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Cargo Logistics Airlift Systems Study (CLASS)

Volume 4. Future Requirements of Dedicated Freighter Aircraft to Year 2008

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CARGO/LOGISTICS AIRLIFT SYSTEMS STUDY (CLASS)

VOLUME IV – FUTURE REQUIREMENTS OF DEDICATED FREIGHTER AIRCRAFT TO YEAR 2008

OCTOBER 1979

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for

Langley Research Center
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PREFACE

In June 1977, the Douglas Aircraft Company (DAC)was awarded Contract No. NAS1-14948 from the Aeronautical Systems 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

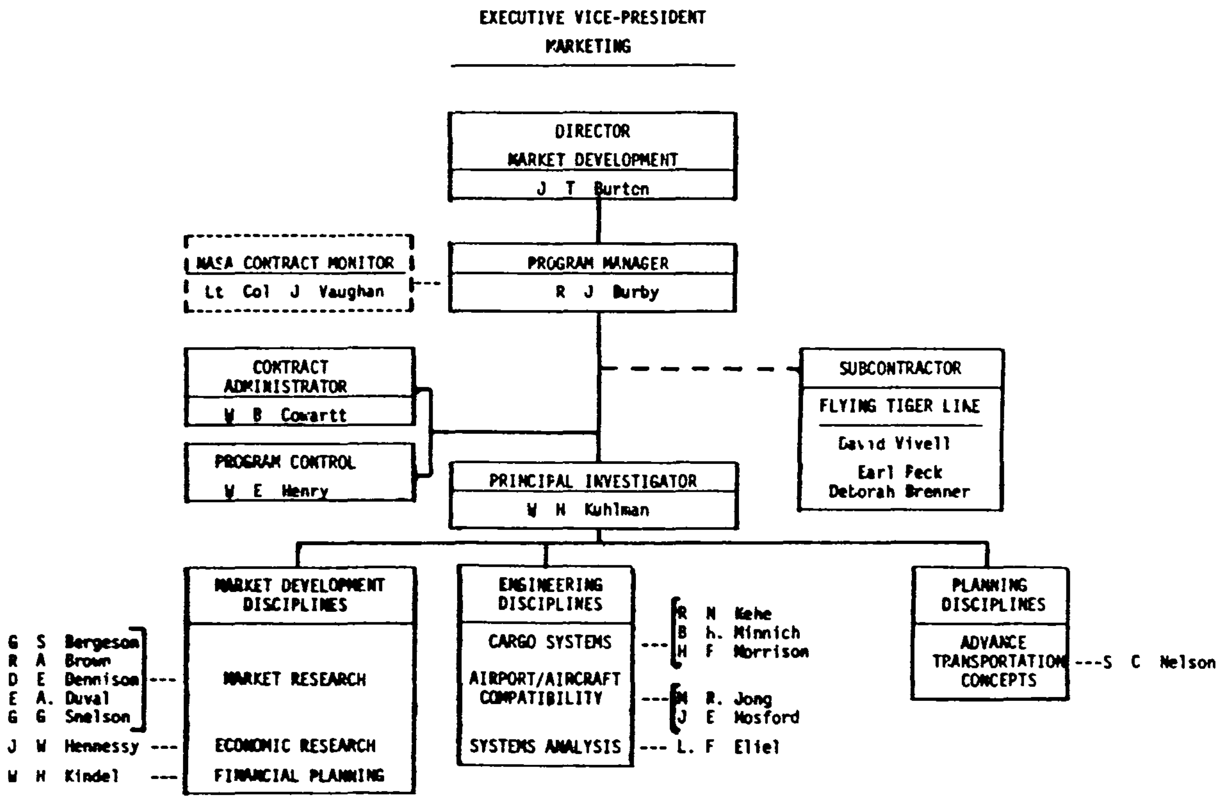
To comply with the scope of the study, the effort was segregated into five discrete tasks.

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 (2 Books) - Cross Impact Between the 1990 Market and the Air Physical Distribution Systems, NASA CR158914
- Volume IV - Future Requirements of Dedicated Freighter Aircraft to Year 2008, NASA CR158950
- Volume V - Summary, NASA CR158951

In October of 1978 DAC was awarded a follow-on to NASA Contract No. NAS1-14948. The primary objective of this contract was to extend the work directed to determining the requirements for a family of dedicated freighter aircraft that would meet the cargo market demand forecasts to the year 2008. This volume of the CLASS final report presents the results of that follow-on effort. A major portion of the requirements analysis was performed by the Advance Transportation Concepts department under the direction of C. W. Heathco.

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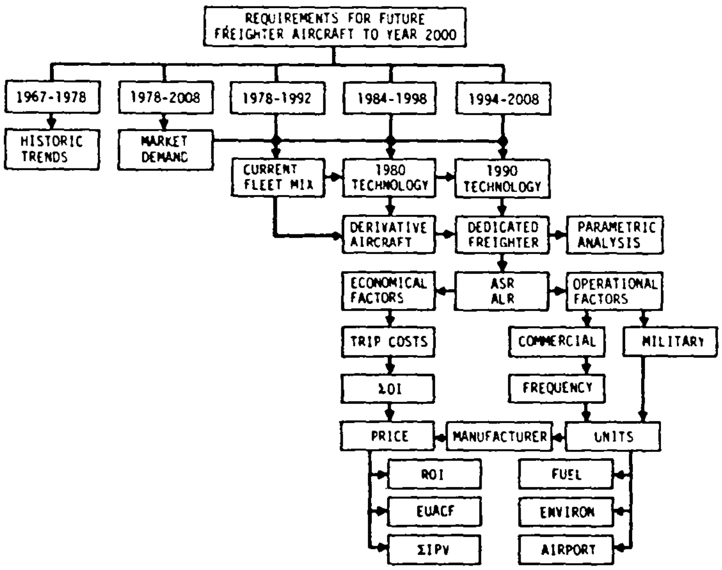
ABBREVIATIONS

A/C	Aircraft		
	A1	Representative Current Small Narrow Body Aircraft with Payload Equal to 14.2 Tonne (15.6 ton)	
	A2	Representative Current Large Narrow Body Aircraft with Payload Equal to 42.9 Tonne (47.3 ton)	
	A3	Representative Current Wide Body Aircraft with Payload Equal to 94.7 Tonne (104.5 ton)	
	ALR	Advanced Long Range Dedicated Freighter	
		ALR_2	with Payload equal to 149.7 Tonne (165 ton) and Two Manufacturers
		ALR_3	with Payload equal to 235.8 Tonne (260 ton) and Two Manufactirers
	ASR	Advanced Short Range Dedicated Freighter	
	LRD	Long Range Derivative Aircraft	
	MRD	Medium Range Derivative Aircraft	
	SRD	Short Range Derivative Aircraft	
APP	Airport Pairs		
ARTKM	Available Revenue Tonne Kilometers = PL x LF x Range		
(ARTSM)	Available Revenue Short Ton Statute Miles = PL x LF x Range		
ASKM	Available Seat Kilometer = Number of Seats x Range		
(ASSM)	Available Seat Statute Miles = Number of Seats x Range		
AT	Available Capacity in Tonnes = Payload		
(AT)	Available Capacity in Short Tons = Payload		
ATKM	Available Capability Tonne Kilometers = PL x Range		
(ATSM)	Available Capability Short Ton Statute Miles = PL x Range		
$C_{L_{TO}}$	Airplane Lift Coefficient at Takeoff		
DOC	Direct Operating Cost		
EUACF	Equivalent Uniform Annual Cash Flow		
FAA	Federal Aeronautics Administration		
FRAME	Future Requirements and Advanced Market Evaluation Computer Program		
HR	Hour		
ICAO	International Civil Air Organization		
IOC	Indirect Operating Cost		
IPV	Investment Present Value		

KG	Kilogram = 2.205 Pounds
KM	Kilometers = 0.6214 Statute Miles
L/D	Aircraft Lift to Drag Ratio
LF	Airplane Load Factor
LFC	Laminar Flow Control
OAG	Official Airline Guide
OI	Operating Income
PL	Aircraft Payload
RD&T	Research Design and Test
ROI	Return on Investment
RTKM	Cargo Market Demand Revenue Tonne Kilometers = Demand x Range
(RTSM)	Cargo Market Demand Revenue Short Ton Statute Miles = Demand x Range
SFC	Specific Fuel Consumption
SM	Statute Miles
S_W	Aircraft Wing Area
T	Metric Tonne equal to 1000 kilograms (2205 pounds)
(T)	Short Ton equal to (2000 pounds) 907.2 kilograms
T_{ENG}	Thrust of Propulsion System
Trip Cost	Direct Operating Cost Less Depreciation and Insurance
Unit	One Aircraft
W_{ENG}	Weight of Aircraft Propulsive Engines
W_{FURN}	Weight of Furnishings in Aircraft
W_{LDG}	Aircraft Weight at Landing
W_{P+N}	Weight of Aircraft Pylons and Nacelles
W_{PS}	Weight of Propulsion System Including Pylons and Nacelles
W_{STRU}	Weight of Aircraft Structure Excluding Pylons and Nacelles

SUMMARY AND CONCLUSIONS

This volume of the CLASS final report presents the results of efforts to define the Future Requirements of Dedicated Freighter Aircraft to Year 2008. To assure continuity with the past and compatibility with the present, growth characteristics of the air cargo systems are outlined for the years 1967 to the present, 1978. The 1978 fleet operations are extended to the year 1992, thus providing an evaluation of current aircraft types in meeting the ensuing increased market demand. Possible changes in the fleet mix and the resulting economic situation are defined in terms of the number of units of each type aircraft and the resulting growth in operational frequency. Among the economic parameters considered are the associated investment required by the airline, the return on investment to the airline, and the accompanying levels of cash flow and operating income. Against this background the potential for a derivative aircraft to enter fleet operations in 1985 is defined as a function of payload size and as affected by 1980 technology. In a similar manner, the size and potential for a new dedicated 1990 technology, freighter aircraft to become operational in 1995 is established. The resulting aircraft and fleet operational and economic characteristics are evaluated over the period 1994 to 2008 as outlined in the accompanying diagram. Finally, the impacts of restricted growth in operational frequency, reduced market demand, variations in aircraft configurations, and military participation, are evaluated.



The results presented herein do not define specific requirements for either the derivative or the dedicated freighter aircraft but rather they identify issues and define the relations of these issues to aircraft size and cost and to fleet operations and airline economics. For convenience, the summary comments are segregated under seven headings that correspond in order to Sections 3, 1, and 5 through 9 in the body of the report. In addition there is the analysis of Airline ROI Versus Tariffs that was performed in the course of preparing this summary and hence is not discussed in the body of the report. Future oriented findings drawn from the results presented in the various sections are all grouped under a single heading.

Historic Trends and Growth

The analysis of the historic development of air cargo operations was based upon data published in the Official Airline Guide (OAG), Air Cargo Guide. These data were examined at three key points in history: September 1967 - First year of available data, August 1971 - Introduction of the wide body jet, and August 1978 - The most current available data.

As of 1978 air cargo operations are dominated by the jet type aircraft which represent about 30 percent of the generic types of aircraft currently in operation. This is substantiated by the following data:

Jet aircraft serve:	57 percent of the airports
	63 percent of the nonstop routes
They also perform:	49 percent of the trips
	81 percent of the total distance flown
and provide:	92 percent of the available capacity
	97 percent of the available capability

There are noticable differences in the use of jet aircraft for cargo operations as compared to that for passengers. A greater percent of the available passenger capability is provided at shorter ranges than for cargo operations although the maximum range flown by the passenger aircraft is 50 percent greater. Although the maximum operational range is less for cargo aircraft, a greater portion of their trips occur over the longer ranges.

Forecasts

The scheduled market forecast developed in Volume 3, Book 1, was utilized as the basis for determining the air freight market demand for all-cargo aircraft out to the year 2008. Utilizing study results contained in Volume 3, Book 2, these baseline data were modified to account for system induced growth factors, the mail and express components of the market, and the changing all-cargo aircraft share of the total air cargo market. System induced growths ranged from 1.3 percent due to improved aircraft-airport compatibility to 11 percent for achieving shipper loaded containers. The all-cargo aircraft market share was increased from an average value of 44 percent in 1978 to 60 percent in the year 2008. This 16 percent increase was considered a realistic change over the 22 year period. The resulting average annual growth rates for the period 1978 to 2008 were 8.6 percent for U.S. Domestic, 7.9 percent for U.S. International, and 12 percent for the Foreign market.

In addition to market demand, the aircraft design characteristics and fleet operations will be affected by system variables that are dependent upon changes in the total environment and upon the accompanying market forces. Among these variables are the distribution of cargo movement, inflation, fuel cost, indirect operating costs, tariffs, and aircraft utilization. Values for these factors were forecast to the year 2008 and entered into the Douglas fleet simulation model as independent variables.

1978-1992 Cargo Aircraft Fleet

The fleet simulation model was based upon the August 1978 issue of the Official Airline Guide (OAG), Air Cargo Guide. The 704 actual airport-pairs were segregated into 133 range elements each encompassing a range increment of 322 kilometers (200 statute miles). The 15 generic types of current jet cargo aircraft were segregated under the three representative models identified below. A minimum constraint, equal to the number of departures per day in 1978, was established for future fleet operations.

REPRESENTATIVE AIRCRAFT CHARACTERISTICS

Model	Types Represented	Design Range-KM (SM)	Design Payload - Tonnes(Tons)	Cruise Speed-M
A1	Small Narrow Bodies(7 Types)	3806 (2365)	14.2 (15.6)	0.78
A2	Large Narrow Bodies(5 Types)	5149 (3200)	42.9 (47.3)	0.80
A3	Wide Bodies (3 Types)	7023 (4364)	94.7 (104.5)	0.85

Utilization of the three representative aircraft during the year 1978 is shown below. The large, narrow-body aircraft type, A2, dominated operations in all statistical areas. Both the A2 and A3 type aircraft were flown to ranges greater than the design range.

1978 AIRCRAFT UTILIZATION

Model	A1	A2	A3
Maximum Operational Range - KM (SM)	3805 (2365)	8755 (5440)	8219 (5108)
Statistics - Percent of Total			
Departures (Trips)	27.1%	58.8%	14.1%
Distance Flown	10.8%	68.1%	21.1%
Available Capacity	9.0%	59.4%	31.5%
Available Capability	3.1%	57.5%	39.4%
Hours Flown	13.1%	67.3%	19.7%

The 70 percent greater range of the A2 necessitated over a 50 percent reduction in payload relative to the design capacity. The A3 with the greater design range was operated 17 percent over design necessitating about a 20 percent reduction below the design payload.

The fleet analysis was extended out to the year 1992 based upon the most effective use of the A1, A2 and A3 aircraft. Without the addition of a new more efficient aircraft, the number of A3 units could steadily increase to a maximum of nearly 400 in the year 1992 as illustrated in Figure S-1.

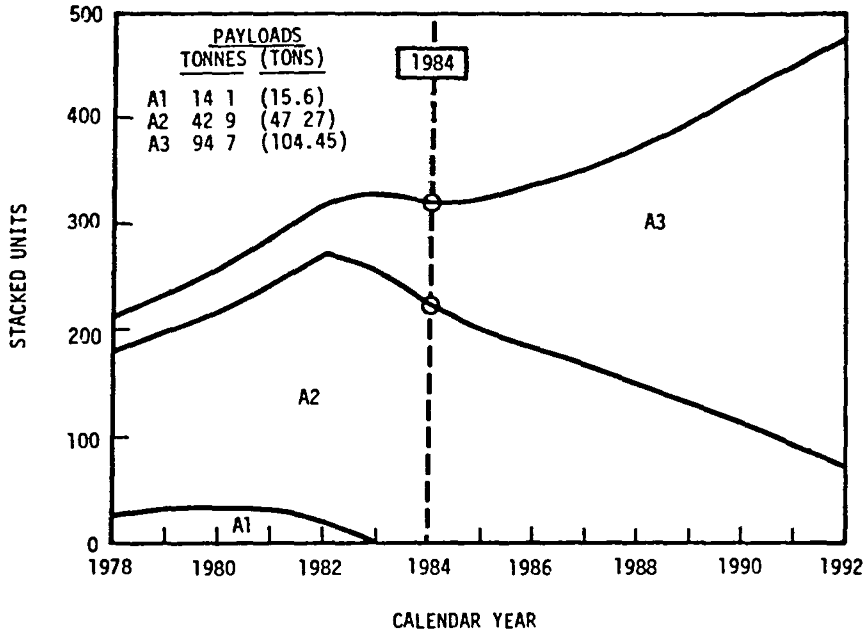


FIGURE S-1. FLEET MIX 1978-1992 REFERENCE FLEET

If available, the number of A1 and A2 units could increase 20 and 60 percent, respectively. The A1's could phase out by 1983 while the A2's could reach a maximum in the mid-80's and be reduced down to about 70 units by 1992. Subsequent to the mid-80's the A2 aircraft will be shifted to shorter range operations.

It must be remembered that results of this and subsequent fleet analysis provide solutions based upon the optimum use of available aircraft for the forecast market demand and system variables. Even if these conditions were met in real life, exterior forces acting in the future environment could result in the airlines deviating from the acquisition and disposal sequences noted herein. However, the results do provide a viable guide to preferred action.

Technology Development

The 1980 technology encompassed five developments that were considered viable for the derivative aircraft projected to become operational in 1985. These developments were viewed as an interim step toward achieving the 1990 technological objectives. It was assumed that the 1985 generation aircraft would develop as derivatives of contemporary configurations. Selection of the 1980 items therefore considered not only the anticipated state of development but also the limitations imposed by the derivative approach. The 1990 technology developments included eight items considered applicable to a new dedicated cargo aircraft projected to become operational in 1995. Among the developments that were evaluated were composites, adhesive bonding, energy efficient engines, improved airfoils, active flight controls and improved aircraft systems.

Utilizing available study and test results, Douglas and NASA first identified the incremental changes to aircraft parameters that could result from each of the considered developments. The resulting incremental changes to design parameters presented below were based upon the respective values for contemporary A3 type aircraft.

IMPACT OF TECHNOLOGY DEVELOPMENTS

	Incremental Changes Relative To Current Aircraft									
Design Parameters	ΔW_{P+N}	ΔW_{STRU}	$\Delta L/D$	ΔSFC	ΔW_{ENG}	ΔW_{FURN}	Mfr. Cost		Maint. Cost	
							A/C	Eng.	A/C	Eng.
Derivative 1980 Tech	-8%	-11.2%	+4%	-8%	-2%		-1%			
Dedicated 1990 Tech	-24%	-32%	+11%	-13%	-4%	-9.5%	-14%	+7.2%	-2%	-5%

1984 - 1998 Derivative Aircraft Fleet

It was postulated that new aircraft derived from current wide body configurations would be developed utilizing 1980 technology so as to be operational in 1985. To define the size of these aircraft and the associated fleet operations and economics, a range of parametric models were each competitively evaluated in fleet operations against the representative A2 and A3 aircraft, reference fleet, over the period 1984 to 1998. These investigations considered three models, a short range, SRD; a medium range, MRD; and a long range, LRD. Each of these models were varied in size over the range of payloads noted below.

PARAMETRIC PAYLOADS FOR DERIVATIVE AIRCRAFT

Model	SRD	MRD	LRD
Design Range - KM (SM)	3219 (2000)	5150 (3200)	7025 (4365)
Design Payload - Tonnes (Tons)	22.7 to 181.4 (25 to 200)	45.4 to 181.4 (50 to 200)	45.4 to 181.4 (50 to 200)

The 1980 technology successfully improved the aircraft cost picture. At comparable payloads the derivative aircraft provided a 20 percent reduction in trip cost (direct operating cost less depreciation and insurance) and a 15 percent decrease in aircraft price relative to the representative A3 aircraft inflated to 1984 dollars. Economic evaluations of the derivative aircraft were based upon a manufacturer's breakeven point of 200 units. This was a viable approach since these aircraft would undoubtedly be produced in passenger versions which would substantially increase the number of units over those required for cargo operations.

Based upon maximizing the airlines' return on investment (ROI), a payload of 149.7 tonnes (165 tones) was the preferred size for the derivative aircraft regardless of their design range. These aircraft increased the airline ROI by 2.5 to 3 percent above the reference fleet. Decreasing the payload to levels more compatible with the size of aircraft that could be derived from current wide body aircraft incurred only small economic penalties. As an example, reducing the payload by as much as 40 percent reduced the airline ROI and total operating income (ΣOI) by the increments noted below for each of the three models.

EFFECT OF REDUCED PAYLOAD

Model	SRD	MRD	LRD
ΔROI Airline	-0.8%	-0.6%	-0.5%
ΔΣOI Airline	-3.0%	-2.0%	0

Such small degradations, less than one percent in ROI and 3 percent in ΣOI, over the 15-year period are essentially negligible unless evaluated relative to the specific and detailed airline financial situation.

The combined implementation of both the short and long range models, payloads of 149.7 tonne (165 ton), provided the preferred economic return as shown in Figure S-2. Note that the MRD was a close second choice with only a slight decrease in airline ROI and a small increase in investment.

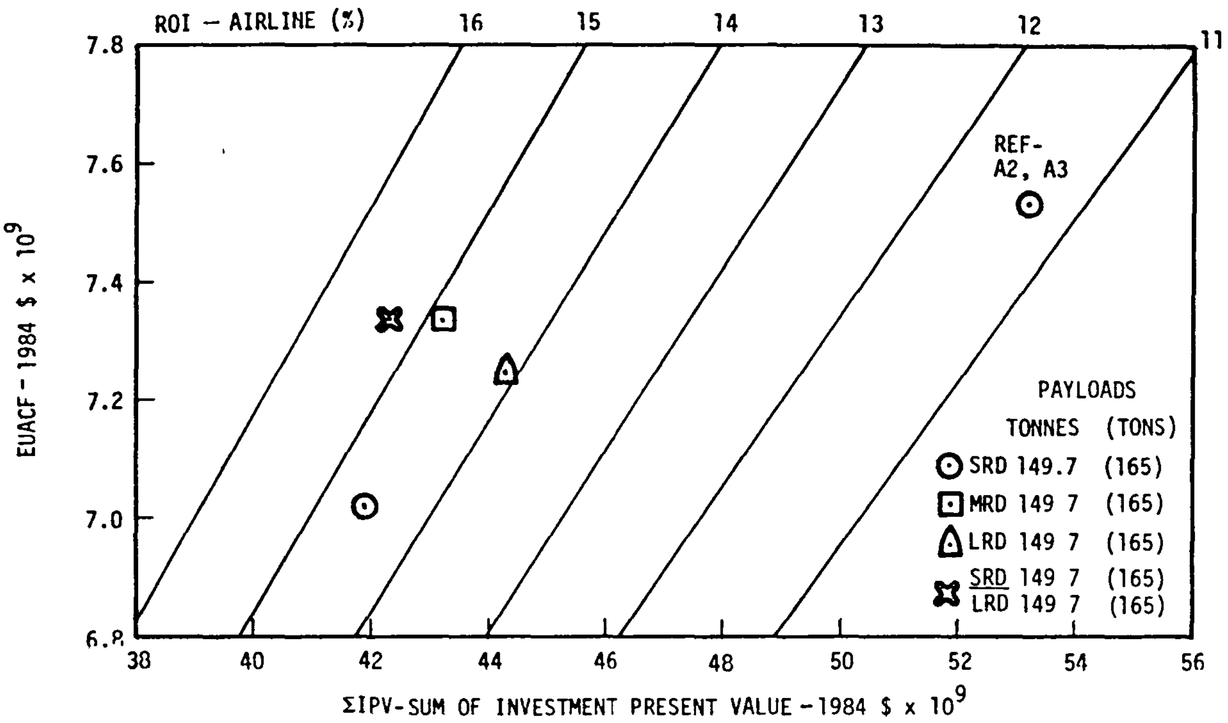


FIGURE S-2. ECONOMIC WORTH – DERIVATIVE AIRCRAFT 1980 TECHNOLOGY

Relative to the reference fleet, the addition of the SRD/LRD combination into fleet operations increased the airline ROI by 3.9 percent; the ΣOI by 30 per cent; and reduced the total investment required, ΣIPV, by 20 percent. Due to the reduced investment the equivalent uniform annual cash flow, EUACF, was reduced 3 percent. However, implementation of only the 149.7 tonne (165 ton) MRD was nearly as preferable resulting in less than 1 percent decrease in airline ROI, a 4 percent decrease in ΣOI, and a 2 percent increase in investment relative to the SRD/LRD combination.

Considering the predominance of the foreign market demand, approximately 70 percent of the total, it is logical that in the case of the SRD/LRD combination each model would be developed by a separate manufacturer. In a like manner if only one model were implemented, such as the MRD, it is quite likely that two manufacturers would be involved. It is expected that additional aircraft will be sold for passenger operations, however, without such additional orders, and/or an increase in price, the return on investment would be marginal making it quite unlikely that either manufacturer would initiate the development of a new dedicated freighter for the post 1995 time period.

As shown in Figure S-3 there was a steady increase in the number of SRD and LRD aircraft, to nearly 400 units in 1998, following their initial introduction in 1985.

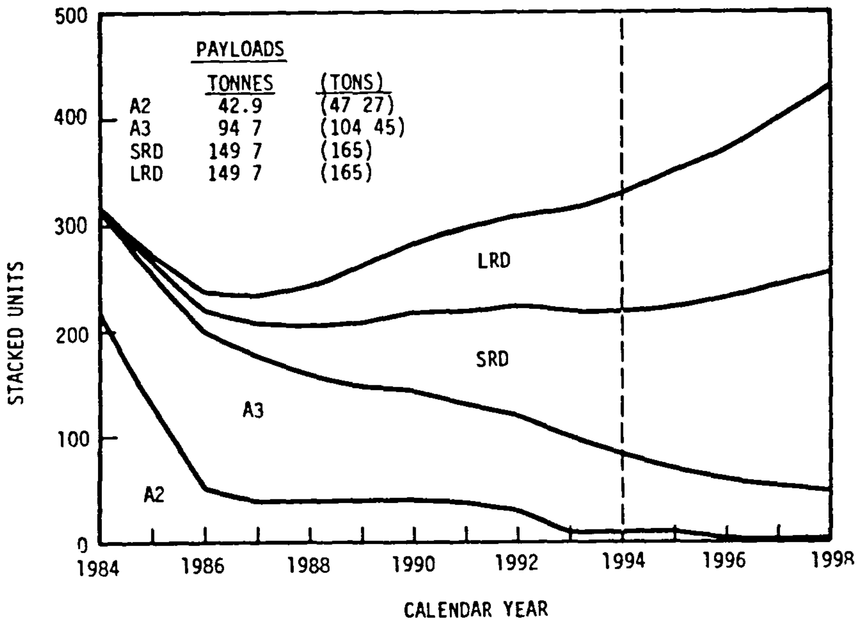


FIGURE S-3. 1984-1998 SRD/LRD FLEET MIX

Simultaneously the number of wide body A3's increased out to the mid-80's as they began to take over from the large narrow body A2 aircraft on the shorter routes. Beginning about 1987 the demand on these shorter routes would grow sufficiently to require the larger more efficient SRD. Comparing the 1994 SRD/LRD combination fleet to the 1984 reference fleet showed a 2.5 percent increase in fleet size, a 250 percent increase in fleet revenue capability, and a 15 percent improvement in the fleet load factor. The SRD experienced the lower load factor indicating that, due to its improved economics, it was utilized on some A3 and perhaps A2 routes that did not quite match its capability.

Since the SRD, LRD and MRD aircraft all have payloads greater than the A3, there was a decrease in departures out to the mid to late 80's at which time the frequency again began to increase due to growth in market demand. In addition, the 149.7 tonne (165 ton) payload SRD, LRD and MRD aircraft resulted in average annual frequency growth rates less than 4 percent indicating that the payload size could be reduced before reaching the 6.4 percent growth forecast for the A2,, A3 reference fleet.

1994 - 2008 Dedicated Aircraft Fleet

The preceding results provided the necessary framework for viewing the requirements for, and the fleet operations of, a new dedicated freighter aircraft utilizing 1990 available technology. These analysis gave consideration to the fact that production of these aircraft would be solely dependent upon the demand generated by cargo operation, with no additional sales for passenger operations. Two models, a short range, ASR; and a long range, ALR; of the advanced dedicated freighter were investigated parametrically over a range of payloads as follows.

PARAMETRIC PAYLOADS FOR DEDICATED AIRCRAFT

Model	ASR	ALR
Design Range - KM (SM)	3218 (2000)	7022 (4364)
Payload - Tonnes (Tons)	22.7 to 362.8(25 to 400)	45.4 to 544.2(50 to 600)

In consideration for the potentially limited demand for a dedicated freighter aircraft, the price of all models was determined on the basis of providing each manufacturer with a 15 percent return on investment as determined by the actual number of units required to meet the cargo market demand and fleet competition. The resulting prices for the short and long range dedicated freighters utilizing 1990 technology are presented in Figure S-4. Prices were established for both one and two manufacturers with the latter data expanded to show the impact of military support.

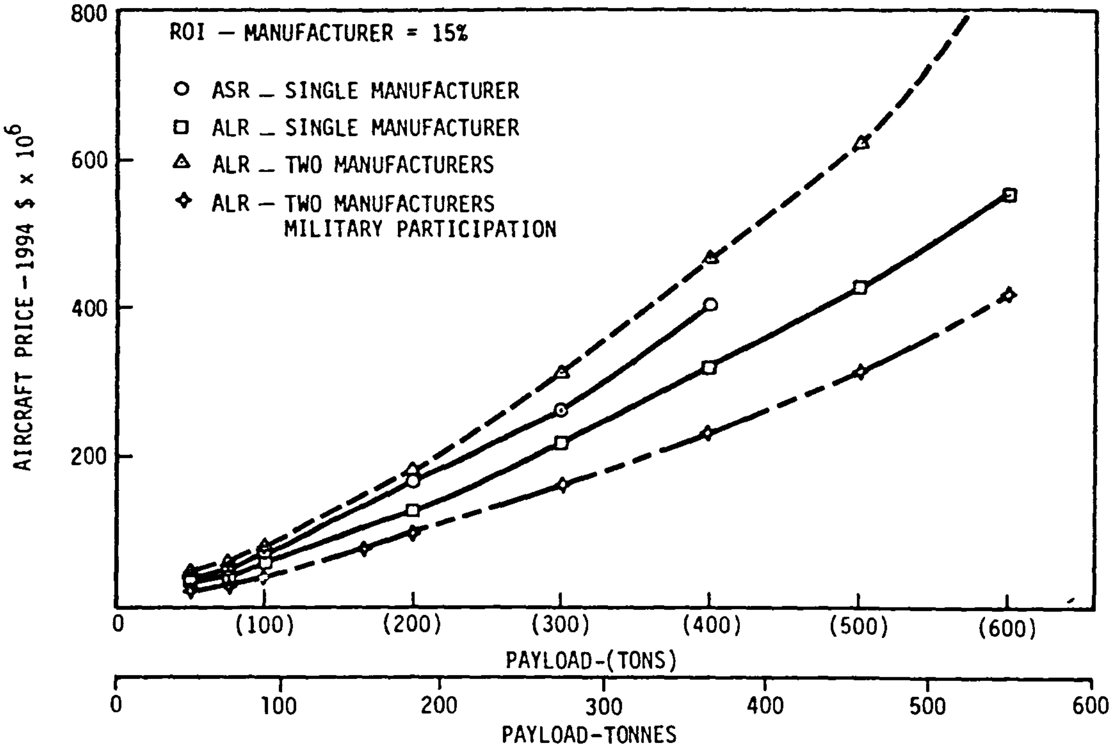


FIGURE S-4. AIRCRAFT PRICE VERSUS PAYLOAD

Comparable trip costs, DOC less depreciation and insurance, for the dedicated freighters are presented in Figure S-5. The trip costs are not affected by the number of manufacturers. Due to the impact of the 1990 technology discussed in the preceding section, the operating cost of the 94.7 tonne (104 ton) payload ALR aircraft was 43 percent below the 0.132 dollars per tonne kilometer (0.193 dollars per ton statute mile) trip cost of the comparable representative A3 aircraft.

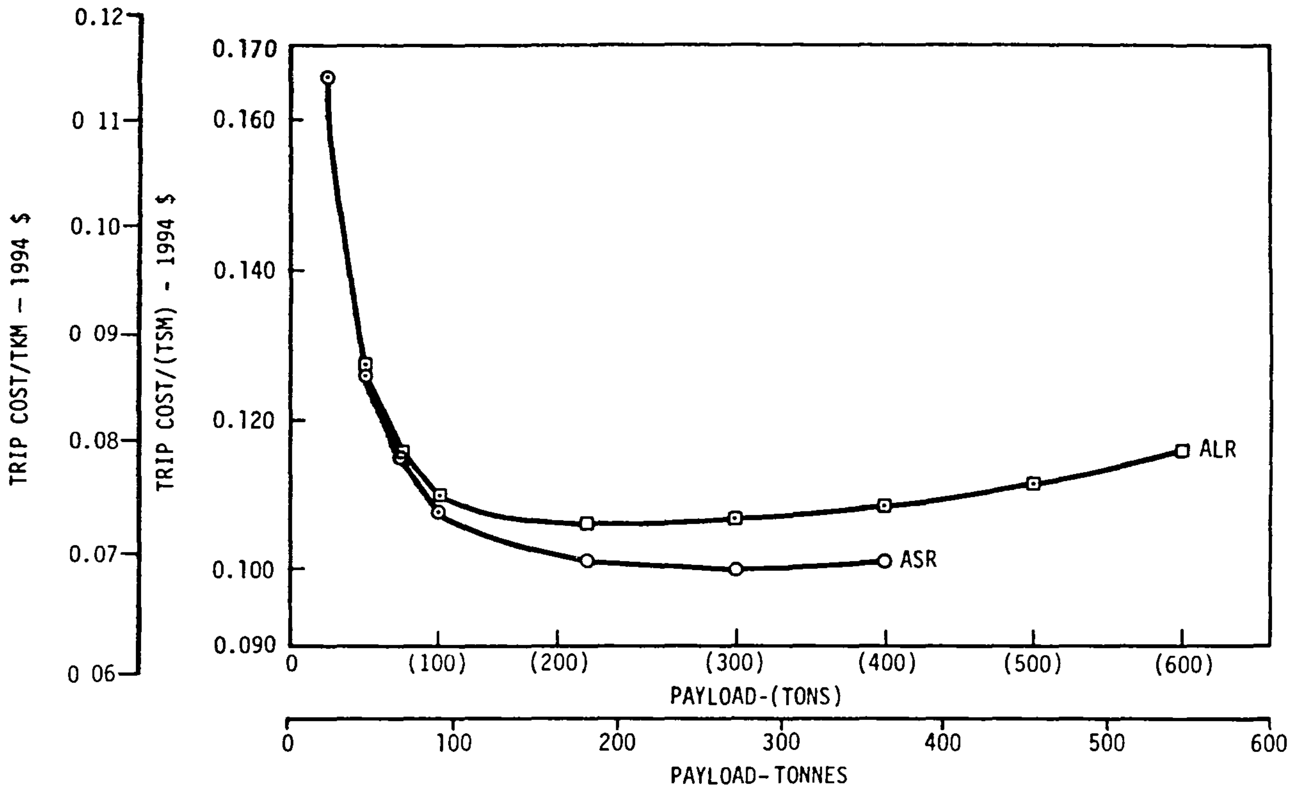


FIGURE S-5. AIRCRAFT TRIP COST VERSUS PAYLOAD

The minimum trip cost occurred at a payload of 181.4 tonnes (200 tons) for the ALR and 272.1 tonne (300 ton) for the ASR.

Single manufacturer per aircraft. - The large number of units required to meet the post 1994 demand combined with the impact of 1990 technology resulted in a substantial reduction in the price of the dedicated freighter. This reduction was exaggerated when the price was determined for a single manufacturer. As an example, for a payload of 94.7 tonne (104 ton) the price of the dedicated freighter was 48 percent lower than the comparable A3 reference aircraft having a price tag of 115.3 x 10^6 in 1994 dollars.

The preferred payload size for the short and long range versions of the dedicated freighter were determined on the basis of a single manufacturer for each version since it was established that the number of manufacturers did not effect the preferred payload size. The associated fleet economics were developed on the basis of only one version being implemented at a time. As an example, in the first case only the short range ASR competed with the reference fleet during the considered time period and the second case considered only the long range ALR being developed. Based upon maximizing the airline ROI while providing the manufacturer with a 15 percent ROI lead to the identification of the 45.4 tonne (50 ton) ASR and the 68 Tonne (75 ton) ALR as the preferred size of these aircraft when competing separately against the reference fleet of A2, A3, SRD and LRD aircraft. Results presented in Figure S-6 show a clear improvement of fleet economics, nearly a 4 percent increase in airline ROI, due to the ALR compared to the reference fleet.

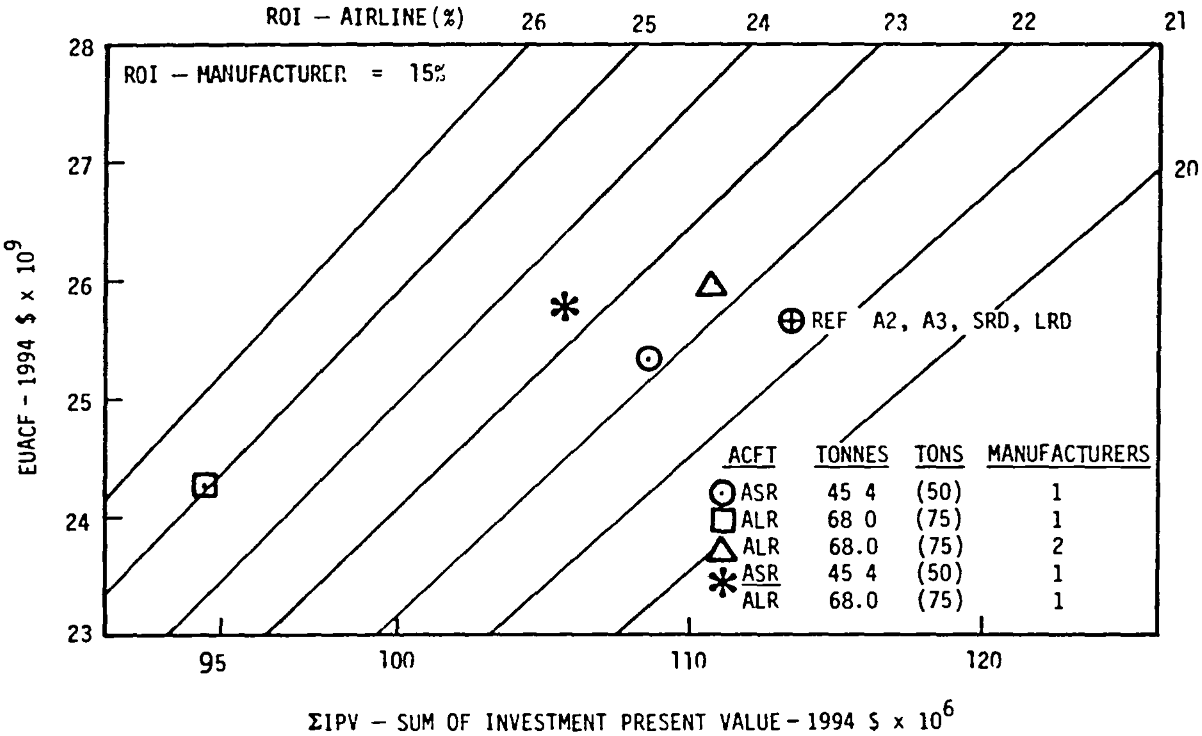


FIGURE S-6. ECONOMIC WORTH — DEDICATED FREIGHTER AIRCRAFT

The comparable impact of the ASR was marginal amounting to an improvement of less than 1 percent. These data pointed out the desirability of the long range aircraft in meeting the 1994-2008 market demand.

The variations in fleet economics that resulted with larger payload aircraft were relatively small when viewed in the context of airline finances. As an example, increasing the payload of either the ASR or ALR by a factor of 2.2, the increase compatible with a payload of 149.7 tonne (165 ton) for the ALR, resulted in the following incremental changes in the respective parameters based upon single manufacturer for each model aircraft.

EFFECT OF INCREASING PAYLOAD

Model	ASR	ALR
Payload Increase - Tonnes (Tons)	45.4 to 99.8 (50 to 110)	68.0 to 149.7 (75 to 165)
ΔROI Airline	-0.5%	-1%
ΔEUACF	+3.0%	+4%
ΔΣIPV	+6.0%	+8%
ΔΣOI	+3.0%	+3%

Although the airlines ROI was decreased and the required investment increased, the resulting values were essentially equal to or slightly better than the comparable values for the reference fleet. At a payload of 362.8 tonne (400 ton) the ALR still showed a 0.6 percent improvement in airline ROI with only a slight increase in investment compared to the reference fleet. On the other hand the ASR matched the reference fleet ROI at a payload of about 136 tonne (150 ton). In addition, the increase in operating income realized with the larger payload is an important consideration in airline economics.

Considering the nature of the market demand and the potential number of aircraft required, it is quite probable that both the ASR and ALR would be developed each by a separate manufacturer. In this case both aircraft would be on the market and would be competing with each other as well as with the A2, A3, SRD and LRD reference fleet. As in the case of the derivative aircraft. improved fleet economics were realized with the combined implementation of the preferred 45.4 tonne (50 ton) ASR and the 68 tonne (75 ton) ALR aircraft as noted in Figure S-6.

This small payload ASR/ALR combination when simultaneously competing in the fleet resulted in a 2 percent increase in airline ROI, 7 percent decrease in investment, and a 7 percent increase in operating income over the reference fleet. The imporvement in cash flow was negligible being less than 1 percent.

Compared to the economic performance of the 68 tonne (75 ton) ALR produced by one manufacturer, the ASR/ALR combination was considerably less desirable. Although the ASR/ALR combination provided a slightly greater operating income, about 1 percent more than the ALR, the ALR provided twice the improvement in airline ROI with 12 percent less investment as illustrated in Figure S-6. However, the real world considerations cast doubts on the viability of a single manufacturer filling the total demand for a dedicated freighter aircraft.

Due to their increased efficiencies, the ASR and ALR aircraft began to capture the market immediately and increased in number to a combined total of 1572 units by the year 2008 as shown in Figure S-7.

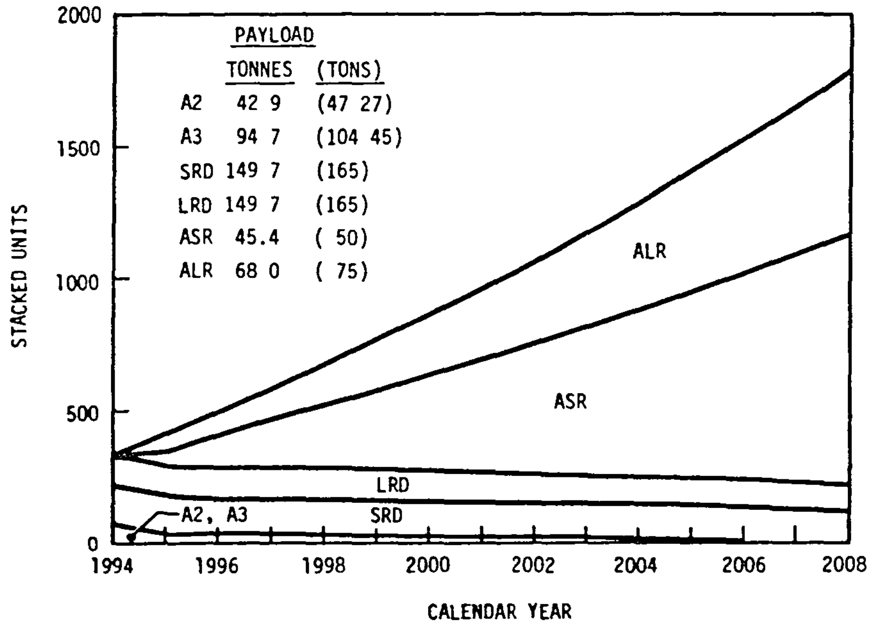


FIGURE S-7. 1994-2008 ASR/ALR FLEET MIX

The current A2 type aircraft phased out by 1996 with the A3's following by 2006. There was a small decrease in the number of SRD and LRD aircraft over the years accompanied by their transfer to shorter range operations. This decrease in operating range was more pronounced for the SRD. Although the fleet economics were favorable, the smaller payloads of 45.4 and 68.0 tonnes (50 and 75 tons) for the ASR and ALR aircraft incurred disadvantages. The resulting combination fleet required over twice the number of aircraft and twice the number of departures of the reference fleet by 2008. The comparable average annual frequency growth rate was 88 percent greater than the reference fleet and 56 percent greater than the 8.1 percent that occurred prior to 1978.

Dual manufacturers per aircraft. - Considering the future growth trends of the cargo market demand, the number of aircraft required to meet this demand, and the projected growth of the foreign aircraft industry, make it very unlikely that all advanced freighter aircraft will consist of a single design produced by one manufacturer. It was therefore concluded that implementation of the ALR by a single manufacturer or the development of only a short range ASR aircraft were not realistic. If only the ALR dedicated freighter were implemented, then at least two designs would be developed each by a single manufacturer.

The increase in aircraft price, 34 percent for the 90.7 tonne (100 ton) size aircraft, that occured with the introduction of a second manufacturer is illustrated in Figure S-4. With two manufacturers the reduction in price of the 94.7 tonne (104 ton) ALR compared to the comparable reference A3 aircraft was reduced to 31 percent. This increase in aircraft price had a considerable impact on fleet economics.

The deterioration of the economic picture that occurs with two manufacturers is illustrated by the 68 tonne (75 ton) ALR aircraft in Figure S-6. In going from one to two manufacturers, the airline ROI was decreased by 2.8 percent while the investment was increased by 19 percent. With two manufacturers the ALR was only marginally better than the reference fleet providing a 1 percent improvement in airline ROI, a 2 percent reduction in investment and a 6 percent increase in operating income.

Although each aircraft of the 45.4/68 tonne (50/75 ton) ASR/ALR combination was, by a single manufacturer, relative to the total aircraft market there were two manufacturers involved making this case comparable to the 68 tonne (75 ton) ALR with two manufacturers. Going from the ASR/ALR combination, reference Figure S-6, to the two manufacturer 68 tonne (75 ton) ALR resulted in a 1 percent decrease in airline ROI, a 5 percent increase in investment and a 1 percent decrease in operating income; thus making the ALR the less desirable. The ASR/ALR combination was therefore used to typify the more realistic, economically selected, fleet mix for the 1994-2008 time period involving two manufacturers. This combination also offered a parallel short/long range comparison to the SRD/LRD component of the reference fleet.

Parametrics

There were four parametric investigations conducted to define the respective impacts of reduced operational frequency, reduced cargo market demand, military participation and aircraft configuration change, on fleet economics and operations. Based upon the results discussed in the preceding section these parametric studies were conducted on the basis of two manufacturers.

Reduced operational frequency. - As seen from the preceding discussion, the impact of assuring the manufacturer a 15 percent ROI was to decrease the payload size in order to achieve an economically viable dedicated freighter. However, in order to meet the market demand, these relatively small aircraft incurred a substantial increase in fleet operational frequency with an accompanying potential conflict with future flow control requirements at many major airports. As an example, the ASR/ALR combination, when integrated in the fleet would increase the number of departures by 12.6 percent annually. This was considerably greater than the 6.7 annual growth due to the reference fleet or the 8.1 percent experienced prior to 1978. While larger payload aircraft would reduce this growth in operational frequency, they would, as we have seen, have an adverse effect upon fleet economics. This problem was investigated on the basis of dual aircraft manufacturers, each realizing an ROI of 15 percent, and upon the long range ALR aircraft operating in competition with the reference fleet of A2, A3, SRD and LRD aircraft. Analysis was performed parametrically for a range of payloads from 45.4 to 455 tonnes (50 to 600 tons).

It was found that the long range dedicated aircraft with a payload of 149.7 tonnes (165 tons) and developed by two manufacturers, designated model ALR_2, would result in a fleet annual frequency growth of 6.7 percent, a value equivalent to that of the 1994-2008 reference fleet. Decreasing the payload to 91 tonnes (100 tons) increased the frequency growth rate to the pre-1978 level of 8.1 percent. In view of the lower frequency and considering the preferred payload size of the derivative aircraft, 149.7 tonne (165 ton), the decision was made to pursue the ALR_2 aircraft.

The degradation of fleet economics resulting from implementation of the ALR_2 is illustrated in the table below relative to the economics of the 68 tonne (75 ton) ALR with two manufacturers, the ASR/ALR combination fleet, and the reference fleet.

IMPACT OF PAYLOAD ON FLEET ECONOMICS

Change Relative To	68 Tonne(75 ton) ALR	ASR/ALR Combination Fleet	Reference Fleet
	Two Manufacturers		
ΔROI Airline	-1.3%	-2.3%	-0.4%
ΔEUACF	+7.0%	+7.0%	+8.0%
ΔΣIPV	+12.0%	+18.0%	+9.0%
ΔΣOI	+3.0%	+2.4%	+9.0%
ΔDeparture (trips) Growth Rate	-3.7%	-5.9%	0

Comparing economic changes that occurred relative to the 68 tonne (75 ton) ALR with the comparable data for one manufacturer (previously discussed on page xxxii) shows that, except for operating income which was unaffected, the economic degradation due to increasing the payload by a factor of 2.2 was greater when two manufacturers were involved. As an example, the airline ROI was decreased an additional 0.3 percent and the investment was increased an additional 4 percent. However, the larger payload succeeded in reducing the annual frequency growth rate 3.7 percent.

The economic degradation experienced in going from the 45.4/68 tonne (50/75 ton) ASR/ALR combination fleet to the ALR_2 was greater than the impact due to payload size. The largest degradation was the 18 percent increase in investment over the ASR/ALR combination fleet. This larger investment resulted in the 2.3 percent reduction in airline ROI in spite of the 2.4 percent improvement in operating income. The latter was due primarily to the reduced trip cost of the larger aircraft, Figure S-5. The real question is whether, in real life, the airline would be willing to realize a smaller ROI in favor of the nearly 6 percent reduction (12.6 to 6.7 percent) in frequency growth. Along with the 55 percent reduction in the number of departures in the year 2008, there was about a 54 percent reduction in the number of aircraft required with the larger ALR_2 aircraft compared to the small payload ASR/ALR combination.

The economic penalties associated with the larger aircraft are brought into focus when viewed with respect to the reference fleet. The ALR_2 reduced the airline ROI to a level below that of the reference fleet. Except for the 9 percent increase in operational income and the reduction in operational frequency, there would be little economic incentive for the airlines to purchase, or the manufacturers to initiate the development of an ALR_2 size dedicated freighter. However, the combined effects of the cargo market demand, airport and/or airways flow control, and perhaps the energy situation, may be sufficient to force the issue, especially if the program were wholly or partially subsidized.

Reduced cargo market demand. - The configuration of a new aircraft, such as the dedicated freighter, is determined on the basis of market demand forecasts extending many years into the future. Once committed, the design cannot be changed for deviations from the forecast values. The question then is what effect will a reduced cargo market demand have on the fleet economics with the new aircraft in operation? Analysis was based upon the ALR_2, 149.7 tonne (165 ton) aircraft produced by two manufacturers. The reduced market demand was obtained by delaying the 1989 forecast demand five years to 1994. This delay reduced the average annual growth rate of the total market from the basic 10.7 percent to 8.5 percent; thus reducing the demand for the year 2008 by 45 percent.

Changes in the economics of the reference and ALR_2 fleets that resulted from the reduced demand are illustrated in the table below. A comparison of these values shows that under conditions of reduced demand the fleet economics would be somewhat degraded by the presence of the ALR_2 aircraft. Relative to the reference fleet, the ALR_2 fleet would provide the airline with a smaller ROI and require a larger investment. However, since the reduction in operating income is the same for both the reference and ALR_2 fleets, the relative severity of the two penalties would depend upon the financial situation of the airlines.

CHANGE DUE TO REDUCED CARGO MARKET DEMAND

	Reference Fleet -A2, A3, SRD, LRD	ALR_2 Fleet
$\Delta\Sigma$Units	-31%	-49%
ΔROI Airline	-3.4%	-5.3%
ΔEUACF	-44%	-38%
$\Delta\Sigma$IPV	-35%	-22%
$\Delta\Sigma$OI	-49%	-49
ΔDepartures (trips) Growth Rate	-1.3%	-1.3%

The SRD, LRD and ALR_2 aircraft would be less competitive in the reduced demand market. In spite of their improved efficiency, these aircraft would lose out to the representative A3 type aircraft which would make up larger portions of both the 1994 and 2008 fleets.

Military participation. - Since the U.S. Air Force is openly interested in the development of an advanced civil-military freighter aircraft, a study was made of the impact of military participation on optimum payload size and fleet economics. The possibility of partial military funding is an important factor since the main study clearly showed the sensitivity of advanced dedicated freighter aircraft competitiveness to the number of units produced as affected by the number of manufacturers.

It was postulated that military participation would occur in a single program directed to the development of an ALR type aircraft; that two manufacturers would be involved in producing the total number of units required, commercial plus military, but only one of these manufacturers would produce the military units with both realizing a 15 percent ROI: that the weight and performance of the commercial version would not be penalized by the military participation in RD and T; and that the military would provide half of the required research, development and test funding (RD&T) and would subsequently purchase a number of units equal to 25 percent of the commercial U.S. Domestic and U.S. International fleets.

The impact of this military participation on aircraft price with two manufacturers is shown in Figure S-4. The reduction in price was about 49 percent at a payload of 149.7 tonnes (165 tons) decreasing to 47 percent for the 544.2 tonnes (600 tons) payload size. Although the preferred payload size remained at 68 tonne (75 ton), the airline ROI was increased and the investment was reduced at all payloads. The fleet economics of the long range aircraft changed from being marginal to clearly better than the reference fleet containing the derivative aircraft. The economic sensitivity to payload size was greatly reduced with the 544.2 tonne (600 ton) payload ALR fleet exceeding the performance of the reference fleet.

The economic benefit of military participation is illustrated by the airline ROI and investment data presented in the table that follows. Cases for the small and large payload ALR's, one and two manufacturers, and with and without military participation, are ordered by the value of the resulting airline ROI. There is an additional case, not considered in this study, which should be economically competitive. This case entails the possibility of one manufacturer of the ALR with military participation but with less commercial sales due to competition from a cargo derivative developed by modifying a new, advanced technology, wide body passenger aircraft.

It is evident from these tabulated data that military participation more than compensated for the penalties associated with going from one to two manufacturers.

IMPACT OF MILITARY PARTICIPATION

Advanced Long Range Dedicated Freighter ALR				
Payload - Tonnes (tons)	Number of Manufacturers	Military Participation	Airline ROI	ΣIPV- 1994$ x 10^9
68.0 (75)	2	Yes	27.8%	78
149.7 (165)	2	Yes	27.0%	83
68.0 (75)	1		25.1%	93
149.7 (165)	1		24.1%	101
68.0 (75)	2		22.3%	111
Reference Fleet	A2, A3, SRD, LRD		21.4%	114
149.7 (165)	2		21.0%	124

For the 149.7 tonne (165 ton) payload aircraft the airline ROI was reduced 3 percent with two manufacturers but was increased 6 percent with military participation. Airline investment was also substantially improved. For the 149.7 tonne (165 ton) payload aircraft, going to two manufacturers increased the required investment 23 percent which in turn was reduced 33 percent by military participation. The attractiveness of military participation was primarily due to sharing the RD and T cost since the military buy would be relatively small amounting to 43 units for the 149.7 tonne (165 ton) size freighter aircraft.

Aircraft configuration change. - In a study of this type there is always the question as to the relative effectiveness of configurations that depart from the conventional. To answer this question two propfan powered aircraft, Propfan 1 and Propfan 2; a turbofan powered Spanloader (distributed payload); and a conventional turbofan powered aircraft equipped with laminar flow control, LFC; were evaluated. These configurations were compared to the 149.7 tonne (165 ton) payload ALR_2 and a 235.8 tonne (260 ton) payload ALR_3. All configurations utilized 1990 technology which provided the incremental changes in design parameters presented below.

1990 TECHNOLOGY PARAMETRIC AIRCRAFT CONFIGURATION

		Incremental Changes Relative to Contemporary Aircraft									
Configuration	M	ΔW_{P+N}	ΔW_{STRU}	$\Delta L/D$	ΔSFC	ΔW_{ENG}	$\Delta C_{L_{TO}}$	Mfg. Acft	Cost Eng.	Acft. Maint. Cost	ΔS_W
Propfan 1	0.8	-7%	-4%	-10%	-20%	+112%			+29%		-10%
Propfan 2	0.7	-11%	-26%	-6%	-30%	+103%			+29%		-14%
Spanloader	0.75	-17.6%	-43%	-13%	-4%			-15%			+10%
LFC	0.85		+6.5%	+22%	+2%	+2%	-13%	+4%		+10%	+8%

All values were based upon the respective values for the advanced turbofan type aircraft.

Based upon the preceding improvements in technology, the trip cost for each type aircraft was determined. Utilizing these values, each of the parametric aircraft were competed against the reference fleet of A2, A3, SRD and LRD aircraft to define the respective number of units required and subsequently the aircraft price. The latter values were based upon two manufacturers each realizing a 15 percent ROI. Results of these analysis are tabulated below.

PARAMETRIC AIRCRAFT CHARACTERISTICS

Design Range - KM (SM)	7022 (4364)					
Configuration	ALR_2	Propfan 1	Propfan 2	LFC	ALR_3	Spanloader
Design Speed @ Cruise-M	0.85	0.80	0.70	0.85	0.85	0.75
Payload - Tonnes (Tons)	149.5 (165)	149.5 (165)	149.5 (165)	140.5 (165)	235.8 (260)	235.8 (260)
Units	573	594	646	568	356	392
Trip Cost @ Design Range/Payload - $/Trip/Tonne ($/Trip/Ton)	511 (463)	524 (475)	468 (424)	461 (417)	510 (463)	555 (503)
Aircraft Price/Payload- 1994 $ x 10^6/Tonne (1994 $ x 10^6/Ton)	0.98 (0.88)	1.08 (0.98)	0.80 (0.72)	1.05 (0.95)	1.13 (1.02)	0.71 (0.65)

Trip cost and aircraft price are presented per unit payload since all configurations were sized for the same design range. The ALR_3 was the highest priced aircraft of the considered configurations and the lowest priced aircraft was the Spanloader which also had the highest trip cost per unit payload. The lowest trip cost was provided by the LFC configuration. Although such comparisons are interesting, the fleet economics developed by each of the respective configurations is the true determinate of their relative worth.

In spite of its higher trip cost, the Spanloader provided the highest airline ROI, the lowest required investment, a 6 percent increase in operating income, and a cash flow essentially equal to that of the reference fleet. The relative worth of this and other considered configurations is graphically illustrated in Figure S-8 with all values based upon two manufacturers. Note that the economic performance of the Spanloader is essentially equal to that of the ASR/ALR combination. The next most productive configuration was the M = 0.7 Propfan 2 which gave the second highest ROI, the second highest income, and required next to the lowest investment with a cash flow 6 percent greater than the reference fleet. Finally, the ALR_2 configuration had the third highest values of ROI, operating income, and cash flow, with the third lowest required investment.

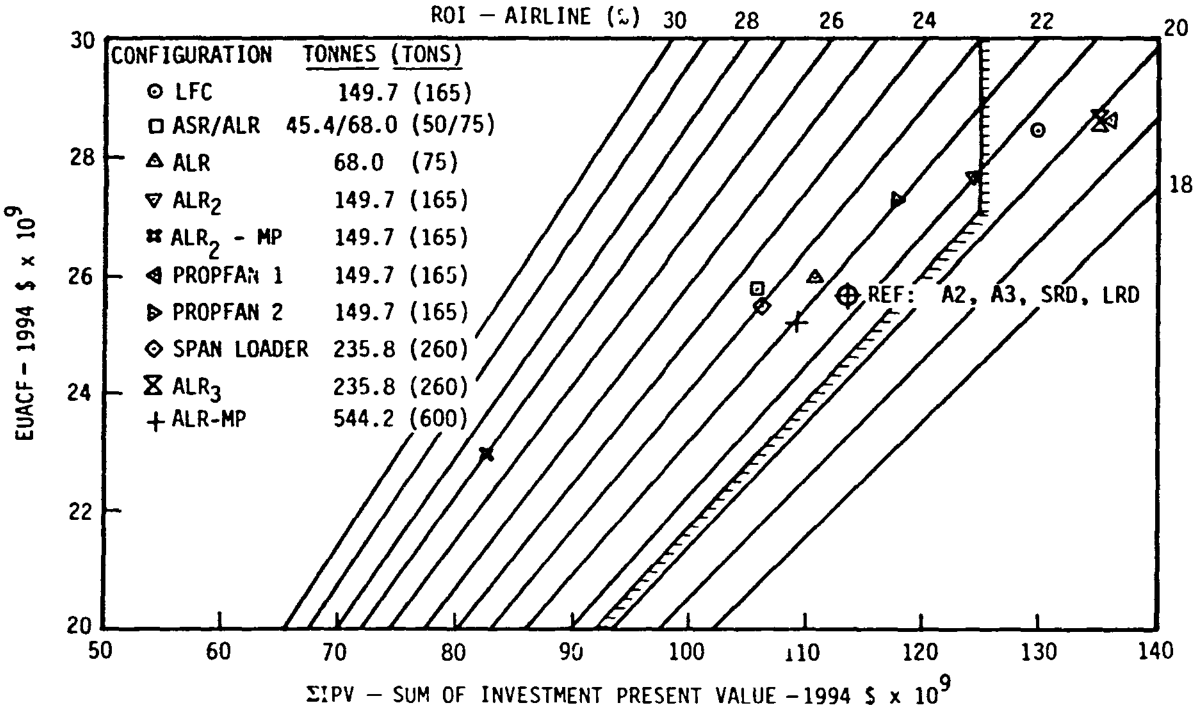


FIGURE S-8. ECONOMIC WORTH OF CONSIDERED CONFIGURATIONS

These data dramatically illustrate the favorable impact of military participation in terms of the ALR_2 and the very large payload ALR.

If those configurations are excluded that have an airline ROI more than 1 percent below and a required investment 10 percent greater than the reference fleet, then only the Spanloader, Propfan 2, and ALR_2 configurations remain along with the previously preferred small payload ASR/ALR combination and the ALR configuration as shown in Figure S-8. From the present point-of-view, the small payload aircraft are less desirable on the basis of the relatively large increase in operating frequency which they entail, annual average growth rates greater than 10 percent. Among the remaining configurations the Spanloader is the least desirable due to the conflict between its geometry and current airport requirements. As discussed in Volume 3, Book 1, operations on current hub airports are essentially limited to aircraft not much larger than the B747 aircraft. Past analysis has shown the considered 235.8 tonne (260 ton) payload aircraft to be near the minimum size at which the Spanloader concept can equal or exceed the effectiveness of a comparable conventional aircraft. While the Propfan 2 showed improved fleet economics over the turbofan ALR_2, it, too, has a qualifying point. Some operators have expressed a reluctance to acquire aircraft having cruise speeds much below the current values of 0.8 to 0.85 Mach number.

Results have shown the benefits of military participation and the resulting combined commercial/military program could bring the larger aircraft, up to 544.2 tonne (600 ton), within the realm of economic feasibility as illustrated by the 544.2 tonne (600 ton) ALR configuration in Figure S-8. However, there are two reasons why large conventional aircraft are less likely to be developed. First, there are the airport dimensional requirements discussed in connection with the Spanloader but equally applicable to conventional designs. Unless such designs are modified or the airport requirements changed, the dedicated freighter aircraft will have a maximum payload around the 149.7 tonne (165 ton) considered. The second reason are the problems stemming from the FAA and ICAO noise suppression requirements discussed in Volume 3, Book 1. Above takeoff gross weights (TOGW) of about 385.5 tonne (425 ton), comparable payloads of about 118 tonne (130 ton) for conventional aircraft, the takeoff noise certification requirement is constant. Present requirements are applicable to aircraft having four or less engines. Since the required thrust increases with TOGW, and hence the number of engines, there will be an upper limit on aircraft size allowable with a selected propulsion system. This upper limit on aircraft size will therefore be determined by the level of development of the quiet engines.

Airline ROI Versus Tariffs

The foregoing economic analysis was based upon the tariff reductions defined in Section 1. These values provided for an 18 percent reduction by 1990 due to improvements in the infrastructure followed by an additional 4.5 percent reduction by the year 2008 due to the introduction of the more efficent derivative aircraft and dedicated aircraft. Fleet economic results, Figure S-6, showed an airline ROI of 21.4 percent for the A2. A3, SRD and LRD reference fleet during this period 1994 to 2008. This value is 6.4 percent above the considered reasonable value of 15 percent; however, implementation of a derivative aircraft smaller than the preferred payload of 149.7 tonne (165 ton) would reduce this value a small amount.

In a competitive industry, especially with deregulation, it is unlikely that such high level of return could be sustained. One result of such unstable condition would be a further reduction in tariffs and hence yield to the airlines. The impact of reduced yield on airline ROI is presented in Figure S-9.

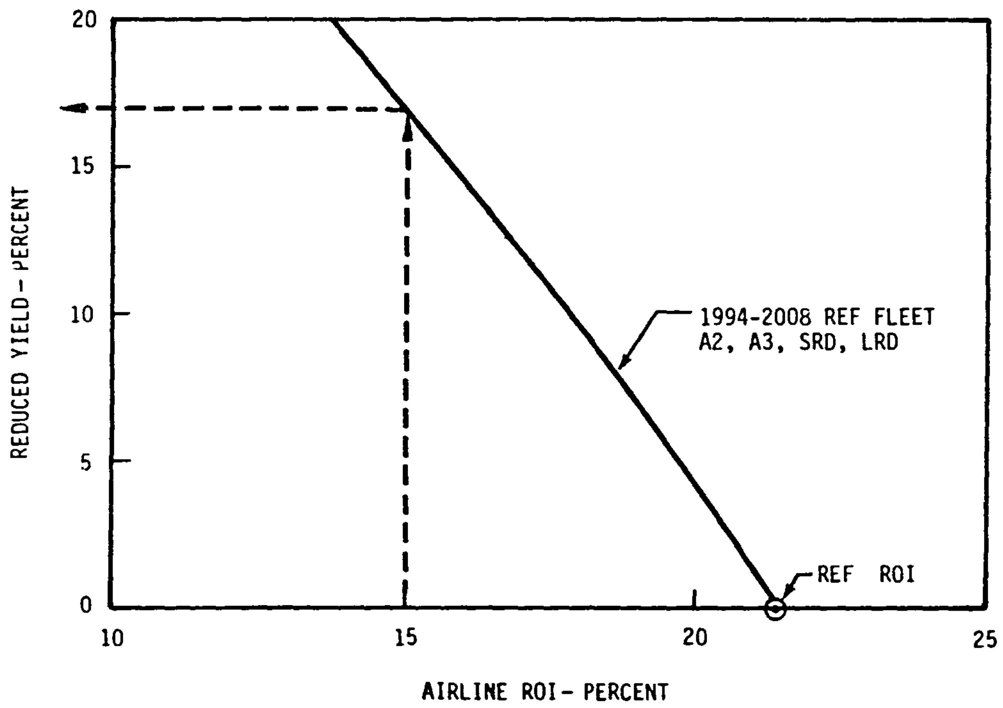


FIGURE S-9. IMPACT OF REDUCED YIELD ON AIRLINE ROI

If the airlines were willing to accept a 15 percent ROI, the yield would be reduced 17 percent. If we assume this reduction is affected over a 10 year period it could provide an average annual reduction in tariffs of about 1.6 percent. Based upon the elasticity of demand noted in Section 1, such tariff reduction could result in about a 2 percent additional average annual growth in market demand.

Conclusions

Under the conditions set forth in this study regarding market demand and system variables, it was concluded that derivatives of current wide body aircraft utilizing 1980 technology are clearly attractive to meet the post-1984 air cargo market demand. However, new dedicated freighters utilizing 1990 technology and produced by two manufacturers are not as clearly attractive when competing against this derivative fleet in the post-1994 period unless certain economic factors, such as military participation in RD and T are considered. Three advanced technology long range aircraft configurations (conventional turbofan, Spanloader, and conventional Mach 0.7 propfan) show sufficient promise to dictate further consideration. The key sequential findings leading to this conclusion are briefly summarized below and segregated under the four time periods considered pertinent to understanding future development of the air cargo system.

Historical. -

- Jet aircraft have paced the development of, and currently dominate, air cargo operations with the nonjets being relegated to shorter range feeder type operations.

Current aircraft fleet. -

- Due to demand growth in the shorter range markets, the small, narrow body aircraft will be replaced by the large narrow bodies which in turn will begin to be replaced by the wide body types in the Mid-80's. The number of wide body aircraft will increase to about 95 units by 1985.

- Although the larger payload aircraft will increase in number, the fleet departure frequency will continue to increase at an average annual growth rate of about 7 percent.

1985 derivative aircraft. -

- 1980 technology developments provided a 20 percent reduction in trip cost and a 15 percent reduction in the price of an aircraft comparable to a current wide body with a payload of 94.7 tonne (104.5 ton).

- The SRD/LRD combination was economically preferred giving a 4 percent increase in airline ROI and a 20 percent decrease in investment relative to the reference fleet. This performance makes the derivatives an attractive addition to the post-1985 airline fleets.

- Although the development of both the short and the long range derivative aircraft was economically preferred, there was very little penalty associated with developing only the medium range aircraft. Compared to the SRD/LRD combination, the 149.7 tonne (165 ton) MRD decreased the airline's ROI by less than one percent.

- Reducing the payload size of the preferred derivative aircraft by about 40 percent, from 149.7 to 91 tonne (165 to 100 tons), reduced the airline's ROI by only one percent.

- The combined number of the preferred 149.7 tonne (165 ton) payload, SRD and LRD aircraft would increase to about 250 units by 1994; however, the current wide bodies would remain competitive but over progressively decreasing operating ranges reaching a maximum of about 150 units in 1986.

- Considering the number of wide body aircraft currently in the market it is quite likely that more than one of these manufacturers will offer future derivatives modified for cargo operations.

- Based upon a 200 unit breakeven point and a 1994 demand for 250, 149.7 tonne (165 ton) payload derivative cargo aircraft, manufacturers would be reluctant to initiate the development of a new dedicated freighter aircraft to be operational in 1995 unless additional units had been sold for passenger and/or military use. However, it is expected that these additional passenger units will be sold.

- The 149.7 tonne (165 ton) payload aircraft would have span, length, height, and gear tread dimensions very near the limiting values established by existing airport regulations. Larger aircraft would create noticeable airport interface problems.

- The 149.7 tonne (165 ton) payload aircraft resulted in a 4 percent increase in the average annual frequency growth rate.

<u>1995 dedicated aircraft.</u> - Under the supposition that the industry will not reverse its past practices, it was assumed that the dedicated freighter would not be modified for passenger operations. In view of the limited market for such dedicated aircraft the economic analysis was performed on the basis of providing the manufacturer or manufacturers with a 15 percent ROI. Without such assurance it is unlikely that a new dedicated freighter aircraft program would be undertaken. Furthermore, considering the characteristics of the future cargo market demand and the forecast situation of the aircraft industry, evaluations were performed for both one and two manufacturers per aircraft model.

Single manufacturer per aircraft:

- With 1990 technology the price of the 94.7 tonne (104 ton) dedicated freighter was 48 percent less than the comparable A3 reference aircraft when viewed in 1994 dollars.

- By assuming a 15 percent manufacturer ROI, the preferred aircraft payload size was greatly reduced, i. e., from 453.6 tonne (500 ton) to 68 tonne (75 ton) in the case of the ALR.

- On the basis that only one aircraft model is offered, either the ASR or the ALR competing with the reference fleet, the preferred sizes of these aircraft were determined to have payloads of 45.8 and 68 tonne (50 and 75 ton) respectively.

- Increasing the preferred payload size of either the short and long range aircraft by a factor of 2.2 decreased the airline ROI by less than one percent and resulted in fleet economics equal to or slightly better than the derivative aircraft fleet.

- The fleet economic performance of the 45.4 tonne (50 ton) ASR was marginal providing less than a one percent improvement in airline ROI over the reference fleet while the 68 tonne (75 ton) ALR improved the airline ROI by nearly 4 percent.

- Fleet economics pointed out the desirability of the long range dedicated freighter in meeting the 1994-2008 cargo market demand thereby underscoring the low probability of only the short range aircraft being developed.

- Considering the number of ASR or ALR units required, it appeared quite probable that both aircraft would be developed by separate manufacturers and hence would be simultaneously competing against the reference fleet and with each other.

- The 45.4/68 tonne (50/75 ton) ASR/ALR combination provided a 2 percent improvement in airline ROI and a 7 percent decrease in investment compared to the reference fleet. However, this combination gave only half the improvement in airline ROI of the ALR alone and required a 13 percent greater investment. The combined number of ASR/ALR units reached 1572 by 2008.

- Both the ASR/ALR combination and the 68 tonne (75 ton) ALR alone were accompanied by substantial increases in the annual growth rate of operational frequency, nearly twice the rate developed by the reference fleet. This behavior was considered a disadvantage that could conflict with projected airport capacities and/or prevent the decrease in airline indirect operating cost to the forecast level of 30 percent of the total revenue.

Dual manufacturers per aircraft:

- Going from one to two manufacturers increased the cost of the 94.7 tonne (104 ton) size aircraft 34 percent. Such increases at all payload sizes substantially degraded fleet economics.

- Production by two manufacturers of the 68 tonne (75 ton) ALR aircraft reduced the airline ROI by 2.8 percent and increased the investment by 19 percent. Whereas with one manufacturer this ALR showed significant improvement (+4 percent in airline ROI) over the reference fleet, with two manufacturers it was marginal (less than a 1 percent increase in airline ROI).

- Parametric evaluation of the payload/operational frequency relationship showed that an ALR with a payload of 149.7 tonne (165 ton) would reduce the annual frequency growth rate to the 6.7 percent of the reference fleet. This size aircraft when produced by two manufacturers was designated the ALR_2. 573 of these aircraft would be required by 2008.

- The economic penalty associated with increased payload was greater when two manufacturers were involved.

- Increasing the payload from 68 tonnes to the 149.7 tonnes of the ALR_2 (75 to 165 tons) decreased the airline ROI by 1.3 percent and increased the investment by 12 percnet.

- With a 9 percent increase in investment and a slight decrease, less than 1 percent, in airline ROI over the reference fleet the ALR_2 with two manufacturers is borderline and would provide little economic incentive for the manufacturers to develop or the airlines to purchase this size dedicated freighter

- The combined effects of the cargo market demand, airport and/or airways flow control, and the world energy situation, may be sufficient to overcome the low economic incentive of the ALR_2 especially if the program were wholly or partially subsidized.

- With either the ASR/ALR combination or with the ALR_2 aircraft, there was a small decrease in the number of SRD and LRD derivative aircraft in the post-2004 period accompanied by their gradual transfer to shorter range operations beginning in about 1996.

- During the period 1994 to 2008 fleet operations could be providing an airline ROI of over 21 percent. Reducing this value to 15 percent would be equivalent to an average annual tariff reduction of 1.6 percent over 10 years with a potential 2 percent additional average annual growth in market demand.

Reduced cargo market demand. -

- Under conditions of reduced cargo market demand, the derivative and dedicated aircraft would be less competitive against the current wide body aircraft.

- The consequences resulting from the changes in fleet economics due to reduced cargo market demand would be strongly affected by the airlines financial position at the time; however, it appears that the undesirable changes could be increased in severity with the presence of a new dedicated freighter in the fleet.

