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# NASA Technical Memorandum 78774

## CHARACTERISTICS OF FUTURE AIR CARGO DEMAND AND IMPACT ON AIRCRAFT DEVELOPMENT (A REPORT ON THE CARGO/LOGISTIC AIRLIFT SYSTEMS STUDY (CLASS) PROJECT)

(NASA-TM-78774) CHARACTERISTICS OF FUTURE  
AIR CARGO DEMAND AND IMPACT ON AIRCRAFT  
DEVELOPMENT: A REPORT ON THE CARGO/LOGISTIC  
AIRLIFT SYSTEMS STUDY (CLASS) PROJECT (NASA)  
45 p HC A03/MF A01

N78-33061

Unclas  
33837

CSCL 01C G3/03

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OCTOBER 1978

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Space Administration

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CHARACTERISTICS OF FUTURE AIR CARGO DEMAND  
AND IMPACT ON AIRCRAFT DEVELOPMENT

(A Report on the Cargo/Logistic Airlift Systems Study (CLASS) Project)

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Introduction

Air cargo in the last 20 years has grown at a rate greatly exceeding that of surface freight modes, and existing world air cargo market forecasts from the major airframe manufacturers predict a continued growth rate ranging from 7 percent to 11 percent per year over the next decade. While such growth is significant, the resulting level of commercial activity would probably not be sufficient to support the development of a dedicated freighter aircraft before the year 2000. These forecasts are based on historical trends in airfreight traffic and world economic conditions and assume no major reductions in overall shipping costs such as might be achieved through dedicated freighter design, economies of scale, and more efficient interface between the ground operations and the surface modes. Projections from historic data thus do not reflect potential market penetration into routine mass shipments that may be possible with an advanced intermodal airfreight system.

Discussions with the shipping and transportation industry generally appear to support the contention that a substantial growth in airfreight volume is possible if an advanced dedicated freighter design is carefully tailored to an integrated freight transportation system. However, the rate of application of technology developments to commercially effective systems will be strongly influenced by the evolutionary growth of the total operational environment. The design specifications for the aircraft thus represents only one of the requirements for an optimized distribution network.

To evaluate the future potential for an advanced air cargo transport, NASA formulated a study entitled "Cargo/Logistics Airlift Systems Study (CLASS)." Two separate contracts were funded. The Lockheed-Georgia Company teamed with Trans-World Airlines (ref. 1) and the Douglas Aircraft Company joined forces with the Flying Tiger Line, (ref. 2), an all-cargo carrier. Each team expended over 10,000 man-hours on this study to obtain survey data, reports, and qualitative assessments from shippers; consignees; airport authorities; air, sea, rail, and motor carriers; and freight forwarders. The objectives of the CLASS project are enumerated in figure 1. An industry/government review committee monitored the progress of this project since its inception. This committee had representation from a major shipper, DOT, NASA, and the USAF Military Airlift Command.

This paper is divided into five major sections:

- (a) Comparison of Contractor Methods
- (b) Current Operations Analysis
- (c) Case Studies
- (d) Demand Forecast
- (e) Advanced Air Cargo Systems Analysis

### Comparison of Contractor Methods

Two separate contracts were awarded for the CLASS project because the proposals offered by the Lockheed and Douglas teams were comprehensive yet differed significantly in the study approach. An outline of the two methodologies is given in figure 2. Lockheed's approach centered around the Case Studies task (shown in heavy outline) in which the survey respondents were first exposed to the 1990 Scenario. This scenario was developed in consultation with the Department of Transportation and NASA and included a general description of the world economic condition and a projection of the cost and performance characteristics of all freight transportation modes and supporting infrastructure in the year 1990. The Demand Forecast, the next task in the block diagram of figure 2, was then derived by combining the results from the Case Studies with macro freight transportation statistics. The Analysis of Advanced Systems task developed an optimal air transportation system around the demand derived from earlier phases of the study. The Current Operations Analysis simply documents current airfreight operations and provides a contrast to the advanced system. In this approach, then, the emphasis was on user response to a new, more efficient and cost-effective air cargo service.

In contrast, a heavy emphasis in the Douglas approach was on the Current Operations Analysis which involved extensive field surveys at terminals and airports followed by a thorough analysis and interpretation of the air system as it functions in mid-1978. The Case Studies and the 1990 Scenario were developed from this evaluation of the current operation. Douglas thus traced the potential evolutionary development that could lead to an advanced air cargo system, with attributes not postulated before the case studies but determined by the execution of the study. The Douglas approach thus has the advantage of incorporating more of the realism offered by today's system and its major operators, but could neglect the potential "breakthrough" benefits of the system described by Lockheed if it could be brought to fruition.

### Current Operations Analysis

An outline of the subject areas covered in the analysis of current operations is shown in figure 3. Both domestic and international operations were reviewed. The extensive data sources used by the contractors in the CLASS project are shown in figure 4 for the domestic operations and in figure 5 for U.S. international and foreign markets. Because of time and space limitations, only a few pertinent findings will be mentioned in this report; the reader is referred to the complete CLASS reports for more detail.

Traffic structure. - To characterize the domestic capacity offered in 1977, figure 6 shows the all-cargo flights inbound and outbound for six major U.S. cities. New York, Chicago, Los Angeles, and San Francisco are seen to dominate the system. Traffic generated in 1976 for the ten major international routes by the carrier members of the International Air Transport Association (IATA) is shown in figure 7(a). Note that the ten routes shown account for over 90 percent of all international freight traffic handled by IATA carriers. Five of these routes are shown on a world map on figure 7(b) to indicate the geographical coverage provided by air cargo and to indicate the routes with the heaviest cargo flow in 1976. The North Atlantic routes shows the heaviest air cargo traffic.

Modal cost comparisons. - Figure 8 provides another illustration of the results of the analysis of current operations. Working with the Transportation Systems Center of DOT and utilizing its own operations data, the Flying Tiger team assembled this modal cost comparison. These total transportation costs include line haul, terminal and pick up, and delivery charges, and are based on 1977 data. Payload data are all converted to a common density of 115.7 kg/m<sup>3</sup>. A second adjustment is made to the data to account for circuitry in which aircraft are assumed to travel along great circle segments (air circuitry factor, C = 1.00). These two alterations permit a realistic comparison of the three modes, and the modifications result in a substantial benefit to the air-mode line-haul costs. Thus, in contrast to contemporary thinking, for a typical stage length the air line-haul costs are only 32 percent higher than truck line-haul costs. A rather startling finding is the significantly higher air terminal costs when compared to either truck or rail terminal costs. Labor costs represent over 90 percent of the terminal costs for both air and truck operations, but air terminal labor costs are over 3 times that for truck terminals. Reasons for these high air costs will be reported in the next section on Terminal operations. In the comparison of air total costs with ocean vessel costs, the study indicates that for the US-UK route (5376 km.), the 747-F has total costs 2.1 times that for a 1250 TEU (20-foot equivalent unit) container-ship. Aircraft fuel costs per tonne are five times the value for the ship and air capital costs are about twice ship capital costs.

Terminal operations. - Airport surveys were conducted at sixteen cities, representing both domestic and international operations (figure 9). Limited information was obtained for all the airports, and detailed data and findings were reported on the five domestic airports visited by Douglas. Each site was examined for operational efficiencies, landside access, saturation, growth potential and constraints on operations or growth due to institutional restrictions such as curfews. Most major U.S. airports have ground access problems which reduce the speed advantage offered by the air mode. Expansion of cargo facilities and even repair of existing capabilities has been hampered if not terminated by environmentalists and no-growth interest groups. Many terminals were found to have inadequate staging, make-up and storage facilities, and expansion at many of the existing sites is precluded.

Terminal costs are a function of the type of commodity, the weight of the shipment, and the number of pieces in the shipment. Since the study results show that 75 percent of all shipments weigh less than 90 kg (200 lbs) (and 85

percent of all pieces weigh less than 25 kg), the high terminal labor costs for the air mode can begin to be understood. Terminal costs can be substantially reduced by greater use of large containers that are consolidated by the shipper; CLASS results show that the cost per unit weight for terminal labor for a 4540 kg (10,000 pound) container is less than 10 percent of the labor costs for handling a 5-piece, 227 kg (500 pound) shipment. In addition to the small size of aircraft shipments, other factors contributing to high air terminal costs include the unusual contours and non-uniformity of air containers, air terminal peaking, and aircraft loading problems including balance and weight considerations. These problems are either unique to the air mode or are particularly severe compared to surface mode terminal operations.

The relative degree of terminal mechanization was studied with the role of the unit-load device (ULD) becoming a central issue. A great diversity was found to exist in levels of mechanization, productivity, and operating capacity. Terminal productivity varied considerably among facilities of equivalent mechanization, indicating differing levels of efficiency. Automation in a true sense is not likely to be achieved because of the package diversity and small shipments handled currently by the carriers. Only with the advent of larger and more standardized ULD's will a higher degree of mechanization likely be achieved. While mechanical hardware presently in existence will be the mainstay of terminal operations through 1990, greater efficiencies (and higher customer satisfaction) will be achieved with the application of computers to the terminal documentation and control functions.

Containerization. - The surveys also examined the role of unit-load devices, both containers and pallets. Carriers generally indicate a preference for ULD type depending on their mode of operation; a CLASS economic analysis indicates, for example, that longer range operations generally favor pallets over containers. This mixed usage deters standardization which is one of the requirements to reduce cargo handling costs. Standardization of ULD's also facilitates interlining, and would pave the way for advanced mechanized equipment. The CLASS study results suggests that there may be a move developing toward container leasing, as exemplified by American Airlines initiating a leasing agreement in March 1977 with Container Transport International for 25 8x8x20 foot units. In addition to promoting standardization, leasing will reduce carrier capital costs and reduce logistic control problems. The carriers are burdened currently with poor utilization of container volume, with an average 54 percent volume utilization. The most frequently used container is the type A "Igloo" accounting for 50 percent of all ULD usage. This is a main-deck container contoured to fit narrow-body aircraft. The wide-body aircraft lower deck container, the LD-3, is the second most popular ULD, representing 25 percent of ULD movement. Additional conclusions on containerization are included in the section on Case Studies.

Institutional factors. - One of the CLASS objectives was to review the institutional issues to assess the influence on future air cargo operations. In addition, the contractors offered their judgment on the results of possible future changes in regulations. These institutional and regulatory issues will have a direct impact on future freighter development and on the economy of operations. Information from both studies identifies three major AACs

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(Advanced Air Cargo System) "issues" in figure 10. Here it is assumed that if civil operating costs increase or capital becomes more difficult to acquire due to an "institutional" change, then the viability of a new aircraft purchase by the carriers diminishes. Likewise, regulation can also affect the prospects for all-cargo airports.

Four institutional issues have been defined on the left side of figure 10. Under curfew restrictions, if modifications to existing aircraft are required and new designs are forced to meet the newer, more challenging noise restrictions, then the fuel efficiency will be degraded. If flight schedules are dictated by worldwide curfews, aircraft will have lower utilization, thereby increasing operator's cost. These environmental pressures will diminish the appeal of carriers in the capital markets when new aircraft funding is required. On the other hand, the threat of curfews could have a favorable effect in justifying the concept of an all-cargo airport removed from some or all of the environmental restraints imposed on current passenger airports.

The effects of deregulation can only be surmised at this point, but educated guesses can be offered. According to CLASS analysis, free entry of carriers into the market will probably lower load factors and raise operating costs for existing carriers, at least in the near future. The unstable investment environment introduced by free entry may discourage lenders due to their increased risk. Capital, when available, will be priced according to the risk. Douglas projects, however, that capital scarcity will be a short-term problem, and that once equilibrium is reestablished following initiation of free entry, the competitive environment will attract investors. Without regulation, the carriers can tailor their service to the customer. Finally, free entry will increase congestion in major hub cities and force some carriers to consider dedicated airports. Pricing freedom and the removal of aircraft size limitations for commuter carriers will have mixed effects which are difficult to gauge.

Many communities have placed restrictions on the growth and/or improvements to their airport facilities. This action is seen to lend more credence to the establishment of new locations for cargo terminal operations.

Either vertical modal integration (multi-mode ownership and operation) or horizontal modal integration (one carrier absorbing others of the same mode) will increase total system efficiency by improved utilization of aircraft, reduced terminal costs, and higher route optimization. A favorable effect is noted for operator costs and capital acquisition where regulations are eased to permit either vertical or horizontal mergers. Transportation companies comprised of several merged operations would have a larger capital base and would represent more lucrative support for new freighter purchases.

Summary of current operations analysis. - A summary of the analysis of the current air cargo system is presented in figure 11. Airfreight remains a specialized, small shipment service. All-cargo service offered to the shipper is spacially and temporally erratic and although there is widespread capacity

offered in the world, roughly one-half of that capacity is in the belly pits of passenger aircraft. Air cargo traffic represents a very small percent of total freight carried by all modes. Because of the specialized service role of today's air cargo operation, the current market is essentially service sensitive rather than price sensitive. The largest competitors for airfreight are the less-than-truckload (LTL) and the ocean container operations. There is a wide variety in sophistication and degree of mechanization in cargo handling at the airport terminals. Terminal operations are highly labor intensive and because of several problems currently unique to air operations, air cargo terminal costs are over three times the terminal costs for truck or rail. Expansion in capacity of U.S. terminals and major airports is constrained by lack of capital, fixed airport boundaries, and environmental and institutional factors. Poor cube utilization of containers degrades the profitability of the carriers.

