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NASA Technical Memorandum 72656

PRELIMINARY ANALYSIS OF HUB AND SPOKE
AIR FREIGHT DISTRIBUTION SYSTEM

(NASA-TM-72656) PRELIMINARY ANALYSIS OF HUB
AND SPOKE AIR FREIGHT DISTRIBUTION SYSTEM
(NASA) 36 p HC A03/MF A01 CSCL 01C

N78-25069

Unclas
G3/03 21561

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APRIL 1978



NASA

National Aeronautics and
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PRELIMINARY ANALYSIS OF HUB AND SPOKE AIR FREIGHT DISTRIBUTION SYSTEM

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SUMMARY

A brief analysis is made of the hub and spoke air freight distribution system which would employ less than 15 hub centers world wide with very large advanced distributed-load freighters providing the line-haul delivery between hubs. This system is compared to a more conventional network using conventionally-designed long-haul freighters which travel between numerous major airports (typical of today's 747-F operation). Both trucks and short haul, "feeder" aircraft are used to deliver cargo to the airports. The analysis calculates all of the transportation costs, including handling charges and pickup and delivery costs. The results show that the economics of the hub/spoke system are severely compromised by the extensive use of feeder aircraft to deliver cargo into and from the large freighter terminals. Not only are the higher costs for the smaller feeder airplane disadvantageous, but their use implies an additional exchange of cargo between modes compared to truck delivery. The conventional system uses far fewer feeder airplanes, and in many cases, none at all. When feeder aircraft are eliminated from the hub/spoke system, however, that system is universally more economical than any conventional system employing smaller line-haul aircraft.

INTRODUCTION

NASA has recently sponsored several studies of large dedicated cargo aircraft (refs. 1-7) which have the potential of offering significant improvements in productivity and efficiency over current wide-body freighters. These aircraft vary in design payload from 0.27 Gg (600,000 lb) to 0.64 Gg (1,400,000 lb) compared to a maximum payload for the 747-F of 0.12 Gg (250,000 lb). All of these advanced designs locate a substantial part, if not all, of the payload and fuel within the wing so that a close match is obtained between aerodynamic and inertial loading. By thus eliminating the major source of in-flight bending moments, the structural weight can be reduced. As the analysis of reference 6 indicates, the distributed-load freighter (DLF) is generally not cost competitive with more conventional, fuselage-loaded designs until the payload exceeds about 0.25 Gg (550,000 lb). Thus, for the design conditions imposed in these studies (8x8 containers, 160 kg/m³ payload density), the minimum gross weight distributed-load aircraft must be at least twice the gross weight of the 747-F.

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The current air cargo market volume, the existing terminal facilities, the route network and the supporting infrastructure preclude the application of these huge aircraft in today's environment. These large freighters would be used almost entirely in intercontinental airfreight operations and the most likely systems design would employ a relatively small number of world wide hub cities. Practical networks may be operational and economically feasible with as few as ten worldwide hub terminals (ref. 3). In this hub and spoke concept, the cargo is delivered to the hub by surface mode or by a short-haul airplane. Boeing estimates the cost for widening existing runways to accept the distributed-load freighter at ten hubs to be quite modest, representing less than 1-percent of the operating costs. This surcharge would impose a negligible impact on total system economics.

The purpose of this report is to present the results of a brief analysis of the hub-spoke distribution system that could support the application of the very large freighters. Total transportation costs are estimated, including transfer costs between modes as well as costs generated by the line-haul, short-haul and surface vehicles. The paper compares the hub-spoke system utilizing the very large distributed-load airplanes to the current network operation incorporating either current wide-body freighters or new airplanes that follow conventional design concepts. This analysis indicates the conditions under which the hub/spoke and large freighter combination could be economically more favorable.

NOMENCLATURE

AIC	aircraft investment costs
B ₁	mean delivery radius for feeder aircraft into hub terminal
B ₂	mean delivery radius for feeder aircraft into conventional line-haul terminal
B ₃	mean delivery radius for trucks into hub terminal
B ₄	mean delivery radius for trucks into conventional line-haul terminal
B ₅	mean delivery radius for trucks into feeder aircraft terminals in hub/spoke system
B ₆	mean delivery radius for trucks into feeder aircraft terminals in conventional system
B ₇	delivery radius (range) for DLF
B ₈	average delivery radius (range) for conventional long-haul airplane

C	ratio of total costs in hub/spoke system to total costs in conventional system
C_S	value of total cost ratio (C) for standard case values (Table I)
D_C	AIC + DOC for conventionally-designed long-haul airplane
D_D	AIC + DOC for DLF
D_F	AIC + DOC for feeder aircraft
D_T	DOC for trucks
DLF	distributed-load freighter
DOC	direct operating costs
H_C	terminal and cargo-handling costs per unit payload weight for long-haul airplane at conventional system terminal
H_D	terminal and cargo-handling costs per unit payload weight for DLF at hub terminal
H_F	terminal and cargo-handling costs per unit payload weight for feeder aircraft at feeder terminal
N_C	number of conventional terminals in system
N_F	number of feeder aircraft terminals in system
R_1	traffic radius for DLF
R_2	traffic radius for conventional long-haul airplane
R_3	traffic radius for trucks into hub terminal
R_4	traffic radius for trucks into conventional system terminal
R_5	traffic radius for feeder airplanes into hub terminal

