-loaded ULDs (CLCs) and import storage was no greater than 1-1/2 days. This is the minimal change for the existing 3 day import storage system of Table 3-6. For the 1-1/2 day import storage system of Table 3-7, the minimal change for an existing 50 percent capacity terminal would necessitate a 100-percent containerized operation where dolly storage could be used.

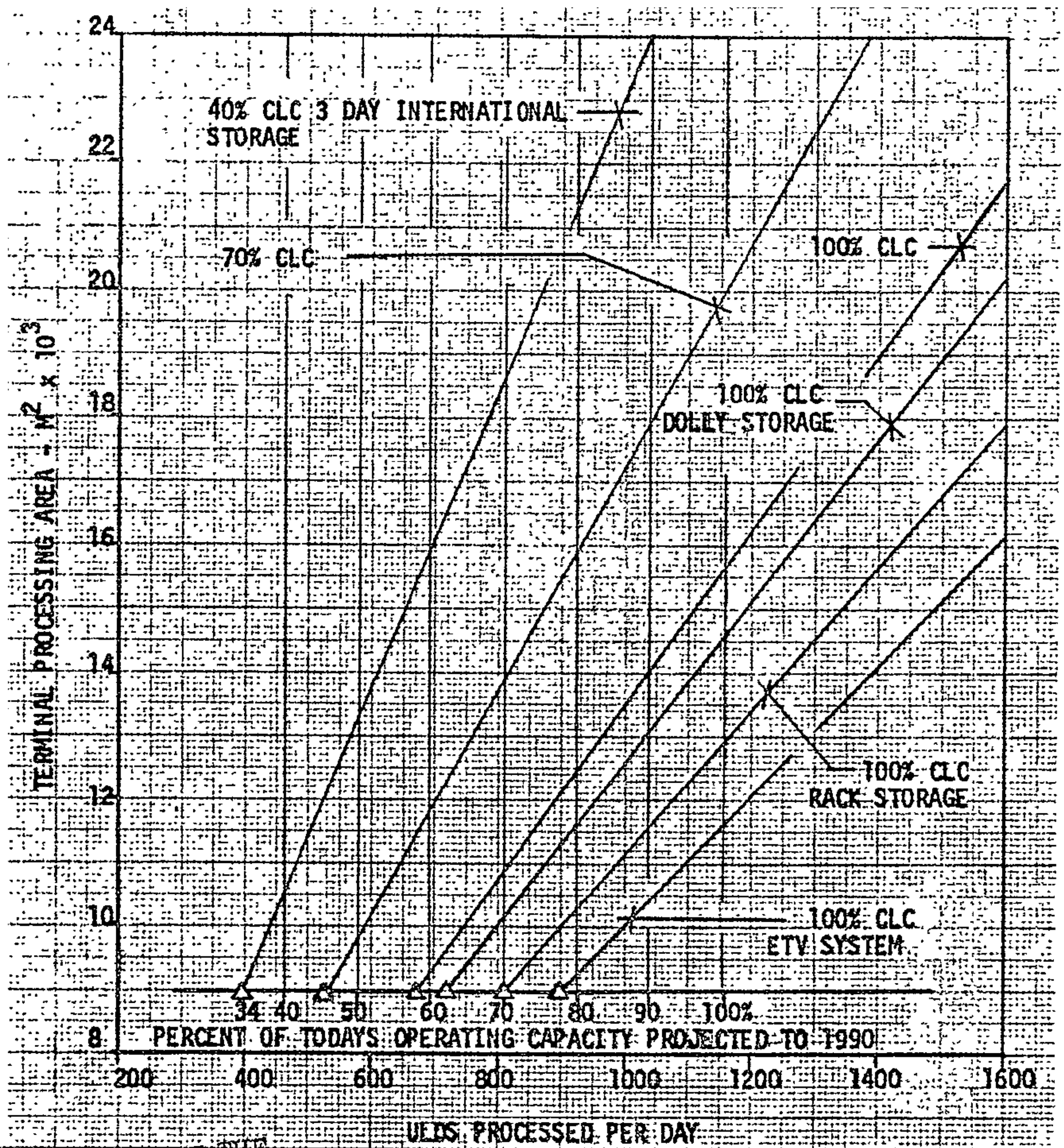


Figure 3-22. Projected Flow Levels for 1990 for Various Percent Operations Today at 3-Day Storage

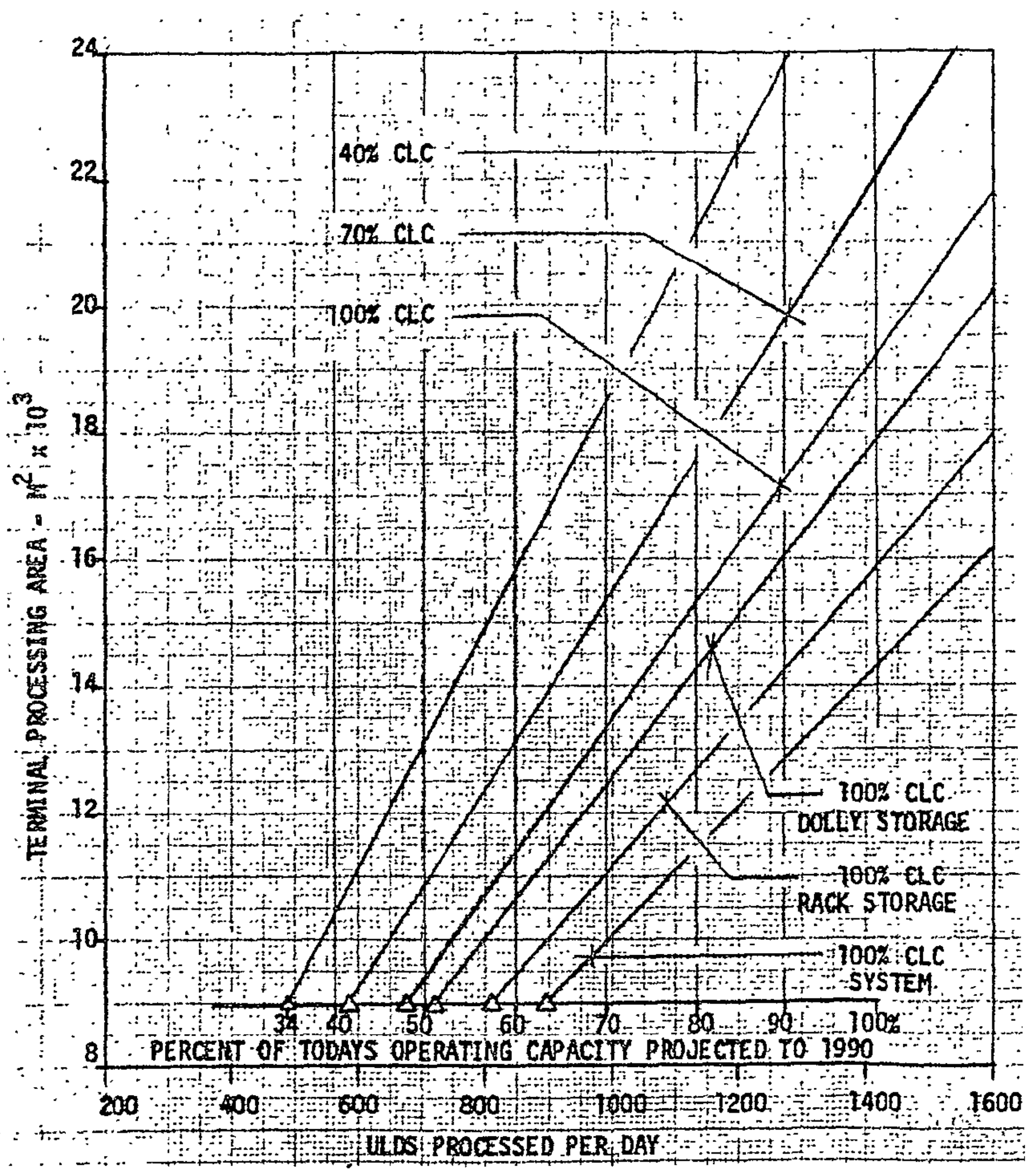


Figure 3-23. Projected Flow Levels for 1900 for Various Percent Operations Today at 1.5-Day Storage

TABLE 3-6

TERMINAL VARIATIONS REQUIRED FOR 1990 FLOW LEVELS FOR ALL-FREIGHTER TERMINAL (3-DAY INTERNATIONAL STORAGE)

Flow Parameters	Operating Percent of Terminal Capacity					
	50%		70%		100%	
	ULD/Day	Area M^2	ULD/Day	Area M^2	ULD/Day	Area M^2
Present Flow	197	9000	276	9000	395	9000
1990 Required Flow @ 8% Annual Growth	579	-	811	-	1157	-
% Shipper Loaded with Varying International Import Dwell Time		Required Area		Required Area		Required Area
40% 1.5 Days	579	10 789	811	15,112	1157	21 559
40% 3 Days	579	13 192	811	18 478	1157	26 361
70% 1.5 Days	579	9000	811	12 628	1157	18 015
70% 3 Days	579	9964	811	13 956	1157	19 910
100% ULDs, No Warehousing	579	7813	811	10 943	1157	15 611
100% ULDs, No Warehousing Dolly Storage	579	7309	811	10 237	1157	14 604
100% ULDs, No Warehousing Rack Storage	579	6457	811	9045	1157	12 903
100% ULDs, No Warehousing ETVs, No. of Levels 1	579	5835	811	8174	1157	11 661
2	579	3497	811	4899	1157	6989
3	579	2494	811	3494	1157	4984

TABLE 3-7

TERMINAL VARIATIONS REQUIRED FOR 1990 FLOW LEVELS FOR ALL-FREIGHTER TERMINAL (1.5-DAY INTERNATIONAL STORAGE)

Flow Parameters	Operating Percent of Terminal Capacity					
	50%		70%		100%	
	ULD/Day	Area M^2	ULD/Day	Area M^2	ULD/Day	Area M^2
Present Flow	241	9000	338	9000	483	9000
1990 Required Flow @ 8% Annual Growth	708	-	993	-	1418	-
% Shipper' Loaded ULDs with Varying International Import Dwell Time		Required Area		Required Area		Required Area
50% 1.5 Days	708	13 192	993	18 503	1418	26 422
40% 3 Days	708	16 132	993	22 625	1418	32 308
70% 1.5 Days	708	11 024	993	15 461	1418	22 078
70% 3 Days	708	12 184	993	17 087	1418	24 400
100% ULDs, No Warehousing	708	9553	993	13 399	1418	19 133
100%, No Warehousing Dolly Storage	708	8937	993	12 534	1418	17 899
100%, No Warehousing Rack Storage	708	7896	993	11 074	1418	15 814
100%, No Warehousing ETVs, No. of Levels	708	7135	993	10 008	1418	14 291
2	708	4276	993	5998	1418	8565
3	708	3050	993	4278	1418	6109

The reason for a greater sensitivity to CLC increase is that no benefit from reduced storage time can be gained without near elimination of bulk handling. The system in Table 3-7 is already processing 22 percent more cargo than that of Table 3-6. The information from these tables is also expressed in Figure 3-21.

Complete cost data for each system variation are presented based on 1976 dollar values. Table 3-8 summarizes the differential change in cost per ULD processed for different variations from the basic all-freight system. In Table 3-8, the cost data are based on capital investment only with terminal area being held constant. Labor costs were not included because the surveyed airlines did not provide sufficient cost data related to each function. However, manpower was examined for each system, and the differential percentages in personnel levels per ULD processed are listed in Table 3-9. Relative manpower between levels is not constant because of the additional aircraft concurrently being handled to meet system capability.

Item 1 of Table 3-8 is the basic all-freight system equivalent to today's operations with 40 percent CLC and 3 day international import storage. All other systems are listed in order of increasing mechanization and decreasing amounts of bulk handling. The cost percentages listed are with respect to the basic system. The 100-percent container system consisting of a three-level stack ETV has a cost per ULD processed equivalent to 28.4 percent of the basic system. For the all-freight system, an 18 percent reduction is accomplished by processing imports in 1-1/2 days rather than 3. Greater relative reductions in cost per ULD are realized from increases in mechanization than are realized from reductions in the amount of bulk handled. Once System 5 or 100 percent operation has been reached, bulk cargo no longer need be considered. These cost values strengthen the containerization/mechanization/reduced import holding time postulate as a means to lower expenses.

Table 3-9 is similar to the preceding cost table but lists the percent of the basic system that each system variation requires in terms of personnel. As the systems vary in complexity or increasing mechanization, the personnel per ULD handled decreases. Some of the next higher levels of mechanization

TABLE 3-8

RELATIVE COST PER ULD PROCESSED FOR SYSTEM TYPES OVER ALL FLOW LEVELS

All-Freight Carrier		
Processing Systems		Unit $ Value
1.	40% CLC, 3-Day International Import Storage	100% Standard Unit
2.	40% CLC, 1.5-Day International Import Storage	81.6%
3.	70% CLC, 3-Day International Import Storage	75.3%
4.	70% CLC, 1.5-Day International Import Storage	67.7%
5.	100% Container System Single Level ETV	59.9%
6.	100% Container System Existing System Without Modification	57.7%
7.	100% Container System Additional Dollies Added to Existing System	54.9%
8.	100% Container System Additional ULD racks Added to Existing System	45.9%
9.	100% Container System Double-Level ETV	38.5%
10.	100% Container System Three-Level ETV	28.4%

TABLE 3-9

RELATIVE MANPOWER PER ULD PROCESSED FOR SYSTEM TYPES AND PEAK FLOW LEVELS

All-Freight Carrier		
Processing Systems		Unit Value
1.	40% CLC, 3-Day International Import Storage	100% Standard Unit
2.	40% CLC, 1.5-Day International Import Storage	91.4%
3.	70% CLC, 3-Day International Import Storage	38.2%
4.	70% CLC, 1.5-Day International Import Storage	35.6%
5.	100% Container System Single-Level ETV	33.7%
6.	100% Container System Existing System without Modification	24.6%
7.	100% Container System Additional Dollies added to Existing System	25.3%
8.	100% Container System Additional ULD Racks added to Existing System	23.3%
9.	100% Container System Double-Level ETV	27.8%
10.	100% Container System Three-Level ETV	20.1%

increase the personnel in relation to the preceding mechanization or level of containerization. This is due to the addition of more aircraft to provide the necessary lift capability. The personnel involved in developing the percentages are only those directly related to processing cargo and loading the aircraft. All these systems were evaluated at maximum productivity with minimum manpower. Table 3-9 shows that a large increase in productivity can be achieved by decreasing the amount of bulk handled. This is represented by a 62 percent reduction in the number of personnel per ULD handled when going from System 1 to System 3. In advancing from 70 percent to 100 percent CLC systems, an additional 4 percent is achievable by reducing bulk. From System 5 (100 percent container operation), the reductions in personnel are attributable to increased mechanization. The relative merits contributed by reduction in piece handling (System 1 to 5) are 3.6 times greater than those derived from mechanization (System 6 to 10).

A composite of terminal cost and personnel per ULD processed is depicted in Figure 3-24. This clearly shows the reductions which can be gained through progressive changes. The basic system is at the upper left and the highly mechanized systems are those at the lower right. All systems expressed will process no ULD larger than an M1 (3 meter length) container. The projected terminals for 1990 will be handling 70 percent or more CLCs and could process 600 or more ULDs per day. The E1 positions in this figure do not show a reduction below the preceding mechanization position 10. The reason for this is that the cost or personnel per ULD processed is directly related to the number of ULDs handled but is also tempered by the airside handling ability. The effect on personnel per ULD is greater than on cost per ULD. This is because the addition of another concurrently serviced freighter requires an additional ground handling crew. By using backup equipment available, only a small addition to terminal ramp cargo-handling equipment is required; and because of the relative difference in ground handling versus in-terminal equipment costs, there is not as noticeable an increase as with the personnel change. The plots level off beyond the 700 ULDs processed per day because of the effect of added infrastructure required for each additional aircraft.

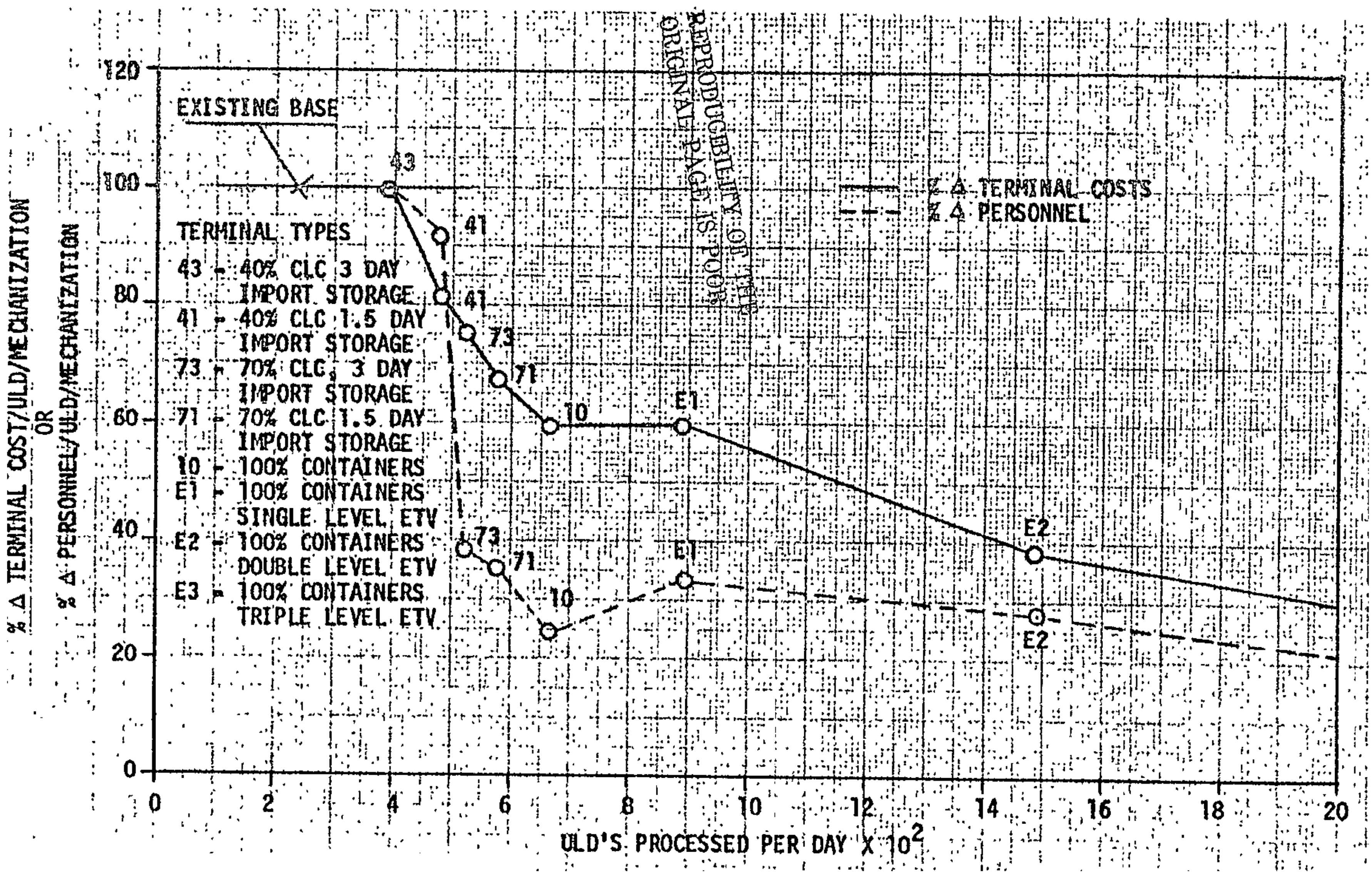


Figure 3-24. Operational Cost and Personnel Variation for All-Freight Carrier

Combination Carrier Terminal 1990 Assessment: Evaluation of the combination carrier operating a terminal at medium mechanization shows that the same advantages may be gained by mechanization and/or containerization as are possible in highly mechanized all-freight terminals. Medium mechanization was chosen for two reasons. First, medium levels of mechanization are typical among a majority of the combination carriers. Second, a comparison between medium and high mechanization would be indicative of related benefits to be derived from upgrading terminals having lower bases of operation.

Figure 3-25 expresses the variation in terminal processing areas versus ULDs processed for different system types. The same system types and operational parameters, such as percent of containerization, mechanization, and international import storage times, were adhered to as were used in the all-freighter operation. The new factors introduced are related to belly freight expressly supporting passenger aircraft operations. This figure shows the rather small increase in processing area that is produced by the type and level of mechanization. The medium mechanization terminal only displays a 6-percent increase between the existing plan and operating equivalent areas.

There are two distinct differences which are evident in Figure 3-25. The 100-percent container operations using either all-dolly or single-level storage racks are to the left of the present operational level point, which suggests that these types of operation are less efficient than the present. The present systems are conveyorized and more area productive than dolly-tug or rack-transporter operations. Also, the type of freight handled and physical shape of the terminal are detrimental to usage of dollies or racks. The terminal shape used for evaluation of combination carriers was very narrow and long which is typical of the existing carrier facilities. The stationary pallet/container conveyor raceways prevalent in many of these are more area productive than dollies or stationary storage racks and more productive than single-level ETV systems not capable of being used for ULD buildup or breakdown functions. The number of ULDs processable per unit time for raceways is less than for ETV rack systems, but lack of the ETV itself releases that area for other uses.

The other systems duplicate patterns established for the all-freight

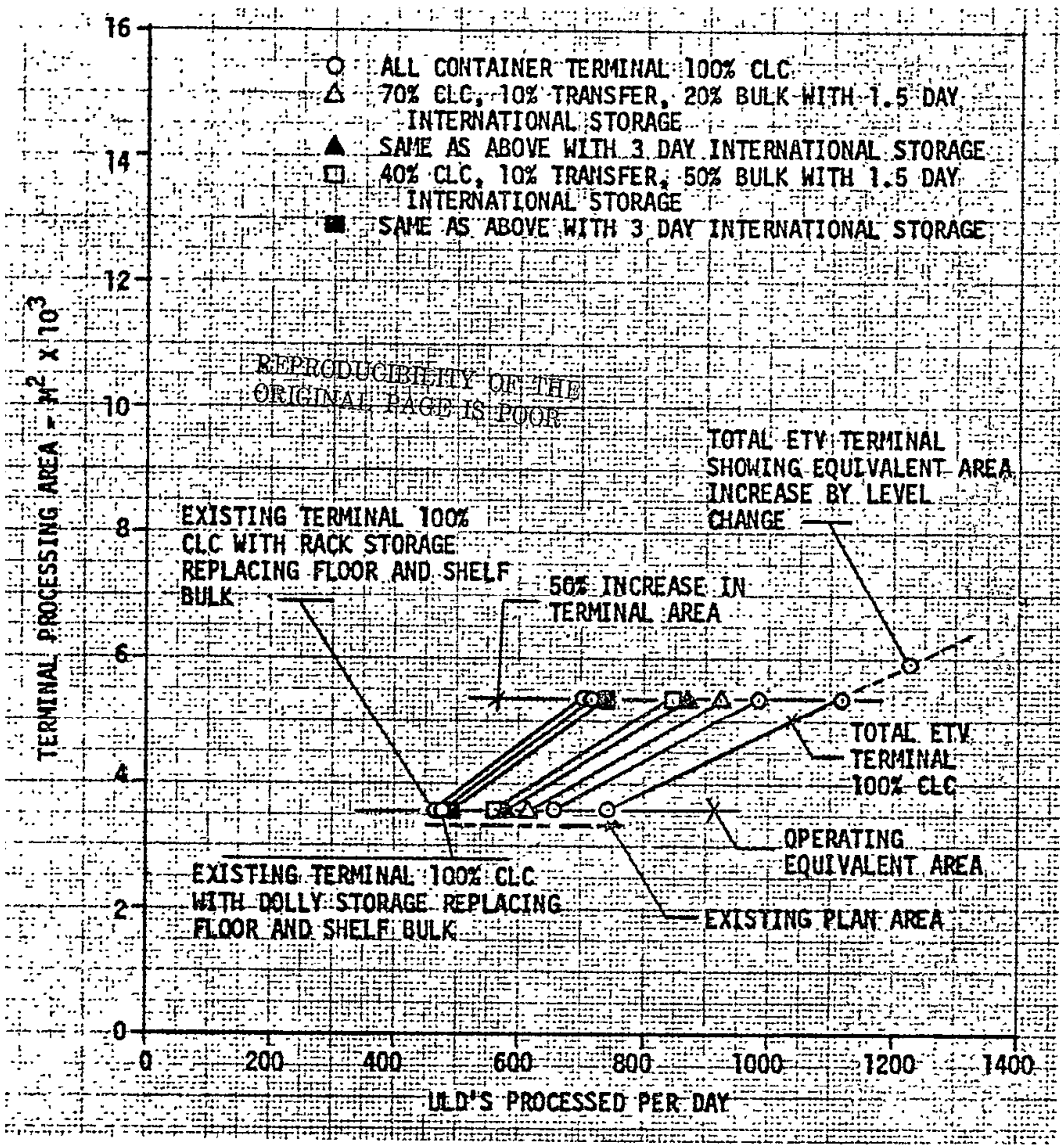


Figure 3-25. Medium Mechanization Terminal Combination Main Deck and Belly Freight Carrier Flow Area Relations

operator (Figures 3-21, 3-22, and 3-23). High-mechanization ETV systems are the most area efficient preceded by varying mechanization associated with reduction in bulk handling and import storage time. The 50-percent increase in area is used only as a convenient upper level to establish the system area/ULD relationships. ULD flow for the existing 40 percent CLC, 3 day import storage operation varies directly with the area, whereas the all-ETV 100 percent container system with no import storage varies at a rate of 1.03 ULDs processed to one unit of area. The improvements which can be made in conjunction with operational trends and expected flows for 1990 are based on these linear relationships.

Figure 3-26 expands the Figure 3-25 data to allow presentation of present terminal capacities projected at 8 percent per annum to 1990. The format used here is similar to that used in Figure 3-21. The existing terminal productivity can be increased 33 percent without a change in area simply through elimination of bulk handling and import storage. If additional expenditures are made for more highly mechanized equipment, an additional 12 percent increase in flow is attainable without expanding the terminal area. As shown on Figure 3-26, all similar terminals operating at more than 50 percent today may not be able to accommodate their projected 1990 flow without expansion in terminal area. These combination freight facilities operating at 70 percent capacity today would require a minimum area increase of 108 percent as compared to a 0-percent change in area for all-freight high-mechanization terminals processing only containers and with no import storage time penalty. If the flow for the all-freight terminal consisted of 40 percent CLC and 3 day import storage, a 106 percent increase in processing area would be needed.

The growth area problems inherent to the combination carrier terminal evaluated are listed in Tables 3-10 and 3-11. Both tables were derived in conjunction with Figure 3-26 and list the current flow, its relationship to the present terminal capacity, and the projected 1990 flow. The projected flow is listed for each system type along with the necessary area needed to accommodate the flow. For 3 day international import storage (Table 3-10), operating capacities of 50, 70, and 100 percent have been listed. Each shows the growth in area needed to allow handling of the number of units listed.

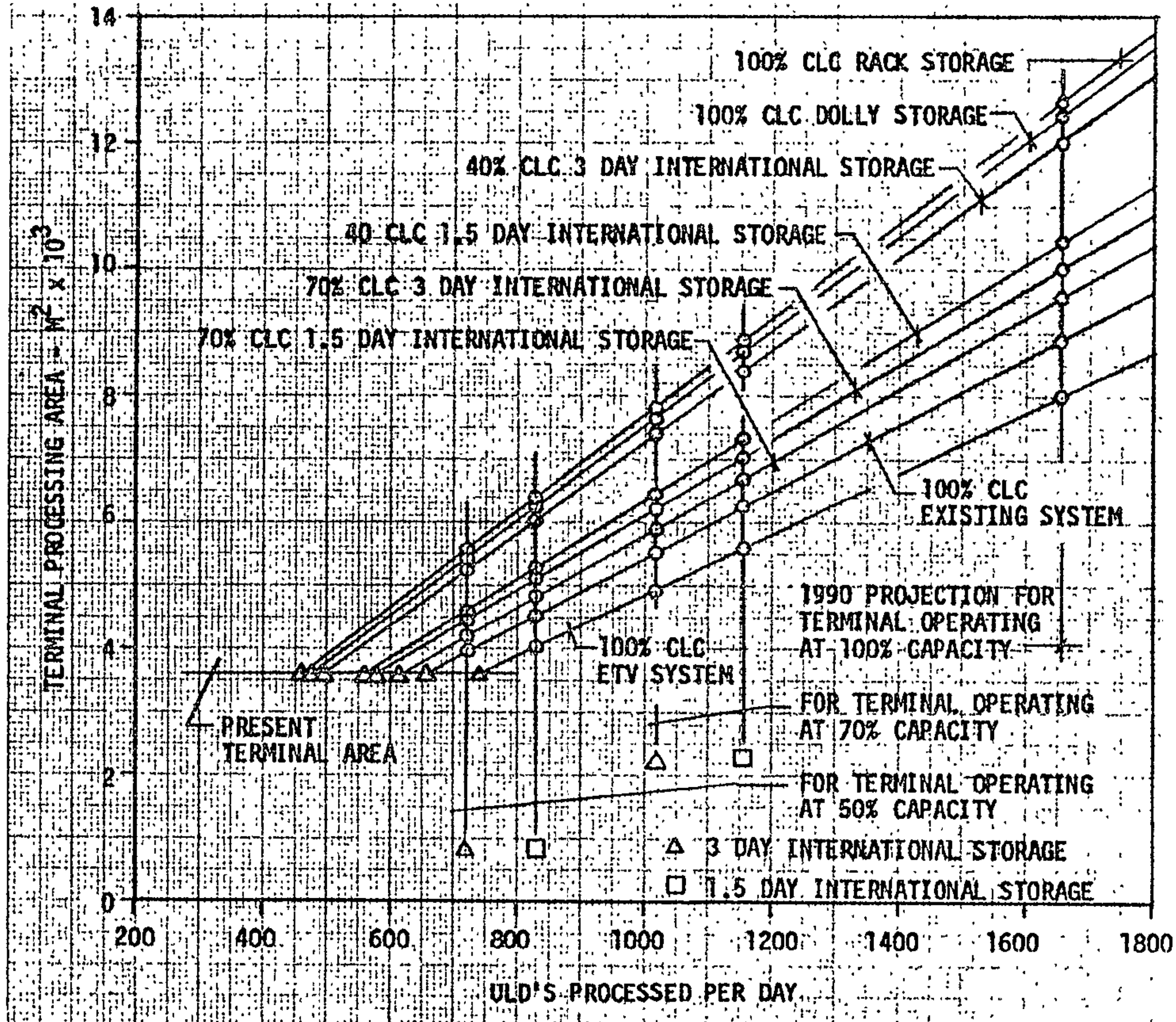


Figure 3-26. 1990 Terminal Comparison Combination Carrier

TABLE 3-10

TERMINAL VARIATIONS REQUIRED FOR 1990 FLOW LEVELS FOR COMBINATION CARRIER TERMINAL (3-DAY INTERNATIONAL STORAGE)

Flow Parameters	Operating Percent of Terminal Capacity					
	50%		70%		100%	
	ULD/Day	Area M^2	ULD/Day	Area M^2	ULD/Day	Area M^2
Present Flow	247	3549	346	3549	494	3549
1990 Required Flow @ 8% Annual Growth	725	-	1016	-	1447	-
% Shipper Loaded ULDs with Varying International Import Dwell Time		Required Area		Required Area		Required Area
40% 1.5 Days	725	4562	1016	6393	1447	9105
40% 3 Days	725	5198	1016	7284	1447	10 374
70% 1.5 Days	725	4177	1016	5854	1447	8337
70% 3 Days	725	4429	1016	6206	1447	8839
100% ULDs, No Warehousing	725	3916	1016	5488	1447	7816
100% ULDs, No Warehousing Dolly Storage	725	5394	1016	7559	1447	10 766
100% ULDs, No Warehousing Rack Storage	725	5498	1016	7705	1447	10 974
100% ULDs, No Warehousing ETVs, No. of Levels 1	725	3454	1016	4840	1447	6893
2	725	2434	1016	3411	1447	4858
3	725	-	1016	-	1447	-

TABLE 3-11

TERMINAL VARIATIONS REQUIRED FOR 1990 FLOW LEVELS FOR COMBINATION CARRIER TERMINAL (1.5-DAY INTERNATIONAL STORAGE)

Flow Parameters	Operating Percent of Terminal Capacity					
	50%		70%		100%	
	ULD/Day	Area M^2	ULD/Day	Area M^2	ULD/Day	Area M^2
Present Flow	282	3549	394	3549	564	3549
1990 Required Flow @ 8% Annual Growth	828	-	1157	-	1656	-
% Shipper Loaded ULDs with Varying International Import Dwell Time		Required Area		Required Area		Required Area
40% 1.5 Days	828	5210	1157	7280	1656	10 420
40% 3 Days	828	5937	1157	8295	1656	11 873
70% 1.5 Days	828	4770	1157	6666	1656	9541
70% 3 Days	828	5058	1157	7067	1656	10 115
100% ULDs, No Warehousing	828	4473	1157	6250	1656	8945
100% ULDs, No Warehousing Dolly Storage	828	6161	1157	8608	1656	12 321
100% ULDs, No Warehousing Rack Storage	828	6279	1157	8774	1656	12 558
100% ULDs, No Warehousing ETVs, No. of Levels 1	828	3944	1157	5512	1656	7889
2	828	2780	1157	3885	1656	5560
3	828	-	1157	-	1656	-

Table 3-11 recounts the same functions for 1-1/2 day international import storage. Both tables show the diminishing need for area as mechanization increases with the exceptions of dolly or stationary pallet container rack storage. Excluding those two, all others show expected reductions associated with conversion of 100 percent container handling and reduction in bulk. Comparing like systems with different import storage times shows a benefit of 12 percent reduction in area when the shorter storage time can be used. This is a smaller reduction in area than for the all-freight systems primarily because of the reduction in peak flow processing. There still is a predominance of flow tendered during the peak overnight period, but because of belly freight in predominantly daytime operations it has been reduced by 16 percent.

Table 3-12 lists the relative capital investment cost necessary for each different system as a percent of the basic system cost. These figures are based upon the cost per ULD processed. On a dollar basis, some of the increased mechanizations levels are less productive than the existing basic system. Steady reduction in cost/ULD follow hand in hand with reduction in bulk handling. Dolly and rack storage systems, even though handling all containers, are less productive. The terminal shape and dolly/rack storage requirements reduce the number of ULDs which can be handled. The single-level ETV system is also less productive. This is due to the high costs to implement such a system and to the reduced number of ULDs handled per unit area in a poorly sized terminal. However, multilevels on the ETV stacker system offset the shape restrictions and produce a greater reduction in cost per ULD.

Table 3-13 lists the personnel requirements for each system as a percent of the basic system. Productivity benefits are expressed as reduction in personnel per ULD handled. Relative manpower between levels is not constant because of the additional aircraft concurrently being handled to meet system capability. System improvements are consistent with Table 3-13, although the single-level ETV system is more productive than the basic system. This is because the terminal shape does not dictate the number of personnel needed to operate the equipment unless a great deal more manpower-dependent equipment must be added to offset it. The dolly/rack storage systems are more productive than the basic system but less so than the existing system operating at 100

TABLE 3-12

RELATIVE COST PER ULD PROCESSED FOR SYSTEM TYPES OVER ALL FLOW LEVELS

Combination Carrier		
Processing Systems		Unit $ Value
1.	40% CLC, 3-Day International Import Storage	100% Standard Unit
2.	40% CLC, 1.5-Day International Import Storage	87.6%
3.	70% CLC, 3-Day International Import Storage	84.2%
4.	70% CLC, 1.5-Day International Import Storage	79.9%
5.	100% Container System Single-Level ETV	109.0%
6.	100% Container System Existing System without Modification	74.7%
7.	100% Container System Additional Dollies added to Existing System	105.0%
8.	100% Container System Additional ULD Racks added to Existing System	102.0%
9.	100% Container System Double-Level ETV	67.8%
10.	100% Container System Three-Level ETV	49.1%

TABLE 3-13

RELATIVE MANPOWER PER ULD PROCESSED FOR SYSTEM TYPES AND PEAK FLOW LEVELS

Combination Carrier		
Processing Systems		Unit Value
1.	40% CLC, 3-Day International Import Storage	100% Standard Unit
2.	40% CLC, 1.5-Day International Import Storage	97.6%
3.	70% CLC, 3-Day International Import Storage	64.7%
4.	70% CLC, 1.5-Day International Import Storage	63.6%
5.	100% Container System Single-Level ETV	54.0%
6.	100% Container System Existing System without Modification	44.4%
7.	100% Container System Additional Dollies added to Existing System	54.0%
8.	100% Container System Additional ULD Racks added to Existing System	51.6%
9.	100% Container System Double-Level ETV	36.0%
10.	100% Container System Three-Level ETV	25.2%

percent containerization. This is directly due to the reduction in ULDs per unit area that can be handled.

Both Tables 3-12 and 3-13 when plotted graphically depict the effects of reduced bulk handling and elimination of import storage. Both the dolly and rack systems were omitted from Figure 3-27 because the physical terminal handicaps eliminate them as probable steps through which expansion will pass. Figure 3-27 displays the other points associated with increased mechanization and containerization. This figure is similar to Figure 3-24 for the all-freight carrier. The greatest productivity is associated with ETV-type systems, while the most pronounced reduction in cost and personnel is contributed by containerization. Combination carriers can handle the 1990 flow without increases in area if they can function with 100 percent containerization. Beyond 1990, massive capital expenditures may have to be made if growth continues. These medium mechanization terminals are height limited and do not have ETVs inside. These factors combined with the less-than-optimum terminal layouts are depicted by the E1 points in Figure 3-27. These points represent mechanizational levels that may have to be surpassed in order to handle the flow. If vertical expansion is restricted, as it is for many of the existing facilities, then new locations or other solutions may need to be sought. Despite the ability to handle and store more ULDs with an ETV system, it does not lend itself efficiently to the belly-freight ULDs. Many operators who handle belly-freight LD type ULDs prefer to move and perform all operations on dollies. This eliminates the intermediate on/offload of the containers from the dollies and their transport by forklift. Such systems, although eliminating handling time, are not area efficient. Terminals which will continue to train LD containers and dollies will need to expand in area before those operating ETV-equipped terminals.