### Case Studies

The issues to be addressed in the Case Studies task are outlined in figure 12. The two contractors used different survey techniques and instruments in accomplishing these objectives and the results of the case studies were put to different use. The final results of the two contractor studies reflect these differences, as will be shown. The survey field is shown in figure 13 to include shippers and consignees, all carrier modes, and freight forwarders.

The survey methods employed by the contractors are also shown in figure 13. Flying Tiger planned and carried out the case study activity for the Douglas CLASS team. Tiger produced and mailed a 5-page survey form which was completed and returned by 551 organizations. This mail survey documented industry response to a number of critical operational issues such as mode choice criteria, centralization of the decision process, the use of information and accounting systems in the mode selection, and the perception of air cargo service. Tiger also visited 33 organizations for open-ended, in-depth interviews.

Lockheed first developed a booklet describing the 1990 scenario and the projected characteristics of the advanced air cargo system (AACS) concept. This complete booklet is included as an appendix in reference 1. The conceptual framework of this AACS as postulated by Lockheed is as follows:

- o The AACS will be available in the 1990's.
- o The AACS will utilize advanced-technology airfreighters optimized for cargo carriage.
- o The advanced airfreighter will serve major domestic and international trade routes, primarily at distances of 800 miles or greater.



- o Regional cargo airports may be separated from congested passenger airports and may, in some cases, utilize military airfields under joint tenancy arrangements.
- o The AACCS will provide coordinated surface-to-air-surface operation in which the motor carrier industry will perform connecting services between the air mode and shippers/consignees as well as connecting services with rail and water modes.
- o A family of all-mode cargo load devices (containers and/or trailers) will have been developed which are suitable for both air and surface use. These load devices will be interchangeable among all modes and not captive to any single mode.
- o Surface carriers have the option of offering the air service to their customers as a segment in a door-to-door through movement, both domestically and internationally.
- o The AACCS will allow shipments to be packed in truckload or container-load lots by shippers, forwarders, and surface carriers without necessity for additional consolidation or break-bulk processing at the airport.
- o Tariffs for intermodal service, including the air segment, will be established on a door-to-door basis covering the total freight movement. A single bill of lading and master waybill will be utilized for the entire movement.
- o No significant regulatory constraints will act to retard system development or use. Future regulatory reforms may permit formation of multimodal transportation consortiums if necessary to achieve full efficiency of an integrated intermodal system.
- o The cumulative effect of direct cost savings related to application of advanced design concepts, indirect cost savings for intermodal containerized operations, and shared cost through the Civil Reserve Air Fleet program has the potential for significant reductions from current air-freight rates.

After absorbing this descriptive material to provide the proper background, the shippers then filled out three booklets to respond to the issues enumerated in figure 12. The carriers responded to a separate carrier booklet after reviewing the scenario document. Each respondent was subsequently visited for a personal interview to go over the response in the booklet and to solicit any qualitative judgments. The 38 shippers and consignees visited by Lockheed are listed in figure 14(a). Most of these firms are prominent in their industry; 65 percent of these companies have annual sales exceeding \$1 billion which places them in the upper half of the Fortune 500 Industrial Companies list. The Case Study surface carriers contacted by Lockheed are listed in figure

14(b). The prime interest in surface carriers was their potential use of the air mode as a substitute service. Finally, in figure 14(c) the product lines represented in the Lockheed survey field are identified to indicate the diversity of commodities requiring transportation by the survey companies.

The economics of air cargo can often be shown to be competitive with the surface modes when all costs of distribution are calculated. The CLASS case studies indicated, however, that the shipper community has not universally accepted the concept of Total Cost of Distribution (TCD). The data necessary to evaluate the various elements of TCD are difficult and costly to derive in some cases. Furthermore, transportation decision-makers are often suspicious of the validity of inventory carrying costs. The decision process is usually decentralized with the transportation manager's performance being measured against his transportation budget. The manager's objective, then, is to minimize transportation costs, not all of the costs of distribution.

The survey respondents indicated a strong bias toward an intermodal airfreight system, primarily because of its service appeal with door-to-door delivery and single carrier responsibility (intermodalism is also a key factor in the promise of better economies in the 1990 system). Douglas estimates the need for 20,000 8x8x20 advanced air containers by 1990. The shippers were not satisfied with today's air containers, however, with most unfavorable comments relating to size and shape. The lower deck ULD's were too small and the igloo containers are poorly shaped for handling outside the airport environs.

The present barriers to increased airfreight use are found to be lack of service rather than rate incompatibility with the surface mode competition. Inadequate pick up and delivery service and poor ground handling were cited as deficiencies in present air cargo operations. Restricted geographic coverage by all-cargo service inhibits many shippers. The issue of cost sensitivity vs. service sensitivity can be illustrated by the sketch in figure 15. The survey results confirm the basic service sensitivity of the 1978 market demand as shown on the top block of the sketch. Demand is relatively inelastic to modest changes in airfreight rates. As the service and capacity demands are fulfilled by a growing air cargo industry, rate decreases will begin to generate additional demand. The market will attract an increasing proportion of routine, cost-sensitive shipments which by 1990 will represent a major share of total demand. The emergency, specialized traffic will grow only in response to increased demand for overall freight transportation as generated for example, by higher GNP.

Another product of the case studies is shown in figure 16 which summarizes the shipper and consignee opinion on the timing of the need for the advanced air cargo system. About 50 percent of the 28 respondents (N = 28) would like to have the AACS operational by 1985.

### Demand Forecast

The first step in analyzing the potential and the timing for new freighter development is the derivation of a traffic forecast. The two CLASS contractors obtained their estimates by substantially different methods as detailed in figure 17. Douglas developed a sound data base for current operations, including regional traffic flows (city-pair and country-pair) for the U.S. domestic, U.S. international, and 44 foreign carrier markets. Next, a series of econometric behavioral equations were developed for each major market segment. As illustrated in figure 17, these projections incorporate judgments on GNP, inflation, currency rate variation, and historical trends for the U.S. and 31 major foreign countries. Forecasts for these different scenarios were projected for each of three aggregated regions: U.S. domestic, U.S. international, and 44 foreign carriers. For the U.S. domestic market, the mid or baseline scenario was based on a constant value through 1990 of the price ratio of air to motor freight. The lower and higher estimates were based on a 2 percent per annum increase and decrease respectively, in this price ratio. For the U.S. international and foreign carrier market, the baseline projection was based on 1976 airfreight yield held constant through 1990. Lower and upper estimates were established by assuming a 2 percent per annum increase and decrease, respectively, in yield. To obtain the demand for all-cargo service (since the economic projections represent total air cargo), Douglas subtracted a fixed 43 percent from these figures to represent belly freight on passenger aircraft. This figure was derived from CAB statistics which showed that 43 percent of total air cargo moved in the passenger aircraft lower decks in 1976.

Lockheed's approach is illustrated in the lower part of figure 17 for the domestic demand calculation. The total freight traffic projection for all modes through the year 2000 was obtained from Department of Transportation sources. The estimate for 1990 total demand were first diminished by inland waterway and pipeline carriage of very low value bulk commodities. The remaining commodities moved by air, rail, and truck were next reduced by eliminating all but manufactured goods. The resulting traffic figure was further diminished by subtracting all traffic moving less than 1287 km (800 miles) (the 1972 Census of Transportation revealed that for manufactured goods 72 percent of rail tonnage and 95 percent of truck tonnage moved less than 800 miles), and by subtracting all freight generating yields less than 2¢/revenue tonne-km (3¢/ton mile). This final figure is denoted the "air penetrable universe." The degree of penetration of this universe was obtained from the case studies and will be shown on the next figure. The final step was to subtract the belly freight forecast obtained by the Air Transport Association (ATA) to obtain the Advanced Air Cargo System (AACS) demand.

Using the Lockheed approach the percent of routine use of the advanced air cargo system (AACS) as a function of the percent reduction of AACS rates from current air systems was obtained from the case study results and is shown in figure 18. For a proposed 45 percent rate reduction, the respondents

indicated an average figure of 19 percent of their regular freight would move by the AACS. This penetration then allows the calculation of the AACS traffic forecast for 1990. The demand level calculated from the case study results is very close to the demand determined from a Lockheed yield correlation based on historical data.

The 45 percent rate reduction is perhaps overly-optimistic and is partly based on preliminary technical and economic studies reported in references 3 and 4. The aircraft operating costs reported in these references were placed on a common basis and are shown in figure 19. The 1995-technology spanloader concept offers about a 56 percent reduction in total operating costs when full advantage is also taken of an intermodal system with a computerized control system.

The result of these dedicated freighter demand forecasts determined by both contractors is depicted in figure 20. High and low estimates are shown for domestic and international markets and, for reference, the actual 1977 data. The Lockheed high and low values are based on two different sources of overall international freight traffic growth (Organization for Economic Cooperation and Development (OECD) and Maritime Administration (MARAD)) and on two levels of penetration. Details of these demand determinations can be found in the published CLASS reports.

Both contractors allocated this projected traffic demand over major world market routes. The Lockheed distribution of their aggregated demand calculation is shown in figure 21 for both high and low AACS demand estimates and for the actual trade volumes over these routes in 1976. According to these figures, the major air cargo route will change from the North Atlantic in 1976 to the North Pacific in 1990, primarily due to increase in trade with Japan and Australia. Figure 22 shows this 1990 low demand prediction overlayed on a world map for the five routes with the highest cargo flow.

#### Advanced Air Cargo Systems Analysis

With the demand forecasts for major market segments as input, the next step in the CLASS project was to exercise route optimization and simulation programs to evaluate advanced aircraft concepts. These programs accept as input the demand levels, air cargo rates, aircraft performance characteristics, and frequencies. The outputs include fleet earnings, total costs, and optimum fleet mix. The application of these programs in the CLASS project is useful for evaluating the relative potential of advanced aircraft concepts, but not to predict which designs might move toward production.

As an example of the output of this exercise, figure 23 shows the calculated fleet mix for the foreign market from 1978 through 1991. It was assumed in this analysis that the conventional advanced design aircraft would be available in 1978. Industry concepts of such advanced conventional designs, but using 1985-technology, are shown in figure 24 with payloads exceeding the 747-F by factors of 1.3 to 1.6. The advanced unconventional aircraft could be represented by the

spanloader shown in Figure 25 (reference 3) which systems studies have addressed for payload capabilities exceeding the 747-F by factors of 2.5 to 5.0. Cost data for the large spanloader are shown in figure 19. The derivative aircraft are seen in figure 23 to drive the contemporary freighters out of the foreign market before 1990. The market requires 108 of these derivatives and by 1991 their number shows a decrease as a result of the increasing utilization of advanced designs in the system. A total of 78 large-capacity, advanced freighter aircraft are identified as needed to fulfill just the foreign market demand up to the year 1991. The U.S. and U.S. international markets will add to this fleet requirement for new freighter airplanes.

This phase of the study evaluated conceptual freighter designs in the derived 1990 markets which included foreign, U.S. domestic and U.S. international traffic projections. Assuming advanced designs are available for introduction in 1978, the results of the study are as follows:

- (a) Contemporary aircraft would be driven out by 1985-90.
- (b) Derivatives would capture a large part of the foreign market.
- (c) Large, dedicated freighters would appear only when cargo traffic has grown substantially higher than today's level.
- (d) Very large, unconventional aircraft (e.g., spanloader, multibody, etc.) would appear after 1990.

Another part of the analysis evaluated the potential advantages of the hub-spoke network concept in solving back haul imbalances. Figure 26 gives the results of this example analysis for three trade routes involving the U.S. with France, Columbia, and Japan. The air cargo tonnes in the rectangles represent 1976 actual data, and the figure above the rectangle shows the existing back haul imbalance. Thus, the U.S. exports to France are shown to be 1.9 times the French imports to the U.S. With the hub system in operation, the data in the circles shows a better balance in the United States air cargo traffic with France and Columbia. However, the back haul imbalance ratio with Japan worsens under the hub system (excess imports over exports to U.S. changes from 2.2 to 2.5), but when the 1990 demand is examined (broken circles), the back haul imbalance ratio drops to an acceptable 1.3 in favor of U.S. exports. Further systems analysis of the hub concept can be found in reference 5.