Military participation. -

- Military participation in the long range dedicated freighter aircraft program, to the extent of 50 percent of RD and T costs and 25 percent of the U.S. commercial aircraft buy, makes a dramatic improvement in the economic attractiveness of the advanced dedicated freighter aircraft. Based upon two manufacturers, military participation increased airline ROI by about 5.5 percent and reduced investment by about 30 percent.

- The fleet economic advantages resulting from military participation would be reduced should military requirements be imposed that increase the weight and/or degrade the performance of the resulting dedicated commercial freighter aircraft.

- The large payload aircraft, greater than 149.7 tonne (165 ton) and less than 544.2 tonne (600 ton), made economically feasible by military perticipation, will be limited in size or restricted in operation by current and projected airport dimensional and noise certification requirements.

Aircraft configuration change. -

- Comparing the considered configurations on the basis of trip cost and aircraft price per unit payload pointed out the following trends:
  - The Spanloader had the highest and the laminar flow control, LFC, aircraft the lowest trip cost.
  - The large, long range conventional aircraft had the highest and the Spanloader the lowest aircraft price for the same payload.
  - The trip cost and aircraft price of the M=0.8 Propfan were higher and those for the M=0.7 Propfan lower than for a comparable conventional aircraft.
  - The LFC aircraft had a higher price but a lower trip cost than the conventional aircraft.

- Based upon fleet economics, the Spanloader was the most preferred, providing fleet economics about equal to those of the ASR/ALR combination. The next most preferred configuration was the M=0.7 Propfan, and finally the conventional 149.7 tonne (165 ton) payload aircraft, ALR_2. All these configurations provided ROI to the airlines that were essentially equal to or greater than the derivative aircraft.

- Three advanced technology configurations show potential and should be considered in further studies, however, each has drawbacks compared to the derivative aircraft. The ASR and ALR optimize at relatively low payloads, less than 68 tonnes (75 tons), resulting in large increases in operational frequency. The large Spanloader has obvious incompatibilities with current airport runways and taxiway widths. The Mach=0.7 Propfan has cruise speed imcompatibilities with airway and airport flow control plus decreased passenger commonality.

In summary. - This study has shown that bigger is not necessarily better and lower trip costs are not a sufficient basis upon which to select a preferred new freighter aircraft size or configuration. Of equal or more importance are the system operational and economic requirements. Those requirements are related to sytem frequency growth, airlines fleet economics, number of aircraft required, and the manufacturer's ROI. In addition, these requirements may be greatly inflenced by other external factors such as the number of competing manufacturers, military purchases of commercial aircraft, and subsidy of research and development.

To assure initiation of the dedicated freighter program the manufacturers must be expected to realize a reasonable return on their investment based upon the number of aircraft produced. When this objective is considered and the aircraft prices are based upon a specific manufacturer's ROI rather than on the normal breakeven approach, the trend with aircraft size is reversed and shows decreasing investment and increasing airline ROI with decreasing payload. Clearly, the manufacturer's ROI and number of units required are prime factors in establishing the desirability of an advanced dedicated freighter program.

Based upon a manufacturer's ROI of 15 percent, dual manufacturers, and maximizing the airline ROI, the following trends in fleet operations were identified. First, the derivative aircraft were larger than anticipated while the payloads of the dedicated aircraft were smaller than expected. Second, the 1994-2008 cargo market demand favored long range aircraft. Third, the economic advantage of the derivative aircraft was greater than that of the new dedicated freighter aircraft. Fourth, there was a definite tenacity on the part of the current A3 type aircraft and then the derivative aircraft to remain in the fleet in competition with the progressively improved new aircraft. Fifth, there was progressive relegation of the reference aircraft and then the derivative aircraft to shorter range applications as each new type aircraft was introduced.

Conclusions drawn from this study indicate that small payloads are economically more viable but pose operational problems such as large frequency increases. On the other hand, large payloads offer operational advantages, lower frequency growth, but at an economic penalty to the airline in spite of their reduced trip cost. These relationships prevented the clear cut definition of requirements for a 1995 dedicated freighter aircraft. The preferred size of the future dedicated freighter will be determined by a set of selected criteria in addition to the design range. While affecting factors have been identified, the selection process has yet to occur as illustrated below for the conventional configuration.

PAYLOAD SIZE SELECTION CRITERIA

Preferred Payload - Tonne (Ton)	Criteria Assumed: two manufacturers each realizing a 15 percent ROI
181.4 (200)	Minimum trip cost
68.0 (75)	Maximum airline ROI
90.7 to 149.7 (100 to 165)	Maintain operational frequency at reasonable level Maintain compatibility with current airport dimensional requirements Achieve an airline ROI ≥ that for the derivative aircraft
149.7 to 544.2(165 to 600)	Military participation: at least 50 percent of RD&T plus a buy equivalent to 25 percent of U.S. commercial fleet Airline ROI ≥ that for the derivative aircraft Limited use of existing major airports
118 to ? (130 to ?)	Meet noise certification requirements (upper value is function of engine characteristics)

Further study. - There are several issues that will undoubtedly exert a strong influence on the preceding conclusions but which have not been adequately covered by the work reported upon in this report. Primary among these are:

- the effect of energy on aircraft size and fleet operations;
- the effect of noise certification requirements on aircraft size and fleet operations as affected by engine design;
- the effect of a new advanced technology passenger aircraft for the post-1994 period with subsequent modification to cargo operations; and
- restrictions on operational frequencies that may be imposed by future airport and/or airways utilization and limitations.

Investigations into the requirements for the future dedicated freighter aircraft should be continued to establish the tradeoffs between these interrelated energy, noise, frequency, and economic issues and the desired payload and resulting fleet economics.

Results of the configuration analysis showed that both the Spanloader and the M=0.7 Propfan 2 configurations have an economic advantage although they provide less fleet economic improvement than the small payload ASR/ALR combination or the derivatives. A portion of this deficiency may be due to these configurations not having been sized to maximize their fleet economic performance. In view of these results it is suggested that the Spanloader and Propfan 2 along with the ALR be the subject of further study, preferably as and integral part of the energy, noise, and frequency investigations outlined in the preceding paragraph.

Section 1

INDEPENDENT VARIABLES

Since the purpose of this effort is to investigate requirements for aircraft to become operational in the post 1990 time period the decision was made to consider the time interval extending to the year 2008. It was therefore necessary to extend the airfreight market forecast of Section 2, Volume 3 for a comparable time period. In developing these data, consideration was given to system induced growth as affected by the market/system cross-impacts investigated in Section 7 through 10 of Volume 3. The magnitude of the mail and express components of the cargo market were evaluated and, when viable, were included in the market forecast.

In addition to the airfreight market forecasts there are additional independent variables whose values must be established for input to the network simulation model. While a portion of these, such as fuel cost, are determined by external forces, reference Section 12, Volume 3, other of the variables, such as indirect operating cost, are also effected by conditions occurring within the airfreight systems as outlined in Section 3 of Volume 3. Applying, for the most part qualitatively, appropriate forcing influences; values for the respective independent variables were derived for the period out to 2008.

Baseline Market Forecast

The airfreight market forecast used in these analysis is an extension of the 1990 forecast contained in Tables 2-3 through 2-10 presented in Section 2 of Volume 3 for the Baseline Scenario 2. These basic values are as determined by the predominating impact of GNP growth in combination with the change in intermodel competitiveness due to price differentials and are uneffected by system induced growth factors. It must also be noted that these values are for freight only and do not include either mail or express.

Airfreight growth to 2008. - As a forecast is extended into the future the confidence in the data for each additional year decreases. This concern is amplified by the fact that in order to forecast a given parameter it is necessary to also forecast the affecting forcing functions. In the case of airfreight the primary forcing function is the GNP of the United States and of the countries with which it trades. To attempt to forecast these values for 30 years, to 2008, would be no better than a considered guess. Therefore, rather than continuing the regression analysis employed out to 1990, Section 2, Volume 3, the forecast was extended using least squares fitting techniques. The following equation generated the best fit for the traffic levels previously generated for the 1977 to 1990 forecast. The resulting values

$$Y = a + bx + cx^2$$

WHERE:

Y = freight traffic in TKM's

x = time (1, 2, 3,....n)

a,c,b = estimated parameters

forecast for the years 1991 through 2010 are presented in Table 1-1 and in Figure 1-1 for the U.S. Domestic, U.S. International and Foreign markets respectively. The relative positioning of the three curves in Figure 1-1 illustrates the large potential of the Foreign market as compared to the U.S. Domestic and International markets. A large portion of the Foreign market is due to the anticipated increase in trade with developing and underdeveloped countries.

The data of Table 1-1 shows a steady decrease in yearly growth rates to the year 2010. This is to be expected because the air cargo system will have matured and the subsequent growth rates will tend toward the levels being experienced by the worlds total freight movement.

Mail and express forecast. - Using data from the CAB, IATA and ATA, an analysis was made to determine the importance of mail and express to the future airfreight system. Results indicated that the quantity of express is essentially negligible amounting to less than four percent domestically and less than one percent for U.S. international operations between the years

TABLE 1-1

SCHEDULED AIRFREIGHT MARKET FORECAST

Year	Baseline Scenario 2								
	U.S. Scheduled Domestic			U.S. Scheduled International			Foreign Scheduled Top 44 Airlines		
	RTKM x 10^6	(*RTSM x 10^6)	Percent Change	RTKM x 10^6	(*RTSM x 10^6)	Percent Change	RTKM x 10^6	(*RTSM x 10^6)	Percent Change
Ref.	Table 2-8 Vol. III		Table 2-8 Vol. III	Table 2-9 Vol. III		Table 2-9 Vol. III	Table 2-10 Vol. III		Table 2-10 Vol. III
1990	15 081.0	(10 329.5)	10.3	9 703.1	(6 646.0)	8.5	60 136.3	(41 189.2)	13.0
1991	16 410.6	(11 240.1)	8.8	10 444.6	(7 153.8)	7.6	66 791.2	(45 747.4)	11.1
1992	17 818.4	(17 818.4)	8.6	11 223.1	(7 687.1)	7.5	73 860.6	(50 589.5)	10.6
1993	19 304.3	(13 222.1)	8.3	12 038.5	(8 245.5)	7.3	81 344.4	(55 715.3)	10.1
1994	20 868.3	(14 293.4)	8.1	12 890.8	(8 829.3)	7.1	89 242.8	(61 125.2)	9.7
1995	22 510.5	(15 418.2)	7.9	13 780.0	(9 438.4)	6.9	97 555.6	(66 818.9)	9.3
1996	24 230.8	(16 596.4)	7.6	14 706.2	(10 072.7)	6.7	106 282.8	(72 796.4)	8.9
1197	26 029.3	(17 828.3)	7.4	15 669.2	(10 732.3)	6.5	115 424.6	(79 057.9)	8.6
1998	27 905.9	(19 113.6)	7.2	16 669.2	(11 417.3)	6.4	124,980.8	(85 603.3)	8.3
1999	29 860.7	(20 452.5)	7.0	17 706.1	(12 127.5)	6.2	134 951.5	(92 432.5)	8.0
2000	31 893.6	(21 844.9)	6.8	18 780.0	(12 863.0)	6.1	145 336.6	(99 545.6)	7.7
2001	34 004.7	(23 290.8)	6.6	19 890.7	(13 623.8)	5.9	156 136.2	(106 942.6)	7.4
2002	36 193.9	(24 790.3)	6.4	21 038.4	(14 409.9)	5.8	167 350.3	(114 623.6)	7.2
2003	38 461.2	(26 343.3)	6.3	22 223.0	(15 221.2)	5.6	178 978.9	(122 588.3)	6.9
2004	40 806.7	(27 949.8)	6.1	23 444.5	(16 057.9)	5.5	191 022.0	(130 836.9)	6.7
2005	43 230.4	(29 609.9)	5.9	24 703.0	(16 919.9)	5.4	203 479.5	(139 369.5)	6.5
2006	45 732.1	(31 323.4)	5.8	25 998.3	(17 807.1)	5.2	216 351.4	(148 186.9)	6.3
2006	48 312.1	(33 090.5)	5.6	27 330.6	(18 719.6)	5.1	229 637.9	(157 286.2)	6.1
2008	50 970.1	(34 911.0)	5.5	28 699.8	(19 657.4)	5.0	243 338.8	(166 670.4)	6.0
2009	53 706.4	(36 785.2)	5.4	30 106.0	(20 620.5)	4.9	257.454.2	(176 338.5)	5.8
2010	56 520.7	(38 712.8)	5.2	31 549.0	(21 608.9)	4.8	271 984.1	(186 290.4)	5.6

*RTSM - Revenue Short Ton (2000 pounds) - Statute Miles

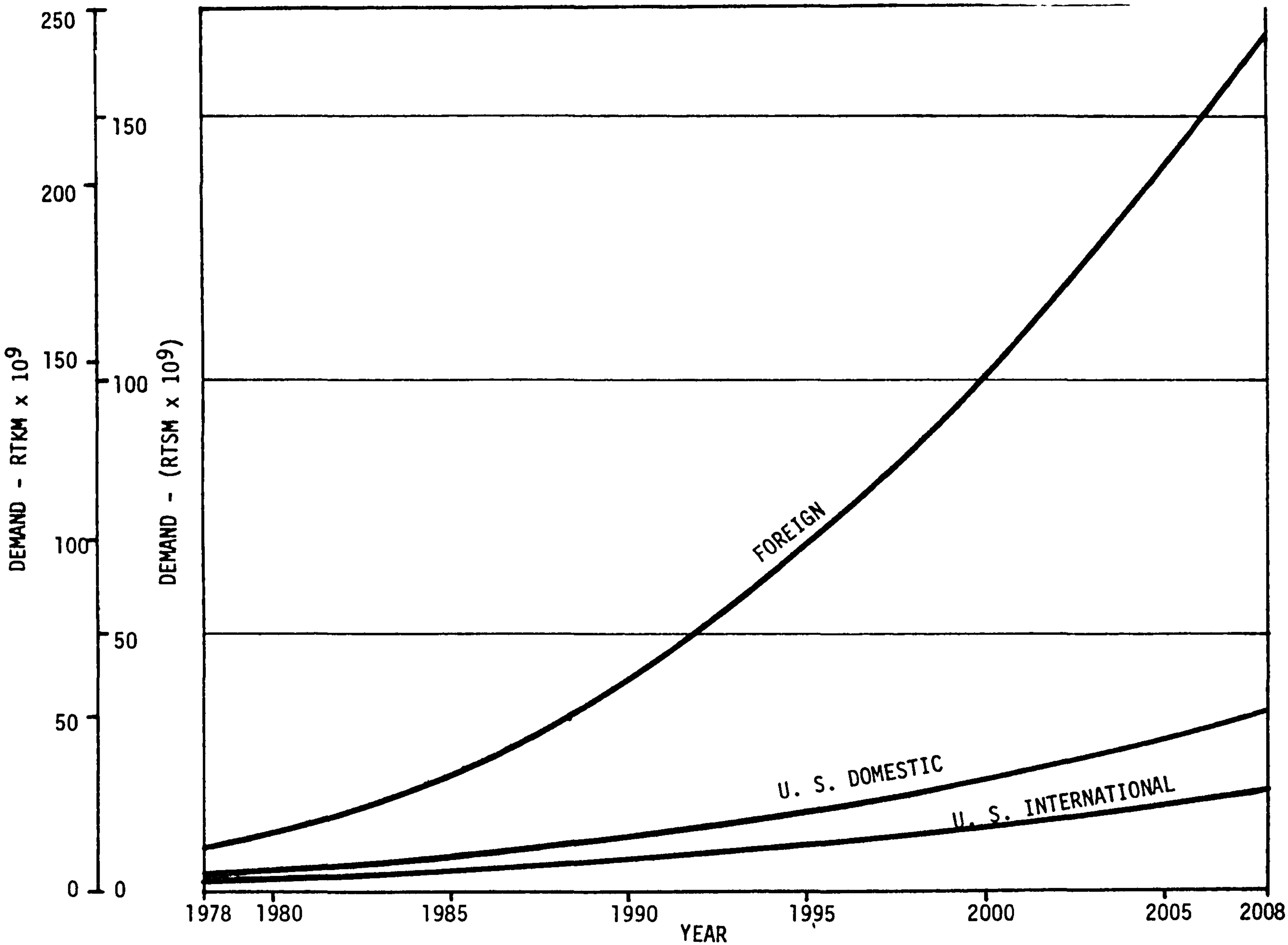


Figure 1-1 Scheduled Air Freight Market Forecast

1971 and 1977. Specifically, the volume of domestic express was equivalent to 3.7 percent of airfreight in 1971 and dropped to 1.3 percent in 1977. Based upon these findings and the fact that the volumes handled by operators such as Federal Express are included in the basic airfreight forecast, the decision was made to ignore this component of air express.

Mail as a percent of airfreight is presented in Figure 1-2 and shows a steady decline of airmail movement in U.S. International operations reaching a 17 percent level in 1977. On the other hand the domestic level has leveled off at about 25 percent. Since these data reflect the combined changes experienced by both mail and freight they do not give a clear picture of the mail segment.

Figures 1-3 and 1-4 show the behavior of airmail in terms of percent annual growth, and the corresponding levels of movement respectively. The annual growth in airmail has been pretty erratic, undoubtedly affected by perturbations such as the recession and the Viet Nam war. On the other hand the levels of airmail movement appear to present a much clearer picture showing a steady drop off in international movement to 600×10^6 tonne - kilometers (410×10^6TSM) in 1977. The level of domestic movement remained about constant between 1971 and 1975 then increased to 1100×10^6 tonne - kilometers (750×10^6TSM) in 1977. The increase between 1975 and 1977 is quite probably due to the Postal Department policy of shipping all first class mail by air.

Considering the scope and nature of these data no attempt was made to apply mathematical techniques to this problem of forecasting future mail movement. Rather, future values were derived through value judgement considering past behavior in combination with potential effecting events outlined in Section 12, Volume 3. An illustrative example of the latter is the anticipated increased utilization of electronic communication in place of the written word. The resulting forecast presents a zero average annual growth rates with the levels of movement averaging out at

U.S. Domestic: 1100×10^6 TKM (750×10^6TSM)

U.S. International: 600×10^6 TKM (410×10^6TSM)

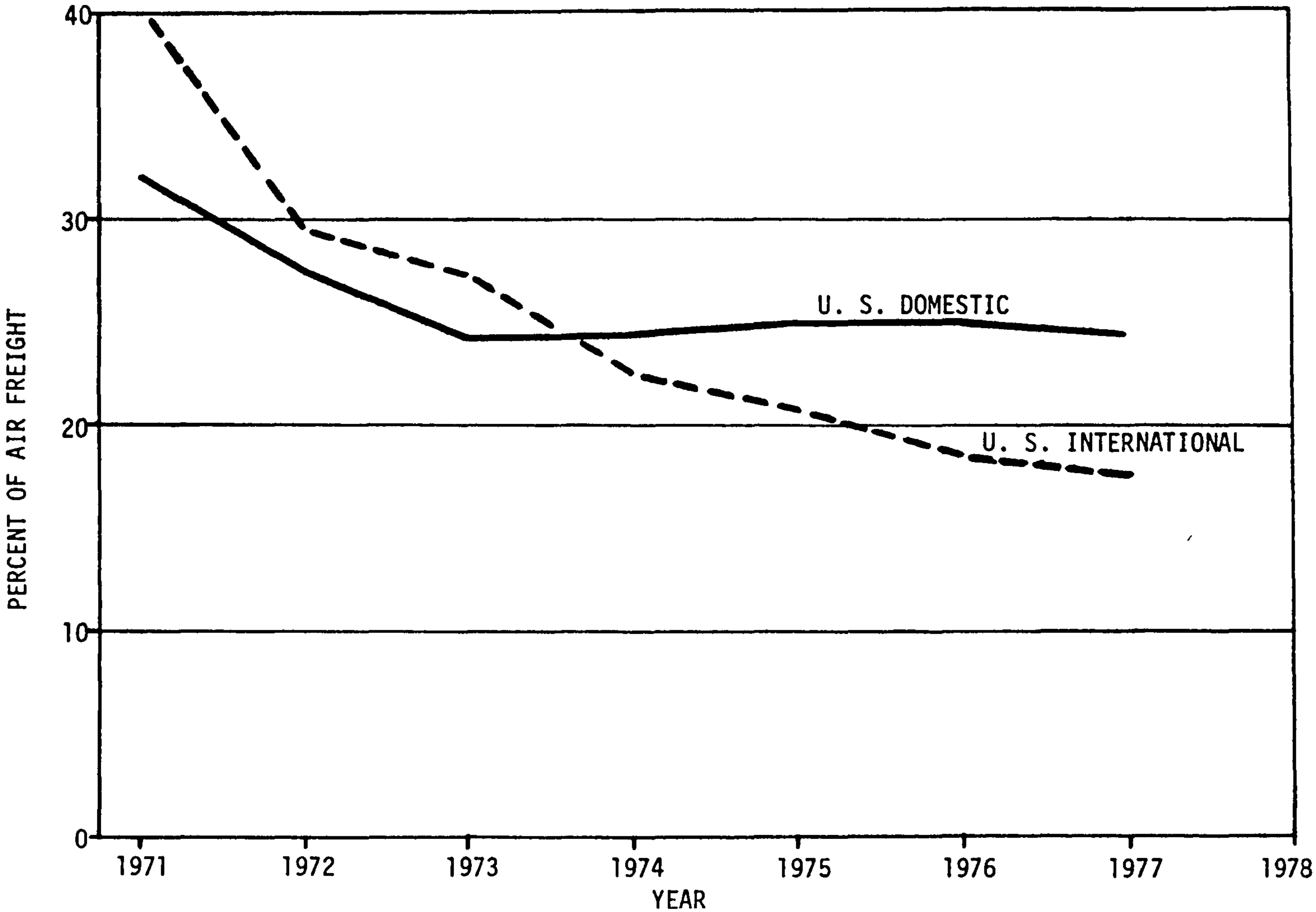


Figure 1-2 Mail Moved by Scheduled Air

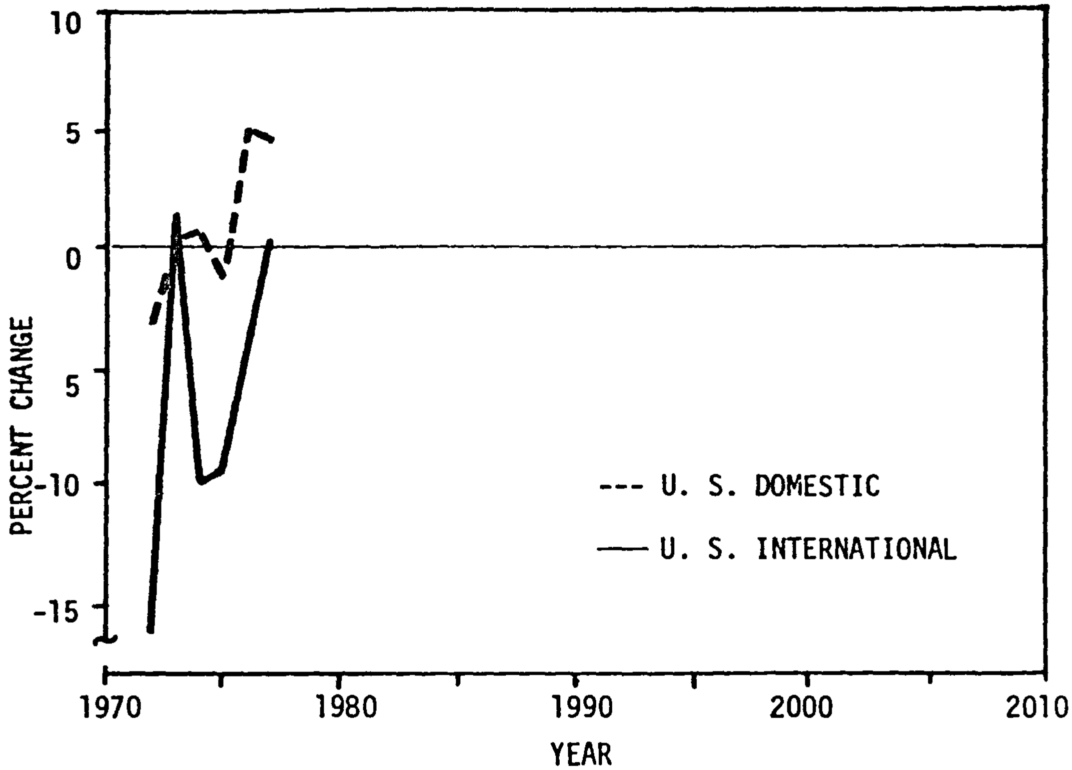


Figure 1-3 Annual Growth in Air Mail

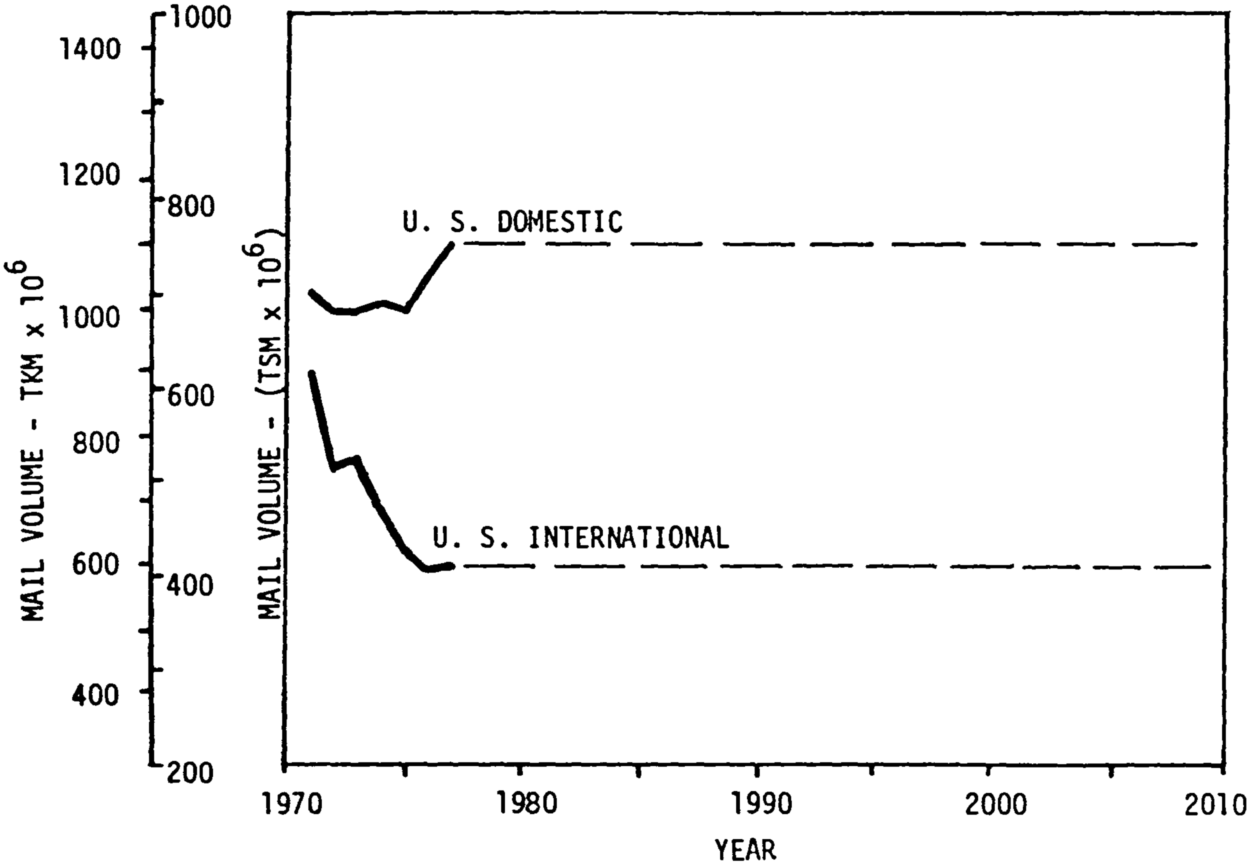


Figure 1-4. Forecast Mail Moved by Scheduled Air

In the absence of adequate data on Foreign airmail movements a forecast was developed based upon an assumed similarity between Foreign and U.S. International activity. The 17 percent for U.S. International airmail shown in Figure 1-2 was applied to the 1977 Foreign airfreight movement of 10 689x10^6 tonne-kilometers (7321x10^6TSM), reference Table 2-10, Volume 3, to give a forecast value for airmail of

Foreign: 1820 x 10^6 TKM (1246x10^6TSM)

The preceding values of airmail movement for the Domestic, International and Foreign market were applied over the years 1978 through 2008. In developing the market forecast it was assumed that all airmail will be handled by all-cargo aircraft and that the above levels of movement will not be affected by the system induced growth factors. In other words the anticipated improvements in service and reductions in cost will not effect the quantity of mail moving by air.

System Induced Market Growth

During the initial CLASS effort,investigations were conducted to define the magnitude of the tariff reductions that could be expected from future system developments and to determine the nature of cost and service elasticities, reference Section 2-10 and 2-7 of Volume 3 respectively. Results of these analysis were utilized to incorporate system induced growth in the all-cargo market forecast. For convenience the data pertinent to these calculations are presented in Tables 1-2 and 1-3. The former presents the tariff reductions realized from the specific system changes identified while the latter table provides the means for converting these reductions into comparable market growth. Table 1-3 also defines the magnitude of the market growth that can be expected from two types of service improvement. Discussions of the respective induced market growth factors are considered under the general headings of cost and service.

TABLE 1-2

POTENTIAL FLEET TARIFF REDUCTIONS

System Changes	Percent
Increased Load Factor	4
Increased Airline Profit	-4
Economies of Scale, Growing Market	6
90-Percent Shipper Packed Container	9
Improved Terminal Technology	2
Emphasis on Aircraft/Airport Compatibility	1
Increased Aircraft Size and Improved Technology	3-6
Total....................................	21-24

TABLE 1-3

ELASTICITIES OF DEMAND

System Change	Increase Market Demand Percent
Cost	
Reducing Air Cargo Tariffs 10%	13
Service	
Reducing Delivery Time 10%	3
Increasing Cities Served 10%	1-1/2

Cost induced. - It should be noted that, with the exception of the new aircraft and to some extend aircraft/airport compatability, all the identified changes, and hence the associated tariff reductions, Table 1-2, could be realized with todays technology. However, none of these changes can be implemented overnight but will require intervals of time that are highly dependent upon the scope and depth of the infrastructural modifications that must be accomplished. These periods of implementation were defined purely on the basis of value judgement by identifying the year in which the change could be expected to be fully achieved and the associated tariff reduction implemented. An average yearly increase was applied over the intervining time period between initiation and achievement.

Aircraft load factor/increased airline profit: Increasing the aircraft load factor from the present 55-60 to 70 percent could provide a four percent reduction in tariffs. As seen from Table 1-2 this reduction is equivalent to the tariff increase required to increase profit before taxes by five percent. For simplicity the improved load factor can therefore be viewed as the source for this profit increase with a resulting negligible effect on the market. The period over which this will occur extends from 1978 to 1995 during which time the average fleet aircraft load factor will increase from present values to 70 percent.

Based upon the estimated market, Table 1-1 and the available fleet capacity, Reference 1-1, the current aircraft load factors were determined to be 57.6, 60.3 and 54.1 percent for the U.S. Domestic, U.S. International and Foreign fleets respectively. Due to the effects of deregulation, and the subsequent settling out process, the domestic aircraft load factors are expected to show the slowest rate of improvement between now and 1985 when compared to the international and foreign values. It is estimated that the domestic factor will increase from the current 57.6 percent to 60 percent by 1985 and 70 percent by 1995. Due to the slightly higher value, 60.3 percent, for the U.S. International aircraft in 1978 and the inherent incentives encompassed by long range operations, the international load factors should increase to 70 percent by 1985.

Due to the level of operations at ranges less than about 4800 kilometers (3000 statute miles), it was estimated that improvements in the foreign aircraft load factors will be similar to the U.S. Domestic reaching values of 60 percent by 1985 and 70 percent by 1995. The more rapid improvement of the foreign load factor, 5.9 percent compared to the 2.3 percent for domestic prior to 1985 is attributed to the absence of deregulatory perturbations at the short ranges combined with the incentives associated with long range operations.

Economy of scale: The economies of scale reported upon in Volume 3 considered in the light of the basic airfreight market growths to 1990, Section 2, Volume 3, are estimated to provide the six percent reduction in tariff shown in Table 1-2. Utilizing the data of Table 1-3 this translates into an additional 7.8 percent market growth for the year 1990 building up at a compound annual growth of about 0.63 percent during the period 1978 to 1990. This induced growth, due to the economics of scale, was applied to the U.S. Domestic, U.S. International and Foreign markets. As an illustration, applying this growth to the basic U.S. Domestic forecast of Table 2-8, Volume 3, gives the following values for the example years noted.

Basic Forecast Ref: Table 2-8, Vol 3				Economics of Scale Induced Growth Forecast		
Year	$RTKMx10^6$	$(RTSMx10^6)$	Annual Percent Change	Percent Change	$RTKMx10^6$	$(RTSMx10^6)$
1979	5 751.2	(3 939.2)	9.8	+0.63=10.43	5 783.8	(3 961.5)
1985	9 364.3	(6 413.9)	9.4	+0.63=10.03	9 749.9	(6 678.0)
1990	15 081.0	(10 329.5)	10.3	+0.63=10.93	16 257.3	(11 135.1)

Following the full impact on the market in 1990 the average annual growth continues at the basic rates given in Tables 1-1 for subsequent years. It is felt that beyond 1990 the major portion of the impact of economics of scale will be reflected in the DOC as effected by aircraft size and utilization.

Shipper loaded containers: With current trends continuing it is reasonable to believe that by 1990 the industry could realize 90 percent shipper loaded containers. This, as discussed in Volume 3, translates into a nine percent reduction in tariffs. As seen in Table 1-2 this is the most important source for tariff reduction and when realized can stimulate an additional 11.7 percent in market growth, reference Table 1-3, by 1990. It will take the 12 years 1985 to 1990 for this system change to mature at a compound annual growth rate of about 0.93 percent. This rate was applied to all three markets, Domestic, International and Foreign in the manner outlined above.

Improved terminal technology: The terminal analysis reported in Section 3 of Volume 3 showed a substantial reduction in equipment and personnel costs for ULD handled if shippers would load the containers, import storage were reduced, and effective vertical storage techniques were applied. Reduced import storage time is a service item which in itself could reduce market growth and will be specifically discussed later in this section. Savings realized from such improvements in terminal equipment and operations could reduce the indirect operating cost by six percent, resulting in a possible two percent reduction in tariffs, Table 1-2. The terminal surveys indicated that it is reasonable to assume that these changes can be realized by 1990 with an accompanying induced market growth of 2.6 percent. In fact such changes must be achieved in order to avoid terminal saturation during the intervening time period. This impact due to terminal improvement was therefore applied between 1978 and 1990 at an annual compound growth rate of 0.21 percent to the Domestic, International and Foreign markets.

Aircraft/airport compatibility: The last and least important to market growth are the improvements in aircraft/airport compatibility discussed in Section 3, Volume 3. An analysis of the associated reductions in indirect operating cost in Section 10, Volume 3, defined the accompanying one percent reduction in tariffs shown in Table 1-2. Once again qualitative evaluation of the existing airport situations indicated that the period to 1990 would be adequate to make the necessary changes. The data of Table 1-3 indicates that this could result in an additional 1.3 percent growth relative to the 1990 market. The comparable compound annual growth of about 0.11 percent was applied to all three markets.

Aircraft size and technology: The analysis of the new aircraft market reported in Section 11, Volume 3, indicates that it will be possible for a larger, advanced technology, cargo aircraft to enter the system during the post 1990 time period. It is the purpose of the analysis reported on herein to determine the size and other requirements of these new aircraft that are compatible with the forecast market. As these larger and more efficient aircraft enter the system they will begin carrying a proportional share of the air cargo thereby reducing fleet tariffs and stimulating additional market growth. In lieu of an iterative analysis of this aircraft/market cross-impact it was assumed that the advanced aircraft would capture 45 percent of the available capacity by the year 2008. Depending upon the reduction in direct operating cost realized, 13 to 23 percent as reported in Section 10 of Volume 3, the resulting reduction in tariffs would range between three and six percent as shown in Table 1-2. For the purpose of the market analysis a mean value of 4.5 percent tariff reduction was chosen. Using the data of Table 1-3 this corresponds to a stimulated market growth of 5.8 percent to be realized in the year 2008. The corresponding compound growth rate of about 0.32 percent was applied to all three markets over the years 1991 through 2008. This approach provides a gradual increase in market stimulation as more and more of the new aircraft enter the system with a corresponding ever increasing influence on system operations and market growth.

Service induced. - Results of the Case Studies, reported in Volume 2, point out the importance of service to the air cargo user and hence to the importance of service as a catalyst in cargo market growth. Two of the more important types of service improvements were considered as a source of market stimulation in analyzing the entire induced growth namely, the number of cities served and delivery time. Both these items appeared high on the list of air cargo user desires.

Cities served: A qualitative judgement reported in Volume 3 states that the domestic deregulation can be expected to increase the number of cities served by 15 percent. This change will not occur overnight but will be a gradual process as current operators grow and new operations of air cargo enter the market. It is expected that the accompanying settling out process will take five to seven years with the full 15 percent being realized about 1985. The data of Table 1-3 shows a comparable induced market growth of 2.3 percent. The corresponding compound growth rate of 0.33 percent was applied for the years 1979 through 1985 to the U.S. Domestic and International markets. The induced growth in the International market being attributed to the fact that the new domestic cities will be provided access to international operations.

Terminal storage: A key advantage of air cargo is the reduced transport time relative to other modes. While there is a place for improvement in domestic operations the areas of deficiency are not as evident as in the case of import storage time enherent in International operations both U. S. and Foreign. An origin to destination delivery time of five days was considered as the representative case upon which to base an estimate of the impact of reduced storage time on market growth. Included in these five days are three days of storage time which is the considered average for a major portion of international operations. Reducing this storage time to 1 1/2 days as discussed in Section 3, Volume 3, would represent a 30 percent reduction in delivery time. Turning to Table 1-3 shows a corresponding potential market growth for the U.S. International and Foreign markets of nine percent. Due to existing international institutional barriers to achieving this change it is anticipated that it will take until 1990 before full implementation will be realized. During the interium this improvement in service will gradually be achieved over an increasing number of routes resulting in an associated induced compound annual growth rate of 0.72 percent for the U.S. International and Foreign markets.

All-cargo aircraft market share. - Civil Aeronautics Board data provided on Form 242 along with IATA and ATA indicated current market shares of 40, 65 and 40 percent for the U.S. Domestic, U.S. International and Foreign markets respectively. These values were for the years 1976 and 1977 and will be presumed to hold for 1978. As we proceed into the future a larger percentage of the air cargo market will be carried by all-cargo aircraft. The actual increase will depend upon the particular market. As an example, the domestic all-cargo operations will increase due to an influx of new operators providing special services, as in the case of Federal Express, and an expansion of routes and cities served by current all-cargo operators such as Flying Tiger. However, it will take a period of adjustment resulting in a conservative five percent increase, from the current 40 percent to 45 percent, by 1985. The maximum rate of increase will occur over the succeeding five years to 50 percent level in 1990 followed by a lower increase to a value of 55 percent in all-cargo aircraft by the year 2000. A liner increase was utilized during the specific periods noted.

The largest capture by all-cargo aircraft is visualized to occur in the U.S. International market where the level will increase from the current 65 percent to 70 percent by 1985. There are two basic reasons why this change will occur, first, increasing trade with developing regions of the world as outlined in Section 12 of Volume 3. Second, the increasing quantities of baggage being carried by international travelers. The fare reductions that have occured are drawing from new markets that encompass travelers who are more apt to purchase and carry sizeable amounts of commodities and personal belongings. The resulting loss, even elimination, of belly space for air cargo is occurring with ever increasing frequency on international flights. This behavior is expected to continue, even increase should the industry see further reductions in fares.

The all-cargo share of the Foreign market will behave similar to the U.S. Domestic out to the year 1990 increasing from the current 40 percent share today to 45 percent in 1985 and 50 percent in 1990. Due to the international portion of this market the post 1990 period will see additional growth in share to 55 percent of the market in 1995 and to 60 percent in the year 2000. As for U.S. International this growth will result from the growing trade with developing regions combined with the changing behavior of the travelers attracted by fares. The expected trend to electronic communication in the place of travel will tend to reduce the business portion of the passenger market. This segment of the traveling public tends to lower the average baggage load per passenger.

If the preceeding changes in all-cargo market shares are viewed in the perspective of the total market, Domestic, International and Foreign combined, the overall change in share that occurs to the year 2000 appears compatible with the gross system and market developments discussed in Volume 3. Based upon the forecast scheduled airfreight markets, reference Tables 2-8 through 2-10, Volume 3, the weighted all-cargo aircraft share for 1978 is 44 percent. Using the data of Table 1-1 gives a comparable weighted average share for the combined markets of 60 percent for the year 2000. The 16 percent increase so demonstrated appears as a viable change over the 22 year period.

Induced airfreight market share. - The preceding system induced growth factors combined with the computed mail volume and the all-cargo aircraft shares provided the basis for deriving the induced airfreight market forecast for all-cargo aircraft. This was accomplished by combining, over applicable years, the induced growth factors with the annual growth percent changes given in Tables 2-8 through 2-10 of Volume 3 and Table 1-1. The all-cargo market share was then derived based upon the resulting revenue tonne-kilometers (revenue ton-miles). Finally the mail increments were added and a new annual change schedule computed. The resultant all-cargo aircraft share of the system induced airfreight market is presented in Table 1-4 in terms of quantities moved and the associated schedule of annual percentage change. The relative size of the respective markets is evident from the plotted data in Figure 1-5.

Comparing the system affected data of Table 1-4 with the basic market forecast of Tables 2-8 through 2-10 of Volume 3 and Table 1-1, shows very

TABLE 1-4

AIRFREIGHT MARKET FORECAST FOR ALL-CARGO AIRCRAFT

WITH

SYSTEM INDUCED GROWTH

METRIC

Year	Baseline Scenario 2					
	U.S. Scheduled Domestic		U.S. Scheduled International		Foreign Scheduled Top 44 Airlines	
	RTKM 10^6	Percent Change	RTKM x 10^6	Percent Change	RTKM x 10^6	Percent Change
1978	3 195.0	-	2 981.7	-	6 836.0	-
1979	3 477.8	8.9	3 314.5	11.2	7 711.9	12.8
1980	3 735.8	7.4	3 641.5	9.9	8 840.9	14.6
1981	4 045.5	8.3	4 004.7	10.0	10 256.1	16.0
1982	4 411.9	9.1	4 407.7	10.1	11 937.8	16.4
1983	4 829.8	9.5	4 878.0	10.7	13 919.5	16.6
1984	5 363.1	11.0	5 436.4	11.3	16 231.9	16.6
1985	5 970.1	11.3	6 060.2	11.6	19 021.5	17.2
1986	6 655.8	11.5	6 671.7	10.0	22 253.0	17.0
1987	7 446.4	11.9	7 357.9	10.3	25 975.4	16.7
1988	8 365.7	12.3	8 114.8	10.3	30 363.0	16.9
1989	9 414.5	12.5	8 956.4	10.4	35 532.8	17.0
1990	10 627.7	12.9	9 892.3	10.4	41 622.3	17.1
1991	11 598.6	9.1	10 626.4	7.4	47 046.9	13.0
1992	12 646.2	9.0	11 408.5	7.4	52 960.5	12.6
1993	13 762.2	8.8	12 230.6	7.2	59 365.2	12.1
1994	14 959.0	8.7	13 090.5	7.0	66 314.5	11.7
1995	16 239.6	8.6	13 989.8	6.9	73 815.3	11.3
1996	17 591.3	8.3	14 927.1	6.7	81.868.6	10.9
1997	19 028.7	8.2	15 901.4	6.5	90 549.9	10.6
1998	20 553.4	8.0	16 926.6	6.4	99 871.6	10.3
1999	22 166.4	7.8	17 987.8	6.3	109 841.0	10.0
2000	23 869.5	7.7	19 100.6	6.2	120 460.3	9.7
2001	25 440.6	6.6	20 247.7	6.0	129 595.9	7.6
2002	27 071.4	6.4	21 446.1	5.9	139 179.3	7.4
2003	28 785.5	6.3	22 676.0	5.7	149 069.4	7.1
2004	30 557.4	6.2	23 956.5	5.6	159 377.0	6.9
2005	32 383.7	6.0	25 287.8	5.5	170 091.1	6.7
2006	34 292.1	5.9	26 645.7	5.4	181 197.2	6.5
2007	36 250.4	5.7	28 052.1	5.3	192 677.5	6.3
2008	38 289.1	5.6	29 507.1	5.2	204 701.7	6.2

TABLE 1-4

AIRFREIGHT MARKET FORECAST FOR ALL-CARGO AIRCRAFT
WITH
SYSTEM INDUCED GROWTH
ENGLISH

Year	Baseline Scenario 2					
	U.S. Scheduled Domestic		U.S. Scheduled International		Foreign Scheduled Top 44 Airlines	
	(RTSM x 10^6)*	Percent Change	(RTSM x 10^6)*	Percent Change	(RTSM x 10^6)*	Percent Change
1978	(2 188.4)	-	(2 042.3)	-	(4 682.2)	-
1979	(2 382.1)	8.9	(2 270.2)	11.2	(5 282.1)	12.8
1980	(2 558.8)	7.4	(2 494.2)	9.9	(6 055.4)	14.6
1981	(2 770.9)	8.3	(2 742.9)	10.0	(7 024.7)	16.0
1982	(3 021.8)	9.1	(3 019.0)	10.1	(8 176.6)	16.4
1983	(3 308.1)	9.5	(3 341.1)	10.7	(9 533.9)	16.6
1984	(3 673.4)	11.0	(3 723.6)	11.3	(11 117.7)	16.6
1985	(4 089.1)	11.3	(4 150.8)	11.6	(13 028.4)	17.2
1986	(4 558.8)	11.5	(4 569.7)	10.0	(15 241.8)	17.0
1987	(5 100.3)	11.9	(5 039.7)	10.3	(17 791.4)	16.7
1988	(5 730.0)	12.3	(5 558.0)	10.3	(20 796.6)	16.9
1989	(6 448.3)	12.5	(6 134.5)	10.4	(24 337.5)	17.0
1990	(7 279.2)	12.9	(6 775.5)	10.4	(28 508.4)	17.1
1991	(7 944.2)	9.1	(7 278.4)	7.4	(32 223.9)	13.0
1192	(8 661.8)	9.0	(7 814.0)	7.4	(36 274.3)	12.6
1993	(9 426.2)	8.8	(8 377.1)	7.2	(40 661.1)	12.1
1994	(10 245.9)	8.7	(8 966.1)	7.0	(45 420.9)	11.7
1995	(11 123.0)	8.6	(9 582.1)	6.9	(50 558.4)	11.3
1996	(12 048.8)	8.3	(10 224.0)	6.7	(56 074.4)	10.9
1997	(13 033.4)	8.2	(10 891.4)	6.5	(62 020.5)	10.6
1998	(14 077.7)	8.0	(11 593.6)	6.4	(68 405.2)	10.3
1999	(15 182.5)	7.8	(12 320.4)	6.3	(75 233.6)	10.0
2000	(16 349.0)	7.7	(13 082.6)	6.2	(82 507.1)	9.7
2001	(17 425.1)	6.6	(13 868.3)	6.0	(88 764.3)	7.6
2002	(18 542.1)	6.4	(14 689.1)	5.9	(95 328.3)	7.4
2003	(19 716.1)	6.3	(15 531.5)	5.7	(102 102.3)	7.1
2004	(20 929.7)	6.2	(16 408.6)	5.6	(109 162.3)	6.9
2005	(22 180.6)	6.0	(17 320.4)	5.5	(116 500.8)	6.7
2006	(23 487.7)	5.9	(18 250.4)	5.4	(124 107.7)	6.5
2007	(24 829.0)	5.7	(19 213.8)	5.3	(131 970.9)	6.3
2008	(26 225.4)	5.6	(20 210.3)	5.2	(140 206.6)	6.2

*RTSM - Revenue Short Ton (2000 pounds) - Statute Miles

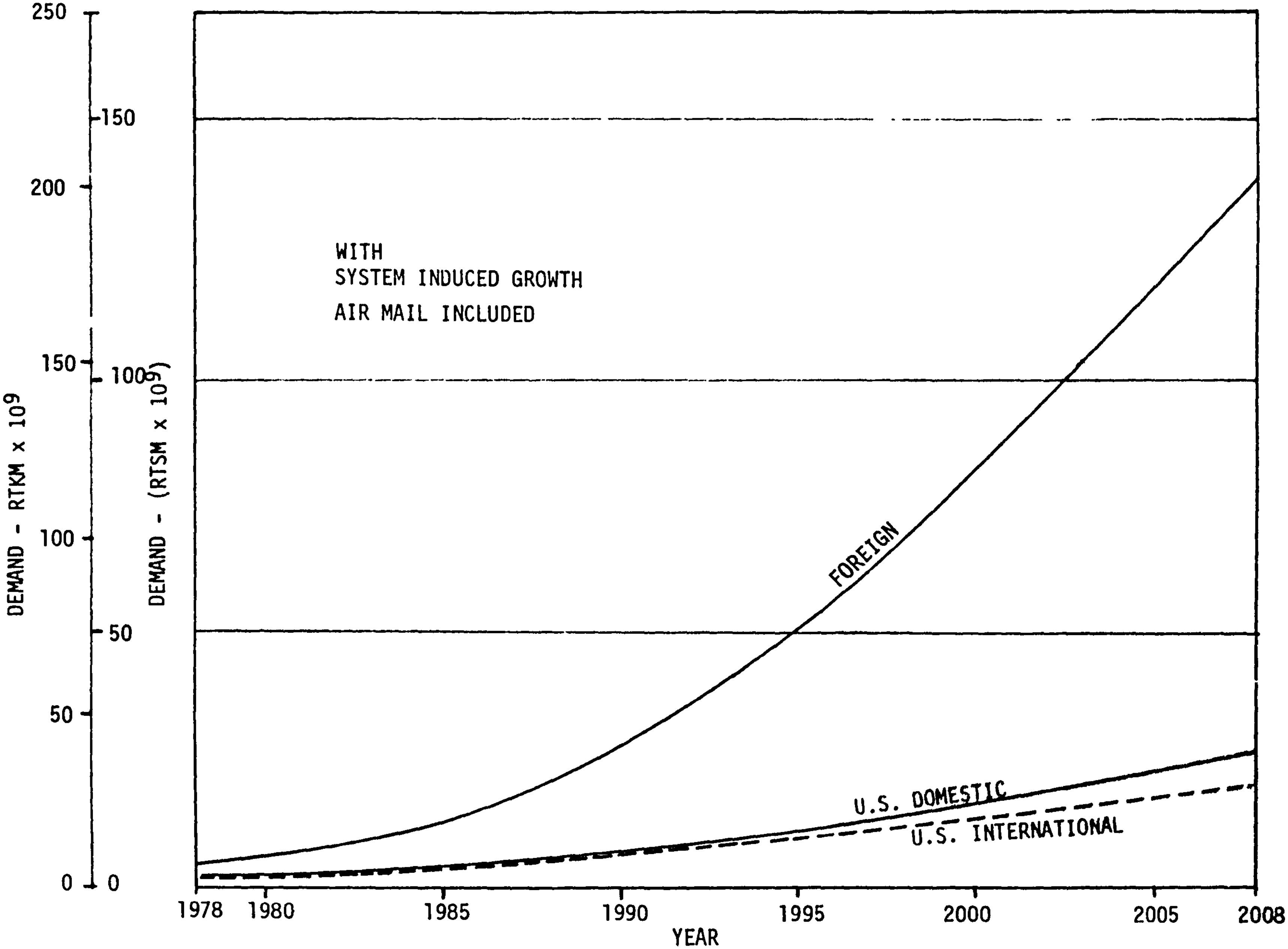


Figure 1-5 Airfreight Market Forecast For All-Cargo Aircraft

small differences, less than one percent, in the annual growth factors for post 1990. However, during the years prior to 1990 when it is postulated that major changes to the system will be implemented the all-cargo aircraft airfreight markets annual growths, Table 1-4, are higher by a maximum of 2.6 percent for the U.S. Domestic for the year 1990, three percent for U.S. International in 1985 and four percent for the Foreign market in 1990. The average annual growth rates for period 1978 to 2008 are 8.6 percent for the U.S. Domestic, 7.9 percent for U.S. International and 12 percent for the Foreign market.

Forecasts of System Variables

The variables discussed in the following paragraphs are dependent upon changes in the total environment and upon the accompanying market forces. In time they have a strong influence upon system econometrics and hence upon the requirements for the aircraft making up that system. Since they represent independent inputs to the computer simulation model their values must be forecast for the time period being considered, in this case to the year 2008.

Distribution of cargo movement with range. - In Section 4 of Volume 3 it was concluded that deregulation will result in an increase in the number of domestic cities served at ranges between 800 and 3200 kilometers (497 and 1865 statute miles). As noted in the discussion of service induced growth above, a 15 percent increase in cities served could result in a 2.3 percent increase in the airfreight market by 1985. If we assume that this entire growth occurs within the ranges noted, the encompassed airfreight market would be increased only 3.6 percent over the level given by the 1976 distribution of Figure 4-2, Volume 3. It was therefore concluded, considering uncertanities in the forecast, that this change in distribution was not of sufficient impact to warrant modification of the simulation model for the post 1985 period.

A similar analysis of the U.S. International distribution, reference Figure 4-3, Volume 3, provided similar results. A 15 percent increase in the number of cities between 2000 and 5000 kilometers (1243 and 3108 statute miles) resulted in a 2 percent increase in airfreight movement over these ranges for the post 1985 period. Again, it was concluded that the model would not be modified for this change in range distribution but that range effects would be considered in the parametric analysis.

Inflation. - Inflation will continue to prevail in the world economy thus effecting all economic aspects of the future air cargo system. This factor along with fuel cost will increase the importance of more efficient aircraft while at the same time increasing their cost relative to aircraft already in the system. In keeping with the scenario of potential events outlined in Section 12 of Volume 3 an average annual inflation rate of 6 percent was applied to all operations out to 2008.

Fuel cost. - Based upon the experience of U.S. airlines the 1978 cost of jet fuel was established at a representative cost of 10 cents and 11 cents per liter (38 and 42 cents per U.S. gallon) for U.S. Domestic and International operations. Based upon Pan American World Airways service at 86 overseas airports a value of 12 cents per liter (46 cents per U.S. gallon) for Foreign operations was defined. It is expected, reference Section 12, Volume 3, that these prices will increase with inflation, 6 percent annual rate, for the full period being considered, to 2008. However, it is also expected that beyond 1985 there will be an additional annual increase of about 3 percent. This additional increase will stem from the worlds growing concern for oil reserves and the approaching balance between production supply and the world's demands.

Using the preceeding cost factors the average fuel costs for the three model time periods were derived. Based upon the respective market sizes a weighted average fuel price of 11 cents per liter (43 cents per U.S. gallon) was determined for the three markets during the period from 1978 to 1985. Increasing this price at an annual rate of 3 percent gave an average un-inflated price of 13 cents per liter (50 cents per U.S. gallon) for the 1984 to 1995 period and 19 cents per liter (71 cents per U.S. gallon) for the period 1994 to 2008. Inflating these prices to the first year of each period 1984 and 1994, increased the average prices to 19 and 48 cents per liter (71 and 181 cents per U.S. gallon) for the periods 1984 to 1995 and 1994 to 2008 respectively. The annual inflation of 6 percent for the years subsequent to 1978, 1984 and 1994 will be applied during the course of the fleet economic analysis.

Indirect operating cost (IOC). - The work reported in Section 8 and 10 of Volume 3 investigated the importance of IOC to total operating cost, to the direct operating cost (DOC), and the impact of future systems developments upon these costs. A primary conclusion reached pointed out the declining importance of IOC and increasing importance of DOC as the suggested infrastructure improvements are implemented. These findings also pointed to the importance of considering this changing relationship in deriving the desired requirements for future, all-cargo aircraft.

Utilizing the CAB Form 41 data for 1977 the current level for IOC was established at an average value of 42 percent of the total revenue for all-cargo operations. Based upon the data of Section 10, Volume 3, the comparable value for the year 2008 was forecast to be 26 percent. This reduced value for 2008 is based upon two premises. First, that the infrastructure changes previously discussed under System Induced Market Growth are implemented by 1990. Second, that new more efficient cargo aircraft began entering service in 1995 and capture 45 percent of the all-cargo market by 2008. Under these conditions an average value of 42 percent of the total revenue was selected for the period 1978 to 1985, 36 percent for 1984 to 1995, and 30 percent for the last period 1994 to 2008.

Tariffs. - In the process of analyzing the impact of change as discussed in the prior sections on System Induced Market Growth, the following tariff reductions were derived for the respective infrastructure developments considered. These data show a potential tariff reduction of 18 percent by 1990

By 1990	Percent
Increasing aircraft load factor - - - - - - - - -	-4
Increased airline profit - - - - - - - - - - - -	+4
Economics of scale - - - - - - - - - - - - - - - -	-6
Shipper loaded containers - - - - - - - - - - - -	-9
Improved terminal technology - - - - - - - - - -	-2

Aircraft/airport compatibility - - - - - - - - -	-1
Sub-Total	18
By 2008	
Aircraft size and technology - - - - - - - - - -	-4.5
Total	22.5

and 22.5 percent by 2008. Since these reductions were utilized in developing the market forecast they were also considered in evaluating the economics of the aircraft operations.

Analysis of the current situation identified 0.231, 0.171, and 0.277, dollars per tonne-kilometer (0.337, 0.250, and 0.404 dollars per ton-mile) as representative tariffs for the U.S. Domestic, U.S. International and Foreign markets respectively. Applying the above tariff reductions gave values of 0.189, 0.140, and 0.227 dollars per tonne-kilometer (0.276, 0.205, and 0.331 dollars per ton-mile) for 1990 and 0.181, 0.134, and 0.216 dollars per tonne-kilometer (0.264, 0.196, and 0.316 dollars per ton-mile) for 2008 in constant 1978 dollars. Assuming linear variations over the intervening years average tariffs were derived for each of the considered time periods. These average values were then inflated to the first year, 1978, 1984 and 1994, of each period resulting in the following tariff levels.

	Dollars per Tonne-Kilometer (Dollars per Ton-Mile)		
Time Period	1978 - 1985	1984 - 1995	1994 - 2008
U.S. Domestic	0.218 (0.319)	0.274 (0.400)	0.468 (0.683)
U.S. International	0.162 (0.237)	0.204 (0.298)	0.350 (0.511)
Foreign	0.262 (0.383)	0.328 (0.479)	0.560 (0.818)

Aircraft utilization. - The OAG data (Reference 1) indicates an average aircraft annual utilization of 3122 hours and industry reports indicate a maximum of 3600 hours being achieved by all-cargo operators. With the potential improvements in infrastructure and in aircraft engines and structure, it is postulated that the average annual utilization can be increased to 3300 hours for the period 1984 to 1995 and to 3600 hours for the period 1994 to 2008.

Section 2

STUDY APPROACH

The purpose of this study was to investigate the design requirements and economic worth of current cargo, derivative cargo, and dedicated freighter aircraft for successive time periods of a future world all-cargo demand forecast to the year 2008. The tasks to accomplish this and their related time periods are presented below:

Requirements for Future Freighter Aircraft
To Year 2008

	Study Tasks		Time Period
	Historic Trends	Section 3	1967-1978
Task 1	Future World Market Demand Projections	Section 1	1978-2008
Task 2	Near Term Cargo Aircraft Fleet Mix	Section 5	1978-1992
Task 3	Derivative Cargo Aircraft 1980 Technology	Section 7	1984-1998
Task 4	Dedicated Freighter Aircraft 1990 Technology	Section 8	1994-2008
Task 5	Parametric Studies	Section 9	1994-2008

The anticipated initial operating capability dates of 1985 for the derivative and 1995 for the all-new dedicated cargo aircraft dictated the respective tasks and the associated considered time periods shown. To assure continuity in considering the future introduction of derivative and new aircraft, the analysis was performed for three time periods; 1978-1992 using current aircraft, 1984-1998 introducing derivative aircraft, and 1994-2008 introducing new dedicated freighter aircraft. The overlapping years assured continuity throughout the entire 1978-2008 study period. The relationship of these time periods to aircraft availability and the air freight market demand is illustrated in Figure 2-1.

Considered Time Periods

The analysis conducted during the course of this study covered the years 1967 to 2008. The actual effort was performed in two phases, the historical phase from 1967 to the present year 1978 and the forecast phase from 1978 to the year 2008 as shown in Figure 2-1. The historical phase traced the development of all-cargo system to where it is today while the forecast phase evaluated anticipated future developments. The historical phase outlined past operations and thereby provided the base upon which to develop the cargo model. The forecast phase considered the future growth of this model and was based upon the forecasts developed during the CLASS, Reference Volume 3.

<u>1978-1992 Time Period - Task 2.</u> - For this time period, the near term, only the current jet all-cargo aircraft were available to satisfy the demand. The required distribution of current aircraft was determined utilizing a simulation covering the period 1978 to 1992. From these results the fleet mix that would occur in 1984 was determined. This fleet of current type aircraft subsequently competed with the new derivative configurations projected to enter the fleet in 1985.

<u>1984-1998 Time Period - Task 3.</u> - This period was concerned with the introduction and growth of new derivative aircraft into the aircargo network. These aircraft were considered as being developed from current configurations with the application of advanced technology available in 1980. Analysis was performed parametrically utilizing a simulation covering the period 1984 to 1998. The first step identified the preferred size of aircraft based upon fleet economics. This was followed by the definition of the fleet that would result when the selected derivative aircraft operated in competition with the fleet of current aircraft defined in Task 2. These results defined the 1994 fleet of current and derivative aircraft types to compete with the new dedicated freighter aircraft over the years 1994 to 2008.

<u>1994-2008 Time Period - Task 4.</u> - In a manner similar to that outlined for Task 3, the analysis for this time period was concerned with the identification and subsequent fleet integration of a new dedicated freighter. These new aircraft, introduced in 1995 and utilizing 1990 technology, were

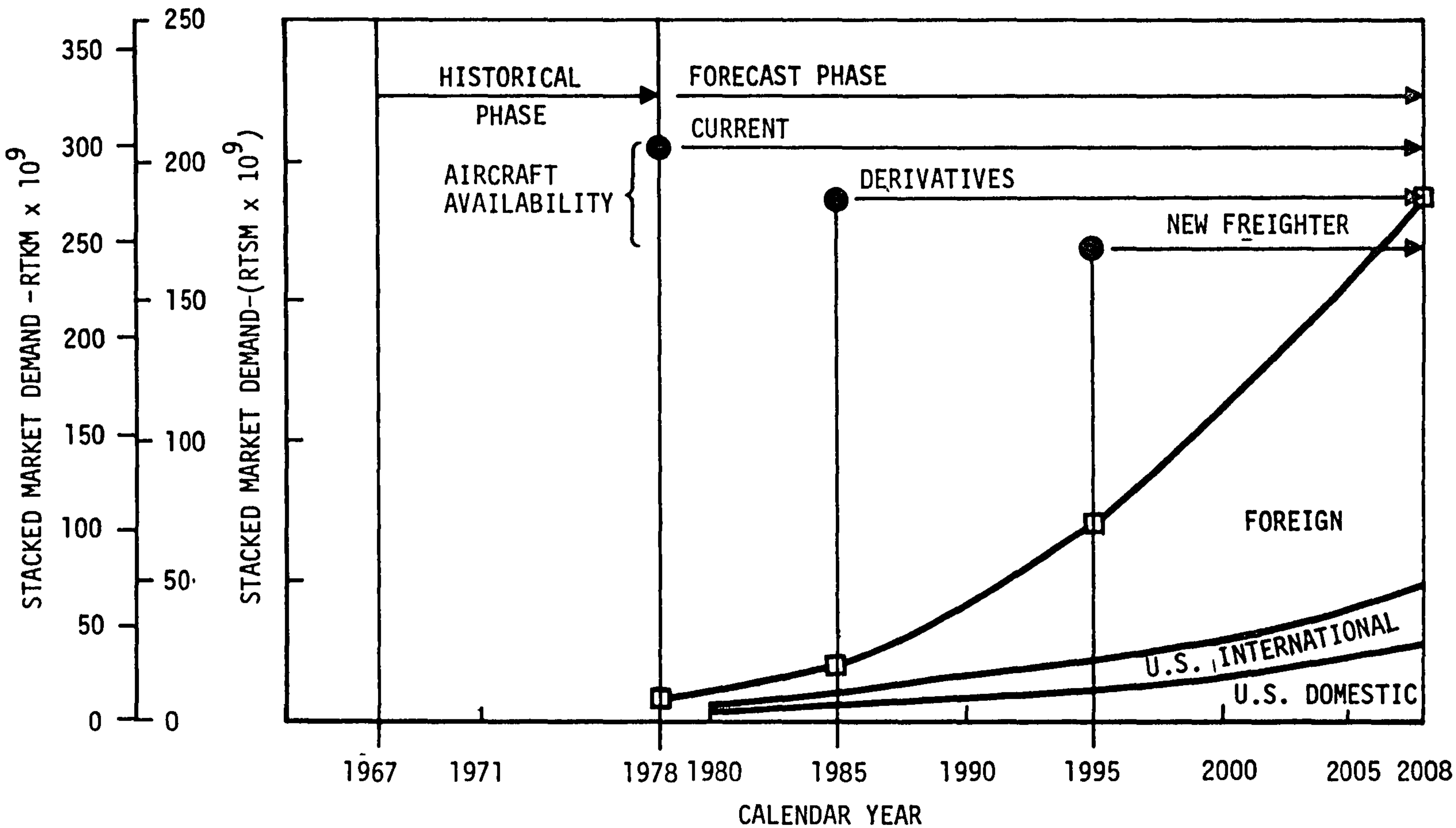


FIGURE 2-1. FORECAST MARKET DEMAND AND STUDY PHASES

evaluated relative to the 1994 fleet of current and derivative aircraft determined in the previous task. Parametric evaluations determined the size of the dedicated aircraft that would most effectively meet the market demand. The fleet economics that would result with the preferred mix of the dedicated, derivative and current aircraft types were then derived out to the year 2008.

1994-2008 Parametric - Task 5. - Analysis of the 1994 to 2008 period was extended to determine the effect of reduced frequency of departures and a reduction in the growth of the cargo market demand. The impact of these variables on the respective fleet mixes and economics was determined. In addition, the relative effectiveness of alternate aircraft configurations were determined. Configurations included propfan powered aircraft designed for Mach numbers of 0.8 and 0.7, a conventional turbofan aircraft equipped with wing laminar flow control (LFC), and a spanloader configuration powered by turbofans.

Study Methodology

A prerequisite to establishing requirements for future cargo aircraft is a consistent set of statistical data to describe the nature, both past and present, of the cargo network. The best available source of such data concerning the actual operational aspects of the cargo system is the Official Airline Guide (OAG), Air Cargo Guide. Consistent Air Cargo Guide data dating back to 1967 forms the cargo data base used in this study.

Historic trends. - The historic trends were obtained from the cargo data base covering the years 1967 to 1978 and using existing retrieval programs.

Operating and economic analysis. - For the forecast study phase the cargo aircraft fleet mix, operational characteristics, and economic worth, for the three study time periods were determined using an existing Douglas simulation program called FRAME (Future Requirements and Advanced Market Evaluation). This program, outlined in Figure 2-2, accepts a cargo system model and related inputs (e.g., cargo market demand growth forecasts) and operational variables

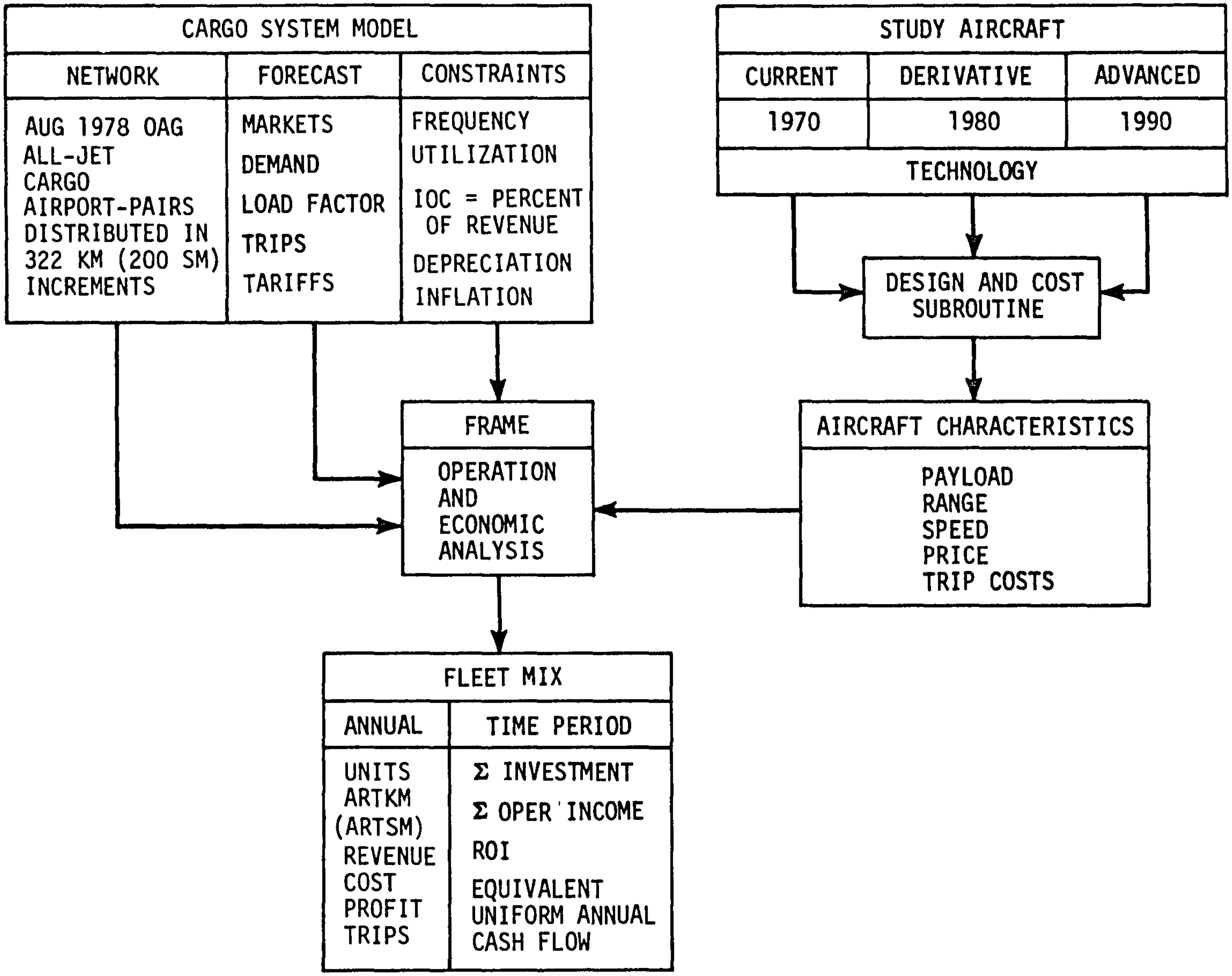


FIGURE 2-2. FUTURE REQUIREMENTS AND AIRCRAFT MARKET EVALUATION — FRAME

(e.g., utilization, frequency, and operational constraints). It also accepts aircraft characteristics (range, payload, speed, trip costs and aircraft price). Using this information, the program then provides annual operational and economic information on the fleet mix of aircraft to satisfy the needs defined by the system model for the time period of concern (up to 15 years).

Aircraft characteristics. - Consistant aircraft design and trip cost characteristics were computed using the Design and Cost Subroutine shown in Figure 2-2. The trip costs were the direct operating costs less the ownership costs (depreciation and insurance). The ownership costs along with the aircraft price were taken into account in the economic evaluation of the fleet annual cash flow and the airlines return on investment (ROI).

Airline return on investment (ROI). - The airline ROI was employed to establish the relative value of alternative aircraft configurations. If two or more candidate configurations are being considered, it is more than likely that they will have differing characteristics, trip costs, and prices. ROI provided the means to compare any number of such configurations on a consistant basis. As an example, a configuration that incorporates technology to lower trip cost at the expense of aircraft price can be compared to a configuration which does not incorporate such technology and hence has a higher trip cost but a lower price.

The number of units of a given configuration, or configurations, were determined by the respective trip costs thus allowinq each one to compete on its own merits unencumbered by airline finances or accounting procedures. The number of units thus determined were employed in defining the aircraft prices which in turn were used to establish the airline cash flow and ROI. These fleet economic values provided a relative measure of the worth of each considered configuration and thereby the basis upon which to select the preferred configurations.

Results. - Results of these analyses defined the airlines operational and economic factors. Operational factors include fleet mix (units), demand split between types of aircraft, and the related trips or departures. Economic factors include the total investment that occurs during the considered time period discounted to current dollars (ΣIPV), Return On Investment (ROI) calculated by discounted cash flow method, Operating Income (ΣOI) defined as revenue minus total operating costs, and the Equivalent Uniform Annual Cash Flow (EUACF) for the time period of concern. EUACF is the total of the cash flow that occurs during the considered time period stated by an equivalent value that assumes even distribution over each of the considered years.

The following sections describe in more detail the development of the cargo model and related inputs, the generation of aircraft characteristics, and the fleet operational and economic results derived for the time periods and aircraft availability discussed in this section.

Section 3

HISTORIC TRENDS

The historic trends effort traces the development of the all-cargo system between 1967 and 1978 utilizing data published in the Official Airline Guide (OAG); Air Cargo Guide. These data consist of statistics pertinent to scheduled worldwide commercial all-cargo operations. As shown in Figure 3-1, these data were affected by the respective aircraft characteristics and airport-to-airport distances. Using a computer retrieval system, the resulting system statistics were examined and pertinent trends in aircraft types, number of trips, available capacity and range were identified.

Due to the large amount of data involved, the decision was made to examine the growth at the three determining intervals noted below.

- September 1967 - First Year of Available Data
- August 1971 - Introduction of the Wide-Body Jet
- August 1978 - Latest Year of Available Data

The historical trends for these three years are discussed in the following paragraphs.

All-cargo Historic Trends

Data of historical interest concerning the worldwide scheduled all-cargo system for the years 1967, 1971 and 1978 are shown in Table 3-1. In August 1978 there were 431 worldwide airports served by all-cargo operations. These airports were connected by 1122 links or nonstop routes.

The data in Table 3-1 illustrate the fact that on a relative basis the larger system growth occurred between 1967 and 1971. As an example, between 1967 and 1971 the daily departures, distance flown, and available capacity, increased by factors of 3, 3.5 and 3.7, respectively. Between 1971 and 1978 the comparable growth rates were only about 1.3 and covered a period of seven years compared to four for the larger growth.