Belly-Cargo Terminal 1990 Assessment: Belly-cargo system variations fluctuate much more widely than do either all-freight or combination freight carrier systems. Figure 3-28, depicting medium mechanization area flow relationships, shows a much wider range of ULDs processed per day. The maxium operating level with 40 percent CLC and 3 day import storage is less than that for the combination carrier, and the maxium number of ULDs

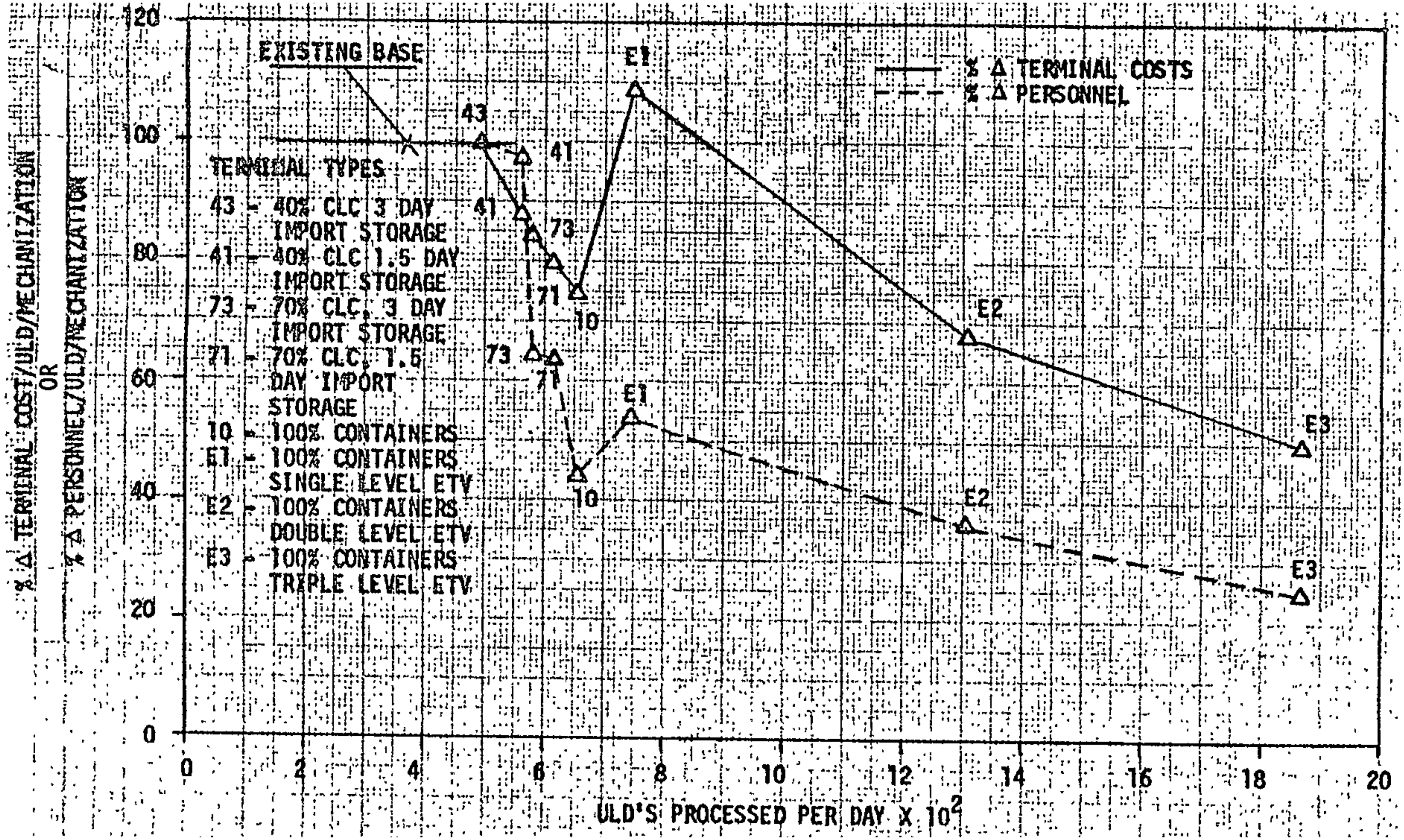


Figure 3-27. Operational Cost and Personnel Variation for Combination Carrier

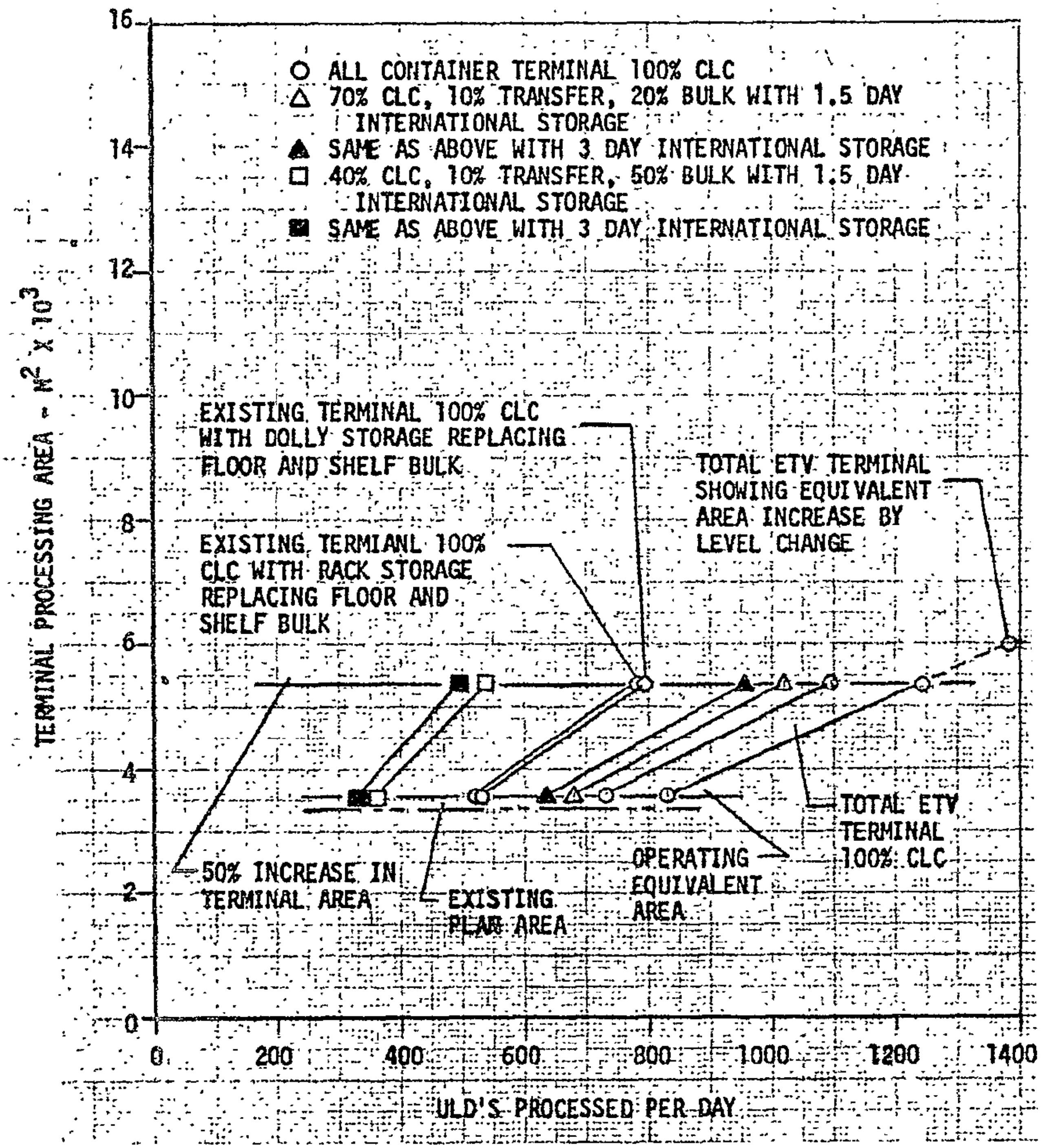


Figure 3-28. Medium Mechanization Terminal
All-Belly Cargo Carrier Flow Area Relations

processable by an ETV system is greater than that for combination carriers. The wide spread is a direct result of the leveling of daily peak cargo load and unload operations associated with passenger aircraft operations. The belly carrier has a nearly distributed flow over the scheduled operating period. The peak freight activity period for belly carriers is an average 26 percent lower than that of all-freight operators and 10 percent less than that of combination carriers. Constant or nearly even flow to, from, and through the terminal allows better area utilization. Nearly one-half of the daily flow is collected over a single 8 hour period leaving the rest of the time for collection and delivery of the remaining cargo.

Figure 3-28 indicates that a 150 percent increase in processed flow is possible without an increase in terminal area. The gain is three times more than that for combination carriers. The same medium-mechanization terminal used for the combination carrier evaluation is also used for the belly carrier. This means that the same physical boundaries affecting systems and equipment apply. The difference in capacities may then be attributed to freight accumulated per area per unit of time. Consequently, with like equipment and maximum number of ULDs per hour per function, the longer the time period that this high volume of cargo can be tendered, the greater is the terminal capacity.

Belly-freight carriers have the highest probability of accommodating their 1990 projected flows. This is shown in Figure 3-29 by the vertical lines representing a 70 percent capacity terminal projected to its 1990 flow level. These lines cross the horizontal base line, which is the existing system, to the left of possible high-mechanization systems. Beyond the farthest system to the right, a growth in terminal area is necessary to accommodate additional flow. For the all-freight system only, the terminal operating at 70 percent capacity projected to 1990 from an existing 3 day import storage facility can handle the flow without area expansion. For a combination carrier only, an existing terminal operating at 50 percent capacity and 3 day import storage can be accommodated at its projected 1990 level without a terminal area increase. Since a majority of the surveyed terminals were at 70 percent of their saturation levels with low efficiency, most should be able to operate within current facilities through 1990. Projecting the 8

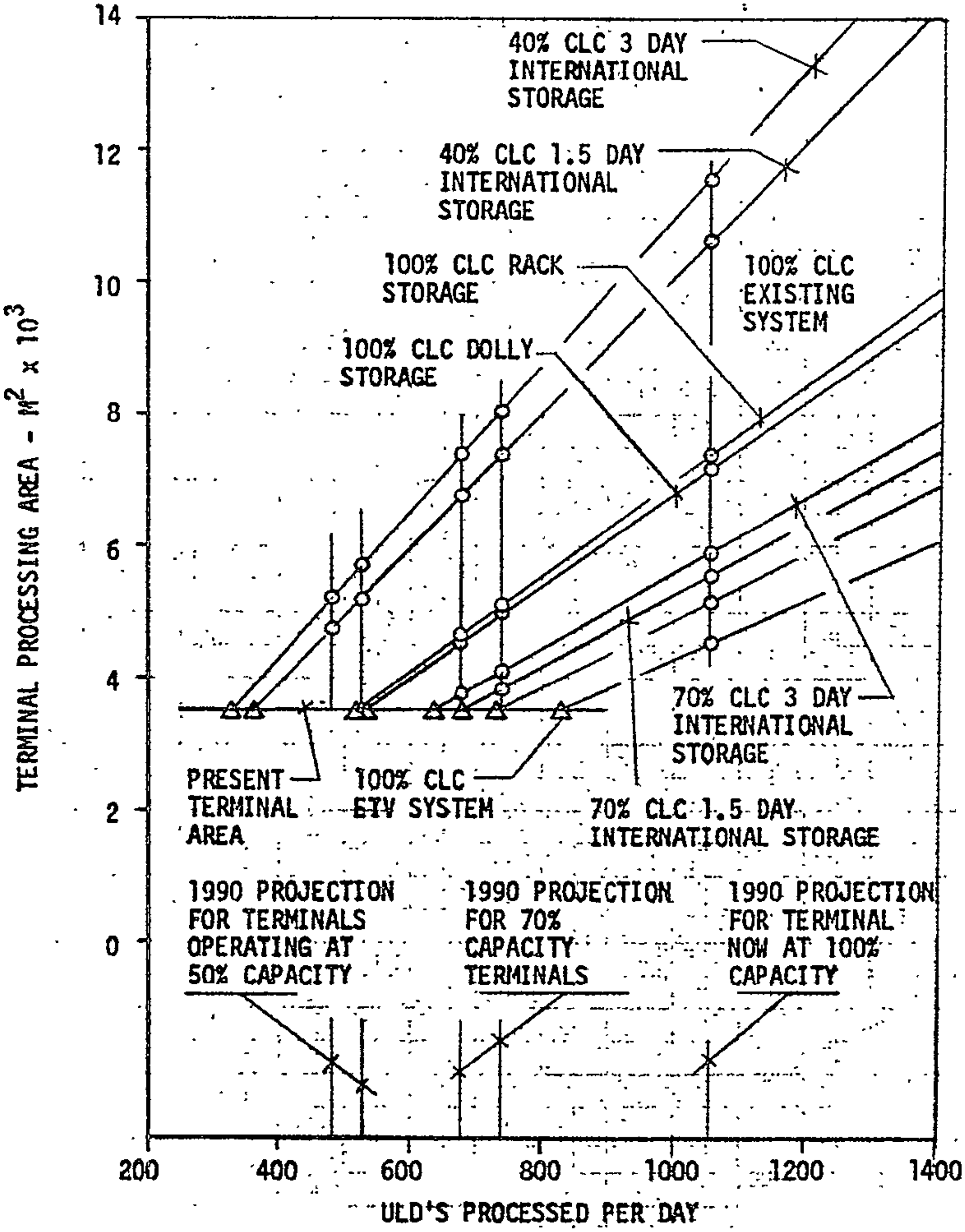


Figure 3-29. 1990 Terminal Comparison Belly Freight

percent annual cargo growth beyond 1990, by 1993 most of the current carriers operating at 70 percent in 1976 will have surpassed permissible flows that could be tendered with foreseeable high-mechanization terminals. Beyond 1993, new terminals/facilites/locations are foreseen.

By comparing Figure 3-26 with Figure 3-29 for combination carriers, it is noticed that the position of dolly and rack storage systems has changed. The belly-freight mix mainly consists of LD load units and a minor number of cargo pallets resulting in the handling of fewer ULDs per unit of time per area. Lower deck modules are usually processed on dollies or individual storage racks. These dollies and racks are rather randomly situated, thus tending to waste area. Dolly or storage rack systems can be more area-conservative when utilized separately.

Tables 3-14 and 3-15 list the area requirements for 1976 system levels as projected for 1990. Table 3-14 lists the requisites for systems based on a 3-day international import storage. For 50 percent-capacity terminals, the present area is adequate if a 70 percent container-handling level is assumed. The 70 percent-capacity terminals can suffice also with a 70 percent containerized system provided that a maximum import storage time of 1-1/2 days is not exceeded. Systems at full capacity today need to expand even if all inequities and inefficiencies are cleared away.

Table 3-15 is similar to Table 3-14 except that the basic system is currently assumed to be operating with a 1-1/2-day storage of imports. The current 50-percent-capacity terminals projected to 1990 can handle the increased flow by increasing containerization to the 70 percent level, while the 70 percent-capacity terminal requires 100 percent containerization and maximum mechanization to get by with present processing areas. Full capacity terminals need multilevel ETV systems which may or may not be permissible depending upon available vertical height and/or building height restrictions.

Differential cost and personnel data are listed in Tables 3-16 and 3-17. These tables are similar to those previously presented for all-freight and combination carriers. In Table 3-16, the cost data are based on capital

TABLE 3-14

TERMINAL VARIATIONS REQUIRED FOR 1990 FLOW LEVELS FOR BELLY CARRIER TERMINAL (3-DAY INTERNATIONAL STORAGE)

Flow Parameters	Operating Percent of Terminal Capacity					
	50%		70%		100%	
	ULD/Day	Area M^2	ULD/Day	Area M^2	ULD/Day	Area M^2
Present Flow	164	3549	230	3549	328	3549
1990 Required Flow @ 8% Annual Growth	482	-	676	-	965	-
% Shipper Loaded ULDs with Varying International Import Dwell Time		Required Area		Required Area	965	Required Area
40% 1.5 Days	482	4765	676	6683	965	9540
40% 3 Days	482	5199	676	7292	965	10 409
70% 1.5 Days	482	2516	676	3528	965	5036
70% 3 Days	482	2685	676	3766	965	5376
100% ULDs, No Warehousing	482	2340	676	3282	965	4685
100% ULDs, No Warehousing Dolly Storage	482	3222	676	4518	965	6450
100% ULDs, No Warehousing Rack Storage	482	3283	676	4605	965	6574
100% ULDs, No Warehousing ETVs, No. of Levels 1	482	2061	676	2891	965	4127
2	482	1430	676	2006	965	2864
3	482	-	676	-	965	-

TABLE 3-15

TERMINAL VARIATIONS REQUIRED FOR 1990 FLOW LEVELS FOR BELLY CARRIER TERMINAL (1.5-DAY INTERNATIONAL STORAGE)

Flow Parameters	Operating Percent of Terminal Capacity					
	50%		70%		100%	
	ULD/Day	Area M^2	ULD/Day	Area M^2	ULD/Day	Area M^2
Present Flow	179	3549	251	3549	359	3549
1990 Required Flow @ 8% Annual Growth	526	-	737	-	1054	-
% Shopper Loaded ULDs with Varying International Import Dwell Time		Required Area		Required Area		Required Area
40% 1.5 Days	526	5200	737	7286	1054	10 420
40% 3 Days	526	5674	737	7950	1054	11 369
70% 1.5 Days	526	2745	737	3846	1054	5500
70% 3 Days	526	2931	737	4106	1054	5872
100% ULD, No Warehousing	526	2554	737	3578	1054	5117
100 % ULDs, No Warehousing Dolly Storage	526	3516	737	4926	1054	7045
100 % ULDs, No Warehousing Rack Storage	526	3583	737	5020	1054	7180
100% ULDs, No Warehousing ETVs, No. of Levels 1	526	2249	737	3151	1054	4507
2	526	1561	737	2187	1054	3128
3	526	-	737	-	1054	-

TABLE 3-16

RELATIVE COST* PER ULD PROCESSED FOR SYSTEM TYPES OVER ALL FLOW LEVELS

Belly Carrier		
Processing Systems		Unit $ Value
1.	40% CLC, 3-Day International Import Storage	100% Standard Unit
2.	40% CLC, 1.5-Day International Import Storage	91.6%
3.	70% CLC, 3-Day International Import Storage	50.9%
4.	70% CLC, 1.5-Day International Import Storage	47.6%
5.	100% Container System Single-Level ETV	68.9%
6.	100% Container System Existing System without Modification	43.9%
7.	100% Container System Additional Dollies added to Existing System	63.0%
8.	100% Container System Additional ULD Racks added to Existing System	59.6%
9.	100% Container System Double-Level ETV	43.0%
10.	100% Container System Three-Level ETV	33.3%

investment only. Both tables indicate that similar advantages can be realized by increasing mechanization and containerization and by the elimination of bulk handling and excessive import storage time with the largest benefits being attributed to reduction to bulk. Relative manpower between levels is not constant because of the additional aircraft concurrently being handled to meet system capability. Further increases are attainable through mechanization except through all-dolly or storage rack systems. These types of mechanized systems are not as area efficient as raceways or roller conveyor systems.

TABLE 3-17

RELATIVE MANPOWER PER ULD PROCESSED FOR SYSTEM TYPES AND PEAK FLOW LEVELS

Belly Freight Carrier		
Processing Systems		Unit $ Value
1.	40% CLC, 3-Day International Import Storage	100% Standard Unit
2.	40% CLC, 1.5-Day International Import Storage	96.4%
3.	70% CLC, 3-Day International Import Storage	64.9%
4.	70% CLC, 1.5-Day International Import Storage	63.1%
5.	100% Container System Single-Level ETV	45.1%
6.	100% Container System Existing System without Modification	47.8%
7.	100% Container System Additional Dollies added to Existing System	59.5%
8.	100% Container System Additional ULD Racks added to Existing System	58.6%
9.	100% Container System Double-Level ETV	35.7%
10.	100% Container Three-Level ETV	32.8%

From a cost viewpoint, single-level ETVs are not as productive as all-dolly or rack systems, but multilevel ETVs do produce additional gains. The single-level ETV does provide gains in personnel productivity; however, the dedicated area swept by the transfer vehicle is the reason for lower productivity from a cost standpoint.

Figure 3-30 depicts the data listed in Tables 3-16 and 3-17. This shows that increased shipper containerization and reduced import storage time results in a greater benefit than does mechanization. Once full containerization has been reached, the rate of reduction in cost and personnel diminishes becoming almost asymptotic to a 35 percent of the base system level. The large investment required to implement an ETV system, as well as the physical incompatibilities between the terminal configuration evaluated and the restrictive layout of an ETV system, result in the decrease in productivity when going from an all-container existing terminal to the all-container ETV terminal. Beyond the implementation point, additional ETV levels offset this reversal and become more productive.

Terminal Improvements: Domestic air cargo terminals onsite studies and data questionnaire surveys conducted to establish a base for this analysis indicate that future saturation from processable cargo will occur under the existing operating conditions. Theoretical evaluation of model terminals under ideal operating conditions provides a basis for examining the reasons leading to saturation, among which are application and area misuses and procedural inefficiencies. Many terminals store international imports solely on the floor, using area that would otherwise be much more productive. International imports are stored an average of 3 days before customs clearance, while domestic inbound and outbound shipments average only 1-1/2 hours storage. Even though imports represent only 27 percent of the inbound freight, they utilize 54 percent of the available bulk storage area. Use of narrow-aisle multilevel racks can reposition 80 percent of this cargo for more efficient storage and area use. A small percentage of oversize cargo that is not compatible with warehouse storage bins will require floor storage.

Another major cause of saturation results from the delay of buildup of container or pallet loads until acceptance cutoff times have been reached.

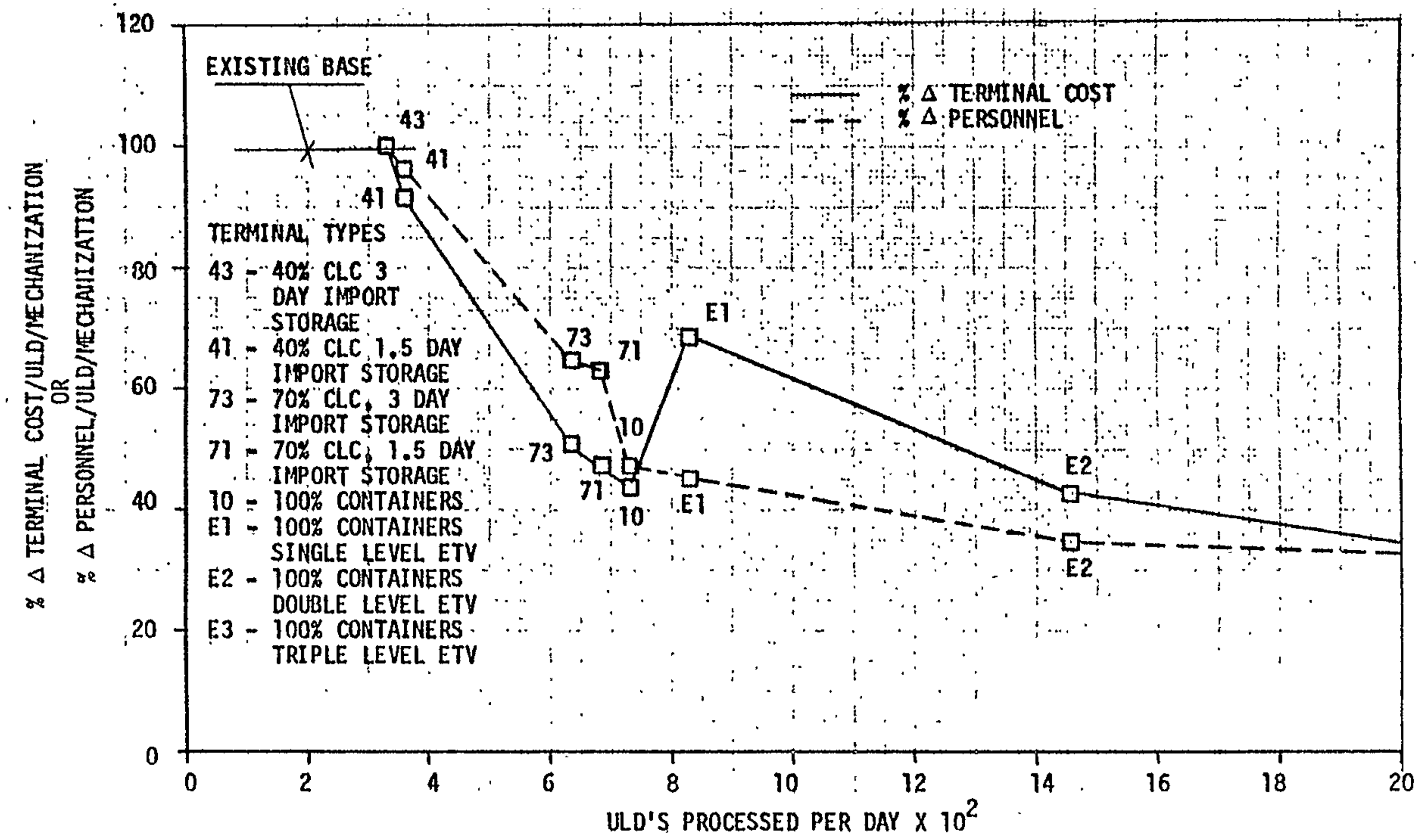


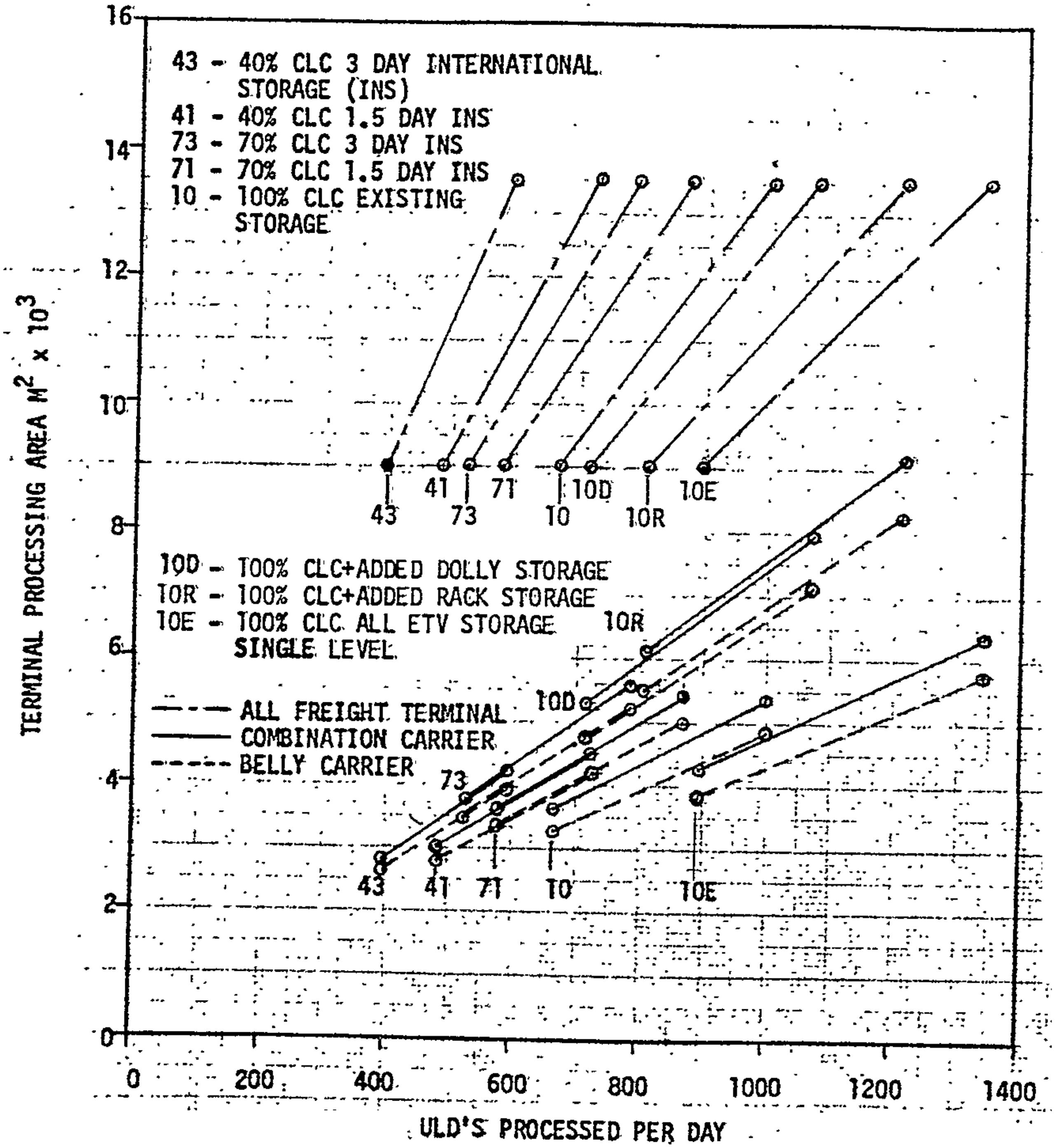
Figure 3-30. Operational Cost and Personnel Variation for Belly-Freight Carrier

This queues available cargo prior to buildup but stagnates the floor area. Since buildup operations are slower than dock handling and staging, this queuing often delays processing of shipper deliveries. For adequate buildup of a ULD, three times its base area should be provided for staging cargo to be loaded. With delivery cargo building up in this staging area, access and movement restrictions are imposed upon processing equipment and personnel. This coupled with short acceptance cutoff times results in very low stacking efficiencies. An adequate amount of cargo required to achieve a good stacking efficiency is but two to three equivalent loads. Load buildups begun once this amount has been reached can reduce both manpower peaking and staging/storage area stagnation and can produce greater stacking efficiencies.

Other factors contributing to flow bottlenecks and saturation are discussed in Volume I, Section 3. These include the following:

- Documentation procedures
- Manual preparation of multiple air waybills
- Tracking and updating of shipments
- Delivery verification and documentation procedures
- Sorting, methods/techniques
- Staging and storage methods/techniques
- Damaged equipment/maintenance
- Storage of inoperable equipment
- Manual handling systems rather than mechanized

The preceding findings provide a less-than-optimistic view of existing operations. However, the beneficial effects derived from varying the amount of bulk handled, the import storage time, and the level of mechanization offer considerable future promise as shown left to right in Figure 3-31 for the three types of carriers surveyed. All-freight carriers with high levels of mechanization are depicted by the upper grouping. The lower grouping consists of both combination and belly carriers with ULD quantities equal to the lower and upper levels of the all-freight terminal systems evaluated. This displays the areas that combination and belly terminal systems would need to handle ULD quantities equal to the like all-freighter terminal



REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

Figure 3-31. Terminal Processing Trends

operation. As an example the combination carrier operating at point 43 would need to increase its terminal processing area 220 percent to reach the upper end of 10R while the all-freight terminal would need only a 50 percent increase in processing area.

Examination of Figure 3-31 also suggests that combination and belly carriers have a greater productivity per unit area than does the all-freight carrier. This is true in the sense that the combination and belly carrier terminals servicing passenger aircraft have a longer daily productivity cycle which develops a higher terminal utilization factor. However, three to four more LD containers would be required to equal the same amount of cargo that can be shipped in M1 (3-meter) containers. This would have a reversing effect on terminal productivity versus carrier type (all-freighter or combination/belly carriers).

Figure 3-32 is a composite of percent cost and percent personnel per ULD processed for all-freight, combination, and belly carriers. The systems are plotted as percentages of their basic systems and show the reductions in cost and manpower levels with increased productivity. As seen, greater reductions in manpower productivity and in cost per ULD processed are possible for all-freight carriers with high mechanization. Also shown is the disparity between combination carrier and all-freight/belly carriers wherein the combination carrier has a higher investment cost level. Trying to accommodate both belly and main-deck freight does not allow maximum development of either type of operation. Combination terminals often need to retain dual equipment to perform similar tasks but with different types of ULDs. Also, they must accommodate freighter operations at the cargo terminal and passenger aircraft belly-pit operations at the passenger terminal.

Stacking efficiency as expressed earlier can result in increases of cargo flow for the same number of ULDs handled or in reduced numbers of ULDs if there is no increase in cargo flow. Figure 3-33 shows the effect of increasing stacking efficiency on the change in cost and personnel per ULD processed. Because stacking efficiency is only associated with bulk handling, there is no effect exhibited to systems processing only shipper-containerized cargo.

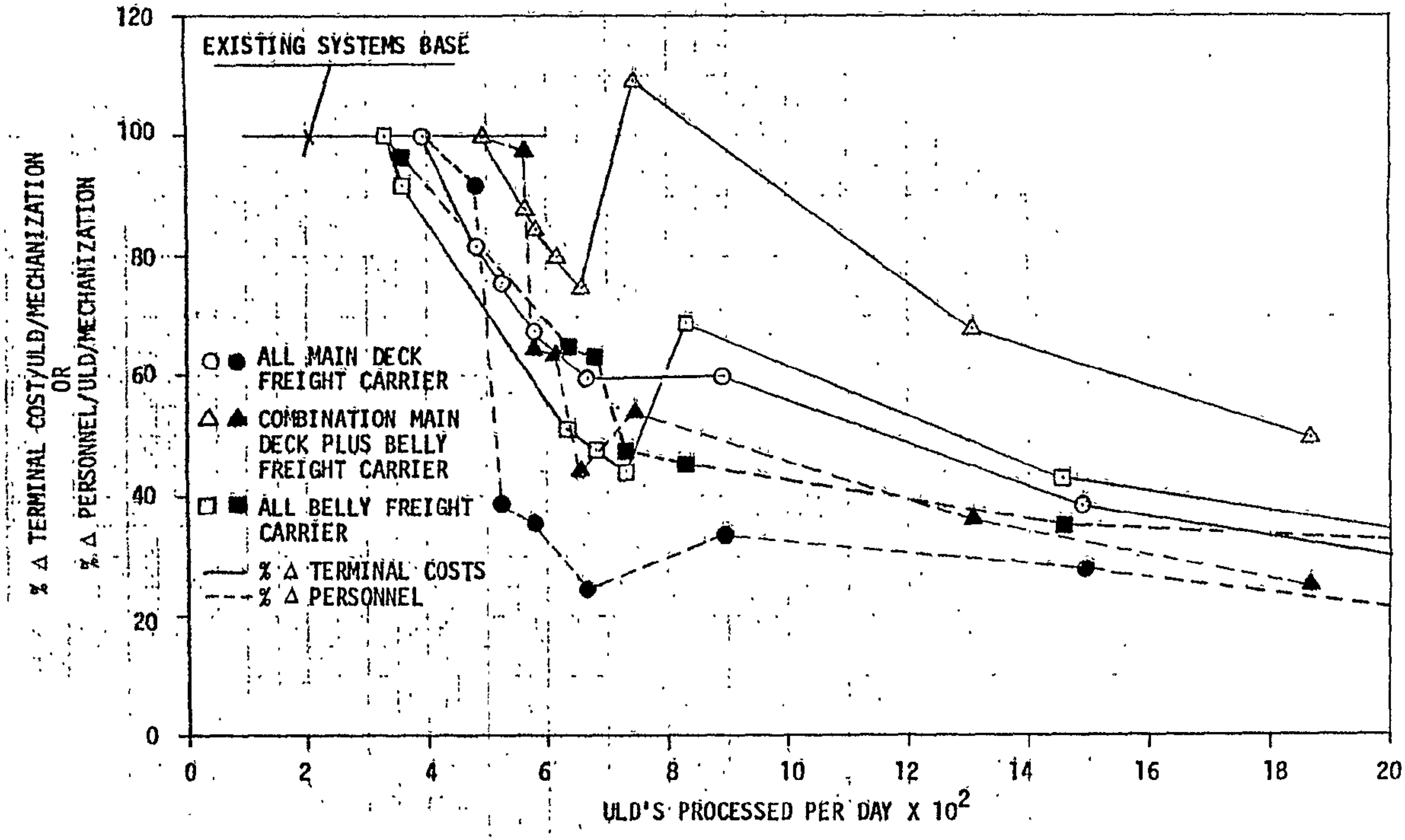


Figure 3-32. Capital Investment and Manpower Variations Composite for All-Freight, Combination, and Belly Freight Carriers

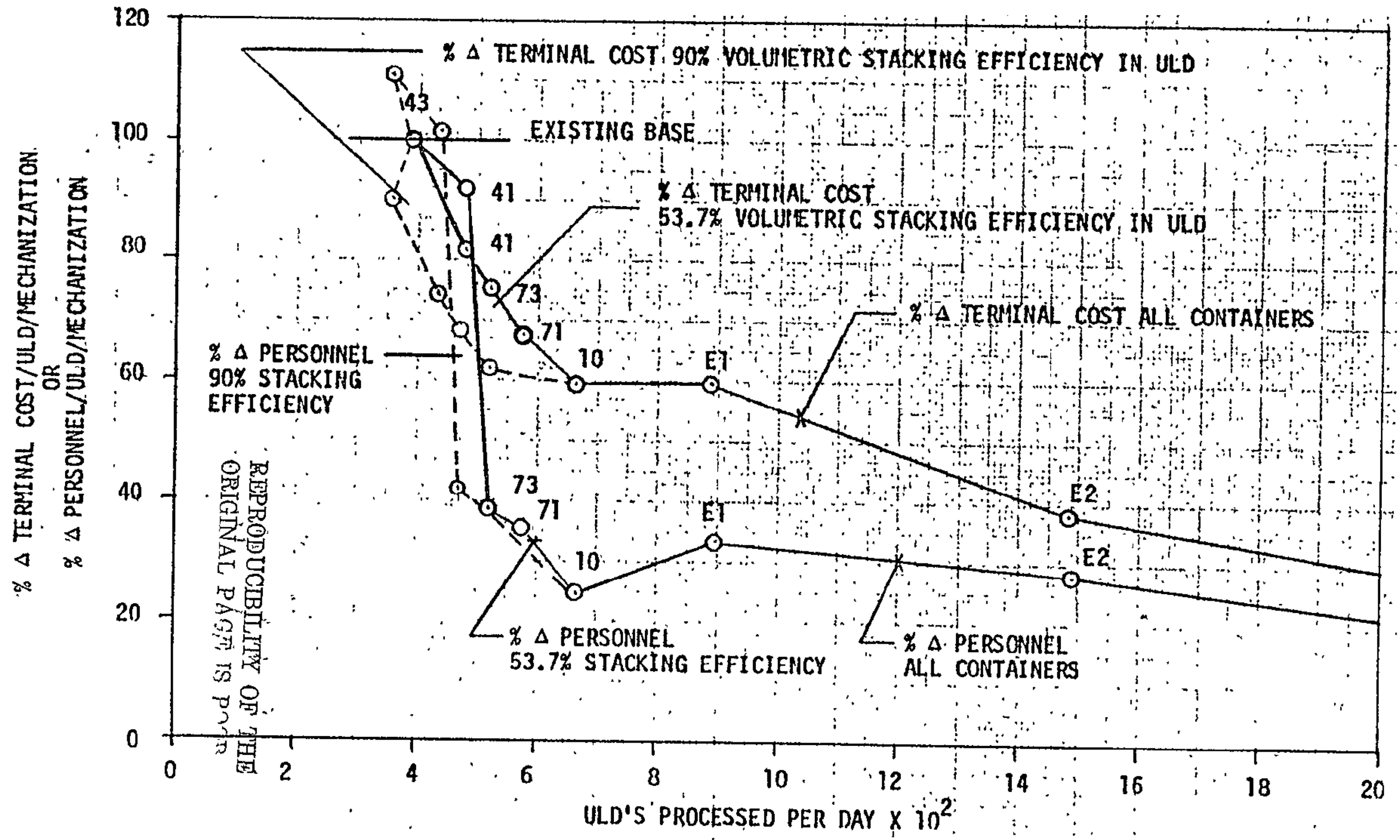


Figure 3-33. Effect of Stacking Efficiency Increase on Operational Cost and Personnel for All-Freight Carrier

The example shown is for an all-freighter carrier. Increasing stacking efficiency from a current 53.7 percent to a maximum practical of 90 percent can reduce the number of ULDs handled by approximately 10 percent. This is equivalent to a 50 percent increase in cargo flow if the same number of containers are processed.

An immediate reduction of investment cost per ULD processed could result from added stacking efficiency without increasing shipper containerization; however, the personnel costs increase for the respective system variations. This is because the same manpower level is required since the number/amount of pieces handled has not changed, even though the number of ULDs handled has decreased.

Future Terminal Concepts: The high-mechanization, 50 percent-bulk terminal used for the previous all-freighter 1990 assessment is pictured in Figure 3-34. Table 3-18 lists the monetary data used to determine the cost per ULD handled. The itemized code numbers correspond to those identified in Figure 3-34. This 1990 terminal patterned after those of today can service five aircraft concurrently. The maximum number of wide-body aircraft that can be handled by this terminal is two, whereas one is the average number of wide-body aircraft which can be serviced by today's terminals. The maximum theoretical throughput for this terminal is determined to be 395 ULDs per day with 40 percent CLC and 3 day import storage. The constraint for this system is the in-terminal saturation from bulk flow which cannot keep pace with forwarder delivery/pickup or airside onload/offload. A reduction in import storage from 3 days to 1-1/2 days will increase the processable flow by 22 percent. Increasing the percentage of CLCs will also increase the flow capability.