#### Concluding Remarks

The "bottom-line" analysis presented in figure 27 summarizes many of the CLASS findings. The figure shows the effects of potential improvements on reducing costs. The six items broken into two time frames represent a reasonable consensus from the two contractor teams for improvements that can lead to an advanced air cargo system. The actual savings that can be achieved will be dependent on how the system evolves; the cost figures on the right side of figure 27 reflect the potential benefits for the system developed in the CLASS

scenario. Improvement to the current infrastructure can occur from 1978 to 1985 with off-the-shelf technology, which when combined with higher load factors for aircraft and containers, can provide up to a 16 percent reduction in total operating costs (TOC) and a 15 percent rate reduction. These benefits are derived primarily from a reduction in IOC (Indirect Operating Costs). Beyond 1985, with IOC reductions accomplished, there will be a greater emphasis on DOC (Direct Operating Cost) reduction. Because advanced freighter concepts will only represent part of the freighter fleet, the total system benefit will be reduced, with only a 3 to 6 percent reduction in rates directly traced to the advanced aircraft. However, the economy of scale and aircraft/airport compatibility benefits are partly attributed to the introduction of advanced freighters which have full intermodal capability and are designed to facilitate the cargo loading process.

A 4 percent rate increase was considered as needed to stabilize the earnings of the cargo carriers. The final net rate reduction from 21 to 24 percent is postulated. Future profit levels will have to increase to induce the capital investments required to serve a greatly expanded air cargo market. The trend to the mid-1980's could be toward modest rate reduction, increased carrier profits, and a proliferation of incentive tariffs directed toward increasing customer-loaded containers, terminal productivity, and container volumetric utilization.

In Douglas' evolutionary approach toward evaluating the future market demand, the econometric projections shown in figure 20 do not include the effects of market stimulation made possible by a higher level of service and lower rates indicated by the analysis in figure 27. Since Lockheed's demand levels in figure 20 include benefits of stimulation through advanced technology and improvements to the infrastructure, a final comparison should include the effects of stimulation on the Douglas projections. The adjusted data for Douglas are shown on figure 28 as the upper, solid line; the dashed line represents the earlier, non-stimulated projection. The 19½ percent increment added to the lower Douglas estimate results from the implementation of the 1978-1985 benefits listed on figure 27. A higher increment of 23.4 percent is applied to high forecast to include two items from the 1985-1990 list, economies of scale and airport compatibility. The Douglas analysts have not included the possible stimulus from the introduction of advanced freighters because from their study findings, such aircraft would not be introduced until after 1990.

The CLASS analysis suggests that the proposed changes in the infrastructure and improved cargo loading efficiencies are as important to improving the airlines' financial posture as is the anticipated large, dedicated cargo aircraft. Without the efficient intermodal capability and the efficient ground systems interface designed into advanced freighters however, tomorrow's air cargo system will not satisfy the shipper's demand for cost-effective, intermodal air cargo service.

## REFERENCES

1. Cargo/Logistics Airlift Systems Study (CLASS). Lockheed-Georgia Company. Volume I, NASA CR-158915; and Volume II, NASA CR-158916, 1978.
2. Cargo Logistics Airlift Systems Study (CLASS). Douglas Aircraft Company. Volume I, NASA CR-158912; Volume II, NASA CR-15813, and Volume III, NASA CR-158914, 1978.
3. Technical and Economic Assessment of Swept-Wing Span-Distributed Load Concepts for Civil and Military Air Cargo Transports. NASA CR-145229, 1977.
4. Olason, M. Lynn; and Reynolds, A. Dean: A View of Air Freight Developments in the Next Decade. Aeronautical Journal, vol. 80, July 1976, pp 294-302.
5. Whitehead, Allen H., Jr.: Preliminary Analysis of Hub and Spoke Air Freight Distribution System. NASA TM 72656, 1978.

## OBJECTIVES

- EVALUATE AND CHARACTERIZE PRESENT OPERATIONS
- CONTRAST AIR CARGO RATES AND SERVICE WITH SURFACE MODES
- EVALUATE INFRASTRUCTURE AND DISTRIBUTION SYSTEM REQUIREMENTS
- EXAMINE ROLE OF ADVANCED FREIGHTERS IN STIMULATING DEMAND
- ASSESS INSTITUTIONAL ISSUES
- ANALYZE 1990 MARKET POTENTIAL FOR AIR CARGO
- RECOMMEND NASA STUDIES AND RESEARCH AREAS

Figure 1. - Cargo/Logistics AirLift Systems Study (CLASS) objectives.



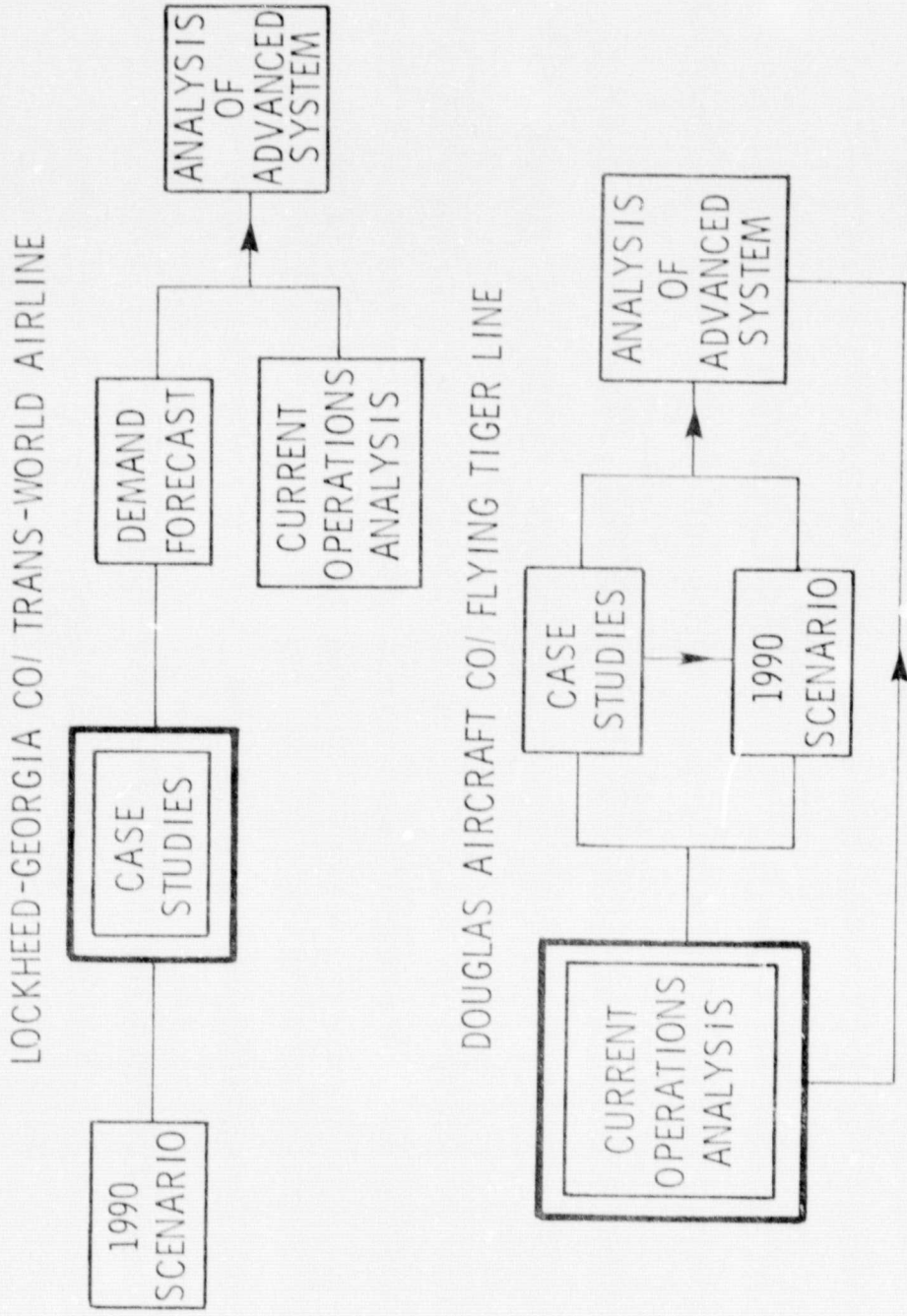


Figure 2. - Comparison of contractor methods.

- MARKET ROUTES (U.S. AND FOREIGN)
  - CITY-PAIR VOLUMES
  - COMMODITY FLOWS
  - CAPACITY OFFERED
  
- AIR ELIGIBILITY CRITERIA
  
- INFRASTRUCTURE
  - TERMINAL OPERATIONS AND PROBLEMS
  - AIRPORT ACCESS
  - AIRPORT CONSTRAINTS AND GROWTH POTENTIAL
  - UNIT-LOAD DEVICES / CONTAINERIZATION
  
- MODAL COMPARISONS
  - VOLUMES
  - RATES
  - SERVICE
  
- POLITICAL AND ECONOMIC FACTORS

Figure 3. - Current operations analysis.

- TRANSPORTATION ASSOCIATION OF AMERICA (TAA)
- DEPARTMENT OF TRANSPORTATION (DOT)
- CENSUS OF TRANSPORTATION
- AIR TRANSPORTATION ASSOCIATION (ATA)
- U.S. DEPARTMENT OF AGRICULTURE (USDA)
- FEDERAL AVIATION ADMINISTRATION (FAA)
- CIVIL AERONAUTICS BOARD (CAB)
- INTERSTATE COMMERCE COMMISSION (ICC)
- OFFICIAL AIRLINE GUIDE (OAG)
- DOUGLAS SHARED STATISTICS PROGRAM
- DOMESTIC CASE STUDY RESULTS

Figure 4. - Major data sources - Domestic.

INTERNATIONAL (U.S. AND FREE WORLD)

- DEPARTMENT OF COMMERCE (DOC)
- INTERNATIONAL AIR TRANSPORTATION ASSOCIATION (IATA)
- INTERNATIONAL CIVIL AVIATION ORGANIZATION (ICAO)
- ASSOCIATION OF EUROPEAN AIRLINES
- UNITED NATIONS (UN)
- OFFICIAL AIRLINE GUIDE (OAG)
- ORGANIZATION FOR ECONOMIC COOPERATION  
AND DEVELOPMENT (OECD)
- U.S. MARITIME ADMINISTRATION (MARAD)
- INTERNATIONAL CASE STUDY RESULTS

Figure 5. - Major data sources - International (U.S. and free world).

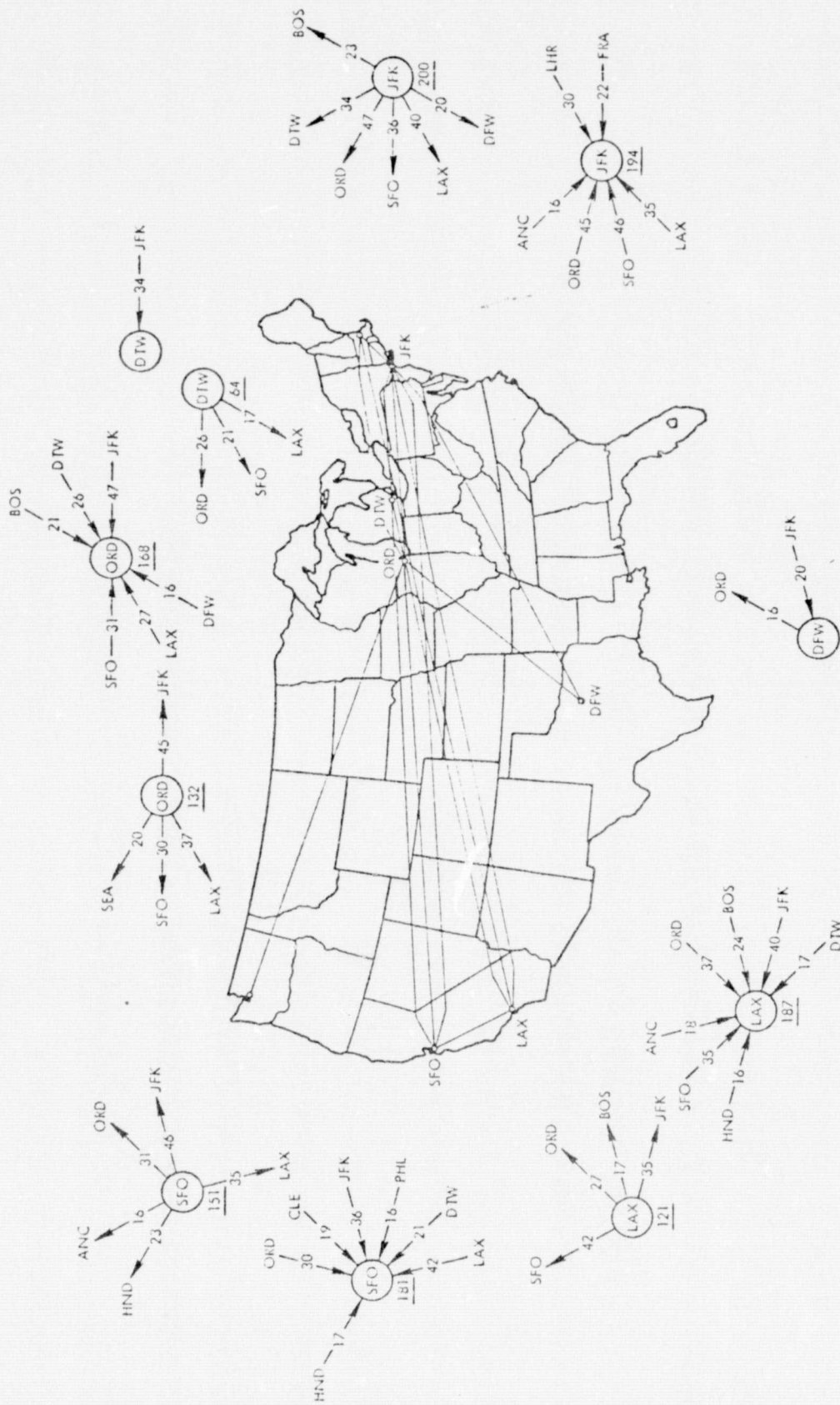


Figure 6. - All-cargo frequencies per week for six major U.S. cities.