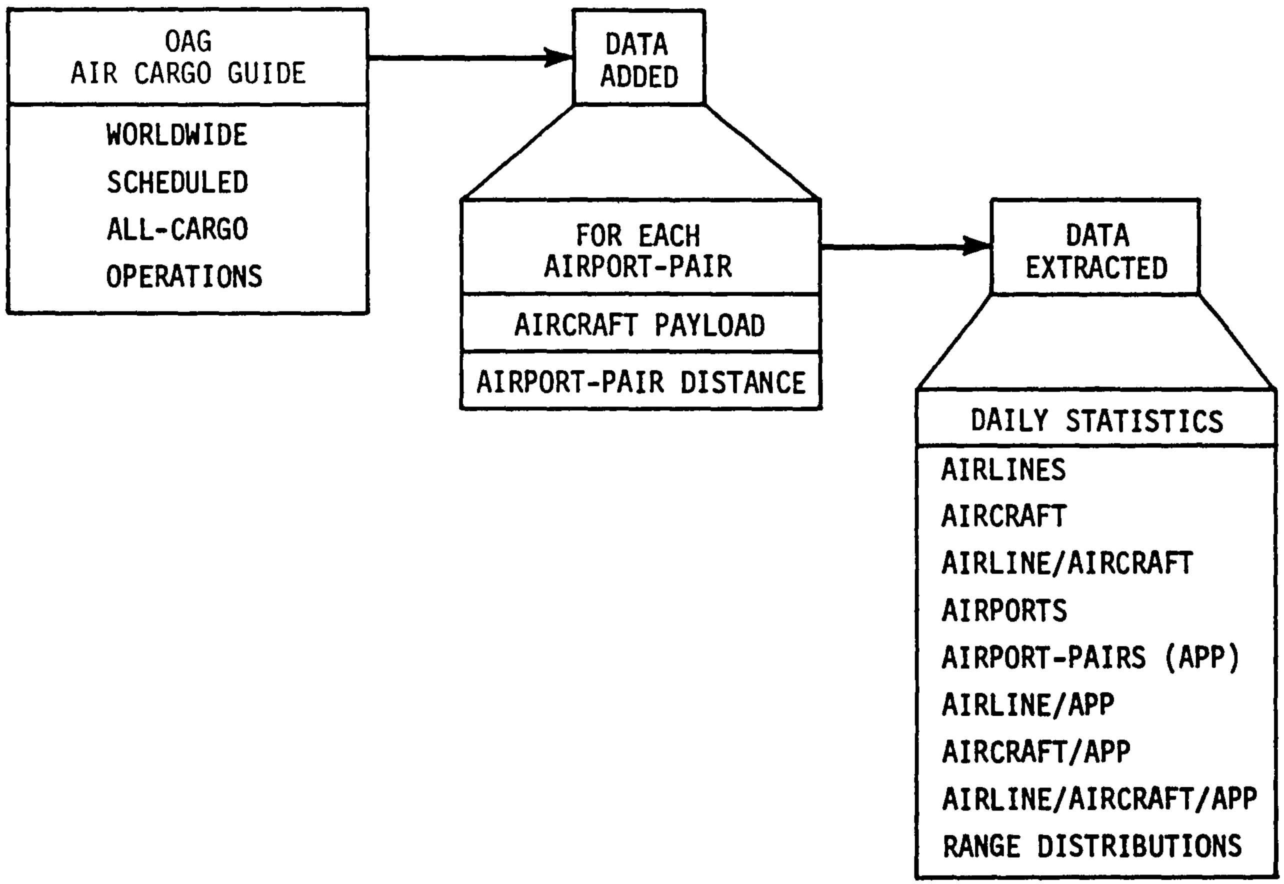


FIGURE 3-1. SYSTEM HISTORIC GROWTH TREND EVALUATION

TABLE 3-1

ALL-CARGO SYSTEM HISTORIC GROWTH

Month Year	September 1967	August 1971	August 1978
Cargo System			
Airlines	20	76	117
Aircraft Types (Generic)	17	43	49
Jet	5	10	15
Nonjet	12	33	34
Airports	-	-	431
Nonstop Routes	-	-	1122
Operations	----------	--- Daily Data ---	----------
Departures (Trips)	293	888	1169
Distance Flown - KM (SM)	319344 (198431)	1129529 (701857)	1547494 (961568)
Available Capacity - AT (AT)	5386 (5938)	19900 (21940)	26789 (29535)
Available Capability - ATKM (ATSM)	7510205 (5144000)	38231383 (26186000)	65210923 (44665223)
Hours Flown	584	2120	2695

Figure 3-2 shows that during the 1967-1978 time period the jet cargo aircraft has dominated and paced the development of the present commercial all-cargo system. The total annual available capability (daily times 365) has grown from 2.740 x 10^9 TKM (1.877 x 10^9 TSM) in 1967 to 23.798 x 10^9 TKM (16.300 x 10^9 TSM) in 1978, with the jet currently performing 97 percent of the total.

The growth trends for the all-cargo system daily available capability and daily operations (trips) are shown in Figure 3-3. The capability increased at a rate of 17.4 percent per year and trips at 10.6 percent per year. The daily capability grew from 7.510 x 10^6 TKM (5.144 x 10^6 TSM) in 1967 to 65.211 x 10^6 TKM (44.665 x 10^6 TSM) in 1978. The daily trips increased from 293 in 1967 to 1 169 daily trips in 1978.

Figure 3-4 shows that the system total all-cargo aircraft daily average capacity per trip grew rather slowly; from 18.4 to 22.9 tonnes (20.3 to 25.3 tons) per trips, a rate of 1.8 percent per year. However, the jet aircraft capacity increased from 22.6 to 42.2 tonnes (24.9 to 46.8 tones) per trip while the nonjets decreased from 12.7 to 3.8 tonnes (14.0 to 4.2 tons) per trip, annual growth rates of 5.7 percent and -11.5 percent, respectively. The jet capacity has almost doubled while the nonjet capacity has declined by 60 percent. Figure 3-5 shows that the average daily range for the system's all-cargo aircraft has grown at a rate of 1.6 percent per year from 1090 to 1323 kilometers (677 to 822 statute miles), an increase of 21 percent. This increase is the result of jet aircraft operations whose average daily range has increased 66 percent from 1302 to 2163 kilometers (809 to 1344 statute milies), an annual increase of 4.5 percent. This increase more than offsets the decline in nonjet operations where daily range decreased 37 percent from 805 to 504 kilometers (500 to 313 statute miles), an annual decrease of 4.1 percent.

Changes have also occurred with respect to the number of daily trips performed by, and capability available from, the jet and nonjet aircraft. The rate of increase in daily trips performed by the nonjets increased more rapidly than that for the jets, 14.4 percent as shown in Figure 3-7 compared

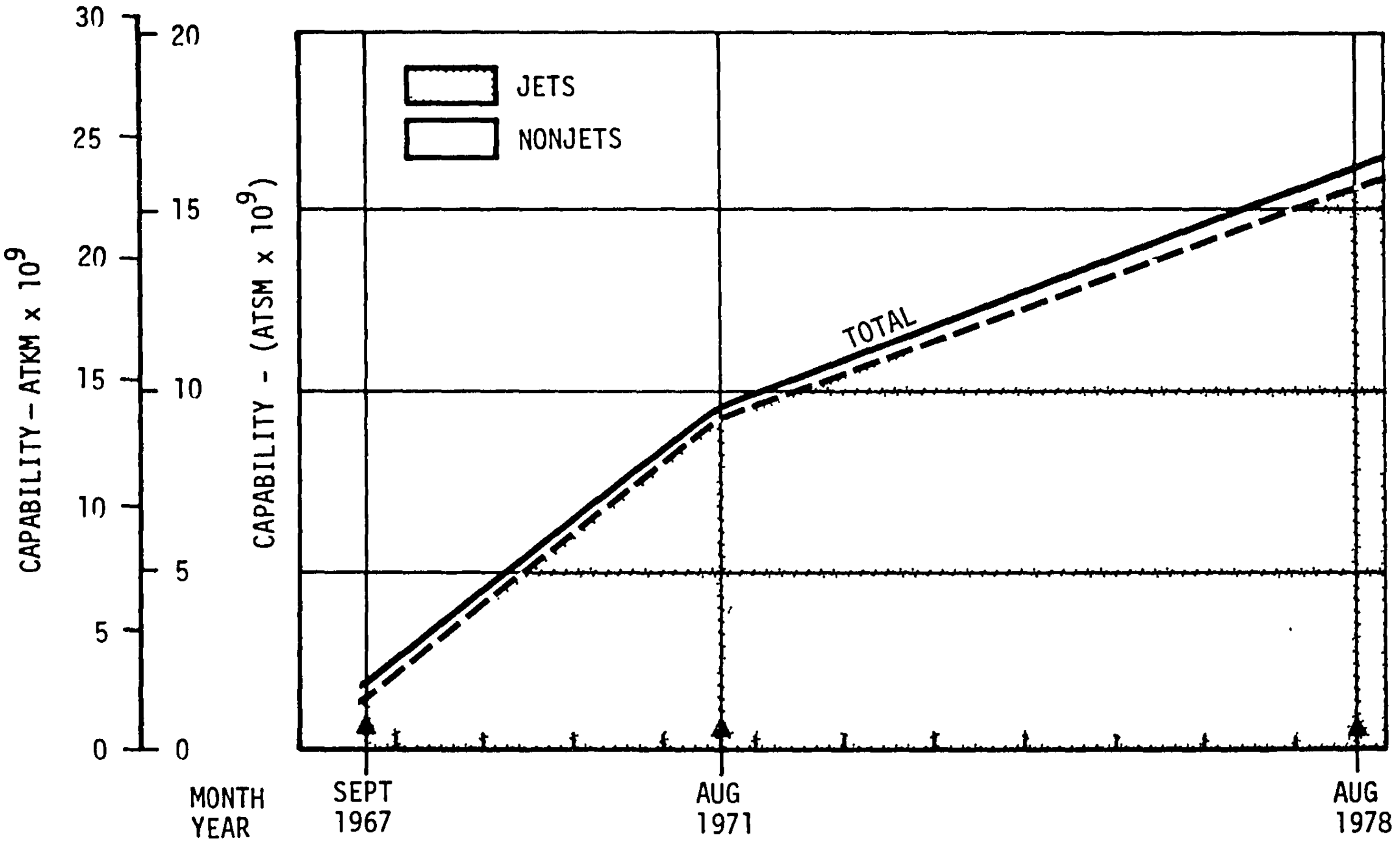


FIGURE 3-2. ANNUAL AVAILABLE CAPABILITY — ALL-CARGO AIRCRAFT

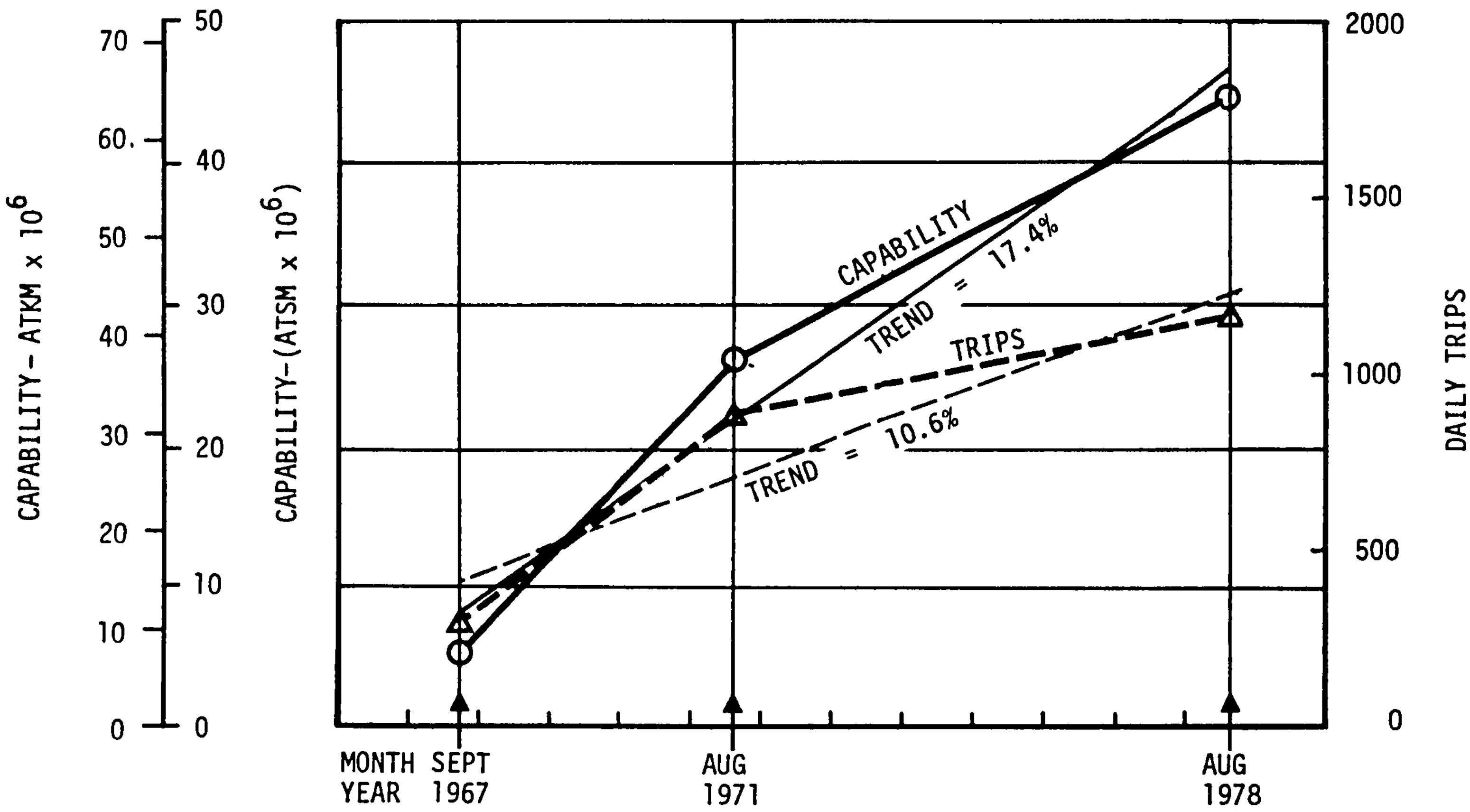


FIGURE 3-3. DAILY AVAILABLE CAPABILITY AND TRIPS — ALL-CARGO AIRCRAFT

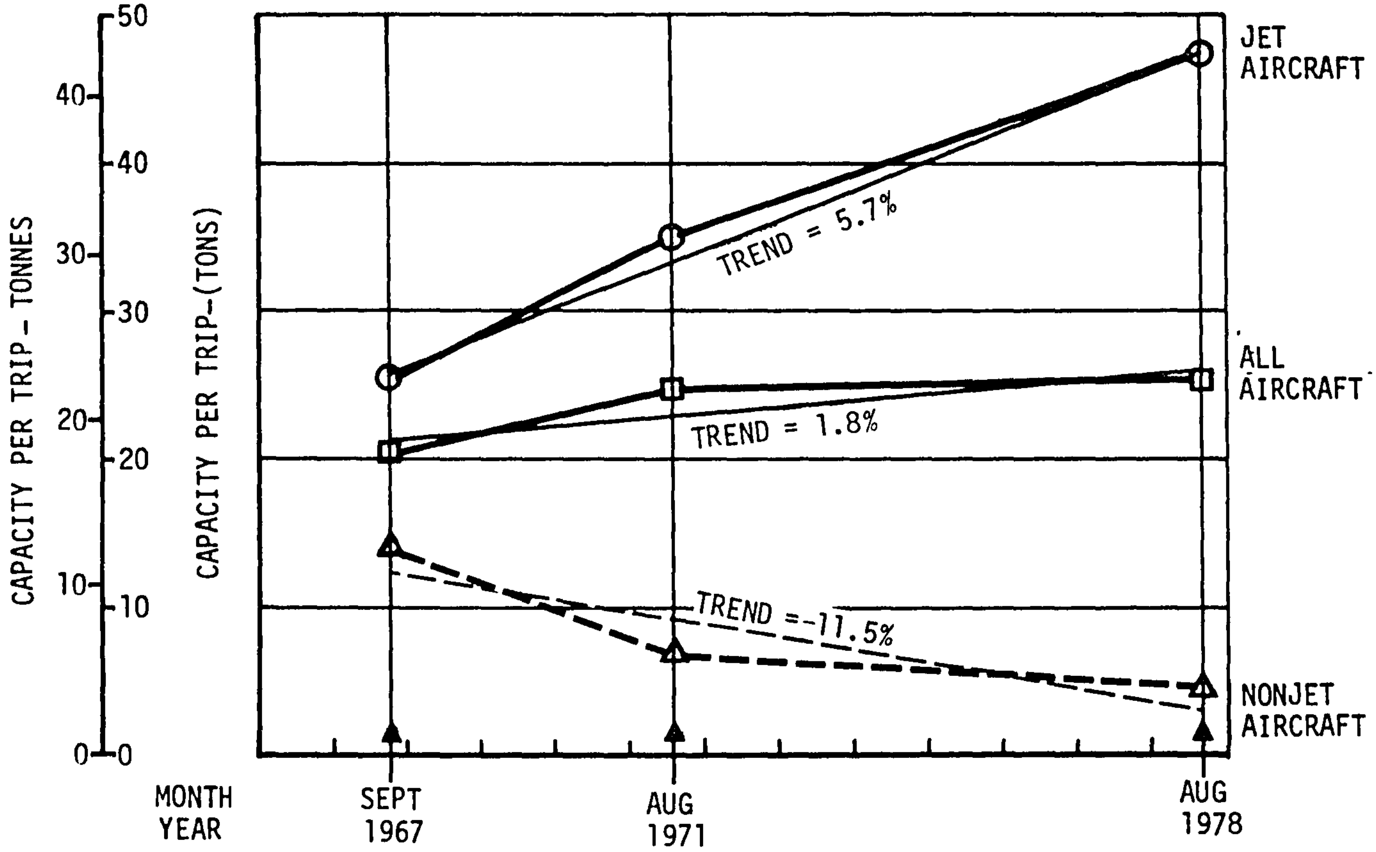


FIGURE 3-4. AVERAGE AVAILABLE CAPACITY — ALL-CARGO AIRCRAFT

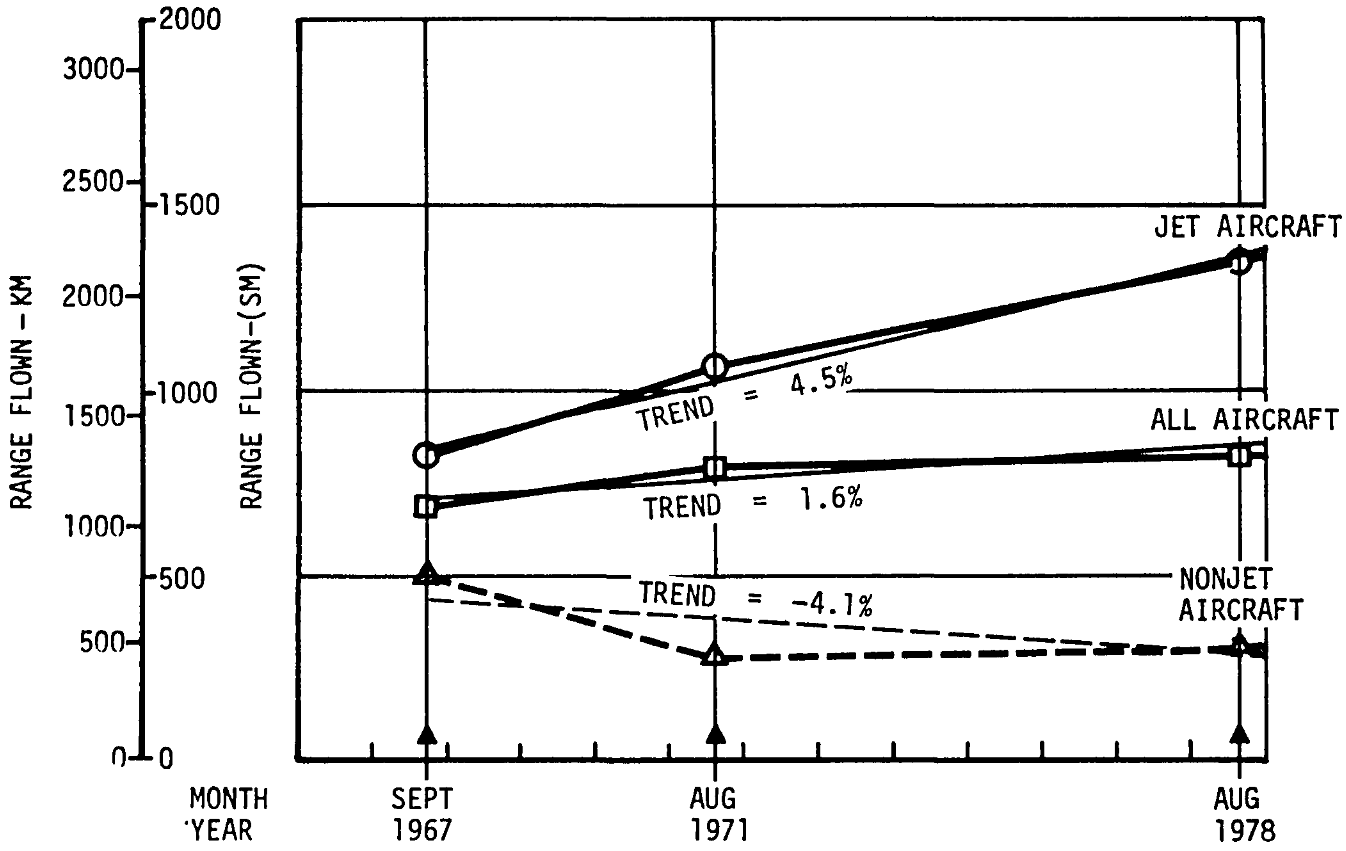


FIGURE 3-5. DAILY AVERAGE RANGE FLOWN — ALL-CARGO AIRCRAFT

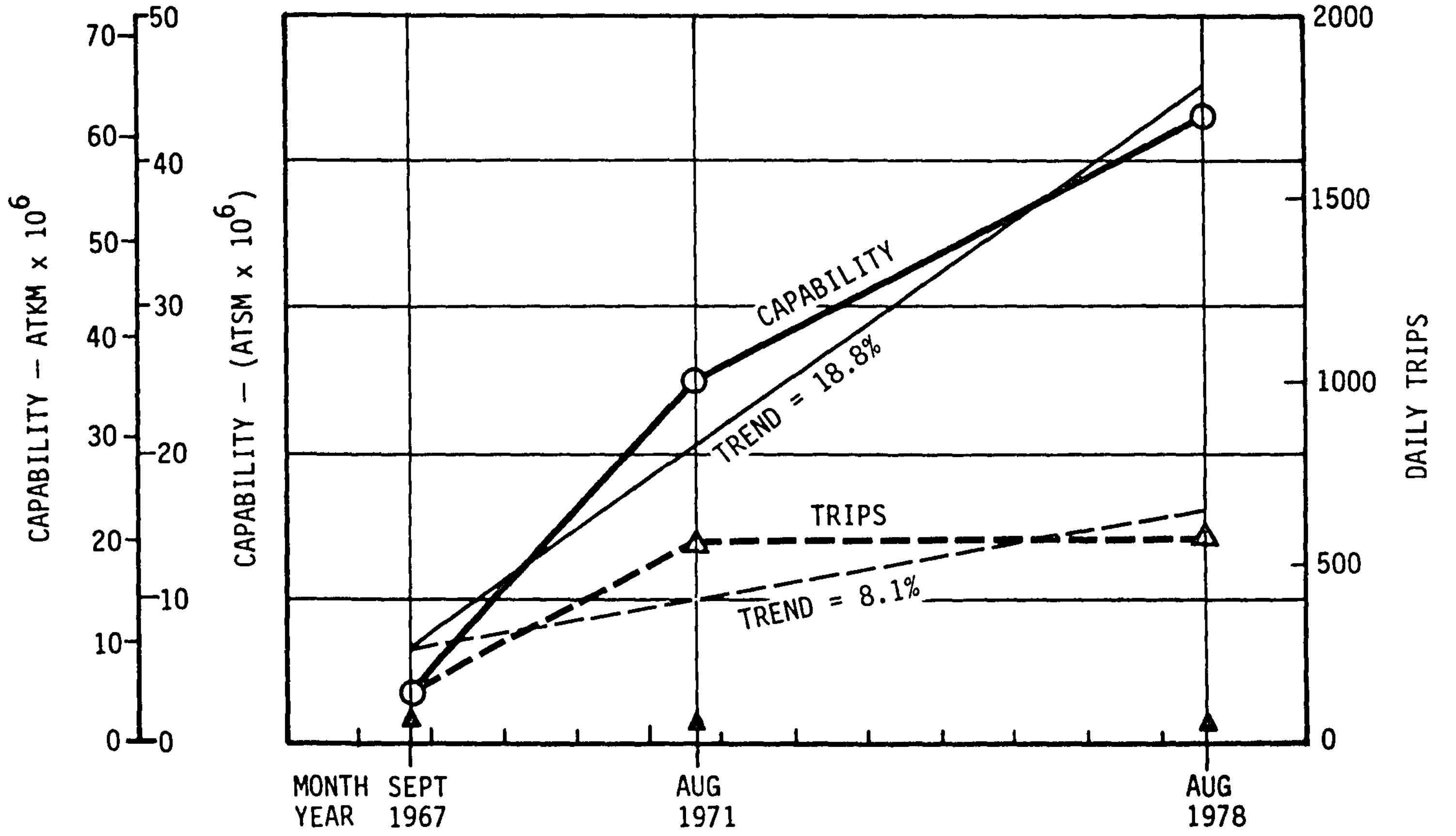


FIGURE 3-6. DAILY AVAILABLE CAPABILITY AND TRIPS — JET CARGO AIRCRAFT

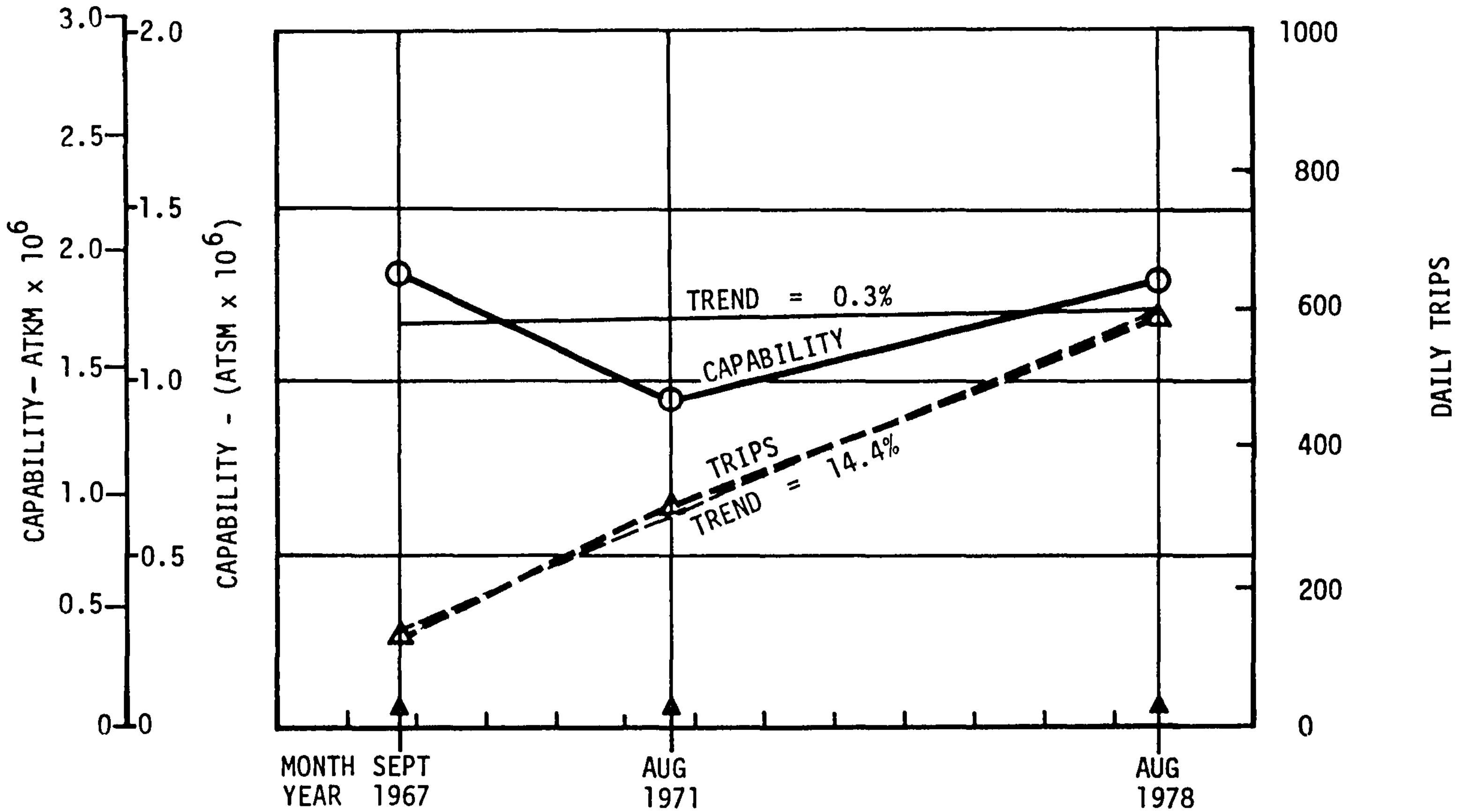


FIGURE 3-7. DAILY AVAILABLE CAPABILITY AND TRIPS — NONJET CARGO AIRCRAFT

to 8.1 percent for the . a slightly greater number of daily trips w[...] The utilization of the nonjets on shorter [...] basis for the relatively large growth [...] reasing average daily range of Figure 3-

The growth in the a[...] he jet aircraft has far exceeded that of [...] aft capability grew by an average annua[...] the comparable non-jet value was only 0 [...] Figure 3-7. This low growth in non-jet capability was the result of the combined effects of the decreasing average daily range, illustrated in Figure 3-5, and the decreasing capacity per trip shown in Figure 3-4.

Current Jet Cargo Aircraft Operations (1978)

The current commercial all-cargo system evolved around and is currently dominated by the all-jet cargo aircraft operations. This is illustrated by the daily operational data for August 1978 for all-cargo operations and for both jet and non-jet aircraft, summarized in Table 3-2. Although the jet aircraft serve 57 percent of the airports and 63 percent of nonstop routes encompassed by the current all-cargo system, their dominance is more dramatically illustrated by their daily operations. Referring to the data of Table 3-2 points out the fact that while jet aircraft perform 49 percent of the trips, they perform 81 percent of the total distance, provide 92 percent of available capacity and are responsible for 97 percent of the available capability. These statistics underline the increased productivity of the jet cargo aircraft although they represent only 30 percent of the generic types of aircraft currently employed in the system. Comparison of trips made with distance flown indicated that the jets are utilized on the longer range routes.

Utilization. - A comparison of the all-cargo aircraft operational data with all passenger aircraft operational data is of interest and is shown in Figures 3.8 and 3.9. Comparing the cumulative capability data presented in Figure 3-8 shows that passenger aircraft currently operate at ranges that are

TABLE 3-2

1978 ALL-CARGO SYSTEM

System	All-Cargo	Jet Cargo	Nonjet Cargo
Airlines	117		
Aircraft Types (Generic)	49	15	34
Airports	431	246	-
Nonstop Routes	1122	704	-
Operations	----------	---------- Daily Data ----------	----------
Departures (Trips)	1169	578	590
Distance Flown - KM (SM)	1547494 (961568)	1250563 (777064)	296959 (184522)
Available Capacity - AT (AT)	26789 (29535)	24520 (27033)	2269 (2502)
Available Capability - ATKM (ATSM)	65210923 (44665223)	63333268 (43379152)	1877655 (1286071)
Hours Flown	2695	1824	871

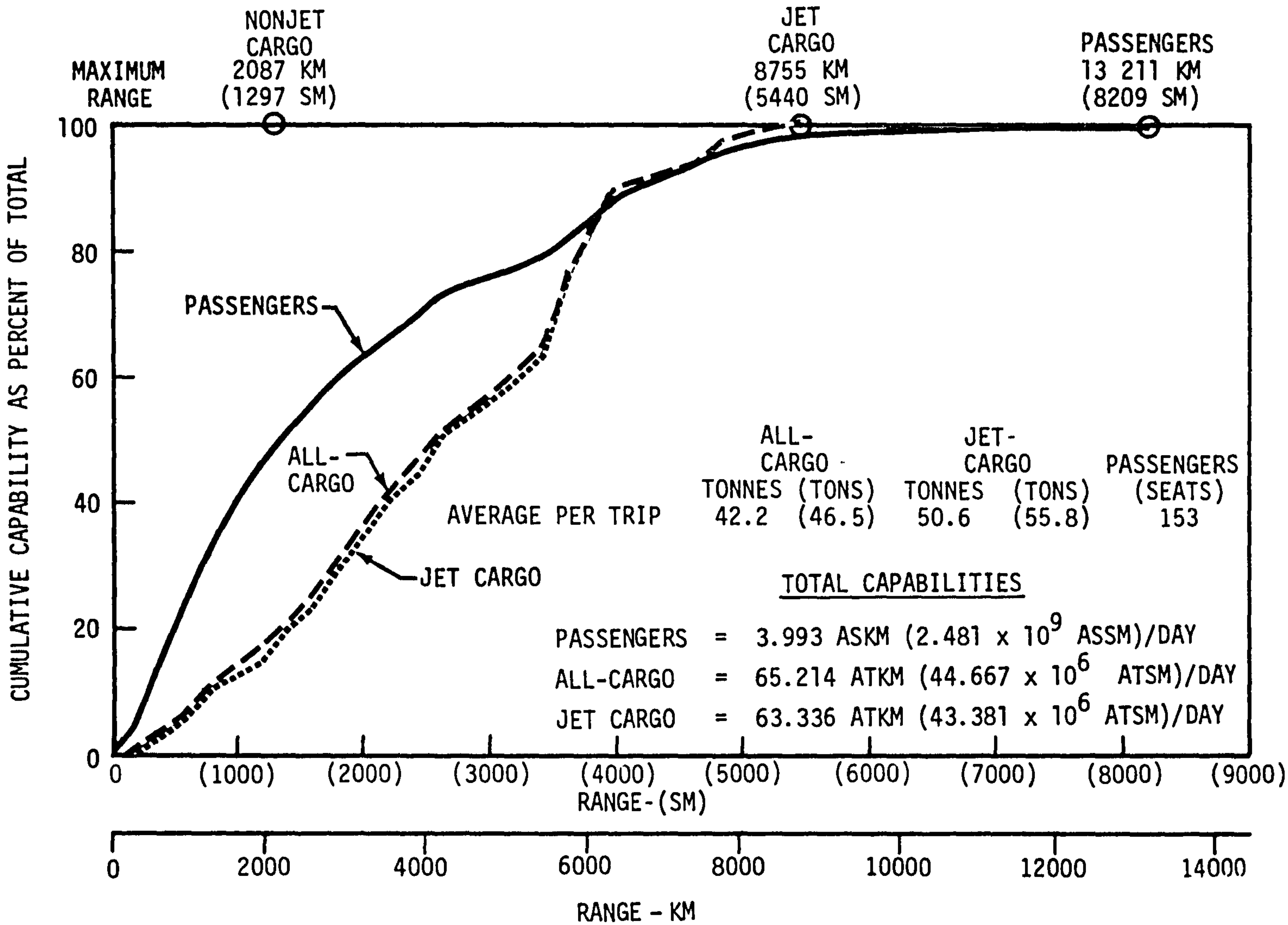


FIGURE 3-8. AVAILABLE CARGO AND PASSENGER CAPABILITY WITH RANGE — 1978

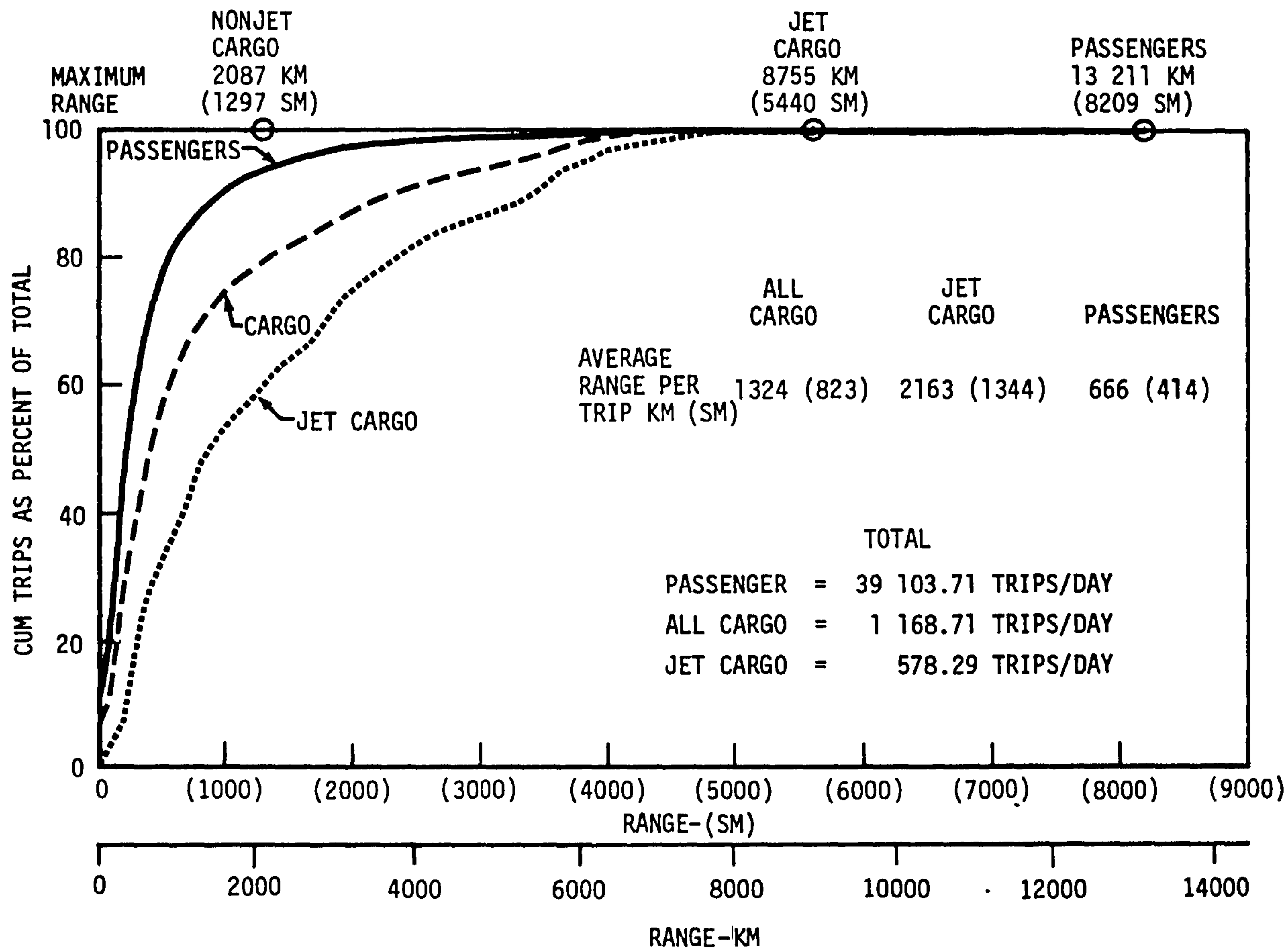


FIGURE 3-9. CARGO AND PASSENGER TRIP DISTRIBUTION WITH RANGE—1978

50 percent greater than cargo aircraft, 13,208 versus 8753 kilometers (8109 versus 5440 statute miles). Also a greater percent of the passenger available capability is provided at the shorter ranges than those for cargo. For example, 50 percent of the passenger available capability (seat-miles) is flown at ranges less than 2172 kilometers (1350 statute miles) while for the cargo, 50 percent of the cargo capability is provided at ranges less than 4183 kilometers (2600 statute miles). The jet cargo daily available capability closely tracks that for the all-cargo and above 2087 kilometers (1297 statute miles) all operations are jet operations.

A comparison of the passenger and cargo daily trips data presented in Figure 3-9 shows that, although a maximum range flown by cargo aircraft is less, 8753 kilometers (5440 statute miles) compared to 13,208 kilometers (8209 statute miles), a greater portion of the cargo total trips occur over longer ranges. This is illustrated by the fact that only 20 percent of the passenger trips are at ranges greater than 885 kilometers (550 statute miles) while a comparable percentage of the all-cargo trips occur over twice that range or 2156 kilometers (1340 statute miles). The magnitude of the passenger short range operations relative to those for all-cargo is evidenced by the total trips flown per day which is 33.5 times greater for passenger than for cargo. The divergence in range between passenger and cargo operations increases with the jet cargo aircraft where 20 percent of the trips are at ranges greater than 3781 kilometers (2350 statute miles) and about 46 percent at ranges greater than 1609 kilometers (1000 statute miles). The conclusion that the jets currently handle the long range operations is further evidenced by their maximum range of 8753 kilometers (5440 statute miles) compared to 2087 kilometers (1297 statute miles) for the non-jet.

<u>Distributions With Range.</u> - Current jet cargo operations were examined in greater detail by considering the distribution of available capability and trips in 322 kilometers (200 statute miles) increments. Figure 3-10 shows the distribution of the total daily available capability with range. These data show a relatively uniform distribution with range as evidenced by the constant slope of the cumulative distribution. The highest capability, 13 percent of the total available capability, is provided between 5471 and 5792 kilometers (3400 and 3600 statute miles) with the next largest of 6.5 percent

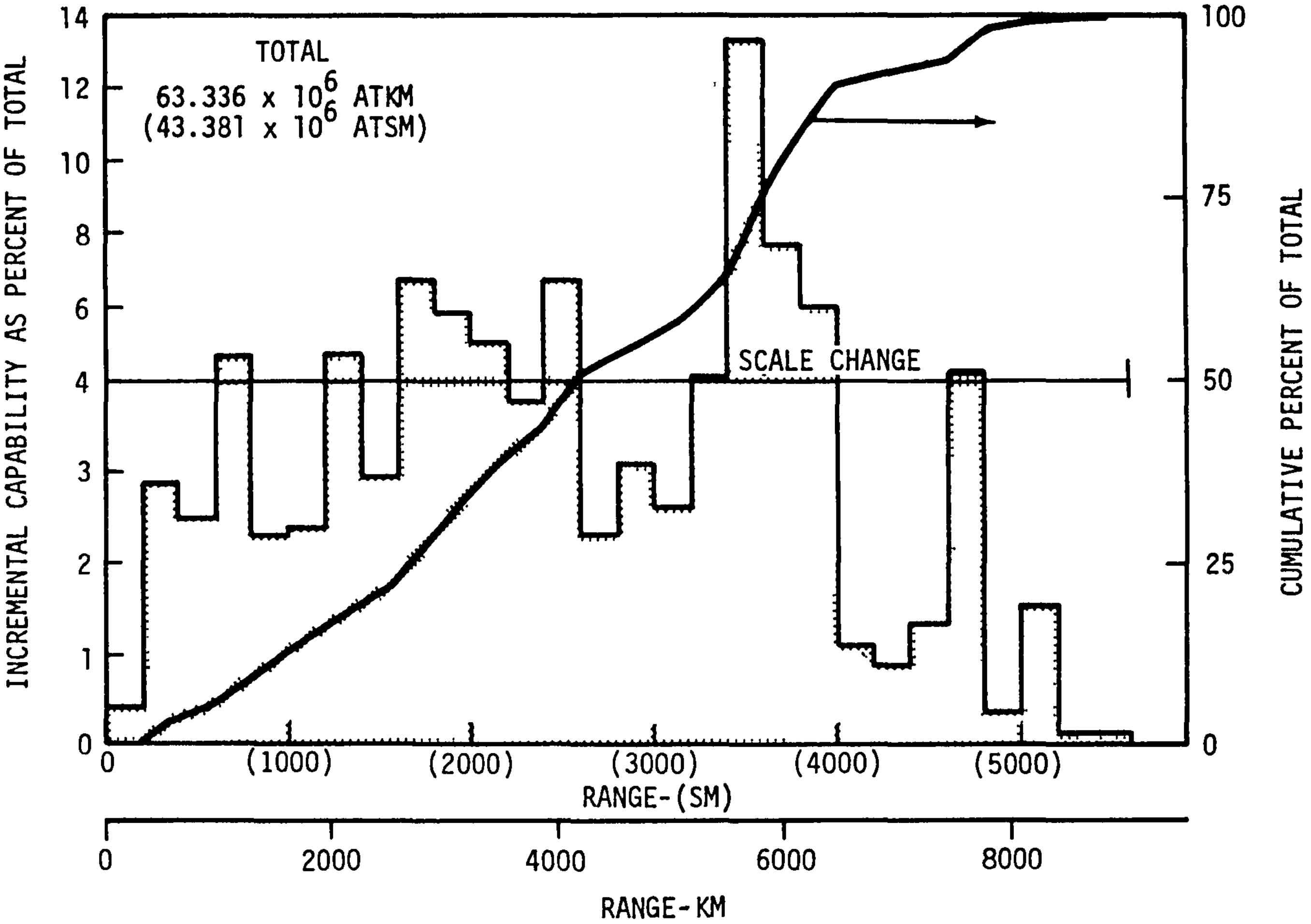


FIGURE 3-10. ALL-JET CARGO AIRCRAFT DAILY AVAILABLE CAPABILITY DISTRIBUTION — 1978

provided between 2574 and 2896 and between 3662 and 4183 kilometers (1600 and 1800, 2400 and 2600 statute miles).

The distribution of trips with range is a different picture, however, as shown in Figure 3-11. The jet trips are skewed toward the shorter ranges with 50 percent of the trips occuring below 1609 kilometers (1000 statute miles). This is less than half the range for 50 percent of the capability as shown in Figure 3-10. The largest number of trips, about 19 percent of the total, occurs at 322 to 644 kilometers (200 to 400 statute miles) and the next largest, about 10 percent, at 965 to 1287 kilometers (600 to 800 statute miles). For the maximum capability increment, 13 percent in Figure 3-10, the associated trips were about 4.3 percent of the total trips, while the largest number of incremental trips, 19 percent, performed only 2.9 percent of the total capability. This distribution of the jet trips along with the distribution of the available capability of Figure 3-10 provided the base upon which to forecast the future growth trends input to the cargo model.

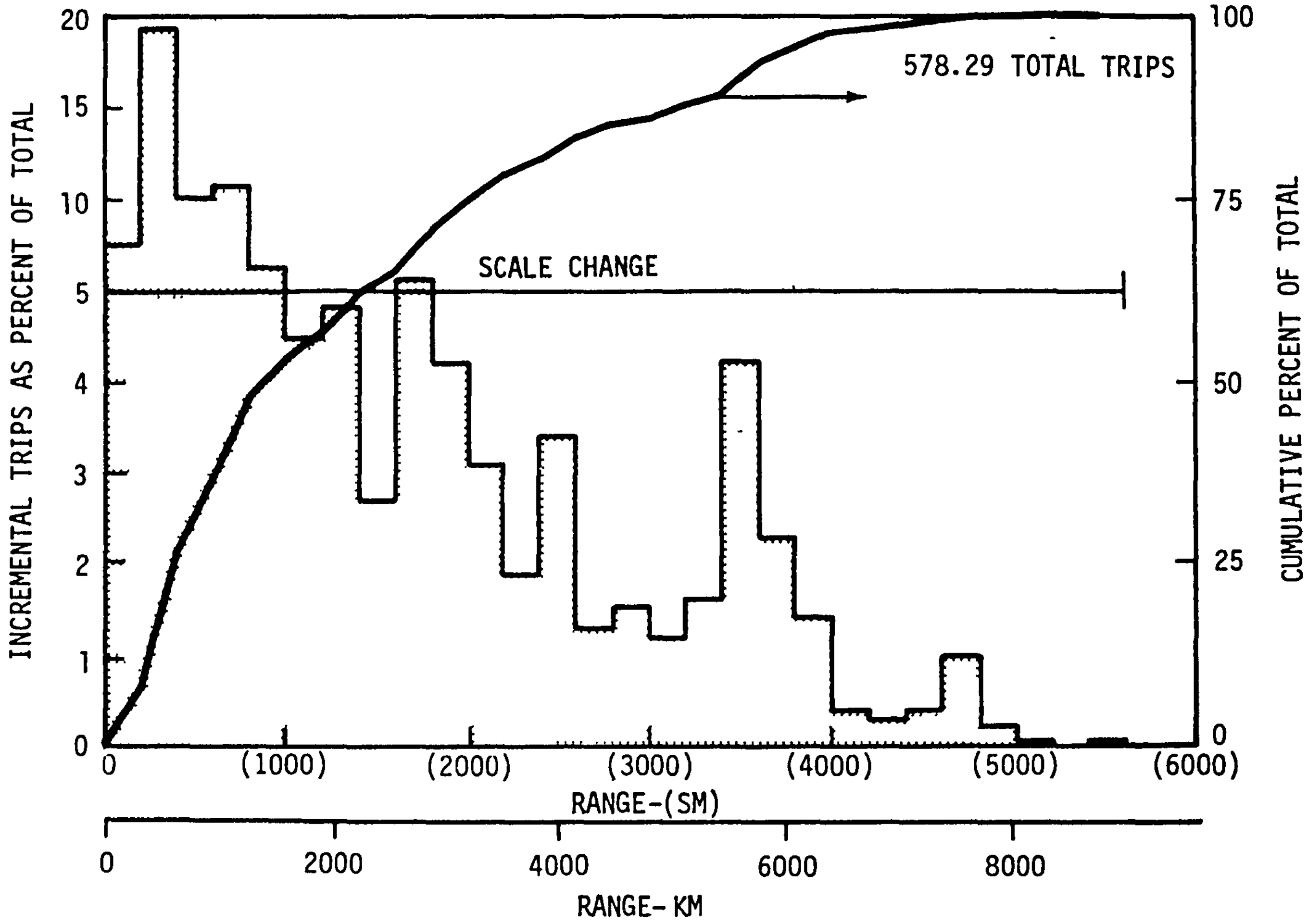


FIGURE 3-11. ALL-JET CARGO AIRCRAFT DAILY TRIP DISTRIBUTION-1978

Section 4

CARGO SYSTEM MODEL DEVELOPMENT

The forecast values for the system independent variables and cargo market demand growth are presented in Section 1. These data were combined with the current jet cargo operational data discussed in Section 3 to define the system model subsequently employed in the simulation analysis.

This section addresses the development of the system model, reference Figure 2-2, as outlined in Figure 4-1. Particular attention will be given to the key steps in the development that are identified within the double lined boxes of Figure 4-1. The model was developed in three segments, thus maintaining the individuality of the three markets, U.S. Domestic, U.S. International and the Foreign markets identified in Section 1.

Jet Cargo Operations

The first step consisted in completing the separation of jet fleet operations from the total OAG scheduled all-cargo operations. This second step is a continuation of that first step which was discussed in the preceding section. The worldwide scheduled all-cargo airport-pairs for August 1978 are shown in Figure 4-2. The resulting jet cargo aircraft daily fleet statistics are summarized in Table 4-1. Attention is called to the fact that each airport-pair (i.e., Chicago-New York) is a single identity regardless of the direction flown. The number of airport-pairs shown, as well as all other parameters given, represent fleet totals, the combined operations of all types of jet aircraft that occur during a representative day. In order to achieve a viable model that would accurately simulate network operations, these statistics were broken down relative to aircraft types and representative airport-pairs in a manner compatible with the computer program capacity.

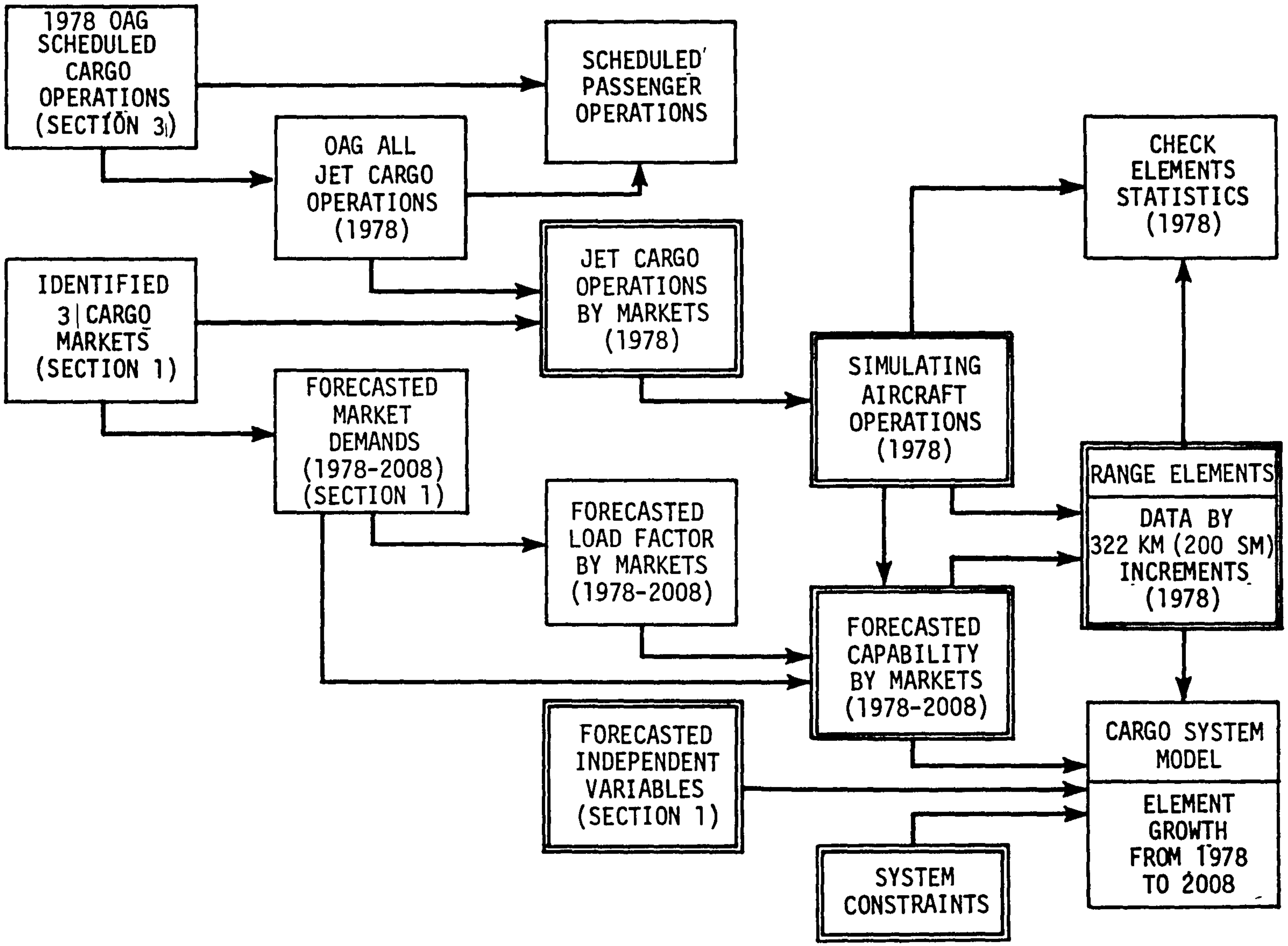


FIGURE 4-1. SUMMARY CARGO SYSTEM MODEL DEVELOPMENT

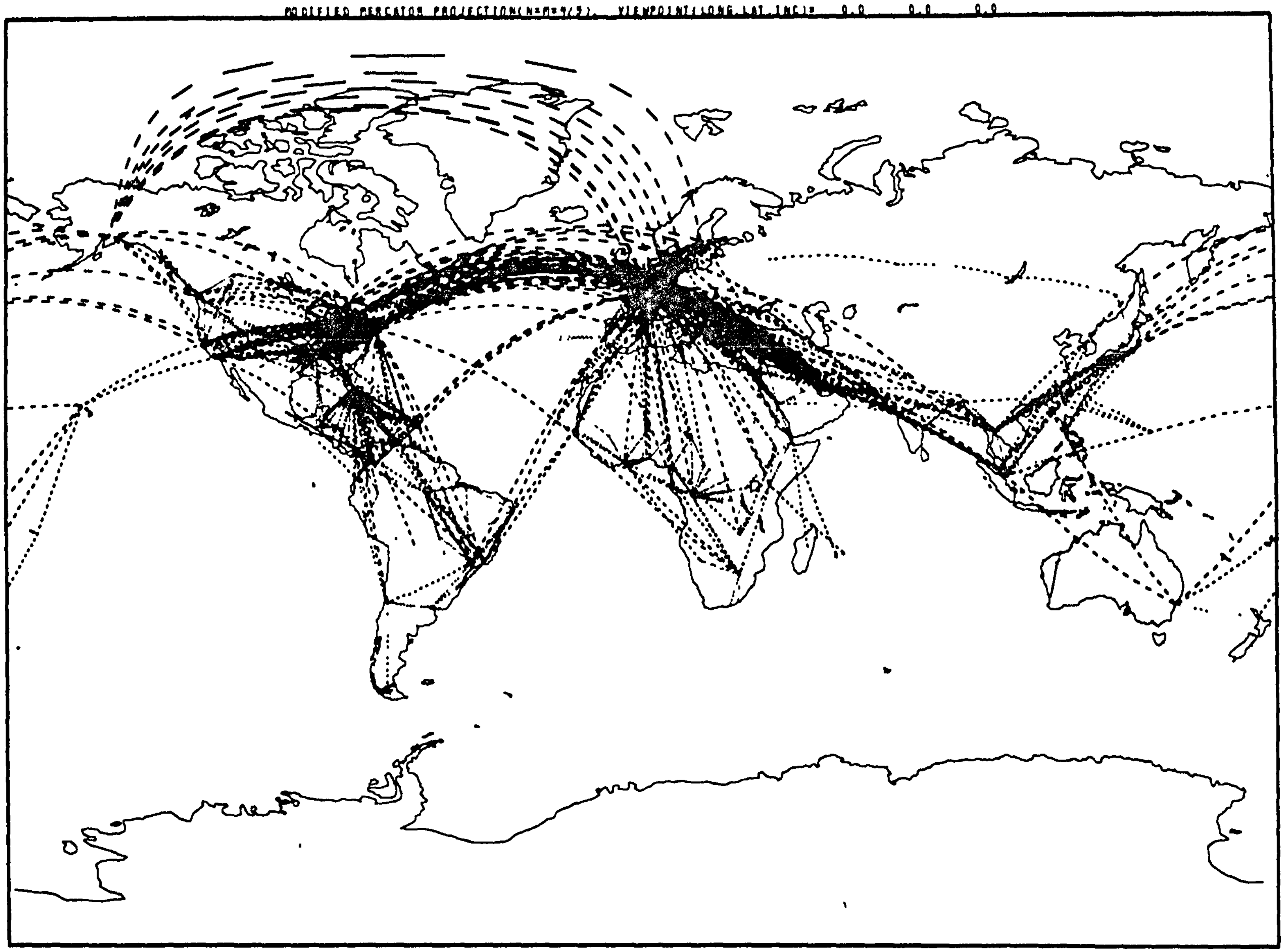


FIGURE 4-2. SCHEDULED ALL-CARGO AIRPORT-PAIRS, OAG AUGUST 1978

TABLE 4-1

1978 DAILY JET FLEET STATISTICS

Market	U.S. Domestic	U.S. International	Foreign	Total
Airport-Pairs	98	76	584	704
Daily Statistics (1978)				
Departures (Trips)	175.86	52.86	349.57	578.29
Distance Flown - KM (SM)	295640 (183702)	178788 (111094)	776137 (482269)	1250565 (777065)
Available Capacity - AT (SM)	8587 (9467)	3854 (4249)	12077 (13315)	24518 (27031)
Available Capability - ATKM x 10^6 (ATSM x 10^6)	15193 (10406)	13541 (9275)	34600 (23699)	63335 (43380)
Hours Flown	450	241	1134	1825

Simulating Aircraft Operations

As discussed in Section 3, the 1978 market demand was served by 15 generic types of jet aircraft. Since additional types would be added in the future, the number yet undetermined, consideration was given to reducing the number of current types to a reasonable level. This section discusses the subsequent identification of representative types, their operating capabilities and their utilization in the 1978 fleet.

Generic Aircraft Types. - Detailed analysis of the 15 generic types of aircraft showed that their capability could be adequately represented by three payload sizes of aircraft. These representative payloads were determined on the basis of the weighted average of the capabilities and capacities of the respective generic types as utilized in the 1978 OAG. The payloads for each type aircraft are presented in Table 4-2 along with the resulting payloads of the three representative aircraft designated as A1, A2 and A3. These data also designate by name the specific OAG identified aircraft encompassed by each of the representative aircraft. Maps showing current airport-pairs for these aircraft are shown in Figures 4-3 through 4-5. The viability of this representation in simulating the overall 1978 jet cargo operations will be discussed later in this section.

Payload-Range Capabilities. - The payload and range capabilities for the three representative aircraft were derived from characteristics available for the respective aircraft identified in Table 4-2. These data were inputs to a computerized performance program which provided the payload-range curves shown in Figures 4-6 through 4-8. To facilitate comparisons, the payloads are presented in these figures in terms of load factor.

The relationships between the design capabilities of the representative aircraft and the utilization experienced in the 1978 OAG operations are presented in Figures 4-6 through 4-8 in terms of daily trips and capability versus range. Figures 4-6 shows that the operational ranges flown by the smallest capacity aircraft, the A1, are less than its design range, 3369 kilometers (2094 statute miles) compared to 3805 kilometers (2365 statute miles). The full payload of 14.15 tonnes (15.6 tons) was available over all the ranges flown.

TABLE 4-2

REPRESENTATIVE AIRCRAFT PAYLOAD DEFINITION

OAG Generic Code	Current All-Cargo Aircraft: Aircraft Name	Tonnes	(Tons)	Representative Aircraft: Study Code	Tonnes	(Tons)
D91	DC-9-10	10.7	(11.8)			
D9F	DC-9 Freighter	10.7	(11.8)			
D9S	DC-9-30/40 Series	12.9	(14.2)			
72F	B727 Freighter (All Series)	17.8	(19.6)	A1 →	14.15	(15.60)
73F	B737-200 Freighter	15.2	(16.8)			
73S	B737-200	15.2	(16.8)			
FJF	Fokker Fellowship (All Series)	6.1	(6.7)			
DC-8	DC-8-10/50	44.2	(48.7)			
D8F	DC-8 Freighter	44.2	(48.7)			
D8U	DC-8-62 Freighter	44.2	(48.7)	A2 →	42.87	(47.27)
703	B707-320/320A	41.4	(45.7)			
70F	B707 Freighter (All Series)	41.4	(45.7)			
D1F	DC-10 Freighter	76.4	(84.2)			
74F	B747 Freighter	94.9	(104.6)	A3 →	94.74	(104.45)
747	B747	112.6	(124.1)			

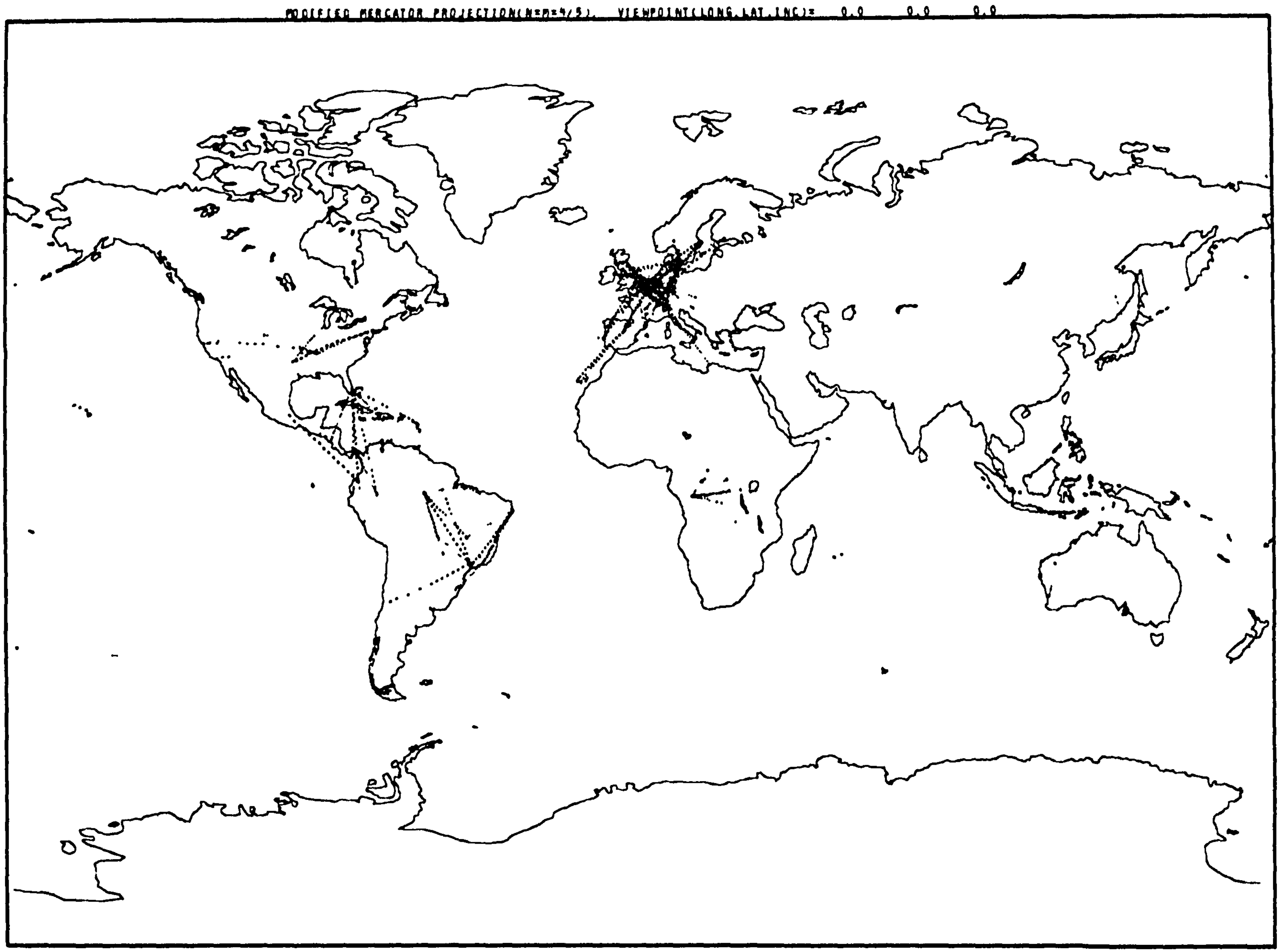


FIGURE 4-3. AIRPORT-PAIRS SERVED BY A1 AIRCRAFT, OAG AUGUST 1978

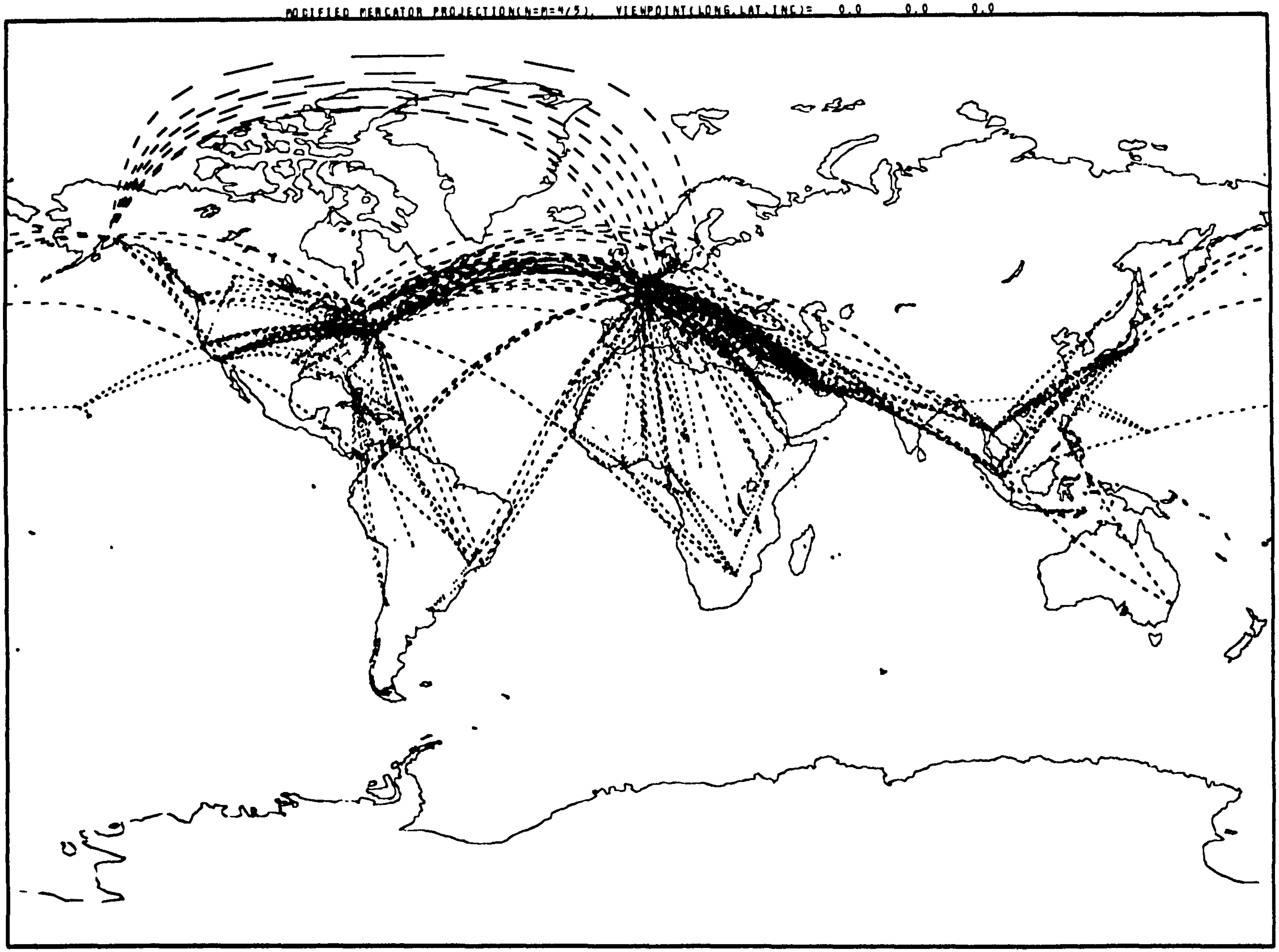


FIGURE 4-4. AIRPORT-PAIRS SERVED BY A2 AIRCRAFT, OAG AUGUST 1978

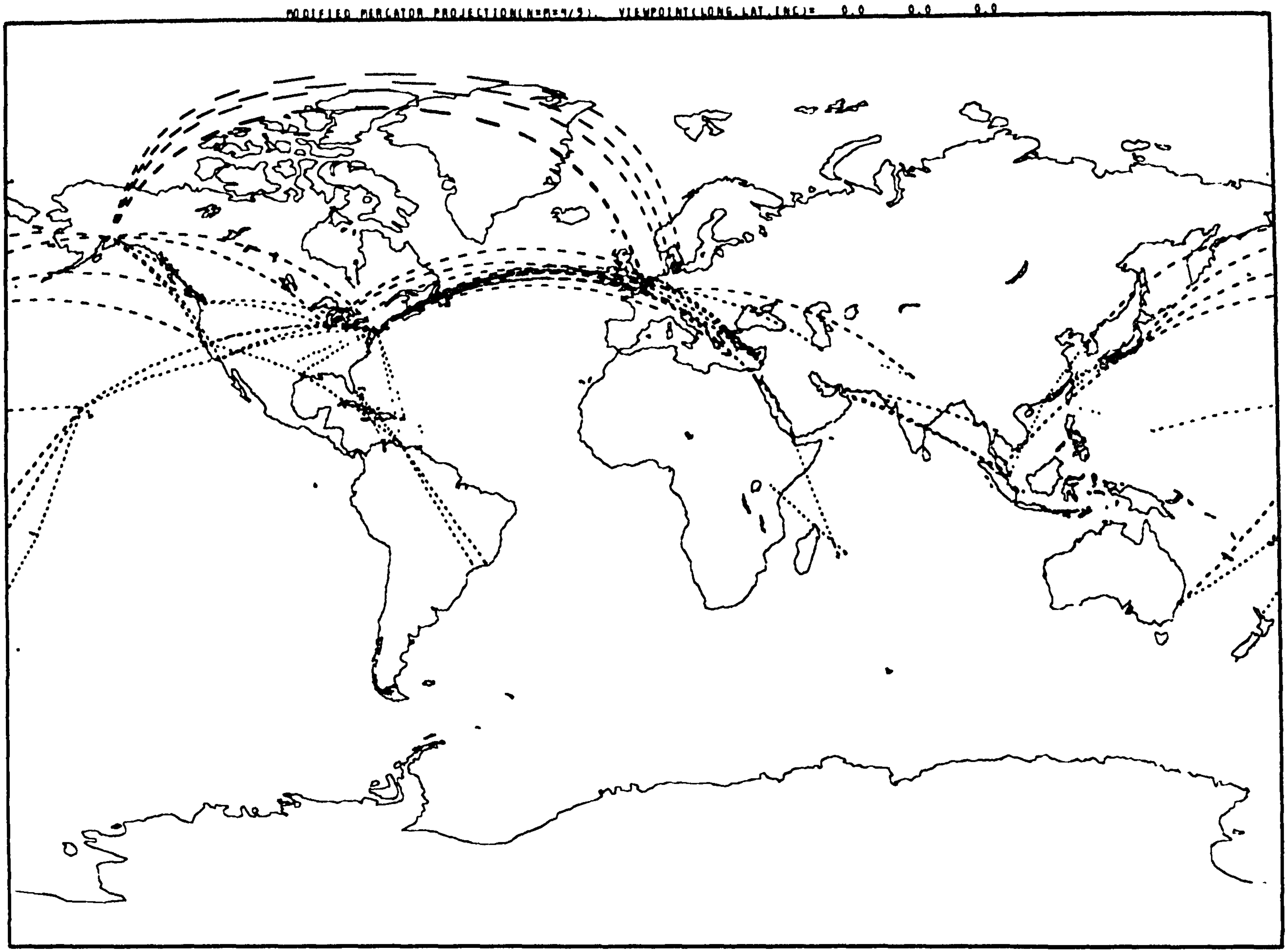


FIGURE 4-5. AIRPORT-PAIRS SERVED BY A3 AIRCRAFT, OAG AUGUST 1978

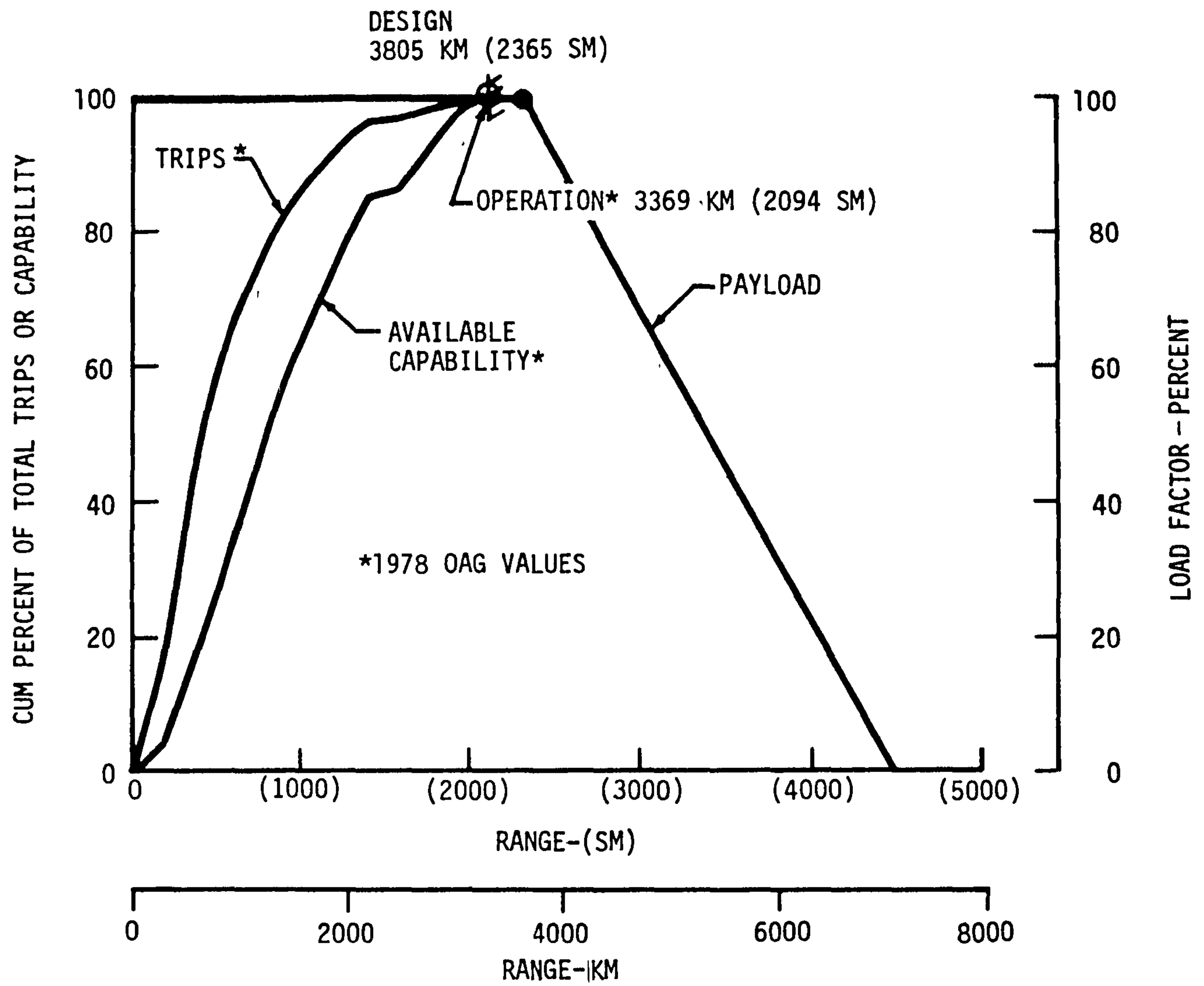


FIGURE 4-6. PAYLOAD-RANGE CAPABILITY FOR A1 TYPE AIRCRAFT

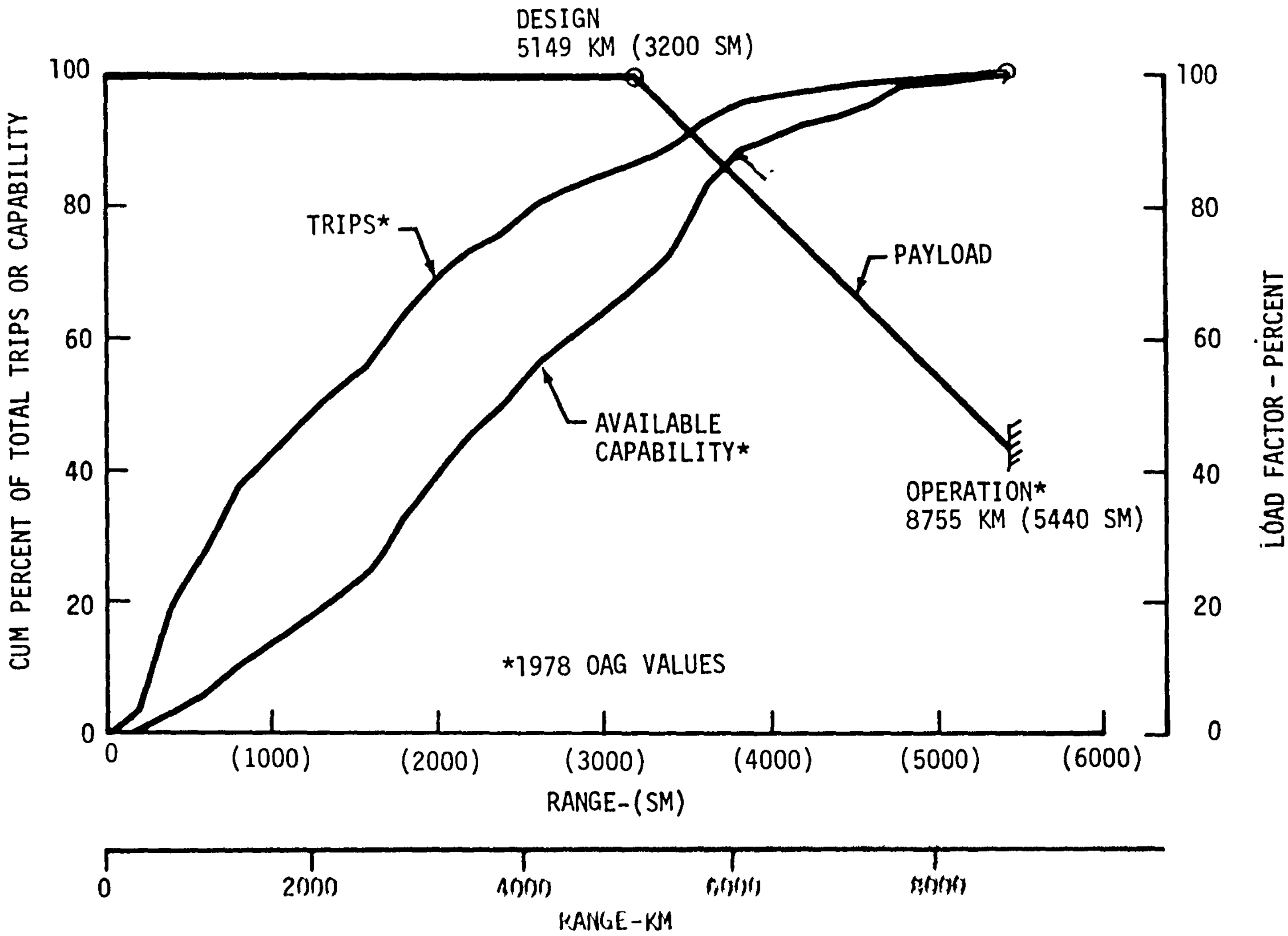


FIGURE 4-7. PAYLOAD-RANGE CAPABILITY FOR A2 TYPE AIRCRAFT

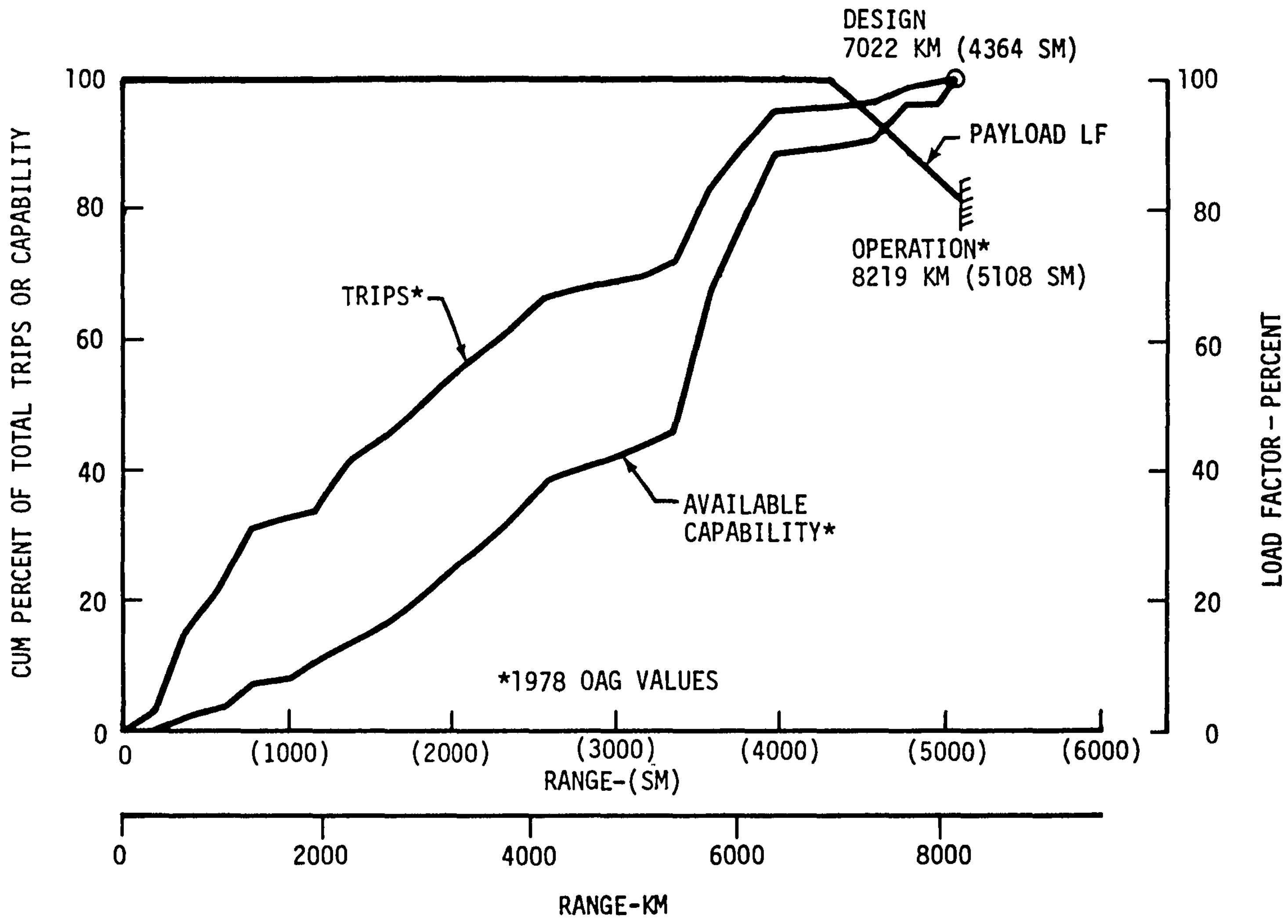


FIGURE 4-8. PAYLOAD-RANGE CAPABILITY FOR A3 TYPE AIRCRAFT

Utilization of the large narrow body aircraft, the A2, varies considerably from that for the smaller A1. The data of Figure 4-7 shows that the 42.87 tonnes (47.27 tons) A2 aircraft is operated at a range of 8753 kilometers (5440 statute miles) well beyond the design range of 5149 kilometers (3200 statute miles). This aircraft is performing 13 percent of its trips and providing 30 percent of its capability at operational ranges well beyond the design range. However, at the maximum operating range the load factor is reduced to approximately 43 percent. If the payload were maintained at a 70 percent or greater load factor, less than 2 percent of the trips and 7 percent of the available capability would not be evaluated correctly.