Once 100-percent containerization and maximum mechanization have been achieved (Figure 3-35), the constraining factor shifts from the terminal to the aircraft. The all-container handling system shown is capable of processing 1275 ULDs per day but would require servicing of six wide-body aircraft concurrently. Since two is the limit, the maximum level is reduced to 920

TABLE 3-18

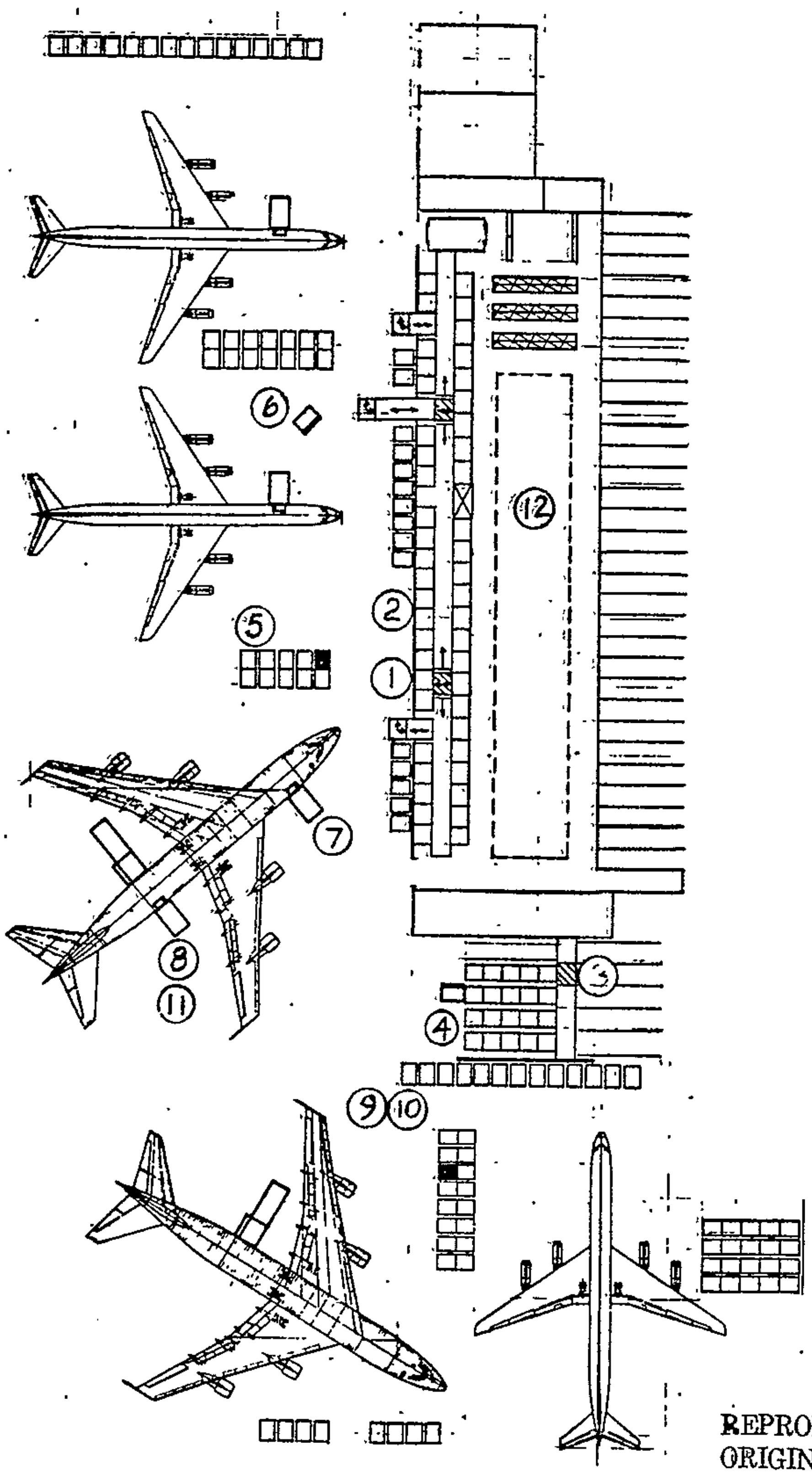
INVESTMENT COSTS - HIGH-MECHANIZATION

LD/M1 50 PERCENT BULK TERMINAL

Design Point: Five Aircraft Concurrently - 395 ULDs/Day

Code*	Description	Cost
1	Elevating Transfer Vehicles and Scales	$ 290 000
2	Multilevel Cellular Storage	100 000
3	Bypass-Transfer Vehicles	80 000
4	Transfer Convey	40 000
5	Staging/Storage Racks	188 700
6	ULD Transporters	210 000
7	Main Deck Loaders	875 000
8	Container Pallet Loaders	325 000
9	Tugs	44 000
10	Pallet Dollies	20 000
11	Mobile Conveyors	75 000
12	In-Terminal Equipment - Standard/ Narrow Aisle Forks, Racks, Bins, Hand Carts, Warehouse Pallets	237 976
	Total	$ 2 485 676

*From Figure 3-34



SEE ITEMIZED
CODE IN TABLE

Figure 3-34. LD/M1 - 50 Percent Bulk Terminal High Mechanization

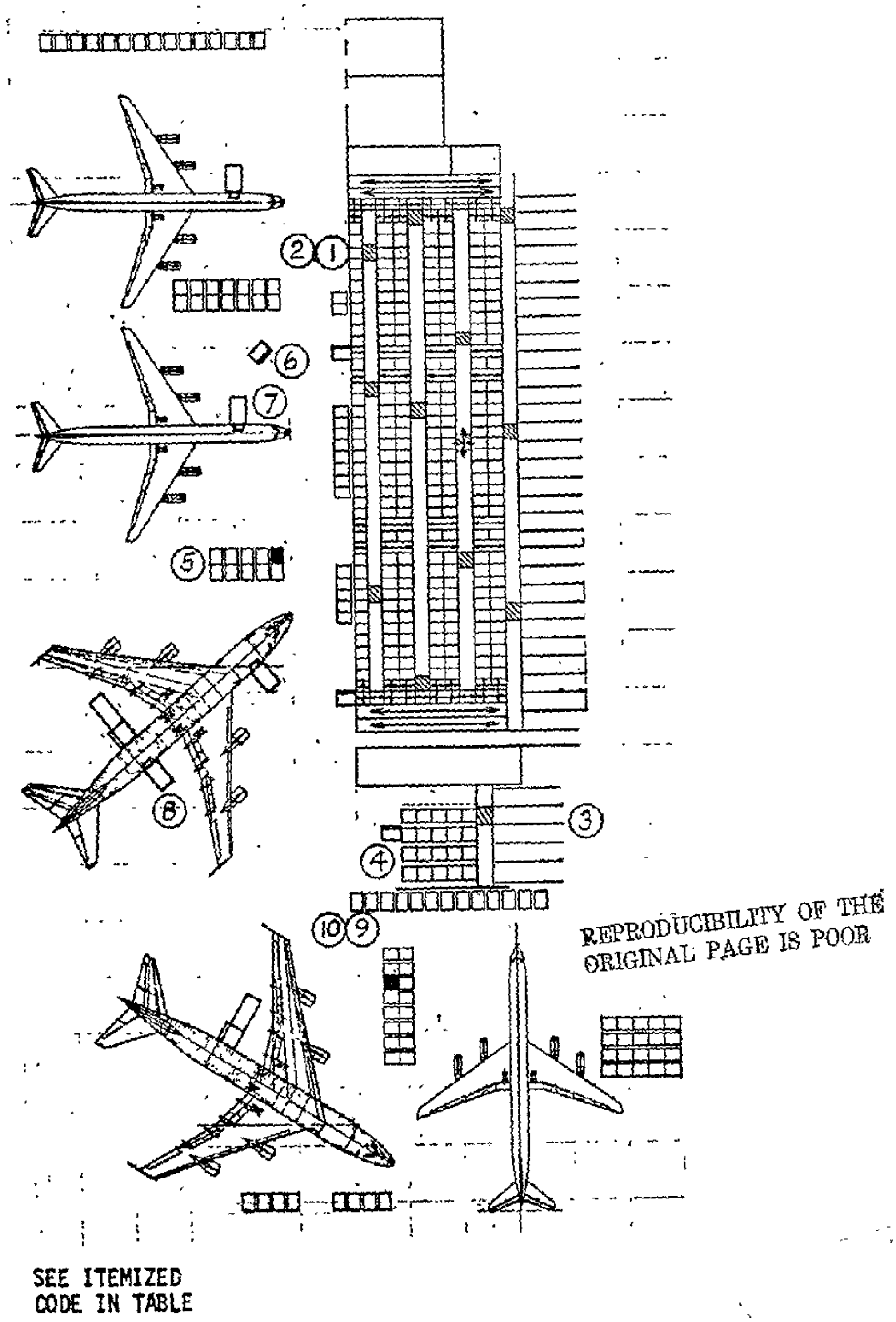


Figure 3-35. LD/M1 All-Container Terminal High Mechanization

ULDs per day. If increased stacking efficiency has become a reality, the flow produced by 1275 ULDs at the lower efficiency can be handled with only 765 ULDs, which is 16 percent below the imposed airside limit. Beyond the benefits associated with improved stacking efficiencies, increases may only be derived through larger aircraft or new ramp facilities.

Table 3-19 lists the investment costs associated with the coded mechanized equipment. Comparing this high-mechanization all-container system with the 50-percent-bulk system shows a 54 percent increase in investment cost. The primary impetus is from the additional ETV systems consisting of ETVs, multi-level cellular storage racks, and bypass-transfer vehicles.

All existing evaluations were conducted using containers no larger than 3 meters in length since only a few carriers are today transporting 2.4-x 2.4-x 6-meter (8-x 8-x 20-feet) containers. Those that are, process them on the ramp or at the truck docks because their terminals are not equipped to handle the longer ULDs. Mechanization is on the rise in this area, and some carriers are now converting or planning to include 6-meter container capabilities in the future. In fact, the technology needed to construct an all or partial M2 (6-meter) container operation is available although ramp and aircraft servicing area are present drawbacks to such growth. Only wide-body aircraft are capable of transporting these large ULDs. Thus, the number of high cube loads or M2 containers will be limited to the number of wide-body aircraft which can be handled at the cargo terminal ramp. As a consequence, growth in the 6-meter container market may be contingent upon larger aircraft and/or larger more capable ramp facilities.

Future terminals for handling 6-meter M2 containers only may be of the type shown in Figure 3-36. The investment costs and design points for this system are listed in Table 3-20. This and other proprietary concepts depicted in Figures 3-37 and 3-38 are among many being studied by the Douglas Aircraft Company. For reasons dicussed in the containerization subsection following, increased usage of the larger more-efficient containers, along with reduced bulk handling, is very likely. Thus, new facilities such as these may be

TABLE 3-19

INVESTMENT COSTS - HIGH-MECHANIZATION

LD/M1 ALL-CONTAINER TERMINAL

Design Point: Five Aircraft Concurrently - 2088 Containers per Day

Code*	Description	Cost
1	Elevating Transfer Vehicle and Scales	$ 890 000
2	Multi level Cellular Storage	665 000
3	Bypass - Transfer Vehicles	560 000
4	Transfer Conveyors	40 000
5	Staging/Storage Racks	188 700
6	ULD Transporters	210 000
7	Main Deck Loaders	875 000
8	Container Pallet Loaders	325 000
9	Tugs	44 000
10	Pallet Dollies	20 000
	Total	$ 3 817 700

*From Figure 3-19

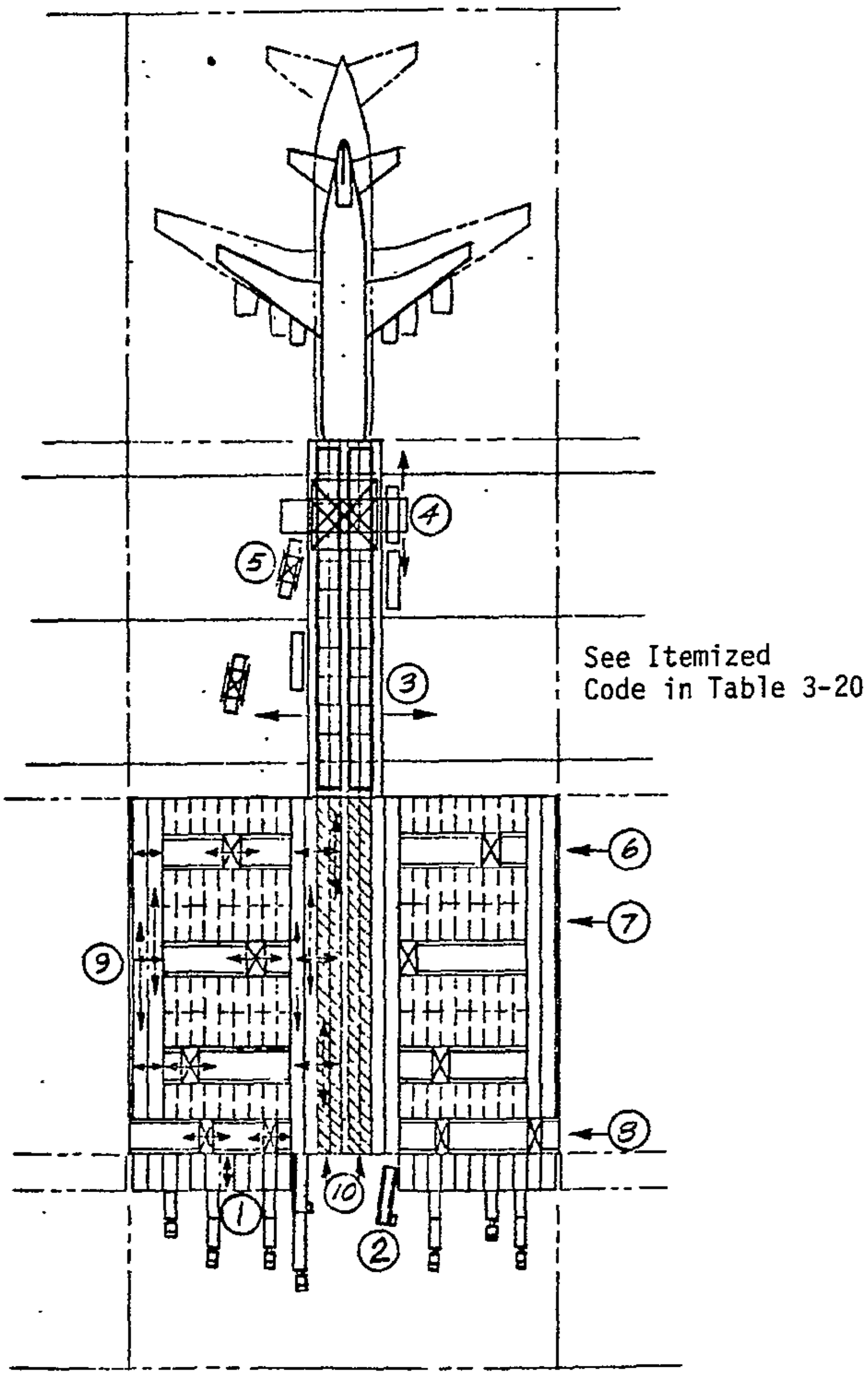


Figure 3-36. High-Mechanization M-2 Container Terminal

TABLE 3-20

INVESTMENT COSTS - HIGH-MECHANIZATION

M-2 CONTAINER TERMINAL

Design Point: Two Aircraft/hour, 96 6- Meter Containers per hour

Code*	Description	Cost
1	Truck Docks	$ 240 152
2	Mobile Loaders	136 450
3	Aircraft Loading Dock and Positioning Carriage	2 349 669
4	Overhead Crane on Loading Dock	245 610
5	Straddle Lifts	136 450
6	Stacker Elevators	818 700
7	Multilevel Cellular Storage	1 679 972
8	Transfer Cars	354 770
9	Transfer Conveyors	1 037 020
10	Staging/Destaging Conveyors	682 250
	Total	$ 7 681 043

*From Figure 3-36

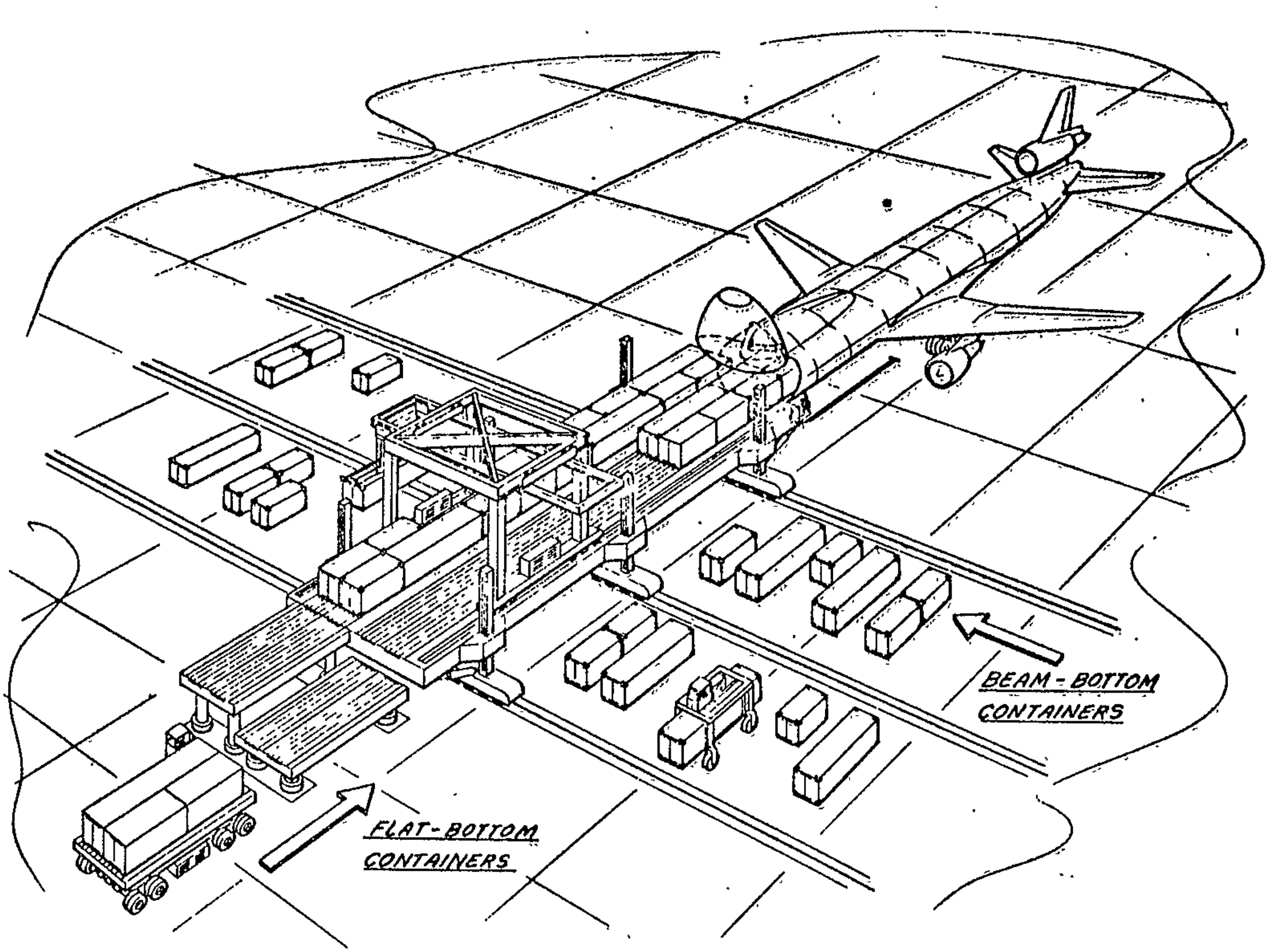
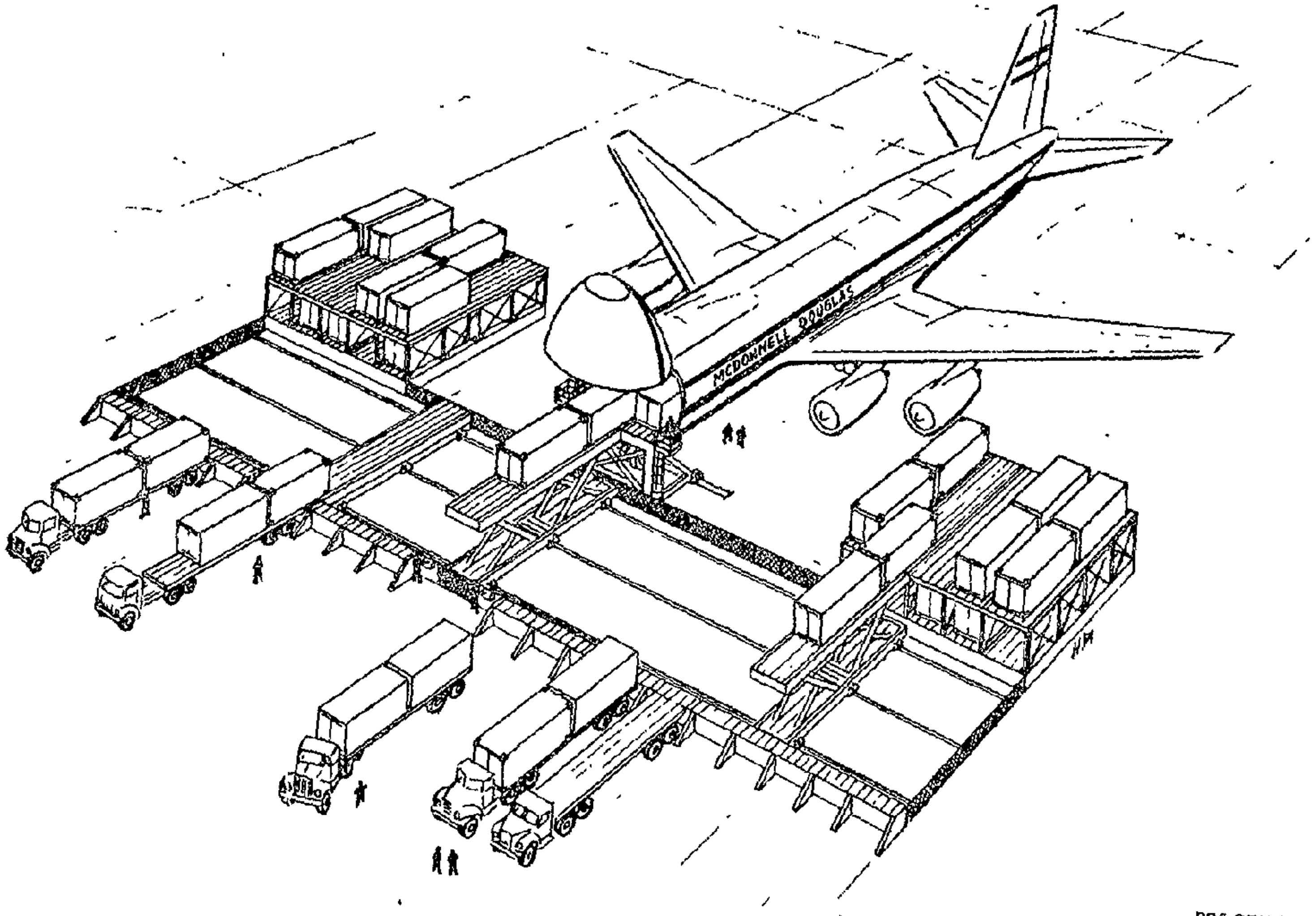


Figure 3-37. Dock Loading Operation



PRG-GEN-23937

Figure 3-38. Alternate Dock Loading Operation necessary to meet the increased demands imposed by future generation aircraft. The equipment sized for these larger ULDs and future freighters will not only be proportionately larger and more costly but will also be proportionately more productive.

Future ground handling systems designed for processing the 6-meter containers will need to provide a greater compatibility with intermodal operations. Flexibility will be needed to handle and transport both flat-bottom air and beam-bottom surface containers. Even though the frequency of use and mix will favor air containers, compatible handling equipment must be provided to handle either type. Efficient ground handling equipment will also help to meet the aircraft potentials and, thereby, enhance aircraft productivity and revenue generation.

If future terminals are to be outgrowths of existing terminals, as many may be, varying remedies to alleviate or compensate for saturation problems or container mix will be necessary. The restrictions imposed by limiting the size of aircraft a service ramp can handle can be offset by either upgrading the ramp, or, if large aircraft are already accommodated, by spreading the cargo processing period over a longer time. The first would allow the operation of larger or future generation freighters while the second would spread the manpower, smooth the terminal flow, and enable higher utilization of the terminal. One or both of these approaches may be necessary as the narrow-body aircraft are phased out.

Expansion to 6-meter or longer ULDs creates different problems for different types of airfreight carriers. All-freight carriers which have been discussed will need to either spread the cargo processing time period, upgrade the ramp capability, and/or operate larger aircraft. The addition of, or switch to, more economical aircraft such as wide-body freighters is a most viable approach as narrow-body aircraft are eliminated and greater quantities of both high cube containers or pallets and 6-meter M2 containers are processed.

For combination carriers, increasing numbers of 6-meter M2 containers can be accommodated by either additional wide-body or larger aircraft, or by shifting the handling of smaller ULDs to combination passenger aircraft (combis) capable of carrying 3-meter long containers and passengers on the main deck. The movement of increasing numbers of smaller ULDs by combis will create greater taxiway and passenger ramp congestion, which probably will not be tolerable. This leaves the combination carriers in the same situation as the all-freight carriers, either upgrade the existing ramps and/or the use of additional or larger aircraft.

Passenger carriers with belly-pit freight operations who have remote cargo terminals and train ULDs on dollies to the aircraft will be faced with solving the passenger terminal traffic congestion. Use of combi aircraft can allow these operators to assume their share of the cargo market growth although it will be secondary since their passenger traffic is of prime importance. These carriers could assume a greater portion of the smaller ULD market that may be set adrift by the other carriers choosing to handle greater quantities of the more efficient 6-meter M2 ULDs.

Figure 3-39 depicts the offload/onload times versus aircraft capacity for the handling of M2 type containers. Existing wide-body freighter aircraft are represented by line 1. The capacity of these aircraft is only 13 M2 type containers. The remaining curve above and beyond the 13 container limit is representative of future freighters of greater length. All other curves are for future aircraft which, when combined with the proper ground equipment, result in shorter turnaround times. The most efficient of these is the double-channel aircraft being serviced by a double-channel dock. These are not the ultimate types of aircraft nor processing systems. Rather, they are only representative of those used for discussion within this study. Other more economical aircraft and supporting systems need to be evaluated as changes in configuration, technology, and environmental factors occur.

Future container terminal relative operational cost and personnel variations are displayed in Figure 3-40. All systems are shown in relation to the existing system, which is the 100 percent base point at the far left side.

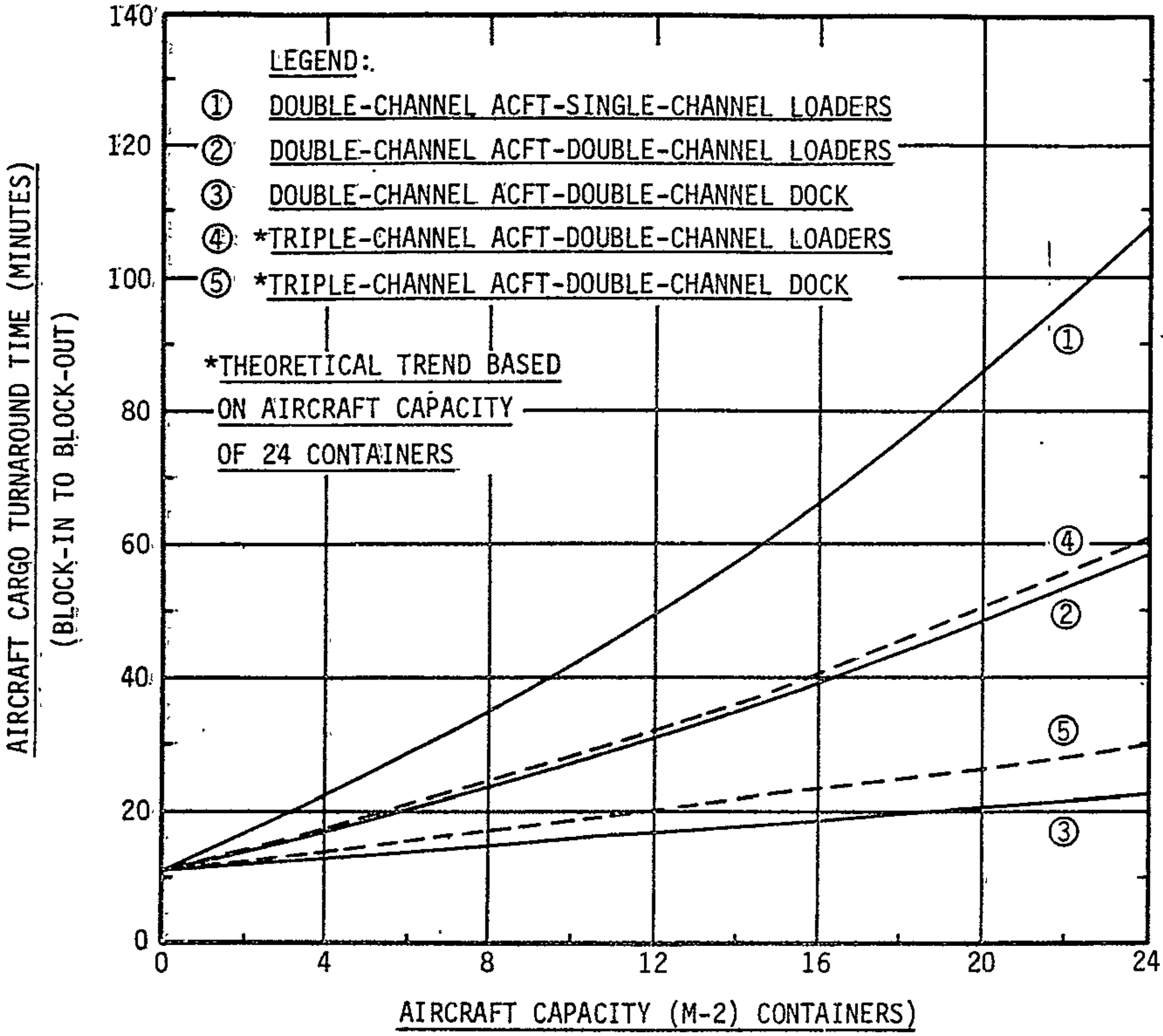


Figure 3-39. Offload/Load Times Versus Aircraft Capacity

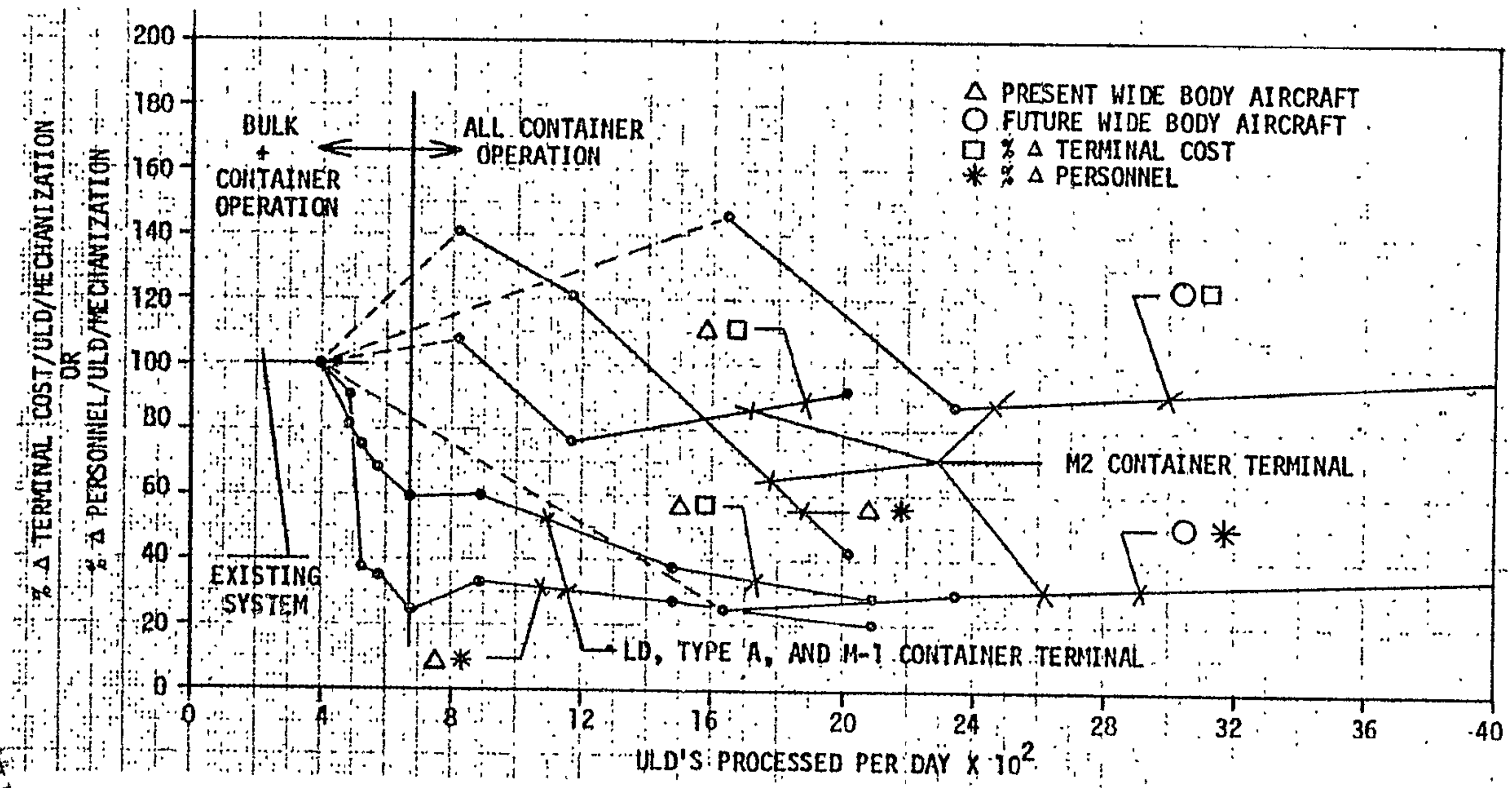


Figure 3-40. Future Container Terminal Operational Cost and Personnel Variation

By 1990, the existing trends will have changed the processing mix to one consisting of 75 percent or more consignor-loaded containers and moderately high levels of mechanization. This air cargo flow mix is in close proximity to the vertical line in Figure 3-40 dividing the bulk-plus-container and the all-container operations. Out to this line, the cost and manpower per ULD processed will decrease while producing relatively small gains in ULD flow. The projected flow will increase from 2.2 to 4.7 times the current levels, which may not be achieved by terminals operating with bulk handling. Area growth for these facilities could solve the problem, as may procedural changes. Without either, shifts of magnitude of two or more in processing will require multiple-level ETV stacker storage systems. These systems, although productive, may only provide relief through 1995 if cargo flow grows by 8 percent per annum. Beyond this point, the existing systems will be saturated and expansion will again be necessary. If larger more economical aircraft are being used along with greater quantities of M2 or larger ULDs, new facilities will be needed. These new facilities will intially be higher in cost and personnel per ULD handled; however, growth in flow will make them more productive.

The effects that cargo flow has on cost for outgrowths of present all-freight carrier terminals and future all-freight carrier M2 type container terminals are shown in Figure 3-41. In this, the relationship between productivities for various systems is normalized on a weight flow basis. When comparing terminals in terms of ULDs handled, the amount of weight transported was ignored even though an M2 ULD is twice the size of an M1 type ULD with twice the weight-carrying ability. This does not invalidate the comparisons in terms of ULDs processed because container handling is related to personnel and types of equipment. The weight processed, on the other hand, is more directly related to direct operating cost and profitability for airline aircraft. On this basis, the M2 container terminals are more productive than highly mechanized versions of present terminals.

As indicated, the maximum cargo flow level may be approximately 5.5 x 10^6 kg per day for type A and M1 container terminals achieving 87.4 percent stacking efficiencies. At this point, where present mechanization expansion has reached its limit, the M2 container terminals take effect. The M2 container

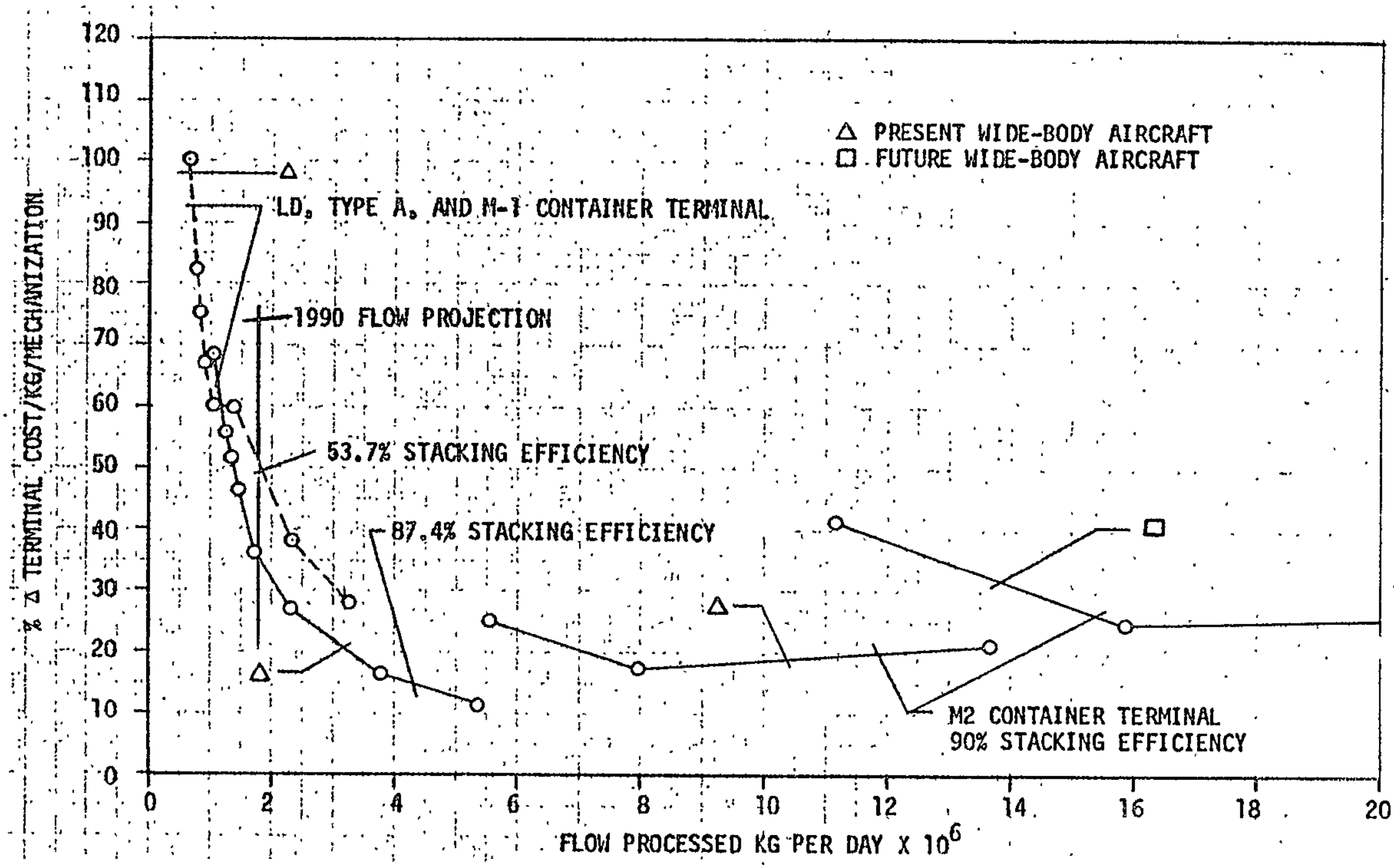


Figure 3-41. All-Freight Flow/Cost Variation

facilities servicing present wide-body aircraft are capable of processing more than 13 x 10^6 kg per day. With future wide-body aircraft, these systems will be capable of processing flows above and beyond those foreseen for the year 2000 based on the development of a compatible surface transport infrastructure. The vertical bar depicting the 1990 flow projected for the baseline terminal shows the relative savings that can be converted to profitability by increasing stacking efficiency in the containers. The present stacking efficiency of 53.7 percent would require a multilevel ETV all-freight terminal, whereas the achievable maximum 87.4 percent stacking efficiency for type A and M1 (3-meter) ULDs indicates that a 100 percent container operation may be all that is required. The reduction in cost per kilogram processed by going from the 53.7 percent to the 87.4 percent stacking efficiency could be 30 percent and could extend the life of the systems half a decade. This would be contingent upon increasing mechanization and vertical expansion to provide more storage area.

Alternative Terminals. - There is a growing need to consider alternative cargo terminals at major urban airports that can ease the problems of costly and limited land, surface traffic congestion, and limited access routes. In addition to easing these problems, alternative terminals and their linking surface systems should also be evaluated on their potential to ease environmental pollution, conserve energy and fuel, and reduce the overall cost of transportation. The following briefly discusses some of the alternative terminals being considered by transportation system planners.

Airline Offsite Cargo Facilities: Offsite cargo terminals are often mentioned as possible solutions for airline cargo terminal problems. With the forecasts of increased flow, offsite extensions of current facilities offer an alternative that needs to be investigated. Many airport cargo terminals are area constrained and have no room for needed local expansion. Therefore, an offsite bulk-cargo terminal could free a significant amount of airport area for aircraft loading and ULD storage/staging functions. In fact, much of the storage could be shifted to the offsite terminal as well. Other advantages include the use of lower-cost land, which would result in lower bulk terminal cost; and the facility could be located away from the highly congested surface traffic area, providing easier access for shippers. The terminal size can be larger and higher, providing increased capacity for short-term storage of international imports; and its location could be chosen for better access by other types of transit.