TOTAL CARGO TRAFFIC = 11,542 RTK

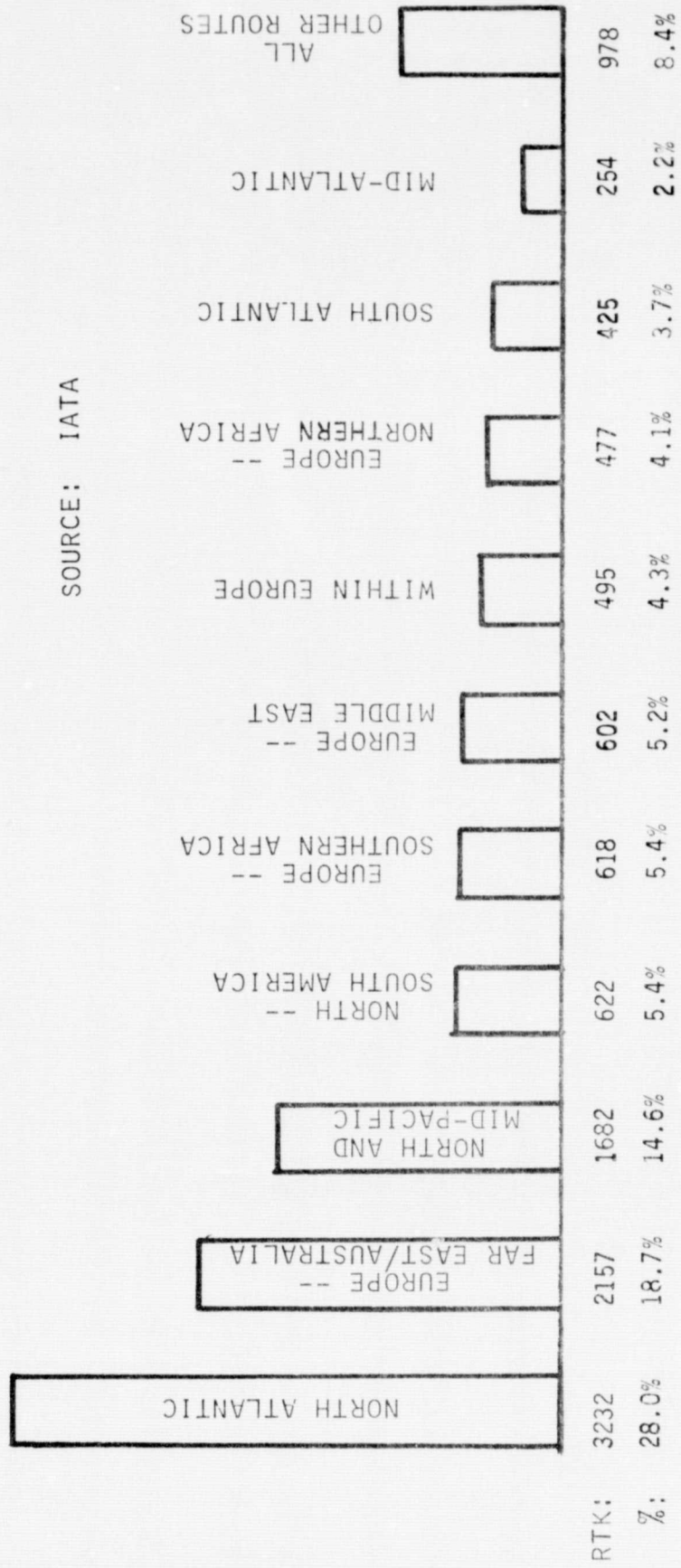
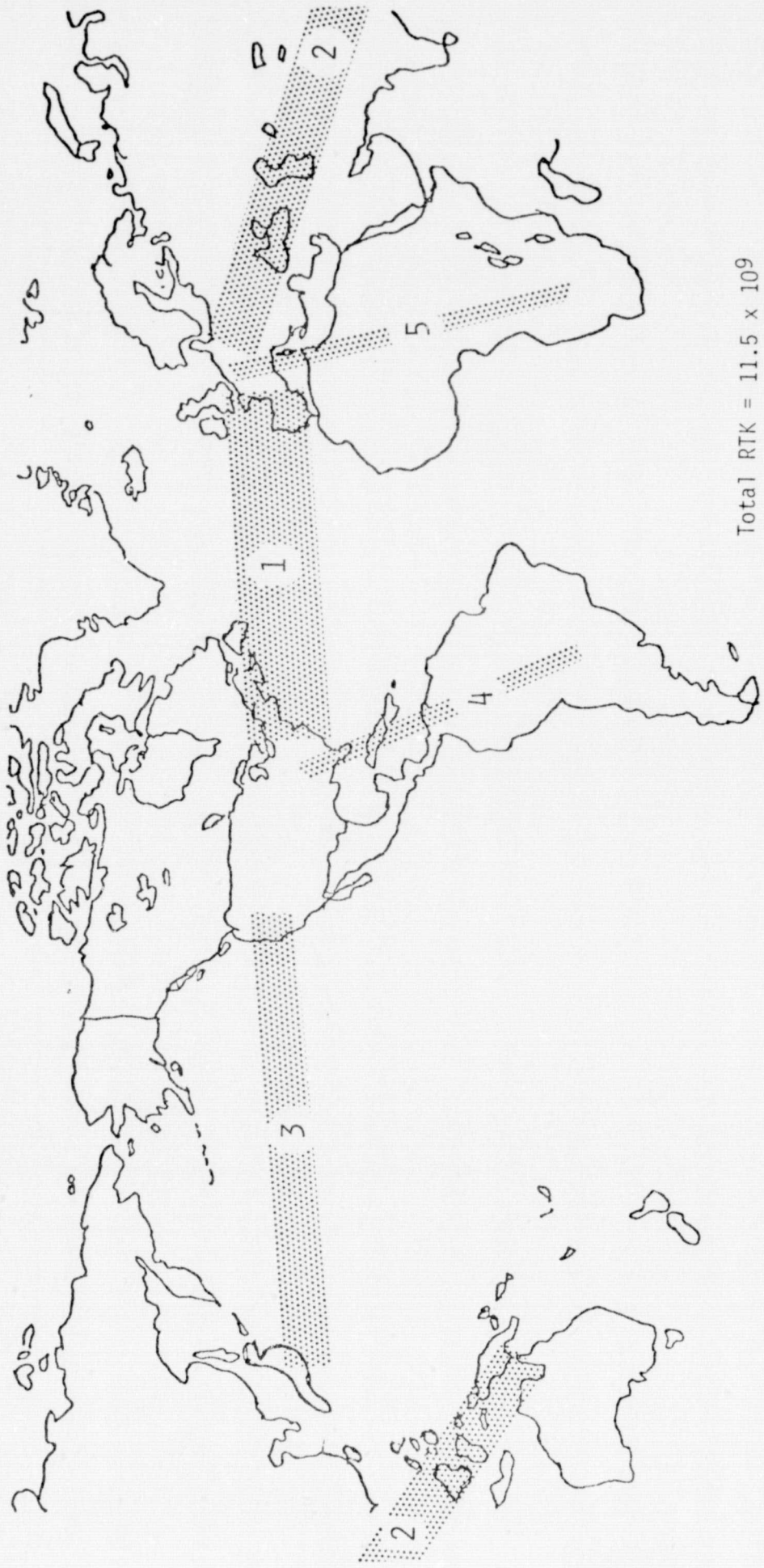


Figure 7(a).- Major international air cargo routes in 1976.



Total RTK = 11.5 x 109

Figure 7(b).- Major international air cargo routes. IATA carriers, 1976  
 (width of band proportional to cargo RTK's.

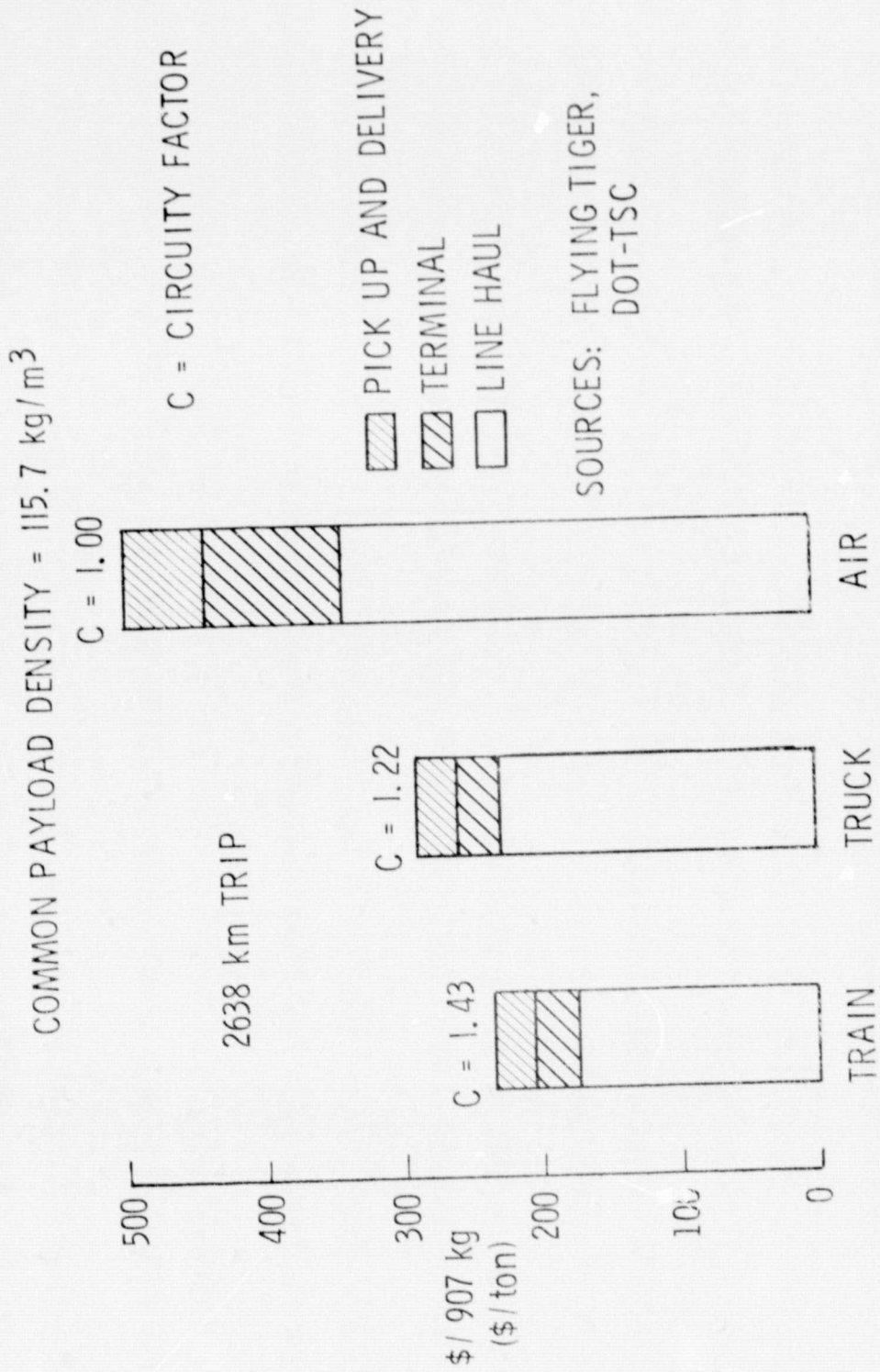


Figure 8. - 1977 modal comparison of transportation cost  
(adjusted for circuitry and payload density).



	DOUGLAS	LOCKHEED
<b>DOMESTIC</b>		
NEW YORK (KENNEDY)	✓	✓
CHICAGO	✓	✓
LOS ANGELES	✓	✓
DALLAS / FORT WORTH		✓
BALTIMORE		✓
MIAMI		✓
DAYTON		✓
ATLANTA	✓	
DETROIT	✓	
<b>INTERNATIONAL</b>		
LONDON		✓
FRANKFURT		✓
PARIS		✓
AMSTERDAM		✓
HONG KONG	✓	
TAIPEI	✓	
TOKYO	✓	

Figure 9. - Airport surveys.