The current wide-body aircraft, A3, are utilized nearer their design range as evidenced in Figure 4-8. This is the largest aircraft in the current fleet with a representative payload of 94.74 tonnes (104.45 tons). This aircraft is utilized to a range of 8219 kilometers (5108 statute miles) which is 17 percent greater than the design range. This maximum operational range can be achieved with a greater than 80 percent load factor. Note that 55 percent of the available capability is provided at ranges greater than about 5310 kilometers (3300 statute miles) using less than 30 percent of the total trips flown.

Maps of the 1978 airport-pairs for the considered markets are shown in Figures 4-9 through 4-11. The fleet operations of the three representative aircraft are summarized in Table 4-3 for each of these considered markets. In the U.S. domestic and foreign markets the A2 aircraft predominate with sizable margins. This type aircraft has the most departures, flys the greater distance and provides more capacity and capability than the A1 and A3 aircraft combined. However, the A3 aircraft stands out in U.S. international operations. These conclusions are graphically illustrated in the market summary portion of Figures 4-12 and 4-13 which also show the dominance of the foreign market. The aircraft summary portion of Figures 4-12 and 4-13 shows that the A2 aircraft account for more than half the available capability with the majority being generated in the foreign market. In a like manner, the foreign market makes the greater use of the A1 aircraft.

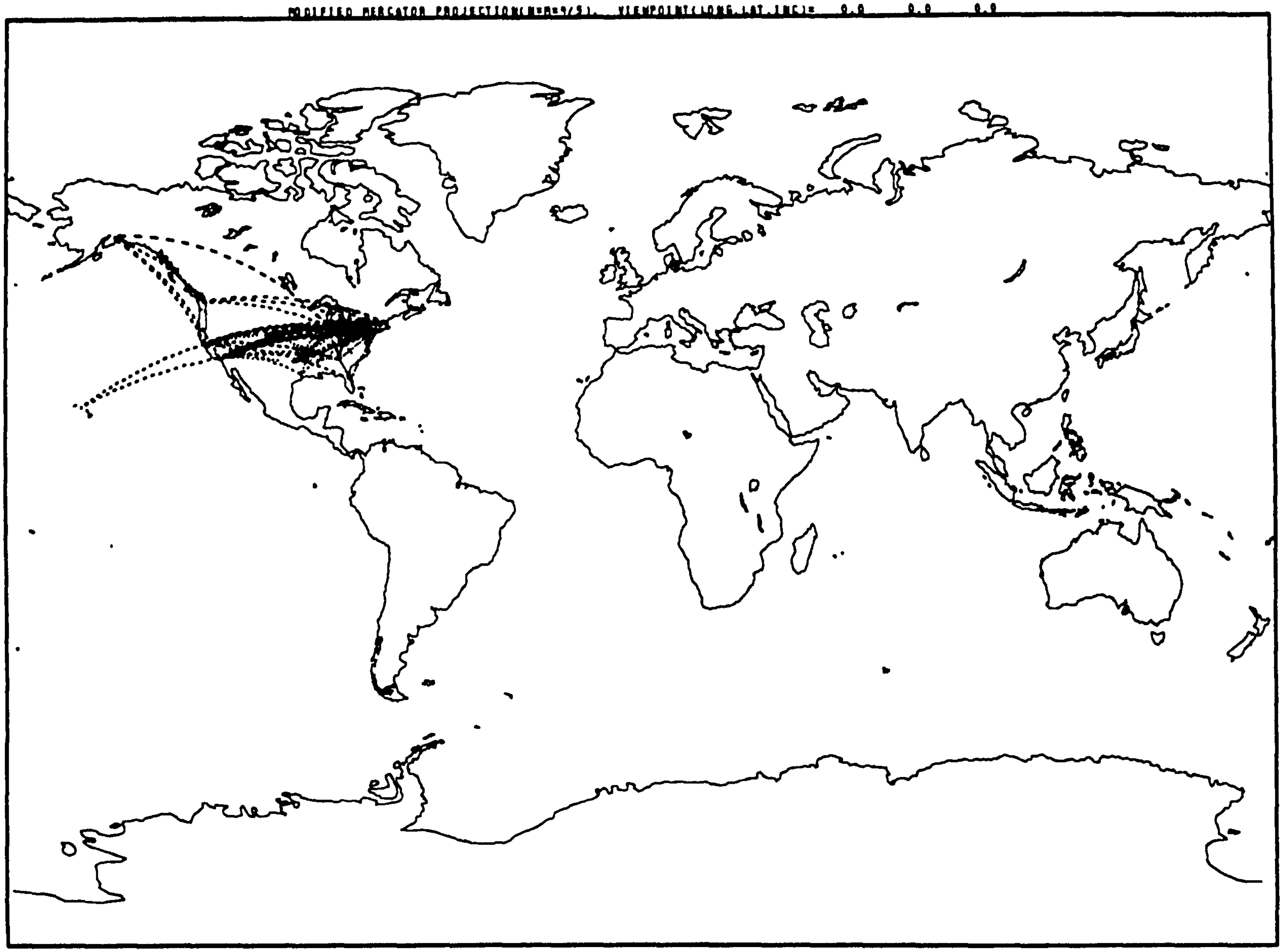


FIGURE 4-9. U.S. DOMESTIC MARKET AIRPORT-PAIRS SERVED BY JET CARGO AIRCRAFT, OAG AUGUST 1978

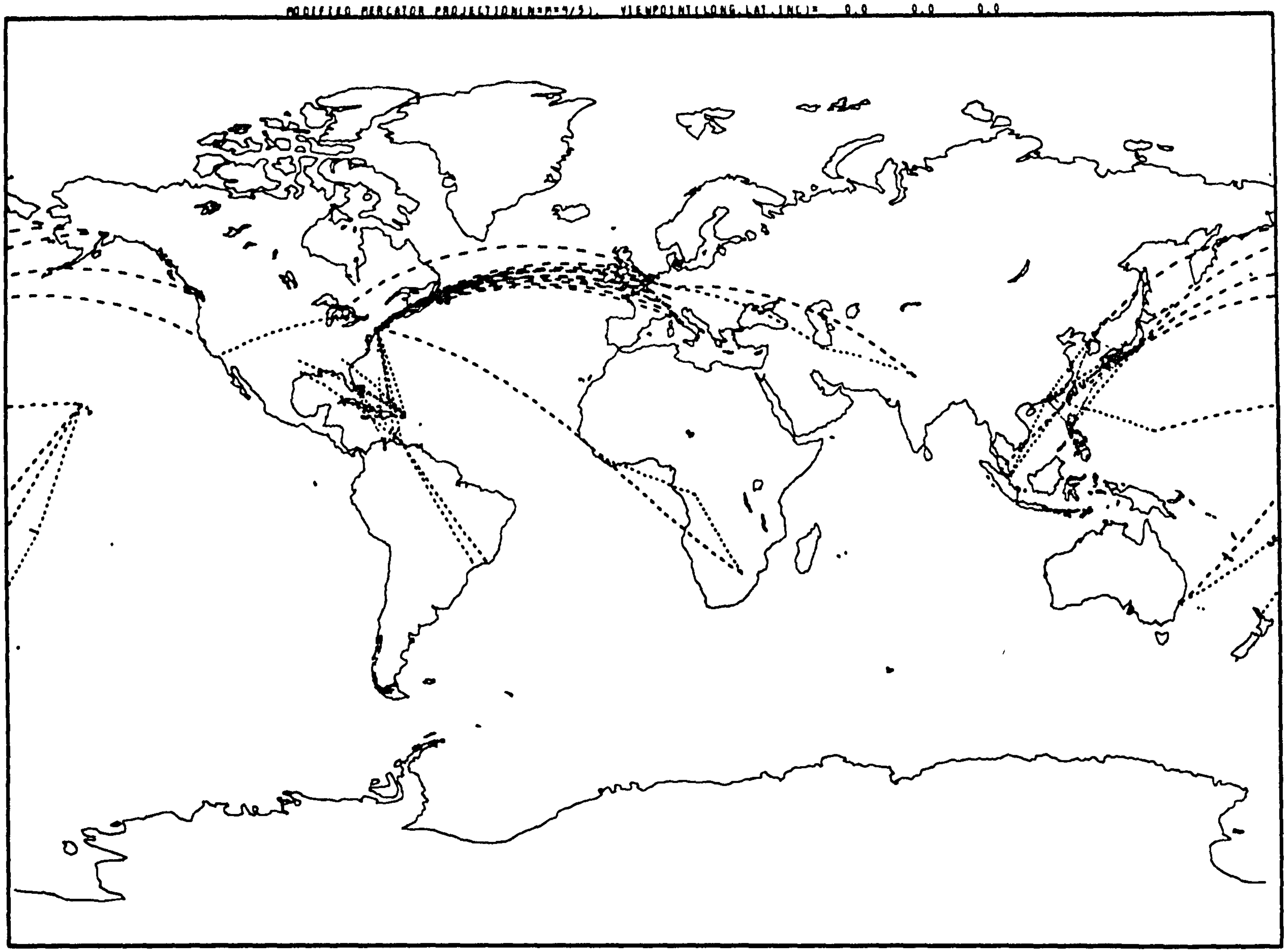


FIGURE 4-10. U.S. INTERNATIONAL MARKET AIRPORT-PAIRS SERVED BY JET CARGO AIRCRAFT, OAG AUGUST 1978

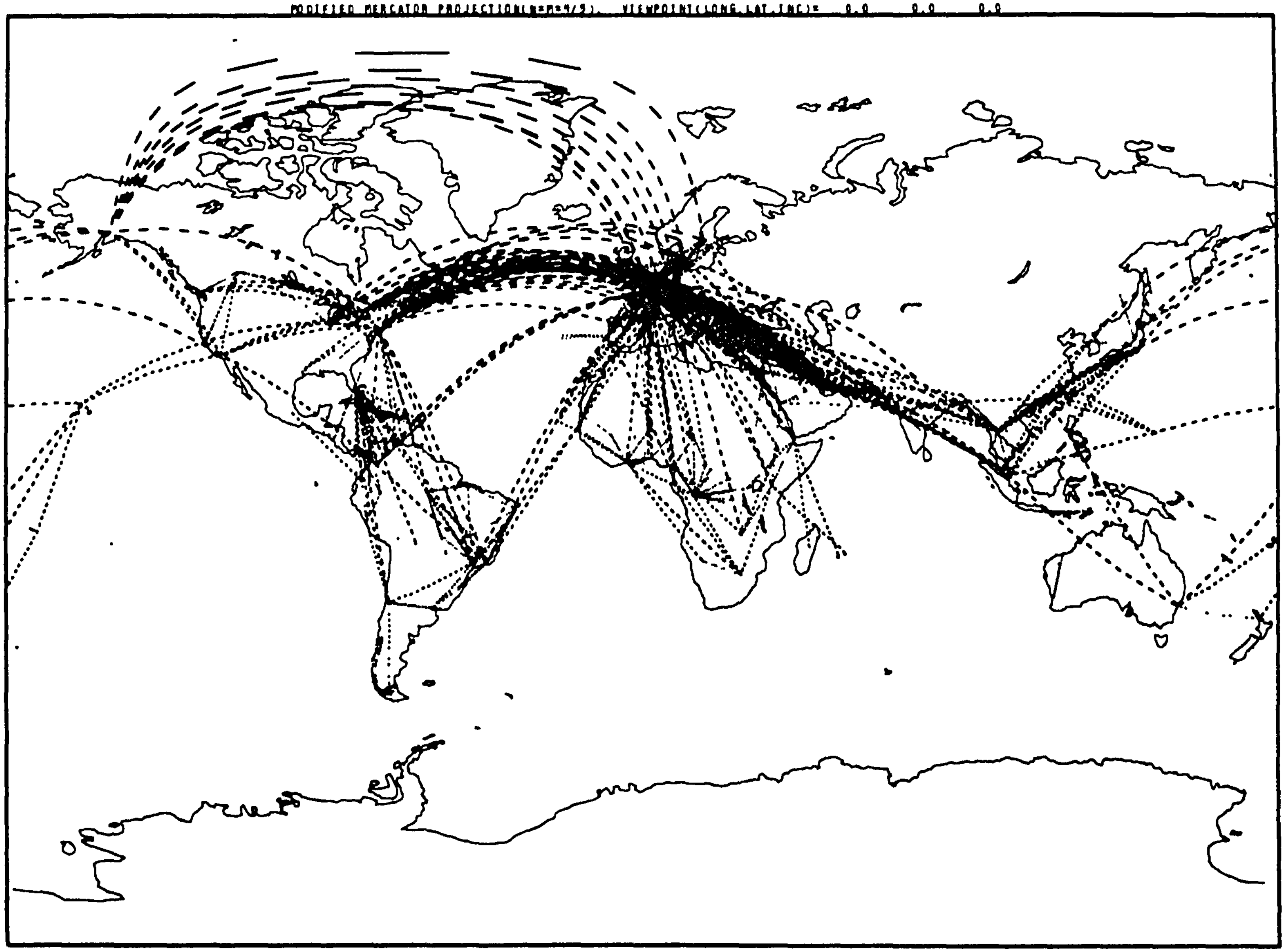


FIGURE 4-11. FOREIGN MARKET AIRPORT-PAIRS SERVED BY JET CARGO AIRCRAFT, OAG AUGUST 1978

TABLE 4-3

REPRESENTATIVE AIRCRAFT 1978 UTILIZATION

Markets	Daily Statistics			
U.S. Domestic	A1	A2	A3	Total
Airport-Pairs	17	80	22	98
Departures (Trips)	20.43	126.57	28.86	175.86
Distance Flown - KM (SM)	23004 (14294)	215340 (133806)	57294 (35601)	295638 (183701)
Available Capacity - AT (AT)	350.7 (386.6)	5498.8 (6062.4)	2737.8 (3018.4)	8587.2 (9467.4)
Available Capability - ATKM x 10^6 (ATSM x 10^6)	404932 (277352)	9350670 (6404598)	5436781 (3723840)	15192838 (10405790)
Hours Flown	36.07	326.34	87.13	449.54
U.S. International				
Airport-Pairs	1	38	45	76
Departures (Trips)	1.43	20.29	31.14	52.86
Distance Flown - KM (SM)	616 (383)	65283 (40565)	112889 (70146)	178788 (111094)
Available Capacity -AT (AT)	25.4 (28.0)	873.9 (963.5)	2954.6 (3257.5)	3854.0 (4249.0)
Available Capability - ATKM x 10^6 (ATSM x 10^6)	10956 (7504)	2817927 (1930096)	10712356 (7377264)	13541239 (9274864)
Hours Flown	1.31	90.31	149.07	240.69
Foreign				
Airport-Pairs	175	404	56	584
Departures (Trips)	135.00	193.00	21.57	349.57
Distance Flown - KM (SM)	111566 (69324)	570831 (354698)	93738 (58246)	766135 (482268)
Available Capacity - AT (AT)	1842.8 (2031.7)	8200.2 (9040.7)	2035.6 (2244.2)	12077.6 (13315.6)
Available Capability - ATKM x 10^6 (ATSM x 10^6)	1576015 (1079467)	24217476 (16587389)	8806976 (6032203)	34600466 (23699059)
Hours Flown	200.80	810.20	122.68	1133.68

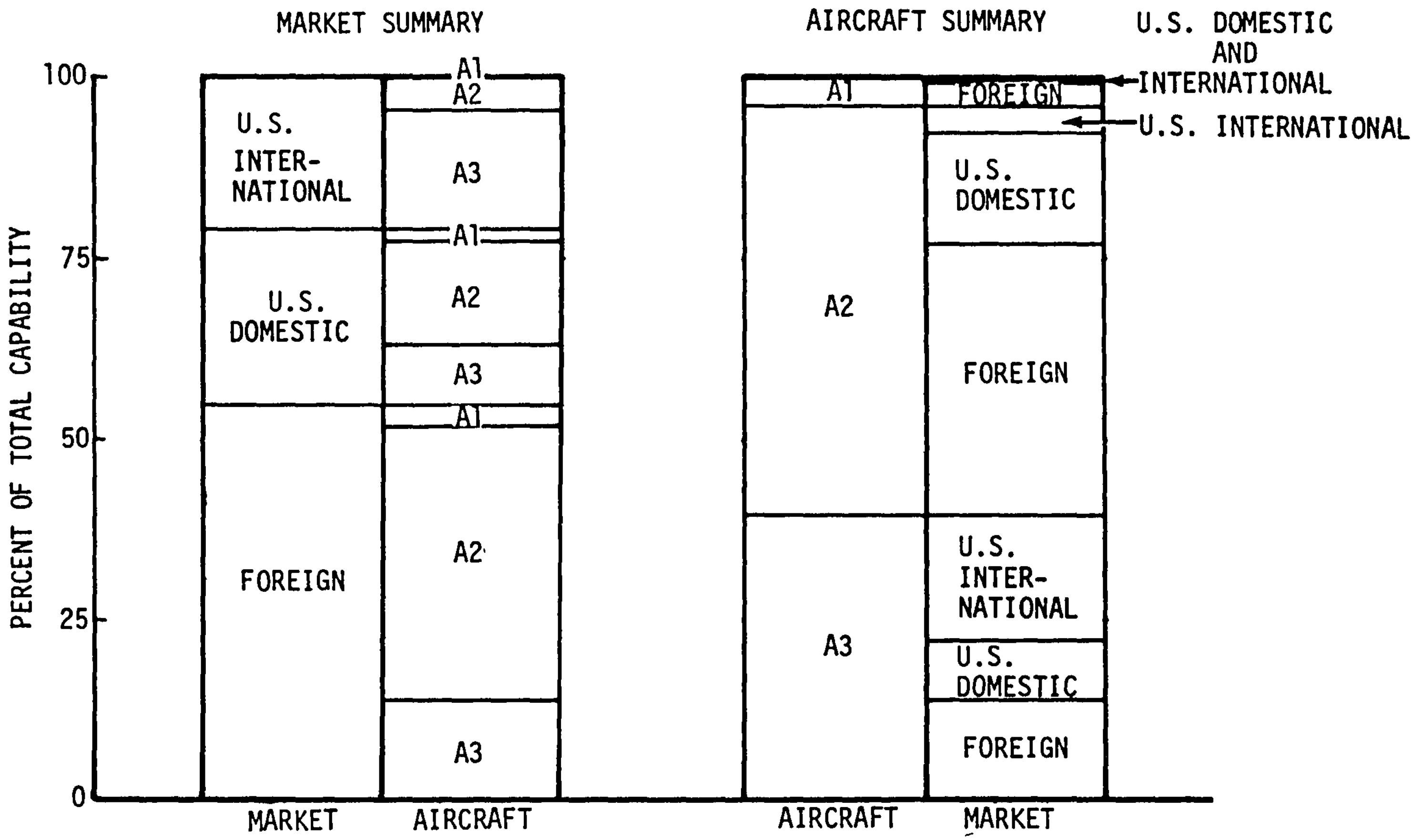


FIGURE 4-12. 1978 MARKET AND AIRCRAFT DAILY CAPABILITY SUMMARY

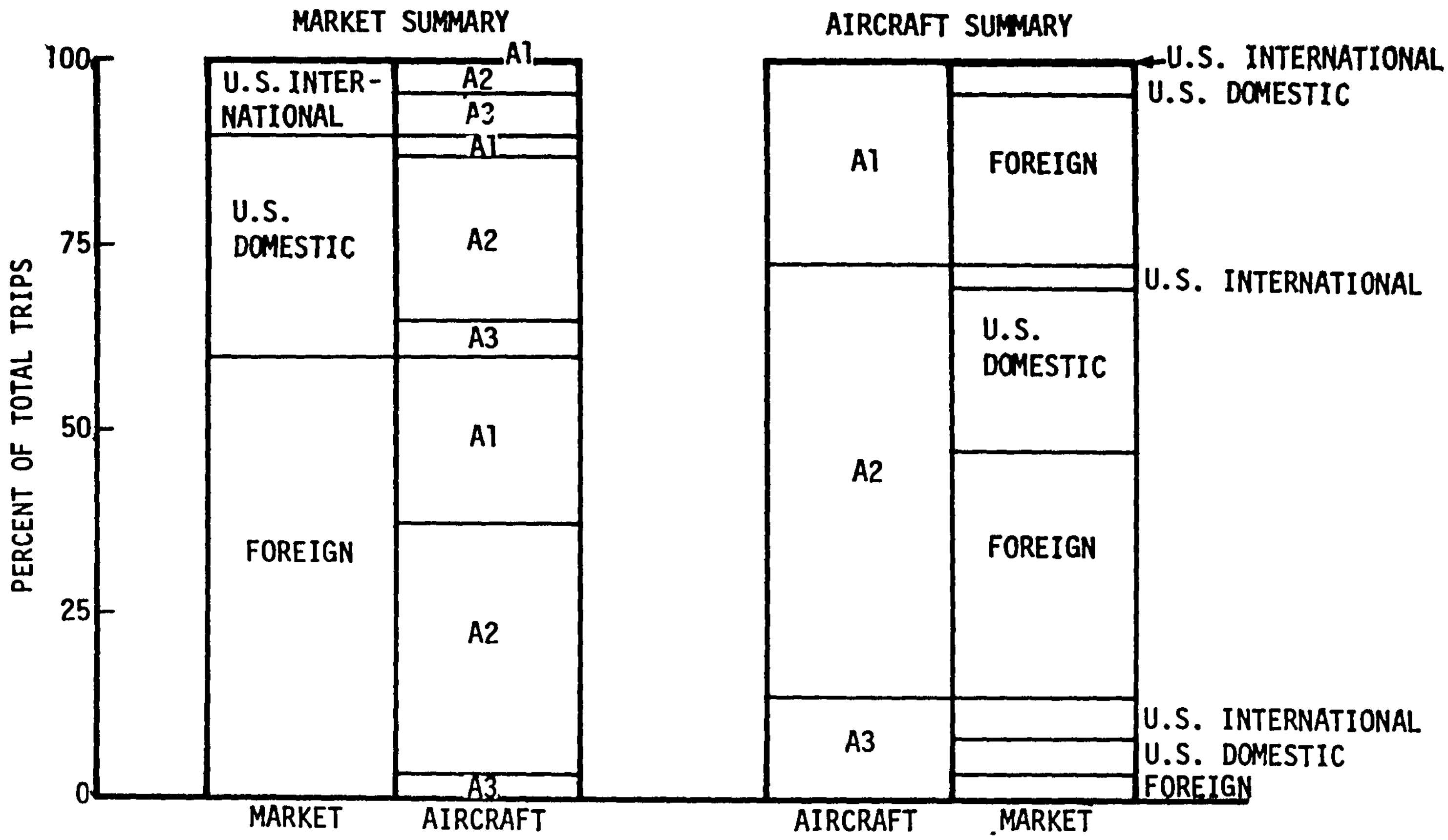


FIGURE 4-13. 1978 MARKET AND AIRCRAFT DAILY TRIP SUMMARY

Cargo Model Range Elements

During their useful life, each of the representative types of aircraft provide service over a wide spectrum of operational ranges within each of the three markets considered. In order to maintain data points within the computer program capacity, the actual OAG ranges were aggregated into 322 kilometers (200 statute miles) elements. As an example, all ranges falling within 3218 to 3540 kilometers (2000 to 2200 statute miles) were collected and identified as a single range element. There were 133 such elements required to describe the three aircraft and three markets in this range increment. A map of 133 airport-pairs representing the 133 elements is shown on Figure 4-14. The available total and revenue (total affected by load factor) capabilities along with the number of departures for each aircraft within each market were then identified under the appropriate element as indicated by the 1978 OAG network data. The annual data for these elements as contained within the system model are summarized and compared to the comparable actual 1978 OAG values in Table 4-4.

The first column of Table 4-4 identifies the three cargo markets and the three representative aircraft. The second column gives the number of different range elements performed by each type aircraft in the respective markets. As an example, the A1 aircraft serves 7 different range elements in the U.S. domestic market, 15 in the international and 12 in the foreign. The remaining four columns present values for system operations as derived from the model with the last three directed to the capability provided by each type aircraft. The total available capability, column 4, is a function of the design payload of the respective aircraft while the available revenue capability, column 6, is the portion available for revenue payload as determined by the aircraft load factors. In Table 4-4 the values in a given row are the totals for a specific aircraft operating in the respective markets shown.

The accuracy of the model in reproducing actual network statistics is illustrated in columns three and four where the OAG values for departures and available capability are compared to the computed values subtotal (model). It is seen that the differences in these values were small. The available revenue capability was derived from the total available capability through

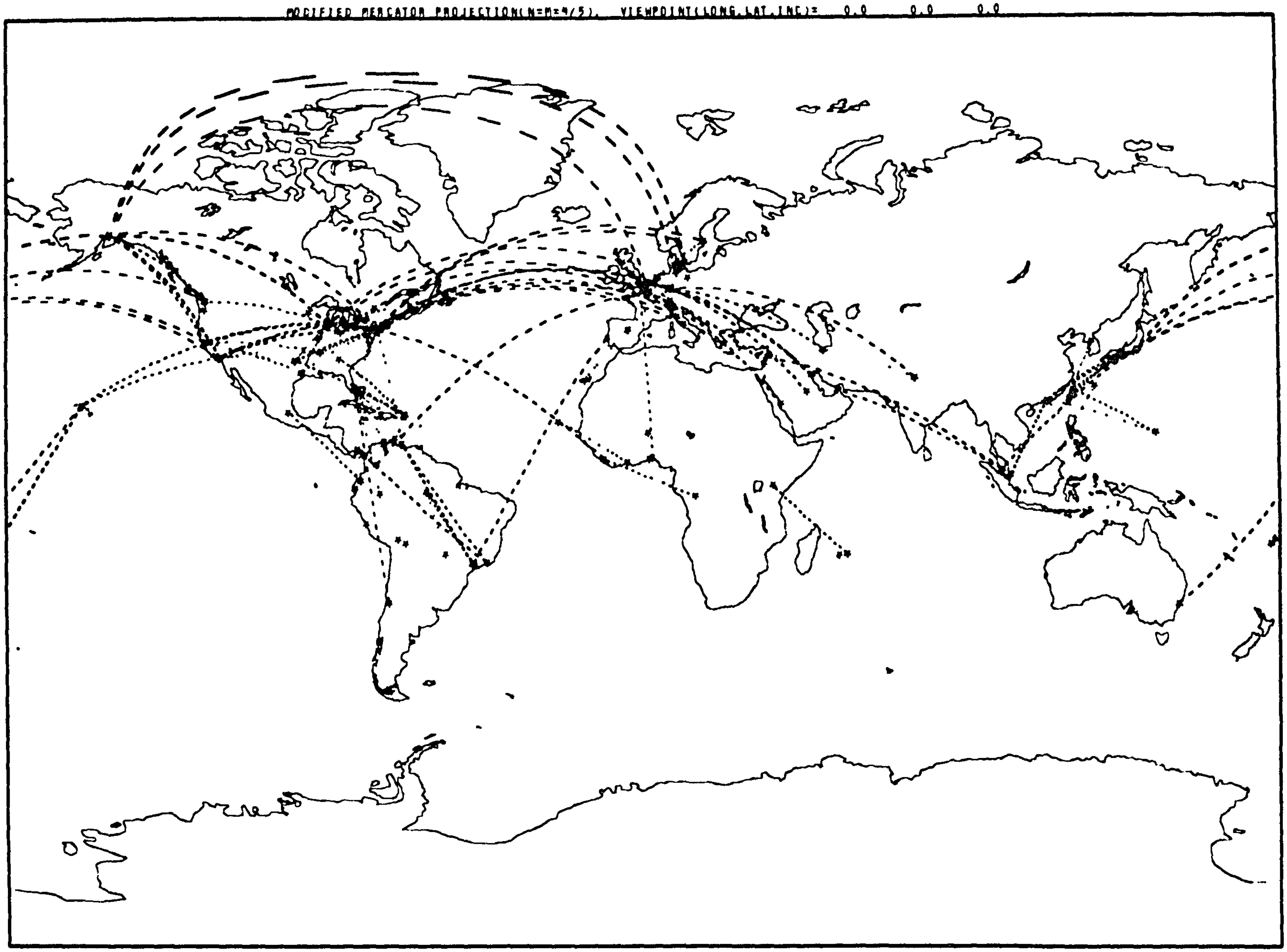


FIGURE 4-14. CARGO SYSTEM MODEL — 133 ELEMENTS REPRESENTING JET CARGO OPERATIONS

TABLE 4-4

1978 CARGO MODEL ELEMENTS

Column: 1	2 No. of Range Elements	3 Annual Departures (Trips)	Annual Capability 4 Available ATKMx10^9	(ATSMx10^9)	5 Load Factor	6 Revenue ARTKMx10^9	(ARTSMx10^9)
U.S. Domestic Market							
A1	7	7456	0.118	(0.081)	57.60	0.069	(0.047)
A2	1	46198	3.371	(2.309)	57.53	1.939	(1.328)
A3	11	10533	1.981	(1.357)	57.60	1.142	(0.782)
Subtotal (Model)	19	64187	5.471	(3.747)	57.56	3.149	(2.157)
OAG		64189		(3.799)			
U.S. International Market							
A1	15	521	0.003	(0.002)	60.30	0.001	(0.001)
A2	27	7404	1.022	(0.700)	60.02	0.613	(0.420)
A3	17	11367	3.904	(2.674)	60.30	2.355	(1.613)
Subtotal (Model)	59	19292	4.929	(3.376)	60.24	2.970	(2.034)
OAG		19294		(3.387)			
Foreign Market							
A1	12	49275	0.577	(0.395)	52.13	0.301	(0.206)
A2	22	70445	8.935	(6.120)	53.48	4.779	(3.273)
A3	21	7874	3.243	(2.221)	53.26	1.727	(1.183)
Subtotal (Model)	55	127594	12.755	(8.736)	53.36	6.806	(4.662)
OAG		127593		(8.650)			
Grand Total (Model	133	211073	23.154	(15.859)	55.82	12.925	(8.853)
OAG Total		211076		(15.836)			

application of the load factors discussed in Section 1; namely, 57.6 for U.S. Domestic, 60.3 for U.S. International, and 54.1 for the Foreign operations. Due to the analytical operations conducted in the program the computed load factors, subtotals of column 5, vary slightly from the desired. Maximum deviation occurred for the foreign market where the model value was about 1 percent low.

Required Fleet Capability (1978-2008)

The forecast market growth rates derived in Section 1, reference Table 1-4, were applied to all range elements making up each of the three market areas. To assure that these demands could be met at the future forecast aircraft load factors derived in Section 1, and shown in Figure 4-15, compatible values of total available capability were computed and input to the model. Values so derived for the 1978 market demand and load factor are presented in Table 4-5. Similarly, values of available capability were developed for the respective markets out to the year 2008 based upon forecast demand and load factors of Section 1. The resulting available capabilities are illustrated in Figure 4-16 in terms of the total for the three markets. However, in the FRAME calculations the unique values for respective markets were maintained.

Independent Variables

Additional independent variables required by the FRAME program are summarized in Table 4-6 along with the values used for the various study time periods. Most of the variables were constants; however, two variables, the utilization and yield data, were input as functions. The utilization was input as a function of aircraft block time, Figure 4-17, and yield as a function of operational range, Figure 4-18. For each of the study time periods these functions were adjusted to give the average utilization and yield for the initial year as given in Table 4-6.

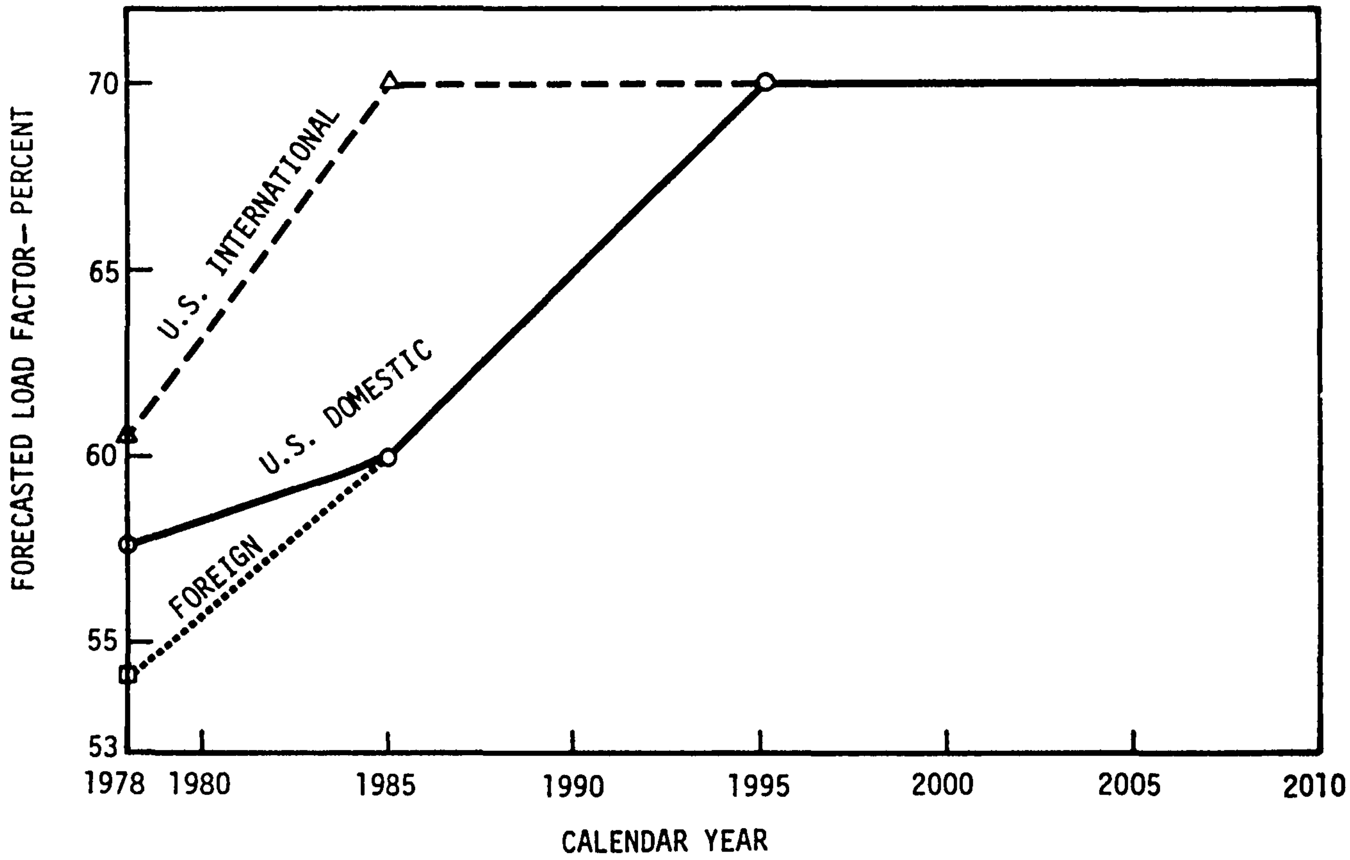


FIGURE 4-15. LOAD FACTOR FORECAST

TABLE 4-5

1978 ANNUAL JET FLEET AVAILABLE CAPABILITY

Market	U.S. Domestic	U.S. International	Foreign	Total
Market Demand (from forecast) - RTKM x 10^6 (RTSM x 10^6)	3194 (2188)	2981 (2042)	6836 (4682)	13011 (8912)
Load Factor - Percent	57.6	60.3	54.1	56.3
Available Capability (from current jet data) - ATKM x 10^6 (ATSM x 10^6)	5547 (3799)	4945 (3387)	12629 (8650)	23120 (15836)

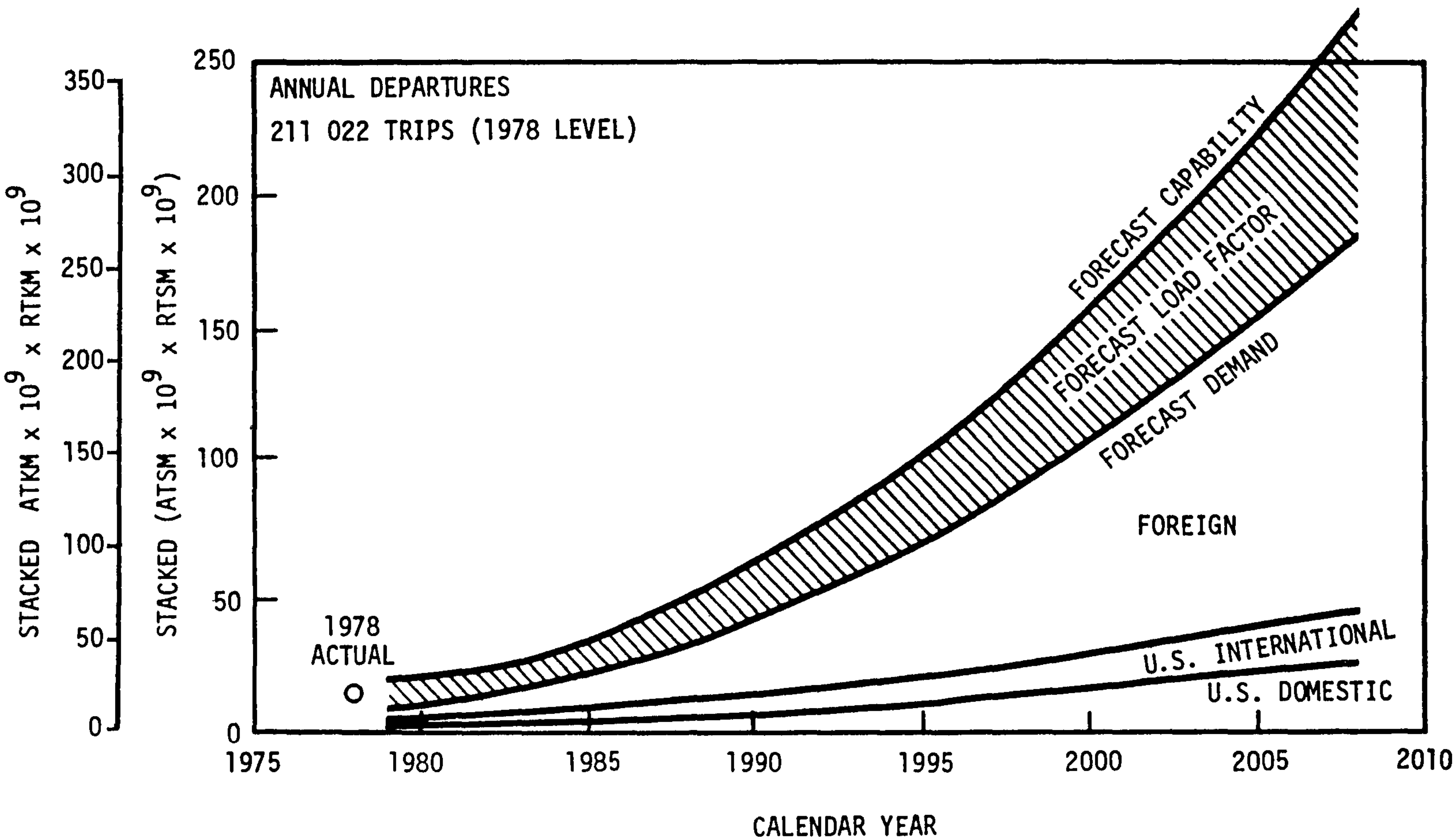


FIGURE 4-16. FORECAST MARKET DEMAND AND FLEET CAPABILITY

TABLE 4-6

INDEPENDENT VARIABLES

Study Time Period Initial Year	1978-1992 1978	1984-1998 1984	1994-2008 1994
Variables			
Inflation Rate - Percent per Year	6	6	6
Income Tax Rate - Percent per Year	48	48	48
Depreciation			
Method	Double Declining to Straight Line		
Period - Years	7	7	7
Residual Value - Percent of Initial A/C Price	10	10	10
Aircraft Financing	Cash	Cash	Cash
IOC - Percent of Revenue	42	36	32
Insurance - Percent of Initial A/C Price per Year	1	1	1
Fuel - Initial Year - ¢/liter (¢/U.S. Gallon)	11 (43)	19 (71)	98 (181)
Utilization - Average Hours per Year	3000	3300	3600
Average Market Yields - Initial Year - $ per RTKm ($ per RTM)			
U.S. Domestic	0.218 (0.319)	0.274 (0.400)	0.468 (0.683)
U.S. International	0.162 (0.237)	0.204 (0.298)	0.350 (0.511)
Foreign	0.262 (0.383)	0.328 (0.479)	0.560 (0.818)

All $ are Inflated from the Initial Year Values at the Inflation Rate.

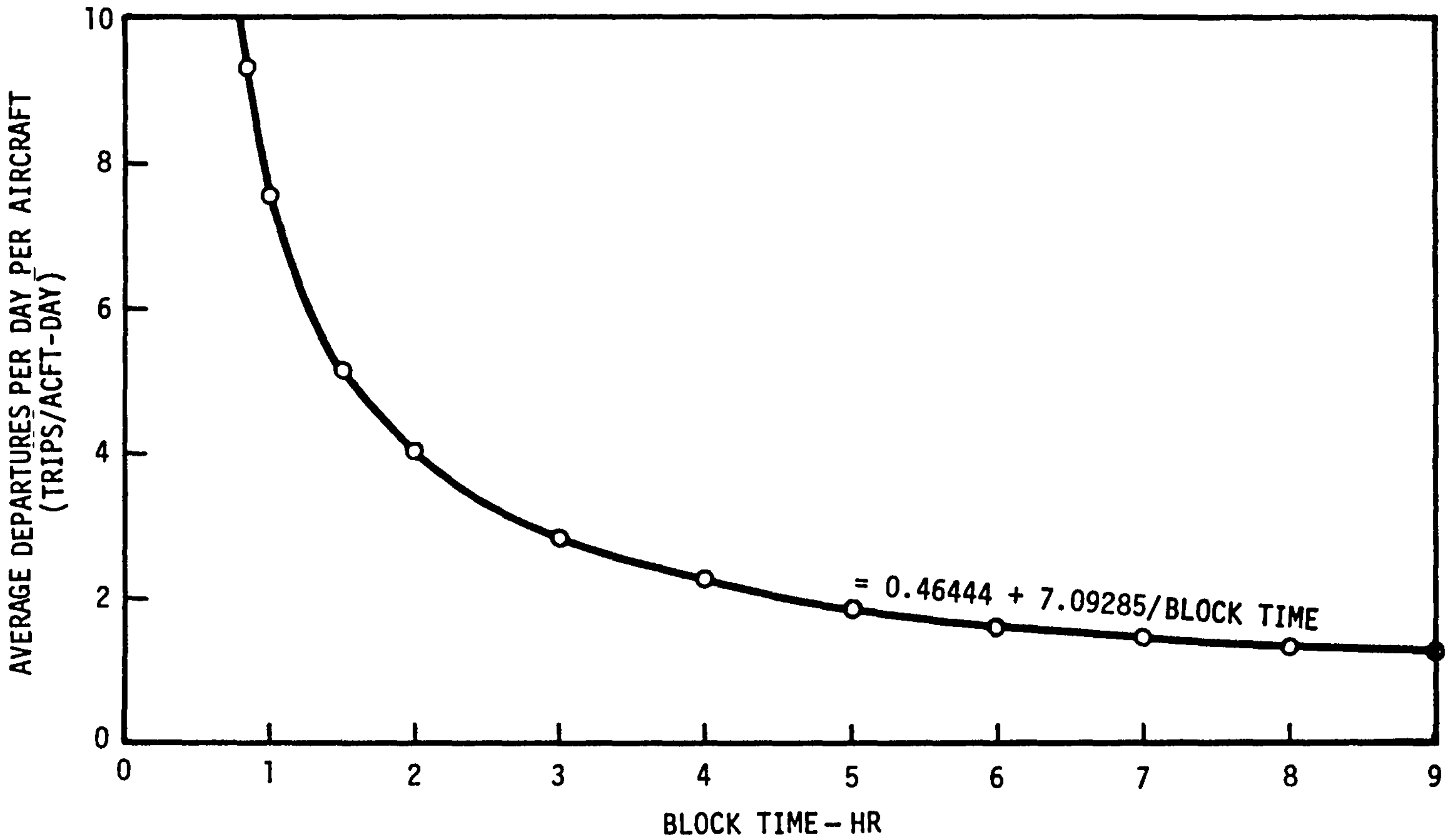


FIGURE 4-17. UTILIZATION VARIATION WITH BLOCK TIME

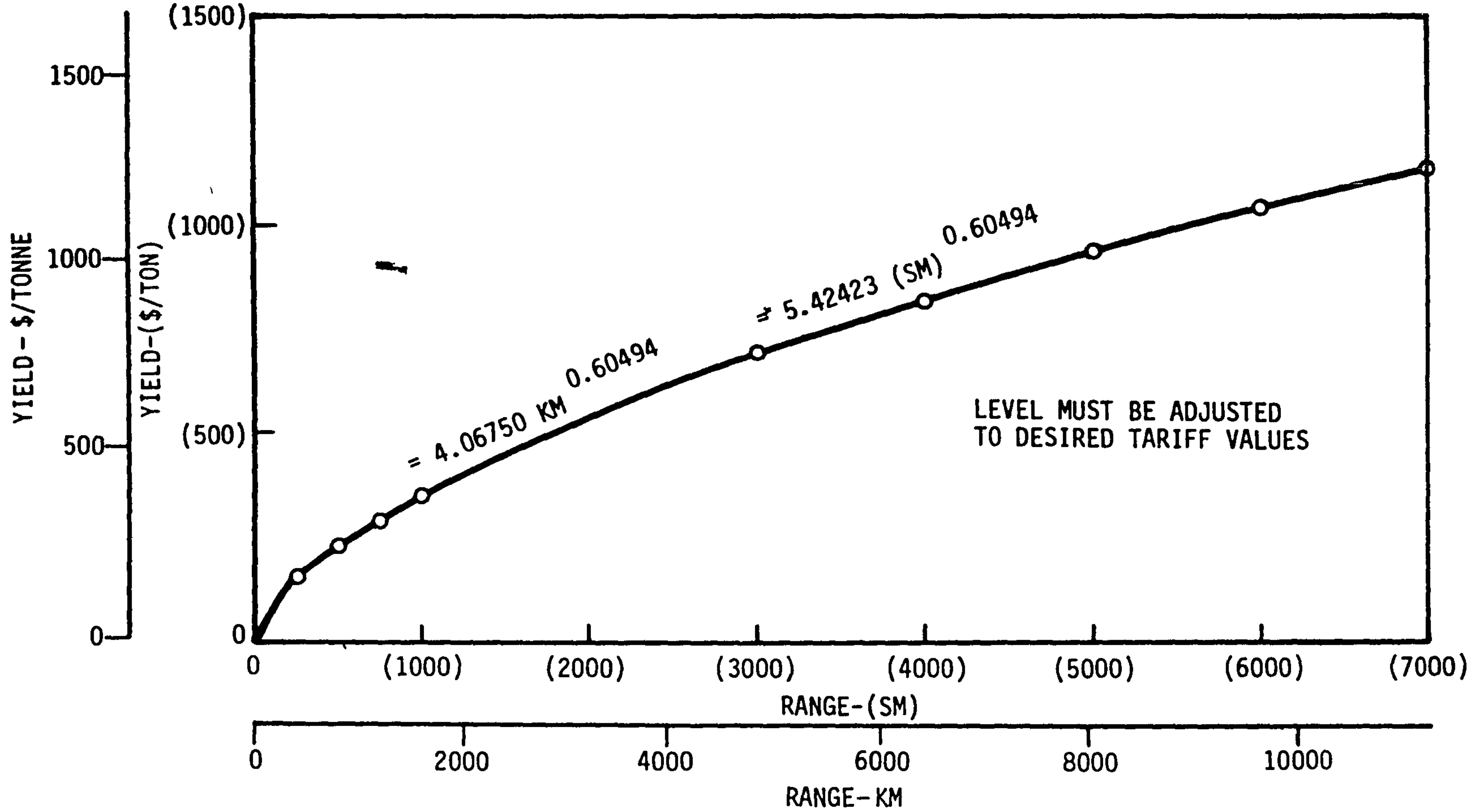


FIGURE 4-18. YIELD VARIATION WITH RANGE

System Constraints

The only system constraints considered during this study were related to the air cargo market demand forecast and the annual trips. The aircraft selected must perform all the forecast demand for each market area at a service level (number of daily trips) equal to or greater than the current (1978) level. The service level on each range element can increase (exceed the current trips) as the aircraft profit on the element increases, but the current level, minimum constraint, must be satisfied. The forecast market demand constraint is defined in Section 1 and shown in Figure 4-16. The minimum service level constraint is summarized below:

SERVICE CONSTRAINT

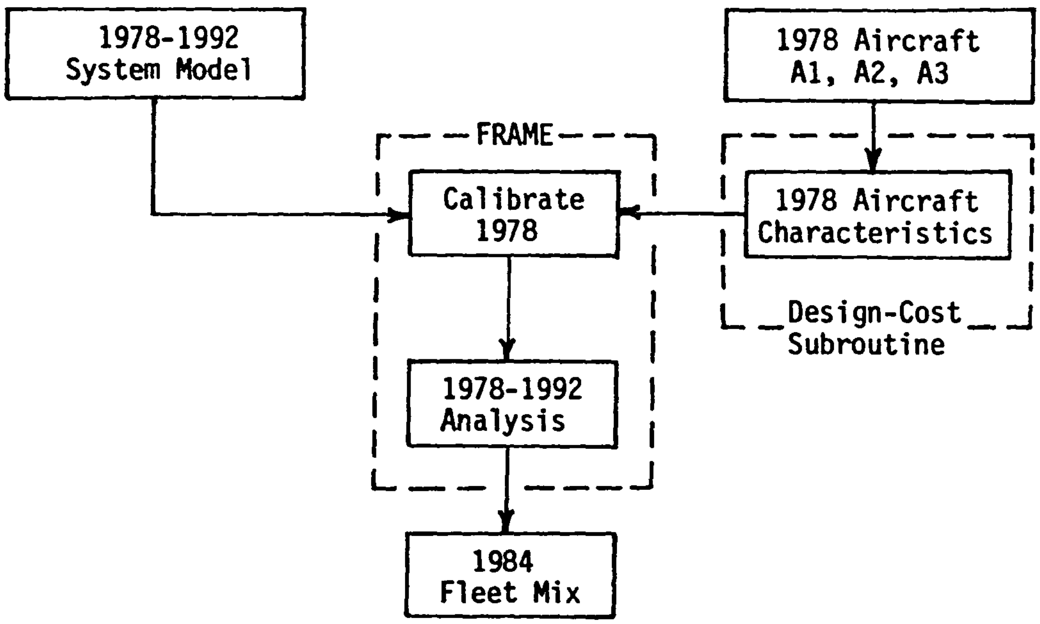
Market Area (1978)	Minimum Daily Trips
U.S. Domestic	64188
U.S. International	19292
Foreign	127592
Total	211072

There was no maximum constraint placed on service since it was considered important to examine the impact of the payload not only upon the ROI but also upon the growth of operational frequency.

Section 5
NEAR TERM CARGO AIRCRAFT FLEET MIX (1978-1992)

One of the initial steps toward identifying the prospects for a new aircraft is to define the 'situation' that will exist relative to current aircraft types and over the time period of interest. As previously mentioned, it is anticipated that a new aircraft derived from current operational aircraft could become available to the airlines by 1985. The discussion that follows is thereby concerned with identifying the fleet of current aircraft that will be operational in 1984 and in defining the associated network operational characteristics. The actual analysis was performed out to the year 1992; thus utilizing the full computer interval available.

Determination of the current aircraft fleet mix utilized the FRAME program as discussed in Figure 2-2. The flow of information for the 1978 to 1992 period is illustrated below.



More detailed aircraft characteristics, relative to those discussed in the previous section, were developed and utilized in combination with the 1978-1992 model. These data were first exercised in FRAME to assure calibration to the actual 1978 data. Once this calibration was achieved, the analysis was continued to provide fleet statistics out to year 1992.

Representative Aircraft Characteristics

A basic objective of these analysis was to achieve a viable relative comparison between all the types of aircraft considered. For this reason all characteristics were determined to a consistent base through the use of a DAC proprietary computer Design and Cost Subroutine. In order to perform fleet evaluations, it was necessary to establish characteristics for the three representative aircraft, A1, A2 and A3, beyond the range-payload data discussed in the previous section.

Characteristics for the representative aircraft are presented in Table 5-1. All dollar values are given in 1978 dollars including the fuel price of 11 cents per liter (43 cents per U.S. gallon) as derived in Section 1. All dollar values were then increased at an annual inflation rate of 6 percent. All basic computations were performed using trip cost rather than direct operating cost (DOC). Trip cost is equivalent to DOC less the depreciation and insurance elements. This approach was taken to avoid combining aircraft operating cost elements with the two financial elements (depreciation and insurance) that in real life are functions of the individual airlines economic situation and accounting procedures. As previously noted, the depreciation and insurance elements are considered in deriving the fleet economic values for returns on investment and cash flow.

Calibration 1978. - To assure compatibility of FRAME results, a calibration run was made utilizing the 1978 data. The program was allowed to select, based on revenue less indirect operating cost and trip cost, the most desirable of the A1, A2 and A3 aircraft for each of the 133 range elements. Results based upon these selected aircraft were then compared to the operational data for 1978 and showed the selected types and numbers of aircraft to be the same as those currently performing the respective elements.

TABLE 5-1

REPRESENTATIVE AIRCRAFT CHARACTERISTICS

1978 Aircraft	A1	A2	A3
Payload - Tonnes (Tons)	14.1 (15.6)	42.9 (47.27)	94.7 (104.45)
Design Range - KM (SM)	3806 (2365)	5149 (3200)	7023 (4364)
Max. Oper. Range - KM (SM)	3370 (2094)	8755 (5440)	8221 (5108)
Design Speed - (M_{cr})	0.78	0.80	0.85
Trip Cost @ Design Range - 1978$	5297	10864	24362
Aircraft Price - 1978$ x 10^6	7.4	16.1	45.4

A summary of the operational comparisons performed during the calibration is presented in Table 5-2. These data show excellent agreement between the calculated, designated as FRAME, and actual values whether of forecast or OAG origin. The reliability of the calculations is primarily evidenced in terms of the hours flown, available capability and load factor. The revenue capability was computed on the basis of the latter two parameters with the assumption that its distribution with aircraft type was identical to that for the available capability as derived from the 1978 OAG.

1978-1992 Analysis. - After calibration, the FRAME program was run for the full 1978-1992 time period. The resulting fleet mix, capability and departure distributions are shown in Figures 5-1, 5-2 and 5-3, respectively. The data of Figure 5-1 shows some growth in all types of aircraft prior to their phase out. The small narrow body aircraft, A1, could phase out in about 1983; however, prior to that time the number in service could increase about 20 percent over today's fleet. As the cargo market demand grows, the cargo volume moving over many of the currently low traffic routes increased sufficiently to require the service of the larger narrow body type aircraft, A2. As a result, the number of these aircraft increased significantly, approximately 60 percent over today's fleet, reaching a maximum in the mid-80's. At that time the forecast cargo demand and fleet economics further stimulated the use of the even larger wide-body aircraft, the A3. The number of these types continued to increase to handle the growing cargo market demand and to replace the economically less efficient A2's.

The capability provided by the A1, A2 and A3 aircraft followed trends similar to those of the fleet mix as evidenced in Figure 5-2. Although the mix of aircraft changed over the years, shifting in favor of the larger more economically efficient types, the total number of departures continued to increase as shown in Figure 5-3. The magnitude of this increase is evidenced by comparing the total departures for any given year to the minimum constraint line as established by current fleet frequency. The increase shown in Figure 5-3 was equivalent to an average annual growth of about 7 percent.

1984 Fleet Mix. - The number and types of current aircraft making up the 1984 fleet represent the competition for the derivative aircraft entering the

TABLE 5-2

OAG - FRAME CALIBRATION FOR 1978 - METRIC

Market	U.S. Domestic			U.S. International			Foreign		
Study Aircraft	A1	A2	A3	A1	A2	A3	A1	A2	A3
Departures - (Trips)									
OAG	7457	46198	10533	522	7405	11366	49275	70445	7873
FRAME	7456	46198	10533	521	7404	11367	49275	70445	7873
Distance Flown - KM x 10^9									
OAG	8.396	78.599	20.912	0.225	23.828	41.204	40.721	208.354	34.215
FRAME	8.396	78.599	20.912	0.225	23.828	41.204	40.721	208.352	34.215
Hours Flown									
OAG	13166	119114	31802	478	32963	54411	73292	295723	44775
FRAME	13659	121301	31231	521	33137	55022	72578	292866	44602
Revenue Capability - ARTKM x 10^9									
Forecast	0.085	1.967	1.143	0.003	0.620	2.358	0.311	4.781	1.739
FRAME	0.069	1.939	1.142	0.001	0.613	2.355	0.301	4.779	1.727
Available Capacity - ATKM x 10^9									
OAG	0.147	3.413	1.984	0.004	1.028	3.910	0.575	8.839	3.215
FRAME	0.118	3.371	1.981	0.003	1.022	3.904	0.577	8.935	3.243
Load Factor - Percent									
Forecast	57.60	57.60	57.60	60.30	60.30	60.30	54.10	54.10	54.10
FRAME	57.60	57.53	57.60	60.30	60.02	60.24	52.13	53.58	53.26

TABLE 5-2

OAG - FRAME CALIBRATION FOR 1978 - ENGLISH

Market	U.S. Domestic			U.S. International			Foreign		
Study Aircraft	A1	A2	A3	A1	A2	A3	A1	A2	A3
Departures - (Trips)									
OAG	7457	46198	10533	522	7405	11366	49275	70445	7873
FRAME	7456	46198	10533	521	7404	11367	49275	70445	7874
Distance Flown - (SM x 10^9)									
OAG	(5.217)	(48.839)	(12.994)	(0.140)	(14.806)	(25.603)	(25.303)	(129.465)	(21.260)
FRAME	(5.217)	(48.839)	(12.994)	(0.140)	(14.806)	(25.603)	(25.303)	(129.464)	(21.260)
Hours Flown									
OAG	13166	119114	31802	478	32963	54411	73292	295723	44775
FRAME	13659	121301	31231	521	33137	55022	72578	292886	44602
Revenue Capability - (ARTSM x 10^9)									
Forecast	(0.058)	(1.347)	(0.783)	(0.002)	(0.425)	(1.615)	(0.213)	(3.275)	(1.191)
FRAME	(0.047)	(1.328)	(0.782)	(0.001)	(0.420)	(1.613)	(0.206)	(3.273)	(1.183)
Available Capacity - (ATSM x 10^9)									
OAG	(0.101)	(2.338)	(1.359)	(0.003)	(0.704)	(2.678)	(0.394)	(6.054)	(2.202)
FRAME	(0.081)	(2.309)	(1.357)	(0.002)	(0.700)	(2.674)	(0.395)	(6.120)	(2.221)
Load Factor - Percent									
Forecast	57.60	57.60	57.60	60.30	60.30	60.30	54.10	54.10	54.10
FRAME	57.60	57.53	57.60	60.30	60.02	60.24	52.13	53.48	53.26

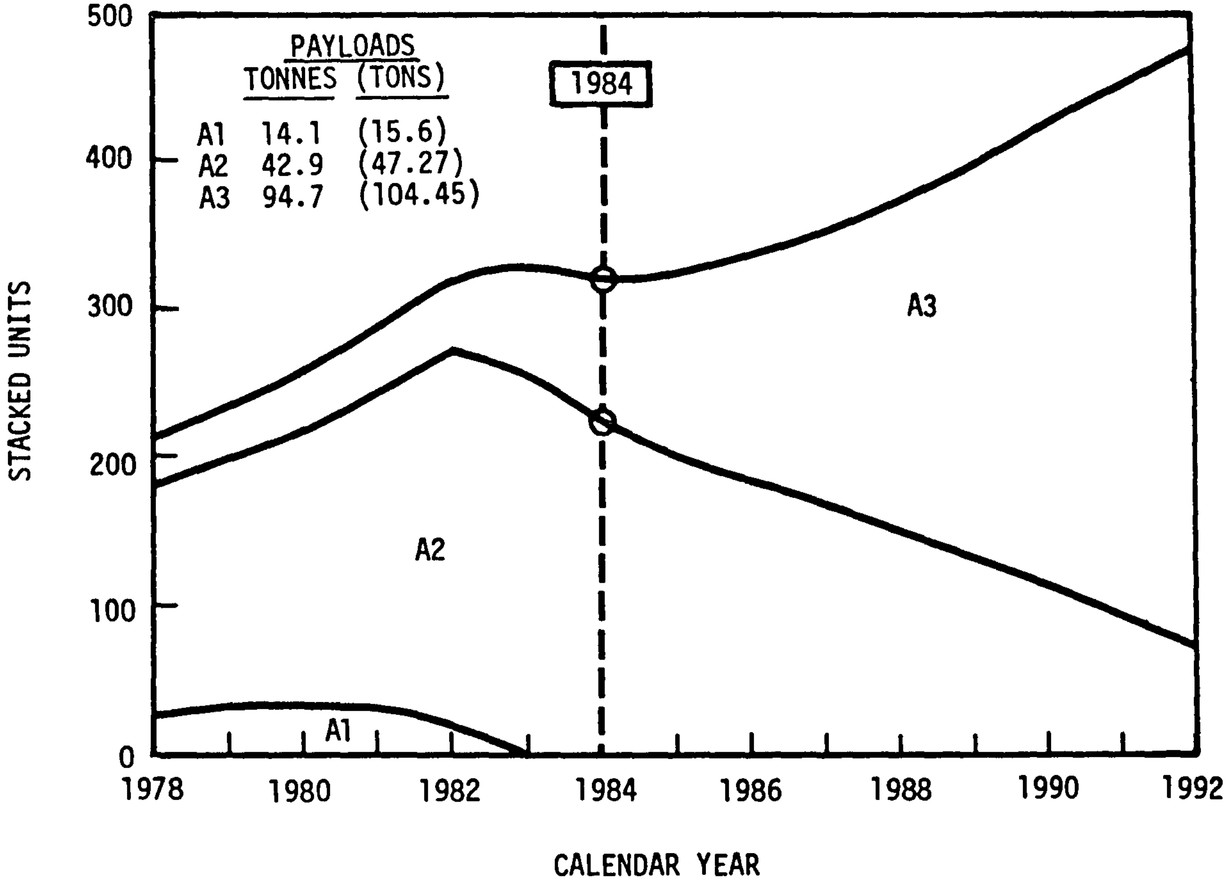


FIGURE 5-1. FLEET MIX 1978-1992 REFERENCE FLEET

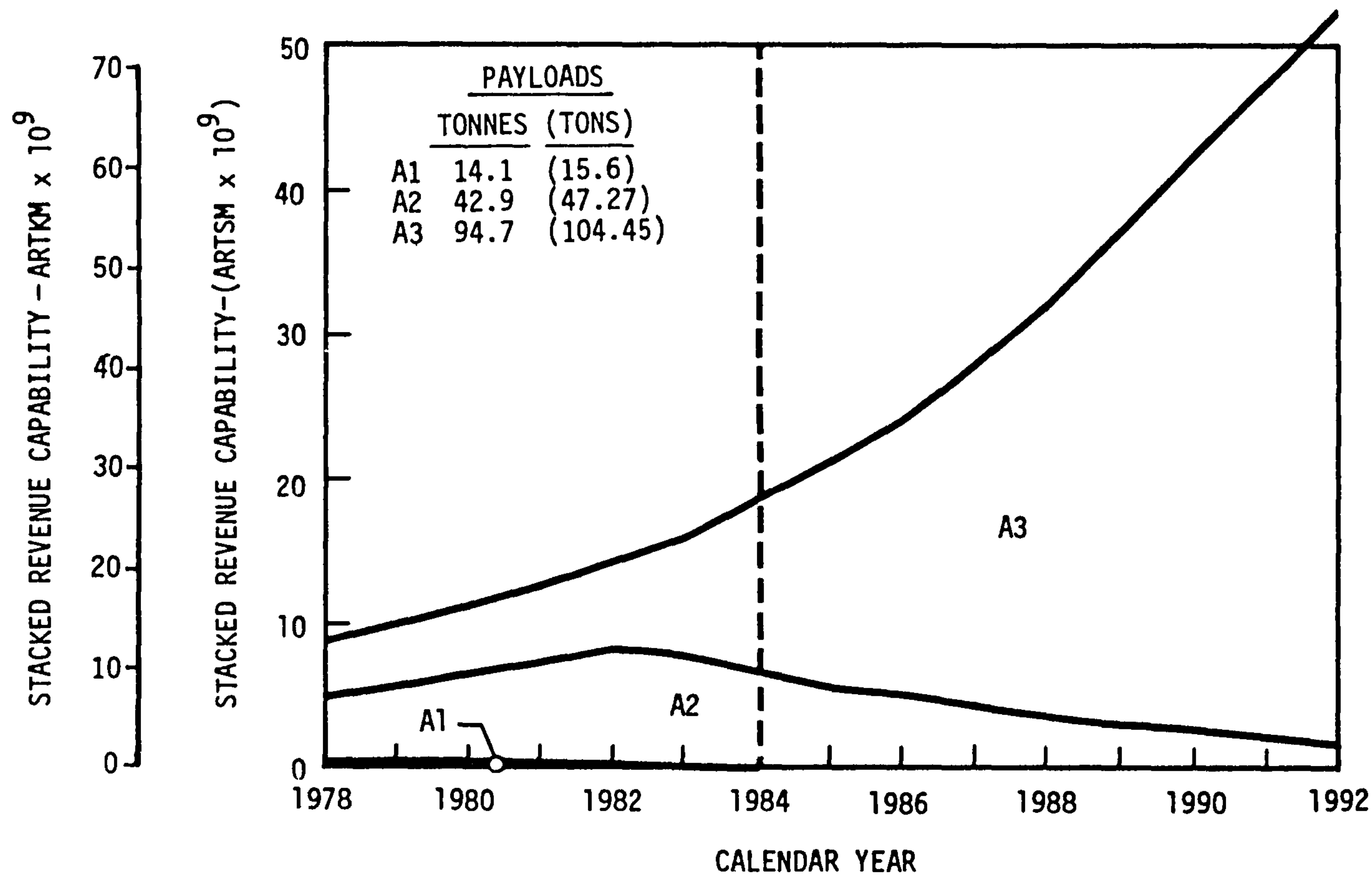


FIGURE 5-2. ANNUAL REVENUE CAPABILITY 1978-1992 REFERENCE FLEET

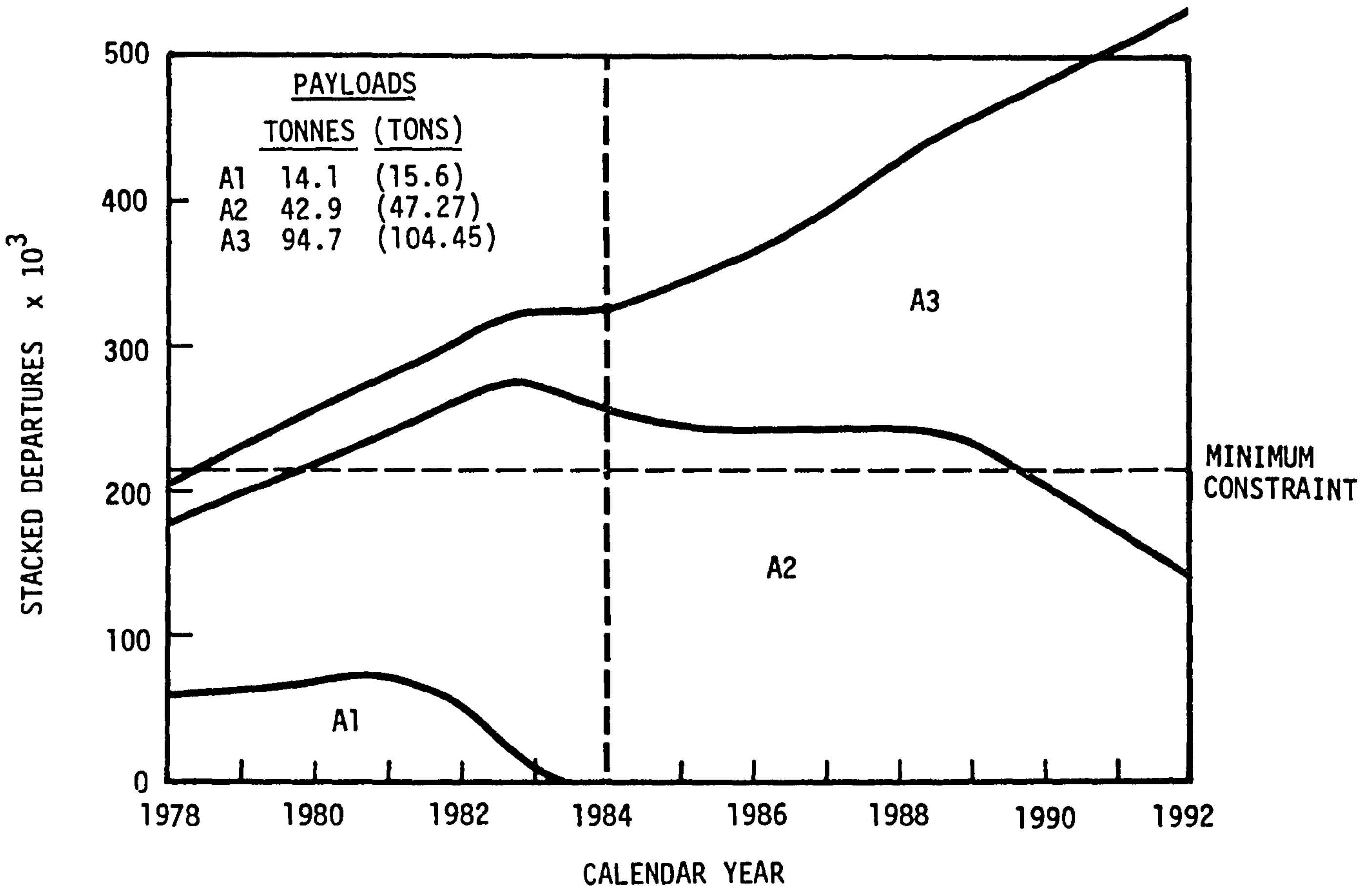


FIGURE 5-3. ANNUAL DEPARTURES 1978-1992 REFERENCE FLEET

fleet in 1985. A cross-section of the data presented in Figures 5-1 through 5-3 for the year 1984 provides the characteristics of this competitive fleet. Since the small payload, shorter range aircraft, A1, became economically uncompetitive and was phased out, the annual statistics for the remaining competitive A2 and A3 types are as follows.