Shifting the bulk handling offsite from the aircraft servicing area will essentially change the type of airport cargo operation from a partial bulk/ partial container to a full container operation. This type of cargo terminal definitely is more productive as established in the preceding analysis. It results in lower expenses and manpower while increasing the number of ULDs processed per unit of time. Equally as important as bulk handling is the import storage demand which occupies 54 percent of the area available for bulk. Larger storage areas could be provided offsite, thus eliminating the saturation of area used for the staging cargo for buildup and its temporary storage after breakdown.

Properly choosing the area location can reduce total cost. Land is at a premium at and near the airports, and increasing passenger traffic creates congestion that quite often delays delivery and pickup of air cargo at the terminal. Consolidating the small-piece shipments at an offsite terminal will reduce the number of trucks servicing the air terminal site since built-up ULDs would be transported between the offsite terminal and the airport providing more efficient use of surface transportation. Approximately eight trucks could service a 91 000 kg aircraft payload, while 100 or more would be required if only bulk were handled.

While the above advantages appear promising, there are also related problems. Many airlines, primarily passenger operators, do not consider offsite bulk handling to be workable. Belly-freight operators specialize in small bulk shipments, and the cargo terminal must be in relatively close proximity to the passenger terminal to facilitate movement of the many small loads between the cargo processing center and aircraft. Another drawback is transfer cargo which, for the belly-freight operator, represents a large portion of the flow. Transfer cargo needs to remain at the airport, and movement back and forth to an offsite terminal would create delays. Much transfer cargo consists of shipments with different destinations which must be broken down and delivered to other carriers to make connecting flights. Transfer cargo now has a 6-hour average storage time to which added delays in offsite transit and documentation would be unacceptable.

Transit to and from the airport is an important issue. Even though the numbers of trucks will be reduced and traffic congestion eased, delays may not be eliminated. Delays in transit of built-up ULDs could result in either the delay of aircraft departures or in the missing of air cargo flights, either of which is unacceptable to the shipper. The forwarders, although possibly finding less congestion in pickup and delivery at an offsite terminal, would be subject to penalties in shipment delivery acceptance times and pickup of inbound cargo shipments due to the added intermediate transit leg. However, if the shipper is tendering ULDs rather than small shipments, he can bypass the offsite terminal with ULD delivery and pickup directly at the airport, thus avoiding the differential time penalties. This is the direction most profitable for the airlines since they do not have the cost of bulk handling.

Another drawback with airline offsite terminal operations which weighs heavily upon marginal profit is the increased overhead. Offsite terminals represent added cost through duplication of facilities, additional short- and long-haul trucks, and increased personnel. The increased personnel in particular drives up expenses. The many advantages and disadvantages require full indepth studies to determine the profitability potential of offsite terminals for each type of carrier.

Joint Tenancy Cargo Terminals: The concept of two or more airlines operating from the same facility to improve terminal, equipment, and personnel utilization, thereby reducing processing costs and land demand, is an approach that should be comprehensively studied as a solution to servicing of larger freighter aircraft and accommodating increased flow. This concept is used in Europe where the national airline and/or airport authority combine to provide cargo-processing facilities and operations to tenant airline customers. In the U.S., little has been done other than the leasing of sites and/or buildings to air-cargo carriers. Some carriers provide contract service for cargo servicing but usually to those operators whose type of cargo service does not compete with their own. This service commonly consists of ramp, loader, and crew servicing of aircraft offload and onload activities. There are varying opinions among the carriers offering contract services to such an extent that a common approach has not been established. Some feel an international carrier should service another international carrier, and conversely, others feel that domestic carriers should service international carriers. Still others are of the opinion the belly-freight and all-freight operators would be compatible. Each of these requires detailed analysis to determine the effect of cost and schedules on formulation of processing procedures and efficient operations. Probably the greatest barrier to civil joint tenancy operations is the competitive aspects of individual airlines, which makes cooperation in common endeavors difficult to achieve.

Another concept of joint tenancy is the sharing of common facilities and equipment of domestic and military systems that would benefit both through reduced investment and operating costs. Common equipment could be used with few scheduling problems, and in times of national emergency the domestic carriers could operate as part of the Civil Reserve Air Fleet (CRAF).

Partial subsidy of purchases of CRAF-committed freighter aircraft can reduce the costs of the cargo airline. Other benefits depending on military or civil airport colocation may include the following:

- Immediate transition to CRAF operations
- Reduction in landing traffic and airway congestion at major civil airports
- Reduction in civil airport traffic through the shifting of surface cargo traffic
- Reduction in noise abatement and curfew requirements by shifting of operations to remotely situated facilities
- Continuation of peak, customer-dictated, night movement of cargo
- Provide a framework for transition to containerization
- Increase commonality in aircraft supporting functions and maintenance

Among the possible drawbacks which airlines feel detract from the monetary gains is aircraft overcapacity. Commercial and military airlift requirements need to be conciliated to allow continual operation at more profitable levels. This may be achieved, for instance, by reduced airline tenancy rentals and/or fees or, with respect to military requirements, by smaller payload aircraft. Other design differences must also be resolved. Military high-wing aircraft provide lower floors that offer drive-on/drive-off capability, truck bed height loading, and compatibility with present military cargo handling equipment. Their high wing and fuselage landing gear carry-through structure increase the weight and reduce aerodynamic performance resulting in increase fuel consumption, which is a critical economical and resource factor. All of these are adverse to basic civil cargo aircraft operating economics and requirements.

The reduction of civil airport traffic by diverting the cargo to a joint military airport location may intensify the problem of peak-time cargo processing. Greater distances from existing forwarder/consignor locations and customer distribution centers will require either earlier cutoff on forwarder acceptance or later departure for delivery to the air terminal. Reduced bulk-cargo handling and increased containerization can offset this time penalty by allowing later acceptance cutoff times by the airline.

As stated earlier, the joint tenancy concept offers many positive and negative features. A thorough evaluation of its potential and influencing factors such as environmental, economical, operational, priority, and procedural needs to be undertaken before any conclusive direction is undertaken.

Containerization

The 1990 direct support infrastructure involves not only the airport and cargo terminal categories discussed in the preceding subsections but also a third and equally important category — unit load devices (ULDs). Whether the ULDs are pallets and/or containers, their influence is felt across the whole transportation and distribution system. As such, the following analysis quantitatively and qualitatively addresses ULD issues pertinent to the whole system including the aircraft. These lead to a concluding evaluation of pallets versus containers which is generally supportive of an expanding role for containers in the future even though certain economic penalties may be involved.

ULD utilization increments. - In looking at the pros and cons of future containerization and projecting a 1990 base, it is necessary to consider a variety of issues. Some of these are quantifiable, whereas others are a matter of value judgment. While the fundamental issue was postulated around how containers can contribute to future air cargo growth, it was also apparent without analysis that a more basic issue requiring solution is the present poor utilization of ULDs. Poor utilization has been a routine finding in surveys over the past decade whether the ULDs are pallet or container loads. In the 1968-1969 terminal surveys conducted by Douglas, 226 contoured pallet loads were found to have a mean cube utilization (stack efficiency) of 52.9 percent, 198 type "A" container loads had a cube utilization of 54.6 percent, and the overall 424 loads had a cube utilization 53.7 percent. Tables 3-21 and 3-22 summarize the results of the 1968-1969 cargo surveys for ULD loads and cargo characteristics respectively. In Table 3-22, all aircraft includes total of freighter plus passenger aircraft plus an approximate equal amount that could not be identified by freight or passenger type.

In a repeat survey with one of the carriers, it was found that their mean cube utilization of main deck ULDs had decreased from 56.8 percent in 1968-1969 to 50.7 percent in 1975. This was accompanied by a decrease in cargo warehouse density with a resultant compounding decrease in cargo loaded density. These reductions were attributable to the fuel shortage and a consequent diversion of cargo to wide-body LD containers with

TABLE 3-21

ULD LOAD CHARACTERISTICS SUMMARY

Module Type Sample Size	Pallets 226			Type A Containers 198			All ULDs 424		
Characteristics	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max.
Module Gross Weight kg	294.8	1558.6	4066.5	405.5	1981.4	5898.2	294.8	1756.0	5898.2
Cargo Weight kg	179.2	1428.5	3932.7	169.6	1720.5	5582.0	169.6	1564.9	5582.0
Pieces Per Load	1.0	43.5	392.0	1.0	48.9	168.0	1.0	46.0	392.0
Cargo Volume cu m	0.5	6.4	11.6	1.5	6.9	10.9	.5	6.7	11.6
Stacking Efficiency %	4.1	52.9	92.0	11.0	54.6	94.6	4.1	53.7	94.6
Warehouse Cargo Density, kg/cu m	36.8	221.1	927.6	60.9	248.3	937.2	36.8	233.9	937.2
Loaded Density, kg/cu m	14.4	116.9	315.6	16.0	136.2	413.3	14.4	126.6	413.3
Onboard Density, kg/cu m	25.6	128.2	322.0	35.2	153.8	432.5	25.6	141.0	432.5

TABLE 3-22

CARGO CHARACTERISTICS SUMMARY

Survey Locations - Quantity	Domestic - 8	European - 4	Total - 12
All Aircraft*			
Shipments	9567.0	5229.0	14 796.0
Pieces	56 179.0	24 048.0	80 227.0
Weight kg	1 647 330.0	569 209.0	2 216 539.0
Volume cu m	7098.0	2501.5	9599.5
Av Shipment Weight - kg	172.2	108.9	149.8
Av Shipment Volume cu m	.742	.479	.649
Av Piece Weight kg	29.3	23.7	27.6
Av Piece Volume cu m	.127	.105	.119
Av Pieces per Shipment	5.9	4.6	5.4
Warehouse Density kg/cu m	232.1	227.5	230.9
Freighter Aircraft			
Shipments	3229.0	665.0	3884.0
Pieces	20 826.0	4895.0	25 721.0
Weight kg	722 863.0	139 804.0	862 667.0
Volume cu m	3023.5	585.9	3609.4
Av Shipment Weight kg	223.9	213.4	222.1
Av Shipment Volume cu m	.937	.895	.929
Av Piece Weight kg	34.7	28.6	33.5
Av Piece Volume cu m	.144	.119	.142
Av Pieces per Shipment	6.4	7.5	6.6
Warehouse Density kg/cu m	239.1	238.6	239.0
Passenger Aircraft			
Shipments	1266.0	1503.0	2769.0
Pieces	4777.0	4094.0	8871.0
Weight kg	92 759.0	70 744.0	163 503.0
Volume cu m	417.9	296.6	714.5
Av Shipment Weight kg	73.3	47.1	59.1
Av Shipment Volume cu m	.331	.198	.258
Av Piece Weight kg	19.4	17.3	18.4
Av Piece Volume cu m	.088	.074	.079
Av Pieces per Shipment	3.8	2.7	3.2
Warehouse Density kg/cu m	222.0	238.5	228.8

promotional rate incentives. Thus, the residual was kept to freighter flights, which had also been curtailed. Since these 1975 reductions were the product of instability and uncertainty of the time, it is more reasonable to use the 1968-1969 overall cube utilization of 53.7 percent (54 percent) as a base for considering future improvements to ULD utilization.

Several increments which can improve ULD cube utilization and revenue cargo weight are identified in Table 3-23. Data base increment number 1 discussed above employs the overall 54 percent cube utilization rather than 52.9 percent and 54.6 percent survey values for pallet and container loads, respectively, which would yield a container differential benefit of only 1.7 percent. These results are considered indecisive at such low utilization levels and are more truly represented by the 5 percent container benefit listed as increment number 5. The 5 percent is derived from the fact that container walls provide natural interior stacking surfaces for filling a load out to its full volumetric potential. Conversely, pallets do not have such stacking surfaces and there is an inherent tendency to back-off from imaginary surfaces which if exceeded would present clearance problems in the aircraft. This tendency is further aggravated by stack instability during the pallet load buildup of likely heterogeneous cargo pieces and the eventual possibility of the netted load shifting to present a clearance problem in the aircraft.

The values for increments 2, 3, and 4 are derived from scale model tests and analyses that are summarized later in this subsection. It will be noted that the incremental values are applicable to both pallets and containers. Of specific interest is the fact that 16-percent load improvement could be derived if sufficient cargo display and selectivity adjacent to the ULD permitted efficient load buildup. The cube utilization improvements shown in Table 3-23 result in proportionately increased actual revenue cargo weights per ULD without exceeding allowable gross loads (based on air cargo warehouse density of 230.9 kilograms per cubic meter). The combined increments of 16 and 14 percent suggest the necessity for sustaining opportunity fill-in cargo backlogs. Since this would result in some cargo being denied space on specific flights, it further suggests that future tariff structures make allowance for a deferred level of service at lower rates which could be used

TABLE 3-23

ULD 1990 CUBE UTILIZATION/CARGO WEIGHT IMPROVEMENTS/GOALS

No.	Increment Description	Pallets	Containers	Remarks
1	ULD Cube Utilization Data Base - B707/DC-8 Type "A"	54%	54%	Existing
2	Sufficient Cargo Availability	+16%	+16%	Increase Market Penetration
3	Improved ULD Cargo Load Buildup Selectivity	+14%	+14%	Revise ULD Terminal Buildup Layout and Operations
4	Increased Cube Utilization Due to Increased ULD Size and Rectangular Shape	0% to +5%	0% to +5%	Scale Effect
5	Increased Cube Utilization Due to Containers	0%	+ 5%	Container Benefit
6	Loss Due to Theft and Damage	- 2%	- 1%	Container Benefit
	Potential Net Cube Utilization	82% to 87%	88% to 93%	Composite of Above
	Container Advantage: 93/87 to 88/82 = 6.9% to 7.3%			

as opportunity cargo to fill out ULD loads. The additional pipeline time associated with a deferred level of air service would be minimal when compared with the pipeline time found in international maritime movements. However, for domestic movements, the time advantage of airlift may be somewhat penalized by deferred service when compared with high-speed surface transport unless incentives are applied.

Increment number 6 in Table 3-23 is the most elusive to quantify. However, based on loss claims it constitutes only a marginal segment of airlift revenues and an even smaller proportion of the total values of cargo in the pipeline. For instance:

- The Air Transport Association (ATA) reports claims ratios of $1.88 in 1970, $1.03 in 1974, and $.72 in 1976. These ratios are per $100 of freight revenue take in; however, they do not account for upward adjustments in revenue rates. As such the reductions may not be as dramatic as indicated. For example, if it took $150 to ship the same cargo in 1976 as it took $100 to ship in 1970, the 1976 claim ratio would be 1.5 x $.72 = $1.08 for comparison with the $1.88 in 1970.
- A major domestic carrier reports 1964 claims ratios of $4.03 with a mixed pallet/igloo operation, $2.04 in 1967 with open-face (netted face) igloos, and $1.12 in mid-1977 with solid igloos (no open face). Again, these figures would not reflect upward adjustments in tariff structures.
- The Airport Security Council aggregate loss ratio including armed holdups for JFK, LGA, and EWR was 0.032 percent in 1969 reducing to 0.003 percent in the first 10 months of 1977. Excluding armed holdups, the loss ratio was brought down from 0.023 percent in 1969 to 0.004 percent in the first 10 months of 1977. These loss ratios are based on value of the cargo and not on airlift revenue.

In each of the three instances above, some portion of the improvement was due to containerization. However, no specifics had been developed. This same generalization was found regardless of the several additional sources solicited, that containerization has reduced losses due to damage and theft.

These sources included cargo insurance underwriters; insurance industry organizations, such as the Insurance Information Institute and the American Institute of Marine Underwriters; and trade publications, such as Container News, Containerisation International, and Insurance Weekly. It seems that the principal benefit of containerization has been in reduction of handling costs, and the reduction in damage and theft has been an incidental bonus. In deference to the insurance industry, it should be pointed out that a large portion of the insurance is written as deductible, which eliminates reporting of all but the large loss claims. Thus, a meaningful assessment by the insurance industry may not be possible.

In light of the foregoing claims and loss ratios, ratios reductions, and their correlation with the introduction of airlift containerization and tighter airport/terminal security measures, increment number 6 in Table 3-23 is assumed at a marginal and conservative 1 percent for containers and 2 percent for pallets, giving containers a differential 1 percent advantage.

Taken in whole (increments 1 through 6) with maximum advantages, pallets could be realizing 82 to 87 percent cube utilization and containers 88 to 93 percent cube utilization rather than the surveyed 54 percent. Thus, the net container advantage shows at 6.9 percent to 7.3 percent or approximately 7 percent over pallets. Notwithstanding whether pallets, containers, or container advantage is being considered, the improvements and goals are clearly evident. Furthermore, the domino effect will increase loaded densities, increase revenues, increase airlift energy efficiency, and impact aircraft and terminal design requirements, to name a few.

Improved container utilization. - From the preceding discussion, the 54 percent cube utilization can also be thought of as a 46 percent shortfall. Of this shortfall, the physical imcompatibility or nonmodularity of heterogeneous cargo pieces with the container interior configuration will always limit achievable maximum cube utilization in the ULD to some total value of less than 100 percent. In order to determine this maximum, which would limit the container achievable maximum payload for any given cargo warehouse density, and extensive ULD loading test and analysis (Report MDC J5382) was completed and published in 1972. This test used piece and shipment cargo characteristics from the 1968-1969 survey data in constructing 1/20 scale cargo pieces and ULDs. A series of controlled loading tests, simulating normal time limited ULD load buildup constraints, and maintaining shipment integrity was then completed. These results are plotted as the solid line segment in Figure 3-42.

These same results per later analysis (MDC J6168 and refinements this study) were found to plot as a straight line (solid) on log-log paper comparing ULD interior available volume (V_a) with the interior volume used (V_u = sum of cargo piece volumes) where $V_u \div V_a$ = cube utilization. This straight line is expressed by the equation $V_u = 0.655441\ V_a^{1.0987}$. Extrapolating this same rationale from the 2.4 x 2.4 x 3 meter data point to a hypothetical 283 cubic-meter (10,000 cubic-foot) container at 99 percent cube utilization as an upper limit, the achievable maximum cube utilization for larger containers becomes $V_u = 0.774498\ V_a^{1.04348}$. These two complementary equations plotted in Figure 3-43 reasonably define the limits of achievable maximum cube utilization as a function of container inside volume.

With respect to the 2.4 x 2.4 x 6 meter and 12 meter containers, the equation yielded values of 90.1 percent and 93 percent respectively. However, it is highly doubtful that anything in excess of 90 percent could be achieved except under the most optimum of conditions. Therefore, this has been indicated as a maximum practical and is shown along with the higher theoretical in subsequent computations.

Shelf Pallet: Inasmuch as the FTL B747F shelf pallet is used in international movements and has certainly proven successful in its sphere of operations, it is included in appropriate elements of this subtask. It also is a generic type that is appropriate to other wide-body aircraft such as DC-10 freighter derivatives. Since this type had not been included in the scale model tests nor did it fit into the usable cube equations, a separate derivation was completed. This derivation is shown in Figure 3-44 which is self-explanatory. The low value of 80 percent is attributable to the fact that the shelf effectively creates two smaller, lower efficiency ULDs. When the shelf is removed, a larger more efficient ULD results, giving a calculated achievable maximum cube utilization of 88 percent for a hard-wall container.

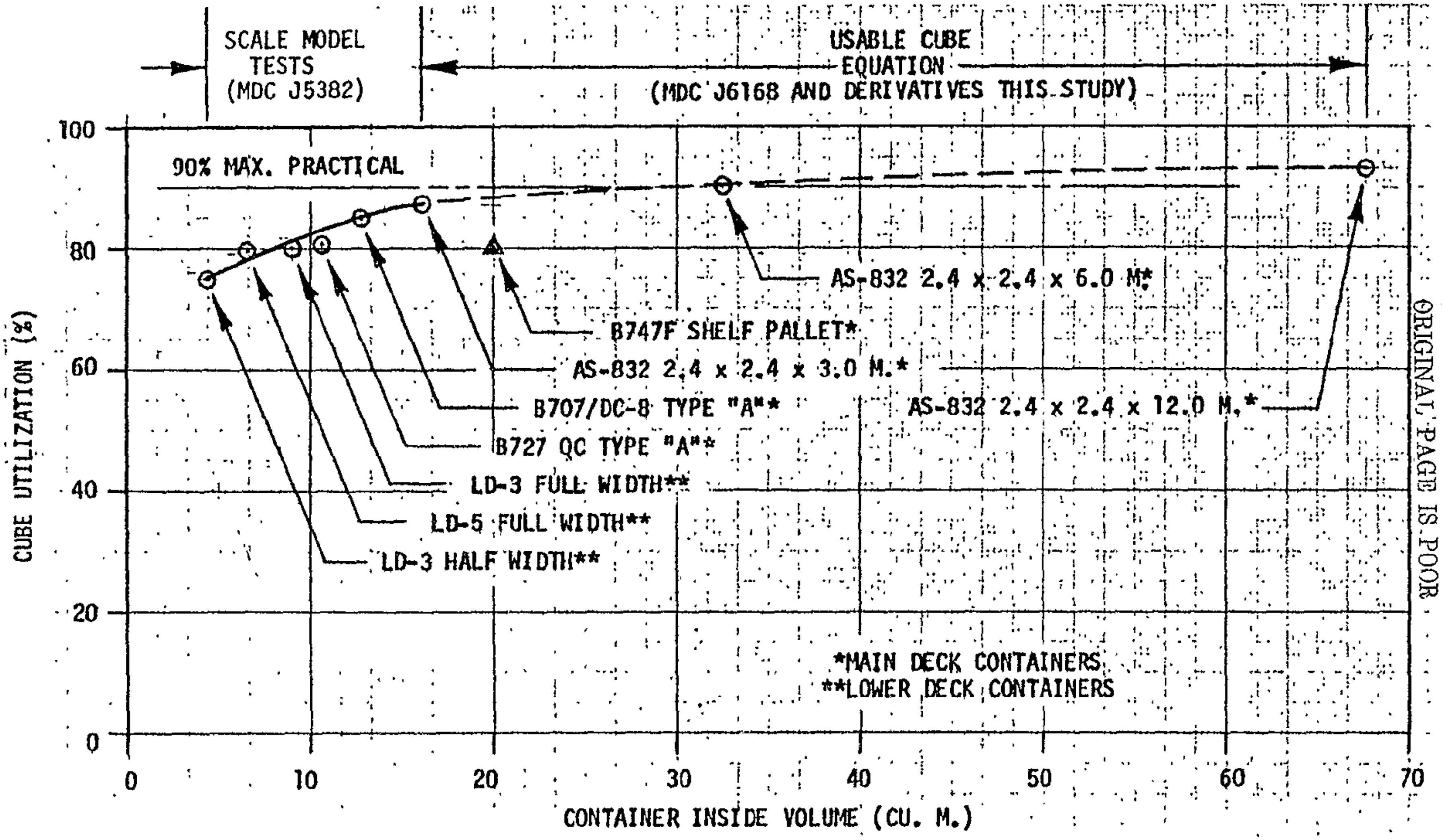
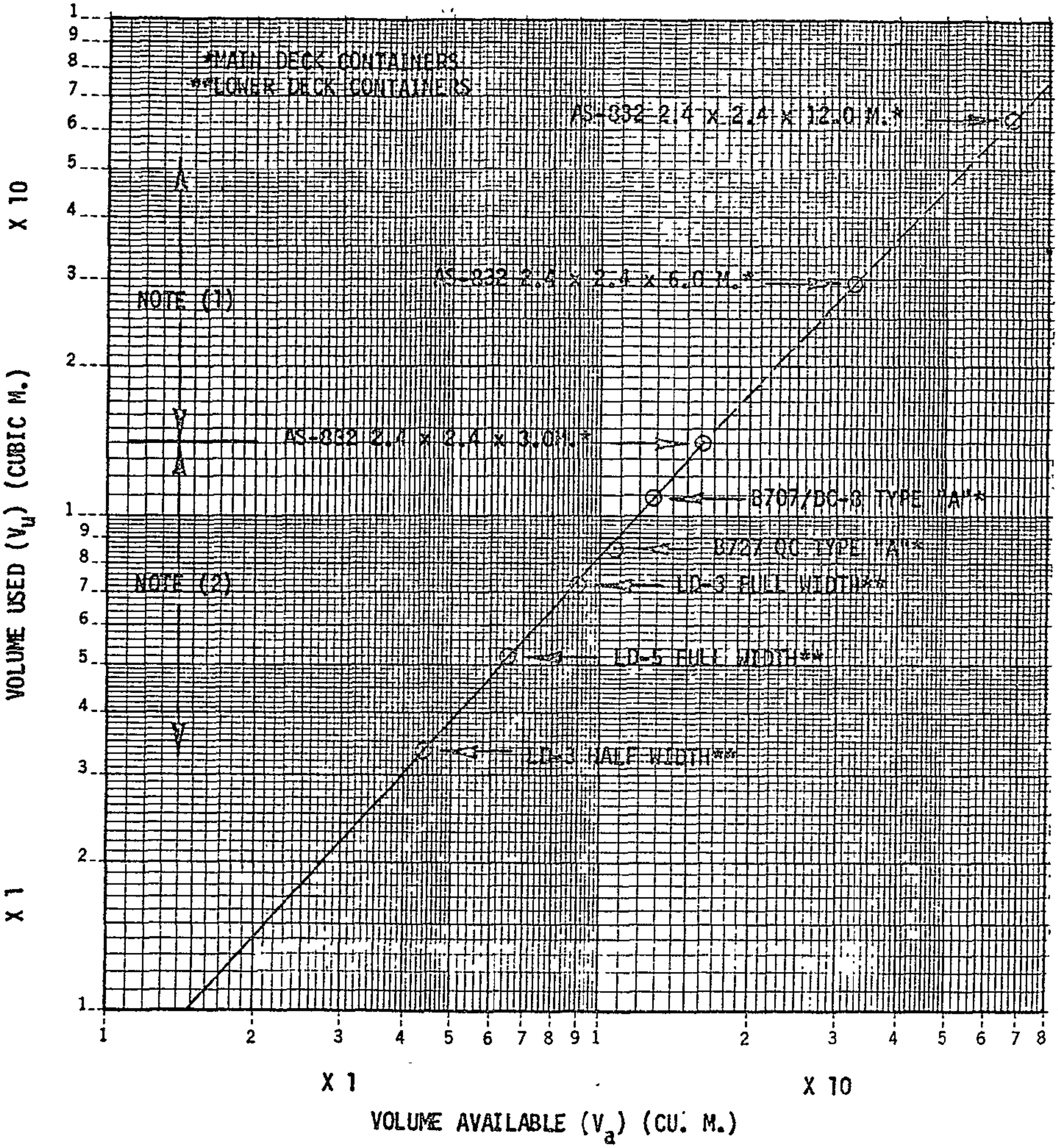


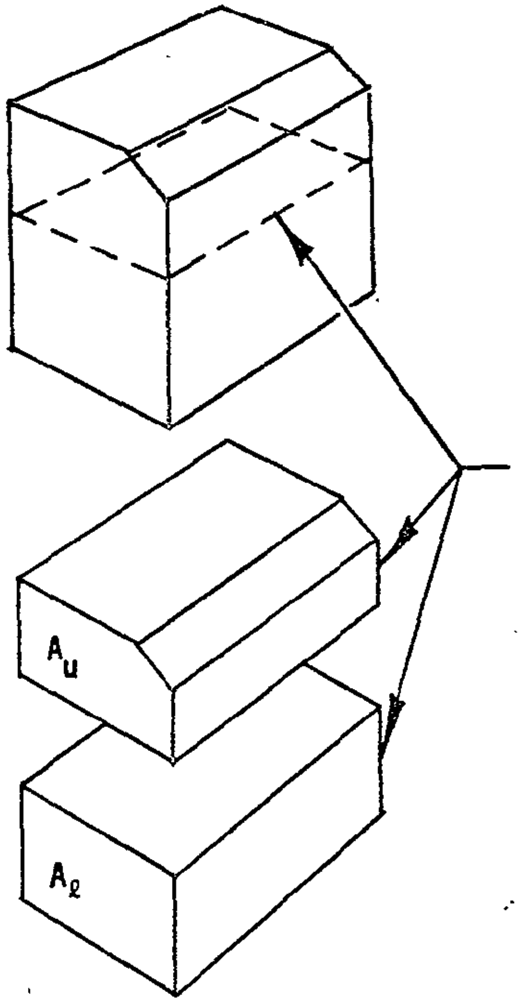
Figure 3-42. Achievable Maximum Cube Utilization



NOTES: (1) USABLE CUBE EQUATION $V_u = .774498\ V_a^{1.04348}$
(METRIC DERIVATION BASED ON MDC J6168)

(2) SCALE MODEL TESTS $V_u = .655441\ V_a^{1.0987}$
(UPDATED METRIC DERIVATION FROM MDC J5382)

Figure 3-43. Achievable Maximum Volume Utilization



GIVEN:

- CONTAINER TARE WEIGHT = 322.1 KG
- CONTAINER INSIDE VOLUME = 19.97 CU M
- CONTAINER GROSS WEIGHT = 6804 KG
- SHELF ALLOWABLE LOAD = 1542 KG

ASSUMPTIONS:

- CARGO WAREHOUSE DENSITY = 230.688 KG/CU M
- ADJUSTABLE SHELF EFFECTIVELY CREATES TWO SEPARATE CONTAINERS FOR COMPUTATION OF ACHIEVABLE MAXIMUM CUBE UTILIZATION
- SET SHELF AT MIDPOINT OF ADJUSTMENT RANGE (1.67 M ABOVE BASE)
- UPPER AND LOWER VOLUMES WILL BE (V_u AND V_ℓ) WILL BE PROPORTIONAL TO UPPER AND LOWER CONSTANT CROSS-SECTION AREAS (A_u AND A_ℓ)
- THEREFORE: A_u = 3.0005 SQ M
  A_ℓ = 4.0876 SQ M
  TOTAL = 7.0881 SQ M

V_u = 3.0005 (19.97)/7.0881 = 8.45 CU M
V_ℓ = 4.0876 (19.97)/7.0881 = 11.52 CU M
TOTAL = 19.97 CU M

CUBE UTILIZATION (C.U.) CALCULATION:

$C.U._u = 0.655441\,(8.45)^{1.0987}/8.45 = 0.809$ (80.9%)

$C.U._\ell = 0.655441\,(11.52)^{1.0987}/11.52 = 0.834$ (83.4%)

$$\text{OVERALL C.U.} = \frac{8.45(0.809) + 11.52(0.834)}{19.97} = 0.823 \text{ (82.3\%)}$$

CHECK SHELF: 8.45 (0.809)(230.688) = 1577 KG > 1542 KG SHELF ALLOWABLE

THEREFORE, CALCULATE OVERALL C.U. BASED ON 1542 KG SHELF ALLOWABLE:

$C.U._u$ (SHELF) = 1542/230.688/8.45 = 0.791 (79.1%)

$$\text{OVERALL C.U.} = \frac{8.45(0.791) + 11.52(0.834)}{19.97} = 0.816 \text{ (81.6\%)}$$

HOWEVER, C.U.'s ARE BASED ON CONTAINER HARD WALL STACKING SURFACES WHICH CAN PROVIDE UP TO 5% HIGHER C.U.'s THAN EQUIVALENT NETTED PALLET LOADS. THEREFORE, SHELF PALLET SOFT WALL STACKING SURFACES WILL DEGRADE C.U.'s BY APPROXIMATELY ONE-THIRD OF THE HARD WALL ADVANTAGE:

(0.33) (5%) = 1.6%

FINAL OVERALL C.U. = 81.6% -1.6% = 80.0%

Figure 3-44. B747F Shelf Pallet Achievable Maximum Cube Utilization

It is understood that FTL has now procured an initial quantity of these high-cube, hard-wall containers which, barring cargo crushability limits with the taller stack heights, can enhance their payload capability within the limits of the payload/range envelope.

End loading versus side loading: Since there has been some indication from container load buildup observations that cube utilization is influenced by relative access and since the scale model tests all involved loading through the wider side opening, a brief analysis was conducted to assess end versus side loading of containers. The basic observation being tested is that the cargo stack height in a container tapers down from the back wall being initially stacked against to a lesser height at the access door. Thus, if the back wall and the access door are the wider of the four perimeter surfaces, cube utilization will be less than they would had they been the narrower. Whether this would have held true if sufficient cargo had been available to develop the container potential is an issue subject to challenge.

Notwithstanding such a challenge, the results of the analysis are pictured in Figure 3-45 which indicate a possible small marginal benefit with end loading. However, this is achieved at the penalty of increased load buildup and breakdown times resulting from longer transit times in the container. Furthermore, the narrower end loading restricts the number of simultaneous side-by-side cargo handling operations in the container that might occur in buildup and breakdown. A poor guess in selecting a fittable size cargo piece for a space will also extract a larger penalty with end loading either because of the longer transit time in withdrawing and substituting another piece, or in leaving it in place with a marginal degradation of cube utilization.

Considering the marginal improvement that may be achieved with end loading along with the possible load buildup penalties, it is doubtful that a strong case could be built for either end or side loading. If anything, today's short closeout times would favor side loading even though a slight degradation of cube utilization may result.

Container capabilities and applied airframe loads: From the preceding, a comparison of the various containers demonstrates a significant trend to

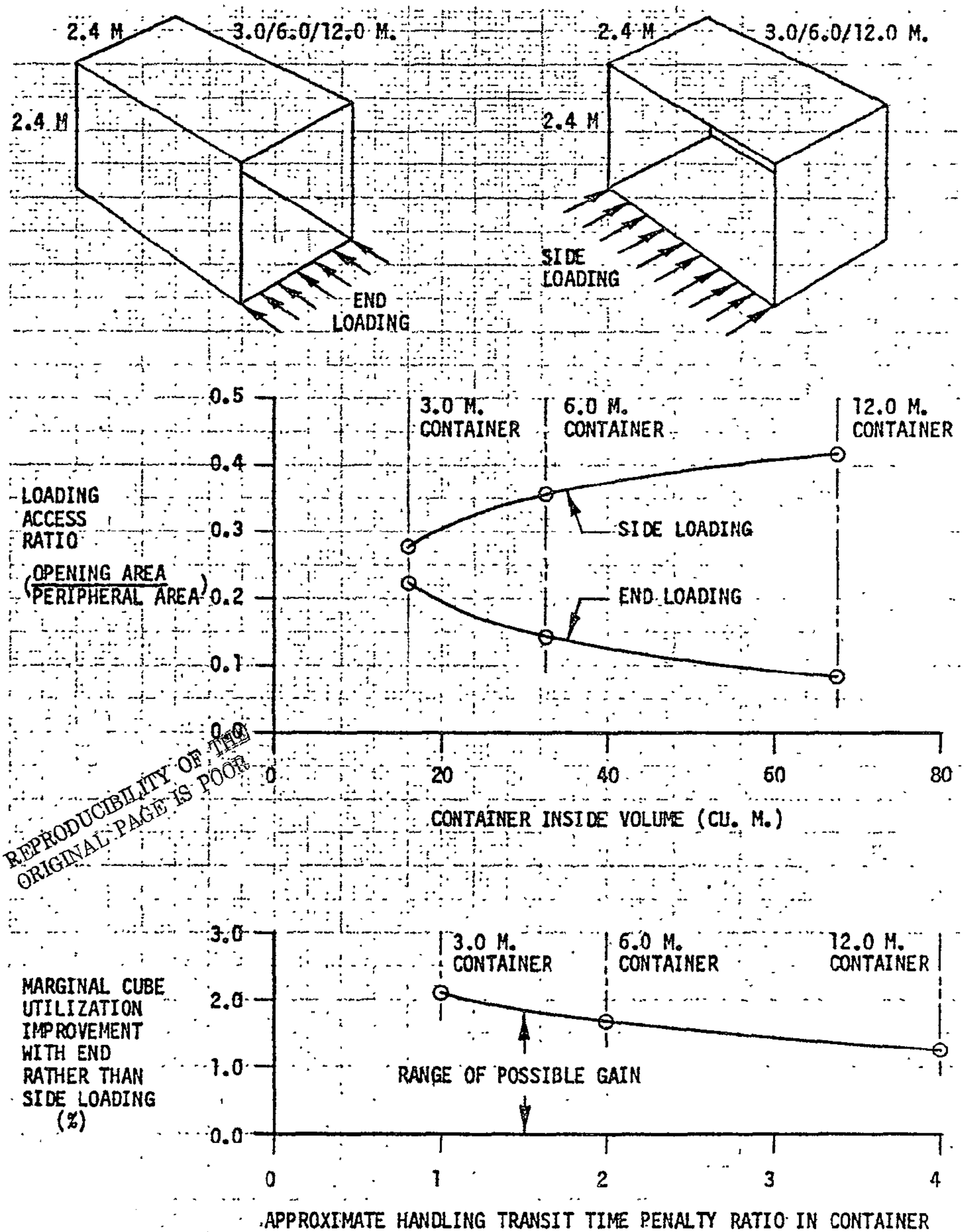


Figure 3-45. Container Loading Access Considerations

improved container and airlift efficiencies with higher-volume rectangular containers. Similar trends would also be evident with equivalent volume and shape pallet loads. Table 3-24 lists in ascending order of container interior volumes the various data to derive specific figures of merit. Particular attention is directed to the 230.9 kg/cu m cargo warehouse density which is a fundamental input to these calculations (columns 4 and 5). This is the mean cargo warehouse density from the 1968-1969 cargo surveys (Table 3-22) and is basically valid since heterogeneous air cargo still dominates the cargo airlift market. If future years result in a different distribution of airlift commodities, this independent variable may shift up or down resulting in similar changes to the dependent figures of merit.

Three particular figures of merit that are of interest in evaluating airlift efficiency are plotted in Figure 3-46. The tare weight ratio (tare weight ÷ cargo weight) is the proportionate nonrevenue-generating penalty compared to the revenue-generating payload. As such, main deck containers generally render a lower more favorable ratio than do the belly containers. The B747F shelf pallet which tends to be a hybrid favoring the pallet category reflects its lower, more favorable tare weight. An example comparison of a pallet load equivalent to the 2.4- x 2.4- x 3-meter container shows that the pallet load tare weight ratio would be only 0.064 compared to the 0.147 of the container. This more favorable ratio is characteristic of pallets when compared with equivalent containers.