INSTITUTIONAL ISSUE ↓ AACS ISSUE →	OPERATING COSTS	CAPITAL ACQUISITION	ALL-CARGO AIRPORTS
NIGHT AND NOISE RESTRICTIONS	●	●	○
DEREGULATION FREE ENTRY PRICING FREEDOM AIRCRAFT SIZE FREEDOM	● / ○ N ○	● / ○ N ○	○ N ○
AIRPORT GROWTH RESTRICTION	●	●	○
MODAL INTEGRATION (VERTICAL OR HORIZONTAL)	○	○	○

KEY: ○ STRONGLY FAVORABLE TO AACS      N - NEUTRAL      ● UNFAVORABLE  
 ○ MODERATELY FAVORABLE      ● MODERATELY UNFAVORABLE

Figure 10. - Impact of institutional issues on Advanced Air Cargo System (AACS).

## SUMMARY

- SPECIALIZED SERVICE (SMALL SHIPMENTS, PERISHABLES, TIME-SENSITIVE, HIGH VALUE, EMERGENCY, SEASONAL)
- WIDESPREAD AIR FREIGHT SERVICE THROUGHOUT WORLD
- SMALL PENETRATION OF TOTAL FREIGHT MOVEMENTS
- SERVICE RATHER THAN PRICE SENSITIVE MARKET
- LARGEST COMPETITORS: LTL AND OCEAN CONTAINER TRAFFIC
- WIDE VARIATION IN SOPHISTICATION OF CARGO HANDLING AND TERMINAL EFFICIENCY
- CONSTRAINED TERMINAL AND AIRPORT CAPACITIES
- POOR CUBE UTILIZATION OF CONTAINERS

Figure 11. - State of the current air cargo system.

- CURRENT DISTRIBUTION AND TRANSPORTATION OPERATIONS
  
- DECISION CRITERIA FOR SELECTING AIR MODE
  
- SENSITIVITY OF AIR MODE SELECTION TO
  - FREIGHT RATES
  - TOTAL DISTRIBUTION COST
  - SERVICE FACTORS
  
- DESIRED ATTRIBUTES OF 1990 ADVANCED AIR CARGO SYSTEM
  
- ESTIMATED DEMAND FOR ADVANCED AIR CARGO SYSTEM

Figure 12. - Case study issues.

SURVEY PARTICIPANTS

- SHIPPERS AND CONSIGNNESS
- CARRIERS - AIR, SEA AND LAND
- FREIGHT FORWARDERS

SURVEY METHODS

- FLYING TIGER (PART OF DOUGLAS TEAM)
  - FIVE -PAGE SURVEY 551 ORGANIZATIONS
  - IN-DEPTH INTERVIEWS 33 ORGANIZATIONS
- LOCKHEED
- DETAILED SURVEY BOOKLETS } 80 ORGANIZATIONS
- FOLLOW-UP INTERVIEW }

Figure 13. - Case study surveys.

ALLIS CHALMERS CORPORATION	GENERAL MOTORS CORPORATION
ALUMINUM COMPANY OF AMERICA	GOLD KIST, INC.
AMF, INCORPORATED	THE GOODYEAR TIRE & RUBBER CO.
BAXTER TRAVENOL LABORATORIES	GROWER-SHIPPER VEGETABLE ASSOCIATION
BECHTEL CORPORATION	HARNISCHFEGER CORPORATION
BLACK & DECKER MFG. CO.	HERCULES, INC.
BUD ANTLE, INC.	INTERNATIONAL BUSINESS MACHINES
J. I. CASE COMPANY	JANTZEN, INC.
CATERPILLAR TRACTOR CO.	MAINE RUBBER INTERNATIONAL
CELANESE CORPORATION	MCCORMICK & CO. INC.
CLARK EQUIPMENT CO.	MONFORT OF COLORADO
D. A. B. INDUSTRIES, INC.	J. C. PENNEY CO., INC.
E. I. DUPONT DE NEMOURS & CO.	RCA CORPORATION
EASTMAN KODAK CO.	SAFEWAY STORES, INC.
EATON CORPORATION	SAMSONITE
EX-CELL-O CORPORATION	SCOTT PAPER COMPANY
THE R. T. FRENCH COMPANY	TEXAS INSTRUMENTS, INC.
FOOD FAIR STORES, INC.	WESTINGHOUSE ELECTRIC CORP.
FORD MOTOR COMPANY	WHIRLPOOL CORPORATION

Figure 14(a). - Lockheed case study shippers and consignees.

MOTOR CARRIERS - GENERAL FREIGHT

ARKANSAS - BEST FREIGHT  
BN TRANSPORT, INC.  
CHIPPEWA MOTOR FREIGHT, INC.  
CONSOLIDATED FREIGHTWAYS CORP.  
COURIER-NEWSOM EXPRESS, INC.  
THE DAVIDSON TRANSFER & STORAGE CO.  
GATEWAY TRANSPORTATION CO., INC.  
IML FREIGHT, INC.  
NEUENDORF TRANSPORTATION CO.  
OVERNITE TRANSPORTATION CO.  
PACIFIC INTERMOUNTAIN EXPRESS CO.  
RIO GRANDE MOTOR WAY, INC.  
SHAY'S SERVICE, INC.  
UNITED PARCEL SERVICE  
WILSON TRUCKING CORPORATION  
YELLOW FREIGHT SYSTEM

MOTOR CARRIERS - SPECIAL COMMODITIES

A. J. METLER HAULING & RIGGING, INC.

MOTOR CARRIERS - HOUSEHOLD GOODS

ALLIED VAN LINES  
NORTH AMERICAN VAN LINES

AIRFREIGHT FORWARDERS

EMERY AIR FREIGHT CORP.

RAILROADS

BURLINGTON NORTHERN, INC.  
SOUTHERN RAILWAY SYSTEM

OCEAN CARRIERS

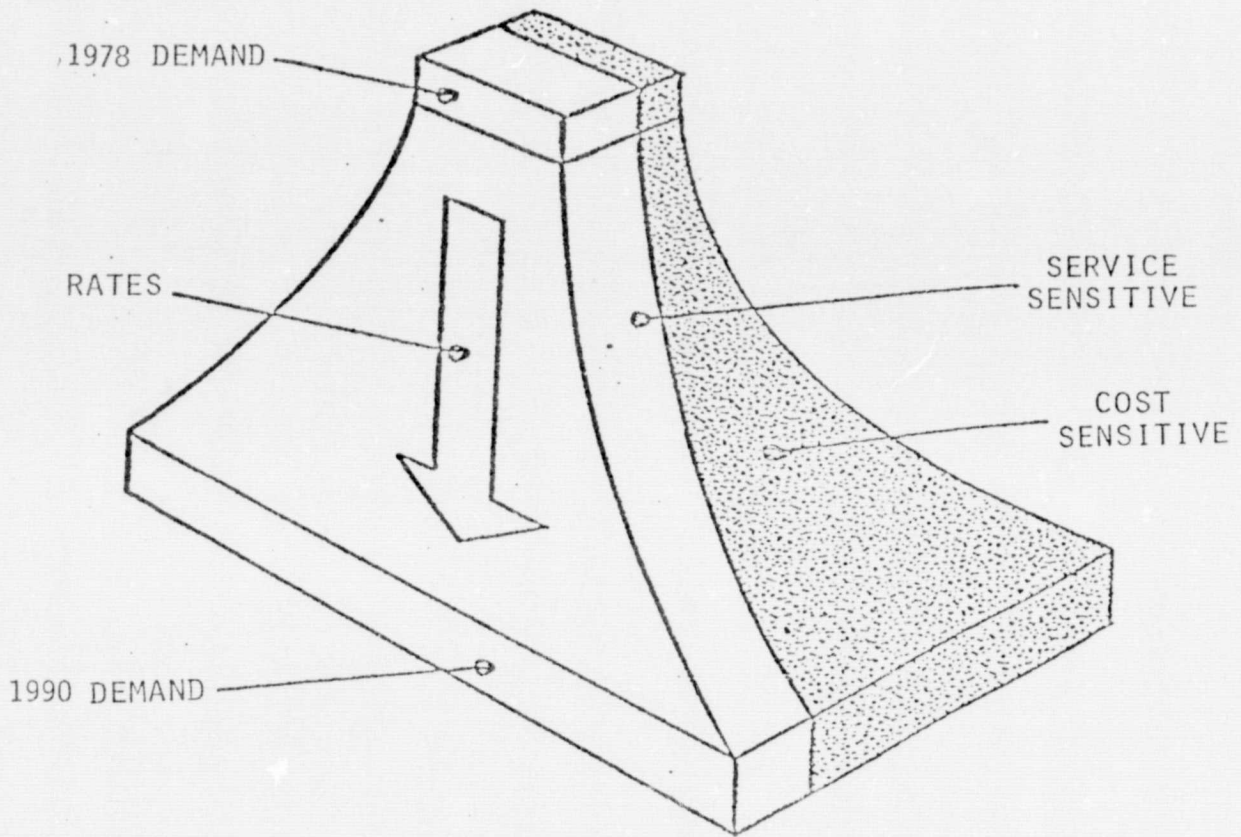
SEA-LAND SERVICE, INC.  
UNITED STATES LINES, INC.

Figure 14(b). - Lockheed case study carriers.

FRESH PRODUCE	FOOD PRODUCTS MACHINERY
LETTUCE	CONSTRUCTION EQUIPMENT
FRESH POULTRY	POWER TOOLS
FRESH MEAT	OFFICE MACHINES
PERISHABLE FOODSTUFFS	ELECTRICAL MOTORS
SPICES	ELECTRONIC COMPONENTS
SYNTHETIC TEXTILE FIBER	HOME LAUNDRY EQUIPMENT
WEARING APPAREL	MOTOR VEHICLES
PHOTOGRAPHIC PRODUCTS	AUTO/TRUCK PARTS
PIGMENTS	ENGINE BEARINGS
INTRAVENOUS SOLUTIONS	TIRES
LUGGAGE	MOTORCYCLES
COILED ALUMINUM SHEET	

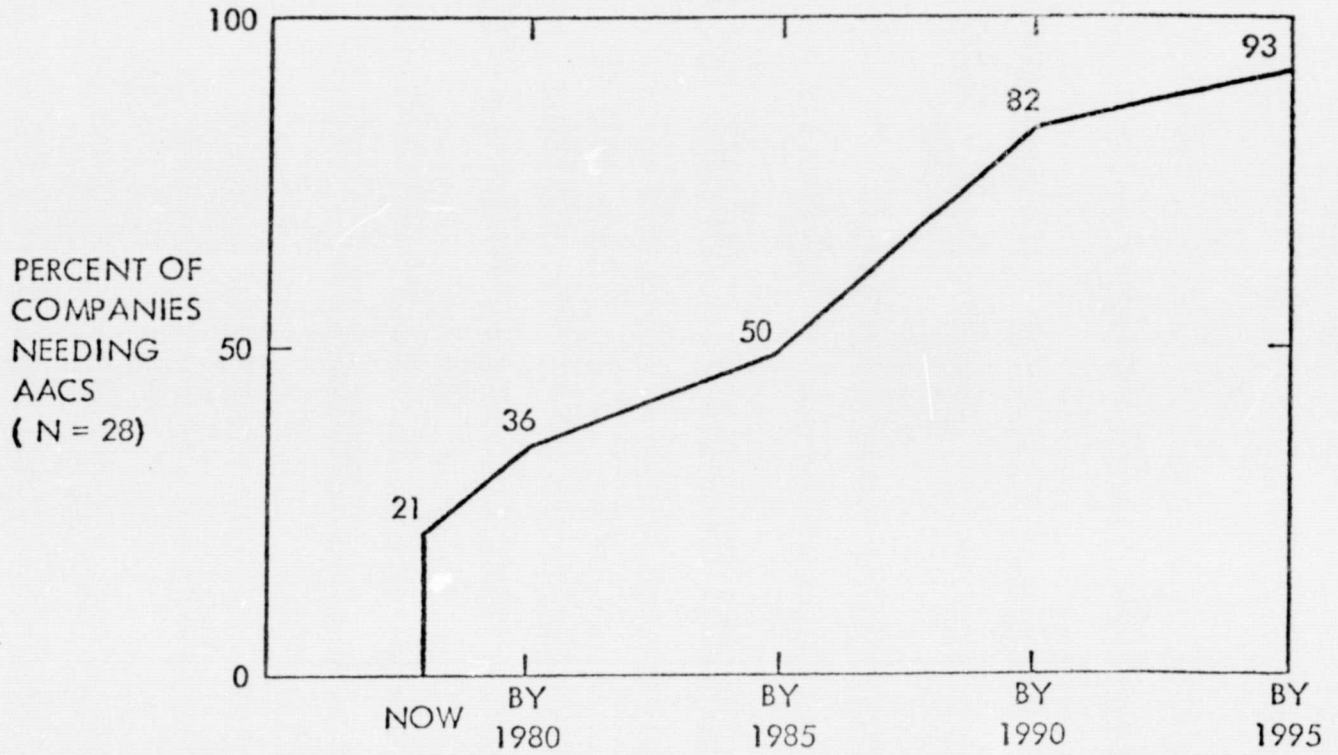
Figure 14(c). - Lockheed case study products.