1984 FLEET ANNUAL STATISTICS

Aircraft Type	A2	A3	Total
Units	224	97	321
Revenue Capability -ARTKM x 10^9 (ARTSM x 10^9)	9.845(6.743)	17.175(11.764)	27.020(18.507)
Available Capability -ATKM x 10^9 (ATSM x 10^9)	16.489(11.294	28.987(19.854)	45.476(31.148)
Load Factor - Percent	59.90	59.25	59.42
Departures (Trips) Growth Rate -Percent per Year			7.7

These data are for the combined U.S. Domestic, U.S. International, and Foreign markets. Although the A3 wide bodies are considerably less in number, they provided a major portion of the available and revenue capabilities but at a slightly smaller fleet load factor. The improved operating economics of the A3 compared to the A2 more than compensated for the lesser load factor experienced. The 7.7 percent growth in frequency is an average annual rate equivalent to the total increase occurring between 1978 and 1984.

Section 6

ADVANCES IN TECHNOLOGY

Considerable effort is currently being devoted to research and development related to improving aircraft efficiencies. These "energy efficient" programs, sponsored and/or performed by the NASA and industry, are expected to continue and will certainly result in technology advances applicable to interium derivative and future dedicated cargo aircraft. This section identifies these advances and provides estimates of the accompanying incremental changes in aircraft characteristics.

The impacts of technology advances are presented as incremental changes to the twelve aircraft design parameters defined below. These incremental changes due to technology advances are based upon the respective values for

ΔW_{P+N} - Percent change in the weight of pylon and nacelle

ΔW_{STRU} - Percent change in weight of aircraft structure excluding pylons and nacelles

$\Delta L/D$ - Percent change in the cruise left-to-drag ratio

ΔSFC - Percent change in specific fuel consumption

ΔW_{ENG} - Percent change in weight of propulsive engines

ΔW_{FURN} - Percent change in weight of power system, electric lighting system, furnishings and air conditioning

$\Delta C_{L_{TO}}$ - Percent change in takeoff lift coefficient

ΔS_{W} - Percent change in wing area

Manufacturing Cost - Percent change in the cost of manufacturing the aircraft or the engine

Maintenance Cost - Percent change in the cost of maintaining the aircraft or the engine contemporary aircraft while those associated with the parametric aircraft are based upon a comparable advanced, conventional, turbofan aircraft. The incremental values for each parameter were developed through a detailed analysis of the results of studies conducted by the NASA, industry, Air Force (unclassified) and McDonnell Douglas. Considered results included data from the NASA sponsored programs on energy efficient engines and transports, laminar flow control, and current results of the New Strategic Airlift Concepts study sponsored by the Air Force. Except for the incremental changes associated with the 1995 parametric aircraft configurations, the values presented are a consequence of composite evaluations of all available data and hence are not referenced to a specific source. Following initial derivation the incremental changes were submitted to NASA for review and approval by Langley personnel.

For clarity the discussions that follow were segregated under the general headings of 1980 Technology, 1990 Technology and 1995 Parametric Aircraft Configurations. The 1980 technology encompasses five developments that were considered viable for the derivative aircraft projected to become operational in 1985. Similarly, the 1990 technology encompasses eight developments considered applicable to new dedicated cargo aircraft projected to become operational in 1995. The incremental changes associated with the parametric configurations were based upon this 1990 technology.

1980 Technology

The technical developments projected to be available for incorporation in 1985 operational aircraft were viewed as an interium step in achieving the 1990 technology. It was also generally agreed during the analysis that the 1985 generation aircraft would develop as derivatives of contemporary configurations. The selection of the 1980 technology therefore considered the anticipated state of technological development in combination with applicatory limitations imposed by this derivative approach to aircraft development. However, the extent to which current components would be utilized in these derivative aircraft was questionable varying with type of aircraft and the manufacturer. It was therefore assumed that the available technology would be applied as modifications to current designs of the effected components. The resulting impacts of the 1980 technology developments are presented in Table 6-1.

Composites. - For the first of these developments it was concluded that by 1980 composites would be proven for application in secondary structures. The extent of this application was limited to approximately 25 to 30 percent of the pylon plus nacelle, 65 percent of the vertical tail and 7 percent of the fuselage. The scope of these applications is compatible with current fabrication and flight test programs.

Improved engines. - Discussions with power plant engineers indicated that current turbofan improvement programs would provide the reduced fuel consumption and engine weight shown in Table 6-1. Three percent of the eight percent reduction in specific fuel consumption was attributed to an improved design, long-duct nacelle, the remaining five percent to engine improvement.

Reduced drag. - It was postulated that the derivative aircraft would not have a new super critical wing, but would utilize a current design. In place of the new low drag wing, improvements in the cruise left-to-drag ratio would be achieved through the combined application of winglets and active lateral flight controls. This approach would avoid the structural weight penalty of the winglets and provide an improvement in the lift-to-drag ratio equal to about half that achievable with the super critical wing.

Active flight controls. - Considering the current state of development, it was considered doubtfull that longitudional active flight control would be sufficiently developed for use in 1985 commercial aircraft. However, lateral applications are already underway and would be employed to provide structural weight reductions compatible with the associated gust elevation and other effects.

Carbon brakes. - A weight reduction equivalent to one percent of the aircraft structural weight was achieved in the analysis by replacing the

Table 6-1

1980 TECHNOLOGY

Technology For Derivative Aircraft	Incremental Change*									
	ΔW_{P+N}	ΔW_{STRU}	$\Delta L/D$	ΔSFC	ΔW_{ENG}	ΔW_{FURN}	Manufacturing Cost		Maintenance Cost	
							Aircraft	Engine	Aircraft	Engine
Composites	-8%	-8%					-1%			
Improved Engine				-8%	-2%					
Reduced Drag			+4%							
Active Flight Controls		-2.5%								
Carbon Brakes		-1%								
Total Impact	-8%	-11.2%	+4%	-8%	-2%		-1%			

*Relative to Current Aircraft

current braking system with carbon brakes. In addition, a substantial reduction in brake maintenance costs appeared quite probable. However, the latter impact could not be evaluated due to a lack of historical data on this cost item.

Total incremental changes. - The total reduction in structural weight is a consequence of the combined effects of the composites, active flight controls and carbon brakes as shown in Table 6-1. The total impact was derived as the product of the remaining affected weight increments 0.92 x 0.975 x 0.99 = 0.888). This procedure provided a weight saving slightly less than the sum of the weight reductions, 11.2 percent compared to 11.5 percent.

1990 Technology

Technology developments forecast to be available for application in the new dedicated future aircraft are presented in Table 6-2. In a broad sense, four of these developments, composites, new engines, active flight controls and carbon brakes, represent further improvements of the 1980 technology shown in Table 6-1. Two of the remaining items adhesive bonding and improvements in aircraft systems, were included for post 1990 application although research and development related to these items is already well underway. It was agreed that 1980 application of these two developments would be premature that meaningful improvements in affected operational components would not be available until 1990.

Although the super critical wing and cargo loading system represents current technology they were not considered for application to the 1985 derivative aircraft. This approach was taken because the super airfoil requires the design and development of a new wing as previously noted, while the cargo loading system can be most effectively employed in a new aircraft dedicated to cargo operations. It was assumed that both these requirements would be met in the design of the 1995 cargo aircraft.

Table 6-2

1990 TECHNOLOGY

Technology For New Dedicated Aircraft	Incremental Change*							
	ΔW_{P+N} / ΔW_{STRU}	$\Delta L/D$	ΔSFC	ΔW_{ENG} / ΔW_{FURN}	Manufacturing Cost		Maintenance Cost	
					Aircraft	Engine	Aircraft	Engine
Composites	-24% / -24%				-3.5%		-2%	
Adhesive Bonding					-10%			
New Engines			-13%	-4% /		+7.2%		-5%
Super Critical Wing		+8%						
Active Flight Control	/ -5.5%	+3%			-1%			
Improved Aircraft Systems				/ -9.5%				
Cargo Loading System	/ -4%							
Carbon Brakes	/ -1%							
Total Impact	-24% / -32%	+11%	-13%	-4% / -9.5%	-14%	+7.2%	-2%	-5%

*Relative to Current Aircraft

Composites. - Investigation indicated that by 1990 composites would be proven for both secondary and primary structures. The weight savings shown in Table 6-2 were based upon application of this material in 74 percent of the pylon and nacelle structure. Application in the remaining structure varied from 8.5 percent in the wing to 65 percent in the vertical tail. A weighted average of these values indicated that about 18 percent of the total aircraft structure was effected. Through application of compatible design techniques both the manufacturing and maintenance costs of the aircraft would be reduced.

Adhesive bonding. - By 1990 this fabrication technique could be sufficiently developed for application in 30 to 35 percent of the aircraft structure. It was assumed that this objective would be achieved thus providing the 10 percent cost reduction noted in Table 6-2. In addition, the expected decrease in fatigue could lower maintenance costs, however, the extent to which this would occur could not be established.

New engines. - It was anticipated that the energy efficient engine program would result in a new turbofan engine with lower fuel consumption, weight and maintenance cost. However it was also concluded that such engine would cost more based upon 1978 dollars. As in the case of the 1980 values, the 13 percent reduction in specific fuel consumption includes a three percent reduction due to an improved design, long-duct nacelle.

Super critical wing. - It appeared reasonable that a new 1995 aircraft would incorporate a wing designed around the super critical airfoil thus providing an increased lift-to-drag ratio over that of current aircraft. The magnitude of this improvement would depend upon the design combination of wing planforms, span and thickness. The 8 percent increase shown in Table 6-2 was based upon achieving a higher aspect ratio at the expense of wing thickness.

Active flight controls. - The incorporation of an active longitudional control system, in addition to the lateral system, would allow a more aft center of gravity location and a reduced horizontal tail area. The result would be a reduction of the structural weight and an increase in the cruise lift-to-drag ratio. There would also be the added advantage of a potential small reduction in manufacturing costs.

Improved aircraft systems. - Systems that were considered included the electrical, hydraulic, avionics, and instruments. Weight reductions would be achieved through the combined effects of design and new materials. These reductions were evaluated and found to vary from seven percent for the hydraulic system to 11.2 percent for the avionics. The average weight decrease for all these systems combined was estimated to be 9.5 percent as shown in Table 6-2.

Cargo loading system. - This proprietary, on-board, loading system could provide a meaningful reduction in the aircraft operating weight empty. Maximum advantage was achieved by incorporating this concept into the new 1995 dedicated aircraft. It should be noted that part of the weight reduction shown in Table 6-2 was realized by the fact that this on-board loading system moves the necessary power and drive-train components out of the aircraft into the ground equipment. The equivalent structural weight reduction of 4 percent, Table 6-1, represents the total that could be achieved.

Total incremental changes. - The total structural weight reduction due to 1990 technology is made up of the four increments resulting from the application of composites, active flight controls, cargo loading systems and carbon brakes. As for the 1980 developments the total impact, relative to current aircraft, was derived as the product of the remaining structural weights (0.76 x 0.945 x 0.96 x 0.99 = 0.683). This provided the weight reduction of 32 percent noted in Table 6-2 compared to 35 percent that would have been obtained by simple summation.

1995 Parametric Aircraft Configurations

The technology developments discussed in the preceding section would be applicable to either turbofan or propfan powered aircraft and/or to variations in airframe configuration. This section presents the incremental change in design parameters due to such airframe conceptual changes when based upon 1990 technology. Data is presented for M = 0.8 and 0.7 propfan powered aircraft, a turbofan powered span loader at M = 0.75, and a laminar flow control equipped, conventional, turbofan configuration at M = 0.85. The associated incremental changes presented in Table 6-3 were based upon a conventional configuration, advanced turbofan aircraft designed for equal payloads as illustrated in Figure 6-1. The aircraft sizes, identified by payloads, were selected on the basis of preliminary study results, reference Section 9.

Since the object of this effort was to determine the effect of configuration change, the changes in design parameters were derived through comparison of specific designs. Values for the propfan and span loader configurations were obtained from the Air Force sponsored New Stratigic Airlift Concepts (NSAC) study (Reference 6-1) currently underway while the laminar flow control data was based upon NASA sponsored study results (Reference 6-2) and parallel in-house efforts. In some cases values for the considered parameters were affected by the results from the NASA sponsored studies of energy efficient transports.

Propfan. - Data for the propfan configurations illustrated in Figure 6-2 was developed to show the impact of both engine type and design Mach number. The respective incremental changes are presented in the first two colums of Table 6-3. It is evident from these data that while the propfan has advantages over the comparable Mach 0.8 turbofan in the areas of structural weight and specific fuel consumption it entails penalities due to reduced cruise lift-to-drag ratio and increased engine weight and cost.

Greater advantages and decreased penalities were achieved when the design Mach number was reduced to 0.7. The largest effect of this reduced cruise speed appeared in the structural weight where the reduction, reference column two Table 6-2, was six times that realized due to engine change, reference column one. This weight reduction facilitated the use of smaller engines that weighed less and required smaller nacelles and pylons. Note that in these discussions engine weight entails the combined weights of the engine, gear box and propeller. These comparisons were also based upon the assumption that propfans of the desired size, would be available in 1990.

Table 6-3

1995 PARAMETRIC AIRCRAFT CONFIGURATIONS

1990 Technology

Incremental Change[1]		Propfan	Propfan	Span Loader	Laminar Flow Control
ΔW_{P+N}		-7%	-11%	-17.6%	
ΔW_{STRU}		-4%	-26%	-43%	+6.5%
$\Delta L/D$		-10%	-6%	-13%	+22%
ΔSFC		-20%	-30%	-4%	+2%
ΔW_{ENG}		+112%[2]	+103%[2]		+2%
ΔW_{FURN}					
$\Delta C_{L_{TO}}$					-13%
Mfg. Cost	Aircraft			-15%	+4%
	Engine	+29%	+29%		
Maint. Cost	Aircraft				+10%
	Engine				
ΔS_W		-10%	-14%	+10%	+8%
Number of Engines		6	6	6	4
M		0.8	0.7	0.75	0.85
Payload - Tonnes (Tons)		149.7 (165)	149.7 (165)	235.9 (260)	149.7 (165)

[1]Relative to advanced turbofan aircraft with high wing

[2]Includes engine, gear box and propeller

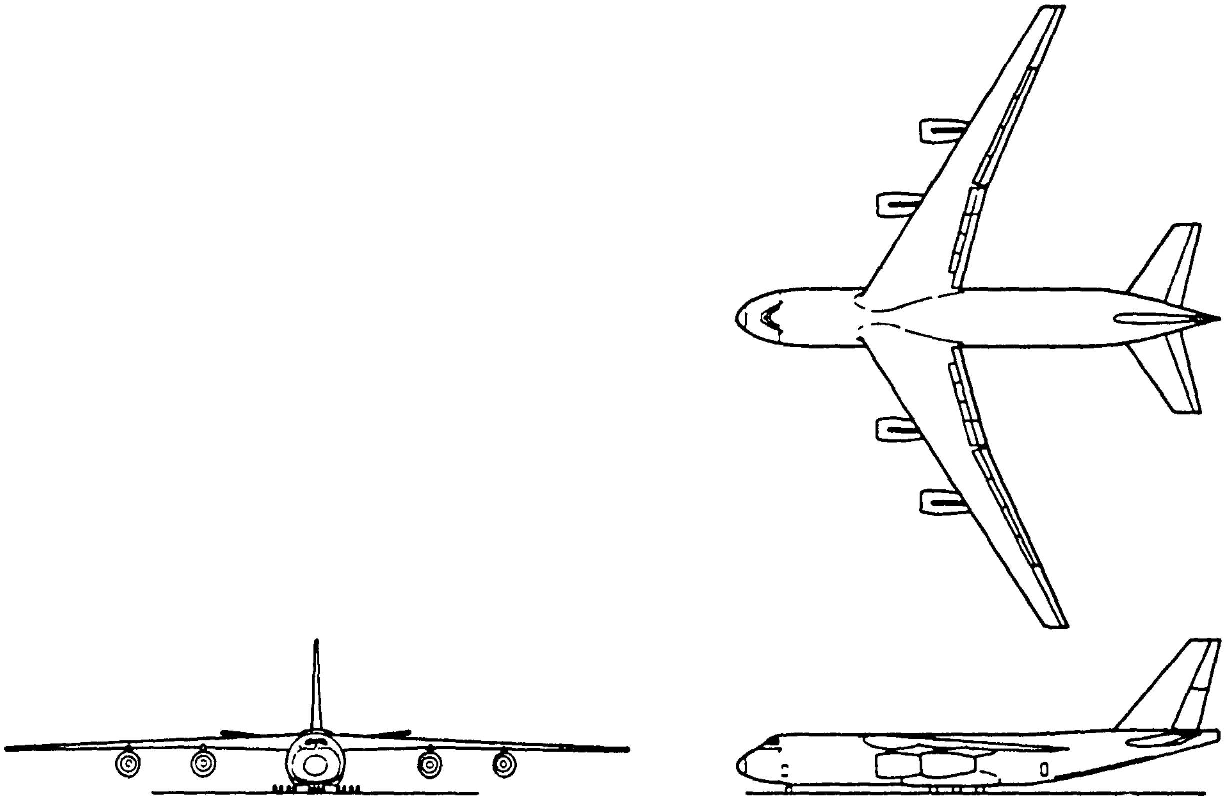


Figure 6-1 Conventional Turbofan Configuration

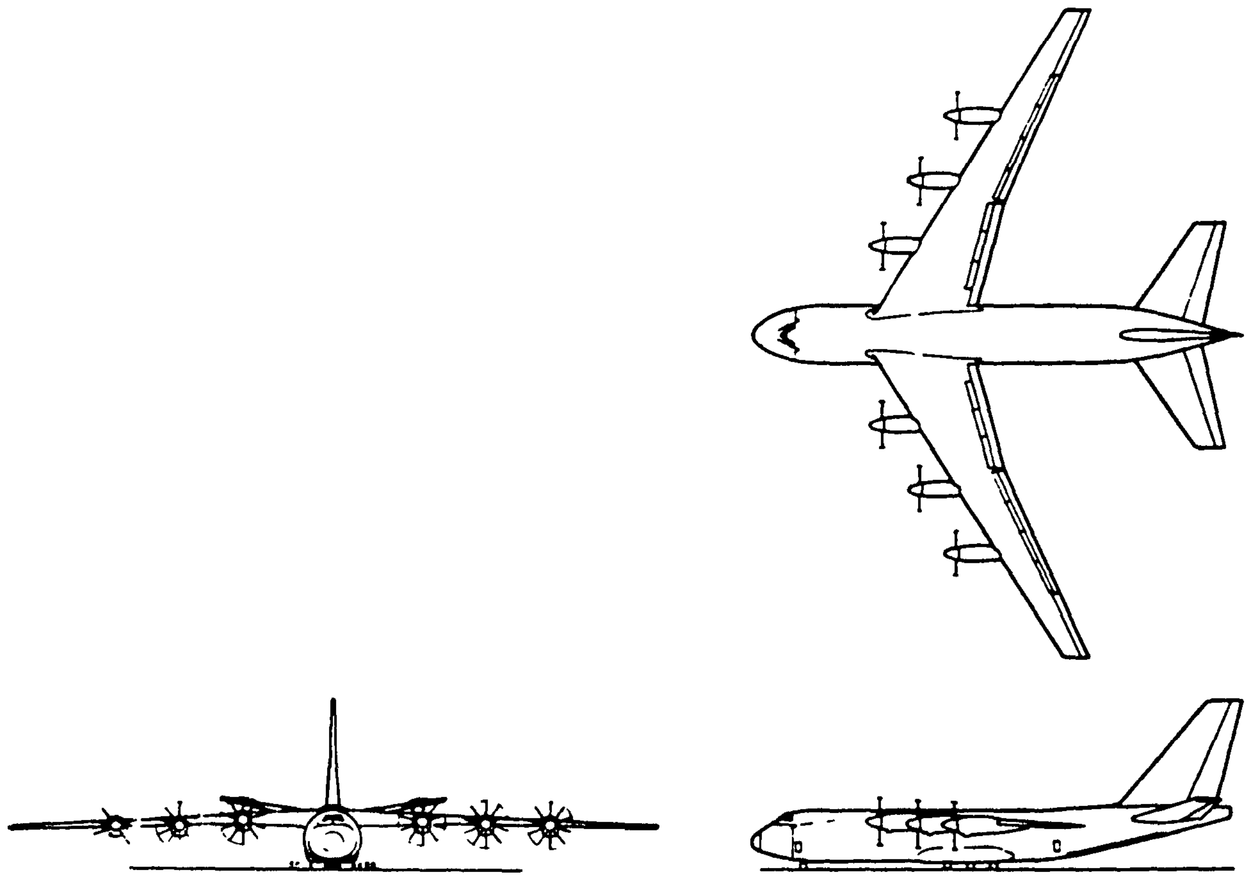


Figure 6-2 Conventional Propfan Configuration

Span loader. - This distributed load, or span loader, configuration is illustrated in Figure 6-3. Over the past several years considerable effort has been directed to acquiring an understanding of the design relationships that determine the efficiency of this unconventional configuration. Results have been unanimous in the conclusion that maximum efficiency is achieved at very large payloads, usually greater than 300 tonnes (330 tons). Therefore, the incremental changes were based upon the largest payload configuration, 235.9 tonnes (260 tons), considered in the NSAC study.

The data presented in column three of Table 6-3 shows a reduction in the lift-to-drag ratio and an increase in wing area associated with the span loader configuration for the payload considered. This was a consequence of the wing span and chord relation that resulted when the containerized payload was accommodated within the contours of the selected super critical airfoil section. The 235.9 tonne (260 tons) commercial payload was accommodated in two spanwise container rows. For commercial operations the oversize payload requirement would be eliminated and the size of the fuselage shown in Figure 6-3 could be substantially reduced.

The more important advantages of the span loader concept were associated with the vehicles structure. By distributing the payload in the wing, the wing weight was reduced as was the weight of the fuselage. In addition, the constant chord wing facilitated design for commonality and provided the reduction in manufacturing cost shown in column three of Table 6-3.

Laminar flow control. - The data shown in the fourth column of Table 6-3 was based upon a conventional turbofan aircraft configuration, reference Figure 6-1, equipped with laminar flow control on the upper surface of the wing. Suction was applied over 85 percent of the chord in combination with a leading edge device for contamination control and a 15 percent trailing edge flap. The absence of high lift leading and trailing edge devices resulted in a decreased takeoff lift coefficient as indicated in Table 6-3. While there was a meaningfull gain in the cruise lift-to-drag ratio, all the remaining affected design parameters were penalized. The increase in specific fuel consumption and engine weight were due to the power units required for the suction system.

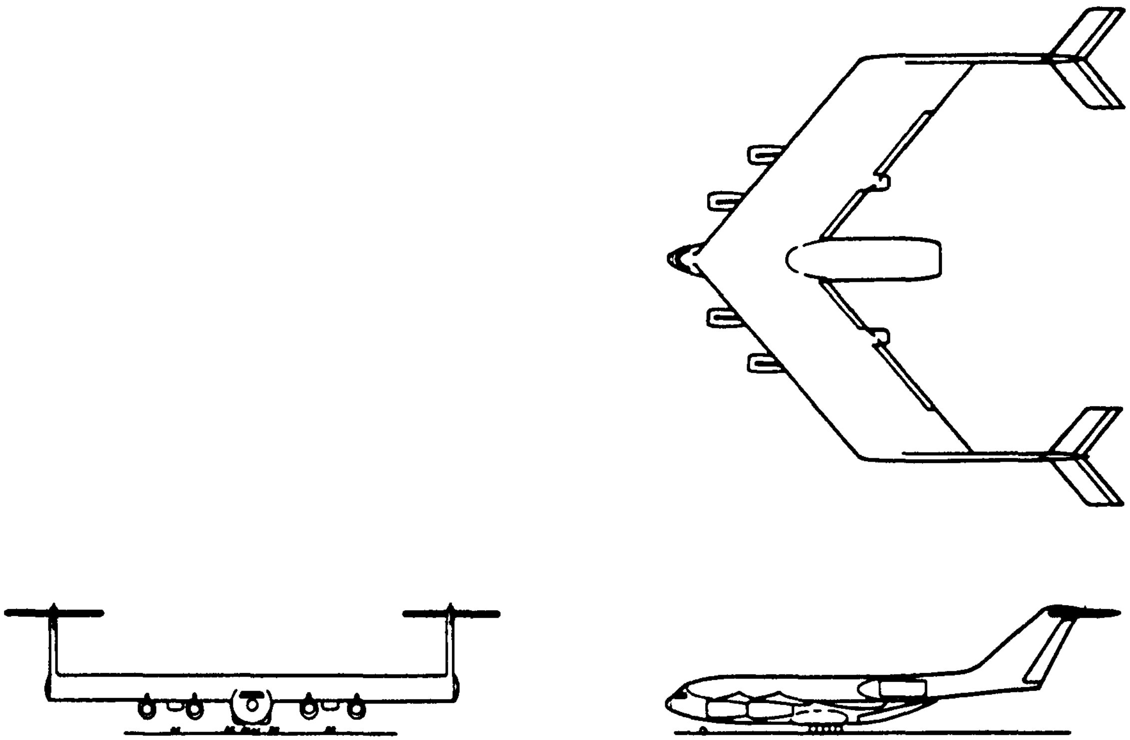
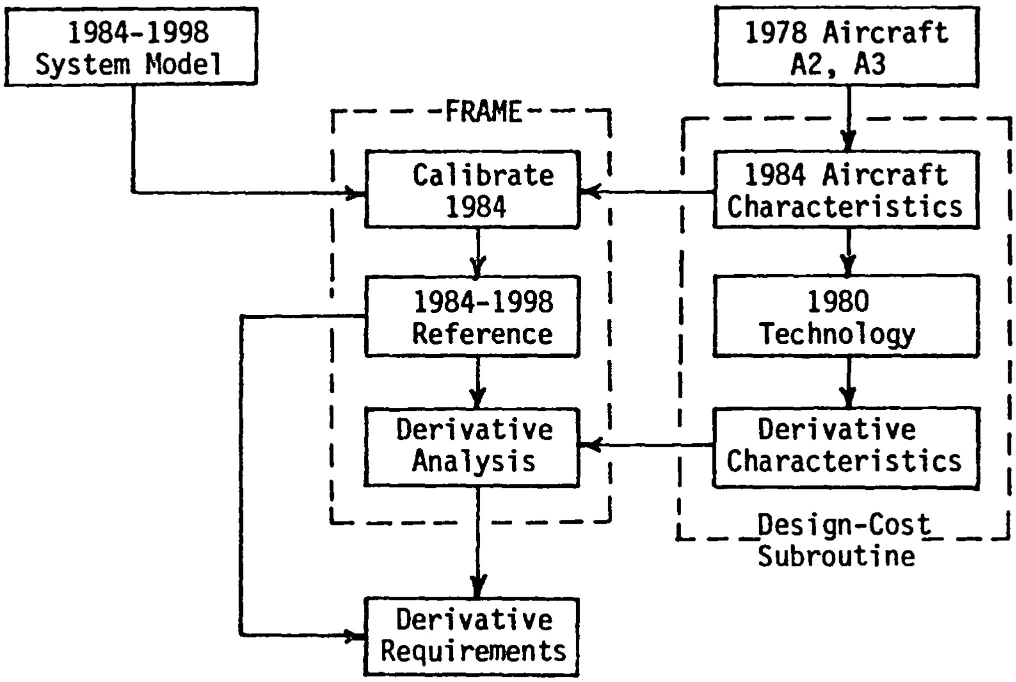


Figure 6-3 Distributed Load (Span Loader) Configuration

Section 7

DERIVATIVE CARGO AIRCRAFT (1984-1998)

The derivative aircraft, scheduled for initial operation in 1985, were investigated over the fifteen year period from 1984 to 1998. The approach taken in applying the FRAME program to these analysis is illustrated below.



Appropriate values of market growth and system variables from Section 1 were utilized to develop a cargo model for the considered time period. This model was then exercised in FRAME to assure compatibility with the values for the 1984 A2 and A3 reference fleet developed in Section 5.

Having assured continuity for 1984, the reference fleet was exercised over the full 1984-1998 time period; thus providing the reference case for evaluating the derivative aircraft. These results were first used to parametrically derive the preferred derivative aircraft and subsequently to show the improvement in fleet economics realized with the introduction of these select derivatives. Finally, the requirements for the 1985 derivative aircraft were defined.

1984 Aircraft

Since the first year for this portion of the analysis is 1984, it was necessary to update the monetary characteristics for the representative A2 and A3 aircraft, reference Table 5-1, to 1984 dollars. These modified values are shown below.

1984 Aircraft	A2	A3
Payload - Tonnes (Tons)	42.9(47.27)	94.7(104.45)
Design Range - KM (SM)	5150(3200)	7023(4364)
Trip Cost @ Design Range - 1984$	17035	38528
Aircraft Price - 1984$ x 10^6	22.8	64.4

All other aircraft characteristics remain unchanged and are the values presented in Table 5-1. As before, the trip cost is equivalent to DOC less the depreciation and insurance. The beginning fuel cost for this period is 19 cents per liter (71 cents per U.S. gallon) for the year 1984. This value and all other costs were increased at an annual inflation rate of 6 percent for subsequent years as discussed in Section 2.

Calibration - 1984. - The FRAME program was run for 1984 with the A2 and A3 aircraft to assure continuity with the 1978-1992 time period and the 1984 cargo demand forecast. The results of this calibration are shown in Table 7-1. Values designated as (New) are those derived herewith for the 1984 to 1998 time period while those designated by (Ref) are those 1984 values developed for the 1978 to 1992 time period in Section 5.

The top set of data compare the new computed values of revenue and available capabilities with the forecast demand. The deviation from the forecast values was very small with the maximum variation about 4 percent occurring for the available capability and load factor (LF) in the foreign market. The mid set of data of Table 7-1 compares the values computed for the representative aircraft A2 and A3. Here the maximum deviation occurred in the revenue capability of the A2 aircraft where the newly computed value was about 4 percent higher than the reference value of Section 5. However,

TABLE 7-1

CALIBRATION FOR 1984

Market	U.S. Domestic					U.S. International					Foreign				
	Revenue		Available			Revenue		Available			Revenue		Available		
Factors	ARTKM $x10^9$	(ARTSM $x10^9$)	ATKM $x10^9$	(ATSM $x10^9$)	LF	ARTKM $x10^9$	(ARTSM $x10^9$)	ATKM $x10^9$	(ATSM $x10^9$)	LF	ARTKM $x10^9$	(ARTSM $x10^9$)	ATKM $x10^9$	(ATSM $x10^9$)	LF
Forecast	5.363	(3.673)	8.983	(6.153)	59.7	5.437	(3.724)	7.662	(5.428)	68.6	16.232	(11.118)	27.419	(18.780)	59.2
FRAME	5.363	(3.673)	9.105	(6.236)	58.9	5.436	(3.723)	7.923	(5.427)	68.6	16.222	(11.111)	28.457	(19.491)	57.1

Factors	Units	Departures (Trips)	Distance Flown		Hours Flown	Revenue		Available		Load Factor (LF)
			KMx10^6	(SMx10^6)		ARTKM $x10^9$	(ARTSM $x10^9$)	ATKM $x10^9$	(ATSM $x10^9$)	
A2 (Ref.)	224	256430	384.532	(238.937)	610203	9.845	(6.743)	16.489	(11.294)	59.70
(New)	222	251028	397.165	(246.787)	622633	10.268	(7.033)	17.032	(11.666)	60.29
A3 (Ref.)	97	72003	305.909	(190.083)	399898	17.175	(11.764)	28.987	(19.854)	59.25
(New)	97	74511	300.283	(186.587)	395201	16.752	(11.474)	28.454	(19.489)	58.88

Totals	Revenue		Available		Load Factor (LF)
	ARTKM $x10^9$	(ARTSM $x10^9$)	ATKM $x10^9$	(ATSM $x10^9$)	
(Ref.)	27.020	(18.507)	45.475	(31.148)	59.4
(New)	27.020	(18.507)	45.486	(31.155)	59.4
Forecast	27.032	(18.515)	44.327	(30.361)	61.0

the number of aircraft units required were identical for both sets of data. Totals are compared in the lower set of figures which show that the deviations from the desired forecast value were essentially the same for both sets of data with a maximum variation of about 3 percent in the fleets available capability and load factor. In total, the data of Table 7-1 testify to the conclusion that continuity between the 1978-1992 and the 1984-1998 analysis had been established.

1984-1998 Reference Fleet. - Having assured continuity for 1984, the program was run to evaluate the A2 and A3 aircraft over the full 1984-1998 time period. These results for the reference fleet are summarized in Table 7-2 and the operational requirements in terms of units, revenue capability and departures are plotted in Figures 7-1, 7-2 and 7-3, respectively.

The data of Figure 7-1 shows that the maximum number of A2 and A3 units given in Table 7-2 occur in the years 1984 and 1998, respectively. Due to the lower operating costs and an improvement in the relationship between aircraft size and market demand, the wide-body A3 type aircraft could completely replace the A2 aircraft by the year 1995. Without the competition of a more efficient derivative aircraft, the number of wide bodies would increase to 748 in order to handle the cargo market demand to the year 1998.

The split of the total revenue capability between the A2 and A3 aircraft is shown in Figure 7-2. These data show variations with time that are similar to that for the number of units, a steady decline for the A2 over the years 1984 to 1995. This steady decrease in the A2 capability combined with the almost constant frequency shown in Figure 7-3, out to the year 1988, indicates that this type of aircraft would be shifted to the shorter range routes as the wide bodies enter the fleet.

1985 Derivative Aircraft

The size, number and fleet competitiveness of the derivative aircraft were determined parametrically utilizing the FRAME program in combination with the Design and Cost Subroutine previously noted. The approach used will be

TABLE 7-2

REFERENCE FLEET 1984-1998

Time Period (1984-1998)	Reference
Units - A2	222
Units - A3	748
ROI Airline - Percent	11.3
EUACF - 1984 \$ x 10^9	7.5
ΣIPV - 1984 \$ x 10^9	53.2
ΣOI - \$ x 10^9	175.4
Departures (Trips) Growth Rate - Percent per Year	6.4

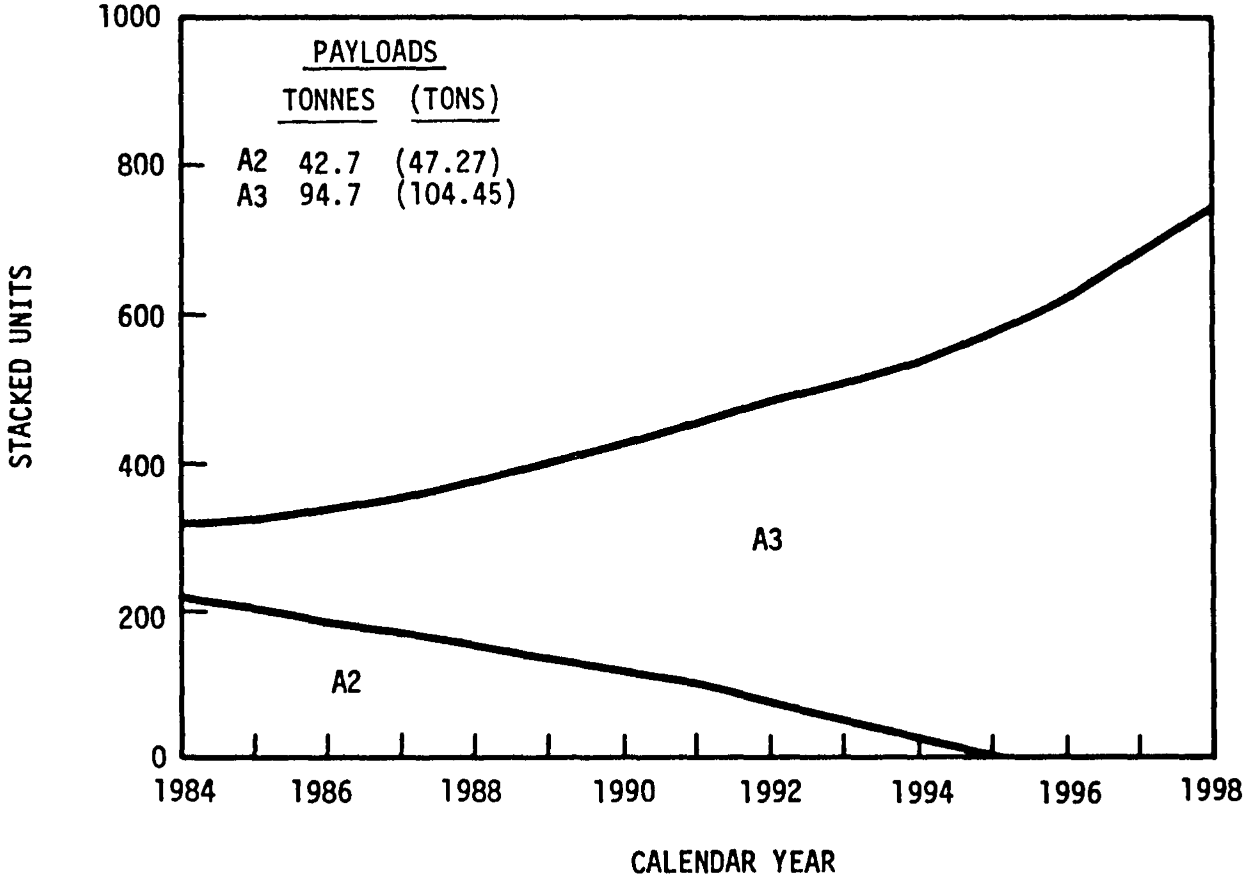


FIGURE 7-1. 1984-1998 REFERENCE FLEET MIX

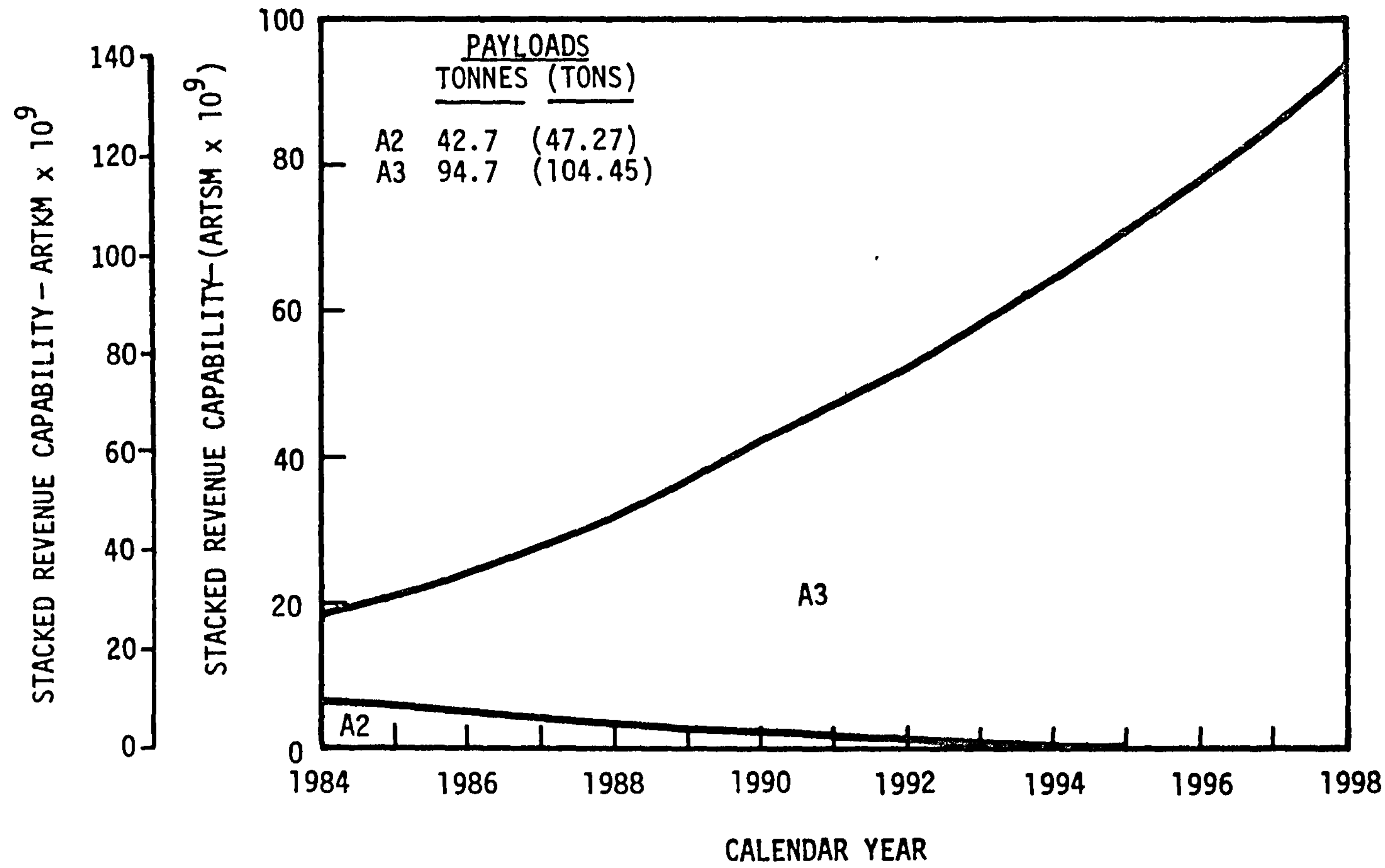


FIGURE 7-2. ANNUAL REVENUE CAPABILITY FOR 1984-1994 REFERENCE FLEET

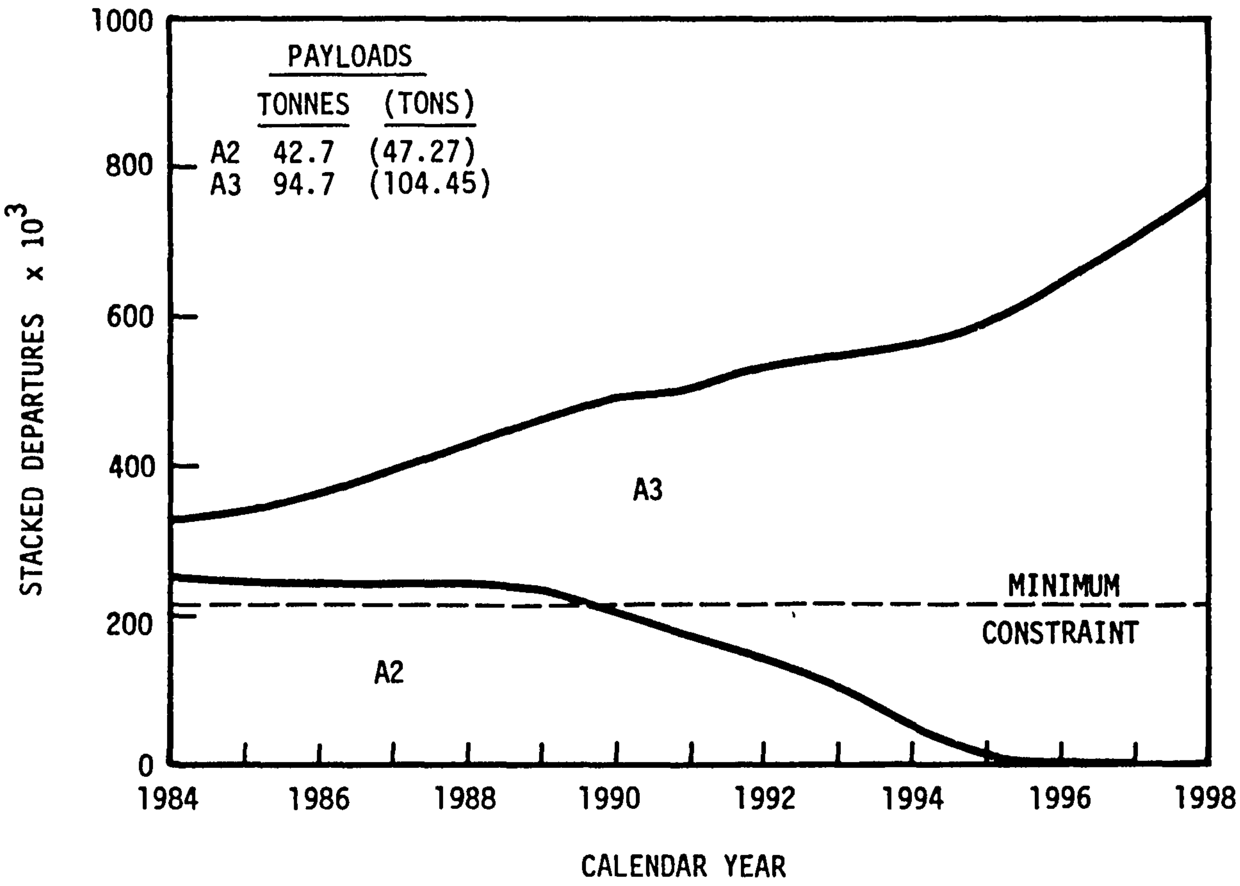


FIGURE 7-3. ANNUAL DEPARTURES FOR 1984-1998 REFERENCE FLEET

briefly discussed in the order of accomplishment beginning with the application of the technology advances, through the derivation of aircraft characteristics and ending with the determination of aircraft size.

Derivative Aircraft Characteristics. - A large number of configurations were parametrically designed using the representative A3 aircraft as a base. The design parameters of this base aircraft were affected by the incremental changes due to advances in 1980 technology, presented in Table 6-1, to obtain the improved values for the derivative aircraft as illustrated in Table 7-3. Note that the ratio used to define the weight of the propulsion system, W_{PS}, consists of the combined weights of the installed engine, the pylon and the nacelle. The latter weights, pylon and nacelle, are therefore excluded from the structural weight, W_{STRU}.

Utilizing the technology improvements, aircraft characteristics were developed for three design ranges. A short range derivative (SRD) for 3218 kilometers (2000 statute miles) was chosen on the basis that the selected usage encompassed 90 percent of the capability provided by the A3 during 1978 as evidenced in Figure 4-6. A long range version (LRD) was designed for 7022 kilometers (4364 statute miles), a range selected to be compatible with the representative A3 aircraft. In order to investigate the effect of range, a third derivative aircraft (MRD) was established for medium range of 5149 kilometers (3200 statute miles). Comparable operating ranges of 4183 kilometers (2600 statute miles) was chosen for the SRD and 8753 kilometers (5440 statute miles) for the MRD and LRD versions. The latter value corresponded to the longest ranges flown by the A3 type aircraft during 1978, reference Figures 4-7 and 4-8.

Each of the three models were considered for a range of payloads that varied from 22.7 tonnes (25 tons) to 181.4 tonnes (200 tons). The specific ranges considered are presented in Table 7-4 along with the resulting trip cost and aircraft price in 1984 dollars. These values are based upon design range, a 1984 fuel cost of 19 cents per liter (71 cents per U.S. gallon), and a production cost breakeven point at 200 aircraft units. Comparing the values for the 90.7 tonne (100 ton) LRD with the A3, reference Page 106 shows a 21 percent reduction in trip cost and an 18 percent reduction

TABLE 7-3

1980 TECHNOLOGY CHANGE

Technology	A3 Aircraft Value	1980 Technology Change - Ratio	Derivative Aircraft Value
Structure - W_{STRU}/W_{LDG}	0.3740	0.888	0.3321
Engine Weight - W_{ENG}/T_{ENG}	0.1721	0.980	0.1687
L/D Cruise	17.4	1.040	18.1
SFC - KG/hr/Deca Newton (lbs/hr/lb)	0.652 (0.639)	0.920	0.600 (0.588)
Propulsion System - W_{PS}/T_{ENG}	0.2919	0.955	0.2789

TABLE 7-4

PARAMETERIZED DERIVATIVE AIRCRAFT CHARACTERISTICS

Market Oper. Range - KM (SM)	Short Range 4183 (2600)		Long Range 8753 (5440)			
Aircraft Model Design Range - KM (SM)	SRD 3218 (2000)		MRD 5149 (3200)		LRD 7022 (4364)	
Payload — Tonnes (Tons)	$/Trip	Aircraft Price-$ $\times 10^6$	$/Trip	Aircraft Price-$ $\times 10^6$	$/Trip	Aircraft Price-$ $\times 10^6$
22.7 (25)	4791	17.4				
45.4 (50)	7077	27.1	14697	28.1	15746	29.2
90.7 (100)	13194	48.6	27854	50.6	30412	52.8
136.1 (150)	18285	64.0	38946	66.6	42936	69.7
149.7 (165)	20000	68.8	42714	71.1	47221	75.1
181.4 (200)	24077	79.8	51722	83.2	57527	87.1

1984 Dollars

in aircraft price. It should be noted that these parametric aircraft were developed analytically utilizing the Design and Cost Subroutine without recourse to graphical layouts.

Derivative Aircraft Sizing. - To evaluate the above derivative aircraft, the FRAME program was exercised to determine the airline ROI as a function of payload, trip cost and aircraft price. Each of the derivative aircraft models was operated in competition with the current A2 and A3 aircraft. Plotting the parametric results provided the means to rapidly determine the airline ROI for any combination of desired payload, trip cost and aircraft price.

A sample of these parametric analysis is presented in Table 7-5 for the short range market and for one of the considered payloads. Payload along with trip cost and aircraft price are parametric inputs with the latter two parameters presented for a range of values. By running these parameterized combinations in competition with the representative A2 and A3 aircraft, the number of derivative aircraft required was determined and the associated values of the airline Return On Investment (ROI) were computed as illustrated in Table 7-5. To facilitate the analysis of other combinations of the input parameters, these results were plotted as shown in Figure 7-4.

Results of the preceding effort provided a range of economic data for the three models of the derivative aircraft. These data were sufficient to identify the most desirable payload size for each model. Data for the SRD are tabulated in Table 7-6. The trends with payload, while pointing in the direction of the larger vehicle, do not clearly indicate a desirable size. To facilitate this selection, the data was plotted as shown in Figure 7-5. Similarly, the data for the MRD and LRD models tabulated in Table 7-7 are presented graphically in Figure 7-6. The number of units of each model required to meet the cargo market demand during the 1984-1998 time period are plotted in Figure 7-7. These data indicate that even if both the SRD and LRD were built, the required number would likely reach the 200 assumed for the manufacturer to break even.

Examination of Figures 7-5 and 7-6 shows that the 136.1 to 181.4 tonne (150 to 200 ton) payload aircraft provided the highest operating income and

TABLE 7-5

TYPICAL PARAMETERIZED AIRLINE ROI DATA

ROI Airline (Example)									
Market	Short Range								
Range -KM (SM)	3218 (2000)								
Payload - Tonnes (Tons)	94.7 (104.45)								
Trip Cost @ Design Range-1984$	8500			14200			18000		
Aircraft Price - 1984 $ x 10^6	40	50	60	40	50	60	40	50	60
ROI Airline - Percent	15.2	14.5	13.9	14.2	13.5	12.9	13.5	12.9	12.2
Units	340			340			340		

TABLE 7-6

SRD AIRCRAFT PARAMETRIC REQUIREMENTS

Aircraft Model	SRD				
Oper. Range - KM (SM)	4183 (2600)				
Design Range - KM (SM)	3218 (2000)				
Payload - Tonnes (Tons)	22.7 (25)	45.4 (50)	90.7 (100)	136.1 (150)	181.4 (200)
Trips Cost @ Design Range - 1984 $	4791	7077	13194	18285	24077
Aircraft Price - 1984 $ x 10^6	17.4	27.1	48.6	64.0	79.8
Units	1307	698	340	241	188
ROI Airline - Percent	11.6	12.9	13.8	14.4	14.5
ΣOI - $ x 10^9	177.0	195.0	204.5	209.5	209.0

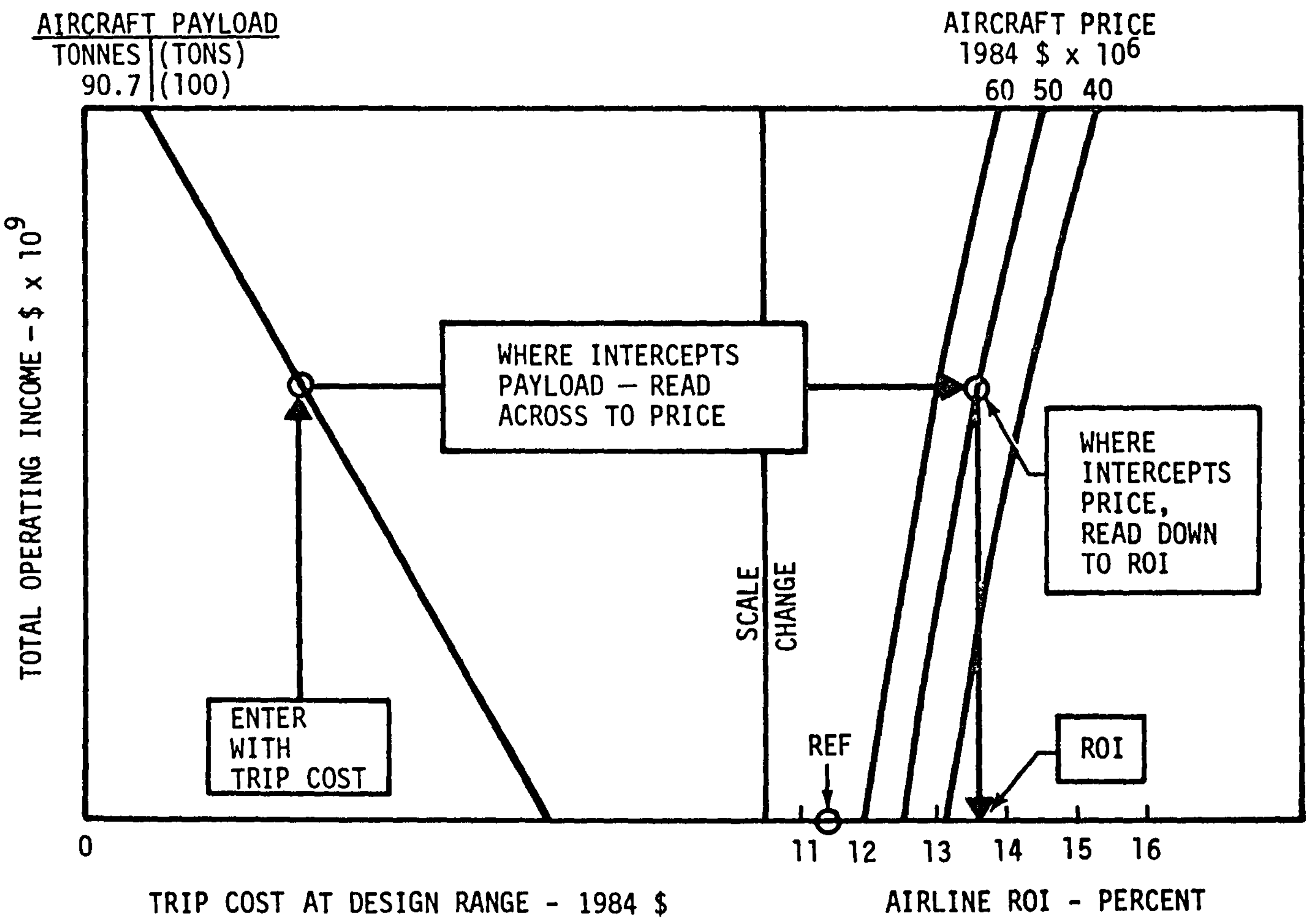


FIGURE 7-4. TYPICAL RELATION OF AIRLINE ROI TO PAYLOAD, TRIP COST, PRICE

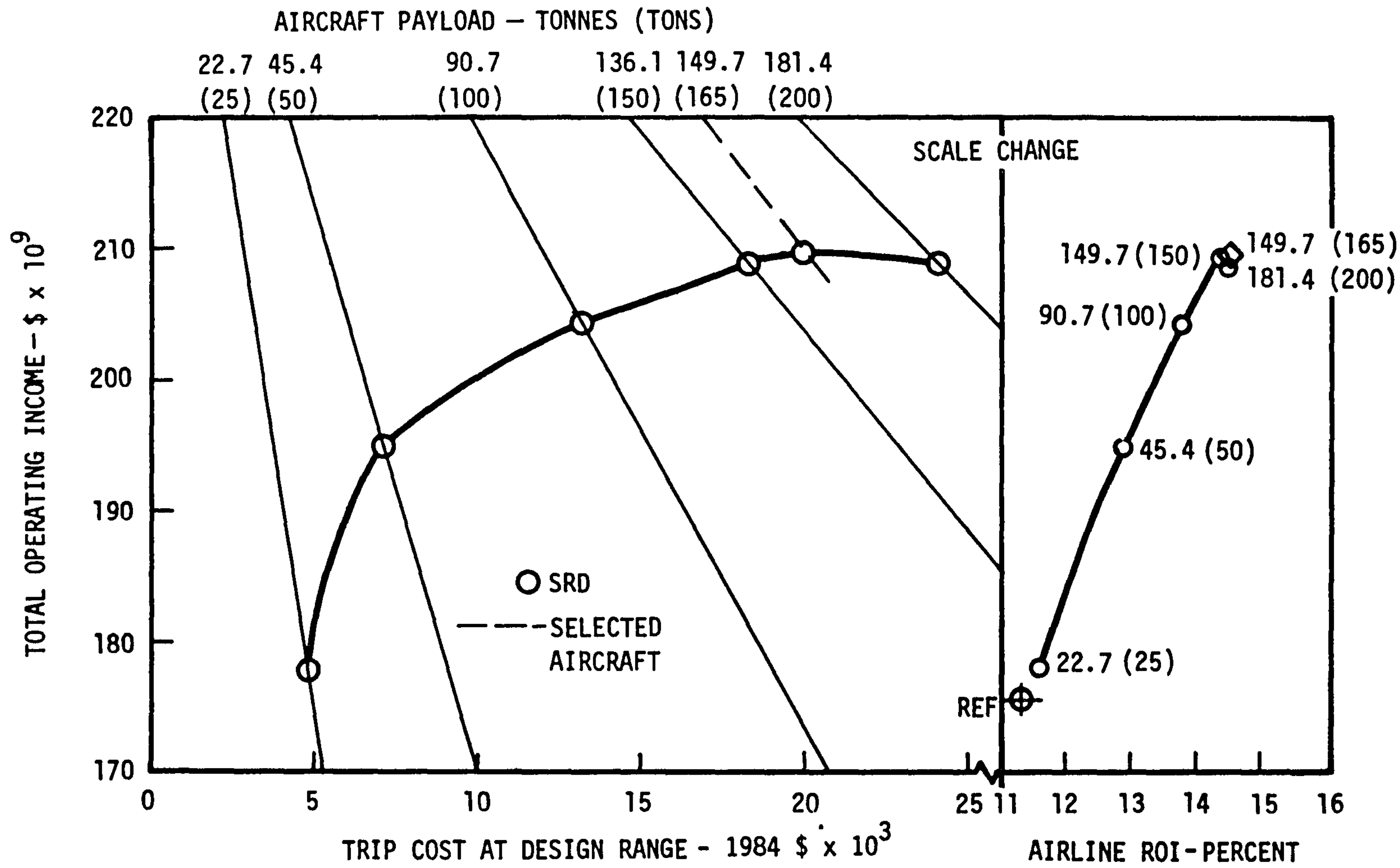


FIGURE 7-5. ECONOMICS OF THE SHORT RANGE DERIVATIVES—SRD

TABLE 7-7

MRD/LRD AIRCRAFT PARAMETRIC REQUIREMENTS

Aircraft Model	MRD				LRD			
Oper. Range - KM (SM)	8753 (5440)				8753 (5440)			
Design Range - KM (SM)	5149 (3200)				7022 (4364)			
Payload - Tonnes (Tons)	45.4(50)	90.7(100)	136.1(150)	181.4(200)	45.4(50)	90.7(100)	136.1(150)	181.4(200)
Trip Cost @ Design Range - 1984 $	14697	27854	38946	51722	15746	30412	42936	57527
Aircraft Price - 1984 $ x 10^6	28.1	50.6	66.6	83.2	29.2	52.8	69.7	87.1
Units	1289	620	436	320	1289	620	436	320
ROI Airline - Percent	12.8	14.2	14.8	14.9	12.2	13.6	14.0	14.0
ΣROI - $ x 10^9	201.0	216.0	220.0	218.5	193.0	207.5	209.0	205.5

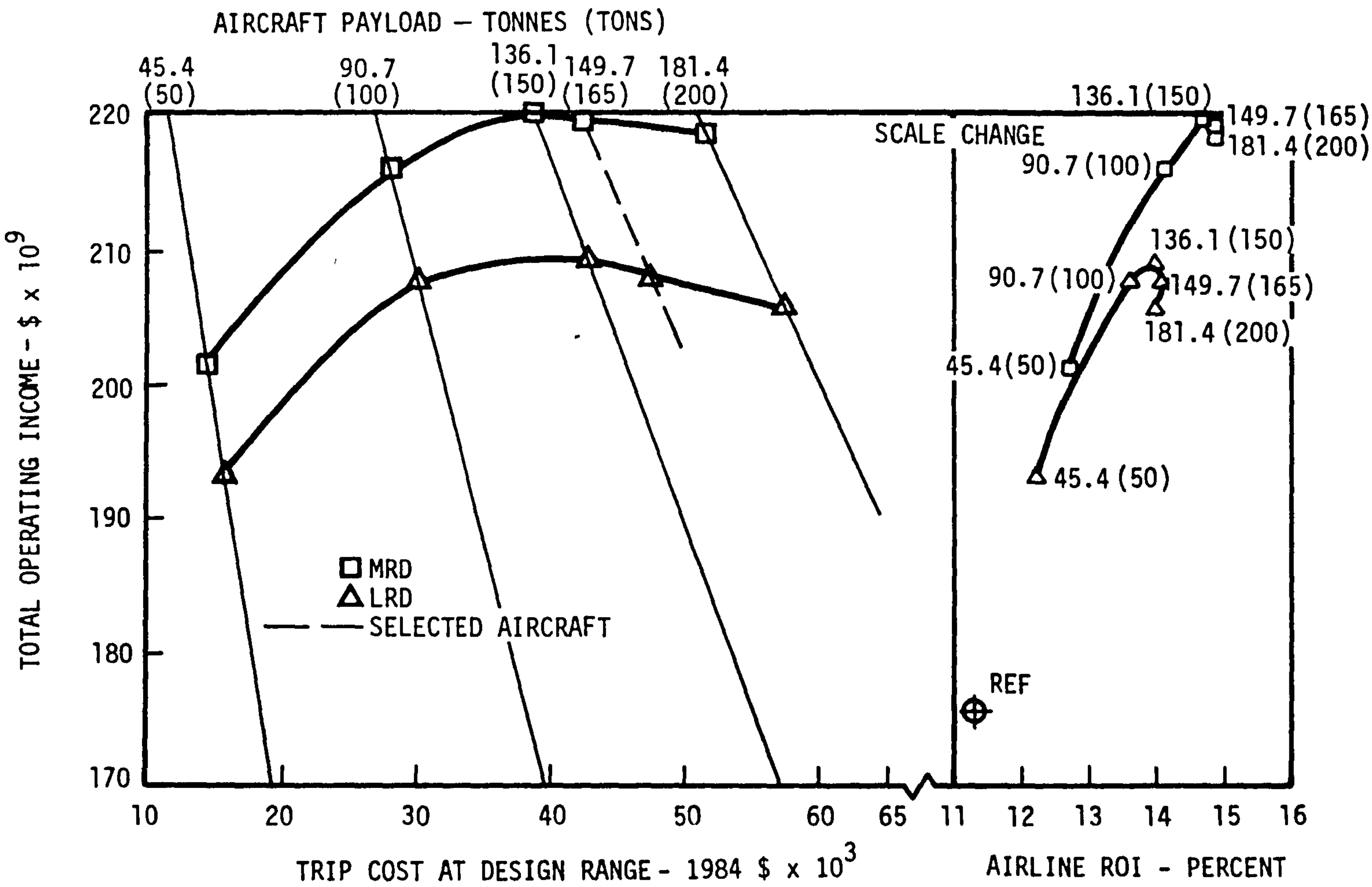


FIGURE 7-6. ECONOMICS OF THE MEDIUM AND LONG RANGE DERIVATIVES – MRD AND LRD

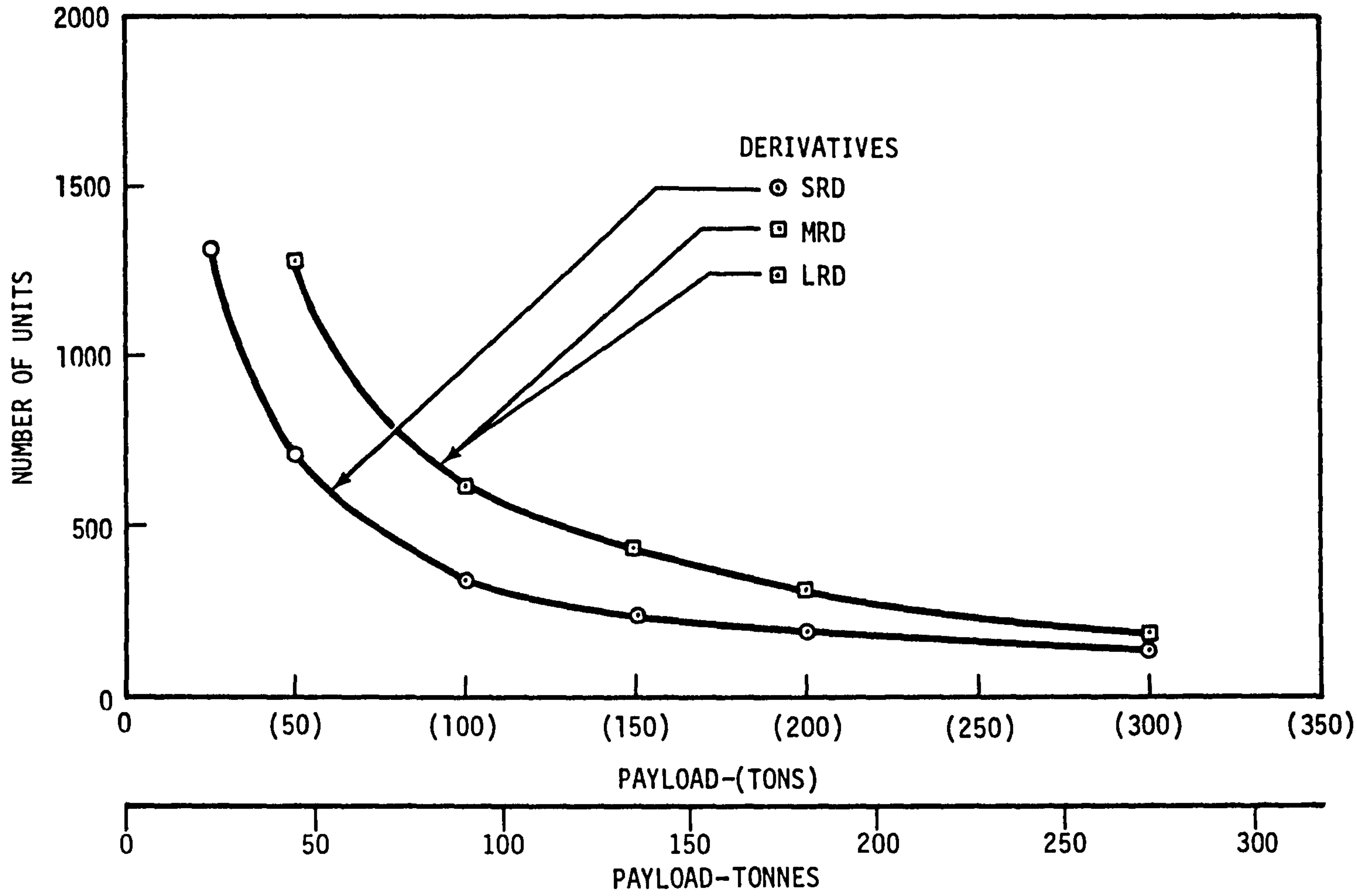


FIGURE 7-7. DERIVATIVE AIRCRAFT UNITS VERSUS PAYLOAD

return on investment to the airlines and indicated that a more desirable size may occur at an intermediate payload. Analysis in this region was expanded and resulted in the selection of the 149.7 tonne (165 ton) payload as the representative size for the SRD, MRD and LRD models. However, it should be noted that the variations in ROI and income for reasonable variations in payload are small when viewed in the perspective of airline economics. As an example, reducing the payload from the 149.7 tonne (165 ton) to 90.7 tonne (100 ton) reduced the ROI a maximum of 0.8 percent and the operating income a maximum of 3 percent. Both these values are for the SRD, loses with the MRD and LRD models are even less. Therefore, although the analysis pointed to the 149.7 tonne (165 ton) payload as being the preferred size, the smaller payloads incur a relatively small penality to the resulting fleet economics.

To complete the definition of the derivative aircraft, the combination of the SRD and LRD was examined. In this case both models simultaneously competed with the A2 and A3 reference fleet. In addition, the analysis of the fleet economics was expanded to include investment and cash flow. Results are tabulated in Table 7-8 and plotted in Figure 7-8. Examining these data shows that the derivative aircraft provide a significant lower investment from 53.2 billion dollars for the reference fleet down to 43.3 billion dollars for the MRD and 42.5 billion dollars for SRD/LRD combination, a reduction of from 17 to 20 percent, respectively. This lower investment also provided a higher ROI going from 11.3 percent up to 14.8 or 15.2 percent, an increase of 3.5 or 3.9 percent, respectively. Specifically, the SRD provided the lowest investment while the combined SRD/LRD provided the highest ROI for only a slight increase in investment over the SRD. The MRD, a single aircraft derivative performing the whole job, required only a slightly larger investment and slightly lower ROI than the SRD/LRD combination. All four possible combinations provide an airline ROI that is very near the 15 percent that is often identified as a desirable economic objective. The SRD/LRD combination was selected as the solution to compete with the new dedicated aircraft during the 1994 to 2008 time period.