Cargo maximum loaded density is another recognized figure of merit. Its basic impacts are (1) in payloads realized per available cargo volume, (2) as a basic input to aircraft payload design density requirements, and (3) in a variety of other considerations such as potential revenue generation and improved fuel efficiencies. The larger containers categorically show a potential for beneficially higher cargo loaded densities. The B747F shelf pallet is an expected exception because the shelf is counterproductive to developing maximum achievable cube utilization. This, in turn, limits its loaded density potential. Were the shelf not there, an equivalent volume hardwall container could develop a cargo maximum-loaded density of 203.2 kg/cu m. In terms of existing aircraft, such as the B747F to which this unit is tailored, it may be that this high a cargo-loaded density would exceed the payload/range curve in which case the higher loaded density would not

TABLE 3-24

ACHIEVABLE MAXIMUM CONTAINER CAPABILITIES

(1) Container Type	(2) Interior Volume (cu m) (Note 1)	(3) Max. Cube Utilization (%) (Note 2)	(4) Max. Loaded Density (kg/cu m) 230.9 x(3) (Note 3)	(5) Max. Cargo Weight (kg) 230.9x(2)x(3) (Note 3)	(6) Container Tare Wt (kg) (Note 1)	(7) Max. Gross Weight (kg) (5) + (6)	(8) Tare Wt/ Cargo Wt Ratio (6) ÷ (5)	(9) Cont Foot-Print Area (sq m) (Note 4)	(10) Acft Floor Loading (kg/sq. m) (7) ÷ (9)
DC-8 Belly	2.10	62.0	143.2	300.6	70.3	370.9	.234	Not Applicable	Not Applicable
LD-3 Half Width (Note 5)	4.39	74.9	172.9	759.2	158.8	918.0	.209	2.40 (3.08)	382.5 (298.1)
LD-5 Full Width	6.54	79.6	183.8	1202.0	272.2	1474.2	.226	4.87	302.7
LD-3 Full Width (Note 5)	9.01	80.0	184.7	1664.3	226.8	1891.1	.136	4.87 (6.23)	388.3 (303.5)
B727 QC Type "A"	10.62	80.6	186.1	1976.4	294.8	2271.2	.149	7.10	319.9
B707/DC-8 Type "A"	12.77	85.0	196.3	2506.3	294.8	2801.1	.118	7.10	394.5
AS-832 2.4x2.4x3.0 M	16.09	87.4	201.8	3247.1	499.0	3746.1	.154	7.29	513.9
B747F Shelf Pallet	19.97	80.0	184.7	3688.9	322.1	4011.0	.087	7.74	518.2
AS-832 2.4x2.4x6.0 M Note 5)	32.57	90.1 (90.0)	208.0 (207.8)	6775.9 (6768.4)	997.9	7773.8 (7766.3)	.147 (.147)	14.77	526.3 (525.8)
AS-832 2.4x2.4x12.0M	67.68	93.0 (90.0)	214.7 (207.8)	14 533.4 (14 064.6)	1896.4	16 429.4 (15 960.6)	.130 (.135)	29.73	552.6 (536.9)

NOTES:
1. From scale model tests (MDC J5382) and/or literature surveys
2. Achievable maximums based on scale model tests (MDC J5382) and usable cube equation (MDC J6168 and derivatives this study)
3. 230.9 kg/cu m from commercial cargo characteristics study (DAC 66616).
4. Parenthetical entries include shadow projection of outboard lower edge chambers
5. Parenthetical entries are based on 90% maximum practical cube utilization

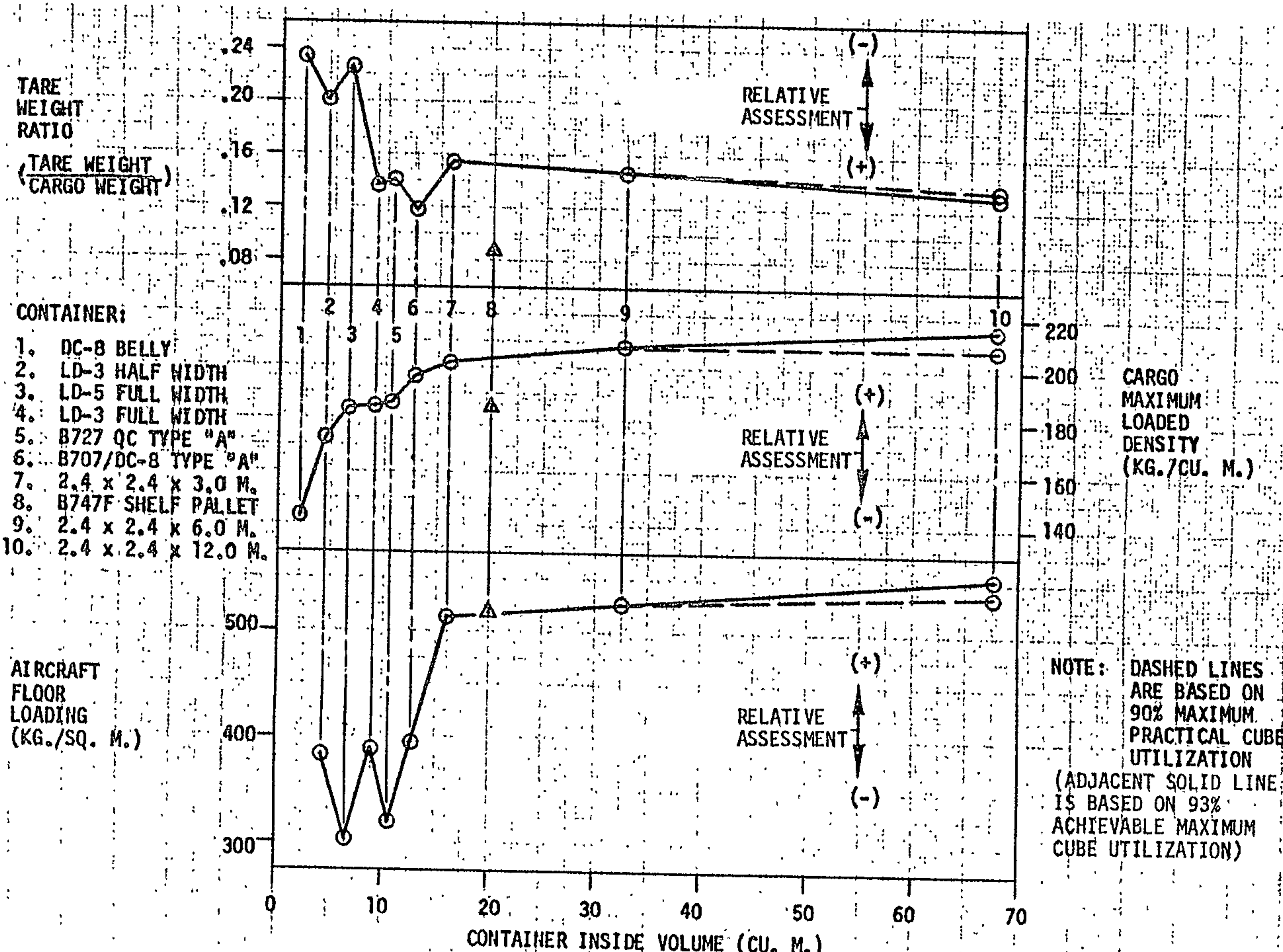


Figure 3-46. Container/Aircraft Figures of Merit

prove beneficial. Comparing a pallet load equivalent to the 2.4- x 2.4- x 6-meter container results in a degradation from the container loaded density of 207.8 kg/cu m down to 191.6 kg/cu m for the pallet. Similar degradations would also occur for the other pallet/container sizes.

The third figure of merit, aircraft floor loading, reveals a substantial increase at the cargo maximum-loaded densities for the rectangular series of main-deck containers. If these high cargo-loaded densities could be consistently achieved in the 1990 future, it would effectively levy new and increased floor and shell strength design requirements on future freighter configurations. When compared with equivalent pallet loads which are not plotted in Figure 3-46, the pallets offer a significant degree of relief. For instance, a 2.4- x 2.4- x 6-meter pallet load exerts a 449.7 kg/cu m floor load as compared to the 526.3 kg/cu m for its container counterpart. But also this floor load relief was accompanied by a differential loss of 534 kilograms of revenue cargo payload because higher cube utilizations (see Table 3-23), loaded densities, and, hence, revenue payloads can be developed in containers. These pallet-associated floor load reliefs and differential revenue payload losses would be typical for the other pallet/container sizes.

In reviewing the plots for the three figures of merit, it is apparent when considering the 90 percent maximum practical cube utilization that little benefit is gained with the 12-meter container other than its ability to handle oversize cargo. It also appears that the 3- and 6-meter containers and the B747F shelf pallet represent a family of ULDs that offer potential advantage for near- and far-term development. Specific application depends on their compatibility with operator usage, range and route structure, and wide-body fleet equipment such as the B747F, DC-10 freighter derivatives, main-deck combination aircraft, and future freighter configurations.

The data of Figures 3-47 and 3-48 depict the applied achievable maximum container capabilities developed from the preceding data. With the exception of the shelf pallet, Figure 3-47 showing gross and revenue cargo loads displays a reasonable linearity with container inside volume. These plots can be used for reasonable payload and gross load approximations for containers with inside volumes other than the identified containers.

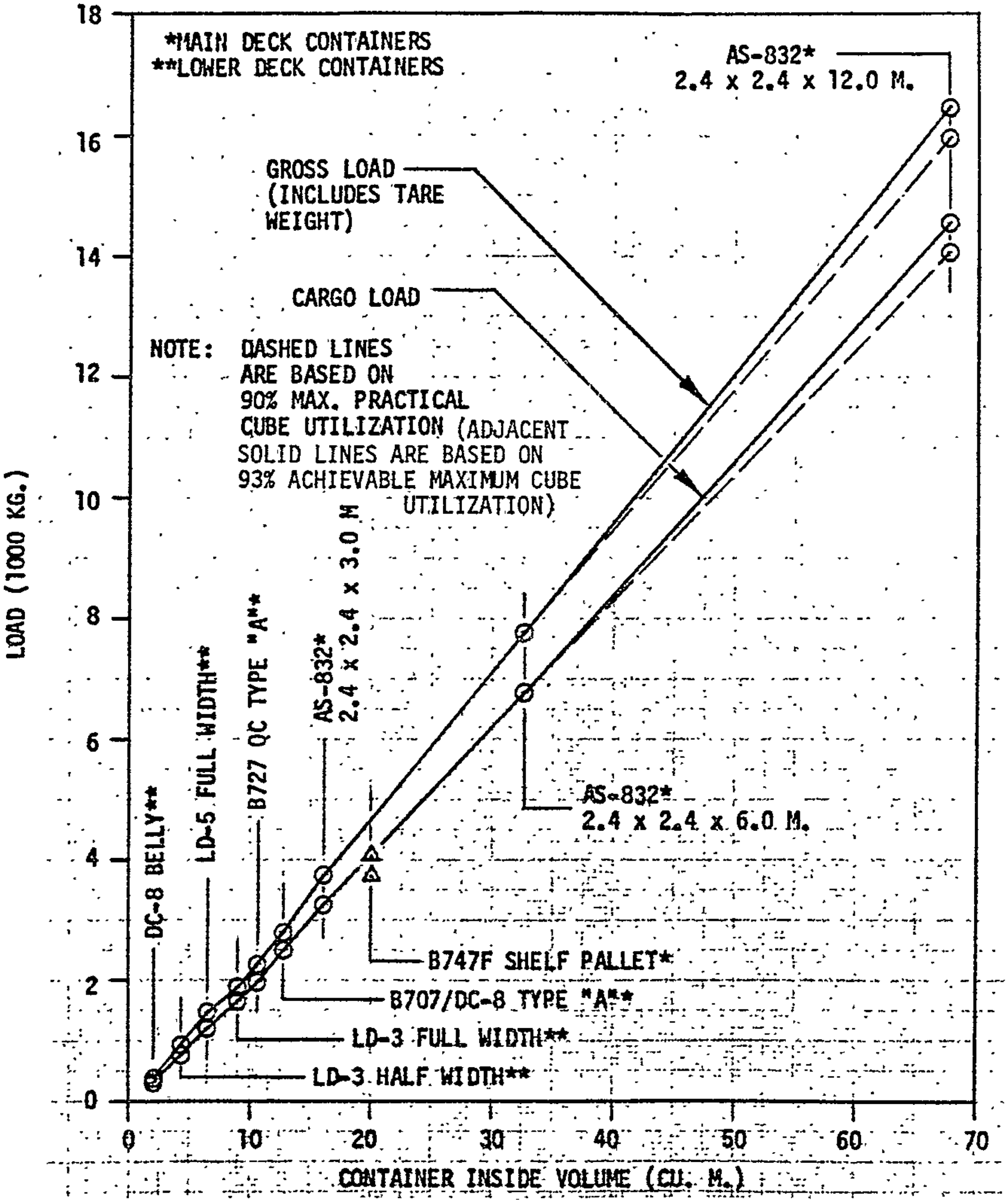
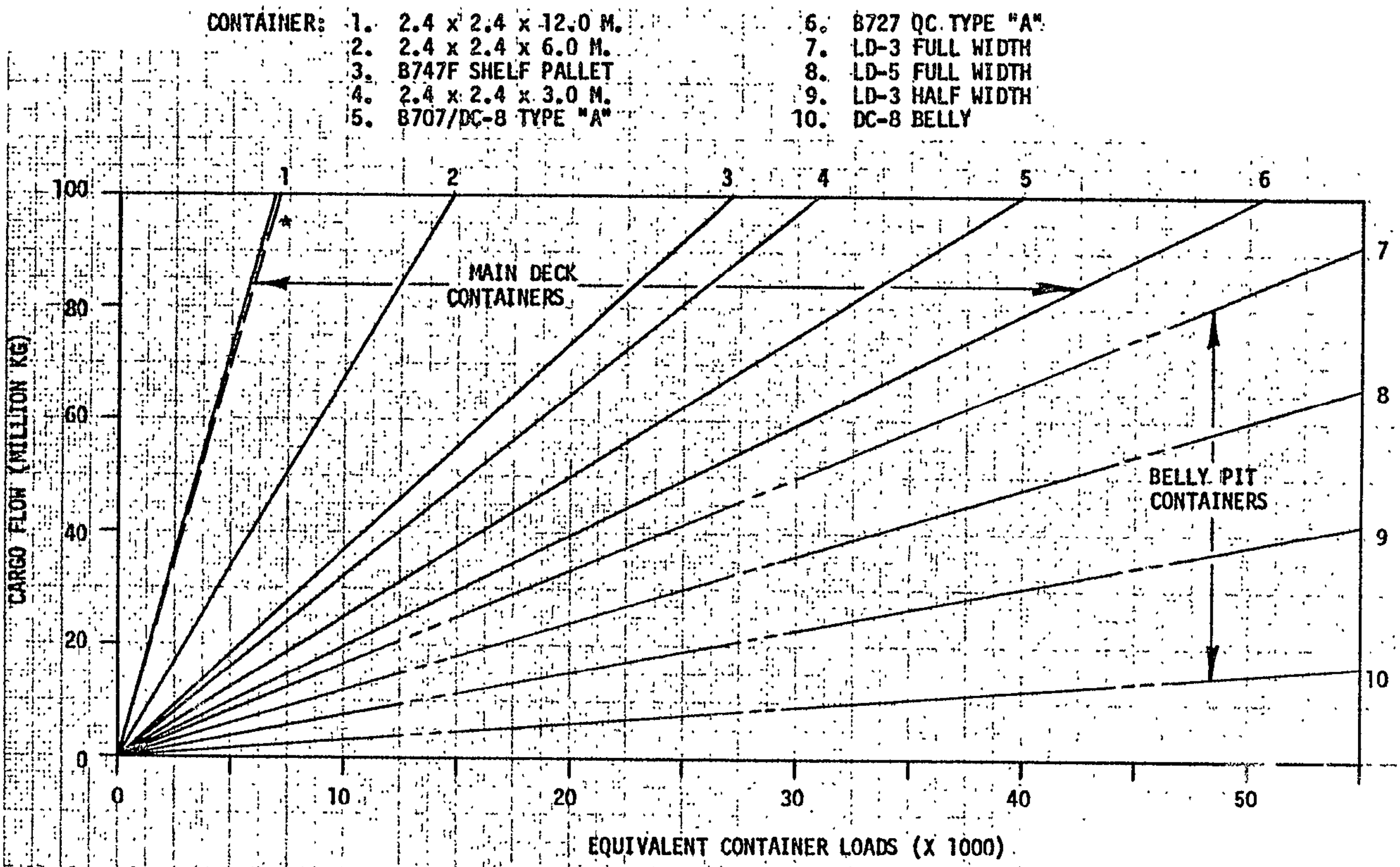


Figure 3-47. Achievable Maximum Container Loads



*DASHED LINE IS BASED ON 90% MAXIMUM PRACTICAL CUBE UTILIZATION
(ADJACENT SOLID LINE IS BASED ON 93% ACHIEVABLE MAXIMUM CUBE UTILIZATION)

Figure 3-48. Cargo Flow Equivalent Container Loads

Figure 3-48 presents plots for equivalent container loads per unit time as a function of actual cargo flow per unit time. For instance, a cargo flow of 40 million kilograms per month through an operator terminal would represent an equivalent of approximately 3000 12-meter, 6000 6-meter, 11 000 shelf-pallet, 12 500 3-meter, 16 000 B707/DC-8-type "A", or 20 000 B727 QC type "A" ULDs per month. This leads to a conclusion that container terminals will benefit substantially from the far fewer handlings associated with large containers. For a given flow level, 6-meter containers will only require approximately half the handlings required for 3-meter containers. Extending this thinking to aircraft laoding also suggests a significant reduction in load/offload times if large rather than small containers are used.

Inherent to the preceding rationale is a premise that large or small ULDs must be handled individually. Recognizing that this need not be so, Douglas advanced handling and loading technology studies have employed aggregate handling and loading concepts to reduce the number of handlings. In principle, this states that an equipment can be sized to accommodate one 12-meter length. This same equipment can then also handle two 6-meter containers, four 3-meter containers, or a mixture of one 6-meter and two 3-meter containers simultaneously. The validity of this concept is based on a compatible loading aperture and directional orientation of the ULDs inside the aircraft.

At slight penalty this 12-meter length can be extended to accommodate four B747 shelf pallets or type "A" ULDs. This commonality is pictured in Figure 3-49 which has made no allowance for clearance spacing between the multiple ULDs. As indicated, the envelope utilization penalties are inconsequential when compared with the mixed load-handling flexibility afforded.

A final comparison of containers relative productivities is given in Table 3-25. This highlights the potential revenue payload advantages enjoyed by the larger containers provided that sufficient cargo is available and that proper load buildup procedures and operations can be employed. This table is read from the evaluated container (left side column) to a compared container column. The evaluated container column is listed in descending order of achievable maximum cargo weight capability. For instance, the 12-meter container has 3.90 percent more payload than two 6-meter containers, 4.68 percent less capability than four B747F shelf pallets, 8.29 percent more

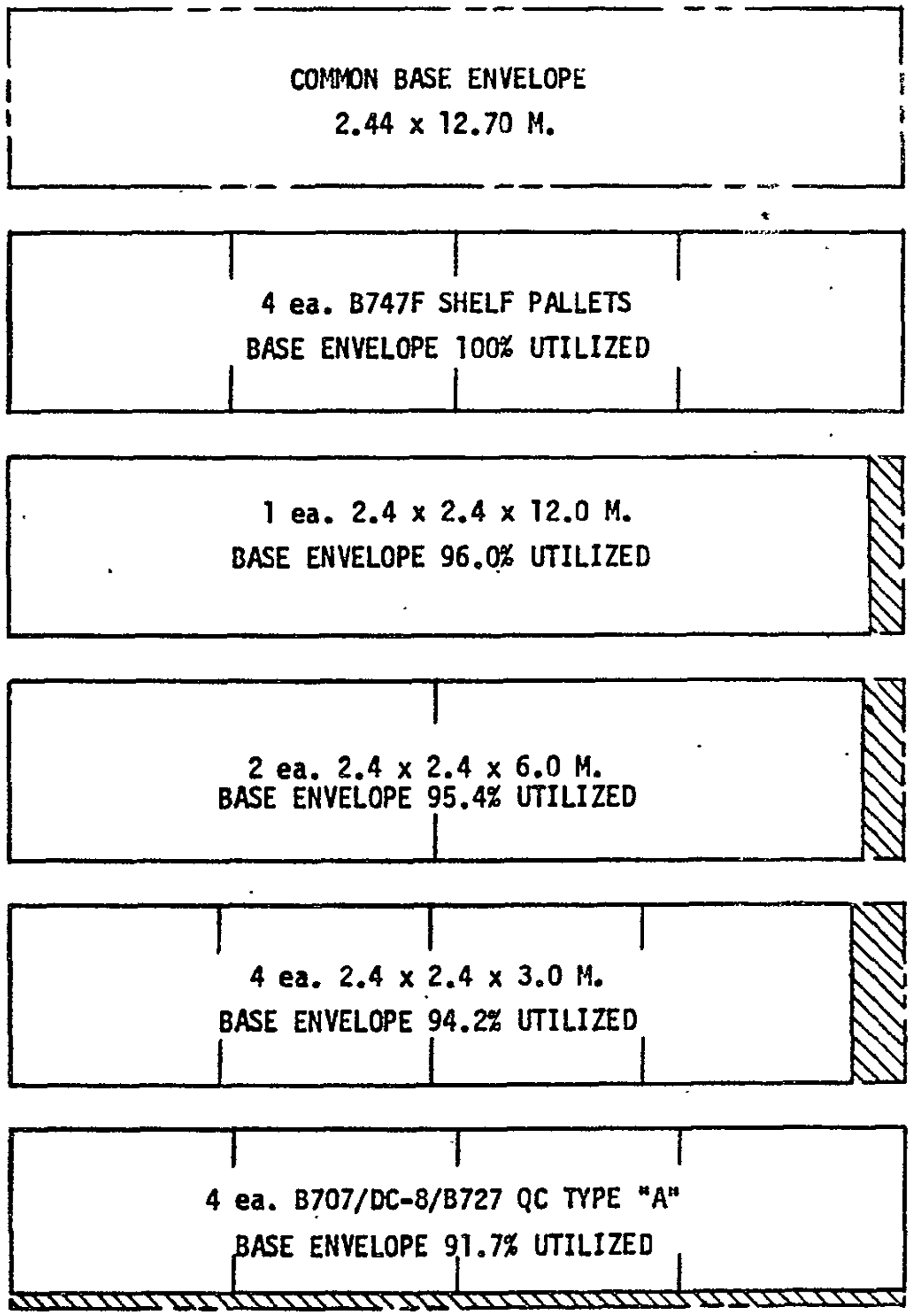


Figure 3-49. Container Base Envelopes Commonality

TABLE 3-25

MAIN DECK CONTAINERS RELATIVE CARGO WEIGHT ADVANTAGES (%)

Evaluated Container (Note 1)	Percent Cargo Weight Advantage of Evaluated Container (Left Side Column) Over Multiple Equivalents Below (Note 2)				
	2.4 x 2.4 x 6 M	B747F Shelf Pallet	2.4 x 2.4 x 3 M	B707/DC-8 Type "A"	B727 QC Type "A"
2.4 x 2.4 x 12 M (Note 3)	+7.24 (+3.90)	-1.51 (-4.68)	+11.90 (+ 8.29)	+44.97 (+40.29)	+83.84 (+77.91)
2.4 x 2.4 x 6 M (Note 3)		-8.16 (-8.26)	+ 4.34 (+ 4.22)	+35.18 (+35.03)	+71.42 (+71.23)
B747F Shelf Pallet			+13.61	+47.19	+86.65
2.4 x 2.4 x 3 M				+29.56	+64.29
B707/DC-8 Type "A"					+26.81

NOTES: (1) Evaluated containers listed in descending order of achievable maximum cargo weight capability.

(2) Approximate common equivalents:

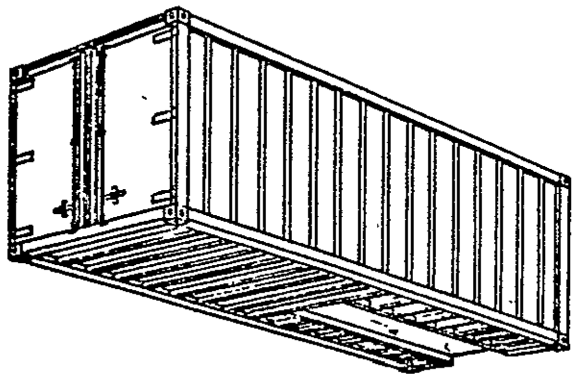
One each 12 M ≅ two each 6 M ≅ 4 each remaining container types
One each 6 M ≅ two each remaining container types
One each B747F shelf pallet ≅ one each B707/DC-8 Type "A" ≅ one each B727 QC Type "A"

(3) Parenthetical entries are based on 90 percent maximum practical cube utilization.

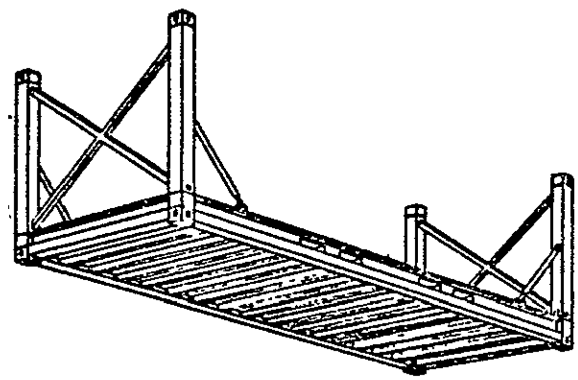
payload than four 3-meter containers, etc. The 6-meter container has 8.26 percent less payload than two B747F shelf pallets, 4.22 percent more payload than two 3-meter containers, etc. The B747F shelf pallet has 13.61 percent more payload than the 3-meter container, and 47.19 and 86.65 percent more payload than the type "A" containers. The 3-meter container has 29.56 and 64.29 percent more payload than the type "A" containers.

Maritime containers. - Even though air and surface containers evidence generic similarities these are outweighed by their dissimilarities. These pertain to handling, restraint, gross loads, and design load factors. Air containers are designed with flat-bottoms for roller conveyor handling and employ restraint latch indents about the perimeter of their base. Conversely, surface containers which are designed for rough handling and for stacking up to six high in containership cells rely on corner support and restraint only. The types are many and varied, but all have standardized upper and lower corner fittings at standard attached centerline distances. This eight-point (four upper and four lower) standardization has enabled a host of benefits including intermixing of container types and a high degree of flexibility in handling methods. Surface containers do not characteristically have flat bottoms and, therefore, are precluded from handling directly on the roller conveyor systems required for air containers. Also, the restraint points are not compatible with aircraft latch restraint systems. These incompatibilities necessitate the use of heavy slave adapter pallets when moving surface containers by air. Typical surface containers are pictured in Figure 3-50.

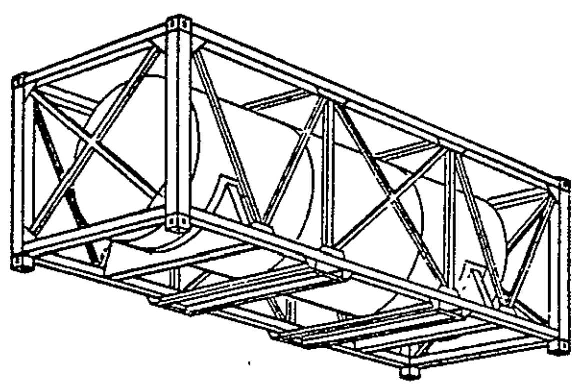
The American National Standards Institute ANSI MH 5.1 series of specifications define ISO (International Standards Organization) surface container requirements. As with the SAE AS-832 air containers, these containers are basically 2.4-x 2.4-meters square in cross section and have 3-, 6-, 9- and 12-meter lengths. Also provided for are 2.6-meter heights which are much in evidence, 7.2- and 8.1-meter lengths in use by Matson Navigation Company, and 10.5-meter lengths in use by Sea-Land Service. Not provided for are high-cube 2.9-meter high containers which are used on some routes where connecting road network underpasses tolerate the additional semitrailer chassis mounted heights. MILVAN containers procured by the Army are to



DRY VAN CONTAINERS



FLAT RACK CONTAINERS



LIQUID CONTAINERS

Figure 3-50. Representative Maritime Containers the standard 2.4- x 2.4- x 6-meter size. Even with the noted variations, all employ the standard eight corner points.

Surface Container Derated Loads: In the matter of container gross loads and operational load factors, there is considerable disparity between air and surface containers as seen in Table 3-26. These are related to one another as follows. Using the 12-meter lengths as an example, at limit load the air container would be good for a download of 68 040 kilograms (20 412 kg x 3.33g) whereas the surface container would only be good for a download of 54 867 kg (30 482 kg x 1.8g). Thus, if the surface container capability is to be good for the 3.33g download, its gross load in airlift should be restricted to 16 460 kilograms. This relationship is expressed as 30 482 kg x 1.8g = 16 460 kg x 3.33g. The surface container restricted gross load of 16 460 kilograms is thus a derated 54 percent of its rated 30 482 kilogram gross load. This relationship is also shown in a later figure for 60 percent at 3.0g and 67 percent at 2.7g.

Lest an adverse conclusion be drawn from the preceding, there are other considerations which may allay any problems associated with operating surface containers at derated loads in airlift. These include the following:

- The derated loads even at 54 percent still yield loaded densities in excess of 275 kg/cu m, which is high for most cargos subject to airlift.
- The 3.33g airlift download is a "flying light" condition which would seldom be experienced in cargo airlift operations.
- Containers good for 3.33g limit download exceed the aircraft floor limit download of 3.0g. This suggests that the 3.33g is conservative and could be reduced or, conversely, that surface containers could fly at higher derated gross loads.
- While penalizing other operational parameters, aircraft could fly at restricted speeds through zones of clear-air turbulence. Navigational aids have been under development which will enable identification of clear-air turbulence as it is approached. Thus, at the reduced speeds, the induced loads would be reduced.

Surface container roof restraint: As seen in the Table 3-26 comparison of design load factors, surface containers are deficient with respect to

TABLE 3-26

AIR AND SURFACE CONTAINER GROSS LOAD AND DESIGN LOAD FACTOR COMPARISONS

GROSS LOADS - KILOGRAMS

Container Length	3 M	6 M	9 M	12 M
AS-832 (Air)	5670	11 340	15 876	20 412
ANSI MH 5.1 (Surface)	10 161	20 321	25 402	30 482

DESIGN LOAD FACTORS

Load Direction Relative to Length of Container	DOWN	UP	Longitudinal	Lateral
AS-832 (Air)	3.33*	1.67*	1.0*	1.0*
ANSI MH 5.1 (Surface)	1.8	0.0	1.8	0.6

*Limit load factors shown @ 2/3 of specified ultimate load factors uploads, whereas air containers have such capability. This could be described as the type of load encountered in an air pocket in which the cargo in the container would tend to burst up through the roof of the container. While some surface containers have such an inherent capability, there is no such requirement levied on them. The only requirement for a surface container roof is that it be capable of sustaining 200 kilograms applied vertically downward, uniformly distributed over any 30.5- x 61-centimeter area. This is a noncumulative load.

A variety of approaches to cope with this critical deficiency have been explored. However, a proprietary surface container roof restrainer approach proposed by Douglas has considerable merit. As shown in Figure 3-51, this takes advantage of the standard upper corner fittings of the container to attach a lightweight airworthy roof restrainer which can employ a variety of design configurations. This approach has been made possible, regardless of surface container roof design, because of the standard interface wherein the four twistlock holes are located to standard dimensions from one another. Thus, the pattern of the four top surface twistlock holes is consistent from one container to the next in any nominal container size.

Maritime container loads: For lack of understanding on the part of many shippers, maritime container cargo is seldom considered a candidate for airlift even though there are large volumes of high-value goods moving in maritime operations that could be diverted to air on an economic basis alone. More often, diversion to airlift occurs when cases of emergency or contingency arise, when environmental or economic perishability become critical, or when customer service or consignee manufacturing outputs are jeopardized. There is evidence of such diversions on a limited basis occurring in present-day operations. Furthermore, air bridge services involving multiple modes are being offered by some carriers today.

Since grossed-out maritime containers do not meet airworthiness requirements, it is necessary to assess the actual gross loads being experienced in maritime operations. If it is found that actual gross loads are sufficiently less than design gross capabilities, the previously discussed concept of gross load derating holds considerable promise. The particular advantage of container loads that do not exceed the derated value is that the containers

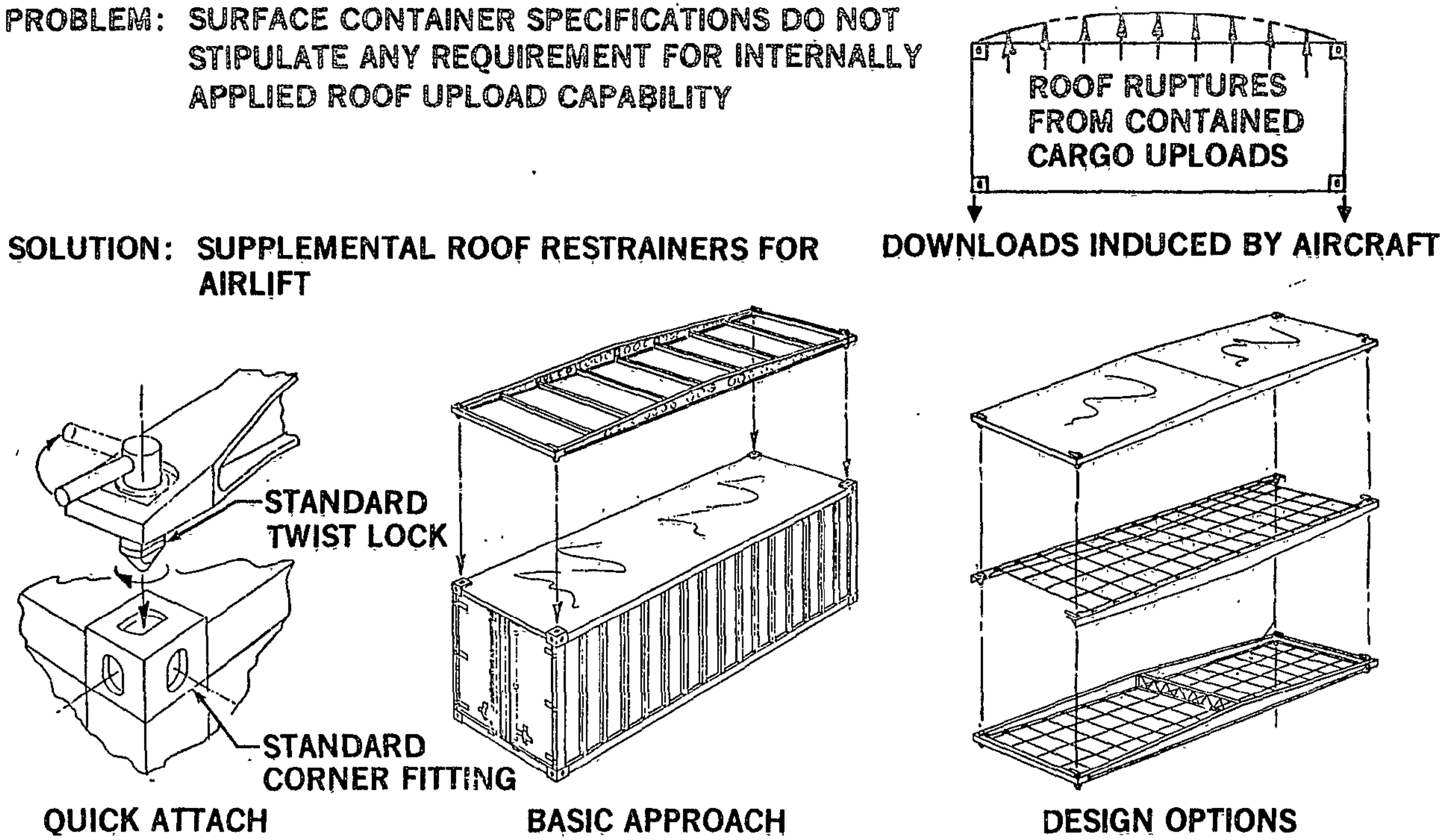


Figure 3-51. Maritime Container Roof Restrainer Concept for Airlift

would not require partial unloading to make them airworthy. Also, if future aircraft container handling and restraint systems could be designed to accommodate both air and surface containers, it would be possible to accept diverted maritime container loads on a routine basis.

Surface container gross loads data were acquired in 1977 through initial contacts with the Ports of Baltimore, Long Beach, Los Angeles, New York/New Jersey, and Oakland; the Maritime Administration (MARAD - Department of Commerce); the Military Traffic Management Command (MTMC - Department of Defense); and several authoritative trade publications. Inasmuch as receipt of further data is still pending, the results are preliminary and subject to further change and refinement.

The most meaningful data received were from the Port of Baltimore and the MTMC. The Baltimore data covered 22 956 6-meter and 61 843 12-meter export container loads for the period January 1975 through June 1976. The MTMC data covered 306 6-meter, 919 10.5-meter, and 128 12-meter export container loads of Direct Supply Support (DSS) cargo containerized by the New Cumberland Army Depot during January through March 1977. Only DSS cargo was initially analyzed since the other major commodity groups moving as MTMC containerized cargo (BX/commissary, household furnishings, and private vehicles) may not have the same priority on available airlift resources in the event of a military contingency. The analysis from these data is presented in Figures 3-52 and 3-53 for 6-meter and 10.5/12-meter container loads respectively.

If the Baltimore data for commercial maritime cargo are representative of 6-meter containers (Figure 3-52), the previously contemplated surface container gross load derating may not be a valid approach to accepting such containers for transhipment by air. This approach was based on the premise that a large majority of surface containers were moving at gross loads considerably lower than their design gross loads. In order to accommodate air mode design load factors, a 6-meter surface container could not have a gross load in excess of 10 973 kilograms. As can be seen, only 25 to 28 percent of the 6-meter containers out of Baltimore would be acceptable unless design load factors could be eased on an exception basis or unless the container could be partially unloaded.

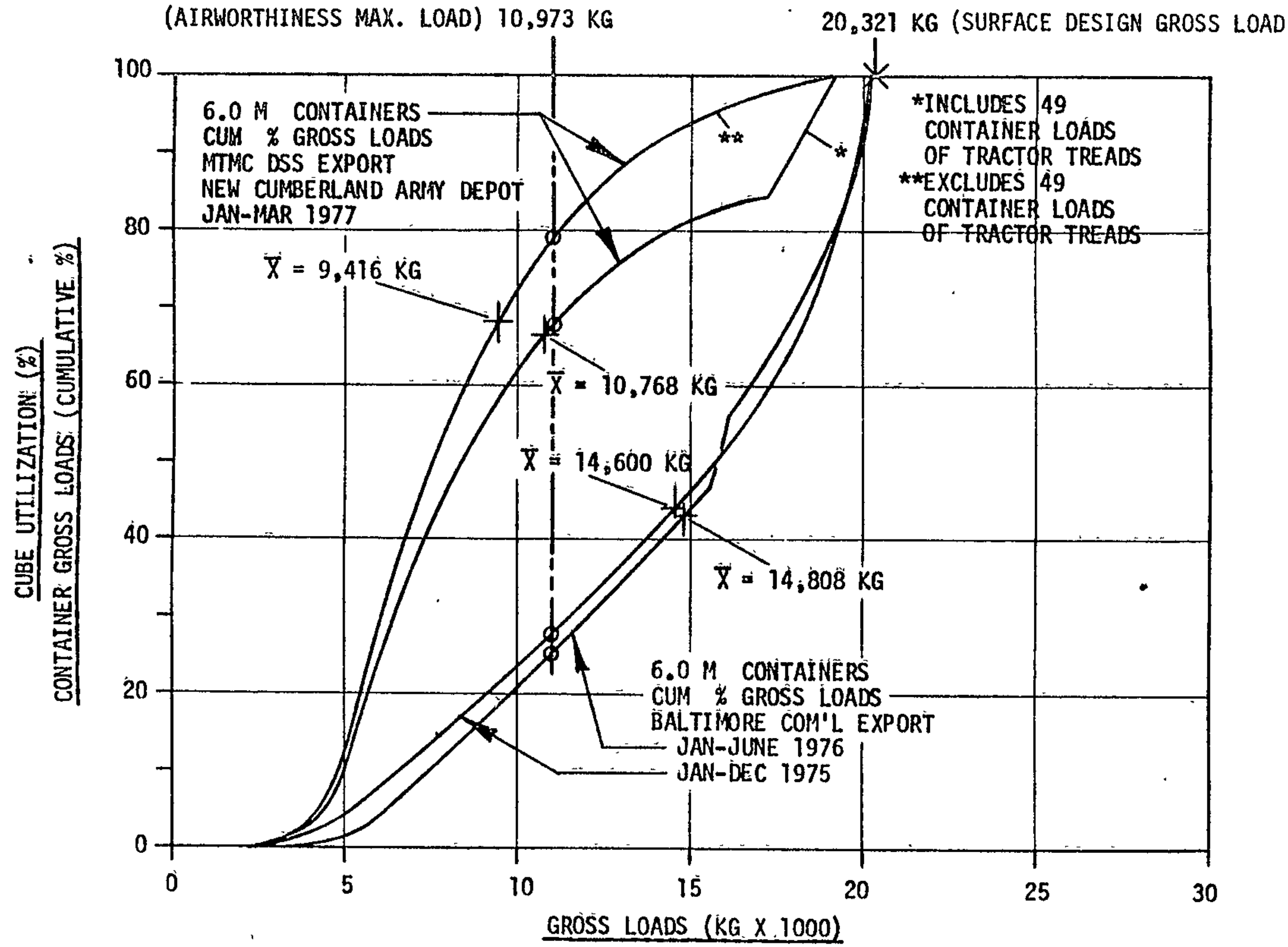


Figure 3-52. Gross Loads Cumulative Frequency Distribution - 6-Meter Surface Containers
(Includes Assumed Tare Weight of 2268 KG/6-Meter Container)

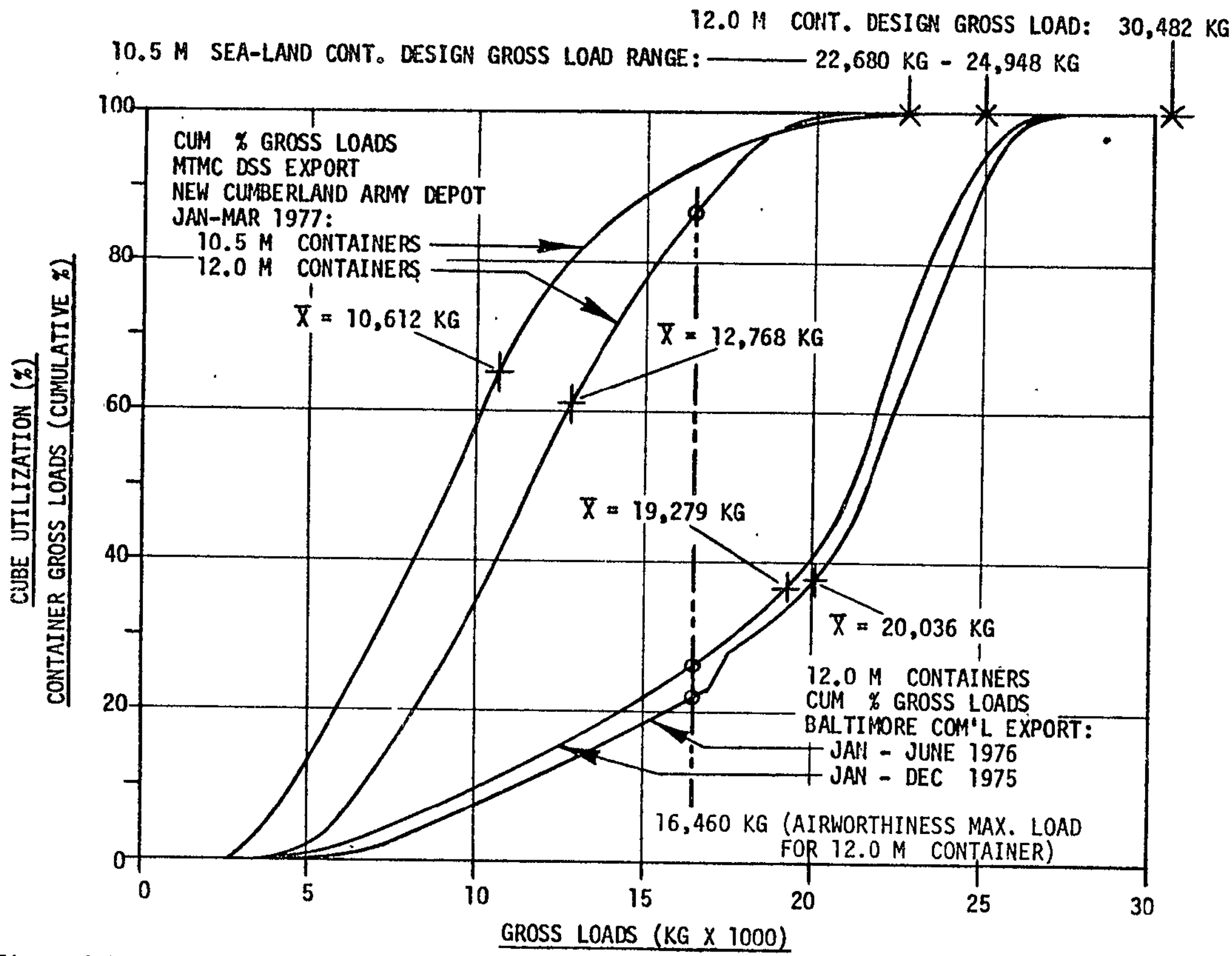


Figure 3-53. Gross Loads Cumulative Frequency Distribution - 10.5 and 12-Meter Surface Containers (Includes Assumed Tare Weights of 2722 KG/10.5-Meter and 3629 KG/12-Meter Containers)

Conversely, a significant 68 to 79 percent of the 6-meter MTMC containers would be acceptable candidates for airlift based on present MTMC container utilization. However, the obviously low MTMC container utilization is probably a reflection of low peacetime demand on a cyclical delivery basis versus actual contracted capacity available. In the even of a contingency diversion of surface containers to airlift, it is not known how long the pipeline lag would be before higher utilizations would be achieved. But, it may be reasonable to accommodate the initial surge by diversion and airlift of the lower gross weight, underutilized surface container loads in the CONUS/POE pipeline, after which sustained maritime surface pipeline buildup would be coincident with higher container utilization.