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Figure 15.- Cost vs. service sensitivity.



N = NUMBER OF SURVEY RESPONDENTS

Figure 16.- Timing of need for Advanced Air Cargo System (AACS).

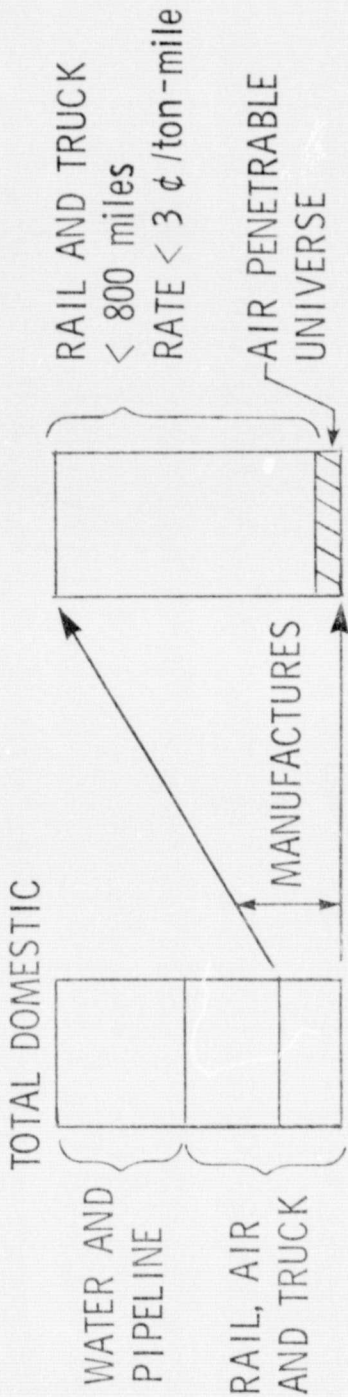
ADVANCED AIR CARGO SYSTEM (AACS)

DOUGLAS

1. ECONOMETRIC PROJECTION FROM 1977 DATA
  - FACTORS GNP, INFLATION, CURRENCY TRENDS, HISTORY
2. SUBTRACT 43% BELLY FREIGHT TO GIVE AACS DEMAND

LOCKHEED

1. DEFINE AIR PENETRABLE UNIVERSE FROM MACRO STATISTICS



2. PENETRATION FROM DOMESTIC CASE STUDIES
3. SUBTRACT BELLY FREIGHT FORECAST TO GIVE AACS DEMAND

Figure 17. - Derivation of 1990 demand and origin-destination flows.

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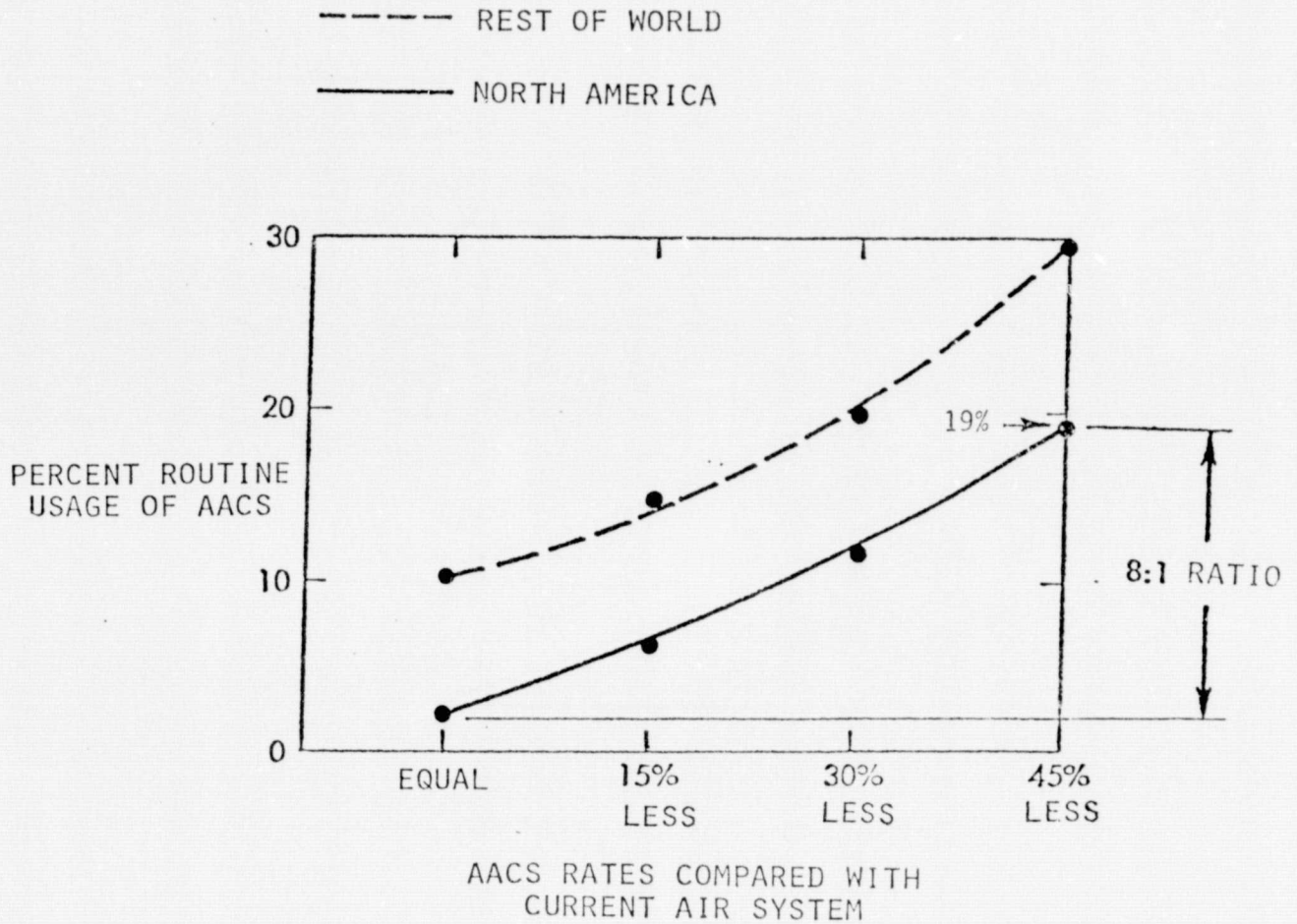


Figure 18.- Probable routine usage of advanced air cargo system by U.S. companies.

1975 DOLLARS

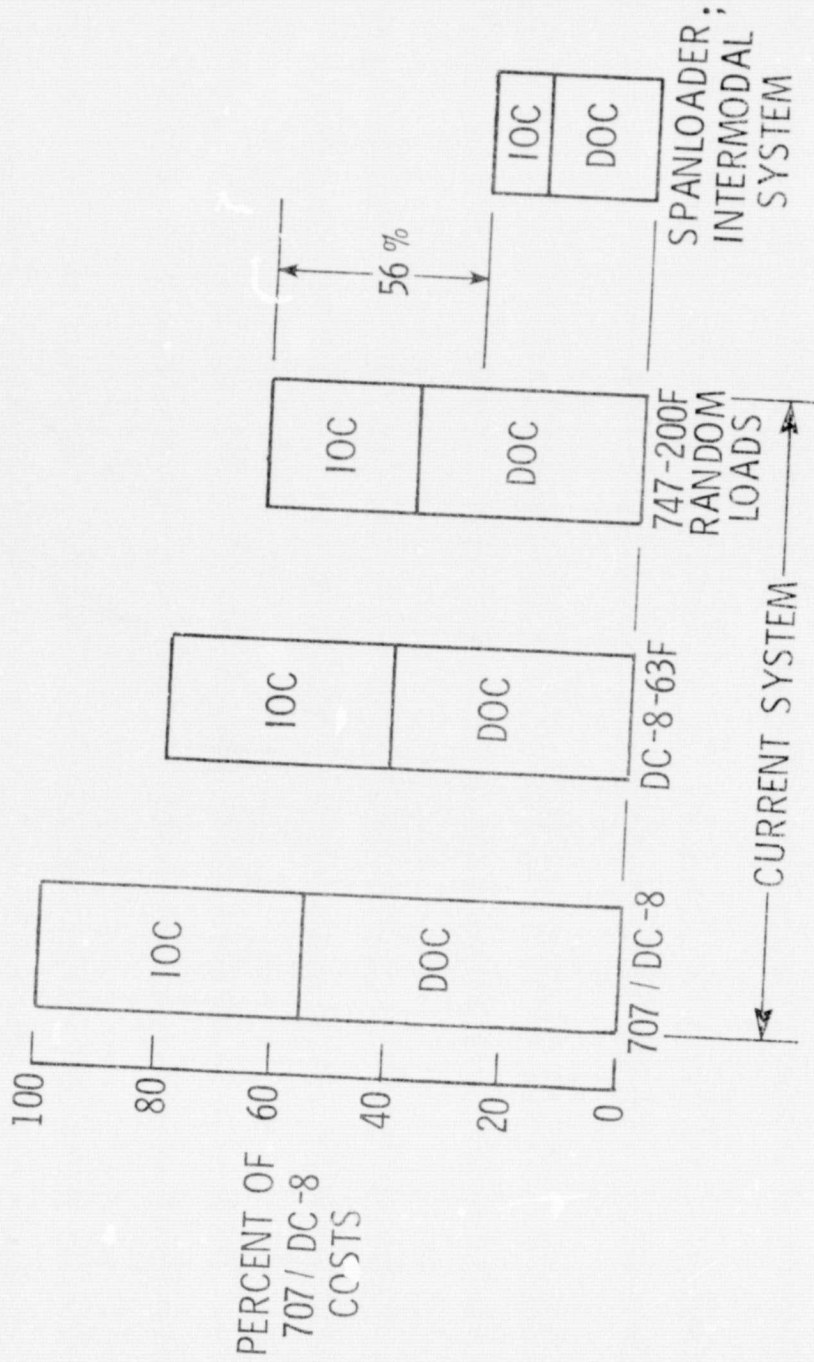


Figure 19. - Aircraft operating costs (1975 dollars).