Other factors entering into the decision of which aircraft to build must include the number of units to be produced and the growth in frequency. The

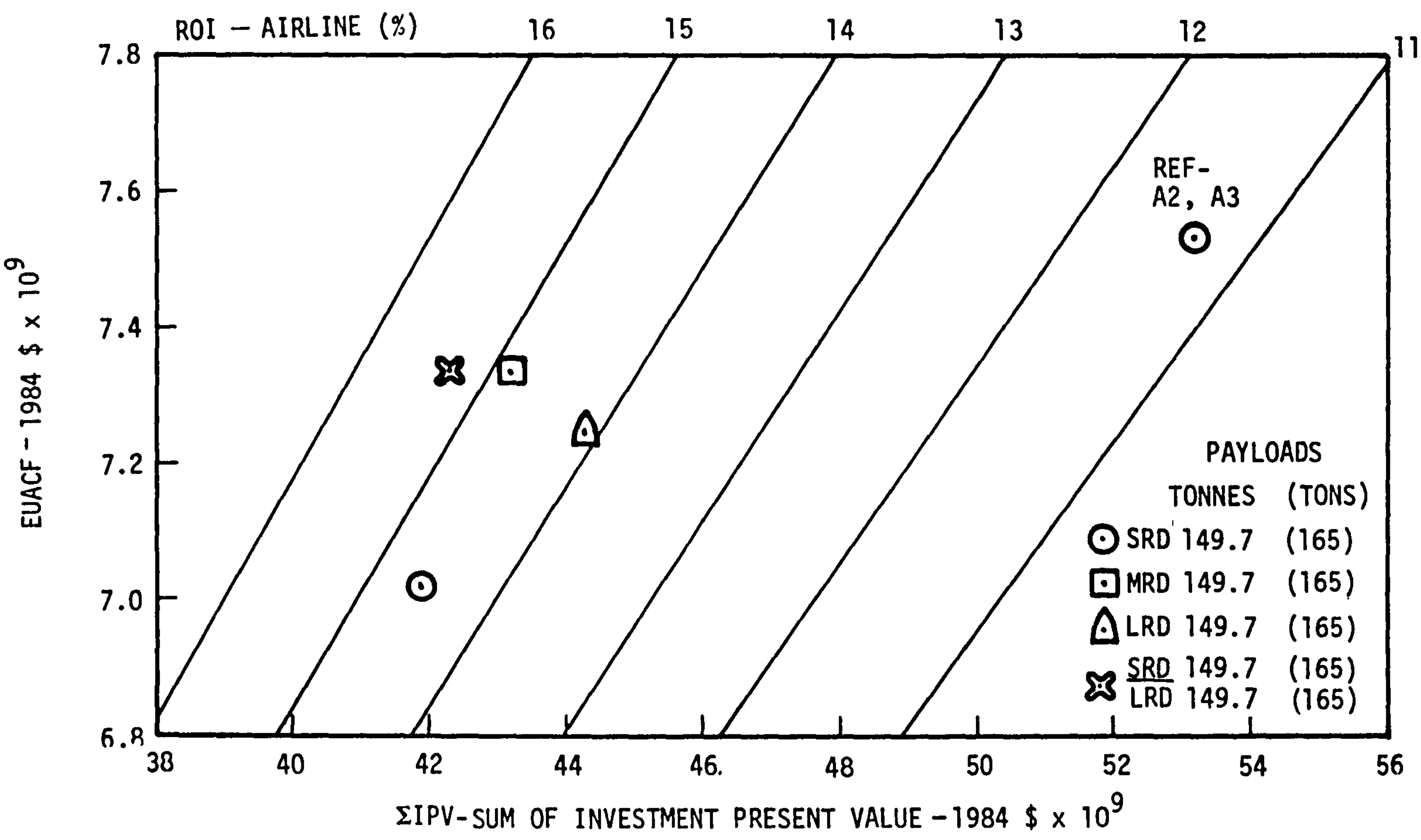


FIGURE 7-8. ECONOMIC WORTH - DERIVATIVE AIRCRAFT

TABLE 7-8

DERIVATIVE REQUIREMENTS

Aircraft Model	Ref.	SRD	MRD	LRD	SRD/LRD
Payload - Tonnes (Tons)	-	149.7(165)	149.7(165)	149.7(165)	149.7(165) /149.7(165)
Design Range - KM (SM)	-	3219(2000)	5150(3200)	7025(4365)	3219(2000)/ 5150(4365)
Trip Cost @ Design Range - 1984 $	-	20000	42714	47223	20000/47223
Aircraft Price - 1984 $ x 10^6	-	68.8	71.1	75.1	68.8/75.1
Units	-	223	397	397	210/176
ROI Airline - Percent	11.3	14.6	14.8	14.1	15.2
EUACF - 1984 $ x 10^9	7.5	7.0	7.3	7.3	7.3
ΣIPV - 1984 $ x 10^9	53.2	42.0	43.3	44.4	42.5
ΣOI - $ x 10^9	175.4	210.2	219.5	207.5	227.8
Departures (Trips) Growth Rate - Percent per Year	6.4	4.0	3.9	4.0	3.4

former has a strong influence on aircraft cost and hence on depreciation and insurance while the latter interfaces directly with the operational limits of existing airports as discussed in Volume 3. Considering the size of the cargo demand forecast for the foreign market, it appears unlikely that the derivative aircraft market could be captured by a single aircraft manufacturer. If the number of MRD aircraft, Table 7-8, is divided between two manufacturers, the number that each produces, excluding passenger versions, would be near the 200 breakeven. In this case a reasonable profit would require the aircraft price be increased above that shown in Table 7-8. A similar situation could exist relative to the SRD/LRD combination if a second manufacturer entered the market for either the SRD or the LRD, or for both. It should be remembered, however, that since the SRD, MRD, and LRD will be derivatives of current wide body passenger aircraft, it is likely that a variation of the derivatives will be sold as passenger versions. Therefore, even if second manufacturers enter the market, the additional passenger units sold should result in maintaining the aircraft price near the values projected in Table 7-8.

There was little difference between the frequency growth produced by the MRD or the SRD/LRD solutions, both growth rates were less than 4 percent as shown in Table 7-8. This rate is approximately half that experienced by jet cargo aircraft between 1976 and 1978.

1984-1998 Fleet Mix

Variations of fleet characteristics with time are shown in Figures 7-9 through 7-11 for the fleet based upon the SRD/LRD derivative aircraft while the data for the MRD based fleet operations is presented in Figures 7-12 through 7-14. There was a steady increase in the number of SRD and LRD aircraft following their initial operation in 1985 as evidenced in Figure 7-9. However, there was also about a 50 percent increase in the number of wide body A3's to 1986. As evidenced in Figure 7-10, this increase was primarily due to their replacing the large narrow-body aircraft, A2. The combined effects of unit, revenue capability and departure to the year 1993, Figure 7-11, indicated that this equipment substitution was occurring on the shorter range routes where traffic growth was sufficient to accommodate the larger

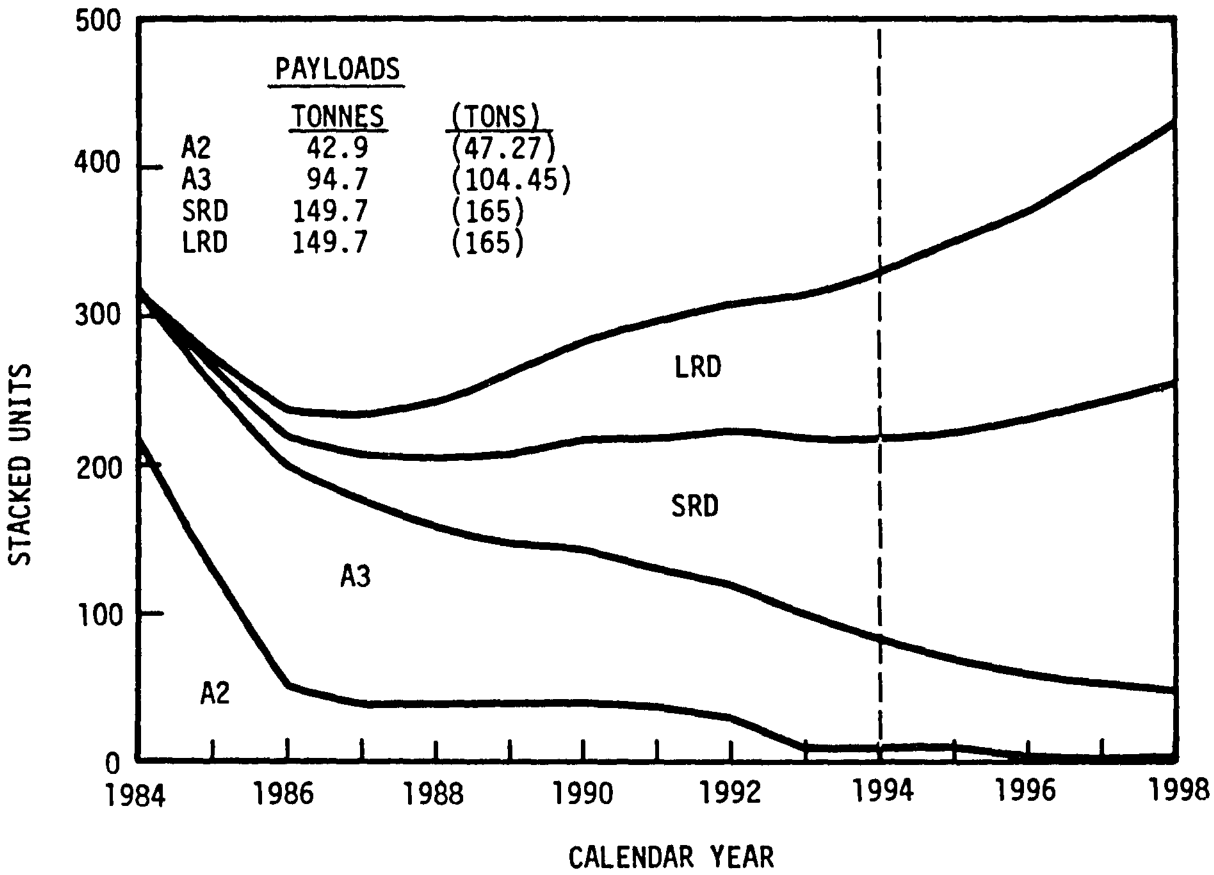


FIGURE 7-9. 1984-1998 SRD/LRD FLEET MIX

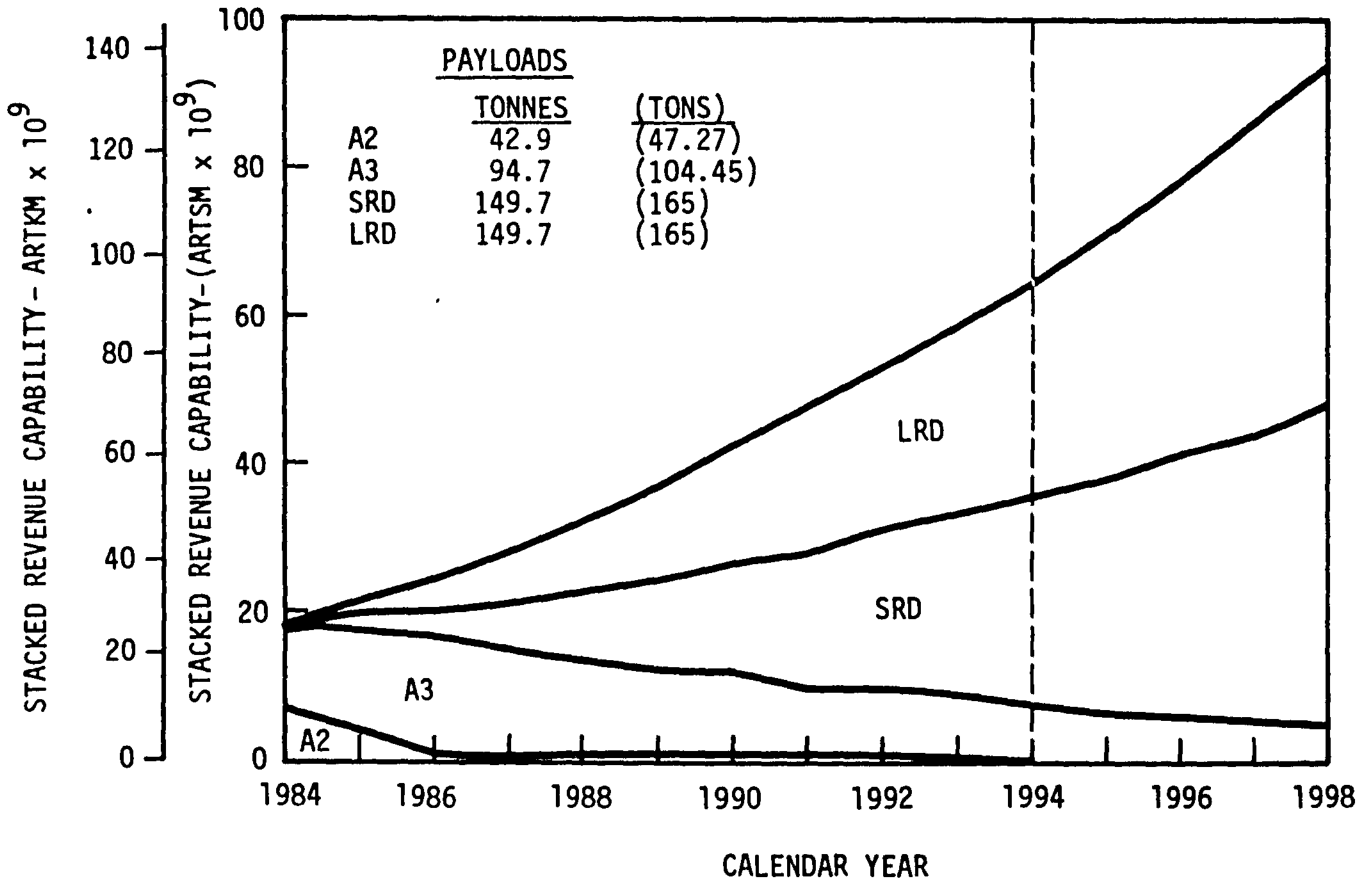


FIGURE 7-10. 1984-1998 SRD/LRD FLEET ANNUAL REVENUE CAPABILITY

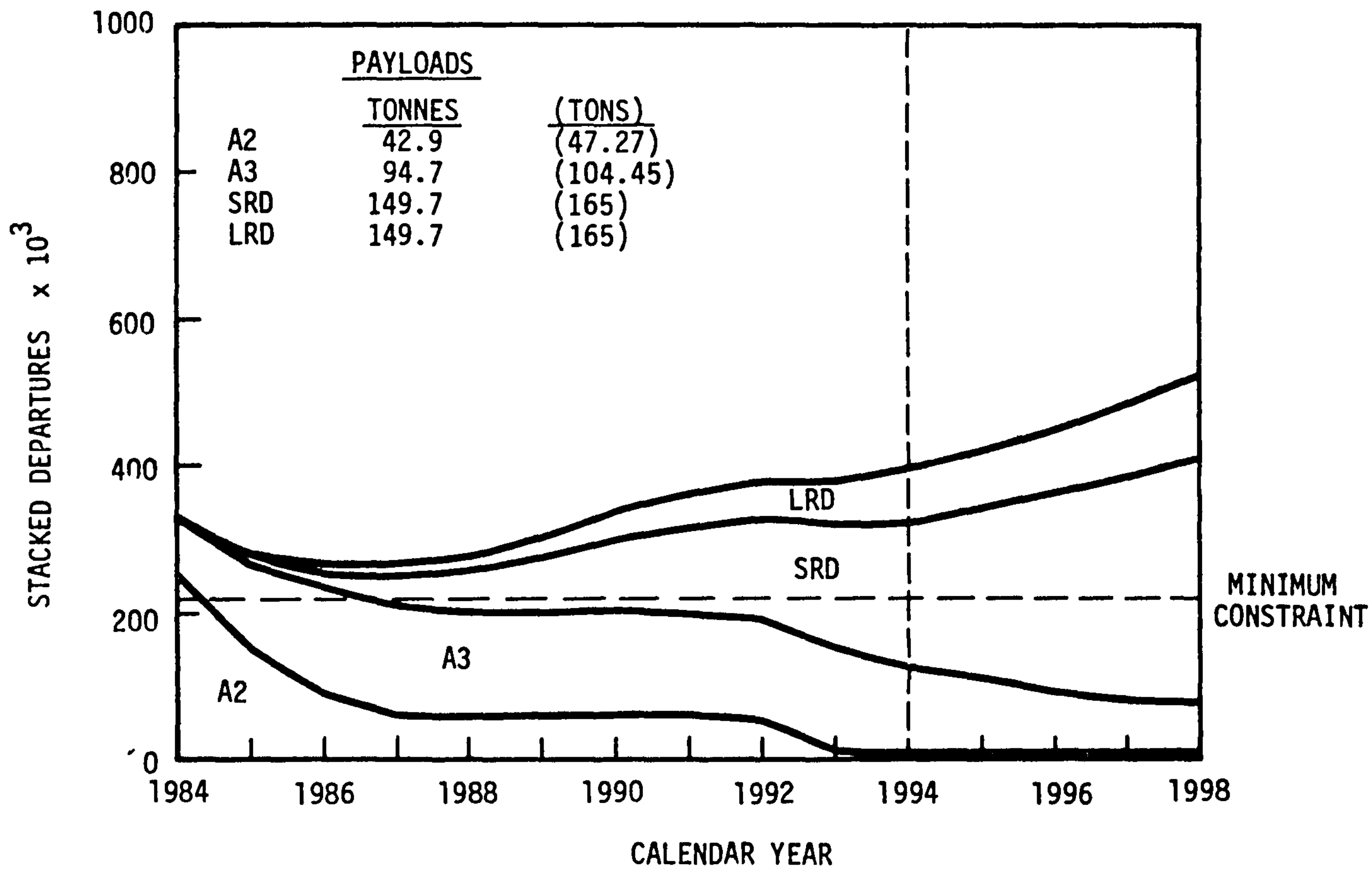


FIGURE 7-11. 1984-1998 SRD/LRD FLEET ANNUAL DEPARTURES

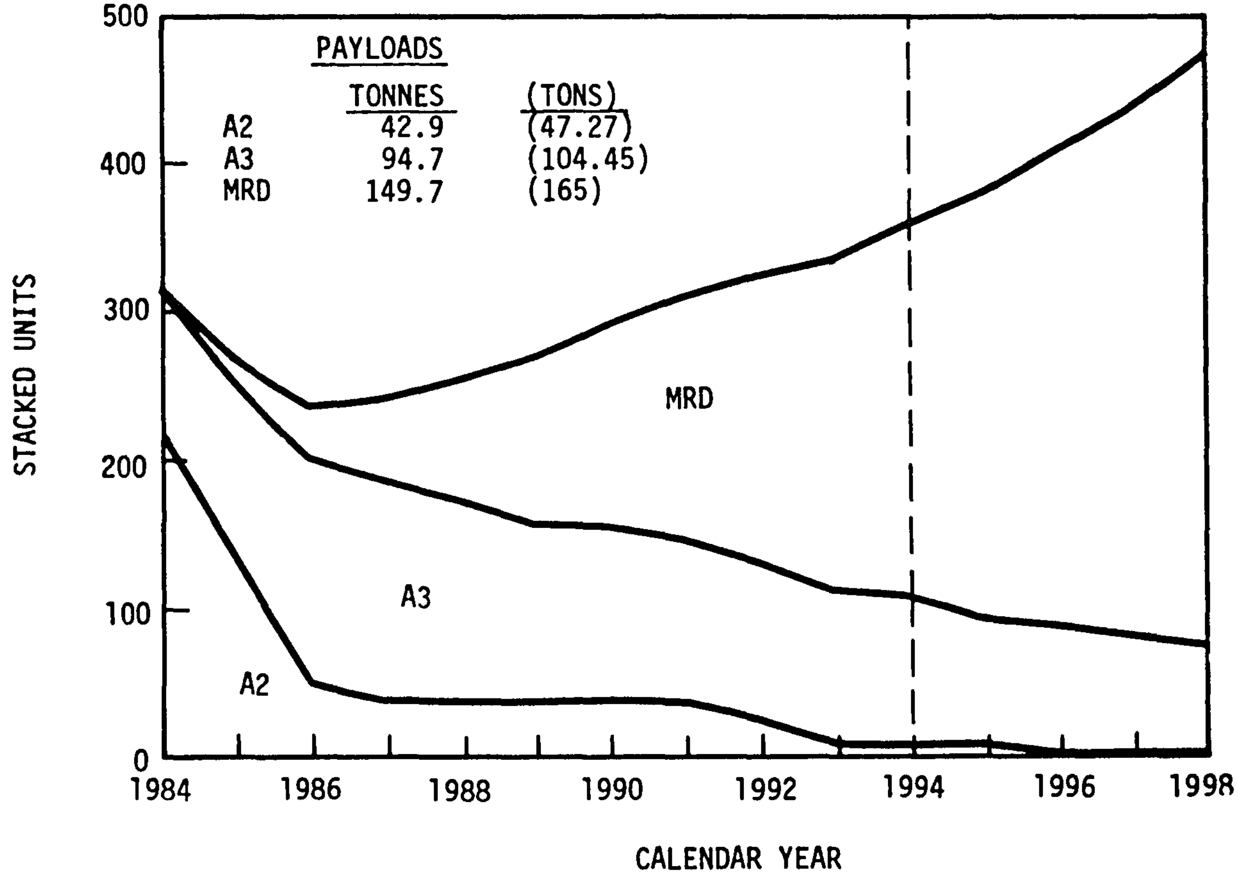


FIGURE 7-12. 1984-1998 MRD FLEET MIX

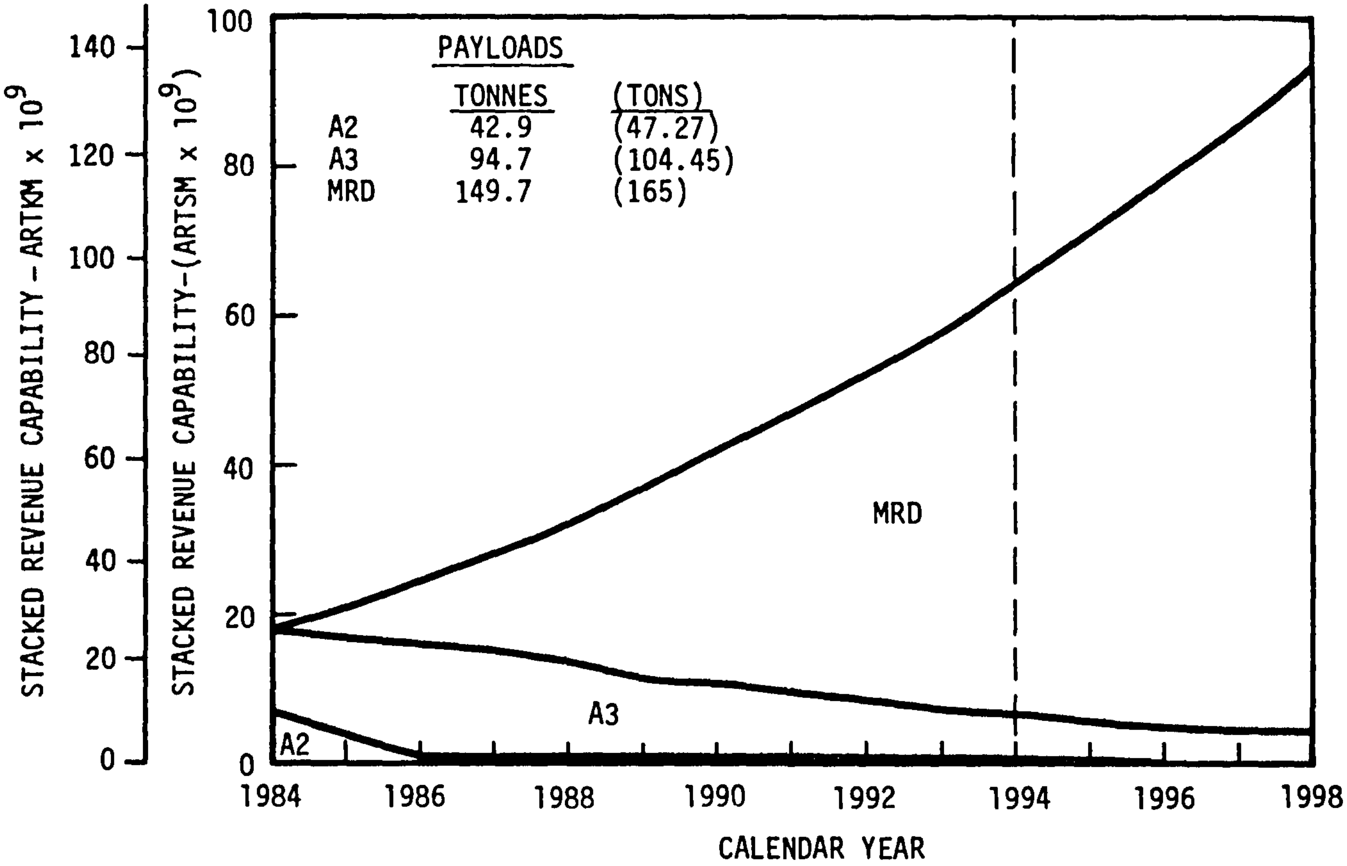


FIGURE 7-13. 1984-1998 MRD FLEET ANNUAL REVENUE CAPABILITY

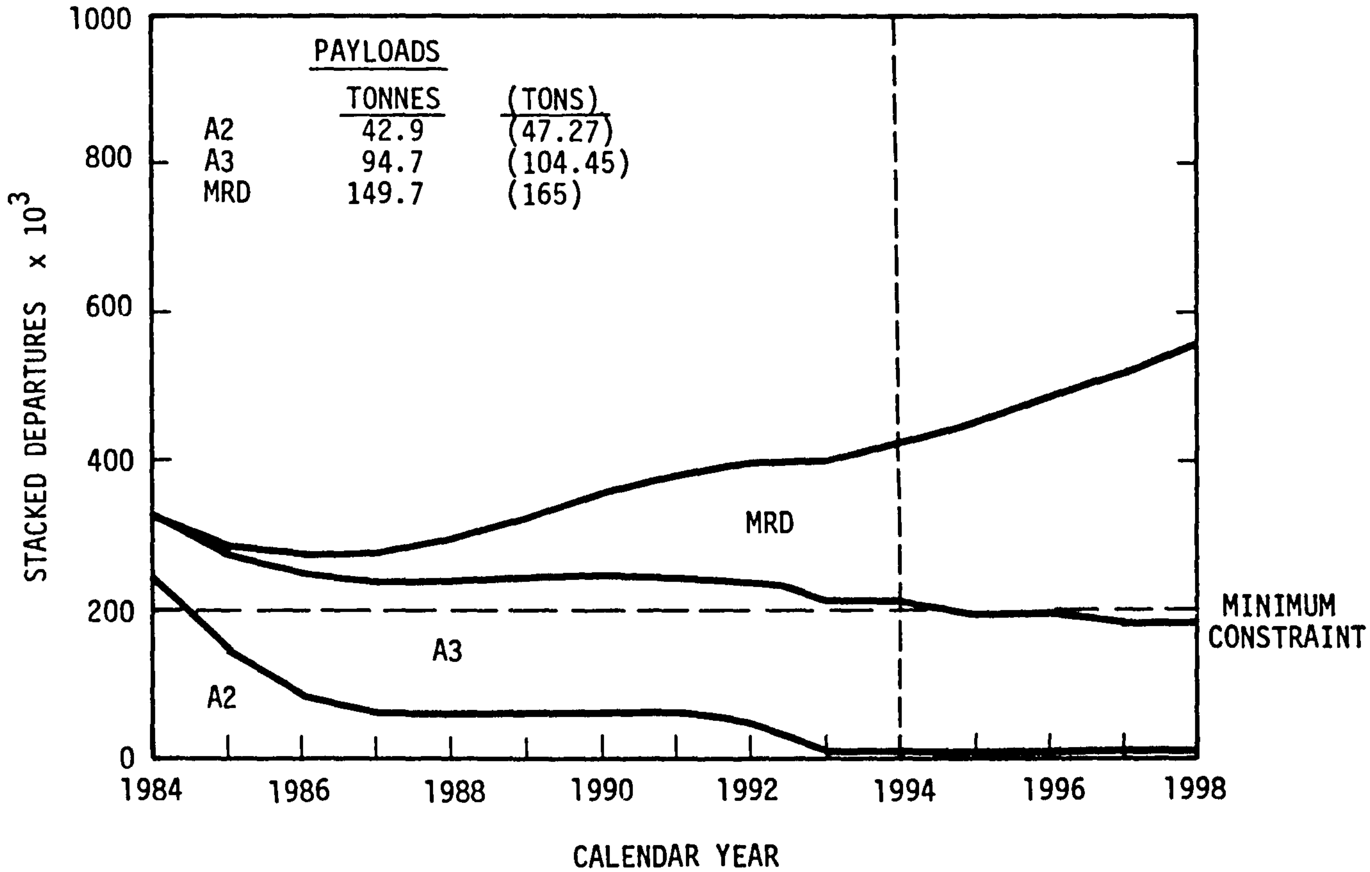


FIGURE 7-14. 1984-1998 MRD FLEET ANNUAL DEPARTURES

aircraft. Beginning about 1987 the more efficient SRD begins to replace the A3's. Although there was a decrease in frequency out to about 1987, the annual value did not fall below the minimum constraint as shown in Figure 7-11. However, this decrease did explain the relatively low frequency growth shown in Table 7-8.

The variations in fleet mix and operations with the MRD were very similar to those occuring with the combined SRD and LRD aircraft as witnessed in Figures 7-12 through 7-14. Comparing the 1998 data for the MRD fleet with that for the SRD/LRD fleet shows that the total MRD fleet is about 9 percent larger, contains 3 percent more derivative type aircraft, and has approximately 65 percent more A3 types remaining (76 versus 46). This was due to the combined effects of the SRD replacing a greater number of A3's than did the MRD and the ability of the MRD to efficiently handle some of the longer range missions of the SRD.

1994 Fleet Mix. - The vertical dashed lines shown in Figures 7-9 through 7-11 indicate the characteristics of the SRD/LRD fleet selected to compete with the new dedicated freighter aircraft during the 1994 to 2008 time period. The 1994 values of the annual statistics for this competitive fleet are as follows:

1994 FLEET ANNUAL STATISTICS

Aircraft Type	A2	A3	SRD	LRD	Total
Units	9	72	136	112	329
Revenue Capability - ARTKM x 10^9	0.387	10.8	41.0	42.1	94.3
(ARTSM x 10^9)	(0.265)	(7.4)	(28.1)	(28.8)	(64.6)
Available Capability - ATKM x 10^9	0.561	15.6	59.9	61.0	137.1
(ATSM x 10^9)	(0.384)	(10.7)	(41.1)	(41.8)	(93.9)
Load Factor - Percent	69.03	69.65	68.42	69.00	68.82

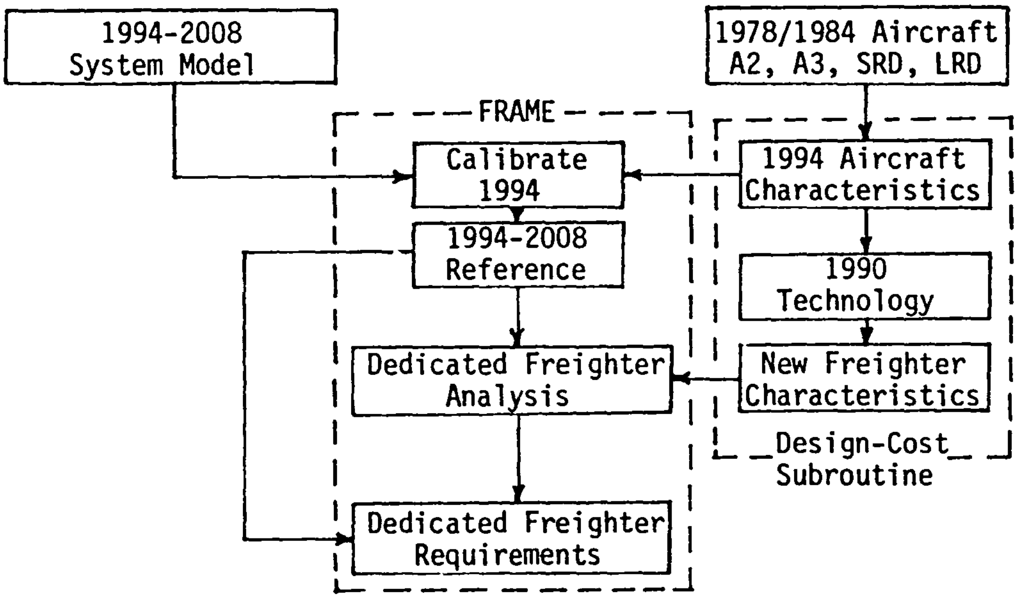
Comparing these values with those for the 1984 A2 and A3 fleet, reference Page 90, shows only a slight increase in the total number of units, eight aircraft or about 2.5 percent. However, the fleet revenue capability increased about 250 percent and the fleet load factor improved about 15 percent. The SRD experienced the lower load factor indicating that due to its improved economics, it was applied on some A3 and perhaps A2 routes that did not quite match its capability.

Even with only one manufacturer for each of the SRD and LRD aircraft the number of units required by 1994, 136 and 112 respectively, would be marginal relative to the manufacturers recovering their investment and realizing a profit. Therefore, unless additional units were sold for passenger operations it is unlikely that either manufacturer would, at that point in time, consider launching a new dedicated freighter program.

Section 8

FUTURE DEDICATED AIRCRAFT (1994-2008)

An approach similar to that used to define the derivative aircraft was applied in identifying the requirements for a new dedicated freighter aircraft to become operational in 1995. This aircraft was based upon the 1990 technology as outlined in Section 6. Selection of the preferred set of requirements was based upon the aircraft fleet operating characteristics for the period 1994 to 2008. These investigations along with calibration and reference fleet performance analysis were conducted using the FRAME program as outlined below.



The desirability of the new dedicated freighter was established in competition with the A2, A3, SRD and LRD fleet defined in the preceding section. The calibration run was performed to assure continuity of this fleet within the 1984 to 1998 and the new 1994 to 2008 models.

1994 Aircraft

The cargo model and the A2, A3, SRD and LRD trip costs and aircraft prices were updated from 1984 current dollars to 1994 current dollars, as shown below. The trip cost does not include depreciation or insurance and is based upon a 1994 fuel price of 48 cents per liter (181 cents per U.S. gallon). For years subsequent to 1994 all costs were increased for an annual inflation rate of 6 percent.

Model	A2	A3	SRD	LRD
Payload - Tonnes (Tons)	42.9(47.27)	94.7(104.45)	149.7(165)	149.7(165)
Design Range - KM (SM)	5150(3200)	7023(4364)	3219(2000)	7023(4364)
Trip Cost Design Range-1994$	50386	87733	45068	106892
Aircraft Price - 1994$ x 10^6	40.9	115.3	123.2	134.5

Calibration - 1994. - The FRAME program was run for 1994 to assure continuity with the 1984-1998 model and the 1994 cargo fleet mix as derived for the 1984-1998 time period in the previous section. The results of this calibration are presented in Table 8-1. The data of Table 8-1 compares the forecast values with the values computed in Section 7 (Ref.) with the (New) values computed with the 1994-2008 model. Results show excellent agreement in all areas with the deviations from the forecast values being less than 1 percent for the computed market and total values. The maximum deviation occurred in the number of trips performed by the A3 aircraft where the new value was 6 percent less than the reference. Three other values in the aircraft table deviated by about 3 percent and one by 2 percent. All other values in this table agree within 1 percent.

1994-2008 Reference Fleet. - Having established continuity for 1994, the program was run to evaluate the A2, A3, SRD and LRD aircraft for the 1994-2008 time period. This gives the reference case for a new freighter aircraft study. The economic results for this reference fleet are summarized in Table 8-2. The airline ROI of 21.4 percent was higher than expected. This result was primarily due to the tariff levels that were derived in Section 1 on the basis of the analysis presented in Book 2 of Volume 3. This analysis postulated that the new aircraft would capture 45 percent of the demand over a ten year period whereas the more efficient derivative aircraft were providing over 85 percent of the capability in 1994 as shown in Figure 8-2.

The operational requirements of units, revenue capability, and departures, for the 1994-2008 reference fleet are presented in Figures 8-1, 8-2 and 8-3,

TABLE 8-1

CALIBRATION FOR 1994

Market	U.S. Domestic					U.S. International					Foreign				
	Revenue		Available			Revenue		Available			Revenue		Available		
Factors	ARTKM x10⁹	(ARTSM x10⁹)	ATKM x10⁹	(ATSM x10⁹)	LF	ARTKM x10⁹	(ARTSM x10⁹)	ATKM x10⁹	(ATSM x10⁹)	LF	ARTKM x10⁹	(ARTSM x10⁹)	ATKM x10⁹	(ATSM x10⁹)	LF
Forecast	14.959	(10.246)	21.679	(14.849)	69.00	13.090	(8.966)	18.701	(12.809)	70.0	66.314	(45.421)	92.107	(65.827)	69.00
Frame	14.955	(10.243)	21.688	(14.855)	68.95	13.084	(4.962)	18.692	(12.803)	70.0	66.285	(45.401)	96.679	(66.219)	68.56

Factors	Units	Departures (Trips)	Distance Flown		Hours Flown	Revenue		Available		Load Factor (LF)
			KMx10⁶	(SMx10⁶)		ARTKM x10⁹	(ARTSM x10⁹)	ATKM x10⁹	(ATSM x10⁹)	
A2 (Ref.)	9	9524	13.074	(8.124)	21191	0.387	(0.265)	0.561	(0.384)	69.0
(New)	9	9521	13.071	(8.122)	21185	0.387	(0.265)	0.561	(0.384)	69.0
A3 (Ref.)	73	111224	159.996	(99.417)	260208	10.553	(7.228)	15.161	(10.384)	69.6
(New)	72	104821	164.176	(102.014)	260545	10.835	(7.421)	15.556	(10.655)	69.7
SRD(Ref.)	136	200383	402.490	(250.096)	578911	41.216	(28.230)	60.248	(41.266)	68.4
(new)	136	203459	400.416	(248.807)	577912	41.010	(28.089)	59.937	(41.053)	68.4
LRD(Ref.)	112	70814	408.423	(253.782)	516340	42.175	(28.887)	61.136	(41.874)	70.0
(New)	112	71673	407.537	(253.232)	515922	42.092	(28.830)	61.003	(41.783)	69.0

Totals	Revenue		Available		Factor (LF)
	ARTKM x10⁹	(ARTSM x10⁹)	ATKM x10⁹	(ATSM x10⁹)	
(Ref.)	94.330	(64.610)	137.105	(93.908)	68.8
(New)	94.323	(64.605)	137.058	(93.876)	68.8
Forecast	94.364	(64.633)	136.487	(93.485)	69.1

TABLE 8-2

REFERENCE FLEET 1994-2008

Time Period (1994-2008)	Reference
Units - A2	9
Units - A3	72
Units - SRD	437
Units - LRD	379
ROI Airline - Percent	21.4
EUACF - 1994 \$ x 10^9	25.7
ΣIPV - 1994 \$ x 10^9	113.5
ΣOI - \$ x 10^9	939.3
Departures (Trips) Growth Rate - Percent per Year	6.7

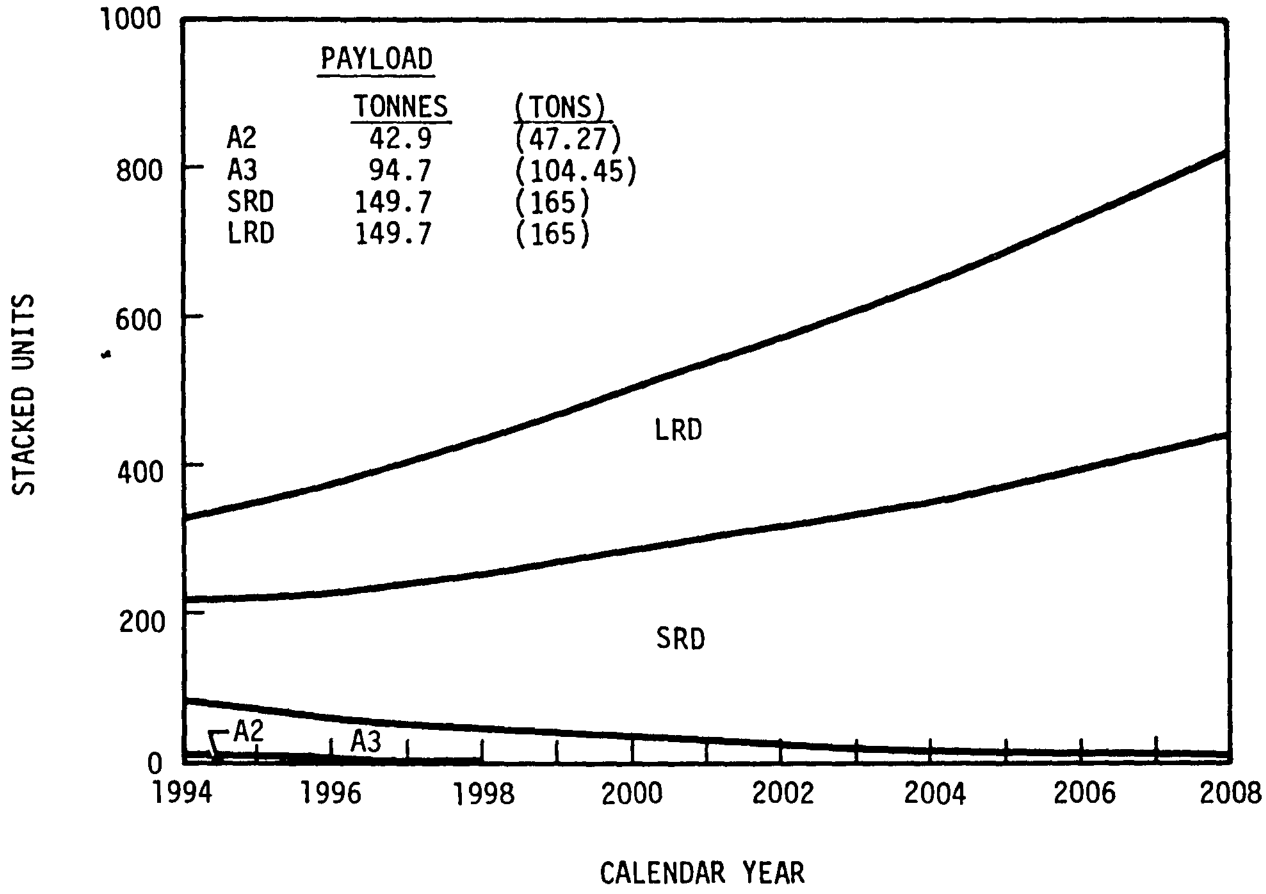


FIGURE 8-1. 1994-2008 REFERENCE FLEET MIX

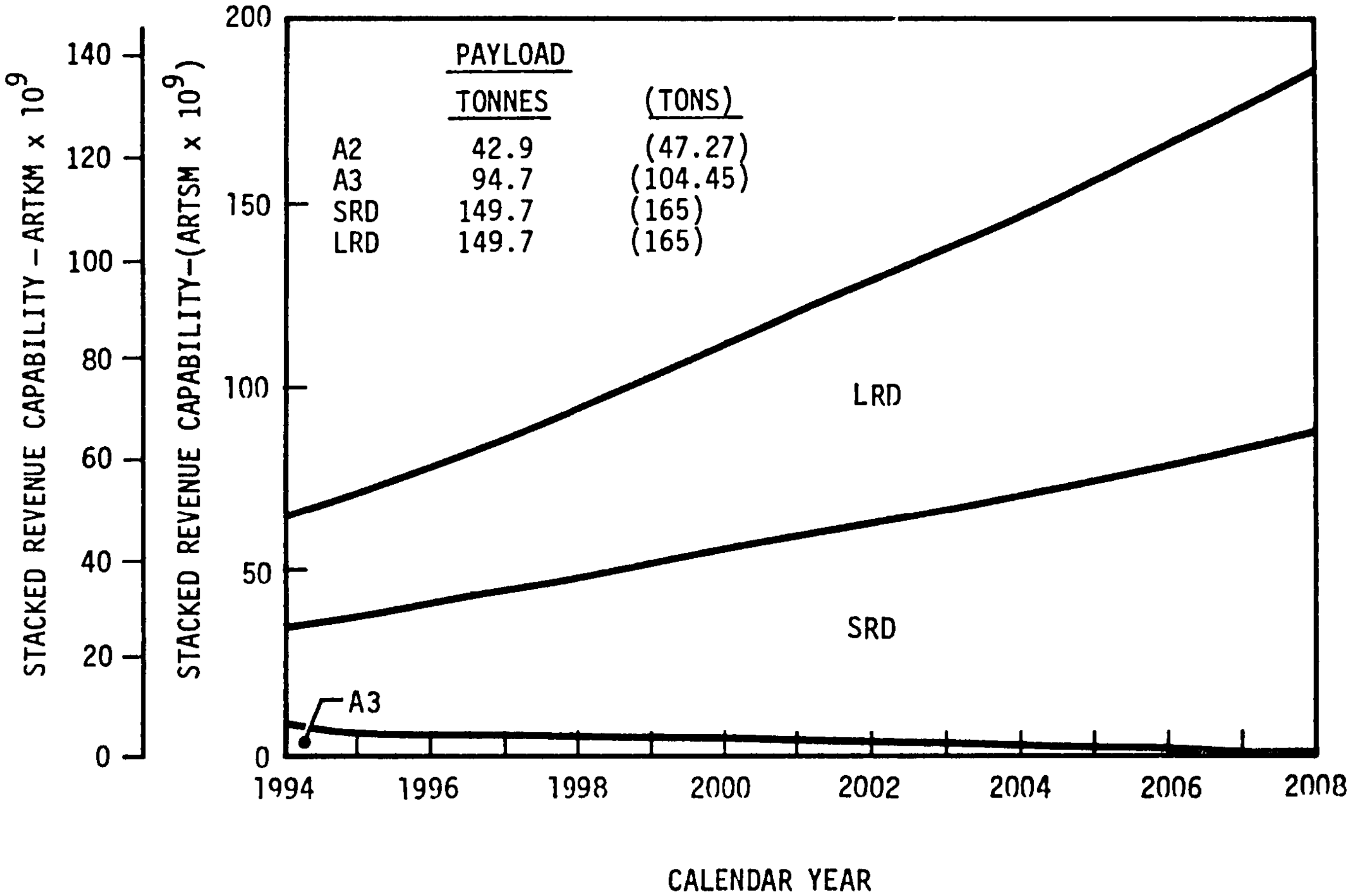


FIGURE 8-2. ANNUAL REVENUE CAPABILITY FOR THE 1994-2008 REFERENCE FLEET

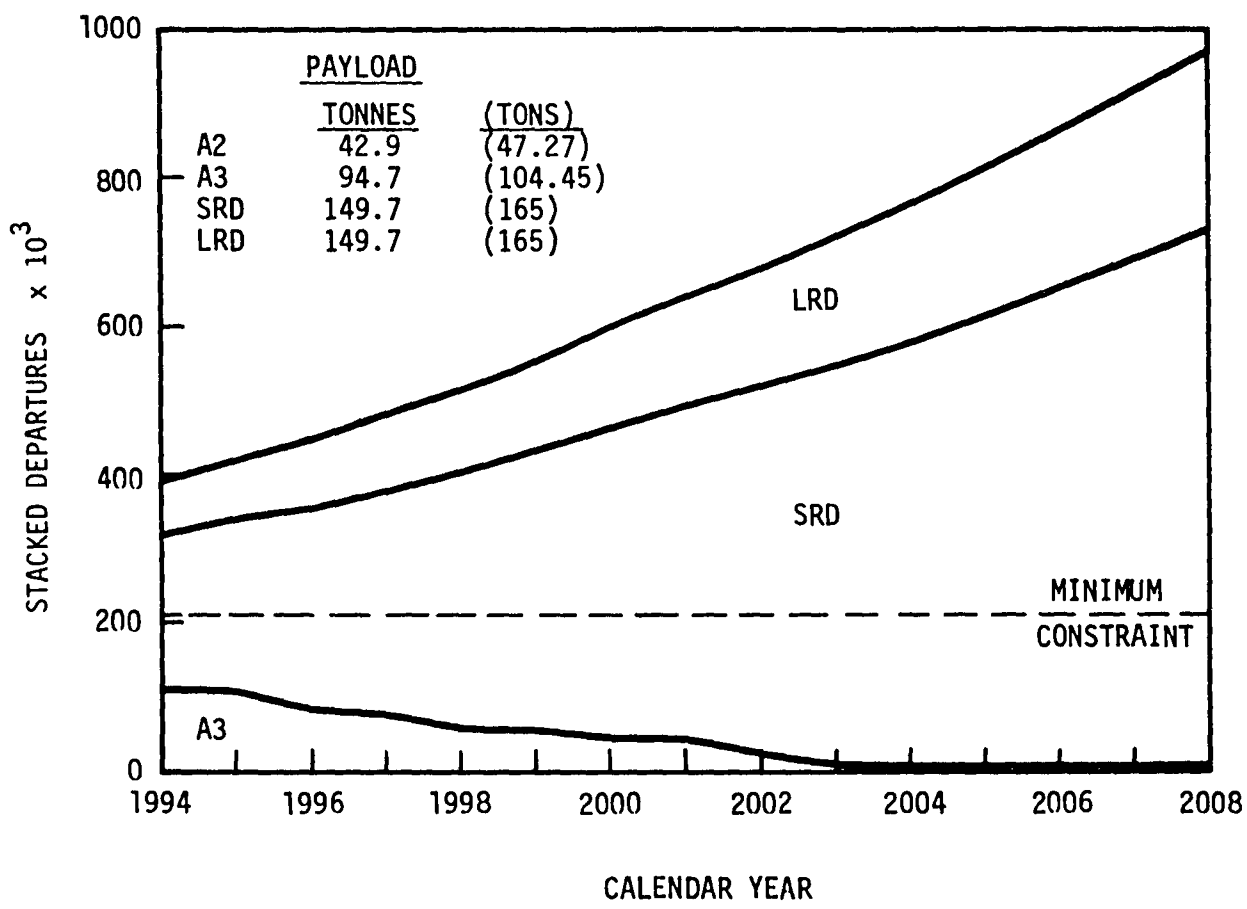


FIGURE 8-3. ANNUAL DEPARTURES FOR THE 1994-2008 REFERENCE FLEET

respectively. Without competition from a new dedicated freighter, the number of derivative aircraft continued to increase to 816 units in the year 2008 and in so doing held the frequency growth to 6.7 percent. The growth in SRD and LRD units was a result of the combined effects of their handling the growth of the cargo market demand and replacing the less efficient A2 and A3 types as evidenced in Figure 8-1. The A2 aircraft phased out in 1998 while the A3 continued on with a few units remaining in the final considered year. The changes in revenue capability and in departures of the respective aircraft types, Figures 8-2 and 8-3, followed trends similar to those for the number of unites. The values of these two parameters for the A2 aircraft were so small they could not be shown to the scales used in Figures 8-2 and 8-3.

1995 Dedicated Aircraft

A prime factor affecting aircraft size selection is the aircraft cost which impacts not only the airline investment but also the DOC of the aircraft. The cost of a given aircraft is dependent upon its design, the number of units anticipated to be produced, and the manufacturer's return on investment (ROI). The problem of manufacturer's profit is accentuated in the case of the dedicated freighter compared to that of the derivative discussed in Section 7. For the latter there is the additional passenger market that can add considerable to the total number of units manufactured. On the other hand, the dedicated aircraft is solely dependent upon the growth of the air cargo system unless past practices are reversed and the industry begins to consider adapting a new dedicated cargo aircraft to passenger operations.

The initial approach to pricing the dedicated freighter applied the usual procedure of establishing a breakeven level of production. Two hundred units were selected as the point in production where the manufacturer's income would match his outgo. On this basis, the aircraft characteristics and fleet economics were parametrically established as illustrated in Table 8-3 for the long range dedicated freighter. These data indicated that a 453.6 tonne (500 ton) payload aircraft would maximize the ROI to the airlines. While this large aircraft was favorable to the airline, it precluded a profit to the manufacturer unless the unit price was substantially increased or the aircraft

TABLE 8-3

PARAMETRIC CHARACTERISTICS 1995 ADVANCED LONG RANGE FREIGHTER

Payload - Tonnes (Tons)	90.7 (100)	181.4 (200)	272.2 (300)	362.9 (400)	453.6 (500)	544.3 (600)
Trip Cost - 1994 $	48210	92198	139755	190841	245468	303647
Aircraft Price - 1994 $ x 10^6 Based on 200 Units	61	104	143	180	215	249
Number of Aircraft	937	473	313	234	190	147
ROI Airline - Percent	24.5	26.1	27.0	27.6	27.9	27.1
ROI Manufacturer - Percent	17.5	4.5	-4.0	-10.0	-15.0	-18.5

was modified for passenger operations. Based upon these results, the decision was made to discard results from the breakeven approach and to proceed with the analysis based upon providing the manufacturer or manufacturers with a reasonable ROI as determined by the number of dedicated freighter aircraft required. Investigations identified 15 percent as a reasonable expected return on the manufacturer's investment. The remainder of this report is based upon this fixed ROI to the manufacturer or manufacturers.

Dedicated Aircraft Characteristics. - The dedicated aircraft considered for the 1994-2008 time period were based upon technology developments forecast in Section 6 to be available in 1990. The incremental changes resulting from these developments, reference Table 6-2, were applied to the design ratios of the A3 aircraft to provide comparable values for the advanced dedicated aircraft configurations as shown in Table 8-4. Reductions in manufacturing and maintenance costs were applied in deriving the aircraft price and direct operating cost, DOC.

The performance and fleet economics were investigated parametrically for two ranges and a multiplicity of payload sizes. Ranges selected were 3218 kilometers (2000 statute miles) for the short range derivative, ASR, and 7022 kilometers (4364 statute miles) for the long range derivative, ALR. These ranges are identical to those considered for the short and long range derivative aircraft. The ASR was considered for a range of payloads from 22.7 tonnes (25 tons) to 362.8 tonnes (400 tons) and the ALR from 45.4 tonnes (50 tons) to 544.2 tonnes (600 tons).

Based upon payload and trip cost, the number of units of each size of the dedicated aircraft were determined in competition with the reference fleet. These results are presented in Figure 8-4. The rapid decrease in units at the smaller payloads is due to the increased cost of operating the large number of small aircraft compared to the cost of the reference type aircraft, A2, A3, SRD and LRD.

With the number of units determined, the price of each size aircraft was determined based upon providing the manufacturer with an ROI of 15 percent.

TABLE 8-4

1990 TECHNOLOGY CHANGE

Technology	A3 Aircraft Value	1990 Technology Change - Ratio	Dedicated Aircraft Value
Propulsion System - W_{PS}/T_{ENG}	0.2919	0.878	0.2563
Structure - W_{STRU}/W_{LDG}	0.3740	0.68	0.2543
L/D - Cruise	17.4	1.11	19.3
SFC - KG/hr/Deca Newton (lbs/hr/lb)	0.652 (0.639)	0.87	0.567 (0.556)
Engine Weight - W_{ENG}/T_{ENG}	0.1721	0.96	0.1652
Furnishings - W_{FURN}/Payload	349.58	0.905	316.37
Manufacturing Cost			
Airframe	1.00	0.86	0.86
Engines	1.00	1.072	1.072
Maintenance and Materials Cost			
Aircraft	1.00	0.98	0.98
Engines	1.00	0.95	0.95
Maintenance and Labor Cost			
Aircraft	1.00	0.97	0.97
Engines	1.00	0.97	0.97

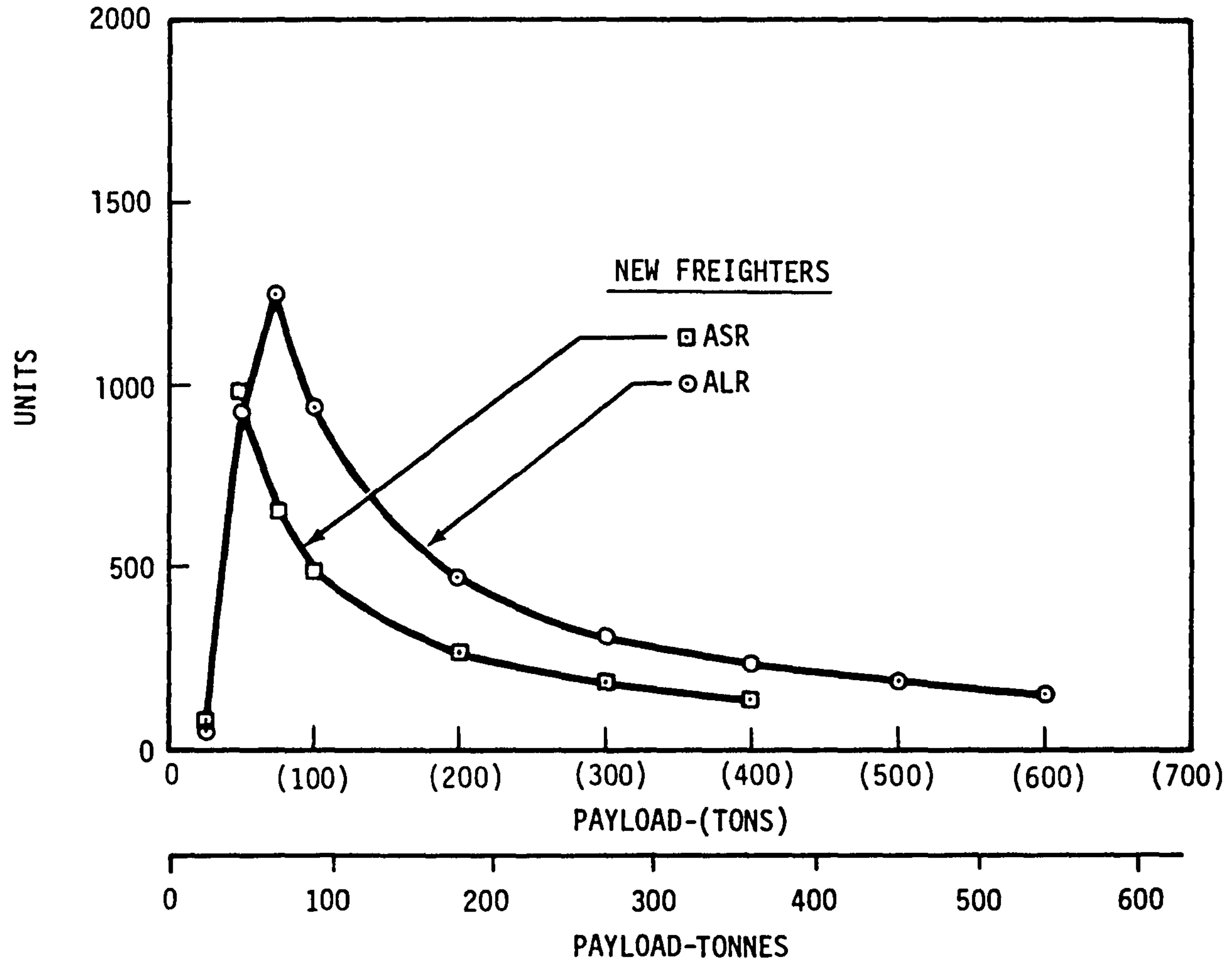


FIGURE 8-4. NUMBER OF DEDICATED FREIGHTER AIRCRAFT VERSUS CAPACITY

These prices in 1994 dollars were determined using company proprietary data and costing procedures. For each payload/unit combination, this program provided a range of manufacturer ROI and aircraft price combinations which were then solved for the desired 15 percent ROI. The prices for the spectrum of dedicated ASR and ALR aircraft payloads were determined as presented in Tables 8-5 and 8-6, respectively. Data for the ALR aircraft were developed for both one manufacturer, 100 percent share, and two manufacturers, 50 percent share.

Dedicated Aircraft Sizing. - The all new freighter parametric aircraft were each evaluated in competition with the reference fleet of A2, A3, SRD and LRD type aircraft to determine their worth during the 1994-2008 time period. The operational and economic results based upon a manufacturer's ROI of 15 percent are summarized in Table 8-7 for the ASR and in Table 8-8 for the ALR parametric aircraft. The unusual high price shown in Table 8-7 for the smallest payload ASR is due to the limited number of units that successfully competed against the reference fleet. The large number of aircraft required to meet the 1994-2008 cargo market demand make it very unlikely that all the advanced freighter aircraft will be provided by a single manufacturer. This view is further substantiated by the growing European aircraft industry when considered in view of the relatively large size of the forecast foreign cargo market demand compared to the combined U.S. Domestic and International demands. It was also concluded during the course of the analysis that it would be quite unlikely that only the short range, ASR, type would be built. If the ASR were developed a long range ALR would also be developed, each by separate manufacturers. If only the ALR were built, there would most likely be two versions offered by two different manufacturers; hence, the two sets of data presented in Table 8-8.

To facilitate comparisons of the various sizes of aircraft, the data of Tables 8-7 and 8-8 are presented graphically in Figures 8-5 through 8-7. It is important to note that these data for a manufacturer's ROI of 15 percent show decreased investment and increased airline ROI with decreasing payload. These economic trends are reversed from those derived with the usual procedure, discussed earlier in this section, based upon a fixed production breakeven point. With a fixed breakeven point, results would show reduced investment and increased airline ROI with increasing payload, the latter illustrated in Table 8-3.

TABLE 8-5

PARAMETERIZED ASR DEDICATED AIRCRAFT CHARACTERISTICS

New Freighter	ASR
Design Range - KM (SM)	3218 (2000)
Manufacturer's Share - Percent	100

Payload - Tonnes (Tons)	Trip Cost @ Design Range 1994 $	Units	Aircraft Price 1994 $ x 10^6
22.7 (25)	8296	79	79.0
45.4 (50)	12619	980	32.0
68.0 (75)	17035	658	51.0
90.7 (100)	21532	493	75.0
181.4 (200)	40213	255	170.0
272.0 (300)	59866	181	265.0
362.8 (400)	80433	136	407.0

TABLE 8-6

PARAMETERIZED ALR DEDICATED AIRCRAFT CHARACTERISTICS

New Freighter	ALR				
Design Range - KM (SM)	7022 (4364)				
Manufacturer's Share - Percent		100		50	
Payload - Tonnes (Tons)	Trip Cost @ Design Range - 1994 $	Units	Aircraft Price - 1994 $x10^6	Units	Aircraft Price - 1994 $x10^6
45.4 (50)	27634	922	35.5	461	48.0
68.0 (75)	37796	1253	42.2	627	56.0
90.7 (100)	48210	937	59.0	468	79.0
181.4 (200)	92198	473	132.0	237	186.0
272.0 (300)	139755	313	222.0	157	317.0
362.8 (400)	190841	234	320.0	117	470.0
453.5 (500)	245468	190	430.0	95	625.0
544.2 (600)	303647	147	562.0	74	885.0

TABLE 8-7

ASR DEDICATED AIRCRAFT PARAMETRIC REQUIREMENTS

		Single Manufacturer - 100% Market and ROI = 15%						
Oper. Range - KM (SM)		4183(2600)						
Design Range - KM (SM)		3218(2000)						
Payload - Tonnes (Tons)	Ref.	22.7(25)	45.4(50)	68.0(75)	90.7(100)	181.4(200)	272.1(300)	362.8(400)
Aircraft Price - 1994 \$ x 10^6	-	79	32	51	75	170	265	407
Units	-	79	980	658	493	255	181	136
ROI Airline - Percent	21.37	20.86	22.19	22.09	21.86	21.11	20.84	19.80
EUACF - 1994 \$ x 10^9	25.654	26.639	25.346	25.762	26.090	26.970	27.343	28.092
ΣIPV - 1994 \$ x 10^9	113.487	120.266	108.568	110.766	113.198	120.558	123.558	132.425
ΣOI - \$ x 10^9	939.299	941.441	952.980	970.951	979.221	991.423	995.152	991.597
Departures (Trips) Growth Rate - Percent per Year	6.7	6.7	11.9	9.8	8.5	6.1	4.9	4.3

TABLE 8-8

ALR DEDICATED AIRCRAFT PARAMETRC REQUIREMENTS

Oper. Range - KM (SM) Design Range - KM (SM)		8753 (5440) 7022 (4364)							
Payload - Tonnes (Tons)	Ref.	45.4(50)	68.0(75)	90.7(100)	181.4(200)	272.1(300)	362.8(400)	453.5(500)	544,2(600)
Units	-	922	1253	937	473	313	234	190	147
		Single Manufacturer - 100% Market and ROI = 15%							
Aircraft Price - 1994 $\$x10^6$	-	35.5	42.2	59.0	132.0	222.0	320.0	430.0	562.0
ROI Airline - Percent	21.37	22.27	25.08	24.79	23.75	22.68	21.91	21.12	20.03
EUACF - 1994 $ x 10^9	25.654	25.776	24.259	24.632	25.485	26.163	26.646	27.430	27.849
ΣIPV - 1994 $ x 10^9	113.487	110.062	93.368	95.775	102.928	109.977	115.370	122.560	130.038
ΣOI - 1994 $ x 10^9	939.299	973.396	995.661	1009.213	1025.277	1021.960	1015.171	1011.039	993.963
		Competing Manufacturer - 50% Market and ROI = 15%							
Aircraft Price - 1994 $\$x10^6$	-	48.0	56.0	79.0	186.0	317.0	470.0	625.0	885.0
ROI Airline - Percent	21.37	20.81	22.32	21.94	20.45	19.32	18.35	17.71	16.32
EUACF - 1994 $ x 10^9	25.654	26.883	25.959	26.477	27.988	29.043	30.011	30.942	32.316
ΣIPV - 1994 $ x 10^9	113.487	121.588	110.659	114.515	128.470	139.712	150.400	159.609	177.519
ΣOI - $ x 10^9	939.299	973.396	995.661	1009.213	1025.277	1021.960	1015.171	1011.039	993.963
Departures(Trips) Growth Rate- Percent per Year	6.7	9.6	10.4	8.9	6.0	4.7	4.1	3.4	3.6

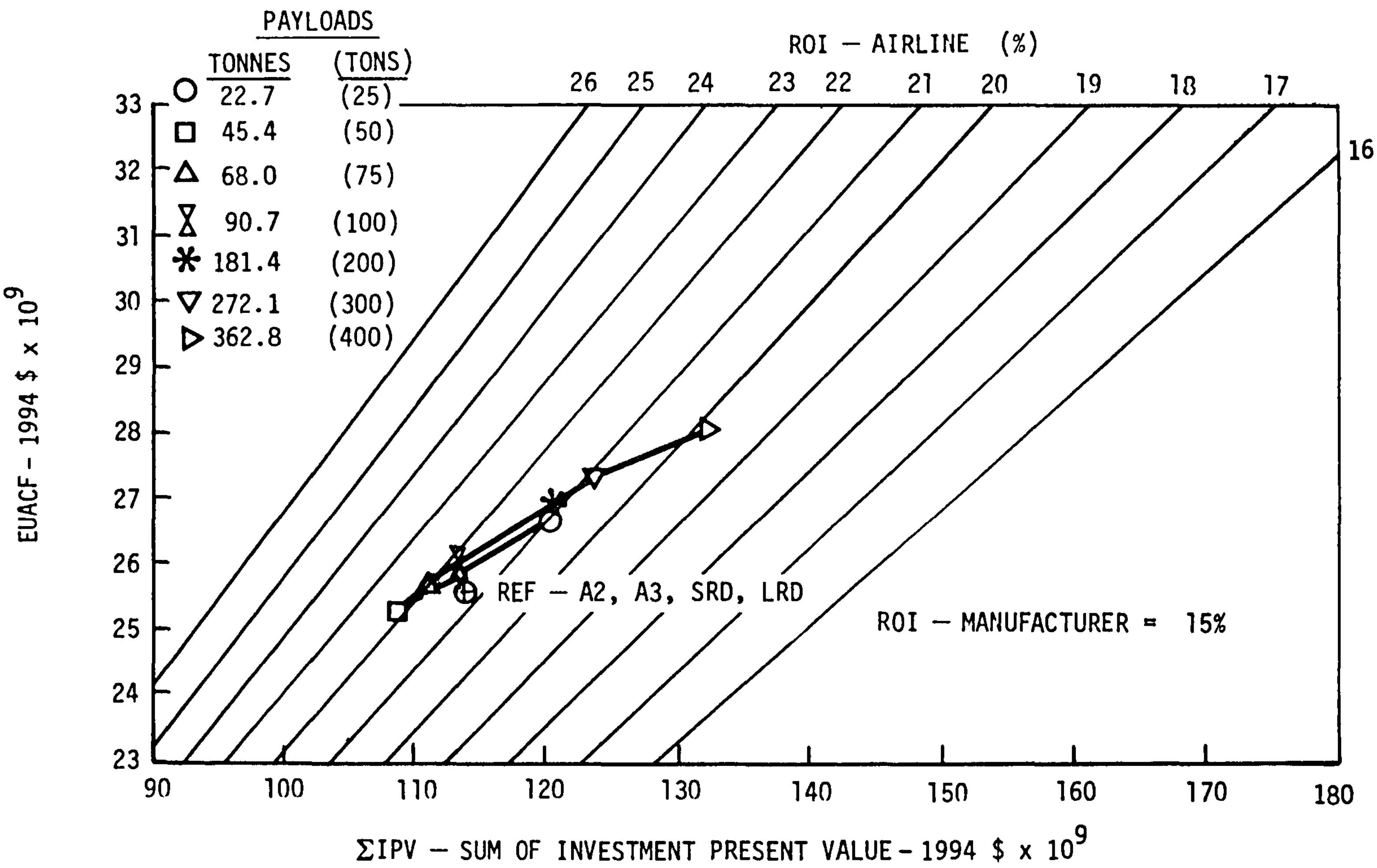


FIGURE 8-5. ECONOMIC WORTH — ASR WITH SINGLE MANUFACTURER

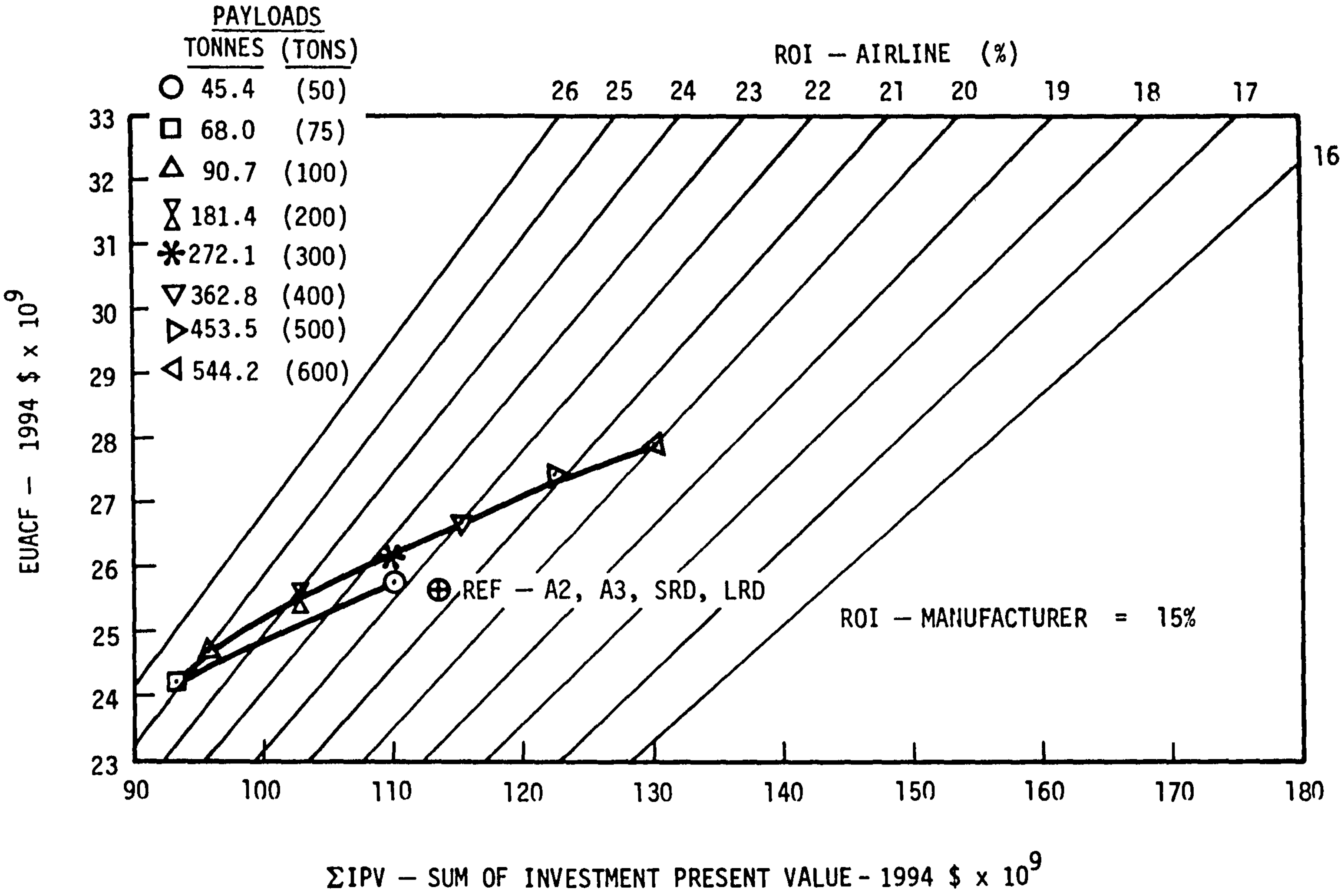


FIGURE 8-6. ECONOMIC WORTH — ALR WITH SINGLE MANUFACTURER

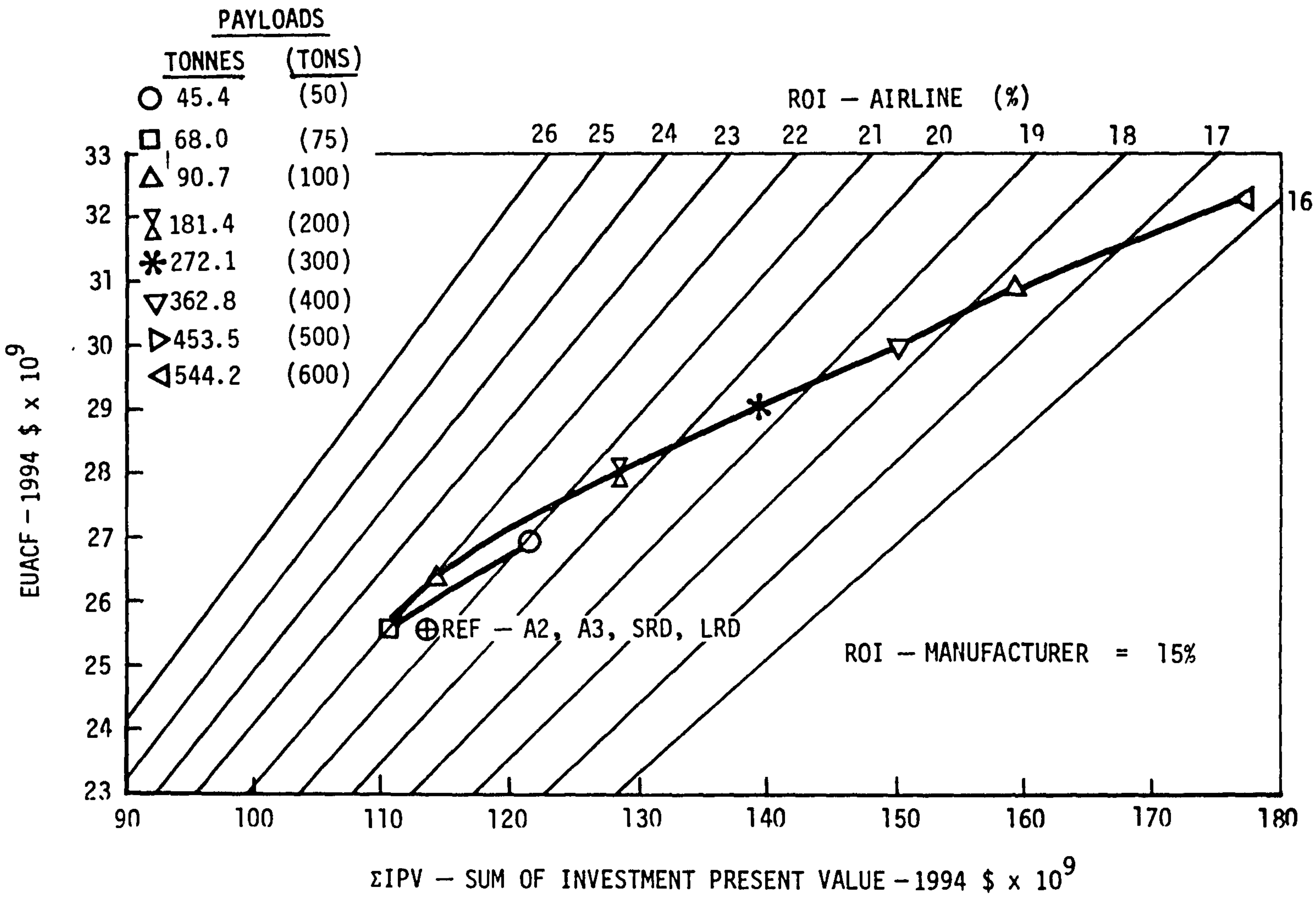


FIGURE 8-7. ECONOMIC WORTH — ALR WITH TWO MANUFACTURERS

As shown in Figure 8-5, the ASR does not offer a dvnamic improvement over the reference fleet. The ASR sized for a 45.4 tonne (50 ton) pavload produced the hiqhest ROI to the airline. At the smaller payloads, i.e., 22.7 tonne (25 ton), the high operational cost precluded their use over all but a few select routes. As a result the number of aircraft required was greatly reduced resulting in increased aircraft price and a subsequent reduction in airline ROI. Althouqh the 45.4 tonne (50 ton) ASR is the preferred size with a single manufacturer, increasing the payload to 90.7 tonnes (100 tons) reference Table 8-7, would still result in a half percent greater airline ROI, a 2 percent improvement in cash flow (EUACF), a slightly decreased investment (ΣIPV), and a 4 percent increase in operating income (ΣOI) compared to the reference fleet. In actual practice the choice within such small range of parametric values, ΔROI = -0.3 percent, ΔEUACF = +3 percent, ΔIPV = +4 percent, and $\Delta\Sigma$OI = +3 percent, between the 45.4 tonne and the 90.7 tonne (50 ton and 100 ton) would be dependent upon the airlines financial situation and their future objectives.