In Figure 3-53 a similar disparity is seen between the 12-meter container commercial loads out of Baltimore versus the 10.5-and 12-meter MTMC container loads. In this case, the gross container loads cannot exceed 16 460 kilograms, which makes only 22 to 27 percent of the Baltimore containers and a large 87 to 93 percent of the MTMC containers eligible candidates for diversion to airlift.

While two 6-meter containers end to end represent a higher gross load than a single 12-meter container in an aircraft, the single 12-meter container results in higher concentrated reactions at the four corners. Thus, both 6- and 12-meter containers will levy independent sets of support and restraint requirements on the aircraft system.

The mean values for the Baltimore and MTMC data are plotted in Figure 3-54 along with the maritime container derated values. In all cases, the mean values for the MTMC container loads (points A, B, E, and F) are below the derated values whereas the Baltimore container loads (points C, D, G, and H) are above. Some basic observations regarding the Baltimore data are noteworthy:

- For the 6-meter containers, the mean loads are only 7.8 percent and 9.3 percent greater than the 67 percent at 2.7g derated value. For the 12-meter containers, they are 1.9 and 5.9 percent less. Therefore, since the presently required 3.33g airworthiness load factor may be unduly conservative, it is entirely feasible that the 2.7g range or even less would be a more realistic design limit

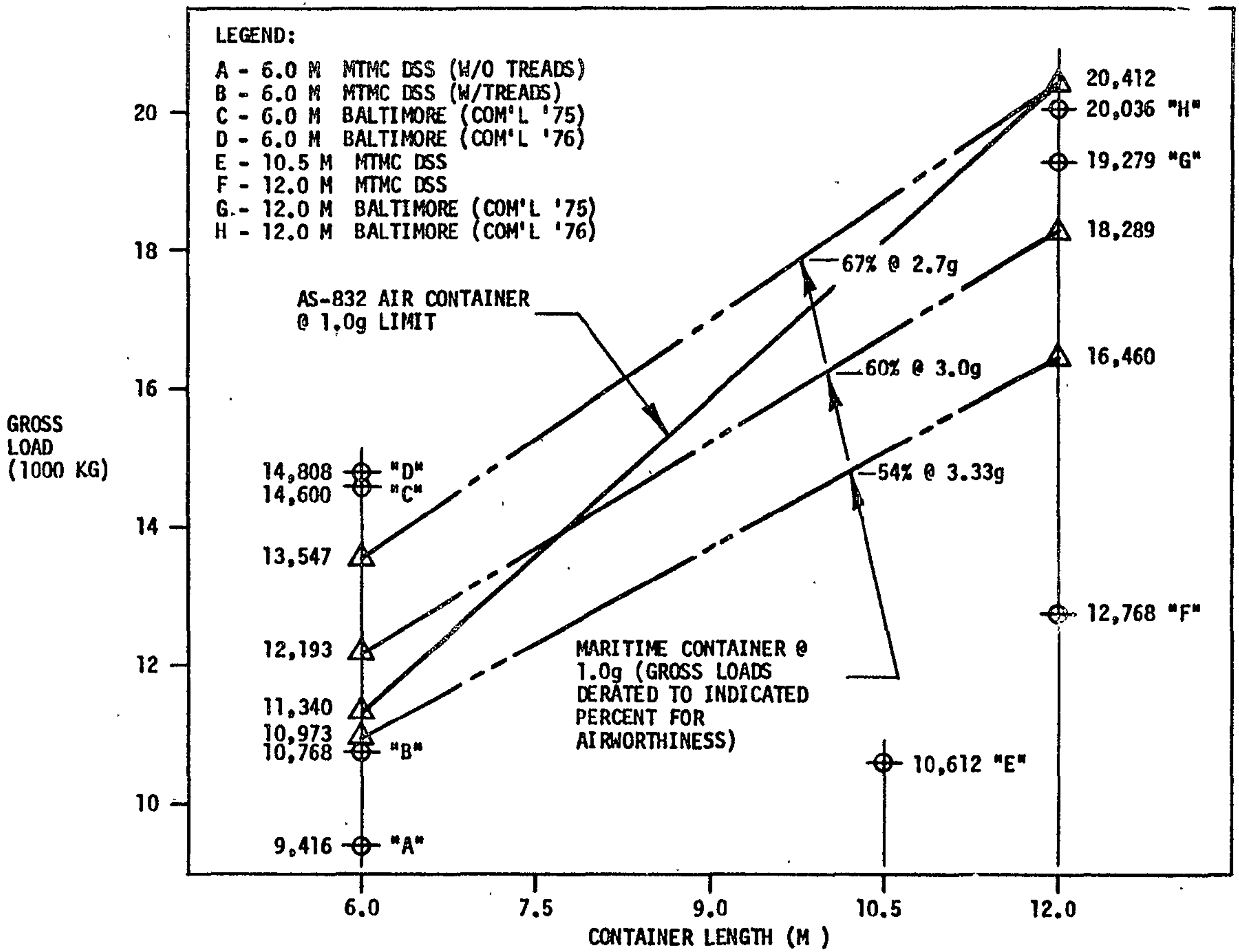


Figure 3-54. Maritime Container Gross Load Derating Correlation

load factor. If this can be shown to be the case, the Baltimore container loads would also be acceptable.

- The Baltimore 6-meter container gross loads ranged somewhat higher than unofficially stated averages moving through other major U.S. ports. This may be a peculiarity of the trade routes and particular operators. If so, it may not represent a composite mean of all maritime container movements through all ports. What is of greater significance is that the high gross loads would include bulk-loaded commodities, such as liquids, grains and ores, scrap iron and steel, etc., much or most of which would be in the higher loaded density lower-value ranges. Assuming this correlation is true, the higher value movements which would be subject to diversion to airlift would be in the lower loaded density ranges. Thus, their container gross loads would be lower and quite possibly acceptable at even the 3.33g load factor.

Even though diversion of maritime containers to airlift is possible, it is so only with substantial penalty as shown in Table 3-27. If present-day handling and restraint methods are to be retained in future freighter aircraft, the tare weight penalty involves that of both the basic container differential plus the airlift slave adapter pallets and restraint nets. Thus, for the 6- and 12-meter sizes, the tare weights are 2.7 and 2.4 times greater for the maritime than the air container. With respect to the tare weight-cargo weight ratios shown, the maritime container loads are based on the actual data mean values, whereas the air containers are based on achievable maximum cube utilizations and mean air cargo warehouse density. On a comparative basis of full gross load capabilities, the maritime containers would have ratios of 0.064 and 0.072, and the air containers would have ratios of 0.096 and 0.102 for 6- and 12-meter containers respectively. The higher tare weight-cargo weight ratios of the air containers are a reflection of the higher flight load design factors and refute the generalized misconception that surface containers are overdesigned for airlift.

TABLE 3-27

COMPARISON OF MARITIME VERSUS AIR CONTAINERS IN AIRLIFT*

Maritime Containers:	Mean Gross Wt (kg)	Cargo Wt (kg)	Container Tare Wt (kg)	Airlift Adapter Tare Wt (kg)	Airlift Total Tare Wt (kg)	Tare Wt/ Cargo Wt Ratio	Container Footprint Area (sq m)	Aircraft Floor Loading (kg/sq m)
6 M MTMC DSS (W/O TREADS)	9416	7148	2268	440	2708	0.379	14.77	667.3
6 M MTMC DSS (W/TREADS)	10 768	8500	2268	440	2708	0.319	14.77	758.8
6 M BALTIMORE (COM'L '75)	14 600	12 332	2268	440	2708	0.220	14.77	1018.3
6 M BALTIMORE (COM'L 1976)	14 808	12 540	2268	440	2708	0.216	14.77	1032.4
10.5 M MTMC DSS	10 612	7890	2722	770	3492	0.443	26.08	436.4
12 M MTMC DSS	12 768	9139	3629	880	4509	0.493	29.73	459.1
12 M BALTIMORE (COM'L 1975)	19 279	15 650	3629	880	4509	0.288	29.73	678.1
12 M BALTIMORE (COM'L 1976)	20 036	16 407	3629	880	4509	0.275	29.73	703.5
AS-832 Air Containers (Previous Anal):	Max. Gross Wt (kg)	Max. Cargo Wt (kg)			COMPARISON →	↕	COMPARISON →	↕
2.4x2.4x6 M **	7774 (7766)	6776 (6768)	998	0	998	0.147 (0.147)	14.77	526.3 (525.8)
2.4x2.4x12 M **	16 429 (15 961)	14 533 (14 065)	1896	0	1896	0.130 (0.135)	29.73	552.6 (536.9)
	Design Gross Wt (kg)						COMPARISON →	↕
2.4x2.4x6 M	11 340						14.77	767.8
2.4x2.4x12 M	20 412						29.73	686.6

*Maritime containers mounted on slave adapter pallets with restraint nets.
**Parenthetical entries are based on 90% maximum practical cube utilization.

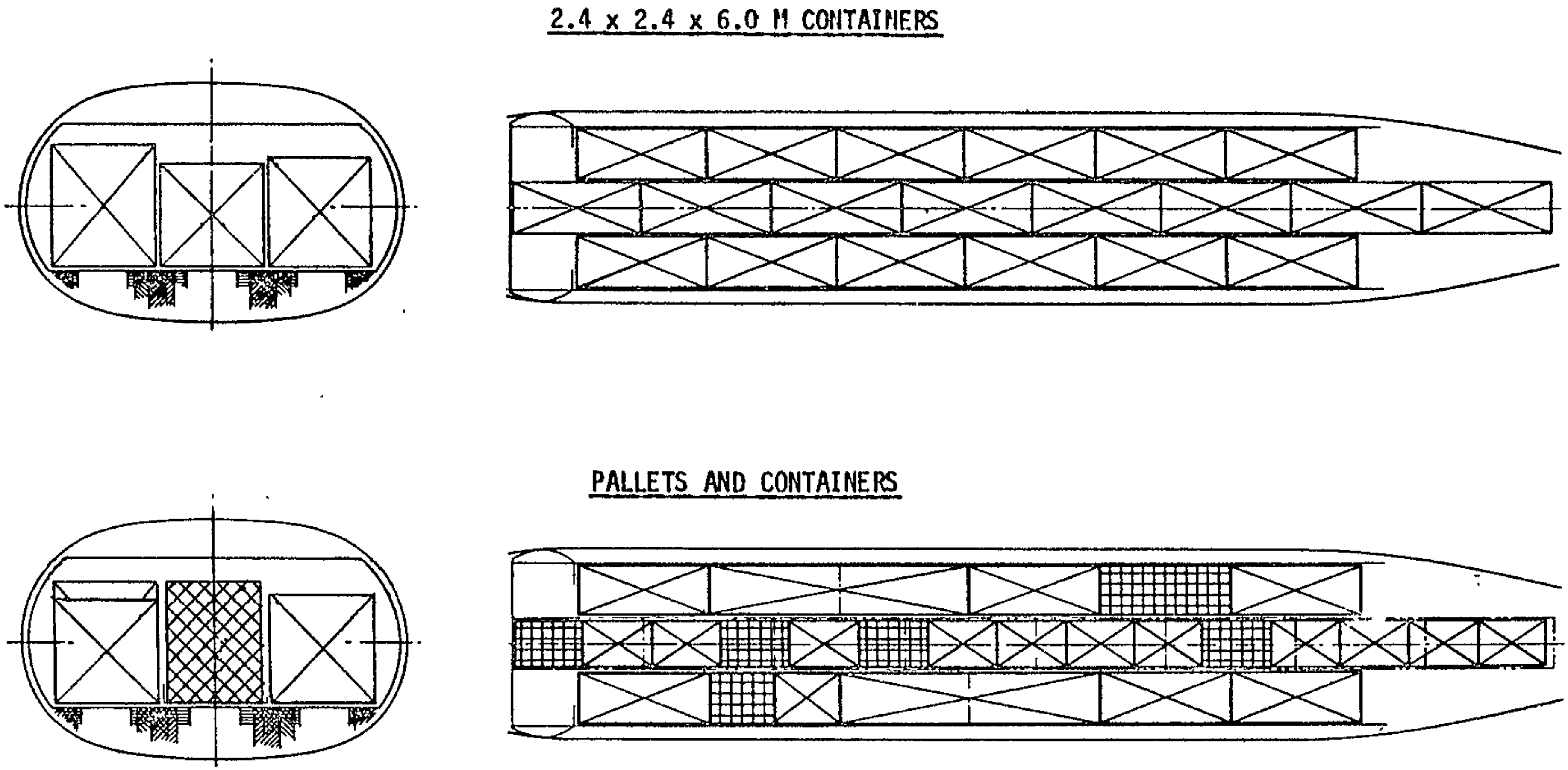
A major impact with design of future cargo aircraft is dependent upon the percentage of total flow that might be diverted maritime container loads and what their gross loads are. As seen in the last column of Table 3-27, the aircraft floor loads have a broad range. For comparison purposes, the maritime container data are compared with the achievable maximums for air containers and the design gross for air containers. If the aircraft floor and shell structure can accommodate the air container design gross loads, it can also accommodate the MTMC container loads, it can marginally accommodate the 12-meter Baltimore container loads, but it cannot accommodate the 6-meter Baltimore container loads. If the aircraft floor and shell structure are designed for the air container achievable maximums, the 10.5-and 12-meter MTMC container loads can be accommodated but neither the 6-meter MTMC or Baltimore container loads nor the 12-meter Baltimore container loads can be accommodated. However, these excessive loads are made up of a low to high distribution of gross loads. Therefore, it is likely that some percentage of the lower-weight containers could be accommodated by placing them over the wing box in the aircraft to minimize fuselage shell bending stresses.

<u>Aircraft and infrastructure compatibility</u>. - ULDs are a common thread impacting the various elements of distribution systems. As air cargo growth has continued, its effects have been felt farther into the interfacing ground systems. These effects have been due in large part to the increased use of containers. Even though compatibility with the aircraft was an implementing consideration, air containers now involve compatibility with shippers and consigners and the intermediate surface transport links with the air cargo terminals. As air cargo growth continues into 1990 and beyond, the container will exert even more influence in all aspects of the total system.

Aircraft system compatibility: Past, present, and near-term generation air freighters are derivatives of passenger aircraft evidencing traditional similarities. As such, air pallets and containers are handled and restrained in the aircraft with traditional means. Whether future generation freighters will break this lockstep will hinge on advances in handling and restraint technology. Development and recent operational introduction of the SAE AS-832 air/land container has been a step in this direction with its side latch restraint indents as opposed to the side restraint rails and end latches used with pallets. However, it still requires roller conveyor handling which extracts certain weight penalties.

If future freighters are not to be compromises of passenger aircraft origins, there is considerable promise for upgraded and/or new technology applications to container handling and restraint, and to airframe configuration and structural design. Evidence of the influence of containers on future freighter configurations is shown in Figure 3-55. This fuselage configuration defined by Douglas is sized to accommodate 6-meter air and surface containers arranged in three side-by-side channels. Standard container heights to 2.9-meters high and nonstandard heights to 3.4-meters will fit within the high ceiling, wide oval fuselage. The 2.4-meter wide container channels will also accommodate rows of 224- x 274-centimeter Air Force 463L pallets or 224- x 318-centimeter commercial pallets at their 224-centimeter width dimension.

The impact of 2.4- x 2.4-meter containers is also being felt in less conventional future cargo aircraft configurations such as straight and swept wing spanloaders. Such configurations have received much attention in both independent and NASA-contracted studies. An interesting sensitivity with spanloader configurations that is less evident with conventional configurations is the impact of 2.9-meter high containers which are being used in increasing numbers. These high-cube surface containers are designed to the same gross loads as their 2.4- and 2.6-meter high counterparts. Provision for the extra height along the span of the wing would reveal a compounding effect first as increased wing thickness, second as increased wing chord length, third as increased weight, fourth as increased drag and power requirement, fifth as increased fuel consumption, etc.



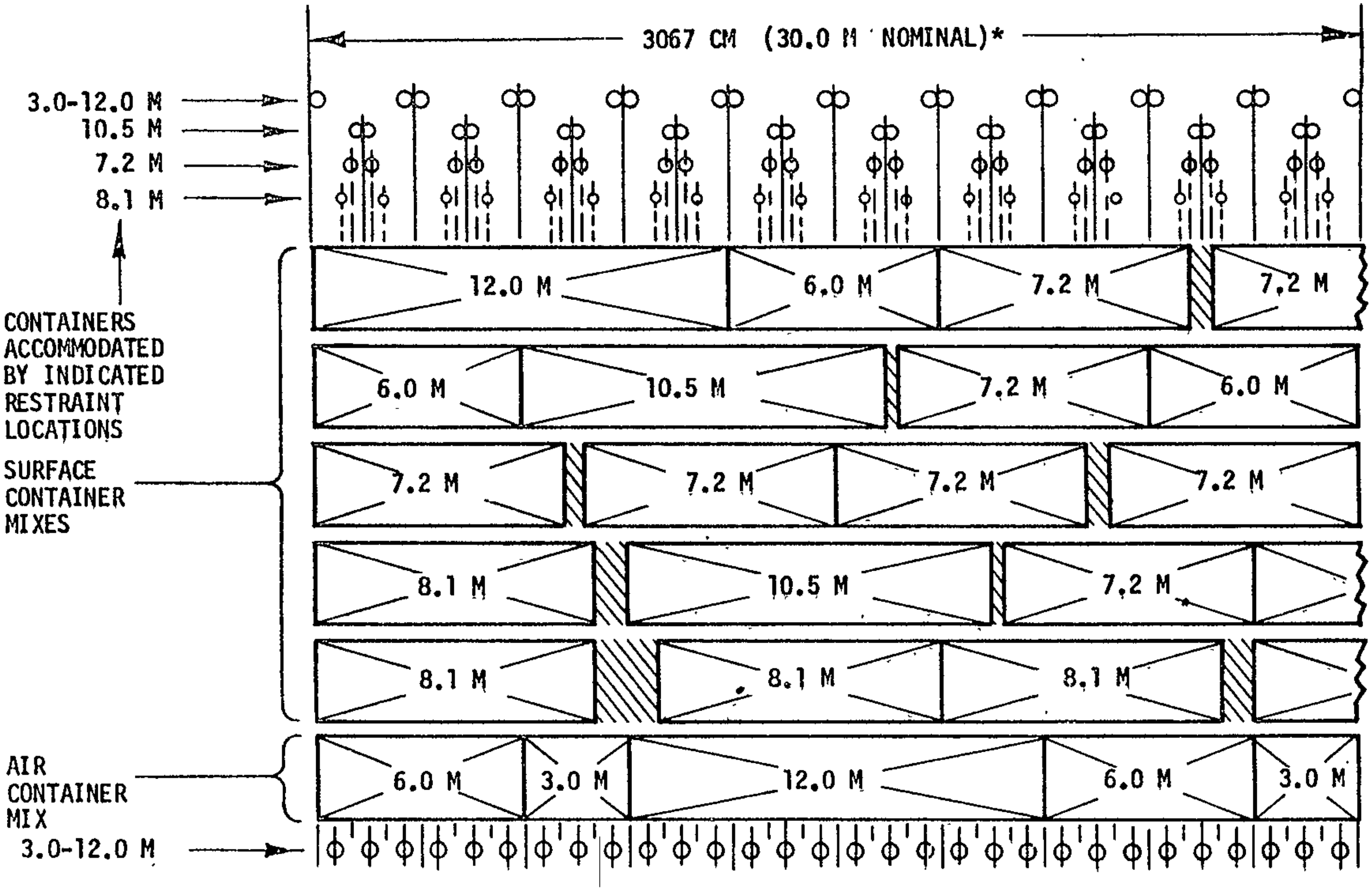
NOTE: ACCOMMODATES STANDARD HEIGHTS TO 2.9 M AND SPECIAL HEIGHTS TO 3.4 M.

Figure 3-55. Container Influence on Future Freighter Configurations

Assimilation of surface containers in aircraft restraint systems presents certain limitations. Even though it would be desirable to accommodate all lengths of surface containers without loss of the cube as shown in Figure 3-56, this would require an infinite number of restraint locations. Therefore, a reasonable compromise would be to basically provide for 3- to 12-meter air and surface containers and allot a limited number of restraint locations in the aircraft for the less common size containers based on need. While the 10.5-meter containers could be accommodated with the addition of restraints at 1.5-meter intervals, accommodating the 7.2- and 8.1-meter containers may be a questionable accession since those lengths individually have the lowest populations.

The influence on fuselage frame or floor beam spacing also results in a slight but compounding change. As shown in Figure 3-57, optimum spacing increments should be multiples of 51.12-centimeter spacing rather than the traditional 50.80 centimeters. This new spacing permits optimum and repetitive load paths from the restraint locations into the supporting structural members rather than the variety of compounding eccentric load paths associated with merging 51.12-centimeter air container restraints into a 50.80-centimeter airframe structural system.

The handling of mixes of flat-bottom air and beam-bottom surface containers has given rise to new design approaches. One such proprietary Douglas concept has been a rollerless container handling system which removes all cargo movement hardware including roller conveyors from the aircraft and makes it a part of a mating loading dock. The aircraft portion of the system consists of longitudinal rails that serve as support members for the containers during flight and as tracks for self-elevating cart trains which are housed in and inserted from a mating loading dock or loader during loading/off-loading. The cart trains are attached to a synchronized powered mover system which is part of the dock or loader. This system permits an aircraft to carry most types of containers while at the same time removing weight and complexity from the aircraft. Not only can rapid cargo turnaround of the aircraft be accomplished by a single operator, but also flat-bottom air container life will be increased since there is not the wear from conveyor rollers. Beam-bottom surface containers will be accommodated without need for heavy slave pallets or adapters and will be automatically latched at their bottom corner fittings.



*INCLUDES ALLOWANCE FOR 7.62 CM CLEARANCE BETWEEN CONTAINERS

NOTE: CROSS-HATCHED AREAS INDICATE NOMINAL LOSSES TO ACCOMMODATE 7.2, 8.1, AND 10.5 M CONTAINERS

Figure 3-56. Potential Nominal Restraint Locations

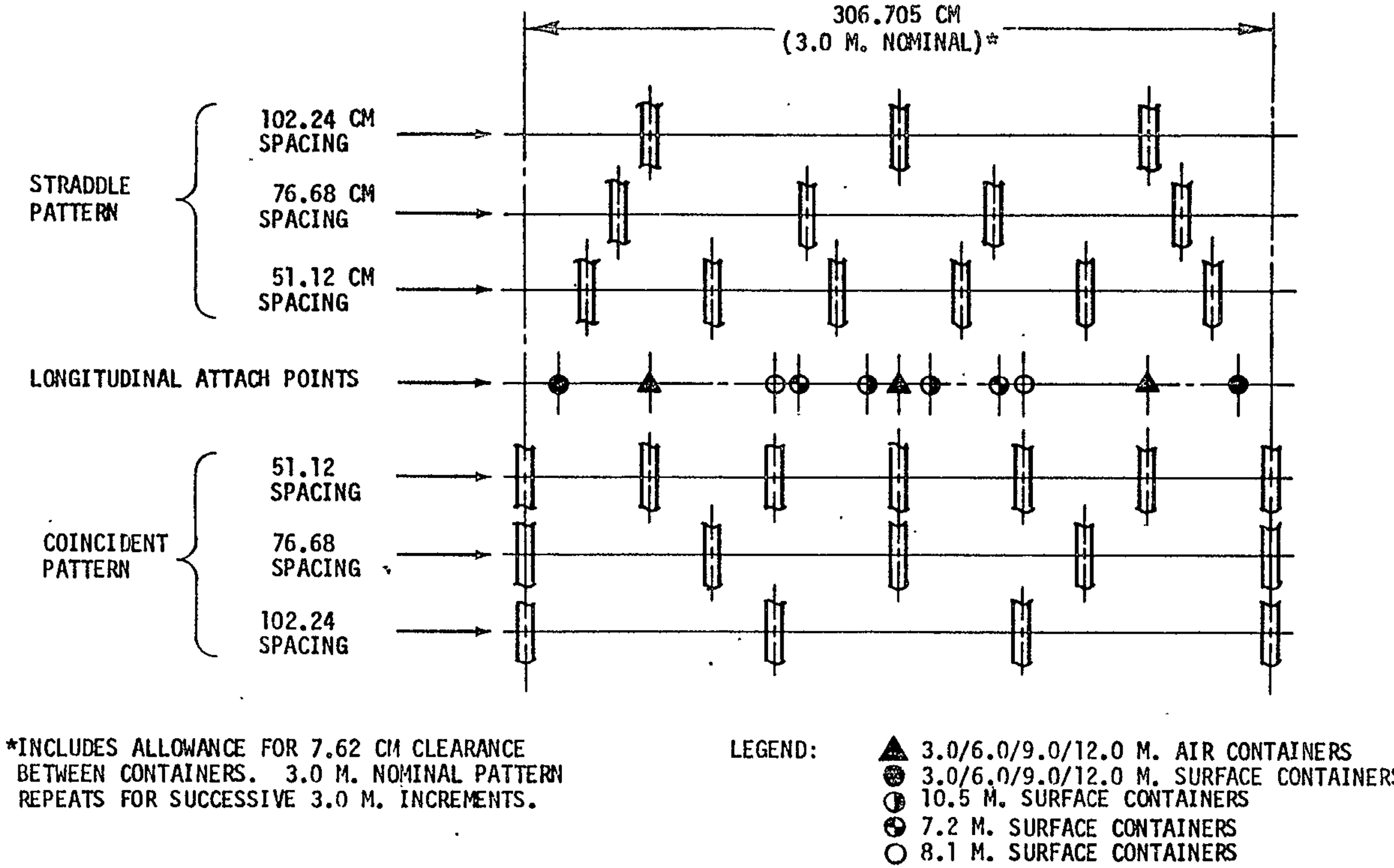


Figure 3-57. Fuselage Frame/Floor Beam Spacing Requirements

The flat-bottom air containers will be automatically latched at their side indents. This concept is basically an open-grid floor of longitudinal rails and lateral floor beams or frames, thus effecting considerable weight savings.

An outgrowth of the rollerless system is a loading-bar system being studied by Douglas. This proprietary concept pictured in Figure 3-58 retains the same advantages and, in addition, is amenable to manual backup redundancy, slave unit applications, total air and surface container compatibility including open-bottom surface containers, and more austere applications. Figure 3-59 depicts the placement of the loading-bar channels which is such that all design specification requirements for the support of air and surface containers can be met in both the aircraft floor system and in the interfacing loading and ground handling equipment. As explained in Figure 3-60, the flanged channels actually provide better distributed support of air containers than do the specified roller conveyor patterns. Since concentrated loads would be introduced into the fuselage at the four corner fittings of surface containers, there will be designated local structural support reinforcements of the outer loading-bar channels. Such reinforcements can be an add-on feature as increasing numbers of surface containers are attracted to airlift.

Infrastructure compatibility: Major categories of the infrastructure system with which ULDs have an interface are the operator cargo terminal, surface transport, shipper/consignee, and system-related issues. The small shipper will have little direct concern with main deck air containers or pallets since for the most part he cannot profitably fill anything greater than submodular sizes, if even them. These sizes are incremental to the larger sizes and can be manually handled or forklifted with equipment that is usually available in-house. These small sizes also pose no particular compatibility problems with the other major categories of the infrastructure system.

The direct support role of airline cargo terminals has dictated their compatibility with type "A" and LD pallets and containers. This and the additional requirements imposed by 2.4- x 2.4- x 6.0-meter (M2) air containers have been discussed in the preceding subsection, Cargo Terminals and Handling Equipment. Since maritime containers also may be diverted through airline cargo terminals, the following summarizes their additional impact on terminal systems that handle only flat-bottom air containers.

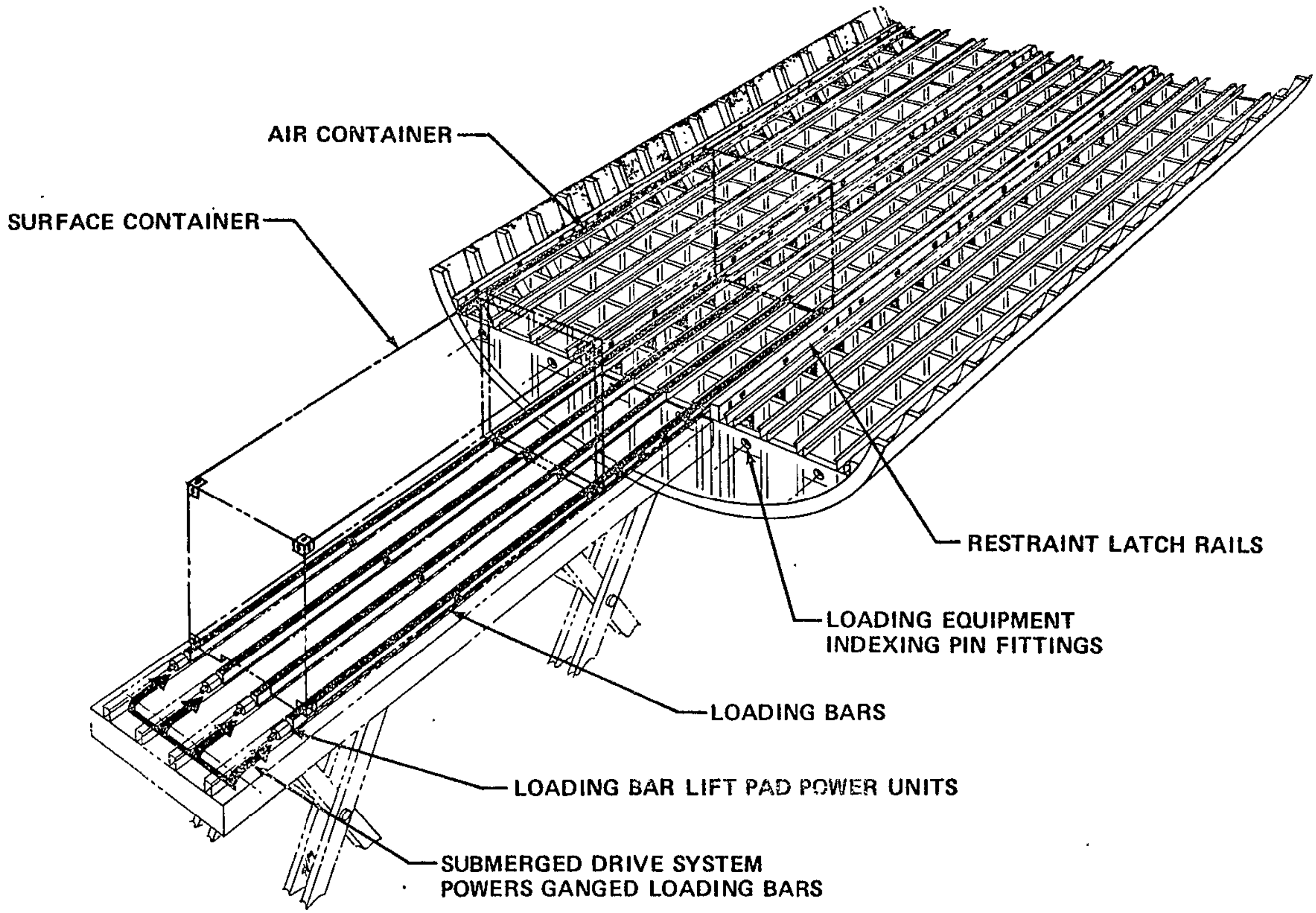


Figure 3-58. Loading-Bar Concept for Handling Air and Surface Containers

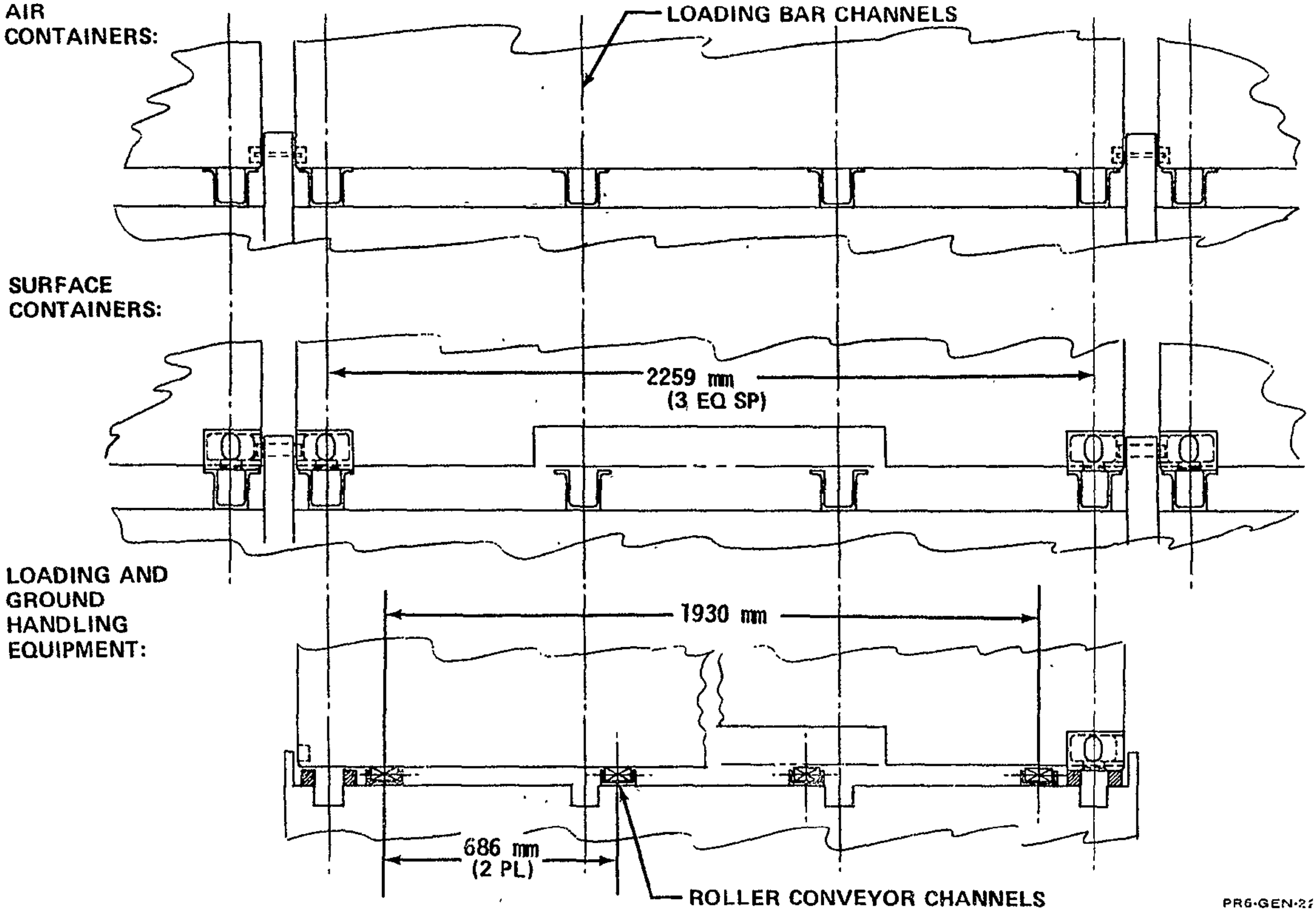
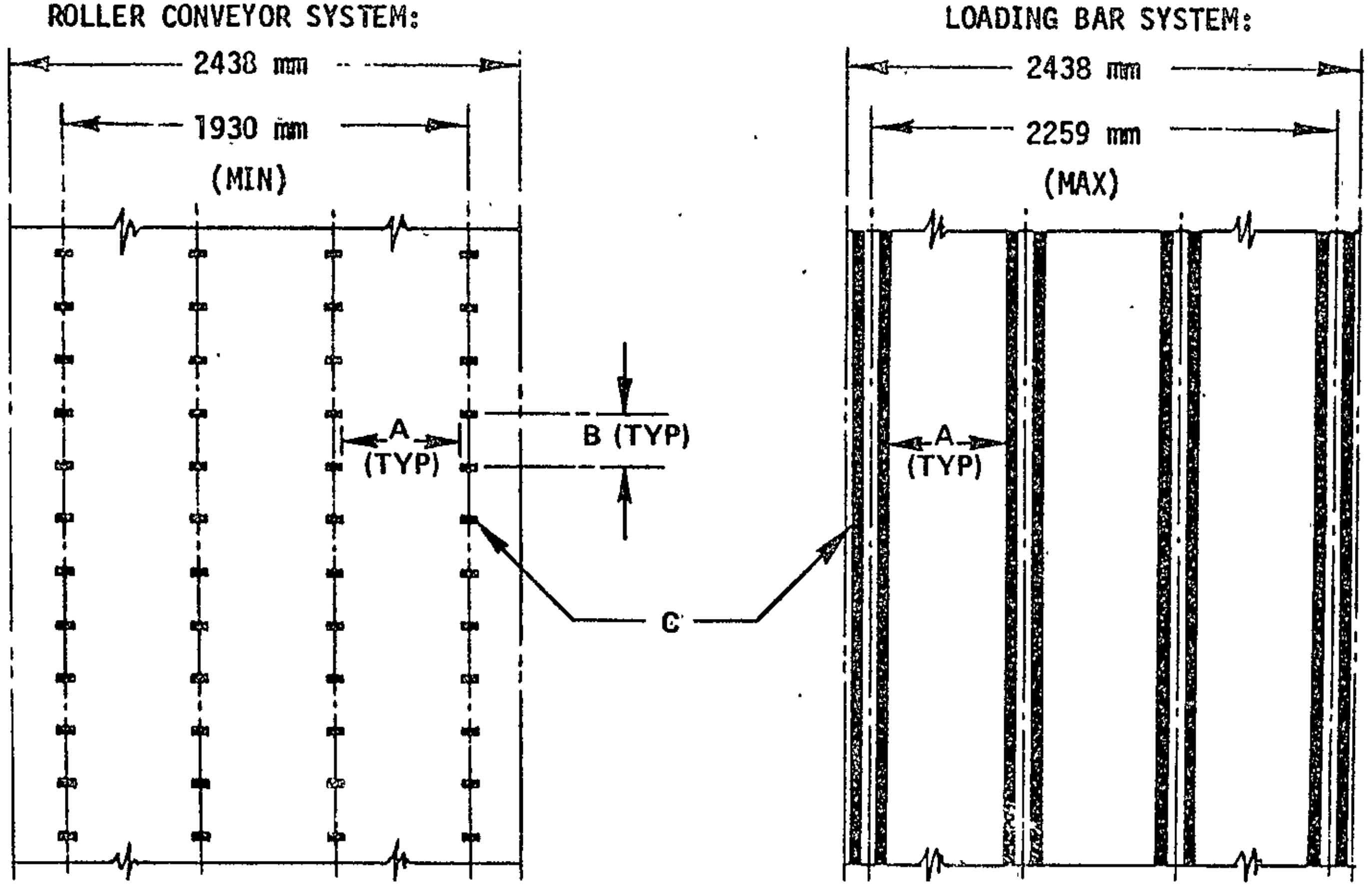


Figure 3-59. Loading-Bar System Compatibility



DESCRIPTION	ROLLER CONVEYOR SYSTEM	LOADING BAR SYSTEM
A. LATERAL UNSUPPORTED DISTANCE	567 mm (MIN)	601 mm (MAX)
B. LONGITUDINAL UNSUPPORTED DISTANCE	254 mm	CONTINUOUS SUPPORT
C. FOOTPRINT BEARING AREA/3.05 M LENGTH	350 SQ CM *	9290 SQ CM

*ROLLER LINE CONTACT WIDTH CONSERVATIVELY ASSUMED AT 1/4 x ROLLER DIAMETER

Figure 3-60. Air Container Support Pattern Comparison

- Maritime containers categorically are not an airline choice for airlift because of the tare weight penalties and compromised airworthiness. Therefore, loading and partially unloading them would not be a routine procedure. However, if because of airlift diversion for emergency or other reason it is necessary to load or partially unload cargo from them, it will be necessary to provide the capability. Unless the container is mounted on a slave adapter pallet, this can probably best be handled from an off-line position involving space, a capable floor, shoring or support, and reliance on manual or mobile means to transfer cargo between the container and the normal processing channels.
- It will normally be the terminal operator's responsibility to adapt a diverted maritime container for airlift. If technological advances in the 1990 time period permit the handling of both air and surface containers in the aircraft, this same capability will be found in the terminal handling system. However, if roller conveyor systems are still employed in the aircraft, it will be necessary to employ slave adapter pallets and restraints with the maritime container. The additional equipment required to accomplish this will include (1) a straddle carrier, forklift, or side loader equipped with container spreaders to lift the container from a trailer chassis to the slave adapter pallet; (2) access or positioning equipment for the overhead placement of the restraint net on the container/slave adapter pallet combination; (3) inventory and storage of slave adapter pallets and nets; and (4) a means for handling the empty 440 kilogram slave adapter pallet on and off the roller conveyorized handling surface (terminal conveyor, conveyorized semitrailer or dolly or aircraft loader).