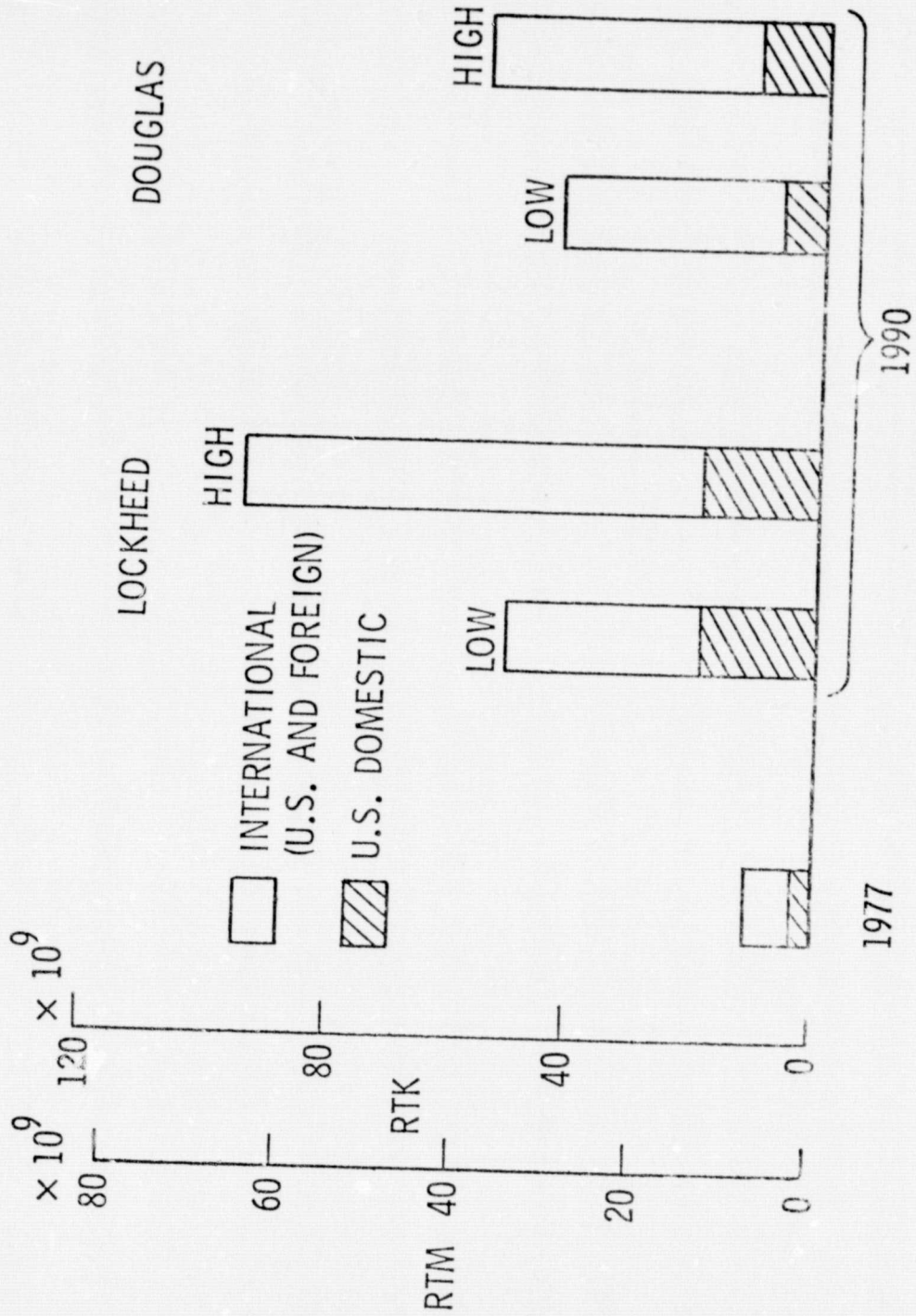
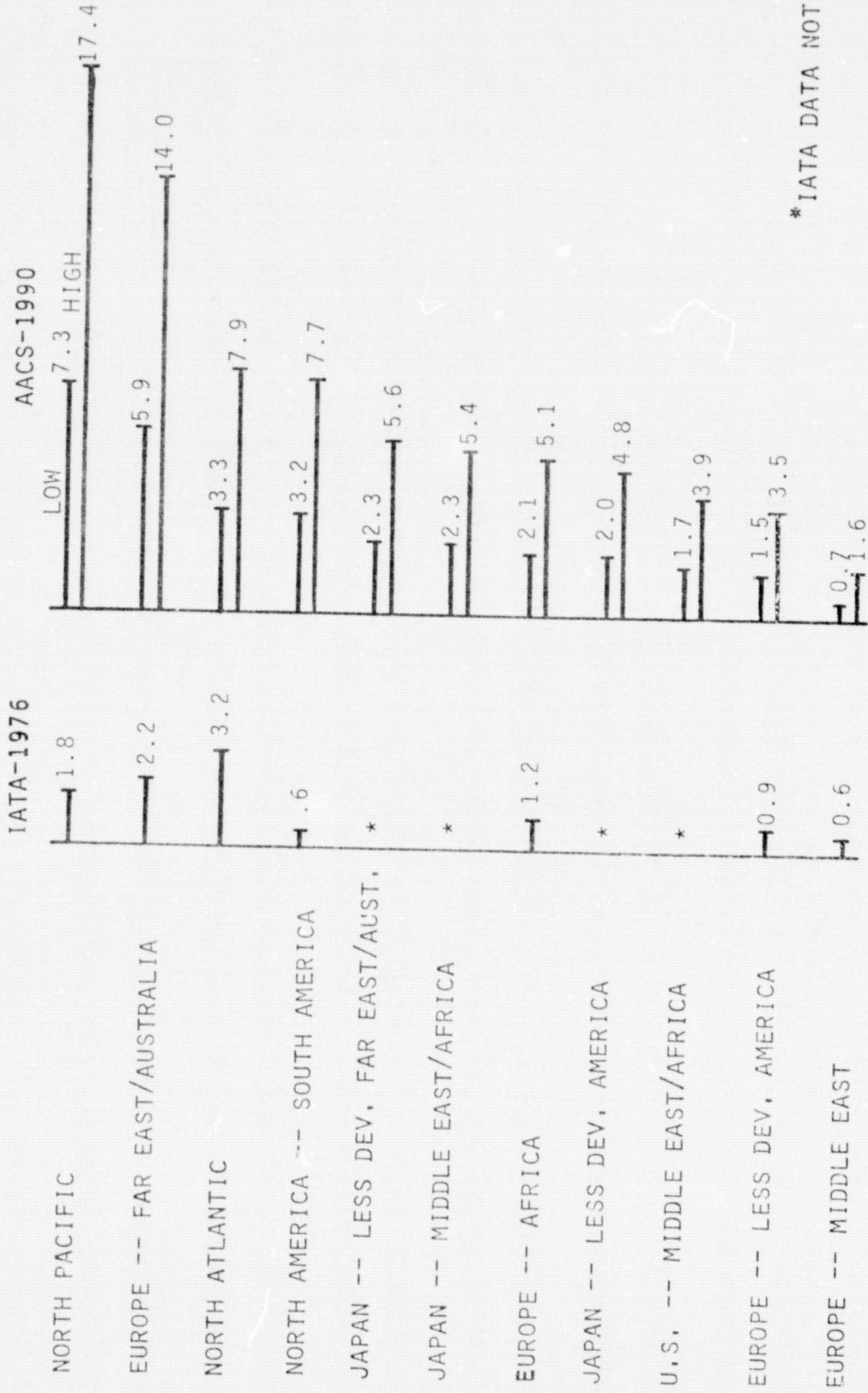


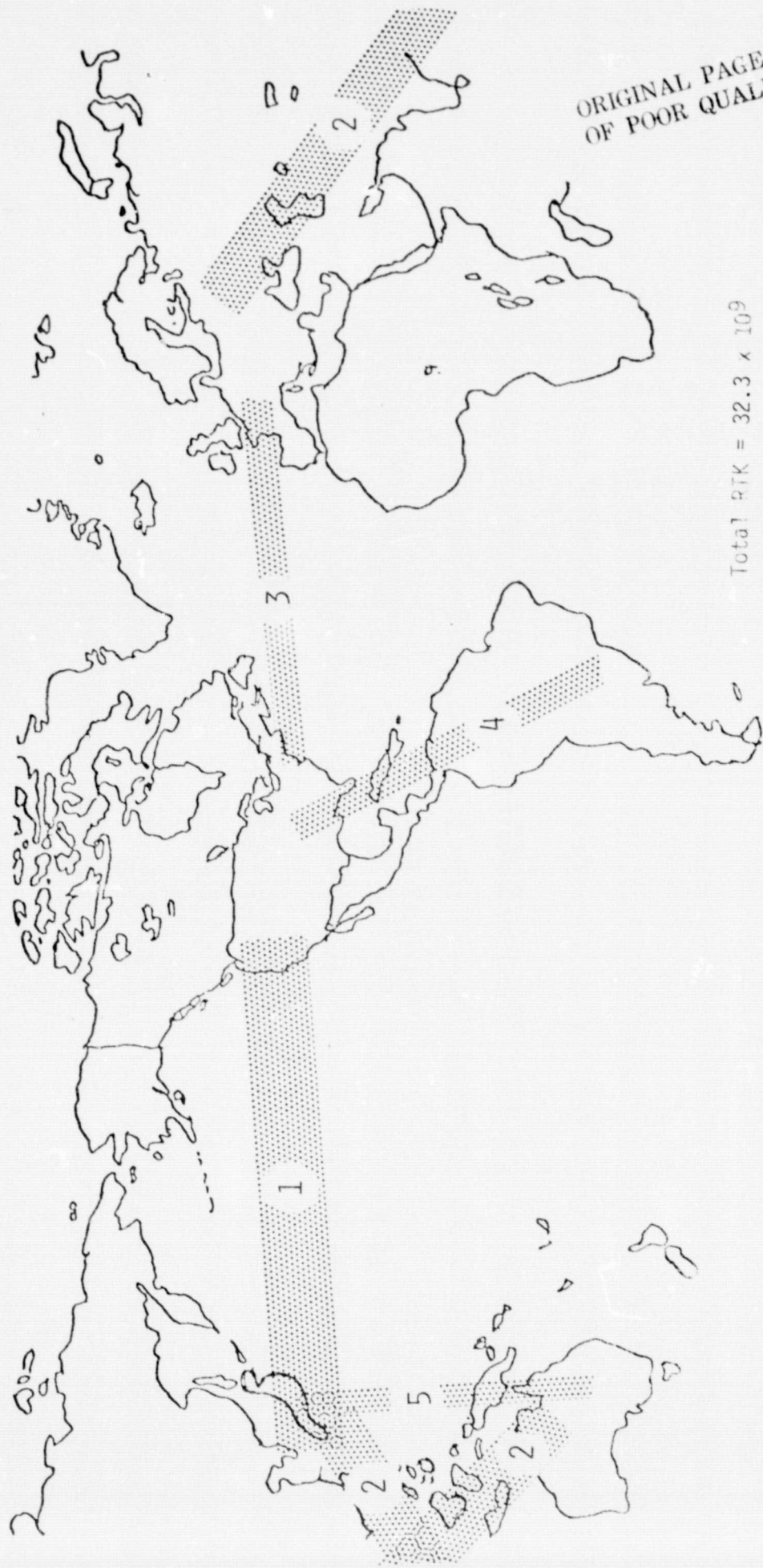
Figure 20. - 1990 all-freighter market forecast.

BILLION REVENUE-TONNE KILOMETERS



\* IATA DATA NOT AVAILABLE

Figure 21.- Advanced Air Cargo System (AACS) Demand - 1990



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Total RTK = 32.3 x 10<sup>9</sup>

Figure 22.- 1990 major international air cargo routes  
(width of band proportional to cargo RTK's).



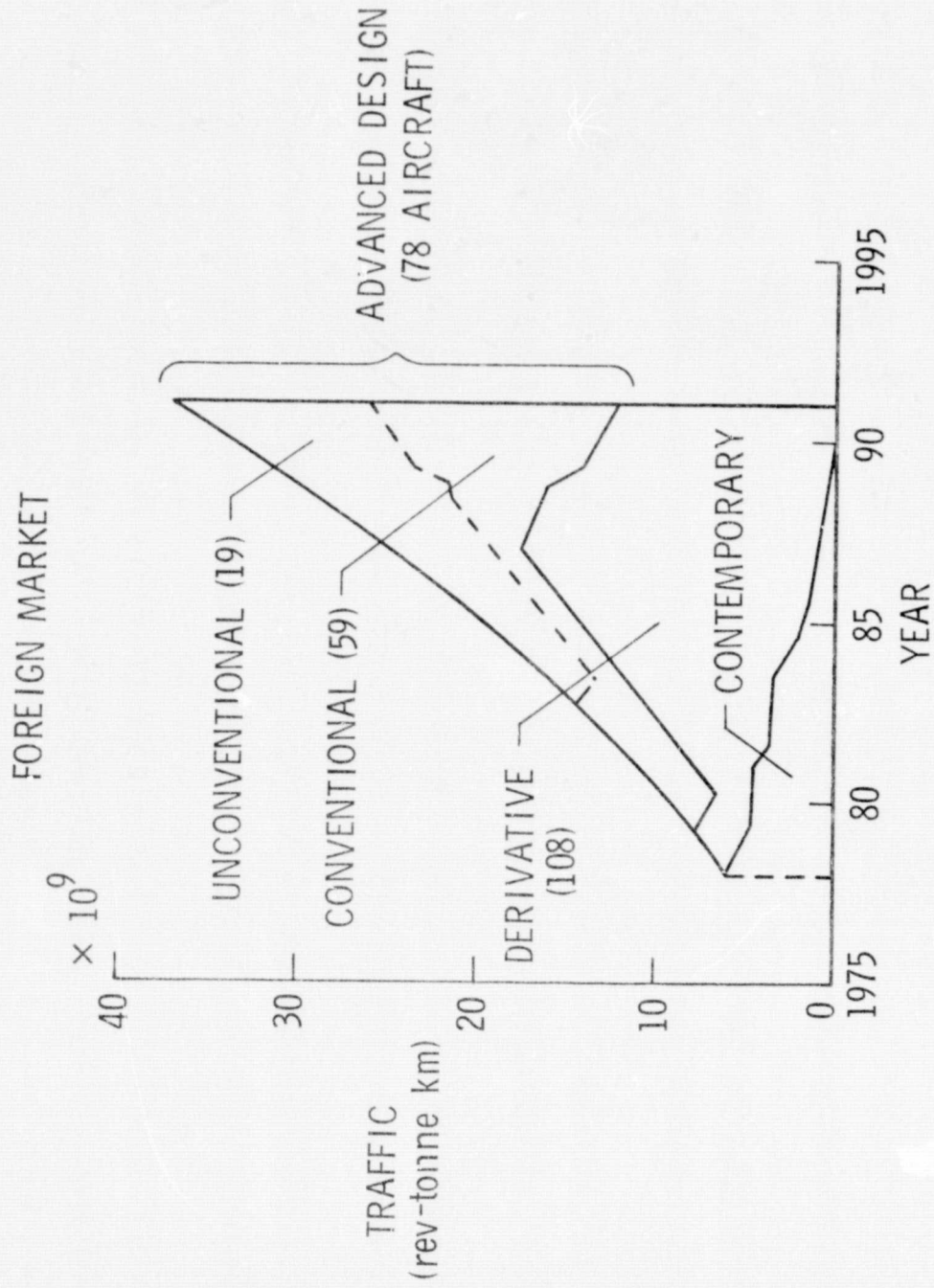


Figure 23. - Example fleet mix analysis.