As shown in Figure 8-6, the ALR with one manufacturer offered a clear advantage over the reference fleet for payloads between 68 tonne (75 ton) and 272.1 tonne (300 tons). In this case the preferred payload was found to be 68.0 tonnes (75 tons). However, once again the relative differences in the fleet economics associated with payloads up to 181.4 tonnes (200 tons) were small. Referring to Table 8-8, single manufacturer, shows penalties of ΔROI = -1.3 percent and a ΔIPV = +10 percent with advantages of +5 percent and +3 percent in cash flow and operating income, respectively. Although the investment penalty for the larger payload is 10 percent, it still represents a 10 percent reduction over the comparable value for the reference fleet combined with 9 percent improvement in operating income. Comparing the data of Figures 8-5 and 8-6 shows a marked preference for the long range aircraft in meeting the 1994-2008 cargo market demand.

Comparing the data of Figure 8-7 for two manufacturers with that of Figure 8-6 for one, substantiates the finding that the preferred payload size was the same for a single or dual manufacturer of the ALR. However, with respect to the economics of the reference fleet, the two manufacturers offered little improvement while the single manufacturer resulted in significant improvements in terms of reduced investment and increased airline ROI. With two manufacturers the airline ROI was 2.7 percent less and the investment was increased by 17 billion dollars. In addition, with two manufacturers the penalties associated with increasing payloads are greater than the values encountered with one manufacturer. The number of manufacturers had no effect on the number of aircraft required or the resulting operating income as shown in Table 8-8.

Based upon the preceding findings, the 45.4 tonne (50 ton) ASR and the 68.0 tonne (75 ton) ALR were subject to further evaluation. These two aircraft were simultaneously competed against each other and the reference aircraft with the price of the ASR and ALR aircraft derived on the basis of two manufacturers, one for each type. Results of this analysis are presented in Table 8-9 and Figure 8-8 along with the previously discussed cases.

The ALR with a payload of 68.9 tonne (75 ton) when produced by a single manufacturer resulted in the lowest investment, a decrease of 18 percent over the reference fleet; the greatest airline ROI, a 4 percent increase over the reference fleet; and next to the highest operating income, up 6 percent over the reference. The economic performance of this case relative to the other 4 cases is shown in Figure 8-8. However, this case is not as realistic as the ALR with two manufacturers or the combination of the ASR and ALR aircraft. Although their performance falls below the ALR single manufacturer case, they still outperform the reference fleet with the combination being the preferred. The ASR, 45.4 tonne (50 ton) and ALR, 68.0 tonne (75 ton), combination provided a 2 percent increase in airline ROI, a decrease in total investment of 7 percent, and a 7 percent increase in operating income over the reference fleet. This ASR/ALR combination was used to calculate the 1994-2008 fleet mix since it represented the more likely case of two manufacturers while providing a parallel short range/long range comparison to the SRD/LRD component of the reference fleet.

1994-2008 Fleet Mix

The impact of the ASR/ALR combination of dedicated aircraft on fleet operations is shown in Figures 8-9 through 8-11. The new, more efficient, dedicated aircraft immediately began to capture the market demand growth and

TABLE 8-9

DEDICATED FREIGHTER REQUIREMENTS

Aircraft Model Payload - Tonnes (Tons)	Ref. -	ASR 45.4 (50)	ALR 68.0 (75)	ALR 68.0 (75)	ASR/ALR 45.4/68.0 (50/75)
Units	897	980	1253	1253	949/623
Manufacturer's Share - Percent	-	100	100	50	100/100
Aircraft Price - 1994 \$ x 10^6	-	32.0	42.2	56.0	32.0/56.0
ROI Manufacturer - Percent	-	15	15	15	15/15
ROI Airline - Percent	21.4	22.2	25.1	22.3	23.3
EUACF - 1994 \$ x 10^9	25.7	25.3	24.3	26.0	25.8
ΣIPV - 1994 \$ x 10^9	113.5	108.6	93.4	110.7	105.7
ΣOI - \$ x 10^9	939.3	953.0	995.7	995.7	1002.8
Departures (Trips) Growth Rate - Percent per Year	6.7	11.9	10.4	10.4	12.6

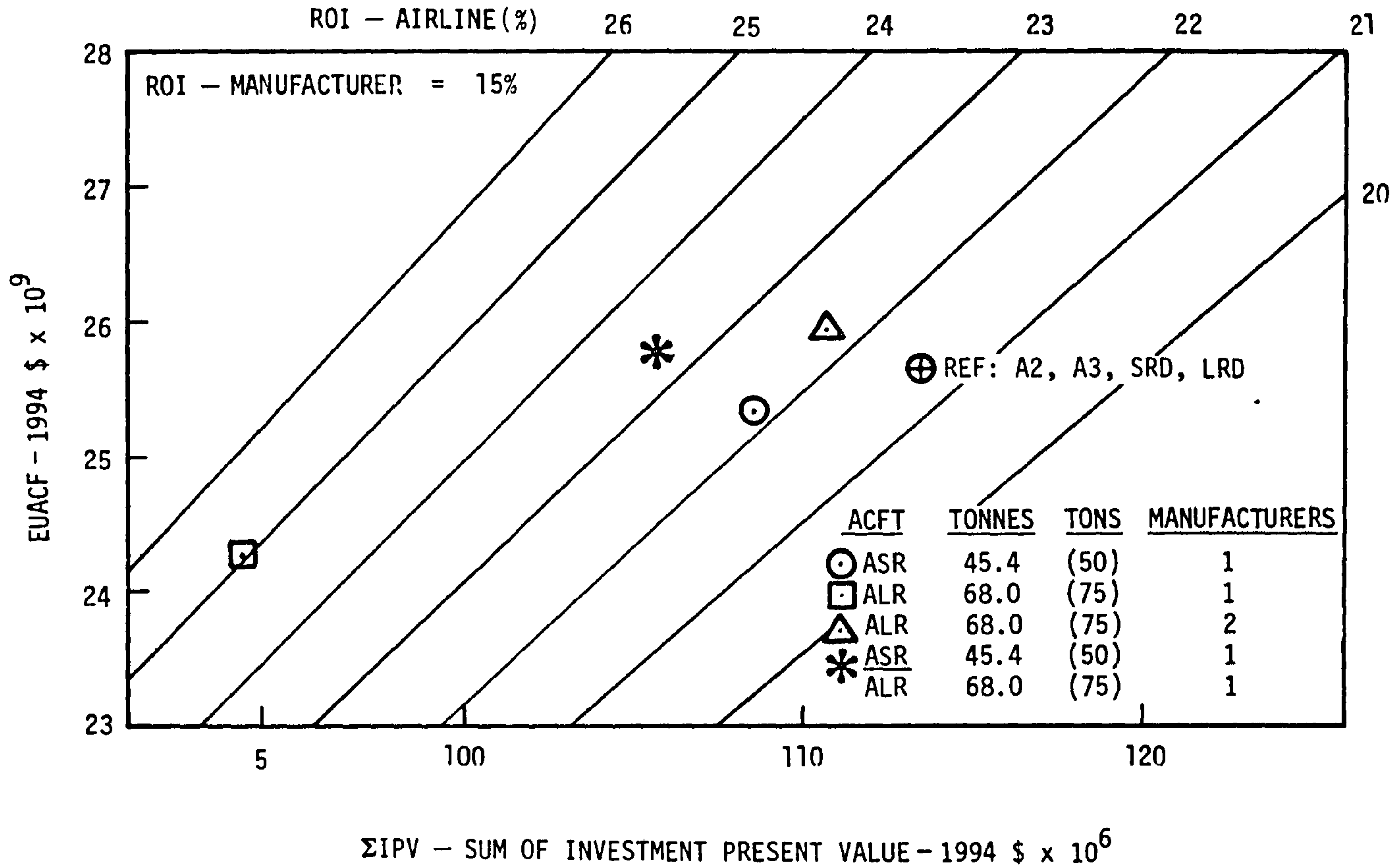


FIGURE 8-8. ECONOMIC WORTH-DEDICATED FREIGHTER AIRCRAFT

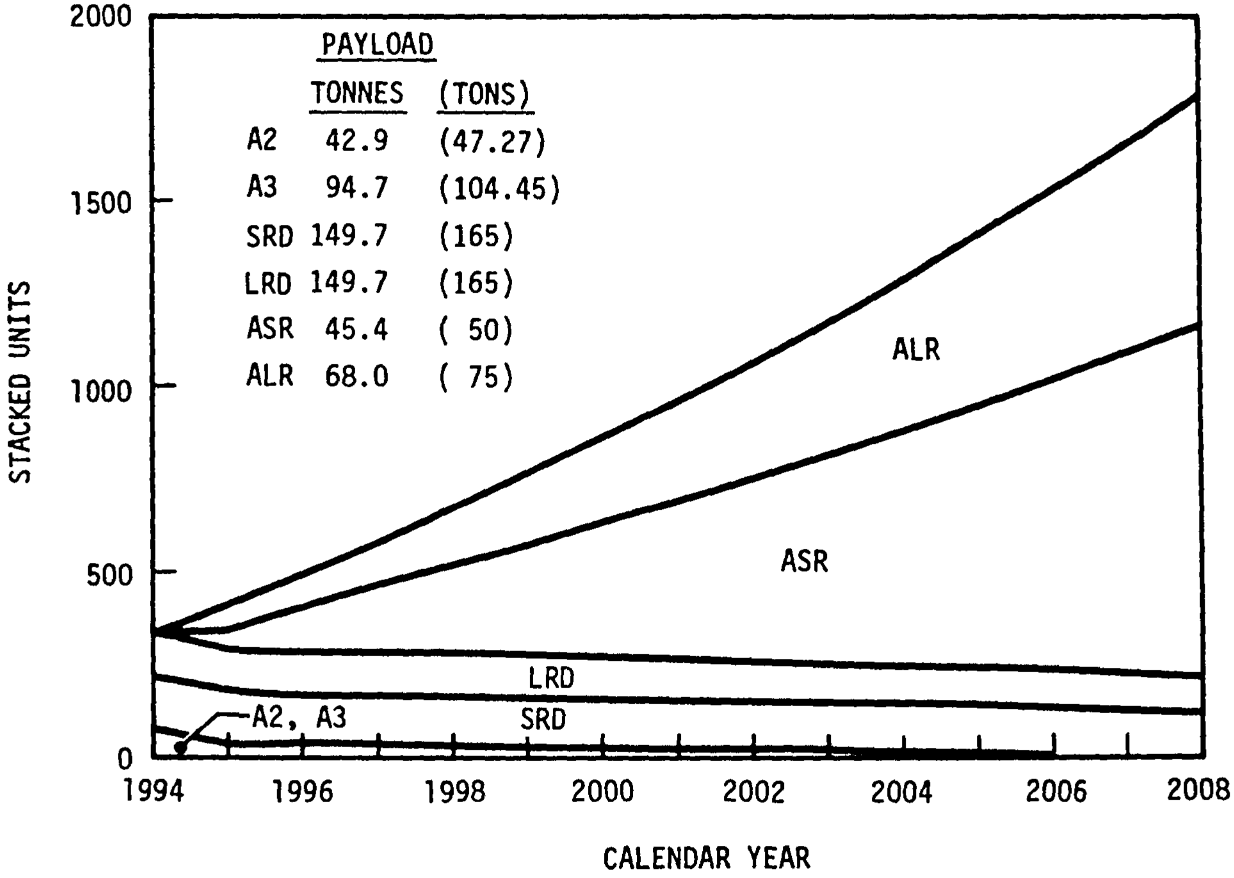


FIGURE 8-9. 1994-2008 ASR/ALR FLEET MIX

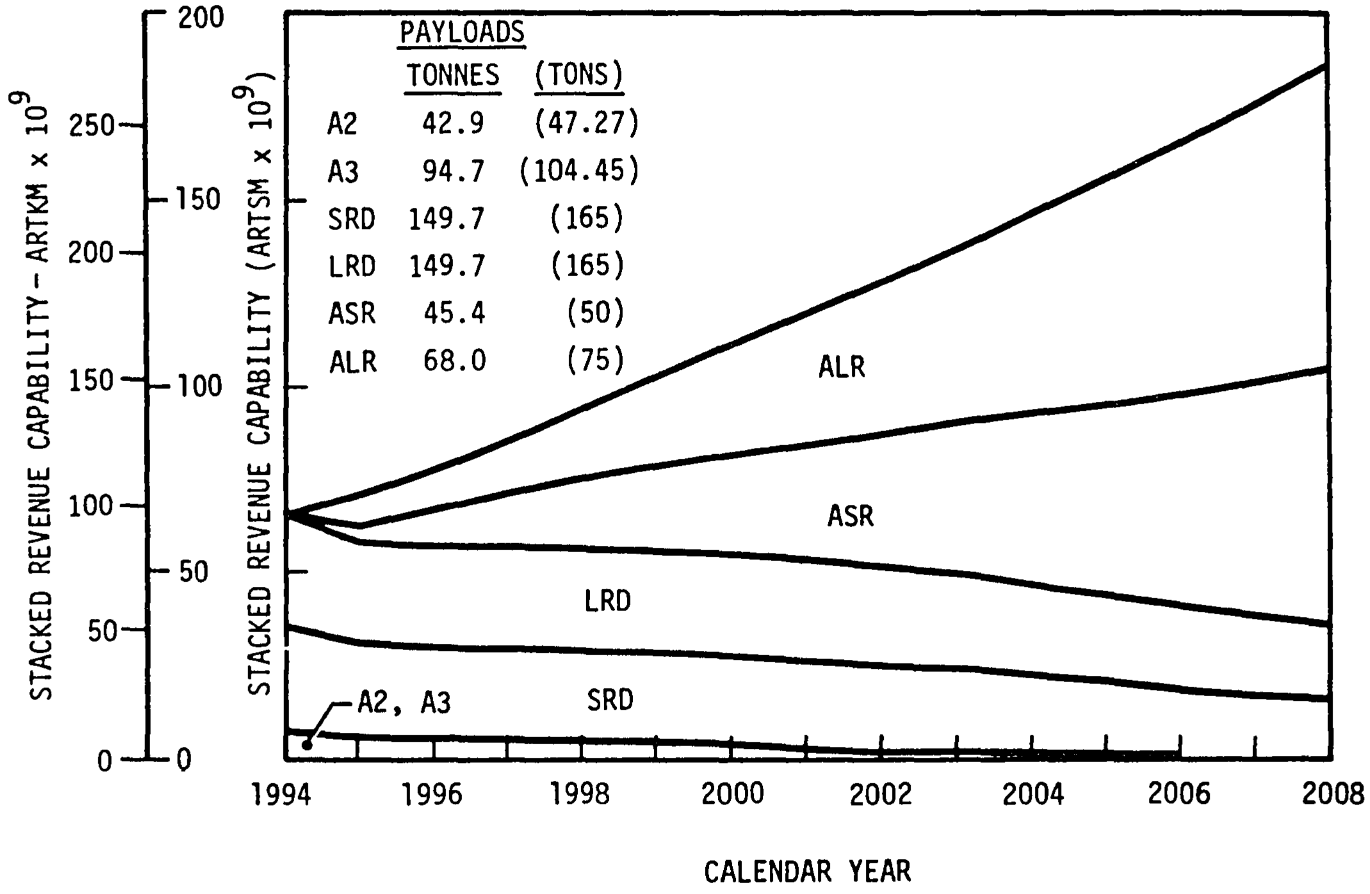


FIGURE 8-10. 1994-2008 ASR/ALR FLEET ANNUAL REVENUE CAPABILITY

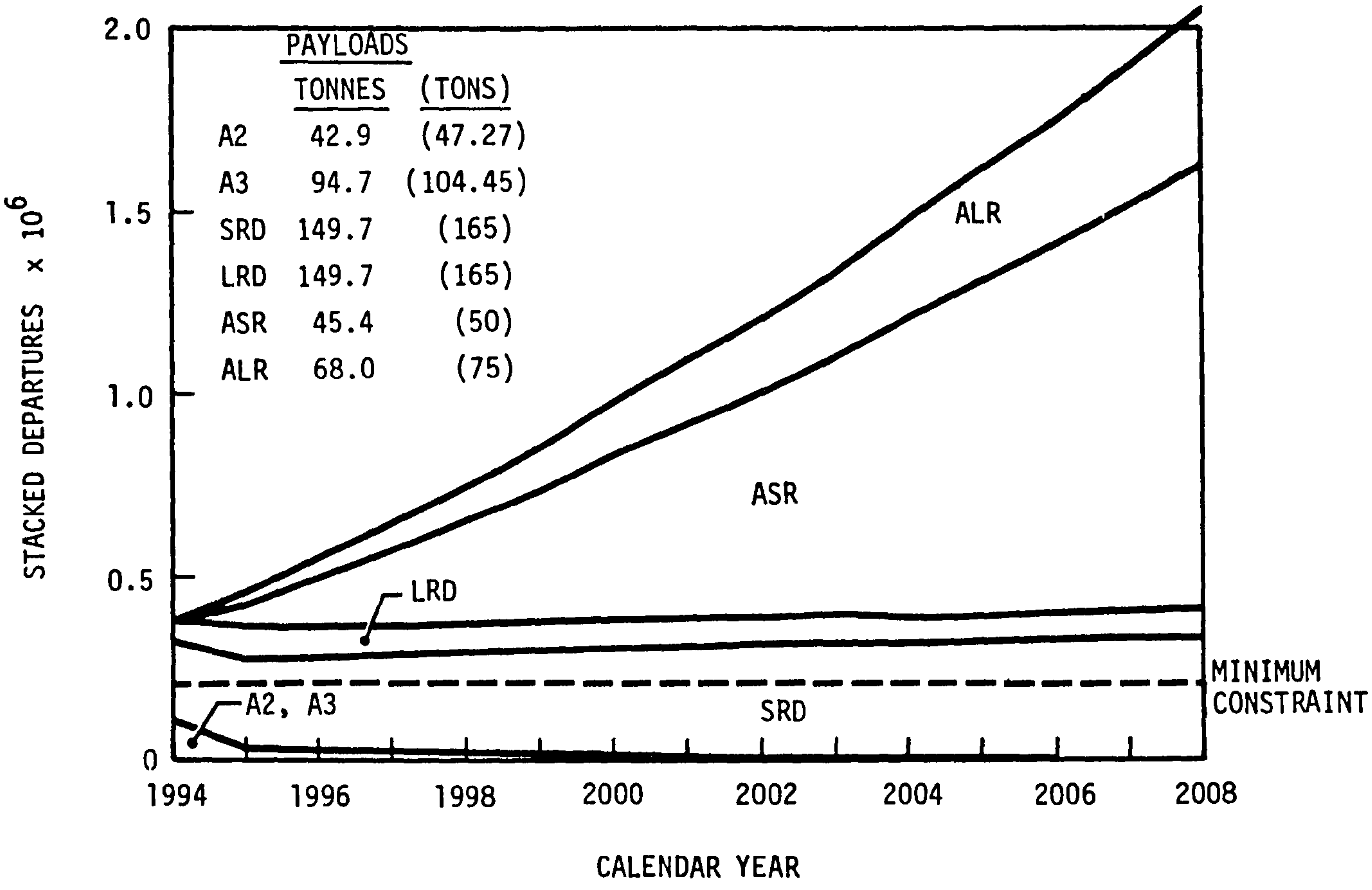


FIGURE 8-11. 1994-2008 ASR/ALR FLEET ANNUAL DEPARTURES

to take over from the remaining representative A2 and A3 aircraft. The A2 were phased out by 1996 while the wide body types, A3, remain in the fleet to the year 2006. There is a slight dual gradual decrease in the number of SRD's and LRD's over the years to 2008 accompanied by a continuous increase of both types of dedicated aircraft.

The trends in revenue capability shown in Figure 8-10 reflect the decreasing number of derivative aircraft. However, these data combined with their changes in frequency in Figure 8-11 indicate that the SRD and LRD were being utilized at ever-decreasing ranges. This shift to shorter ranges being more pronounced for the former type aircraft as evidenced by the relatively greater increase in the number of departures for the SRD's.

Referring to Figures 8-1 and 8-9, these data show that in the year 2008 over twice the number of aricraft were required in the ASR/ALR fleet as with the reference fleet. This was due to the reduced payloads of the ALR and ASR aircraft compared to LRD and SRD. Although this increase in fleet size was favorable to aircraft price and thereby fleet economics, it increased the annual departure growth rate from 6.7 percent for the referenced fleet to 12.6 percent for the ASR/ALR fleet. The implications of this frequency change will be discussed in greater detail later.

1978-2008 Fleet Summary

The data in Figures 8-12 through 8-14 summarize the changes in fleet characteristics that would result from the introduction of derivative aircraft in the year 1985 and new dedicated freighters in 1994. As each of these aircraft types were introduced, they immediately began to impose changes on fleet size and the distribution of revenue capability and departures between aircraft types.

It should be recalled that these summary plots are based upon the preferred sizes of SRD, LRD, ASR and ALR aircraft that were selected on the basis of providing the airline with a maximum ROI under the condition that two manufacturers would be involved in the introduction of the derivative and dedicated

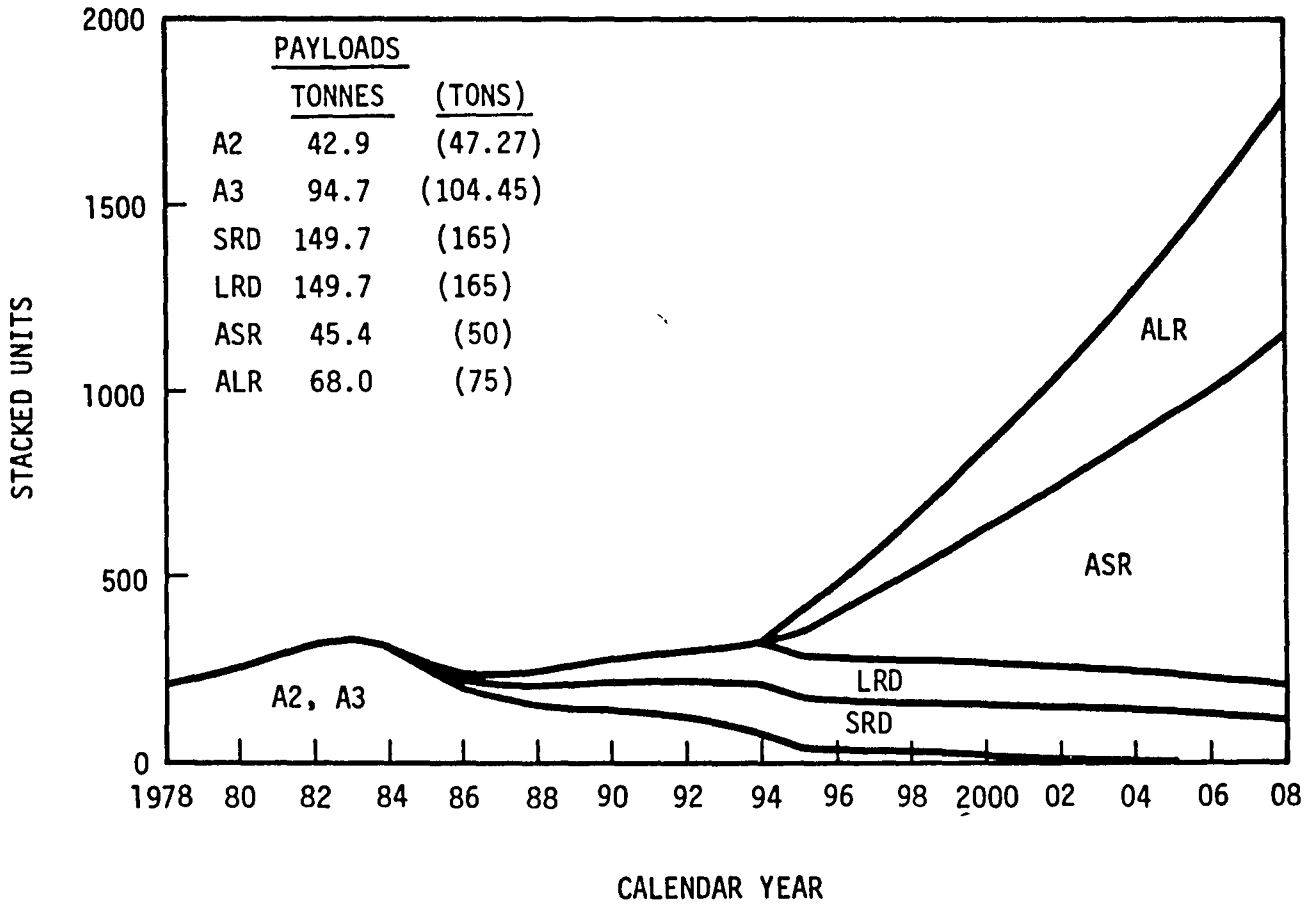


FIGURE 8-12. 1978-2008 FLEET MIX SUMMARY

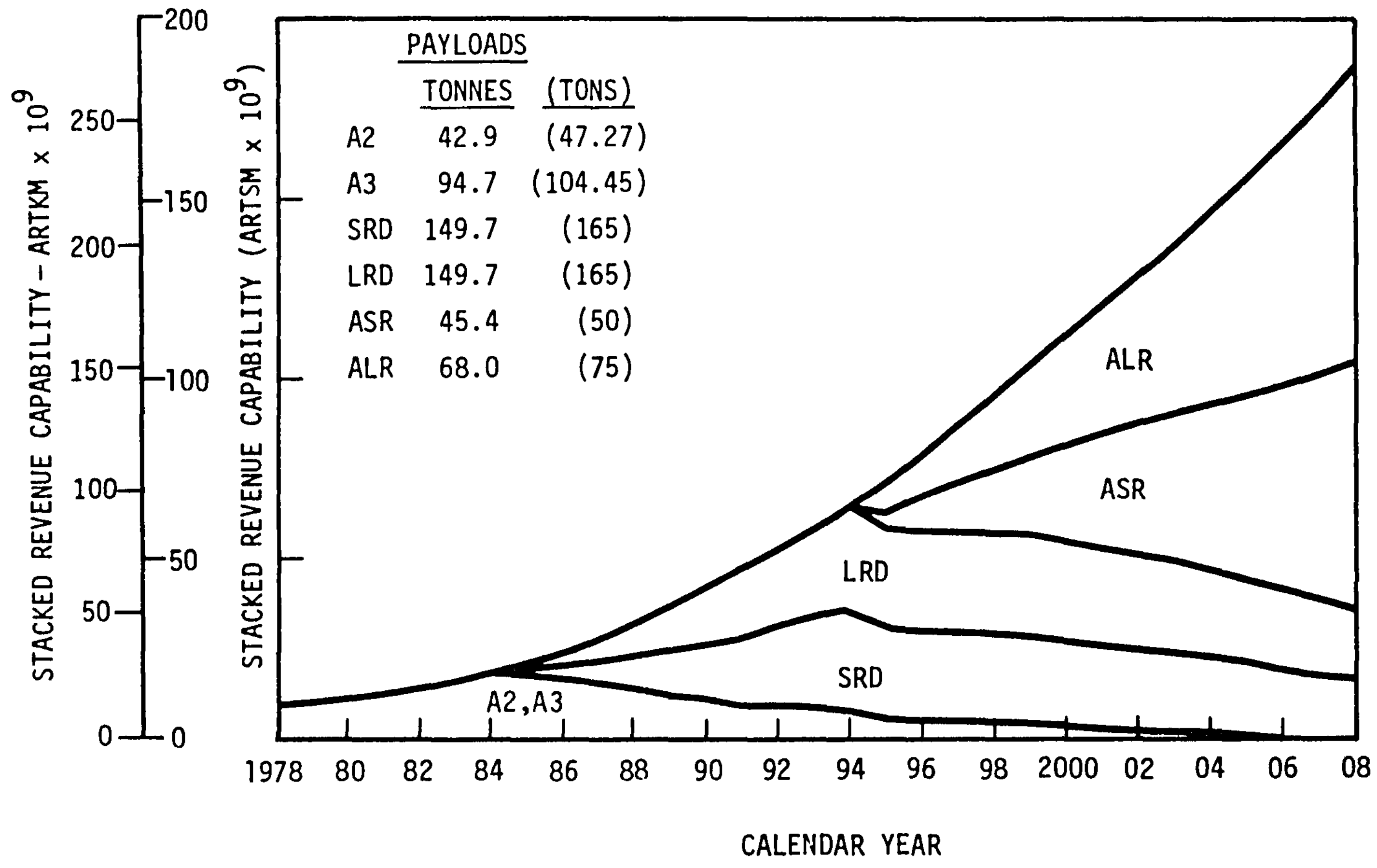


FIGURE 8-13. 1978-2008 FLEET ANNUAL REVENUE CAPABILITY SUMMARY

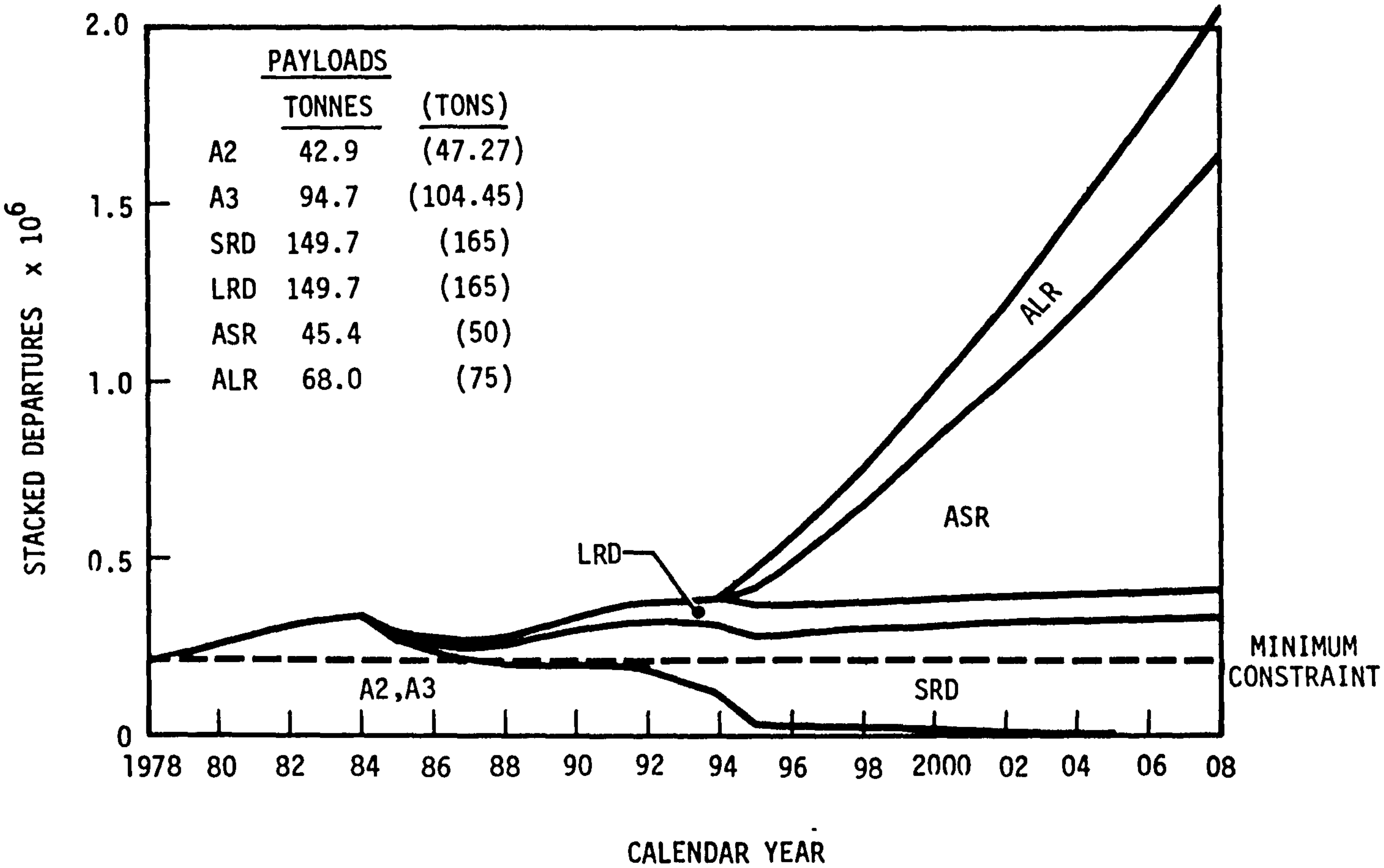


FIGURE 8-14. 1978-2008 FLEET ANNUAL DEPARTURES SUMMARY

types. With this in mind there are several observations that generally categorize the trends in fleet operations. First, the derivative aircraft are larger than anticipated while the payloads of the dedicated aircraft are smaller than expected. Second, the tenacity of the current A3 type aircraft and then the derivative aircraft to remain in the fleet in competition with the progressively improved new aircraft. Third, the progressive relegation of the reference aircraft and then the derivative aircraft to shorter range applications as each new type aircraft was introduced.

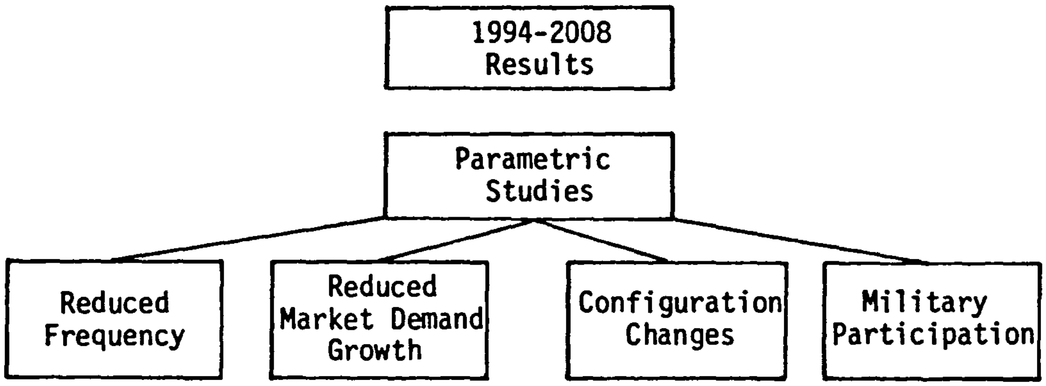
A point of concern and one deserving of further consideration is the impact of departure frequency in selecting the size of future aircraft. Figure 8-14 shows the variation in number of annual departures to the year 2008. Between 1978 and 1984 the number of departures per year increased 55 percent, an annual average growth rate of 7.6 percent. From 1984 to 1994 this growth rate was reduced to an average value less than 2 percent. However, subsequent to 1994 the increasing cargo market demand was handled by the relatively small payload ASR and ALR and as a consequence the annual growth rate increased to 12.6 percent resulting in a 426 percent increase in the number of departures in the year 2008 compared to 1994. The CLASS airport and terminal surveys discussed in Volumes 1 and 3 indicate that such increase in the frequency of operations could lead to serious saturation problems at many major airports. Such consequences could be realized in spite of the ground installation improvements projected out to the year 1990. In addition, the forecast reduction of indirect operating cost to 30 percent of the total revenue, reference Section 1, could not be achieved under such conditions of increased frequency.

While the preceding congestion problems suggest the need for the reduced frequencies afforded by larger aircraft, reference Tables 8-7 and 8-8, conventional aircraft configurations for payloads much in excess of 149.7 tonnes 165 tons) will encounter airport oriented problems due to their length, span, gear tread, and noise. Based upon these findings, investigations into the relations between aircraft frequency, size and configuration, and fleet economics, were included in the parametric studies discussed in the section that follows.

Section 9

PARAMETRIC STUDIES

Included in the study were parametric investigations of the effects of reduced frequency, reduced growth, configuration changes and military participation. These are shown below.



Due to the importance of frequency to aircraft sizing and fleet economics, its investigation was conducted first. Results of the frequency analysis were utilized to define the size of the aircraft to be considered in the remaining studies. The discussions that follow are presented in the order in which the efforts were performed.

Since the primary concern of this study was to determine the requirements and potential for a new dedicated freighter aircraft, the parametric studies were limited to the 1994 to 2008 time period. The reference fleet for these analyses therefore consisted of the fleet of A2, A3, SRD and LRD types determined in Section 7.

Reduced Frequency

The objective of this parametric study was to assess the impact of reduced frequency on fleet economics and hence aircraft size. Results of the dedicated freighter analysis discussed in Section 8 led to the selection of the 45.4 tonne (50 ton) ASR and the 68.0 tonne (75 ton) ALR aircraft. As previously noted, the summary of fleet operations presented in Figure 8-14 showed a dramatic increase in frequency during the 1994-2008 time period due to the low payloads of these selected new freighter aircraft. The associated average annual growth rate of 12.6 percent was 56 percent greater than the growth for jet freighters prior to 1978 and twice the growth rate of the 1994-2008 reference fleet.

Frequency-Payload. - Figure 9-1 shows how the frequency growth rates varied as a function of payload for the new freighters examined during the 1994-2008 time period (data from Tables 8-7 and 8-8). Also highlighted is the historic growth rate of 8.1 percent for the 1969-1978 time period and the growth rate of 6.7 percent for the 1994-2008 time period reference fleet based upon the 147.7 tonne (165 ton) derivative aircraft. Below payloads of 90.7 tonne (100 ton), the frequency growth was higher than both the historic trend (1967 to 1978 time period) and the growth for the reference fleet (1994 to 2008 time period). However, as shown in Section 8, these lower payloads were best at meeting the manufacturers' ROI of 15 percent with two manufacturers while maximizing the airline ROI at values greater than the reference fleet.

Larger aircraft reduce frequency growth but also reduce airline ROI, as shown in Figure 9-2, reference Tables 8-7 and 8-8. Increasing the payload of the ALR with two manufacturers to 104.3 tonne (115 ton) matches the historic frequency growth of 8.1 percent as shown in Figure 9-1 and provides an airline ROI of 21.7 percent, Figure 9-2, slightly more than the reference fleet value of 21.4 percent, reference Table 8-2. Increasing the payload further to 149.7 tonne (165 ton) matches the 1994-2008 reference fleet frequency growth and provides an ROI of 21.0 percent which is slightly less than the reference fleet ROI of 21.4 percent. Such differences can be consiaered negligible when viewed in the framework of airline economics. The ALR_2 aircraft with a payload of 149.7 tonne (165 ton) and produced by two manufacturers was therefore used to show the impact of reduced frequency.

Fleet Economics. - The economic results of the reduced frequency analysis are shown in Table 9-1 for comparison with the reference and combined ASR/ALR fleet results. The impact of developing a single type of aircraft with long

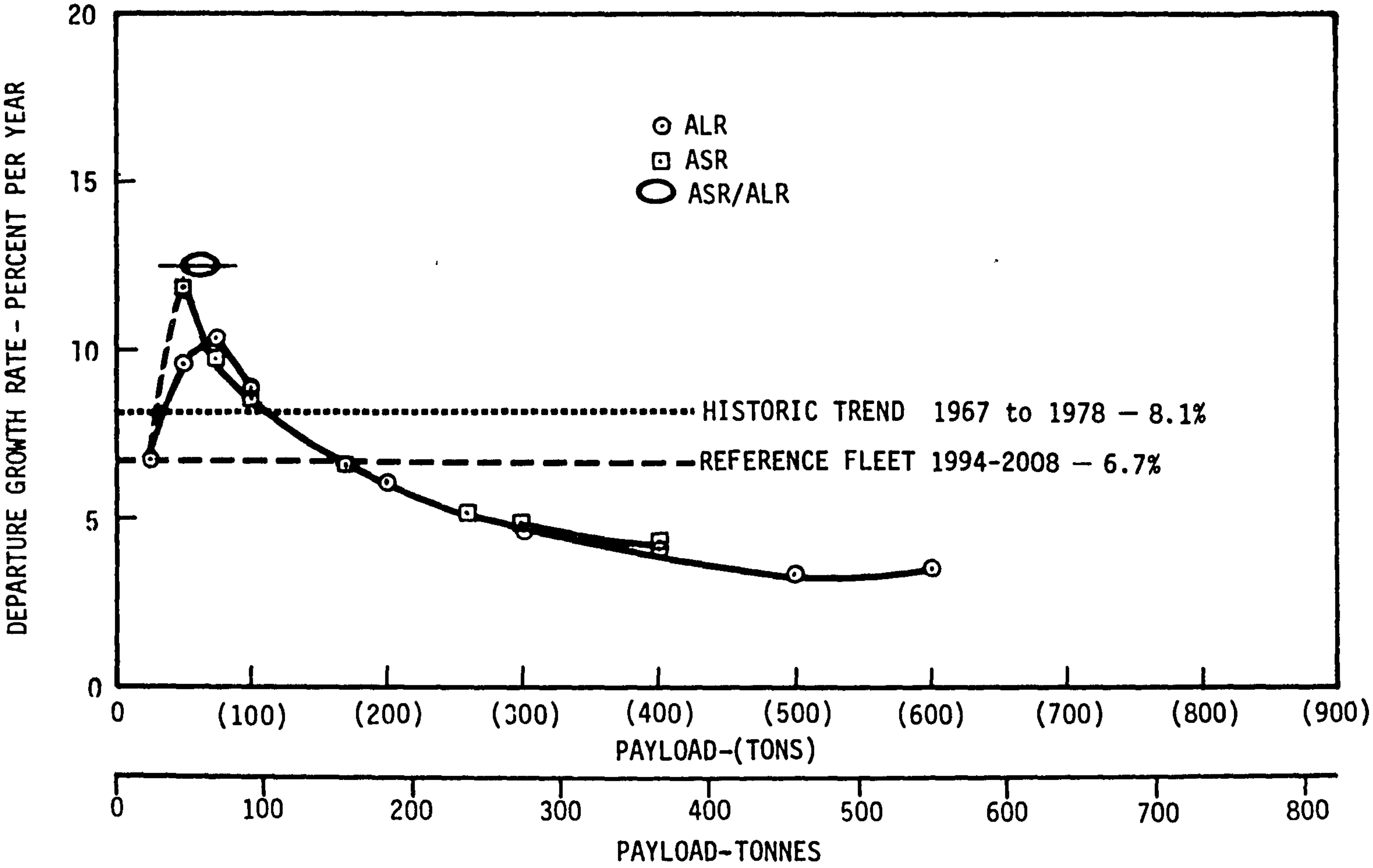


FIGURE 9-1. DEDICATED FREIGHTER FREQUENCY GROWTH RATES (1994 TO 2008)

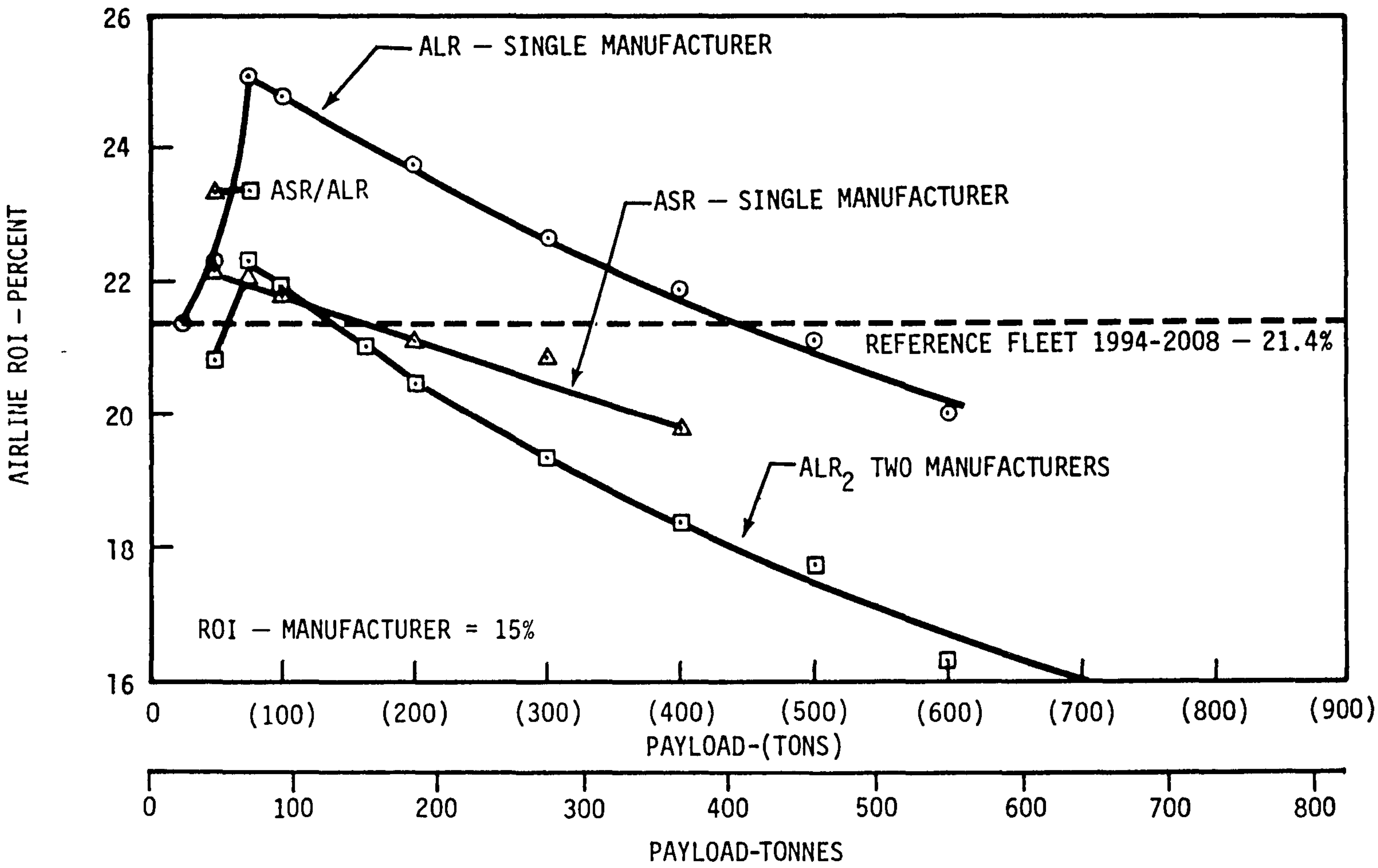


FIGURE 9-2. AIRLINE ROI FOR 1994-2008 FLEET

TABLE 9-1

REDUCED FREQUENCY - RESULTS

Model	Ref.	ALR_2	ASR/ALR
Design Range - KM (SM)		7022 (4364)	3213(2000)/7022(4364)
Payload - Tonnes (Tons)		149.7 (165)	45.4 (50)/68.0 (75)
Trip Cost @ Design Range - 1994 $		76398	12619/37796
Units		573	949/623
Manufacturers/Share - No./Percent		2/50	2/100
Aircraft Price - 1994 $ x 10^6		146	32.0/56.0
ROI Airline - Percent	21.4	21.0	23.3
EUACF - 1994 $ x 10^9	25.7	27.7	25.8
ΣIPV - 1994 $ x 10^9	113.5	124.2	105.7
ΣOI - $ x 10^9	939.3	1027.0	1002.8
Departure (Trip) Growth Rate - Percent per Year	6.7	6.7	12.6

range capability and increased payload, ALR_2, compared to the small payload ASR/ALR fleet is to improve the airlines economic situation relative to operating income and cash flow while penalizing them relative to investment and return on investment. Examining the data of Table 9-1 shows an 18 percent increase in investment for the ALR_2 fleet over the ASR/ALR fleet. This increase is to a large extent the cause for the 2.3 percent reduction in ROI to the airline. The increased investment also contributed to the 7 percent increase in cash flow; and a favorable 2.4 percent improvement in operating income, an important consideration in airline economics.

Compared to the reference fleet, the large ALR_2 based fleet gives a 0.4 percent less ROI with a 9 percent increase in operating income. There is a notable increase in investment being 9 percent greater then the reference fleet and 18 percent higher than for the combined ASR/ALR fleet. These and other economic trends are graphically illustrated in Figure 9-3. It is evident here that the economics of the ALR_2 fleet is being penalized by the greater investment required for the more expensive aircraft due primarily to the reduced number of units required.

Fleet Operational Results. - The data of Figures 9-4 through 9-6 illustrate the effect of the larger ALR_2 aircraft on the number of units required, on the distribution of revenue capability, and on departures. Note that in Figures 9-4 and 9-5 the values for the ASR/ALR fleet are stacked with the LRD, SRD, A2 and A3 values but do not include the ALR_2 values. The number and phaseout of the reference fleet was identical for the ALR_2 and the ASR/ALR solutions as illustrated in Figures 9-4 and 9-5. The reason is that all these new aircraft, ASR/ALR and ALR_2, were more efficient than the aircraft in the reference fleet; hence, if given the opportunity they could have replaced the entire reference fleet in 1995. However, such replacement schedule would not be possible. A more realistic approach was therefore taken; namely, to limit the rate at which replacement would occur. This was achieved by an algorithm in the FRAME program which established a replacement rate on the basis of the market demand growth. Since the ASR, ALR and ALR_2 were all more efficient than the reference fleet, both solutions replaced the reference aircraft at the maximum allowable rate. Utilizing the larger aircraft reduced the number of dedicated aircraft from 1572 to 573 units, Table 9-1, a reduction of 64

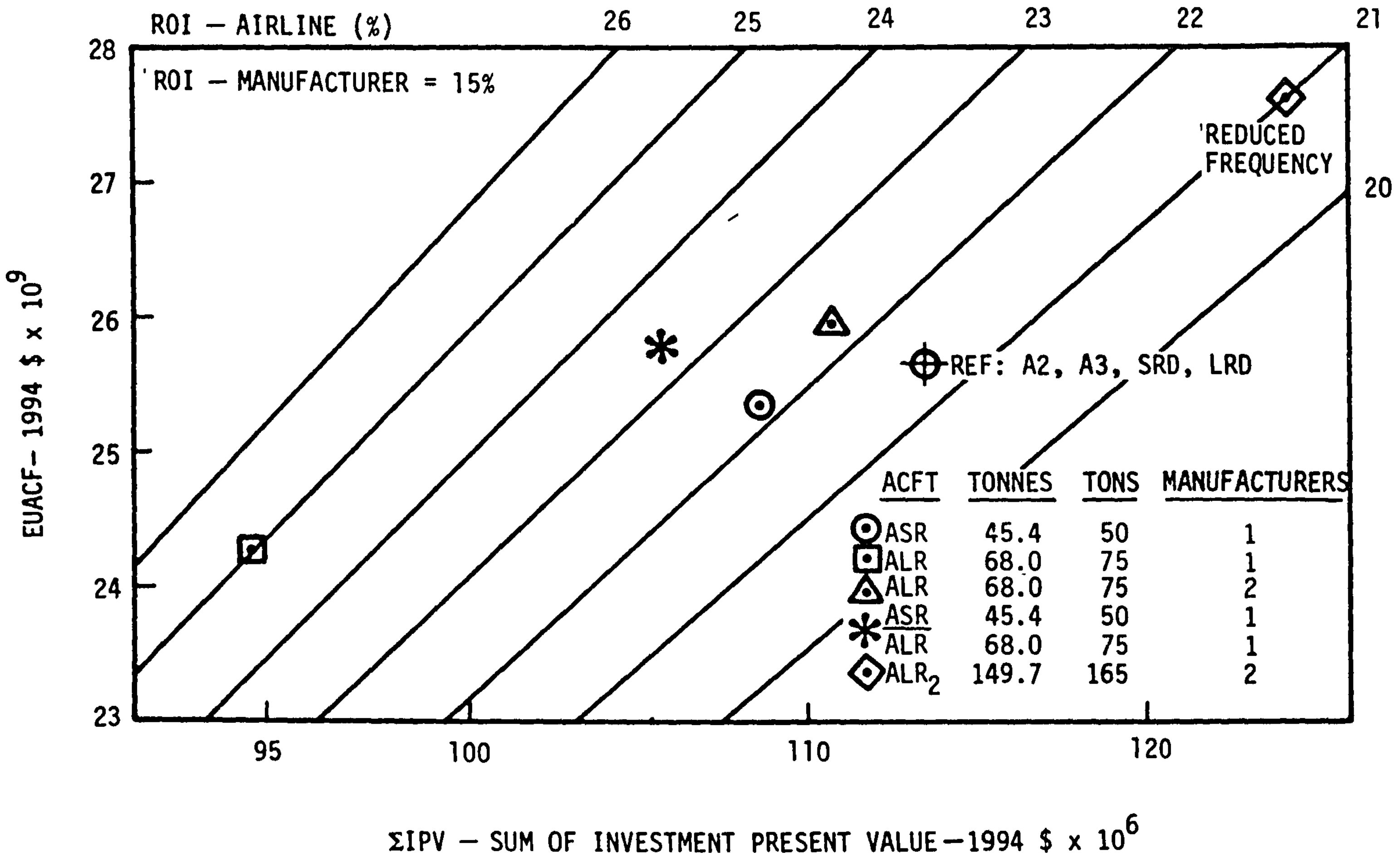


FIGURE 9-3. ECONOMIC WORTH — REDUCED FREQUENCY

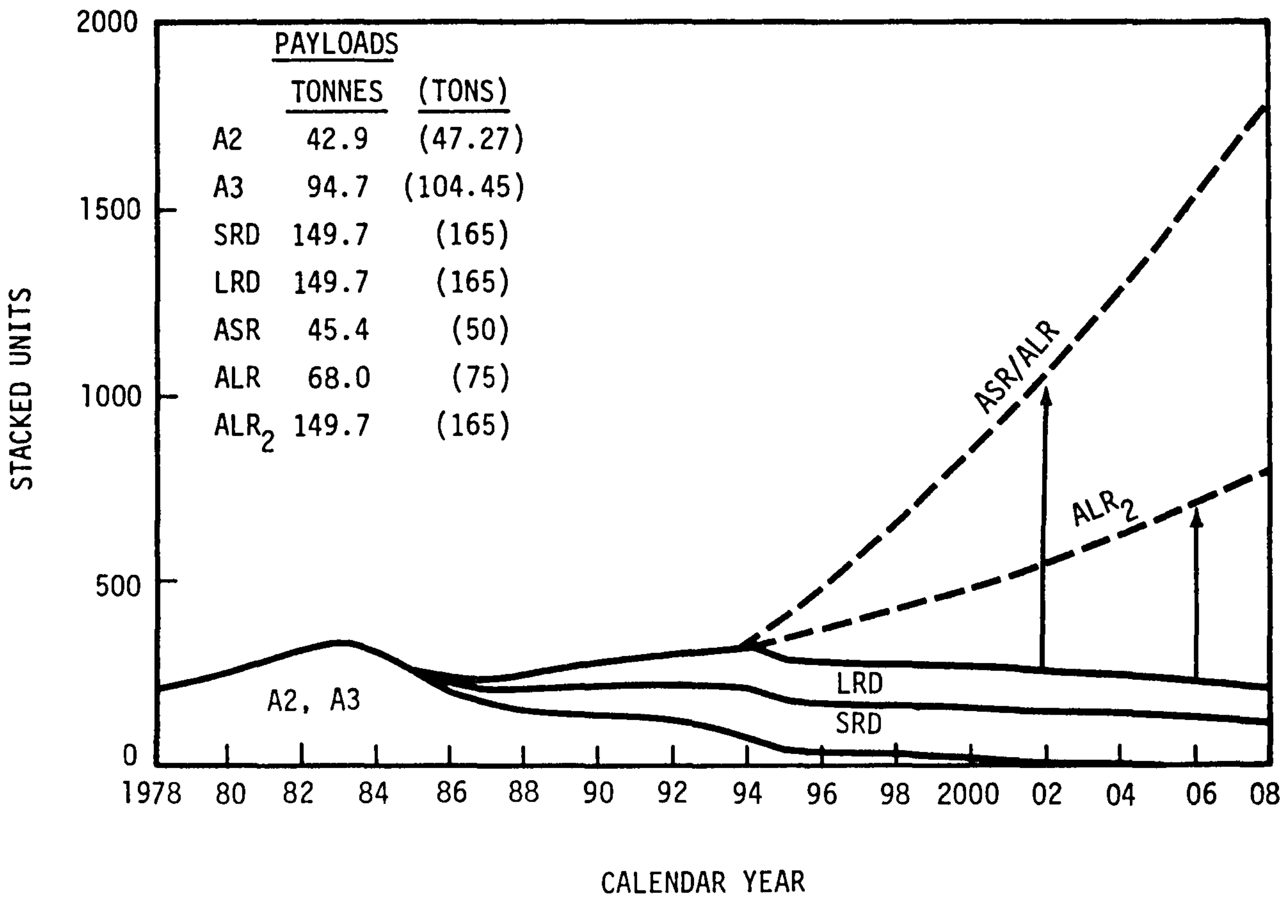


FIGURE 9-4. 1994-2008 REDUCED FREQUENCY FLEET MIX

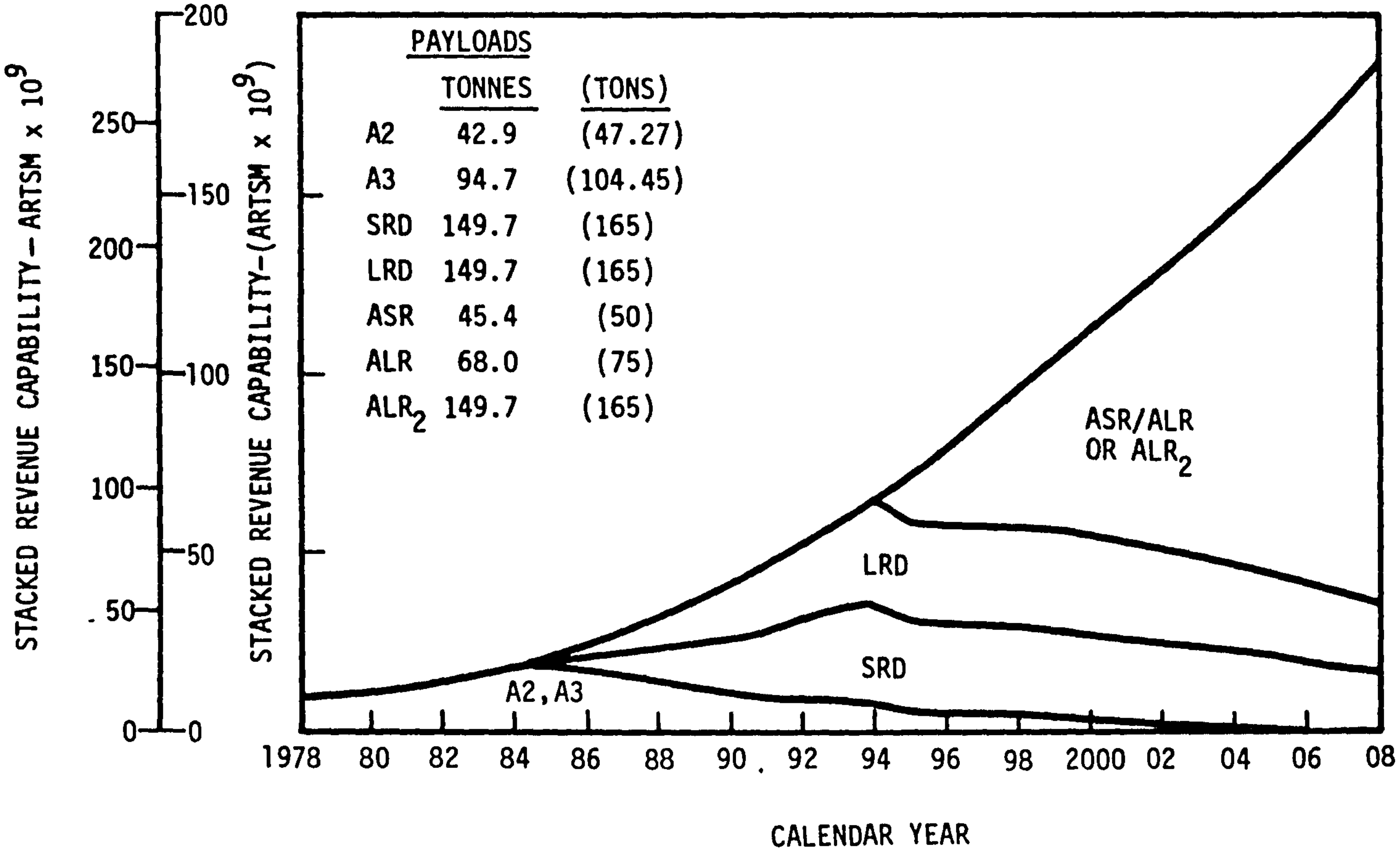


FIGURE 9-5. 1994-2008 REDUCED FREQUENCY FLEET ANNUAL REVENUE CAPABILITY

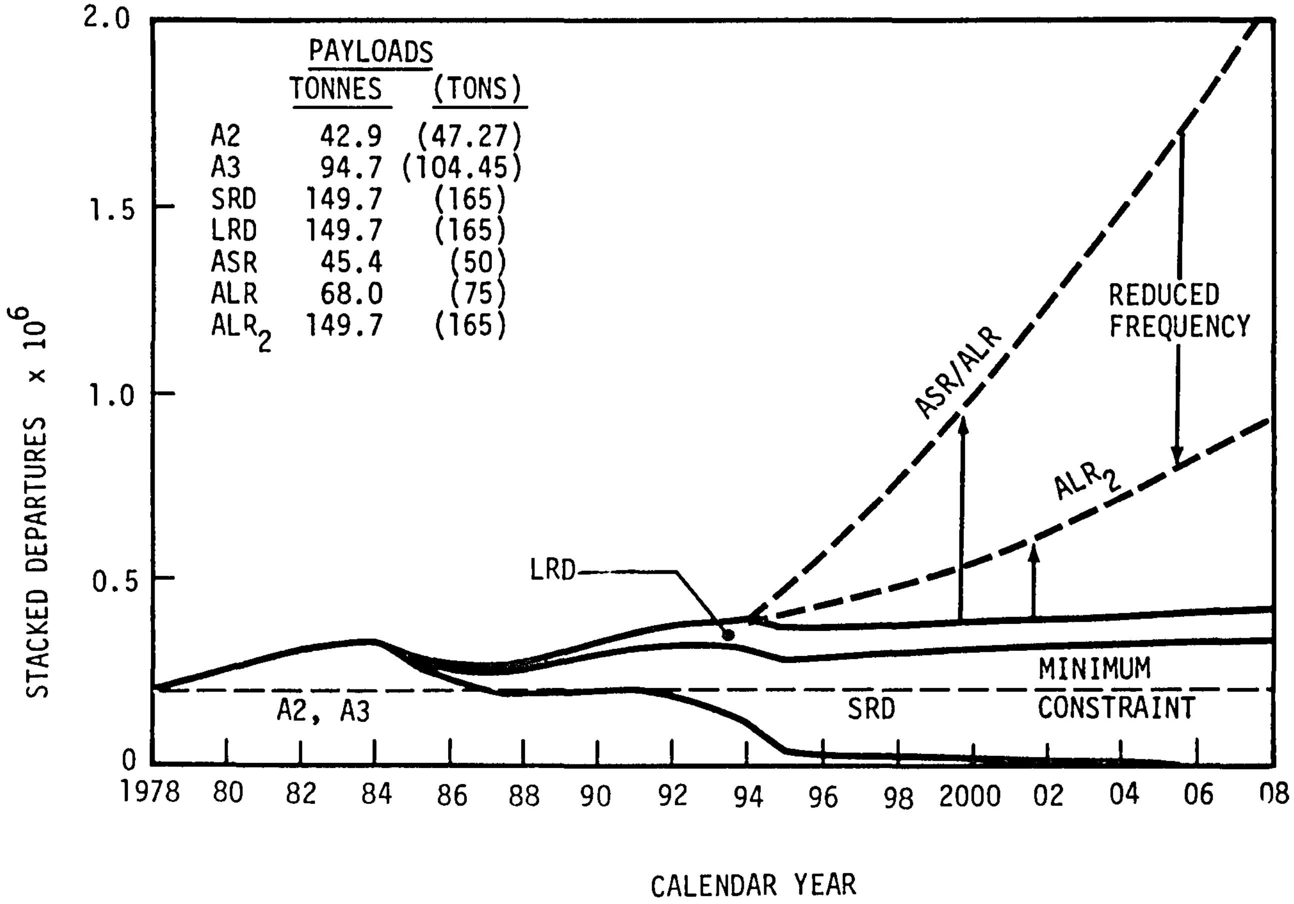


FIGURE 9-6. 1994-2008 REDUCED FREQUENCY FLEET ANNUAL DEPARTURES

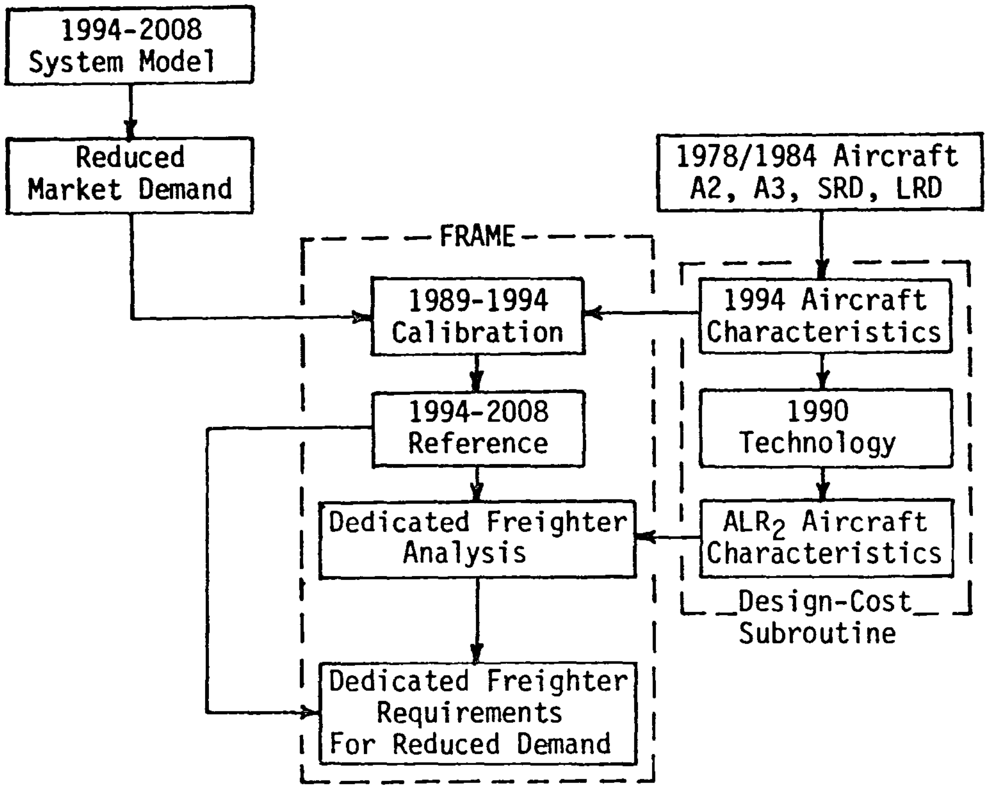
percent. This resulted in a reduction of about 56 percent in the total number of aircraft required in the fleet, as shown in Figure 9-4.

As seen in Table 9-1, the fleet frequency growth rate was cut in half with the ALR_2 aircraft as compared to operations with the ASR/ALR combination. The annual departures in the year 2008 were reduced about 55 percent. These decreases in operating frequency appear more compatible with the forecast capacities of major airports. This opinion is strengthened when one considers the growths in passenger aircraft operations projected for the same time period. The ALR_2 aircraft, with a 149.7 tonne (165 ton) payload, appears the more realistic solution and will therefore be used in the parametric studies that follow.

1994-2008 Reduced Demand

An investigation was made to assess the impact of reduced market demand growth during the 1994-2008 time period on the requirements for the all-new ALR_2, 147.7 tonne (165 ton) payload, dedicated freighter. The purpose is not to determine a new size aircraft to fit the reduced demand but rather to determine what effects the selected ALR_2 would have on the fleet economics. The reason for this approach is the fact that new aircraft, such as the ALR_2, are designed and built based upon market forecasts for periods of 10 to 20 years beyond the projected initial operating date. Once the engineering and production have been initiated, the design cannot be modified to fit an actual decreased cargo market demand.

The approach taken in performing these analyses is outlined below.



The primary difference between this and the analysis of Section 8 rests with the market demand portion of the 1994-2008 Cargo Model. For this reason the market demand is shown as a separate entity in the above diagram.

Analysis of the market growth characteristics of Section 1 led to the conclusion that the most realistic approach to decreased demand was to delay the market growth rather than to arbitrarily decrease the level by some selected percentage. To accomplish this, the 1989 demand forecast level was delayed 5 years to 1994 as illustrated in Figure 9-7 for the combined U.S. Domestic, U.S. International and Foreign markets. The annual growth rates for the years beyond 1994 were held unchanged. This delay in market growth reduced the total market average annual growth rate from 10.7 percent to about 8.5 percent per year, a reduction of about 21 percent in the annual rate. With the delayed growth, the total market demand for the year 2008 was reduced about 45 percent. With the revised market demand level established, the FRAME program was recalibrated to assure continuity with the 1989 solution for the 1984-1998 time period developed in Section 7.

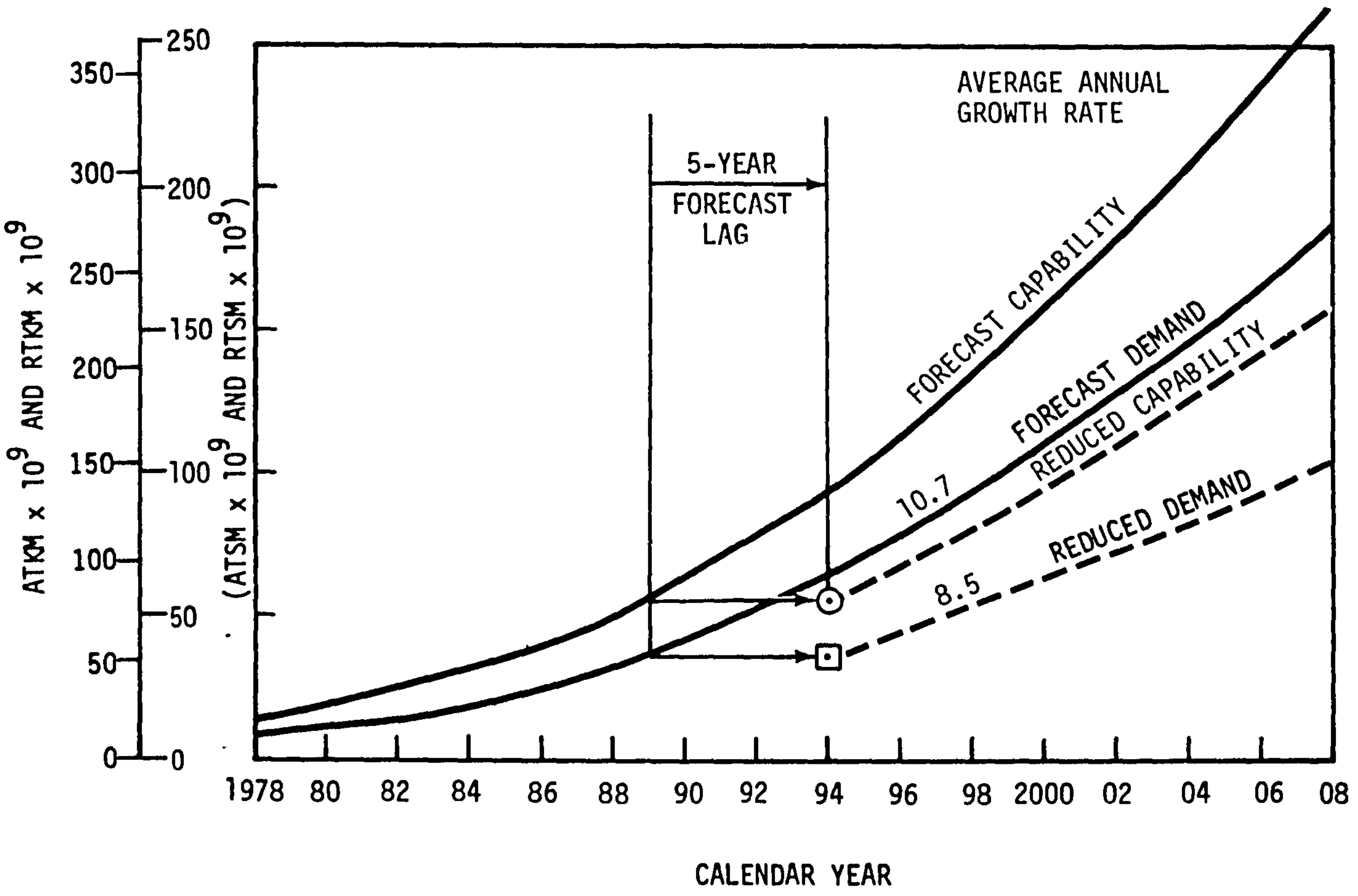


FIGURE 9-7. REDUCED GROWTH — AIRFREIGHT TOTAL MARKET FORECAST FOR ALL-CARGO AIRCRAFT

1994 Reference Fleet. - Having calibrated to assure continuity, the current and derivative aircraft were then evaluated over the full time period to obtain the 1994-2008 reduced demand reference fleet as shown in Table 9-2. Comparing the reference fleet for the reduced demand to that for the forecast demand derived in Section 8, Table 8-2, shows a depleted economic situation. While the investment required was reduced 35 percent, the cash flow was reduced by 44 percent and the airline ROI was down 3.4 percent. These results are graphically illustrated in Figure 9-8. Not shown in this figure is the 49 percent reduction in operating income that would have a strong impact on the airline's economic situation.