Compatibility of airlift ULDs with surface transport systems has been readily achieved with little problem and only moderate differential investment. Based on present-day systems, and with no expectancy of radical change, the surface network interfacing the cargo terminals employs truck equipment almost exclusively. Therefore, compatibility with other surface transport modes for the time period of this study need not be considered. The following briefly capitulates pertinent considerations.

- Adaptation of existing 244-centimeter-wide roadable equipment to the 224-centimeter wide type "A" configurations has been easily accommodated by the economical and sometimes makeshift addition of roller conveyors and minimal restraints. The limited height as well as the limited width of the type "A" configurations makes them particularly compatible with closed-van truck equipment for use in regions with severe weather. In areas of temperate climate, it is not uncommon to see them on public thoroughfares being transported with rollerized flat-bed trucks.
- Palletized loads are not and will not be found to any significant extent in surface transport. This stems from potential loss problems associated with theft and damage and the susceptibility to netted load shifts of the cargo as it bumps, bounces, and sways through public streets and traffic. The soft wall B747F shelf pallet falls in this category, but also will be limited by height restrictions in many cities and countries. Its 300-centimeter height plus a flatbed with roller conveyor height of up to 142 centimeters for a total of 442 centimeters makes it unpassable beneath many overpasses.
- Rectangular air and surface containers at their 244-centimeter width match the usual maximum highway width limits of 244-centimeters for vehicles and loads. Since surface container lower corner fittings can be restrained with twistlocks into their bottom surface, this has given rise to a large population of skeletal ISO semitrailer chassis which support and restrain the containers at these four lower points only without exceeding the 244-centimeter highway width. Type II air containers with lower corner fittings are also accommodated by these trailers. As a point of interest, the airlines are now specifying the heavier type II air containers with upper and lower corner fittings. This enables their handling to be accomplished with a variety of mobile hoisting equipment rather than being totally reliant on roller conveyor equipment. This also benefits shippers, consignees, and surface transport operators who may not have conveyorized handling capabilities.
- Both types I and II air containers with their flat bottoms can be handled on conveyorized flatbed trucks or semitrailers. In some cases, this has been easily accommodated with add-on roller conveyor

sections which are secured to the flat bed surfaces. In other cases, special semitrailers have been marketed which integrate both roller conveyors and powered transfer systems for conveying the containers on and off the semitrailer. However, since type I containers do not have corner fittings to secure restraints into, alternate methods must be employed. Use of the side restraint indents at the bottom edge are precluded since this would violate the 244-centimeter highway width. As such, the alternates have included lashing over the top of the container and/or securing at the lower edge restraint indents of the front and rear end walls. In any event, compatibility of rectangular air containers with surface transport has been easy to achieve with basic rolling stock that can be easily modified on short order.

- Several enhancement spinoffs occur with respect to ULD/surface transport compatibility. These include (1) the substantial reduction in fuel associated with trucking container loads of cargo to and from the operator cargo terminal as contrasted with multiple truck movements of individual noncontainerized shipments, (2) the corresponding reduction in surface vehicle congestion which is usually critical at and around major airports, and (3) similar reductions in truck fleet investment and operating costs (fuel, licenses, drivers wages, etc.).

Shipper/Consignee compatibility with main deck air containers and pallets seems to evoke considerable concern. However, this need not be since adapting operations to accommodate use of them is not disruptive nor is a large investment if any required. To the contrary considering all aspects, the shipper/consignee stands to benefit from incentive tariffs if the cargo involved is sufficient to properly utilize the ULD size selected. The ease with which shipper/consignee adaptation can be achieved is substantiated in the following.

- The smaller airlift containers such as type "A" configurations, 2.4- x 2.4- x 3-meter containers, and LD containers individually occupy only a relatively small portion of dock or floor space. A shipping dock itself queues cargo which must be individually handled to it and individually again into a truck. If the container is located at the dock, it can serve as the queuing device accepting cargo that is handled to and stacked into it as one operation. As a consolidated and closed load, the container is then handled as a single item onto the surface transport. Thus, the net individual handlings are less for an incremental savings. The additional equipment is minimal involving only a pallet-size conveyorized stand abutting or on the dock, a low-height conveyorized pallet dolly, or simple skate roller conveyor segments placed on the dock. If truck height mismatches are a problem, this can be accommodated with a pallet-size conveyorized scissor lift, truck rear axle leveler, or manually positioned truck wheel lift ramp wedges.

- If the shipper/consignee is a large-volume air shipper using the smaller airlift containers, consideration should be given to loading directly into them at the output end of the production/packaging line or warehouse order picking function. This would substantially cut down on multiple single-piece handlings between the production or warehousing functions and the shipping dock. While it would require provisioning of adequate transit aisleways, pallet dollies, and tow tractors or equivalent movement means, this is only a matter of scale since those would not be added functions. Far greater productivity per handling/transit cycle would be gained for a realizable savings in handling costs.
- For the shipper/consignee involved with 2.4- x 2.4- x 6-meter and larger air containers, there is a demand on truck ramp or truck dock space since it is not normally practical or feasible to integrate such sizes further into his system. Space permitting adjacent to or on the truck dock, the approach can be basically the same as previously noted for the small airlift containers. However, there is the added consideration with large containers abutting the dock that they be oriented for end loading. This results in aligning the length of the container perpendicular to the dock face which may be ramp-space limited or may curtail other truck ramp operations. Even though this is the norm for shippers/consignees presently using surface containers, it may present a problem to those with limited ramp space who grow into use of the large containers.
- A further consideration that must be reckoned with when occupying ramp space is whether or not the air container will be left in position on the trucker's semitrailer during loading, which is

commonplace when using surface modes, or whether a dock height abutting conveyorized stand is to be permanently positioned for placing the large container on. In the first case, a prolonged loading/offloading retention time may involve additional charges by the trucker, whereas the second case involves a modest investment and maintenance cost and loss of that dock position to other activities even when not in use for air containers. In any event, achieving compatibility with the large air containers is an issue that is easily enough worked with, and the reduced shipper/consignee handling costs provide sufficient leverage to assure workable solutions.

System issues: There are additional compatibility aspects of containers that are more appropriately addressed separately from the three preceding categories. First among these are submodular ULDs and container interior compatibility. Submodular ULDs mentioned before enable a small shipper to consolidate his own shipment under seal and derive certain tariff incentive breaks, provided that certain minimum loaded densities or weights are met or exceeded. These submodular ULDs are not structurally certified and, therefore, must be subsequently stowed in structurally certified netted pallet loads or containers. As submodules, they are normally sized to nest with other submodules in a contoured or rectangular configuration to cube out the available interior volume of the pallet or container. However, they tend to be self-defeating as far as developing achievable maximum cube utilization. Even though appearing to nest nicely, the unused cube inside the individual submodules may be quite extensive unless the shipper has enough appropriately sized cargo pieces to develop high cube utilization inside the individual submodules. In addition, the variety of submodules tendered by different shippers may be diverse enough that collectively they cannot be nested to fill out the container/pallet configuration with an optimum arrangement.

Aside from the questionable utilization efficiencies, the use of submodular ULDs can offer definite handling efficiencies throughout the system since it reduces multiple-piece handlings. It may prove a definite asset to airline operators having cargo hub air networks. In these cases, operators with flights from point "A" to hub "B" for multiple connecting flights to points "C", "D", and "E" stand to gain if there is sufficient cargo to fill the submodules. Assuming such is the case, only submodules rather than multiple cargo pieces need to be handled at hub "B" when breaking down the container load from "A" for redistribution to containers bound for points "C", "D", and "E". The military services with their extensive resupply networks to overseas forces have effectively employed submodular units of their own sizing and design in surface containers.

Another benefit of submodules that is receiving increasing attention and has a promising future is their use for consumer direct retail marketing. In this application, the submodule moves from the shipper through the transport system and wholesale distribution to the supermarket or retail outlet. Here it is placed on the sales floor, is uncapped or opened up as a display unit, and the retail customer selects directly from it. Thus, only one forkliftable submodular ULD is economically handled through the entire distribution process. The design of the tineways in the base of these units is such that manual or power-assist pallet trucks used in large retail establishments can move the loaded units on and off the sales floor.

Container investment, ownership, tracking, maintenance and repair, availability, repositioning because of out-of-balance flow directions, etc., are problems that shippers and operators would rather avoid. They are categorically a system issue since a system-wide compatible solution or solutions have to be provided for. As the larger 2.4- x 2.4- x 6-meter air container come into greater prominence, so will the above problems. A viable solution seems to be found in leasing programs such as used extensively in maritime container pool businesses. The basic shortcomings of container pools are a loss of shipper or operator identity which is of questionable value and reliance on an outside agency to assure availability of containers when and where needed. The large maritime container pool leasors as a means of building a reliable business foundation have been able to anticipate and solve such issues before they become problems. Although in its embryonic stages, an air container leasing pool has been established by Container Transport International (CTI). One domestic carrier has established its 2.4- x 2.4- x 6-meter air container operations using this pool at lease rental rates of approximatley $7/day/ container. It seems a reasonable assumption that such pooling will become an increasing business as use of the 2.4- x 2.4- x 6-meter air container develops future momentum.

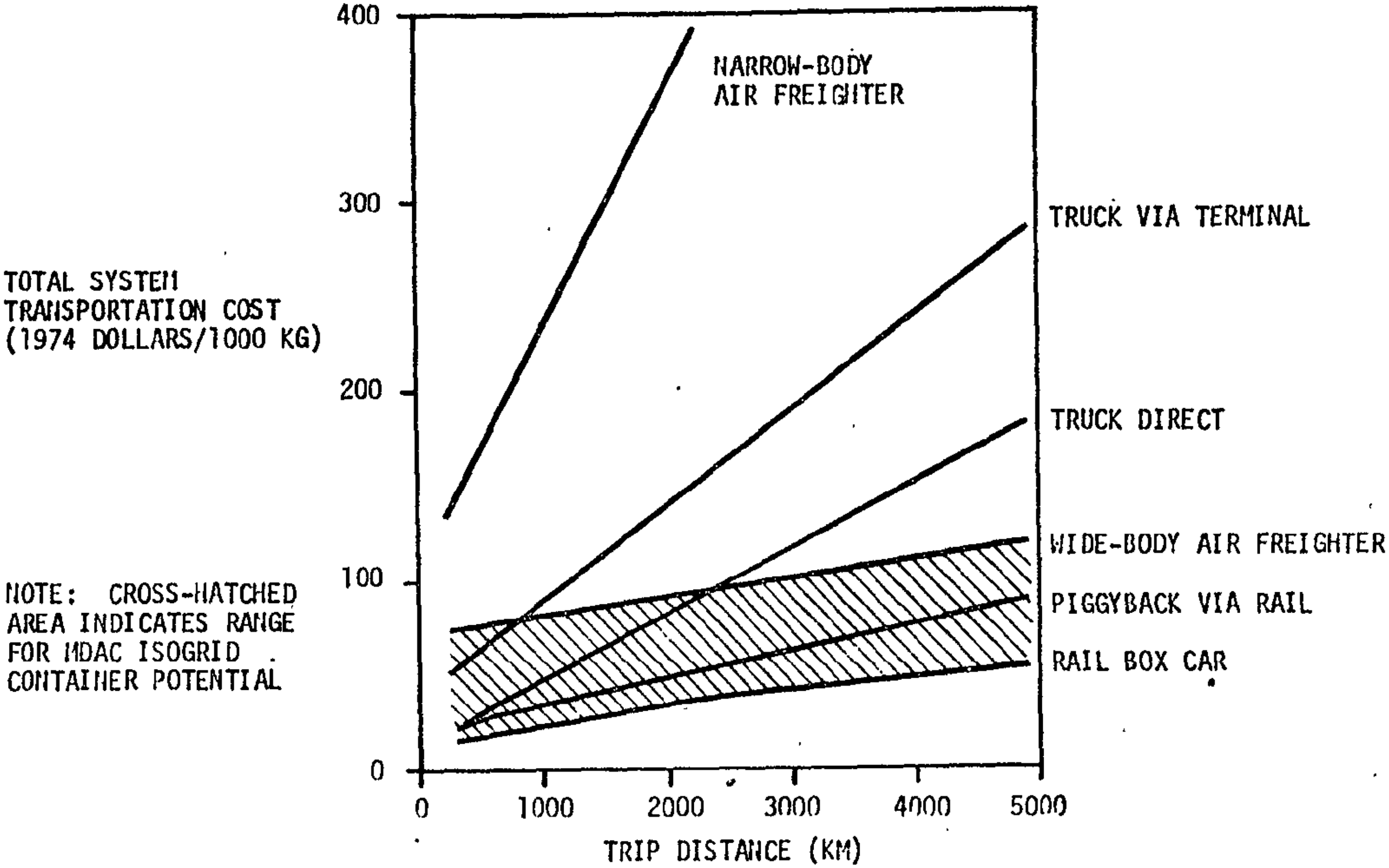
Other broad-base system considerations involving air containers relate to regulatory, jurisdictional, and other matters. These are considered outside the scope of this subsection; however, they do bear mention in the way of questions as follows:

- What will be the impact of small amounts of hazardous cargo in a 2.4- x 2.4- x 6-meter air container filled principally with non-hazardous cargo?
- Will there be additional certification requirements imposed on the design and construction of containers moving across international borders similar to that of surface containers? TIR (French abbreviation) certification is now regulated by the Container Customs Convention for surface containers. This certification agreed to by participating countries allows sealed tamper-proof containers to cross all their common borders between origin and destination without being opened for customs inspection.
- As more and more air container loads are consolidated between shippers and consignees, will labor unions intercede as happened with maritime dock workers when their jobs were displaced by containers? Although this does not seem likely, it is something for which rational counterproposals should be developed.

1990 improvements. - Not only can transport vehicles and systems benefit from materials, manufacturing, and technology advances, but so can containers. Evidence of this is found in the proprietary container design under development by the New Products-Diversification Division of McDonnell Douglas Astronautics Company - East (MDAC-E). The potential benefits from introduction and operation of advanced technology containers such as this serves as a foundation for the anticipated 1990 improvements. Based on MDAC-E data and analyses, their Isogrid container when compared with present-day surface containers can result in tare weight reductions on the order of 30 percent or better and manufacturing/sales price cost reductions of the same magnitude. The potential application of this technology on total system transportation costs as a function of trip distance is shown by the crosshatched area of Figure 3-61.

As shown in Figures 3-62 and 3-63, initial usage of the Isogrid design is for intermodal surface containers. Without even considering air container derivatives, the tare weight reductions of the surface containers will make

- TARE WEIGHT OF EXISTING CONTAINERS LIMITS THEIR USE IN AIR FREIGHT (CURRENT WEIGHT 40 KG/CU M - DESIRED WEIGHT 16-24 KG/CU M)
- MDAC ISOGRID BOX HAS POTENTIAL OF APPROACHING THE DESIRED WEIGHT.



DOOR TO DOOR SYSTEM COSTS AS A FUNCTION OF LENGTH OF HAUL - GENERAL SERVICE

Figure 3-61. Outlook for Continuous Fiber Composites Products (CFCP) in Airfreight Containers (Adapted From MDAC Chart 9-1213)

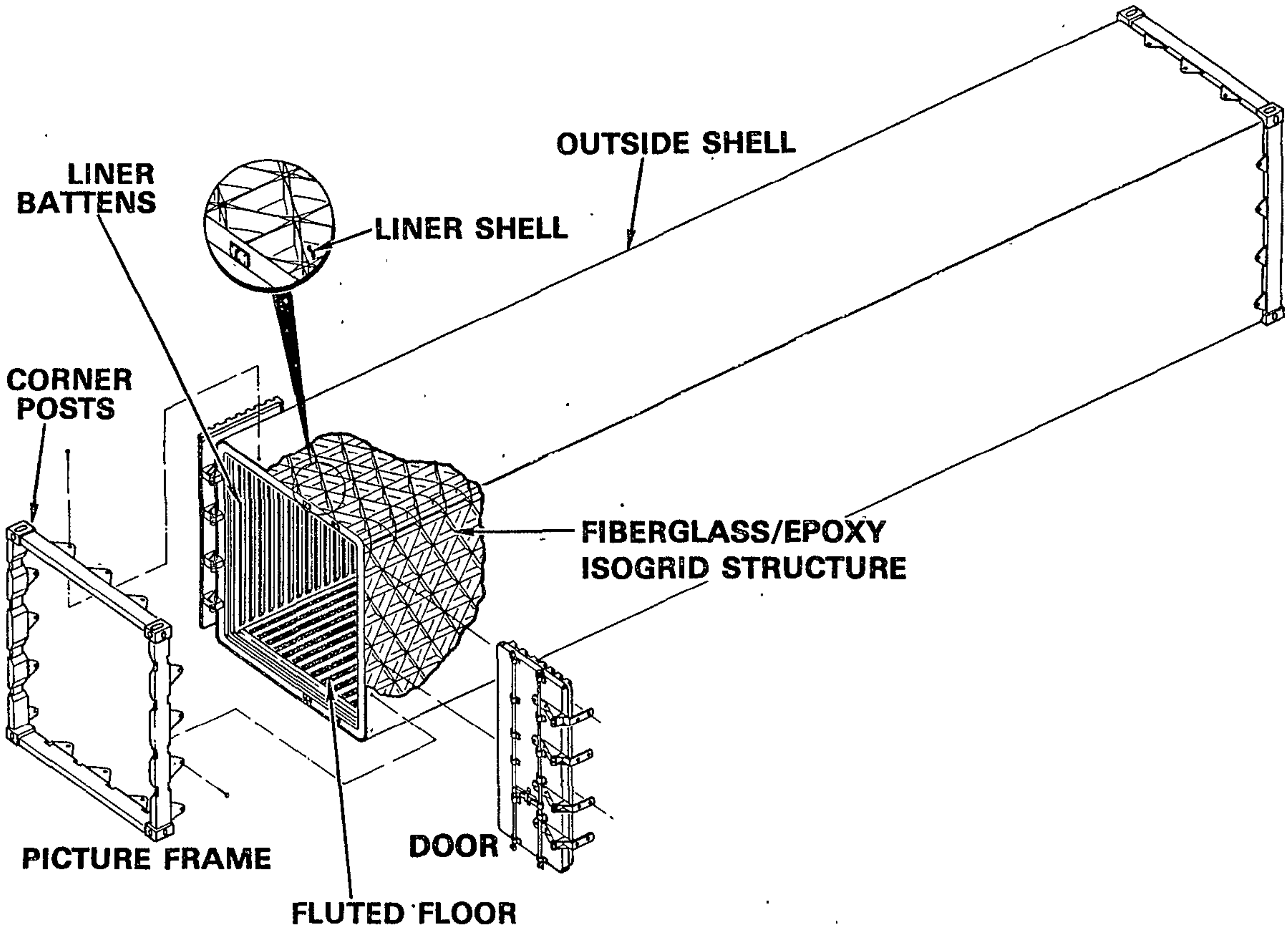


Figure 3-62. MDAC 40-Foot Isogrid Intermodal Container

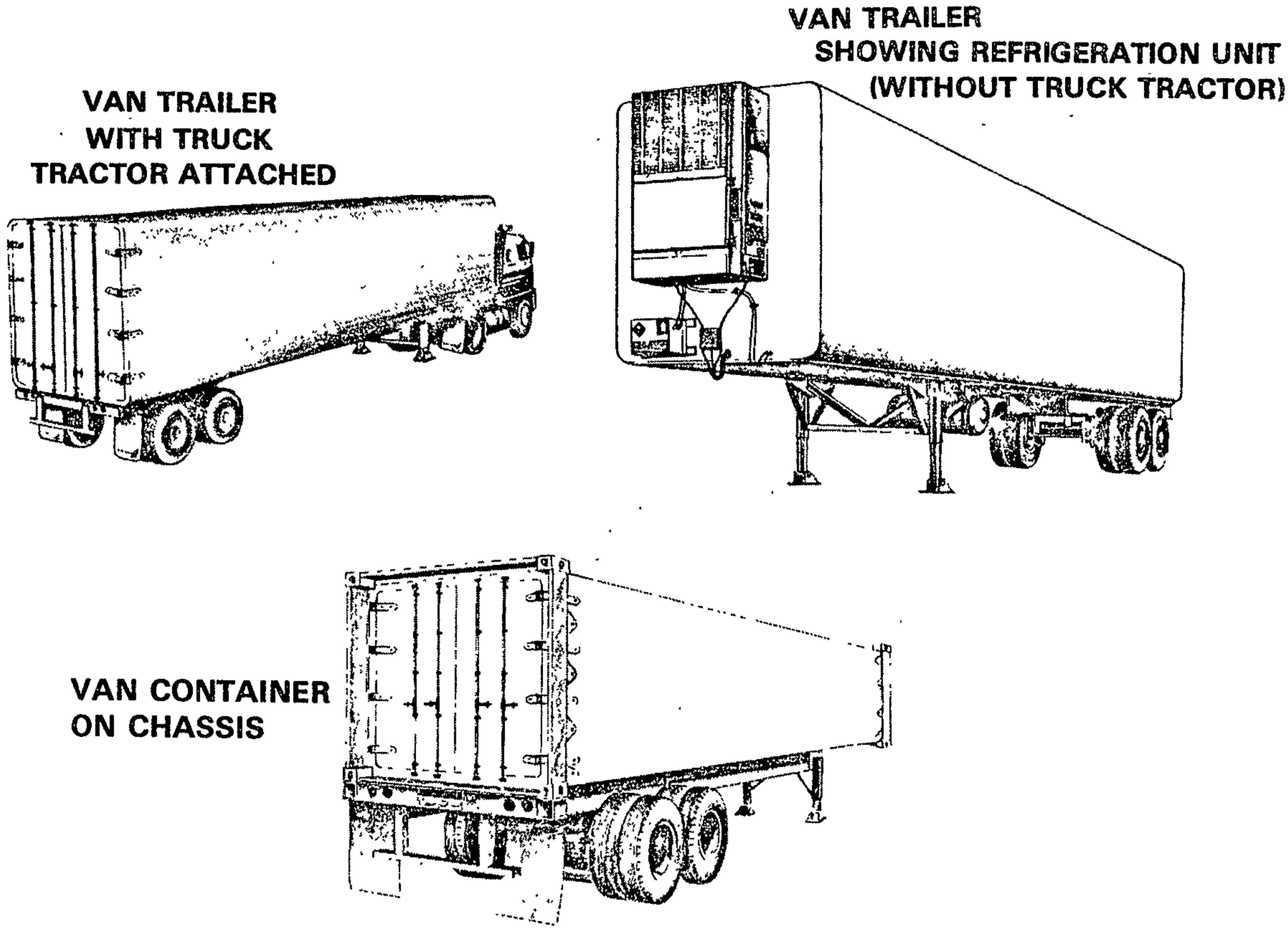


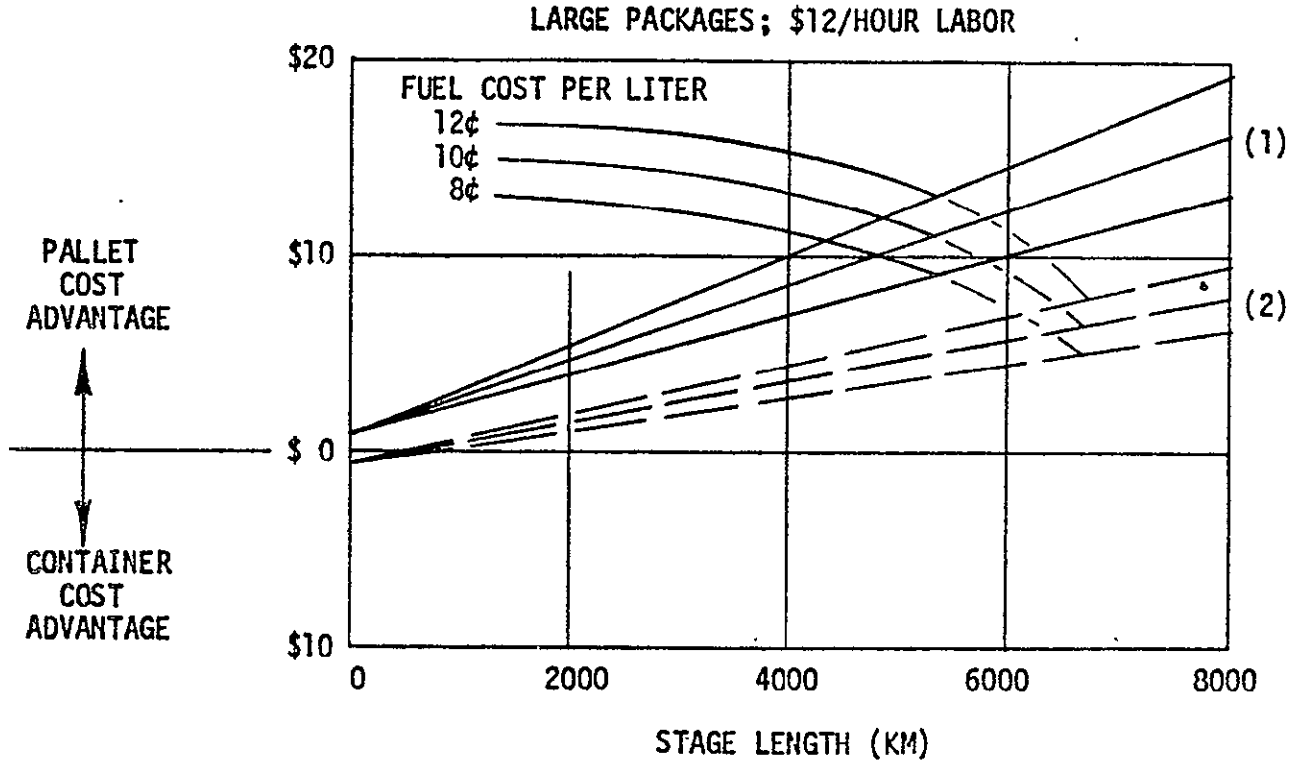
Figure 3-63. MDAC Isogrid Cargo Container/Van Applications

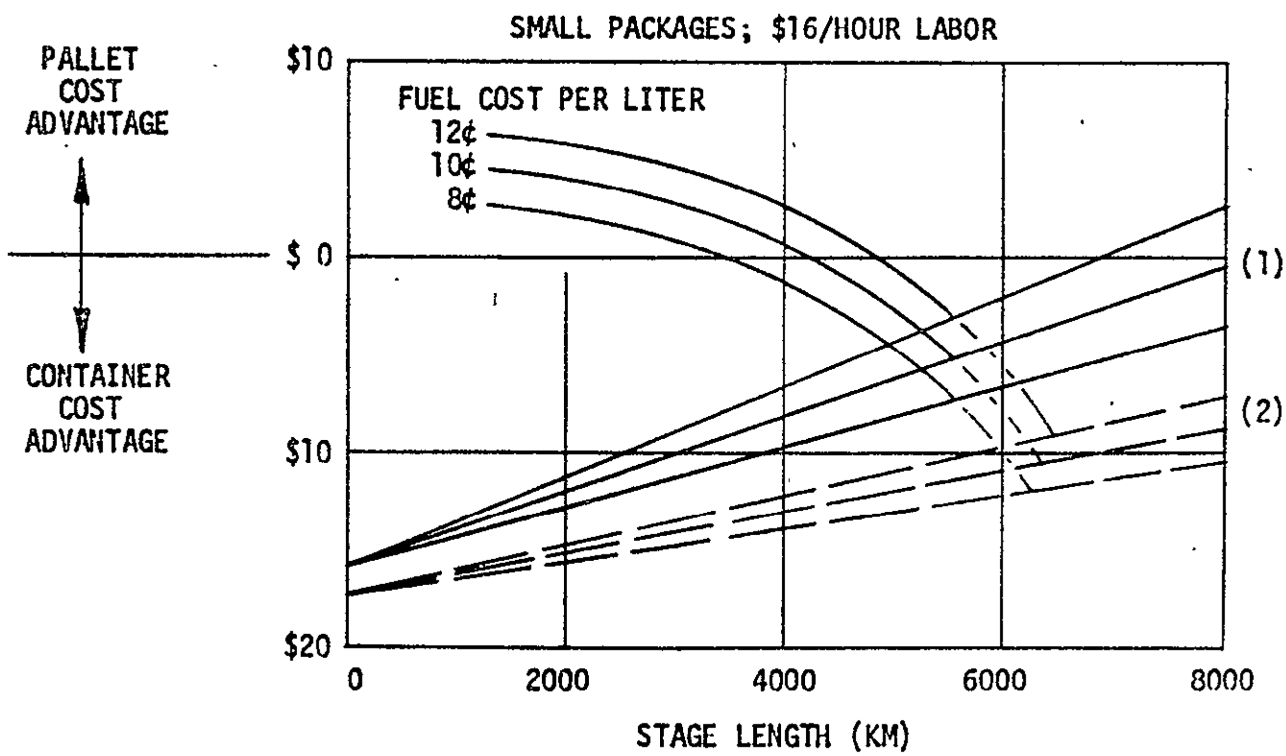
them more acceptable for diversion to airlift. When considering airlift derivatives incorporating side and end restraint latch indents and reinforcements for ball mat and roller conveyor handling, the tare weight reductions can be a conservative 25 percent or better. Such reductions are considered realistic and achievable and further the importance of the container role in future air cargo growth. In addition, the Isogrid design inherently provides the required roof upload restraint which is a previously discussed shortcoming of surface containers.

In order to evaluate 1990 improvements on a common basis, the same methodology is used as that in developing the current curves found in Figure 3-31, Volume I. The basic input data and resulting manipulations were changed to reflect the reductions in tare weight and ULD purchase price expected of the Isogrid container or other beneficial container advances. These were done for the B747F only since it is typical of wide-body applications and since DC-8/B707 freighters or their successors will have a smaller share of the 1990 freight tonne-kilometers. Changes to the input B747F data items are as follows:

- Tare weight
  - 244- x 606-centimeter pallet and net - 440 kg (no change)
  - 2.4- x 2.4- x 6-meter air container - 720 kg (24-percent reduction from 948 kg)
- Purchase price (based on 1976 dollars)
  - 244- x 606-centimeter pallet and net - $3200 (18-percent reduction from $3925)
  - 2.4- x 2.4- x 6-meter air container - $5000 (44-percent reduction from $9000) - current 1978 procurements of increased quantities are down to approximately $7000 from original $9000. Therefore, with quantity procurement and production by 1990 this will stabilize to approximately $5000.

Based on the above changes, both the current (solid line) and 1990 (dashed line) cost curves are shown in Figure 3-64 for large- and small-package ULD buildup/breakdown costs. As can be seen, there is a substantial shift favoring use of containers. The major influence in this shift is the assumed 24 percent reduction of container tare weight which lowered the fuel expenditures and resulted in much shallower cost curves. It should be remembered from Section 3, Volume I, that large and small packages were each analyzed at $12 and





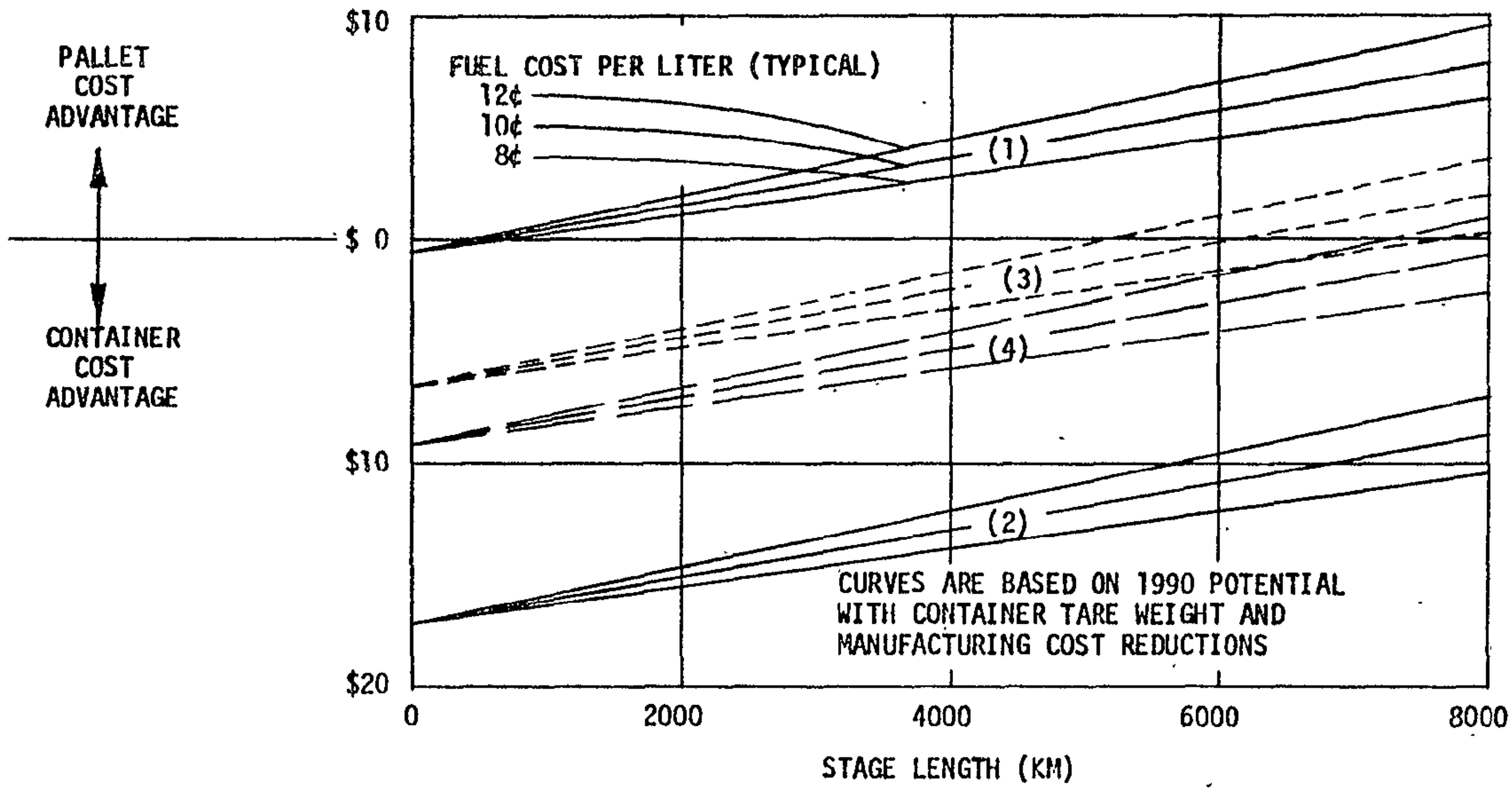
NOTES: (1) CURRENT - FIGURE 3-31, TASK 1 PRELIMINARY REPORT.
(2) 1990 - POTENTIAL WITH CONTAINER TARE WEIGHT AND MANUFACTURING COST REDUCTIONS.

Figure 3-64. Economic Comparison of ULDs - Main Deck B747F Per 2.4- x 2.4- x 6-Meter ULD Per Flight

$16/hour labor. In the case of the large packages, the $12/hour labor resulted in a greater pallet advantage than did the $16/hour labor. Conversely with small packages, the $16/hour labor gave the container a greater advantage than did the $12/hour labor. Thus, only the labor rates resulting in the higher pallet or container advantages were plotted so that the extreme potentials could be bracketed.

At this point in the 1990 analysis, it became apparent that an extreme sensitivity was attached to the cost increment dealing with large- versus small-package handling in building up the pallet or container load. This concern is justified on the basis that independent variables dealing with terminal procedures, cargo availability, job classifications, etc., can influence the efficiency of load buildup and breakdown and whether a pallet or container offers the least incremental labor cost or if they are equal. However, the incremental 40 man-minute closing cost (pallet netting) remains a valid container advantage. Therefore, the 1990 curves (solid line) with all cost increments are replotted in Figure 3-65 (from Figure 3-64) for comparison with desensitized cost curves. These desensitized curves (3) and (4) eliminate the questionable differential labor cost dealing with large- versus small-package handling but retain the valid closing cost (pallet netting). Based on this approach, the container may have a 1990 cost advantage out to international ranges of 6000 to 8000 kilometers and more depending on fuel, labor, and load buildup/breakdown costs.