Figure 24.- Industry concepts for 1985 technology freighters.

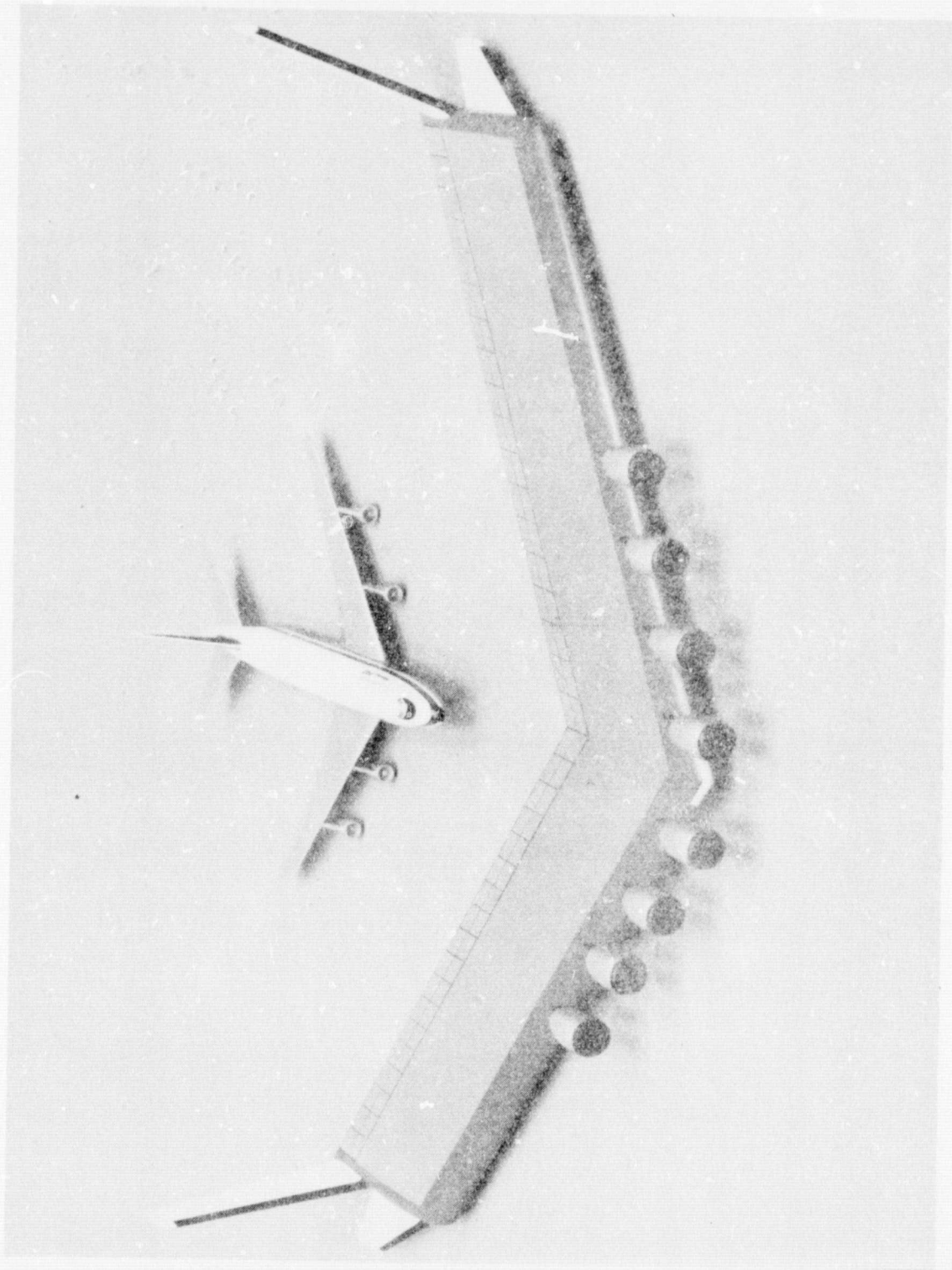


Figure 25.- Comparison of swept-wing spanloader and Boeing 747-F.

KEY

X.X BACK HAUL IMBALANCE RATIO  
 [ ] AIR CARGO FLOW IN 1976 (1000 TONNES)  
 ( ) AIR CARGO FLOW WITH HUB SYSTEM -- 1976  
 ( ) AIR CARGO FLOW WITH HUB SYSTEM -- 1990

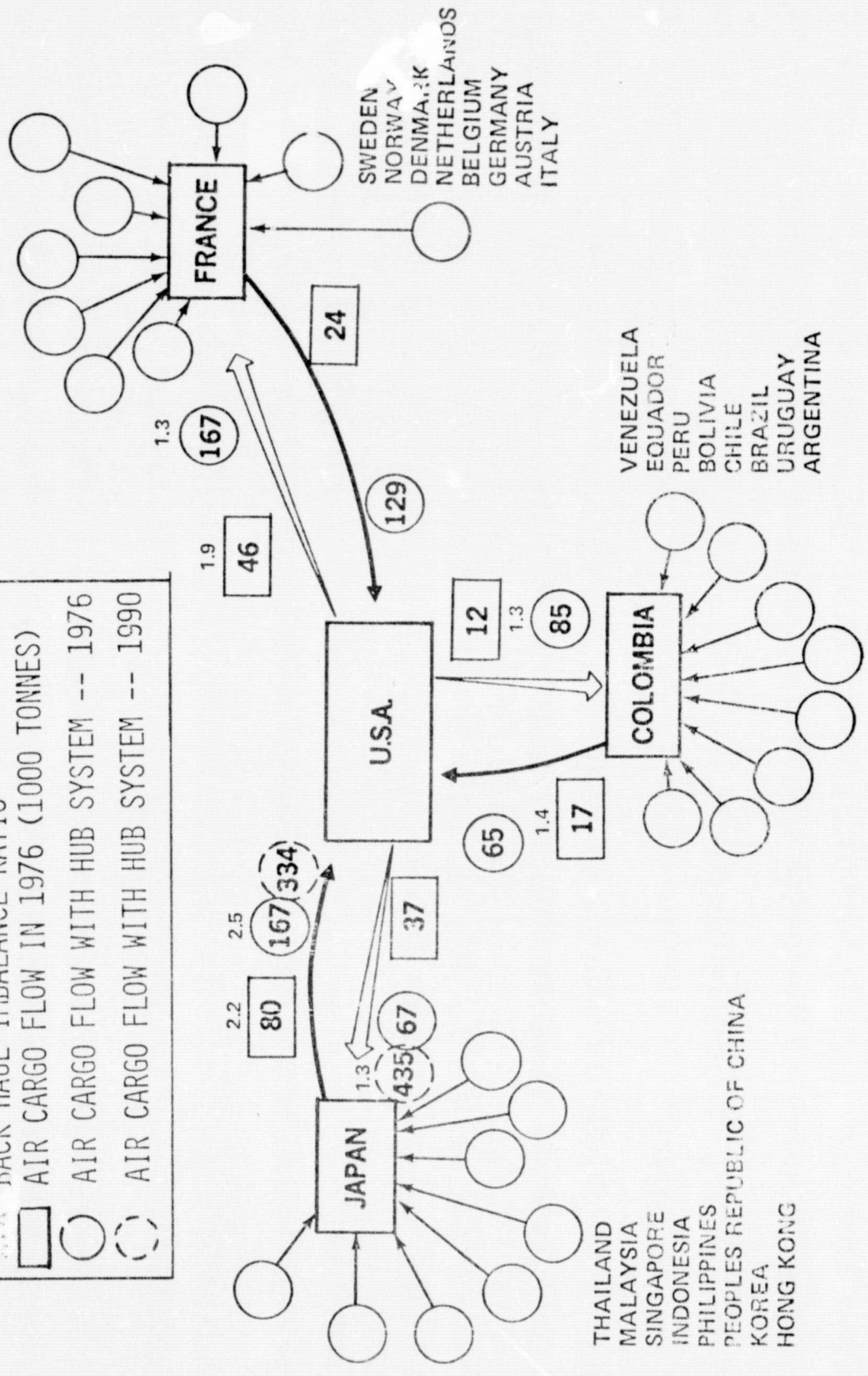


Figure 26. - Back haul balance with hub/spoke concept.

IMPROVEMENTS		PERCENT REDUCTIONS				
		DOC	IOC	TOC	RATES	
1978-1985	● INCREASED LOAD FACTOR (65-70 %)	7		4	4	15
	● SHIPPER-PACKED CONTAINERS WITH INCREASED CUBE UTILIZATION FROM 54 TO ABOUT 85 %		23	10	9	
	● IMPROVED TERMINAL TECHNOLOGY		6	2	2	
1985-2000	● FREIGHTER AIRCRAFT/AIRPORT COMPATIBILITY		4	1	1	10-13
	● ECONOMY OF SCALE WITH LARGE VOLUME OPERATION		15	6	6	
	● ADVANCED TECHNOLOGY FREIGHTER	13-23		7-12	3-6	
	● INCREASED AIRLINE PROFIT				-4	
TOTALS		20-30	48	30-35	21-24	

Figure 27. - CLASS results - "The bottom line."

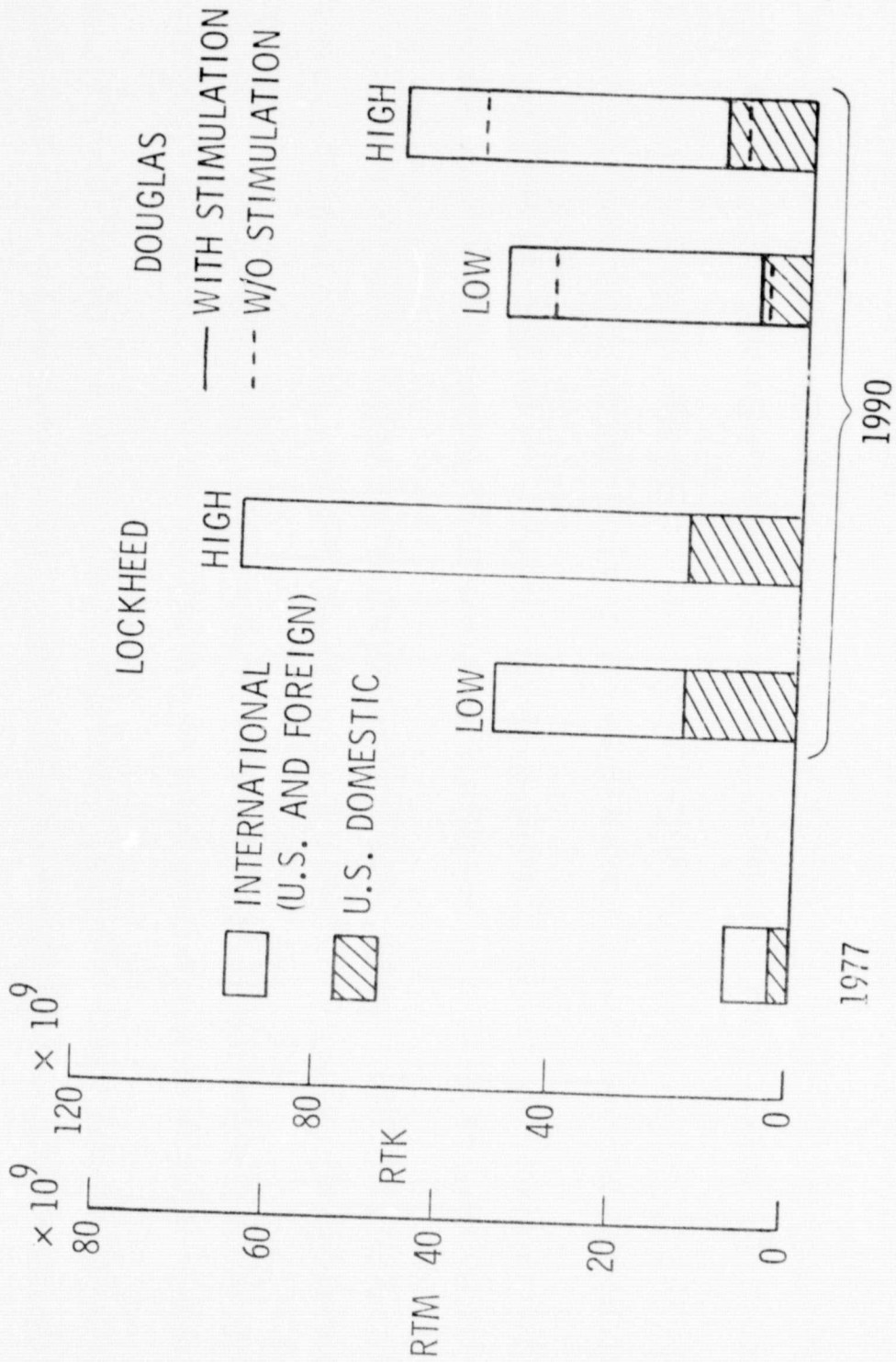


Figure 28. - 1990 all-freighter market forecast (Douglas data includes technology and infrastructure stimulation).