Shown in Table 9-2 and Figure 9-9 is the impact which the reduced demand had upon the number and types of aircraft making up the fleet. The reduced demand put increased emphasis back on the A2 and A3 types, increasing their numbers by factors of 5 and 1.5, respectively, and decreasing the derivative aircraft by over 40 percent. Comparing the data of Figure 9-9 with that of Figure 8-1, we see that the utilization of the A2 was extended six years to 2004 and that the current wide-body A3 remained relatively strong with over 50 units remaining in the fleet in the year 2008. Viewing the fleet operations in Figures 9-10 and 9-11 shows that with the reduced demand the A3 type aircraft remained in the fleet performing the job which the SRD captured under conditions of the forecast demand. Although the annual growth of frequency was decreased 1.3 percent, Table 9-2, the annual level of fleet departures remained above the minimum constraint.

1994 Dedicated Aircraft. - The ALR_2, 149.7 tonne (165 ton), aircraft characteristics, range, payload, and trip cost were the same as those used in the preceding reduced frequency study, reference Table 9-1. The aircraft price was increased to the values below due to the decreased number of units required to satisfy the reduced growth. As before, these values are based upon two manufacturers, each realizing an ROI of 15 percent. The price of fuel was 48 cents per liter (181 cents per U.S. gallon). The number of ALR_2 aircraft required was reduced 40 percent due to the reduced demand, which in turn increased their price by 35 percent.

TABLE 9-2

REDUCED DEMAND REFERENCE FLEET

Time Period 1994-2008	Forecast Demand	Reduced Demand
Units - A2	9	44
Units - A3	72	107
Units - SRD	437	254
Units - LRD	379	212
ROI Airline - Percent	21.4	18.0
EUACF - 1994 \$ x 10^9	25.7	14.5
ΣIPV - 1994 \$ x 10^9	113.5	73.9
ΣOI - \$ x 10^9	939.3	475.9
Departures (Trips) Growth Rate - Percent per Year	6.7	5.4

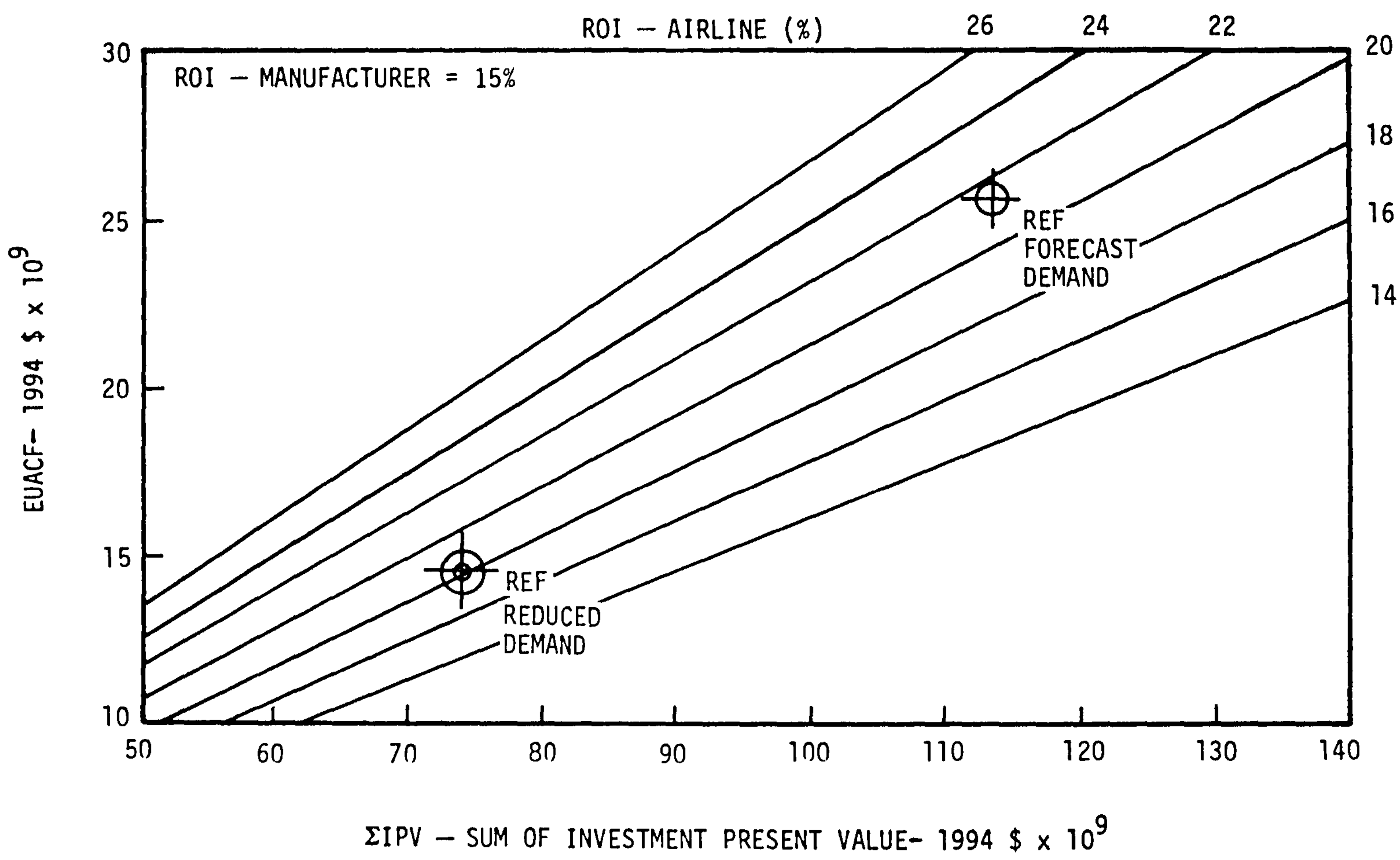


FIGURE 9-8. REDUCED DEMAND — REFERENCE FLEET ECONOMICS

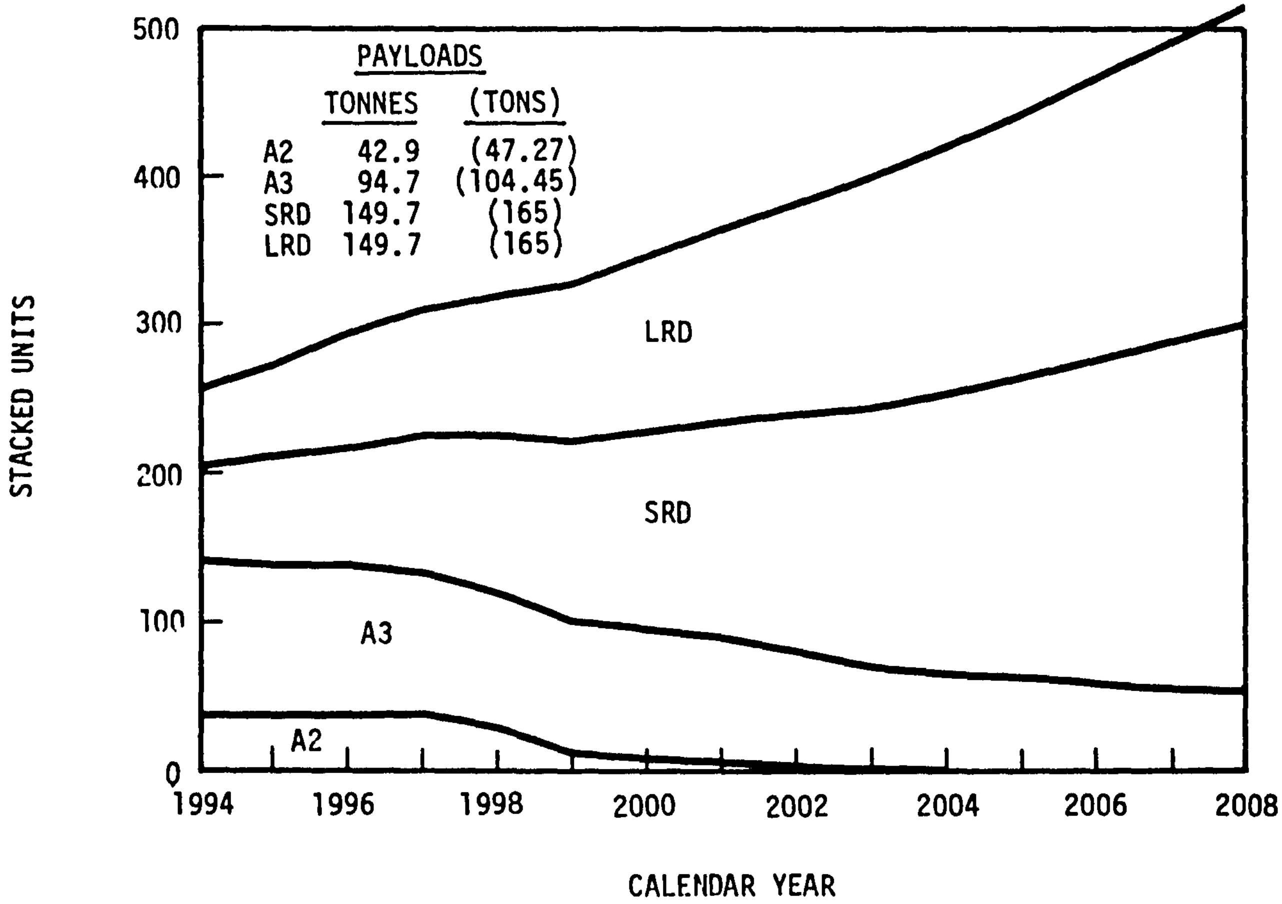


FIGURE 9-9. REDUCED DEMAND—1994-2008 REFERENCE FLEET MIX

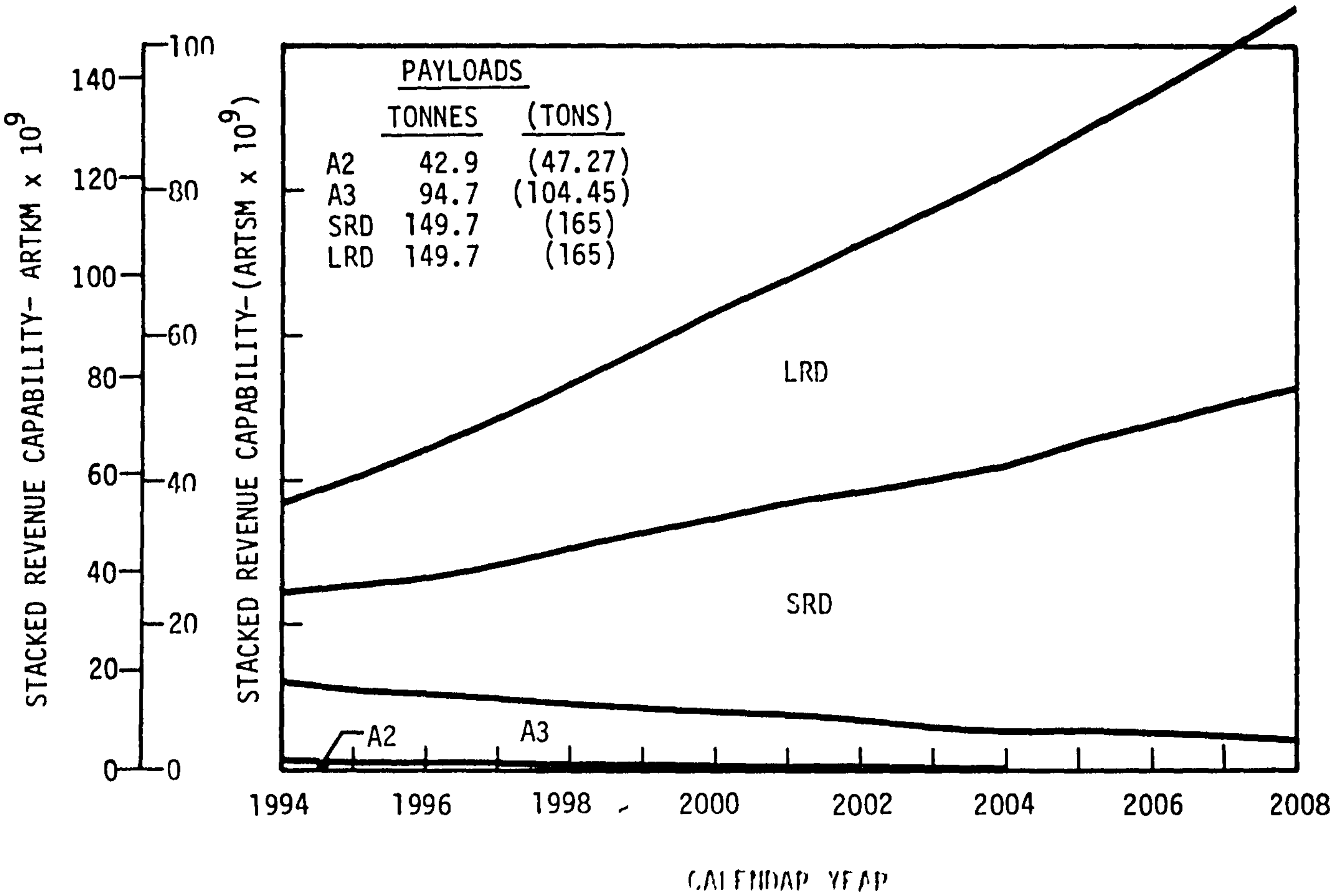


FIGURE 9-10. REDUCED DEMAND — 1994-2008 REFERENCE FLEET ANNUAL REVENUE CAPABILITY

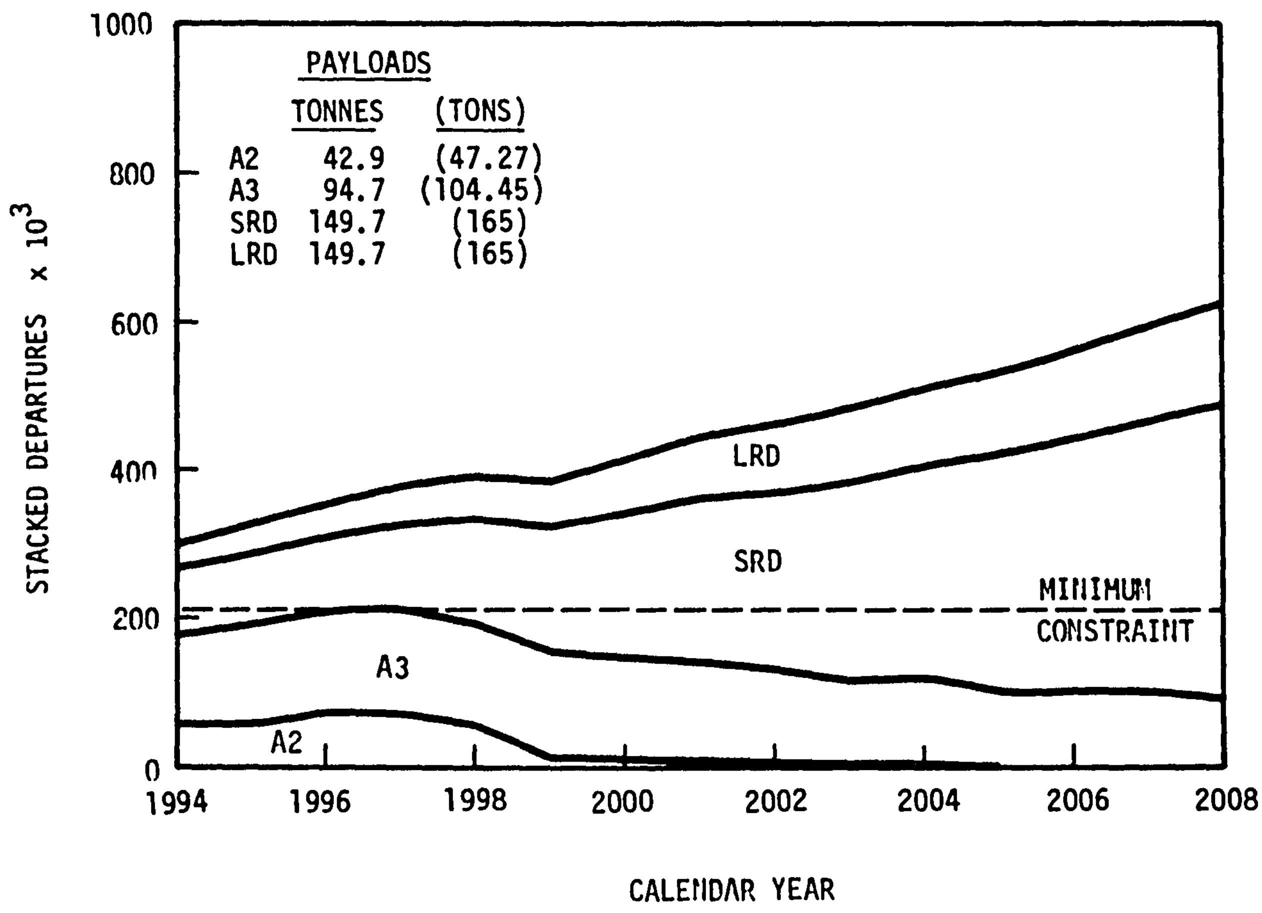


FIGURE 9-11. REDUCED DEMAND — 1994-2008 REFERENCE FLEET ANNUAL DEPARTURES

Aircraft	ALR2	
Payload - Tonnes (Tons)	149.7 (165)	
Market Demand	Forecast	Reduced
Units	573	344
Aircraft Price - 1994$ x 10^6	146	197

Fleet Economics. - We have seen that the economics of the 1994-2008 reference fleet suffered substantially under the conditions of reduced demand. The questions remaining are, first, will the ALR_2 be as competitive in the reduced demand environment and, second, will the resulting fleet economics suffer equally with that of the reference fleet? To answer these questions the ALR_2 aircraft was run in competition with the A2, A3, SRD and LRD type aircraft. Results of this analysis are presented in Table 9-3 and Figure 9-12.

Comparing the respective values for the two demand levels (forecast demand values from Table 9-1) show a 49 percent reduction in the airline's operating income, a value equal to that experienced by the reference fleet, Table 9-2. The airline's ROI is reduced 5.3 percent and the investment by 22 percent. Both of these effects are more unfavorable than was experienced by the reference fleet. However, the reduction in cash flow is less, 38 percent compared to 44 percent for the reference fleet. A portion of this difference was due to the fact that the reduction in investment due to the reduced demand was less with the ALR_2 aircraft than with the reference fleet. It appears then that the operators would economically suffer a little more if they had the new dedicated ALR_2 in their fleet than if they had continued using the A2, A3, SRD and LRD types. Since the reduction in operating income is the same in either case, the severity of ALR_2 ownership penalty due to decreased market demand would be strongly influenced by the airline's financial conditions at the time.

The Operational Results. - The impact of reduced demand on fleet operations is presented in Figures 9-13 through 9-15 in terms of units, revenue capability and frequency, respectively. Not only was there a reduction in the number of ALR_2 required but also a change in the distribution of aircraft types within the fleet. With the forecast demand about 75 percent of the 1994 fleet were

TABLE 9-3

REDUCED DEMAND - ALR_2 AIRCRAFT REQUIREMENTS

Aircraft Payload - Tonnes (Tons)	ALR_2 149.7 (165)	
Demand	Forecast	Reduced
Units	573	344
Manufacturer's Share - Percent	50	50
Aircraft Price - 1994 \$ x 10^6	146	197
ROI Airline - Percent	21.0	15.7
EUACF - 1994 \$ x 10^9	27.7	17.1
ΣIPV - 1994 \$ x 10^9	124.2	96.4
ΣOI - \$ x 10^9	1027.0	521.4
Departures (Trips) Growth Rate - Percent per Year	6.7	5.4

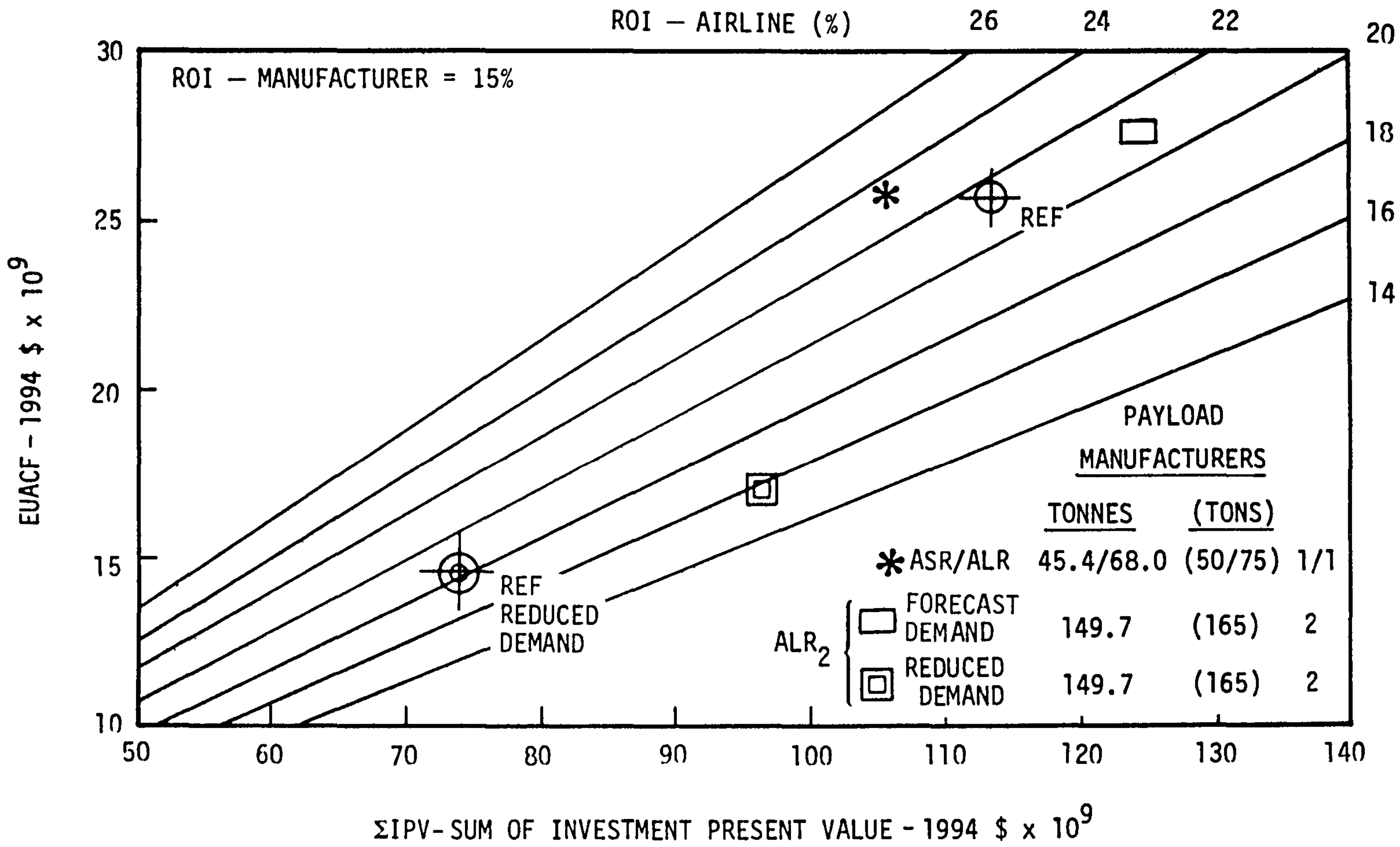


FIGURE 9-12. REDUCED DEMAND — ALR_2 ECONOMIC WORTH

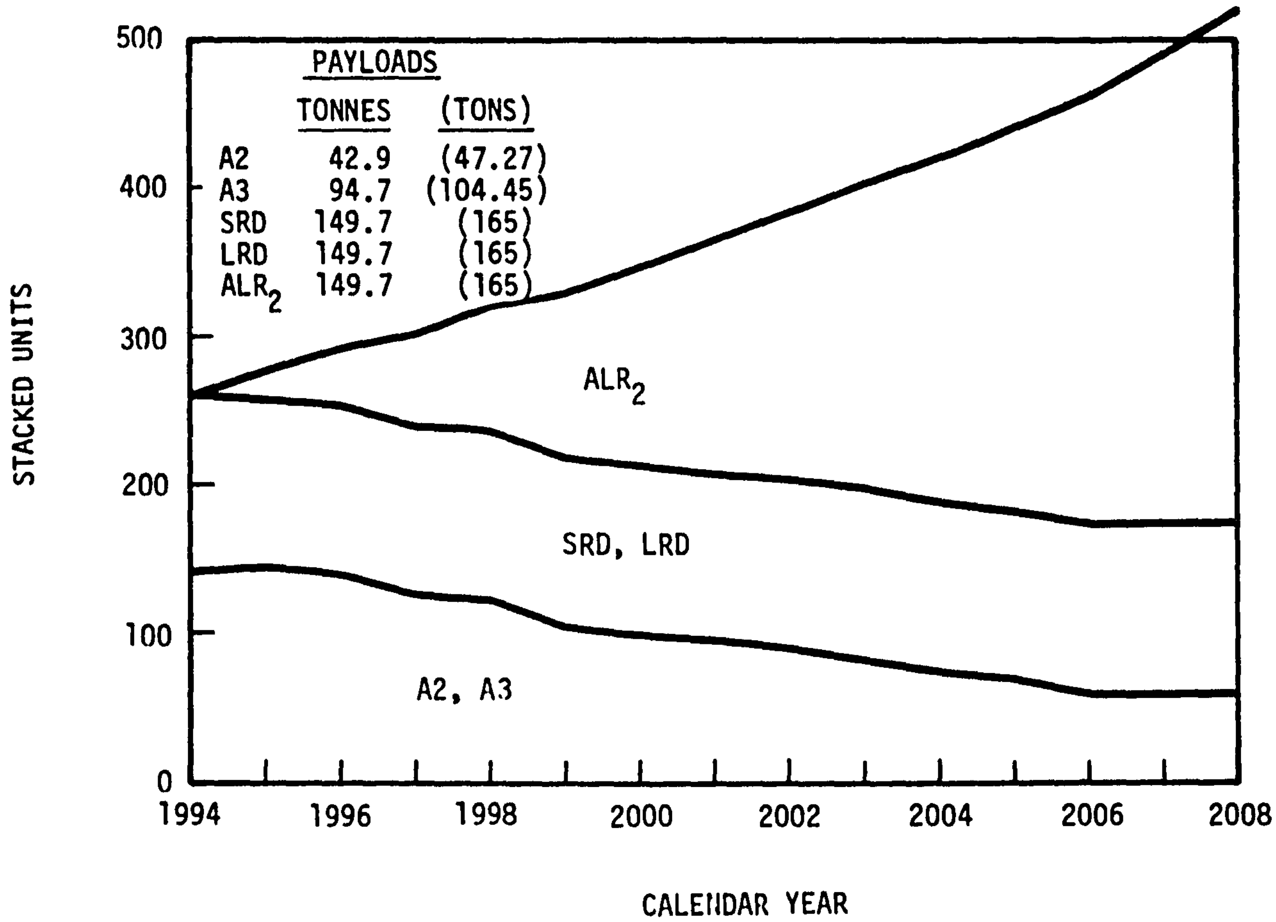


FIGURE 9-13. REDUCED DEMAND — 1994-2008 ALR_2 FLEET MIX

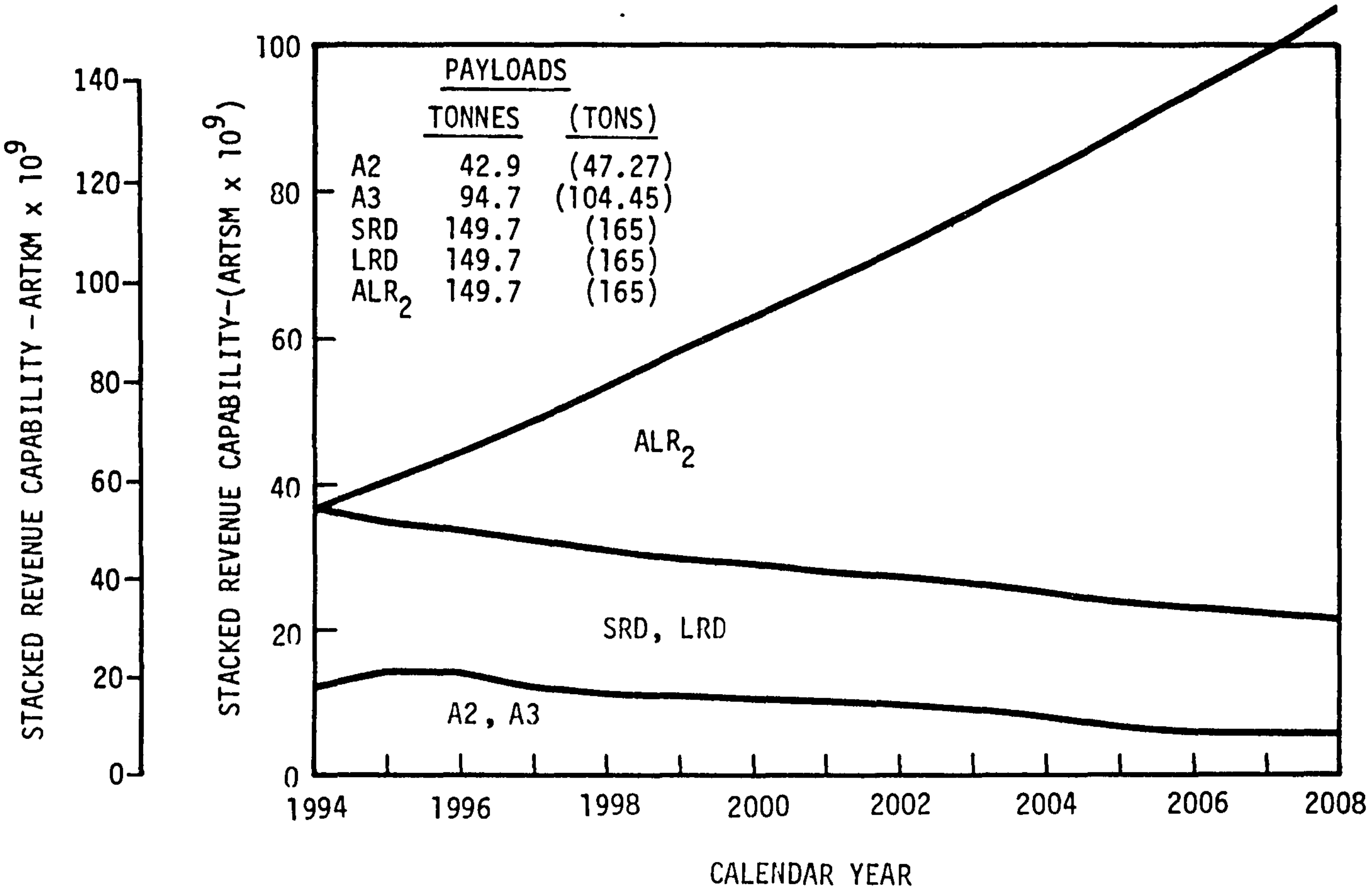


FIGURE 9-14. REDUCED DEMAND — 1994-2008 ALR_2 FLEET ANNUAL REVENUE CAPABILITY

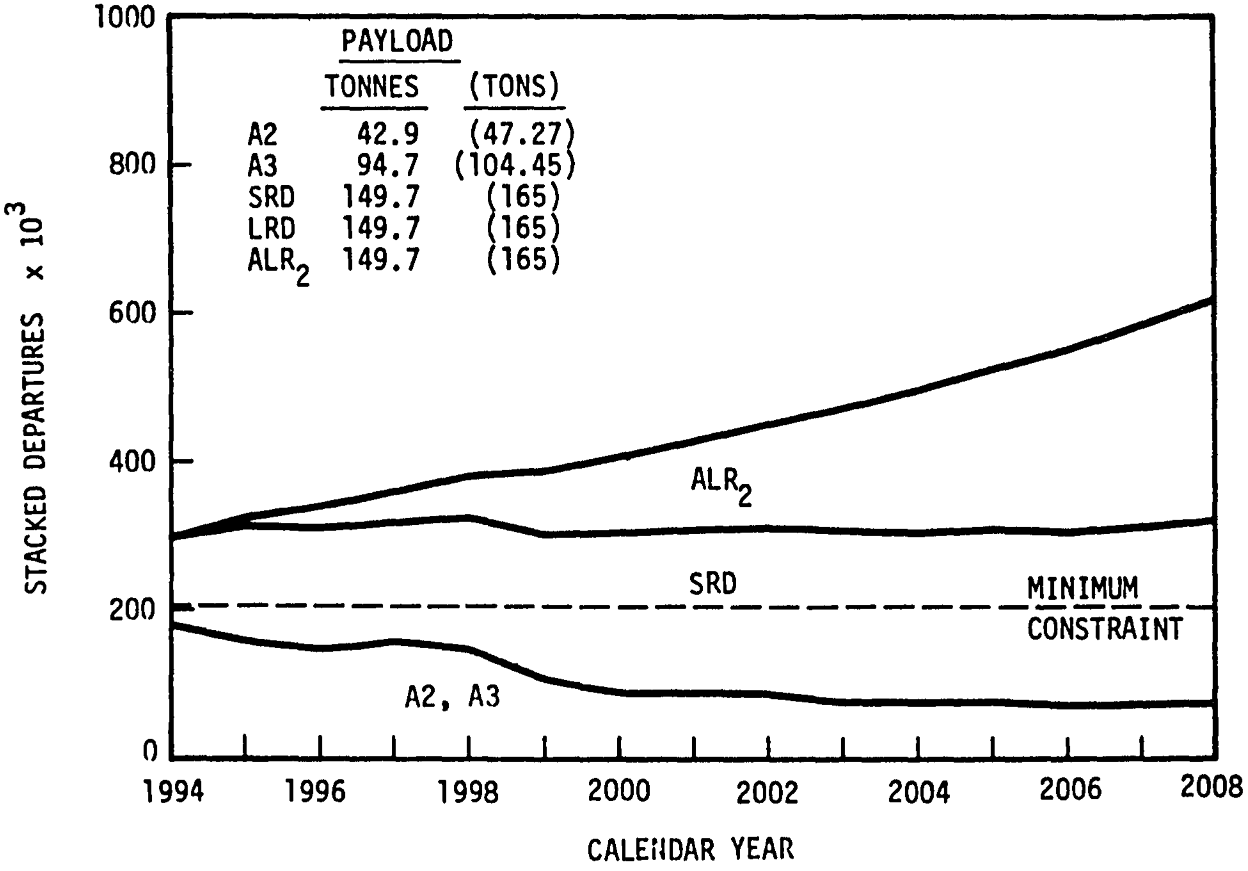


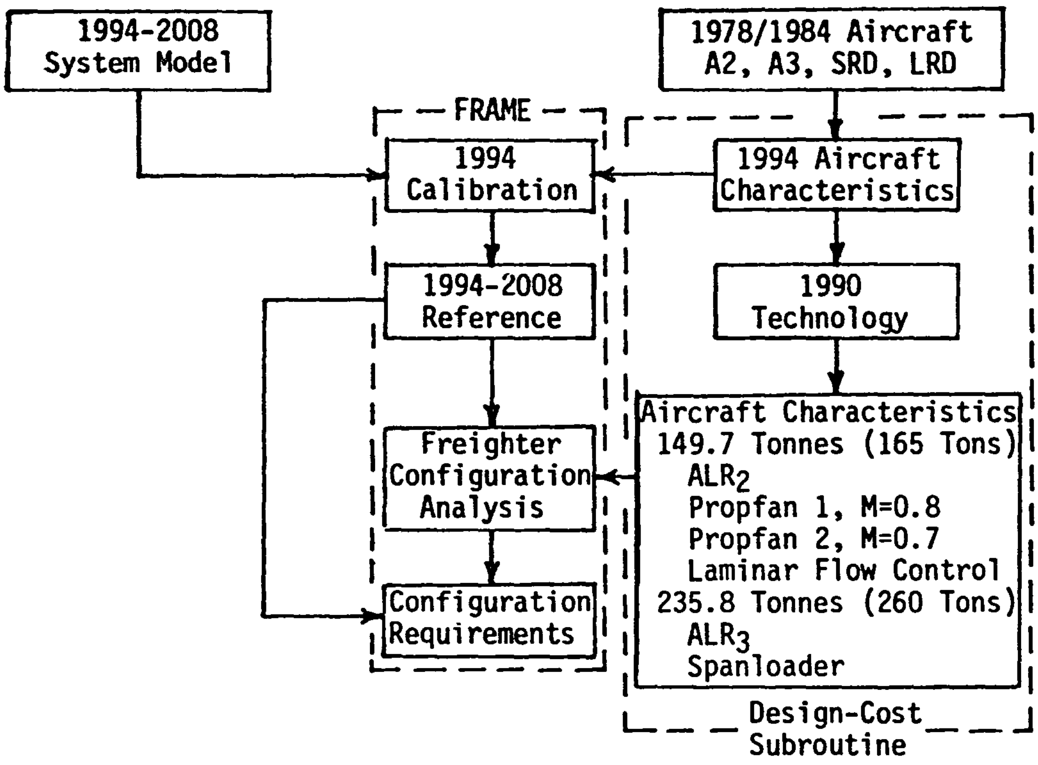
FIGURE 9-15. REDUCED DEMAND — 1994-2008 ALR_2 FLEET ANNUAL DEPARTURES

SRD and LRD types, Figure 9-4. By the year 2008 the A2, A3 aircraft had phased out with the ALR_2, making up over 70 percent of the fleet the remainder in SRD and LRD's. But with the reduced demand, over half the units were A2 and A3 types in 1994. As seen in Figure 9-13, these current aircraft remained through 2008, making up about 13 percent of the fleet in that final considered year, while the SRD/LRD combinations represented only about a quarter of the fleet with the remaining approximately 60 percent being the dedicated ALR_2. These results indicate that under conditions of the reduced demand, the ALR_2 was less competitive, losing out to the A2 and A3 types as did the SRD and LRD's, but to a lesser extent.

Referring to Figures 9-14 and 9-15 indicates that changes in the distribution of capability and departures between aircraft types were similar to the variations in the number of respective units. There was a gradual decrease in these variables for the A2 and A3 aircraft indicating that their utilization remained about the same with capability and departures decreasing as the units were phased out. On the other hand, while the number of SRD and LRD units showed little change, the revenue capability provided by these types gradually decreased while the number of departures increased. These results indicated that they were being transferred to the shorter range operations similar to the change encountered under conditions of the forecast demand as seen in Figures 9-5 and 9-6.

Configuration Changes

The analysis of new aircraft discussed thus far has been concerned with conventional aircraft configurations with swept wings, turbofan engines and designed for M = 0.85. In a study of this type, there is always the question as to the relative effectiveness of configurations that depart from the conventional approach. To answer this question, analysis similar to those discussed in the preceding section were performed on five distinct configurations as outlined below.



These configurations included two versions of a propfan powered aircraft of conventional design, a turbofan powered spanloader (distributed payload) type, and a conventional turbofan aircraft configuration equipped with laminar flow control (LFC) on the upper surface of the wing. These were compared to the 149.7 tonne (165 ton) ALR_2 and a 235.8 tonne (260 ton) payload ALR_3 versions of the new dedicated freighter. All configurations are fully described in Section 6.

For these evaluations the cargo model is identical to the 1994-2008 version developed in Section 8 and therefore a calibration run was not required. The 1994 reference fleet, consisting of the A2, A3, SRD and LRD, was that developed in Section 8 corresponding to the characteristics given in Table 8-2.

Configuration Characteristics. - Incremental changes to the various design ratios provided by the 1990 technology advances are provided in Table 6-3. These changes are summarized in Table 9-4 relative to the design ratios of the advanced turbofan, long range aircraft of a conventional con-

TABLE 9-4

CONFIGURATION CHANGES - 1990 TECHNOLOGY

Configuration	ALR	Propfan 1		Propfan 2		Span Loader		LFC	
	Aircraft	Technology Change		Technology Change		Technology Change		Technology Change	
Technology	Value	Ratio	Value	Ratio	Value	Ratio	Value	Ratio	Value
Propulsion System - W_{PS}/T_{ENG}	0.2563	0.93	0.0847	0.89	0.0811	0.874	0.0751	1.00	0.2563
Structure - W_{STRU}/W_{LDG}	0.2543	0.96	0.2441	0.74	0.1882	0.57	0.1450	1.065	0.2709
L/D - Cruise	19.3	0.90	17.4	0.94	18.1	0.87	16.8	1.22	23.6
SFC - Kg/hr/Deca Newton (lbs/hr/lb)	0.567 (0.556)	0.80	0.454 (0.445)	0.70	0.397 (0.389)	0.96	0.544 (0.534)	1.02	0.578 (0.567)
Engine Weight - W_{ENG}/T_{ENG}	0.1652	2.12	0.3502	2.03	0.3354		0.1652	1.02	0.1685
ΔC_L @ Takeoff	1.284		1.284		1.284		1.284	0.87	1.117
Manufacturing Cost									
Airframe	1.00		1.00		1.00	0.85	0.85	1.04	1.04
Engines	1.00	1.29	1.29	1.29	1.29		1.00		1.00
Maintenance Cost									
Airframe	1.00		1.00		1.00		1.00	1.10	1.10
Engines	1.00		1.00		1.00		1.00		1.00

figuration. When applied through the Design and Cost Subroutine, these data resulted in the characteristics for the respective configurations presented in Table 9-5. The trip costs (DOC less depreciation and insurance) were based upon a fuel cost of 48 cents per liter (181 cents per U.S. gallon) and were adjusted for the maintenance cost changes due to technology given in Table 9-4. Factors for maintenance cost are for the combined effects of material and labor. Aircraft prices are based upon two manufacturers producing the units shown in Table 9-5, each realizing an ROI of 15 percent. The aircraft prices were also adjusted for the manufacturing cost factors given in Table 9-4.

Based upon past industry design studies of the spanloader configuration, the larger payload, 235.8 tonne (260 ton), was chosen to be evaluated. This size of the spanloader configuration is very near the lower end of the range of payloads at which its effectiveness begins to exceed that of a conventional configuration. It is interesting to note in Table 9-5 that the lowest trip cost is provided by the LFC aircraft while the lowest aircraft price is for the turboprop designed for M = 0.7. This configuration also requires the largest number of units while the spanloader requires the least and has the highest trip cost.

Fleet Economics. - Each configuration was evalutated for its ability to meet the 1994-2008 forecast market demand when operating in competition with the 1994 reference fleet. The resulting requirements for each configuration are presented in Table 9-6 with the relative economic worth graphically shown in Figure 9-16.

Comparing the configurations on the basis of the four economic parameters, ROI, cash flow, investment and operating income leads to conclusions regarding the relative desirability of the respective aircraft types. The Spanloader provided the highest ROI to the airline and the lowest required investment. It also resulted in a cash flow essentially the same as for the reference fleet while providing a 6 percent increase in operating income. The next most productive configuration was the M = 0.7, Propfan 2 which gave the second highest income, 12 percent above the reference fleet and surpassed only by the LFC. It also requred next to the lowest investment and resulted in the second highest airline ROI. It also had an equivalent cash flow of

TABLE 9-5

CONFIGURATION CHANGES - AIRCRAFT CHARACTERISTICS

Design Range - KM (SM)	7022 (4364)					
Configuration	ALR_2	ALR_3	Propfan 1	Propfan 2	Span Loader	LFC
Design Speed @ Cruise - M_{cr}	0.85	0.85	0.80	0.70	0.75	0.85
Payload - Tonnes (Tons)	149.7(165)	235.8(260)	149.7(165)	149.7(165)	235.8(260)	149.7(165)
Trip Cost @ Design Range-1994 $	76390	120309	78374	69955	130894	68870
Units	573	356	594	646	392	568
Aircraft Price - 1994 $ x 10^6	146	267	161	119	168	157

TABLE 9-6

CONFIGURATION CHANGES - ECONOMIC REQUIREMENTS

Configuration	Ref.	ALR_2	ALR_3	Propfan 1	Propfan 2	Spanloader	LFC
Payload-Tonnes (Tons)		149.7(165)	235.8(260)	149.7(165)	149.7(165)	235.8(260)	149.7(165)
Units		573	356	594	646	392	568
Aircraft Price - 1994 \$ x 10^6		146	267	151	119	168	157
ROI Airline - Percent	21.4	21.0	19.7	19.7	22.1	23.0	20.7
EUACF - 1994 \$ x 10^9	25.7	27.7	28.7	28.7	27.3	25.6	28.5
ΣIPV - 1994 \$ x 10^9	113.5	124.2	135.5	136.1	117.4	106.3	129.7
ΣOI - \$ x 10^9	939.3	1027.0	1023.1	1018.7	1055.7	999.2	1056.1
Departures (Trips) Growth Rate - Percent per Year	6.7	6.7	5.2	6.7	6.7	5.2	6.7

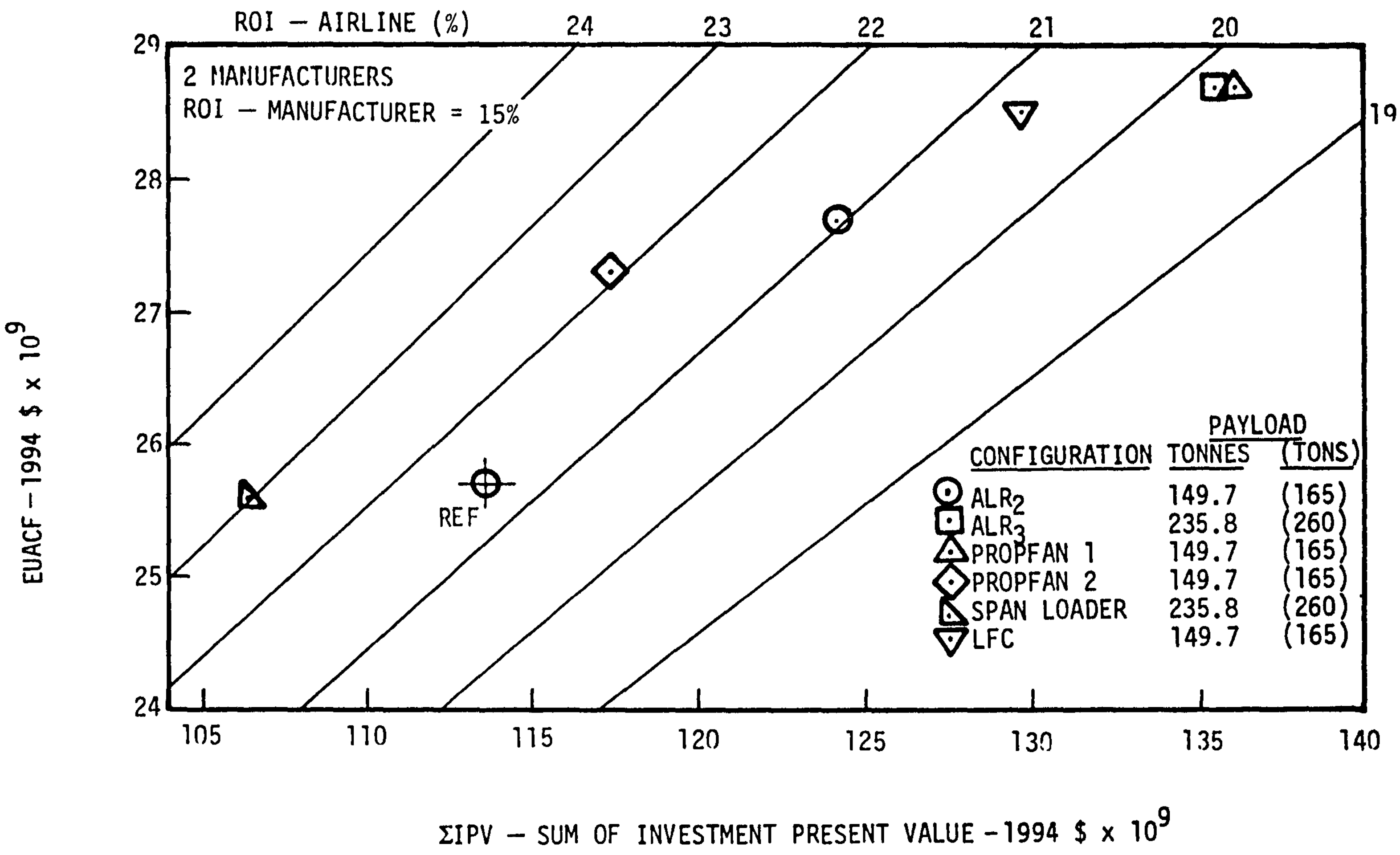


FIGURE 9-16. CONFIGURATION CHANGES — ECONOMIC WORTH

6 percent greater than the reference fleet. Finally, the ALR_2 configuration had the third highest operating income, cash flow, and airline ROI, and the third lowest required investment. Relative to the reference fleet, the ALR_2 required a 9 percent greater investment and gave about the same airline ROI while increasing the operating income by 9 percent.

It is interesting to note that the larger payload ALR_3 was less effective than the smaller ALR_2 surpassing the latter only in the area of cash flow where the ALR_3 value was equal to that for Propfan 1, the highest value developed by the considered configurations. This and the other relationships are shown in Figure 9-16. If those configurations are excluded that have an airline ROI not more than 1 percent below, and a required investment less than 10 percent greater than, the reference fleet then only the Spanloader, the Propfan 2 and the ALR_2 configurations remain. The latter configuration with an investment of 9 percent greater than the reference may be considered borderline. These three configurations along with values for the ASR/ALR combination and for the small 68.0 tonne (75 ton) ALR with two manufacturers, reference Table 8-9, are shown in Figure 9-17.

Of the dedicated freighter aircraft configurations that were evaluated, the small payload 45.4/68.0 tonne (50/75 ton) ASR/ALR combination offered the highest economic worth as shown in Figure 9-17. However, the 2 percent improvement in airline ROI over the reference fleet provided by this combination was not as dramatic as the 4 percent improvement realized by the SRD/LRD combination of derivative aircraft, reference Figure 7-8. It should be noted that the payload sizes of the Spanloader and Propfan 2 configuration, were not optimized and this could account, at least in part, for their relatively small economic improvement over the reference fleet, hence, both these configurations deserve continued consideration in later studies.

In addition to fleet economics there are other infrastructure related considerations that must be evaluated in selecting configurations for development. As previously discussed, the ASR/ALR combination resulted in a relatively large increase in operating frequency, an average annual increase of 12.6 percent, and therefore may not be a strong contender for future production.

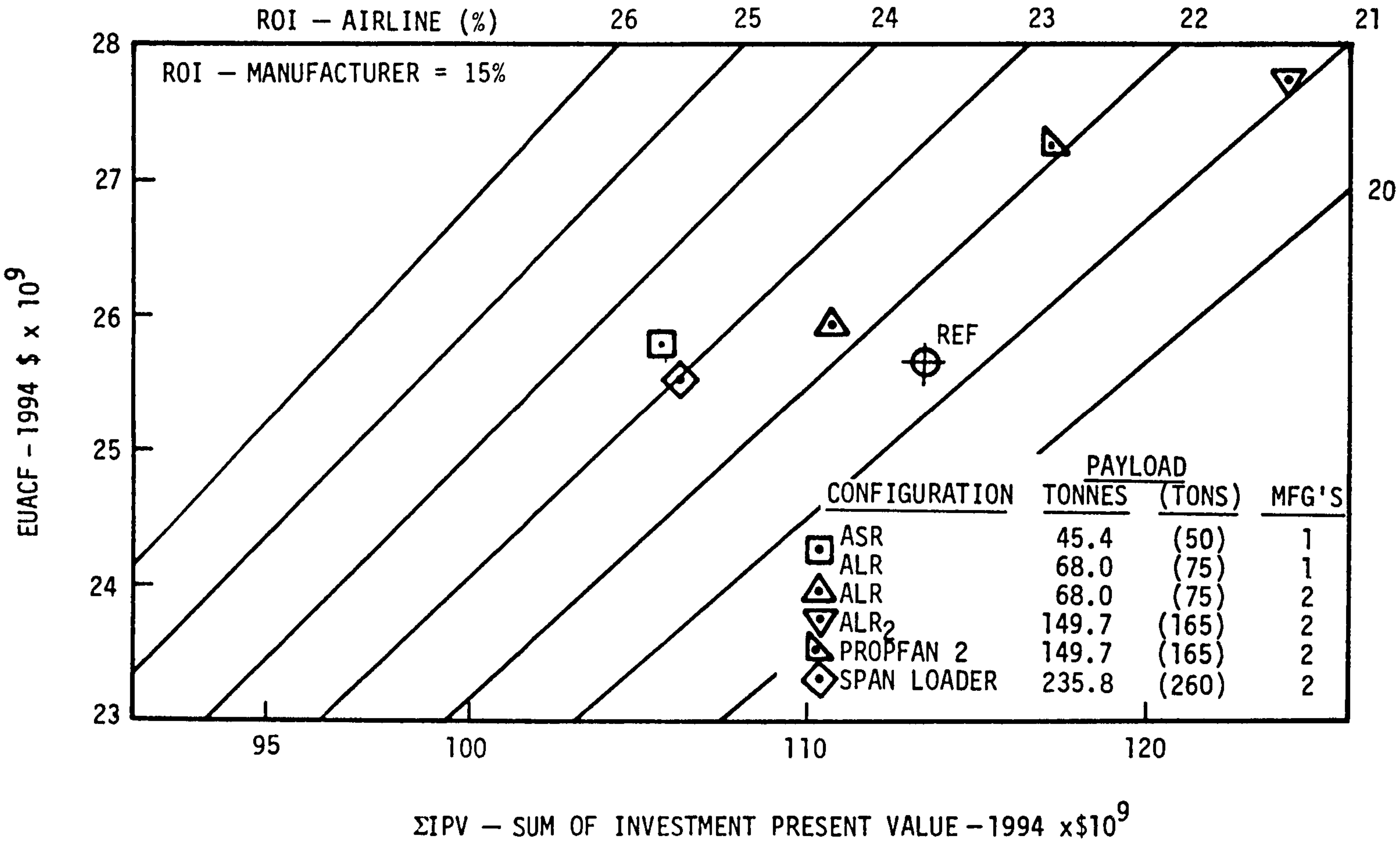


FIGURE 9-17. CONFIGURATION CHANGES — ECONOMIC SUMMARY

The Spanloader and ALR_2 configuration have potential conflicts with airports in the U.S. and abroad that is not evident from these fleet operational results. The large span and gear tread associated with these configurations could be in conflict with runway and taxiway widths and clearances and with the parking areas adjacent to cargo terminals. As discussed in Volume 3, Book 1, operations on current hub airports are essentially limited to aircraft not much larger than the B747 aircraft. For future airports, Group 4, FAA standards specify 67 meters (240 feet) as the maximum allowable wing span, and landing gear treads not to exceed 152 meters (50 feet). While the ALR_2 would be marginal in view of those requirements the Spanloader would be definately restricted in fleet operations without substantial changes in airport and/or aircraft configurations. Although the Propfan 2 showed improved fleet economics over the ALR_2, it too has a qualifying point. Some operators have expressed a reluctance to acquire aircraft having cruise speeds much below the current values of 0.8 to 0.85 Mach number. The airways are now keyed to the higher speed and the entrance of a M = 0.7 aircraft on prime routes may result in difficulties comparable to those encountered when the jet aircraft began operating in combination with the slower reciprocating engine aircraft.

Fleet Operational Results. - The impact of the more promising configurations on fleet operations is shown in Figures 9-18 through 9-20. It should be noted that values for the ASR/ALR, Propfan 2, ALR_2, and the Spanloader have not been stacked. As an example, the dashed curve for the total fleet size with the ALR_2 aircraft does not include the Spanloader units. The Spanloader with its payload of 235.8 tonne (260 ton) showed the smallest growth in frequency, Figure 9-20, amounting to an average annual growth rate of 5.2 percent as shown in Table 9-6. The ALR_2 and Propfan 2 configurations were the same size and therefore had the same annual departures, however, due to its reduced block speed the Propfan 2 required the larger number of units, Figure 9-18.

Military Participation

Thus far in viewing the dedicated freighter aircraft for commercial cargo operations, we have seen the interrelations between market demand, aircraft

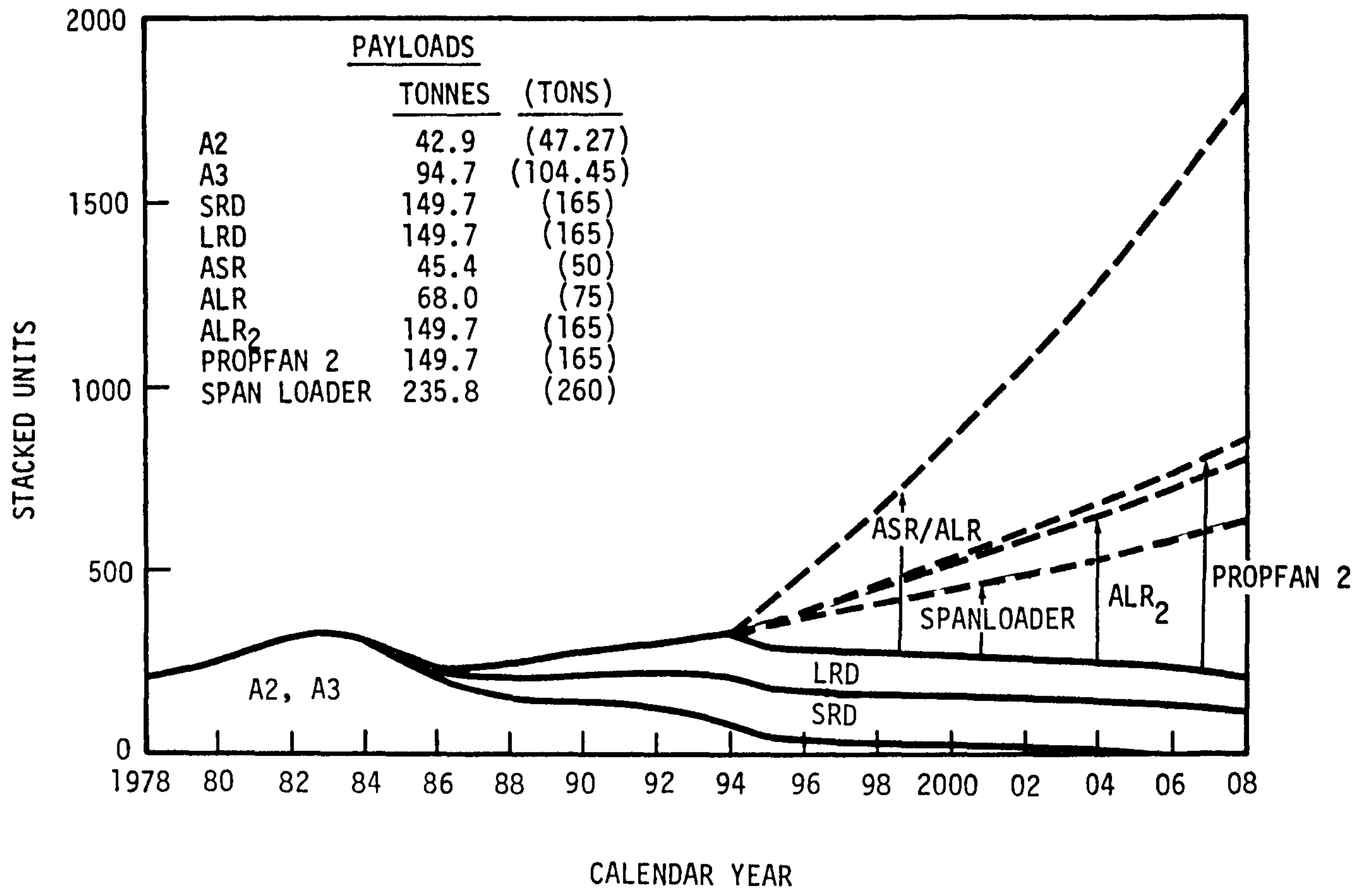


FIGURE 9-18. CONFIGURATION CHANGES — 1978-2008 FLEET MIX SUMMARY

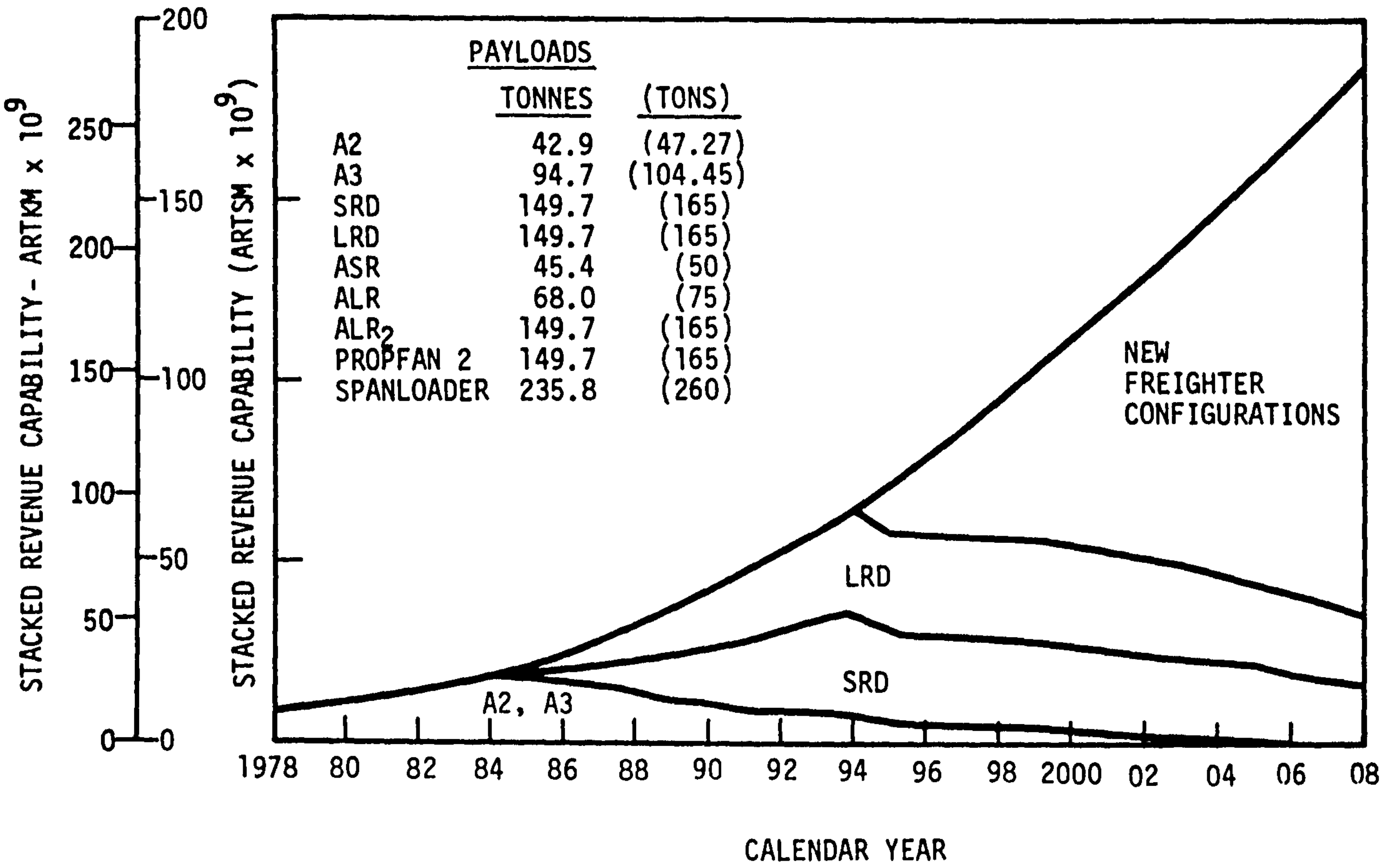


FIGURE 9-19. CONFIGURATION CHANGES — 1978-2008 FLEET ANNUAL REVENUE CAPABILITY SUMMARY

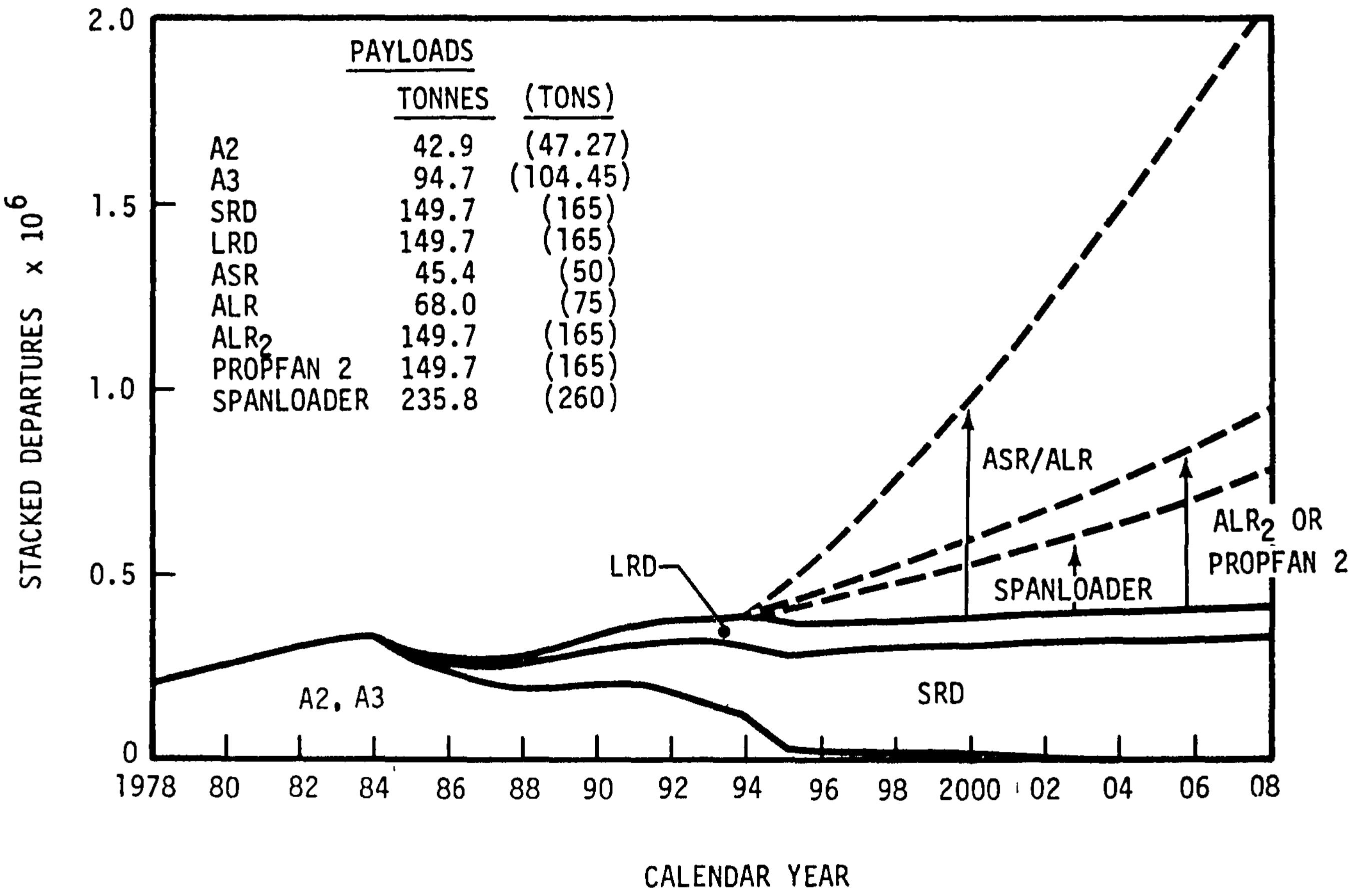


FIGURE 9-20. CONFIGURATION CHANGES — 1978-2008 FLEET ANNUAL DEPARTURES SUMMARY

size, and the resulting return on investment realizable by the airline. We have seen how aircraft price negates the economic benefit of the large, improved technology aircraft and point to the small payload aircraft as the preferred size when viewed with respect to the reference fleet. This interrelation between aircraft size and fleet economics could be partially compensated for through some form of program subsidy. Since the U.S. Air Force is openly interested in developing an advanced dedicated freighter aircraft, Reference 9-1, an analysis was conducted to determine the impact of military participation in the aircraft development and production programs.

It was postulated that military participation would occur in a single program directed to the development of an ALR type aircraft; that two manufacturers would be involved in producing the total number of units required, commercial plus military, but only one of these manufacturers would produce the military units with both realizing a 15 percent ROI; and that the military would provide half of the required research, development and test funding (RD&T) and would subsequently purchase a number of units equal to 25 percent of the commercial U.S. Domestic and U.S. International fleets. It was further postulated that the military purchase of these aircraft would be directed to meeting their demand for the air transport of freight that would be comparable to the commodities transported by commercial airlines. Outsize cargo, such as tanks and cranes, would be carried by military unique aircraft such as the C-5. On this basis the weight and performance of the aircraft were not altered to accommodate military unique requirements.

The impact of military participation resulted in about a 49 percent reduction in aircraft price at a payload of 149.7 tonnes (165 tons) decreasing to 47 percent for the 544.2 tonnes (600 tons) payload size. A major portion of this reduction was due to sharing the RD&T cost since the military buy was relatively small, 43 and 11 units for the noted payloads, repectively.

Competing these parametric aircraft against the A2, A3, SRD and LRD did not affect a change in the preferred size of payload, it remained at the 68.0 tonne (75 ton) previously identified. What it did do was to increase the airline ROI, reduce the cash flow, and reduce the investment required at all payloads as shown in Figure 9-21. It also reduced the sensitivity of the fleet

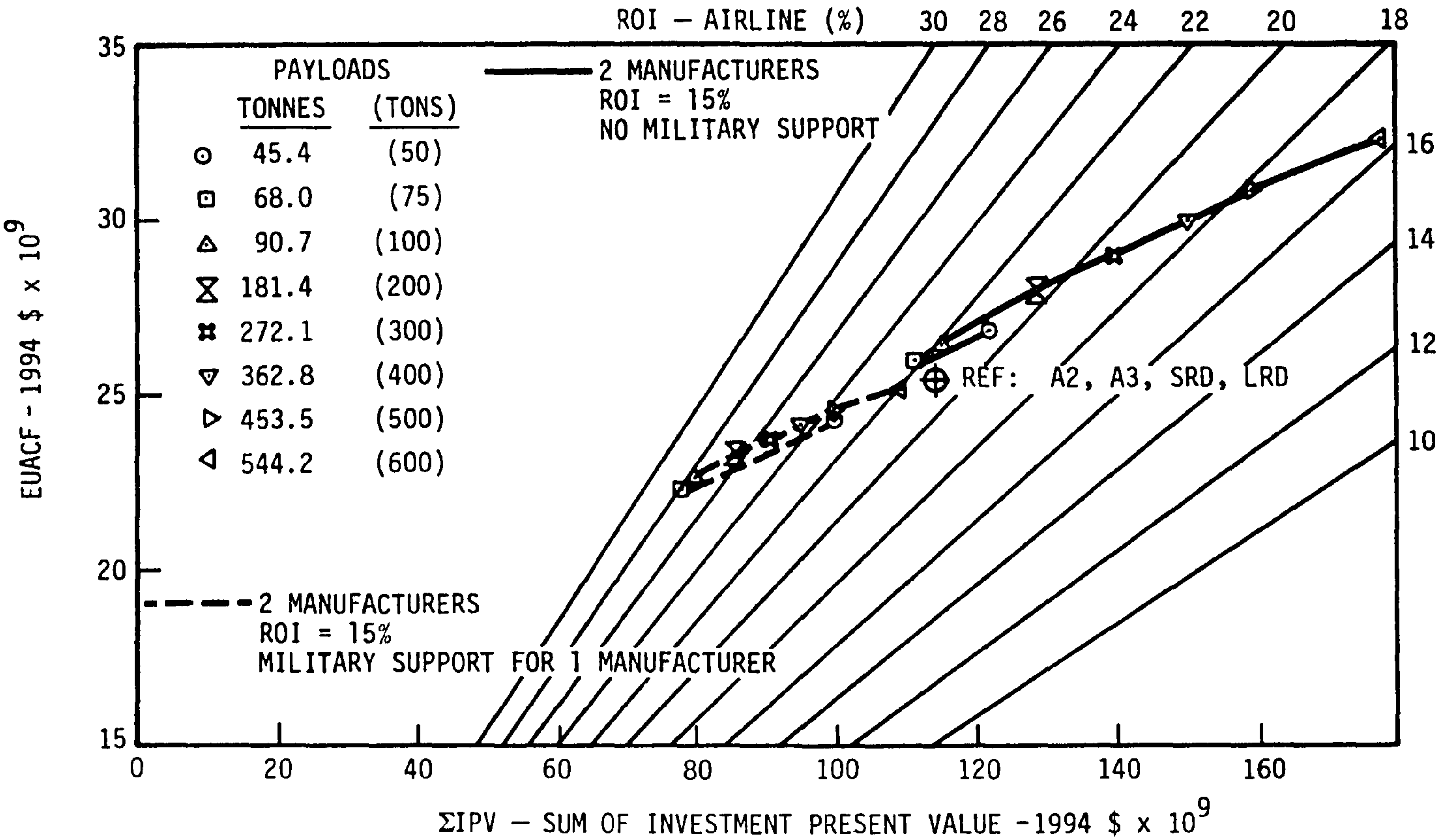


FIGURE 9-21. IMPACT OF MILITARY SUPPORT ON ALR DEDICATED FREIGHTER ECONOMICS

economics to payload size. For the 149.7 tonne (165 ton) payload ALR_2, military participation increased the airline ROI 6 percent and the cash flow was decreased 17 percent with the latter being primarily due to the 33 percent decrease in investment. The operating income which is a function of airline trip cost remained unchanged. With military participation, the fleet economics of 453.5 tonne (600 ton) payload aircraft were essentially as good as those for the 45.4 tonne (75 ton) aircraft developed solely by the commercial industry. The 149.7 tonne (165 ton) payload ALR_2 aircraft developed with military participation provided an airline ROI 5.6 percent higher and an investment 27 percent less than the reference fleet.

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