Realizing that container tare weights represent a deficit with respect to pallets but also that they have a potential to generate larger revenue payloads than pallets led to the analytical comparison of Table 3-28. This parametric comparison varies 1990 container tare weight reductions between 10 and 40 percent, and cargo weight increases between 4 and 10 percent because of the inherent utilization advantages of containers (Table 3-23). For each container size, the two variables are paired in ascending order from least improvement to most improvement so that a maximum range of net cargo weight benefits or deficits can be developed. By way of explanation, the container tare weight deficit is its current weight less the parametric tare weight reduction compared with the tare weight of the pallet and net. The container cargo weight increase advantage over the pallet is its available interior volume times the mean air cargo warehouse density times the parametric percent improvement. These two results are compared in the last column for the



NOTES:
(1) LARGE PACKAGES @ $12/HOUR INCLUDING DIFFERENTIAL BUILDUP, CLOSING, AND BREAKDOWN LABOR COST.*
(2) SMALL PACKAGES @ $16/HOUR INCLUDING DIFFERENTIAL BUILDUP, CLOSING, AND BREAKDOWN LABOR COST.*
(3) $12/HOUR INCLUDING DIFFERENTIAL PALLET CLOSING LABOR COST ONLY.*
(4) $16/HOUR INCLUDING DIFFERENTIAL PALLET CLOSING LABOR COST ONLY.*

*TABLE 3-10, TASK 1 PRELIMINARY REPORT.

Figure 3-65. ULD Economic Sensitivity to Buildup, Closing, and Breakdown Costs - Main Deck B747F Per 2.4- x 2.4- x 6-Meter ULD Per Flight

TABLE 3-28

1990 CONTAINER TARE AND CARGO WEIGHT DIFFERENTIAL INCREMENTS

ULD Size (m)	Tare Weight (kg)				Interior Volume (Cu m) V_a	Actual Cargo Weight Increase (kg) $230.9 \times V_a \times (\%)$**	Net Cargo Weight Benefit (Deficit) (kg)
	Pallet and Net	CONTAINER					
		Current	Less (%)*	Deficit			
2.4 x 2.4 x 3 m	140	450	45.0 (10%)	-265.0	16.09	148.6 (4%)	-116.4
			90.0 (20%)	-220.0		222.9 (6%)	+ 2.9
			112.5 (25%)*	-197.5		260.1 (7%)**	+ 62.6
			135.0 (30%)	-175.0		297.2 (8%)	+122.2
			180.0 (40%)	-130.0		371.5 (10%)	+241.5
2.4 x 2.4 x 6 m	440	1000	100.0 (10%)	-460.0	32.57	300.8 (4%)	-159.2
			200.0 (20%)	-360.0		451.2 (6%)	+ 91.2
			250.0 (25%)*	-310.0		526.4 (7%)**	+216.4
			300.0 (30%)	-260.0		601.6 (8%)	+341.6
			400.0 (40%)	-160.0		752.0 (10%)	+592.0
2.4 x 2.4 x 12 m	880	1900	190.0 (10%)	-830.0	67.68	625.1 (4%)	-204.9
			380.0 (20%)	-640.0		937.6 (6%)	+297.6
			475.0 (25%)*	-545.0		1093.9 (7%)**	+548.9
			570.0 (30%)	-450.0		1250.2 (8%)	+800.2
			760.0 (40%)	-260.0		1562.7 (10%)	+1302.7

*1990 Container tare weight reductions may range as high as 40 percent. However, a 25 percent reduction can be reasonably anticipated.

**1990 Container cargo weight benefits may range up to 10 percent over equivalent pallets. However, a 7-percent benefit can be reasonably anticipated.

net cargo weight benefit or deficit. It is felt that a reasonable probability exists for achieving the midrange improvements of 25 percent container tare weight reduction and 7 percent container cargo weight advantage. This results in a small net cargo weight benefit credited to the containers.

Figure 3-66 plots the tare weight deficits, cargo weight benefits, and range of potential net weight benefits of containers relative to pallets and nets for the three sizes considered. Also included is the net weight benefit for 1990 based on the anticipated 25-percent reduction in container tare weight and 7 percent improvement in cargo weight resulting from container versus pallet usage. The important thing in this assessment is that the net cargo weight benefit be maximized. Even though it is not a one-to-one tradeoff, it would be counterproductive with any ULD if it costs more in additional tare weight than can be gained in revenue cargo weight.

If tare weight reductions of 25 percent in 1990 are extended to the Baltimore and MTMC maritime container loads discussed earlier, a significant reduction of tare weight/cargo weight ratios and aircraft floor loadings can be realized. These reductions are listed in Table 3-29 for 2.4- x 2.4- x 6-meter and 12-meter containers. As compared with the air containers listed, the 6-meter Baltimore tare weight/cargo weight ratios are nearly as favorable, whereas the MTMC ratios are not because of underload utilization. The 12-meter air containers still show a substantial advantage over the Baltimore and MTMC container loads.

In the case of aircraft floor loadings, the actuals (including tare weight reductions) experienced with the MTMC 6-meter container loads will be somewhat higher than those anticipated for air containers (based on mean air cargo warehouse density and achievable maximum cube utilization). However, the MTMC container loads will be comfortably less than the floor loading imposed by grossed-out air containers. The Baltimore container loads are considerably in excess of either data entry for the 6-meter air containers. The 12-meter containers compare somewhat more favorably with only the Baltimore container loads being in excess of the anticipated air container floor loads but less than the floor loads from grossed-out air containers. These comparisons suggest that selective diversion of surface containers to airlift where justifiable may have a stronger potential than usually thought. This will be particularly so if 1990 aircraft on-board handling and restraint systems are

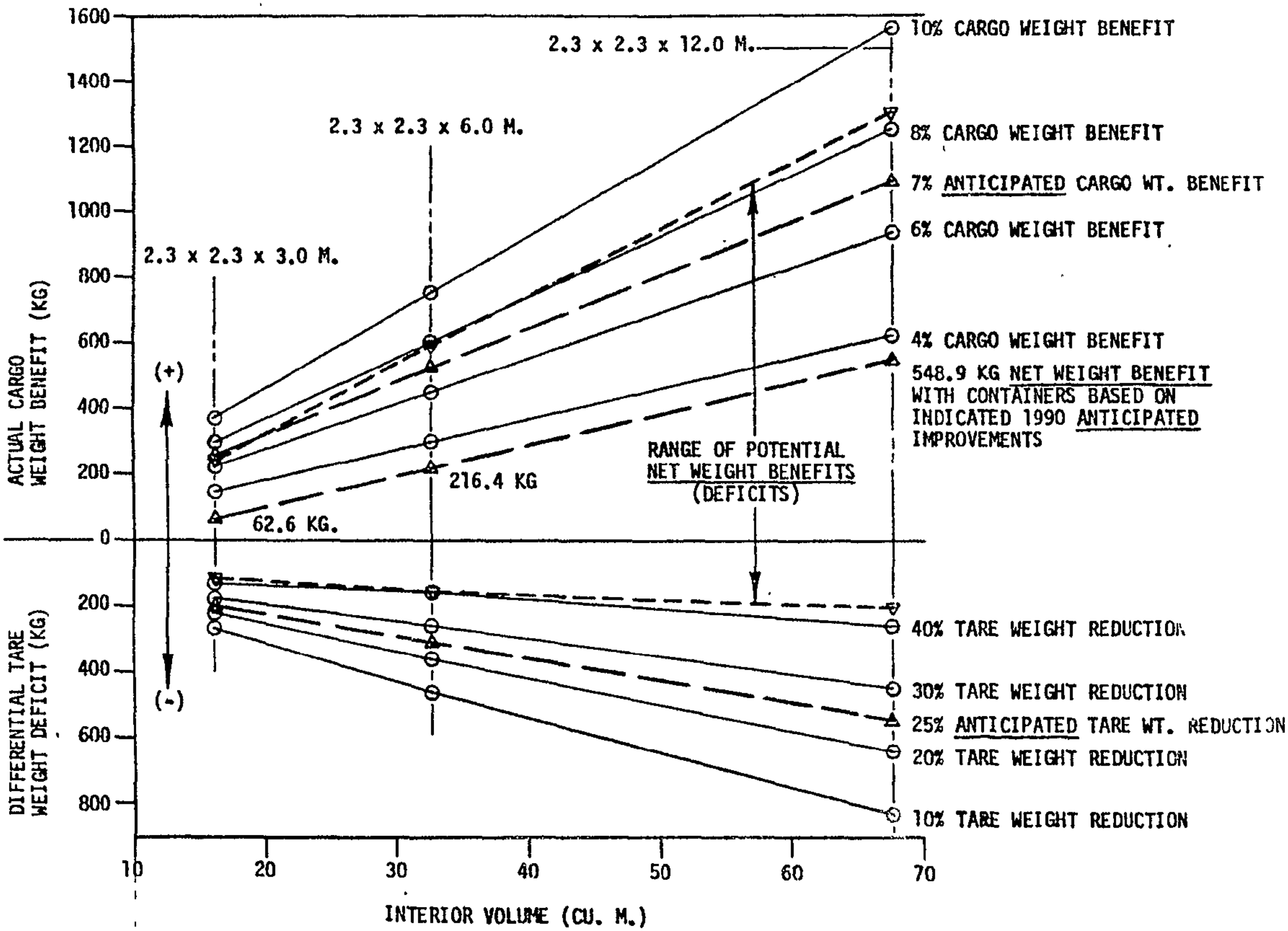


Figure 3-66. Differential Revenue Cargo Weight Benefits With Containers

TABLE 3-29

1990 COMPARISON OF MARITIME AND AIR CONTAINERS IN AIRLIFT

Container Size Group	Tare Wt/Cargo Wt Ratio		Aircraft Floor Loading (kg/sq M)	
	CURRENT	1990*	CURRENT	1990*
6 M Containers				
Maritime MTMC DSS (W/O TREADS)	0.379	0.238	667.3	599.1
Maritime MTMC DSS (W/TREADS)	0.319	0.200	758.8	690.6
Maritime Baltimore (Com'l 1975)	0.220	0.138	1018.3	950.0
Maritime Baltimore (Com'l 1976)	0.216	0.136	1032.4	964.1
Air AS-832 (Previous Analysis)	0.147	0.111	526.3	509.5
**	(0.147)	(0.111)	(525.8)	(509.0)
Air AS-832 (Design Gross)	Not Applicable	Not Applicable	767.8	767.8
12 M Containers				
Maritime MTMC DSS (10.5 M)	0.443	0.259	436.4	380.8
Maritime MTMC DSS (12 M)	0.493	0.298	459.1	398.9
Maritime Baltimore (Com'l 1975)	0.288	0.174	678.1	617.9
Maritime Baltimore (Com'l 1976)	0.275	0.166	703.5	643.4
Air AS-832 (Previous Analysis)	0.130	0.098	552.6	536.6
**	(0.135)	(0.101)	(536.9)	(520.9)
Air AS-832 (Design Gross)	Not Applicable	Not Applicable	686.6	686.6

*1990 Based on anticipated tare weight reductions of 25 percent.
**Parenthetical entries are based on 90 percent maximum practical cube utilization.
(Preceding entry is based on 93 percent achievable maximum cube utilization)

of the rollerless or loading-bar types previously described, which can handle both air and surface containers.

There are other container-related improvements which may be evident by 1990 or beyond. Three of these are USAF related dealing with (1) its transition from 274-centimeter-wide to 244-centimeter-wide ULDs, (2) the potential for joint tenancy cargo terminals, and (3) joint industry/military development of future civil/strategic transports. By policy statement issued in the early 1970s, the USAF indicated the necessity to accommodate 2.4-meter wide containers in its airlift requirements and its eventual transition from the 274-centimeter wide 463L system to a 2.4-meter wide system. The prospect of joint tenancy cargo terminals at selected USAF air bases was identified by Douglas in 1975 and is now included in USAF study plans for future strategic airlift systems. The coupling of width reduction with joint tenancy cargo terminals is a natural consideration since commercial users of future wide-body freighters will be handling a majority of 2.4-meter wide ULDs. Also, USAF planning considers use of an organic segment of these same freighters which could operate through the same joint tenancy cargo terminals. Therefore, concurrent implementation and transition could provide resource benefits and savings.

The planning for 2.4-meter wide containers in major USAF cargo terminals, such as Travis AFB, is already evident. In the case of Travis AFB, the new mechanized airfreight terminal (Building 977) has provided bypass conveyor handling and storage system equipment for 2.4- x 2.4- x 12-meter containers. With respect to joint tenancy cargo terminals, an initial ministudy funded by NASA did much to highlight potential problem areas in such joint utilization. However, the concept has many positive aspects which will be borne out in more detailed studies now being planned by USAF.

In addition to the first two items, the third complementary activity involves advanced studies being conducted by industry, NASA, and USAF for future civil/strategic transports such as the C-XX. These transports are envisioned as mergers, tradeoffs, and compromises between civil and military requirements which will lead to the eventual joint industry/government development, implementation, and IOC of large cargo aircraft. These will be operated by airlines having a CRAF commitment and by USAF with an organic fleet. Because of the civil requirements, the primary sizing and systems will be dominated by a 2.4-meter wide system. This factor could be the means whereby the Air Force accomplishes its transition from the 274-centimeter wide 463L system to the 2.4-meter wide system. Thus, the 2.4-meter wide container is playing an important role in three developments concurrent in the same future timeframe: (1) large civil/strategic aircraft such as the C-XX concept, (2) Air Force transition to the 2.4-meter wide handling and restraint system, and (3) operation of joint tenancy cargo terminals at selected USAF air bases and civil air fields.

The question often arises regarding the future of collapsible containers. The stated benefits deal with less terminal storage space for empty containers and deadheading of collapsed and stacked containers to points of need. However, the future of such containers has little promise because of inherent adverse factors which are attested to by knowledgeable industry authorities. The related problems include the following:

- Collapsible containers introduce hinged or pinned corners and joints which result in leakage problems. Hinged or pinned joints and the collapsing mechanisms involve additional manufacturing costs and detrimental tare weights.
- Collapsible containers are not self-collapsing or self-erecting. Therefore, personnel and possibly powered-assist means are required to accomplish these functions. Also at their weights, a forklift or hoist is required to stack and unstack the collapsed containers.
- Aircraft or containerships on out-of-balance trade routes would tend to move with open container positions or slots in the low flow direction. Therefore, empty containers can be deadheaded in these open positions with no loss in revenue payload. This is a common means of repositioning empty containers to points of need in a balanced system. Thus, except in extreme queuing or shortage situations, there would be no justifiable need for the extra costs and problems associated with collapsible containers. Maritime operators or container leasors on such rare occasions will negotiate a containership charter for repositioning empty containers. It may also be that the containership itself needed repositioning because of the same out-of-balance route.

The 1990 improvements should also include consideration of the Transportation Facilitation Center (TFC) concept which merges customer cargo pickup and delivery, and cargo consolidation operations in productive urban industrial areas under one responsible service entity. This concept which was developed by the Ralph M. Parsons Company under a study contract from DOT may have aspects that can enhance the potential for large airlift containers. The TFC itself can offer cost reduction, fuel conservation, lowered traffic congestion, and service benefits if investors, brokers, truckers, shippers, and consignees can cooperatively merge their interests. It is somewhat akin to airfreight forwarder offsite terminals. However, because it tends to be a larger scope with locations in urban industrial centers, it may have a better potential for collection and assembly of LCL (less than container load) shipments into large container loads for air shipment. Thus, the participants stand to gain from the basic TFC benefits plus deriving the service benefits of containerized airlift.

Contoured pallets versus rectangular containers. - Whether pallets or containers are better ULDs in air cargo systems is a logical question of this analysis. Unfortunately, the scope of the total distribution system and its many variables, as well as the several contoured and rectangular pallets and containers that would have to be evaluated one against another, makes it pointless to derive one sweeping concisive conclusion. Such a singular conclusion could also be challenged and refuted based on one's particular viewpoint. An example of this might be the international carrier over long distances who favors palletization in his particular system as compared with the domestic carrier over his shorter transcontinental distances who favors use of containers.

In light of the above rationale but still desirous of a reasonable evaluation, an approach was formulated that would apply an unweighted quantitative summing scheme to simple advantage indicators. These pallet or container advantage indicators are in some cases based on quantitative findings in the analysis or are known to exist in the industry. In other cases, they are a qualitative response based on background and sound judgment. These advantage indicators found in Table 3-30 are listed for each subentry to five groups of evaluation factors: economics, utilization, future potential, service compatibility, and operations. Particular attention is invited to the notes at the bottom of the table for qualifying remarks.

TABLE 3-30

ULD BENEFIT INDICATORS SUMMARY

Evaluation Factor (Note 1)	ULD Advantage (Note 2)	
	Contoured Pallet/Container Category (Note 3)	Rectangular Container Category (Note 4)
A. Economics		
Tare Weight	X	
Cargo Losses		X
Revenue Generation		X
Short-Haul Airlift (National)		X
Long-Haul Airlift (International)	X	
ULD Investment	X	
ULD Maintenance	X	
Handling Equipment Investment	X	X
	5	4
B. Utilization		
ULD Payload		X
Aircraft Cube	X	
Aircraft Payload	X	X
	2	2
C. Future Potential		
Small Shipper CLC	X	
Large Shipper CLC		X
Cargo Growth		X
Technology		X
	1	3
D. Service Compatibility		
Customer Service/Satisfaction		X
Customer Activity Cycle	X	
Physical Distribution System		X
Infrastructure/Energy Issues		X
Customs/Regulatory Constraints		X
	1	4
E. Operations		
Load Buildup/Breakdown	X	X
Terminal Handling	X	X
Aircraft On-Board Systems	X	X
Surface Transport		X
Customer Compatibility	X	
Intermodal Compatibility		X
	4	5
TOTAL	13	18

NOTES:

(1) Detail factors are only listed under their area of primary impact even though their influence has been accounted for in the other related areas.

(2) Both ULD categories are indicated where no significant advantage exists or where compensating advantages exist.

(3) Typified by belly pit and type "A" ULD configurations.

(4) Typified by AS-832 2.4- x 2.4- x 6-meter containers.

In the following, an appropriate remark, brief explanation, or rationale for assigning the advantage to the contoured pallet/container and/or rectangular container category is presented.

- Economics
  - Tare weight. The lower tare weight is a significant advantage held by pallets with differences varying down to three and four times less.
  - Cargo losses. The advantage generally accrues to the container as found in the analysis. This factor is a merging of losses resulting from theft, pilferage, damage, and reported missing. Sound judgment further indicates that the less exposure identifiable cargo has to scrutiny, the less apt it is to be stolen.
  - Revenue generation. If fully utilized to its achievable maximum capability per the analysis, the container in generating a higher cargo load will generate more revenue than an equivalent pallet.
  - Short-haul airlift (national). The analysis gives containers a distinct advantage. The future advantage may be even greater if tare weight and purchase price reductions such as anticipated with the MDAC-E Isogrid container can be realized.
  - Long haul airlift (international). The advantage lies with pallets per the analysis. This may become more marginal in the long-term future if tare weight reductions and purchase prices for containers can be effectively reduced.
  - ULD investment. Pallets and nets are much cheaper, holding an obvious advantage ranging down to three times less.
  - ULD maintenance. Container down-time and maintenance costs will be higher since exposure to damage from forklifts and other handling equipment is inherently greater with its walls, doors, and roof thus giving the pallet the advantage.
  - Handling equipment investment. This is seen as a probable wash-out considering equal cargo flow levels. For instance, it takes approximately equivalent equipment and attendant investment to handle and store two type "A" configured pallets/containers as it does to handle and store a single 2.4- x 2.4- x 6-meter container.

Utilization

- ULD utilization. As demonstrated in the analysis, containers have the advantage with their potential for developing higher achievable maximum-revenue cargo weights.
- Aircraft cube. This advantage lies with the pallet which can be contoured out to the fuselage interior cross-sectional shape to the extent that the loading door height will allow passage. Conversely, the rectangular container may be likened to a square peg in a clearance-size hole.
- Aircraft payload. This is considered an equal advantage to either the pallet or the container. Taken in the future context of pure freighters, and not as passenger aircraft derivatives, the aircraft will be designed with a payload capability commensurate with contoured pallets, rectangular containers, or a compromise between the two.

Future potential

- Small shipper CLC (consignor-loaded container). The smaller ULDs categorized in the contoured pallet/container category (note 3 of Table 3-30) have a distinct advantage since the small shipper has a better opportunity to fill one whereas he could not fill out the larger ones associated with the rectangular container category (note 4 of Table 3-30).
- Large shipper CLC. The rectangular container category has the advantage for the opposite reason expressed in the preceding small shipper CLC reasoning.
- Cargo growth. The same marketing, service, and user acceptance forces that have brought containerization from nothing to its present position will continue to favor and give advantage to containerization over palletization.
- Technology. Container potential tare weight reductions and design improvements along with related improvements in future aircraft and infrastructure handling systems give the container a decided advantage. The pallet has little potential for improvement.

Service compatibility.

- Customer service/satisfaction. There is little doubt that use of secure containers has improved customer confidence and assurance of load integrity with minimum risk of loss due to pilferage or damage. The use of containers has also permitted shippers to minimize extra or special protective packaging. While both generalized ULD categories have continers, the advantage was allocated to the rectangular container category since the alternate category includes the less-secure pallet loads.

Customer activity cycle. The advantage seems to lie with the smaller contoured pallet/container category. This conclusion is reached since most shippers consolidate and ship at the end of a daily work cycle, and consignees expect inbound cargo for induction into their activity at the start of a daily work cycle. With most shippers not generating sufficient cargo in a day to fill the larger rectangular container category, the advantage is defaulted to the smaller. If a shipper has to delay shipment of a container to a second day because of insufficient cargo to fill it out at the end of his first-day work cycle, much of the advantage of airlift will be lost.

Physical distribution system. The larger rectangular container has a decided advantage in the future since it is the catalyst for improved airlift and overall distribution economics and service. It serves not only as a transport tool but as a mobile warehouse that can move clear through a transport and distribution system to a supermarket receiving dock. Positioned here it is a temporary warehouse for consumer short-duration seasonal commodity demands.

Infrastructure/energy issues. Little explanation is required here to justify the advantage held by the larger rectangular container category. Since fewer surface transport cycles than when moving small units can result, the noticeable benefits can include reduced fuel expenditures, reduced traffic congestion on already over-burdened arterials, reduced overall exhaust emissions and air pollution, and a resulting increased public and political acceptance.

- Customs/regulatory constraints. Again the larger rectangular container units have an advantage because of the sealed tamper-proof security which they can offer. The savings in time and resources can be significant with increasing movements under bond across different national borders, through points of entry, and on to final destination where a single customs processing finally occurs.

Operations

- Load buildup and breakdown. This is seen as a tradeoff favoring neither ULD category in particular. For instance, it is easier to load a pallet because of all-around access, but the load stacking on it requires more care than does stacking into a hard-wall container with its restricted access. Also detracting from the obvious access advantage of the pallet is the added burden of netting the load, whereas door closure on a container is an easy task.
- Terminal handling. This also is seen as an equal tradeoff for reasons similar to those advanced for ULD investment in the Economics group.
- Aircraft on-board systems. Again, the advantage cannot be assigned in favor of either ULD category since this is a fundamental design problem. Similar degrees of complexity will be involved for each ULD category whether it is a manual movement of the ULD and setting of restraint latches or a powered movement automatic latching system.
- Surface transport. The advantage is to the larger rectangular container category for reasons similar to those summarized in Infrastructure/energy issues under Service Compatibility plus an advantage of better load integrity. Palletized loads are subject to load shifting in highway transport, which can imperil the load in transit or can make restacking a necessity before it is loaded into the aircraft.

Customer compatibility. The smaller contoured pallet/container category has an inherent advantage because its smaller size has so slight an impact on customer operation, equipment, and facilities. Any investment to accommodate it can be minimal. Even with larger flow levels requiring multiple containers, the smaller units are more adaptable and more easily handled within a facility having restricted aisleways and maneuvering constraints.

Intermodal compatibility. The larger rectangular container category is typified by AS-832 2.4- x 2.4- x 6-meter containers which were configured and designed with surface and maritime intermodal compatibility as a requirement of their type-II options. Conversely, the smaller contoured pallet/container category has limited compatibility with land surface modes, requiring a modest handling and restraint adaptation of the transport vehicle. Compatibility with the maritime mode can only be achieved by housing the air unit in a maritime container or flat-rack. The obvious advantage accrues to the larger rectangular container category.

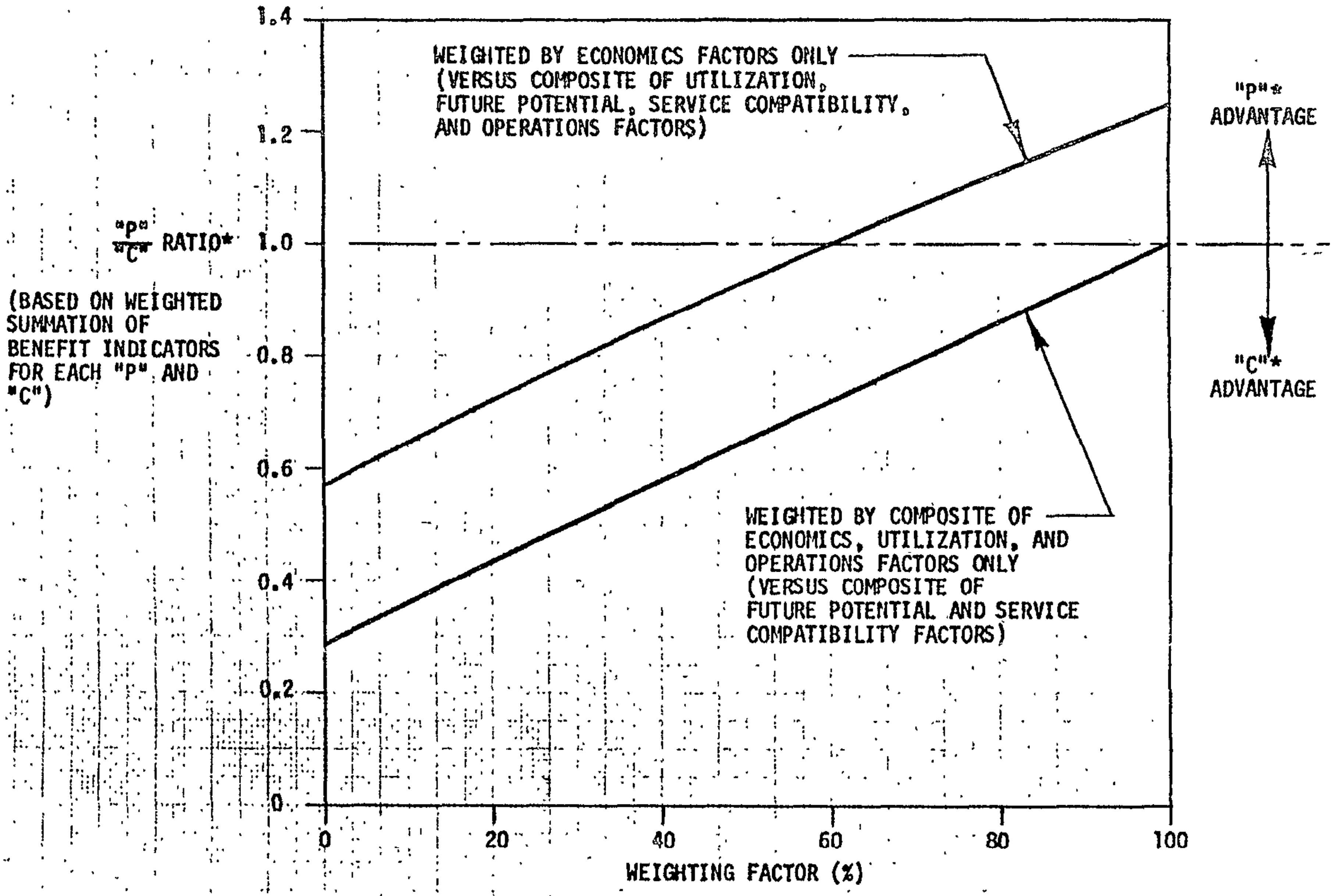
A simple summing of the above described advantages as found in Table 3-30 gives a small 18 to 13 future edge to containers. The vast interplay among the 31 factors and a diversity of opinion on their order of importance depending on one's interests (or biases) make it meaningless to assign weighting factors. Such assignments though made in good judgment would be controversial and lead to challenged results. Also, a numerically weighted level of advantage of one ULD category over the other for each of the 31 factors would have resulted in similar challenges to the results.

Since both vertical and horizontal weighting of the evaluation factors have been avoided, it is still desirable to develop some insight as to the relative importance of the five groups. Rather than do this for all the possible single and multiple combinations, two combinations of particular interest were selected for weighting sensitivity.

The first of these is the economic factors group which would probably exert the greatest influence in any evaluation, selection, and decision-making process. Therefore, the remaining four groups are considered as collectively having equal but no greater influence. In Figure 3-67, the upper curve is a plot of the relative weighting of economics versus the composite average of the remaining four evaluation factors groups. This curve displays an advantage to the rectangular container category for economic factors weighting ranging from 0 out to 60 percent where the advantage shifts. From this 60 to 100 percent weighting of economic factors, the advantage increases with the contoured pallet/container category. The result suggests that the economic factors must be in a dominant position if pallets and not containers are to have the advantage.

The derivation of the above involved simple allocation of the subtotal pallet and container advantage points for the economics category versus the composite average of the subtotal pallet and container advantage points of the four remaining categories. Thus, the economics category point ratio is 5 to 4 (pallets to containers) and the average of the remaining is (8 ÷ 4) to (14 ÷4) equalling 2 to 3.5 (pallets to containers). The weighting was then allocated between 0 and 100 percent for the economic factors. For example, weighting the economic factors at 40 percent resulted in a 3.2 to 3.7 (pallet to container) advantage point distribution of 0.865 in favor of containers. The 3.2 points were the sum of (40 percent x 5) plus (60 percent x 2) and the 3.7 points were the sum of (40 percent x 4) plus (60 percent x 3.5).

The second sensitivity check involved a comparison of the composite average of the three inherently objective evaluation groups (economics, utilization, and operations) versus the composite average of the two remaining, more subjective, nonoperator-oriented evaluation groups (future potential and service compatibility). This was done to test the influence exerted by the two less definable evaluation groups. The results are plotted as the lower curve in Figure 3-67. If the objective evaluation group composite is weighted at 100 percent (leaving 0 percent for the subjective evaluation group composite), there is no advantage realized by either the pallet or



* "P" = CONTOURED PALLET/CONTAINER CATEGORY "C" = RECTANGULAR CONTAINER CATEGORY

Figure 3-67. ULD Advantage Sensitivity to Evaluation Factors Weighting container category since their subtotal advantage points are equal at 11 each. However, as soon as any weighting greater than 0 percent is assigned to the subjective evaluation group composite (subtotal advantage points of 2 and 7 for pallet and container categories respectively), a pronounced trend develops favoring the rectangular container category. The derivation of the second sensitivity curve involved the same procedural steps as the first: (1) normalization of the evaluation groups (three versus two), (2) allocation of weighting percentages, and (3) summing of weighted points to establish the pallet-to-container advantage relationship.

As stated initially, the method of assigning unweighted advantage indicators in this evaluation of pallets versus containers was not conceived to produce conclusive evidence. What would prove best for one sector of the total distribution system would not necessarily apply to another. However, it is felt that the evaluation rationale employed, the identification of individual evaluation factors, the grouping of the individual factors, the assignment of advantage, and the gross sensitivity checks did provide a meaningful assessment. This assessment points to containers as a useful tool in promoting future air cargo growth. This finding is not so much for economic reasons it is for marketability reason.

<u>1990 potential demand for rectangular air containers</u>. - Assuming that the preceding assessment holds true, a significant demand for rectangular air containers in 1990 will be in evidence. Derivation of this demand excluding mail and parcel post is quantified in Table 3-31 using the 1990 baseline air-freight forecast scenarios for U.S. domestic, U.S. international, and foreign carrier segments (Section 2, Volume III). The potential demand was developed based on two parametric variables. The first was the share of the daily flow based on a 6 day week that would be moving in these containers. Shares of 25, 50, and 75 percent were employed as representative of a most pessimistic to most optimistic range. Conversely, this would leave the respective residuals of 75, 50, and 25 percent for belly pits, contoured pallets and containers, and 2.4- x 2.4- x 3-meter containers. No allowance or consideration was given to 2.4- x 2.4- x 12-meter air containers since their incidence would be so slight.

TABLE 3-31

DERIVATION OF 1990 INVENTORY REQUIREMENTS FOR 2.4 x 2.4 x 6.0 M. AIR CONTAINERS

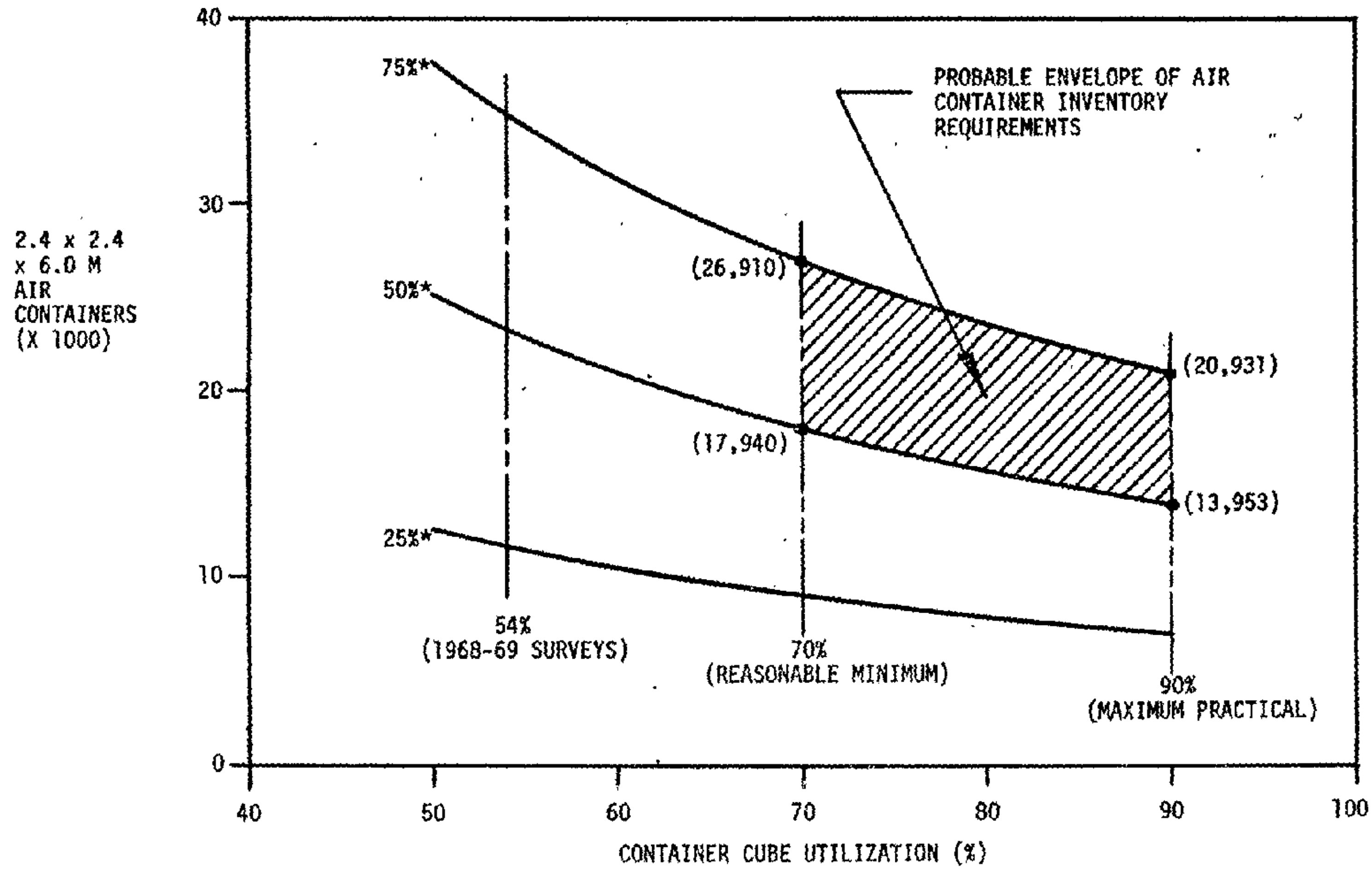
Segment	Annual Tonne-Km (Millions) (Note 1)	Average Route (km)	Daily Tonnes (312D/yr)	Share of Daily Tonnes (Note 2)	Equip. 2.4- x 2.4- x 6-Meter Containers (Note 3)				
					@ 6.768 Tonnes (90% C.U.)	@ 6.016 Tonnes (80% C.U.)	@ 5.264 Tonnes (70% C.U.)	@ 4.512 Tonnes (60% C.U.)	@ 3.760 Tonnes (50% C.U.)
U.S. Domestic	15 081.0	2835	17 050	4262 (25%)	630	708	810	945	1134
				8525 (50%)	1260	1417	1619	1889	2267
				12 788 (75%)	1889	2126	2429	2834	3401
U.S. International	9 703.1	6533	4760	1190 (25%)	176	198	226	264	316
				2380 (50%)	352	396	452	528	633
				3570 (75%)	528	593	678	791	949
Foreign Combined	60 136.3	4684 (AVG. U.S.)	41 150	10 288 (25%)	1520	1710	1954	2280	2736
				20 575 (50%)	3040	3420	3909	4560	5472
				30 862 (75%)	4560	5130	5863	6840	8208
Total	84 920.4	4323	62 960	15 740 (25%)	2326	2616	2990	3489	4186
				PROV. QTY	6978	7848	8970	10 467	12 558
			(NOTE 5)	31 480 (50%)	4652	5233	5980	6977	8372
				PROV. QTY	13 956	15 699	17 940	20 931	25 116
				47 220 (75%)	6977	7849	8970	10 465	12 558
				PROV. QTY	20 931	23 547	26 910	31 395	37 674

NOTES:
1. From baseline 1990 scenario (excludes mail and parcel post).
2. Residual percentage accommodated in belly pits and contoured pallets/containers.
3. Revenue airfreight tonnes (columnar subheadings) based on indicated cube utilization (C.U.) percentage.
4. Excludes centrally planned economies.
5. Based on provisioning factor of 3 (1 in the air + 2 in the ground system).

The second parametric variable was the cube utilization achieved in the container which was varied from 50 to 90 percent. The 50 percent would be a worst case being slightly lower than the 1968-1969 survey data, and the 90 percent would be the maximum practical based on earlier analysis in this subsection. It also was assumed that the 1990 air cargo warehouse density would not vary appreciably from the 1968-1969 survey results of 230.9 kg/cu m. The combination of this with the container available interior volume and cube utilization variable resulted in the equivalent revenue tons per container shown in the columnar headings.

With the revenue tons per container established, the required number of containers in the air mode based on the daily flows were then determined. Even though freighter aircraft daily utilization rates can vary up to 11 and 12 hours indicating multiple productivity or long range in a given flow, the containers moving in them will normally realize only a single productive air trip per day plus ground system time. Thus, daily multiple productivity of containers is negligible. However, a major consideration in determining required container quantities is accounting for those that are in the ground system. Industry experience including both air and maritime has shown that a provisioning factor of approximately three is required. This is made up of one container in the air while two are on the ground in the terminal, in surface transport, and/or at the shipper or consignee facility. The equivalent container totals of Table 3-31 list both the basic air mode requirement and the provisioned quantities required (including air mode).

The preceding derivation of 1990 container inventory requirements is plotted in Figure 3-68. The cross-hatched envelope represents the probable range of requirements and suggests that approximately 20 thousand 2.4- x 2.4- x 6-meter air containers will be needed. Based on the 1990 projected purchase price of $5000/container (1976 dollars) used in this analysis, a container fleet investment of $100 million is involved. With the 6 year useful life also used in this analysis, the result is a replacement value of $16.7 million per year alone without considering the value of the annual increase in quantities to support growth. Since 65 percent of the tonne-kilometer demand is projected for foreign carriers, this can represent a small opportunity to incrementally improve the U.S. balance of trade deficit if U.S. container manufacturers can successfully compete on the foreign market.



*ALLOCATION OF REVENUE AIRFREIGHT TONNES EXCLUDING MAIL AND PARCEL POST
(U.S. DOMESTIC, U.S. INTERNATIONAL, AND FOREIGN EXCLUSIVE OF CENTRALLY PLANNED ECONOMIES)

Figure 3-68. 1990 Inventory Requirements for 2.4- x 2.4- x 6-Meter Air Containers

Another point of interest is that the better the cube utilization realized, the lower will be the investment cost in containers to support a given level of airfreight flow. While this benefit to the airlines diminishes the container market potential for manufacturers, it may improve air cargo growth sufficiently to increase the longer-term market demand for containers.

Since this study excluded mail and parcel post, the category has not been included in the projected 1990 inventory requirements for air containers. Even though mail and parcel post basically bypasses the terminal system, it does represent a significant potential additional demand for air containers. This demand has become more evident with the airlift of first class mail. The additional demand ranges up to 25 percent so that the inclusive demand may be approximately 25 000 containers in 1990 for an investment of $125 million rather than the suggested 20,000 at $100 million.