R_6	traffic radius for feeder airplanes into conventional system terminal
T	total cargo load enplaned in system (same for hub/spoke and conventional systems)
T_C	cargo load through each conventional, line-haul terminal
T_D	cargo load through the hub terminal
T_F	cargo load carried by feeder aircraft into hub terminal or into each conventional system terminal
T_T	cargo load carried by truck into hub terminal or into each conventional system terminal
W_C	design payload of conventional line-haul airplane
W_D	design payload of DLF
W_F	design payload of feeder airplane

Subscripts

C	conventional system
D	hub/spoke system using DLF airplane

DESCRIPTION OF MODEL

A description of the model employed in this study is facilitated by reference to figure 1(a). There are two systems to be compared, the hub/spoke system using very large distributed-load freighters (DLF) and the more conventional operation employing more conventional long-haul airplanes (either advanced designs or current wide-bodies). A prescribed cargo load is assumed to be delivered between two hubs, and the DLF is then sized to accept that load as its payload, that is

$$T = T_D = W_D \quad (1)$$

The number of conventional aircraft and consequently the number of conventional line-haul terminals is determined by the assumed payload capacity of the conventional airplane,

$$N_C = T/W_C \quad (2)$$

The cargo load through each conventional line-haul terminal is then

$$T_C = T/N_C \quad (3)$$

All aircraft are assumed to operate with a 100 percent load factor; as a result, the calculation accepts a nonintegral number of conventional aircraft (the excess payload past the last integral number can be assumed to define a single smaller payload airplane). Only one aircraft is assumed to depart from each terminal in either system.

To provide retail delivery of the cargo into and from the line-haul terminals, truck and short haul or "feeder" airplanes are employed. Thus in the hub/spoke system,

$$T_D = T_{FD} + T_{TD} \quad (4)$$

and, in the conventional system,

$$T_C = T_{FC} + T_{TC} \quad (5)$$

Trucks are also used to provide delivery into the feeder aircraft terminals.

The modeling is constructed on the assumption that cargo traffic generated for a given terminal is proportional to the area of a circle prescribed by the radial distance measured from the terminal center. Only the traffic-gathering radius for the DLF (R_1) and the truck traffic radius into the hub terminal (R_3) are prescribed; all other traffic radii in figure 1(b) are determined by the calculation. The calculated traffic radius of the traffic in the conventional system (R_4) can be less than but not exceed the input value of the truck traffic radius in the hub/spoke system (R_3).

The traffic generated beyond the range of the truck in either system is delivered by feeder aircraft into the respective line-haul terminal. The traffic radii for the feeder airplanes (R_5 and R_6) are determined by the prescribed feeder airplane characteristics and the remaining traffic area beyond the truck range. Thus, in the hub/spoke system,

$$R_5 = \sqrt{\frac{R_1^2 - R_3^2}{T_{FD}/W_F}} \quad (6)$$

and, in the conventional system,

$$R_6 = \sqrt{\frac{R_2^2 - R_4^2}{T_{FC}/W_F}} \quad (7)$$

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In the sample layout of figure 1(b), the DLF payload was three times that of the conventional aircraft. Thus the sum of the three areas in the conventional distribution system is equal to the area of the circle of the radius R_1 in the hub/spoke system. The conventional airplane traffic radius is given by

$$R_2 = R_1 \sqrt{W_D/W_C} \quad (8)$$

In determining the transportation costs, operating costs are assigned to each vehicle in the system (D_C , D_D , and D_T). Costs generated by truck delivery into the feeder terminals are also included in the transportation cost summation. In calculating these costs, it is necessary to define effective delivery radii for each transportation mode (fig. 1(c)). Within each prescribed delivery area, it is assumed that the effective delivery radius divides the delivery zone into two equal areas. Thus, the mean delivery radius for the truck into the hub terminal becomes

$$B_3 = R_3 / \sqrt{2} \quad (9)$$

and the mean delivery radius for feeder aircraft into the conventional line-haul terminal is

$$B_2 = \sqrt{\frac{R_2^2 + R_4^2}{2}} \quad (10)$$

The remaining delivery radii are calculated in a similar manner. The total transportation cost for each system is then calculated by adding the combined terminal and handling charges to the total transportation costs for all vehicles used in the door-to-door delivery.

Transportation costs are of course predicated on trip distance, and a problem arises in the determination of a general expression for the average distance between long-haul terminals in the conventional system once the hub-to-hub spacing (equivalent to DLF range) has been selected. The conventionally-designed aircraft are deployed from N_C terminals and arrive at a like number of terminals at the completion of the long-haul delivery. A method for determining average long-haul delivery radius for the conventional aircraft (B_8) can be described by reference to figure 2. Four different conventional distribution networks are represented in this figure, with the DLF delivery radius (B_7) being equivalent to the spacing between hubs (A to B, A to C). The problem for a given network is to determine and then average all possible trip combinations for the conventional aircraft departing from and arriving at the conventional terminals. The variables in this problem are the number of conventional terminals, the distance of the terminals from the hub, the hub spacing (B_7), and the orientation of the origin terminal system with respect to the destination terminal system. It is assumed that the terminals are equidistant from the hub and that the spacing between centers is uniform. The four cases depicted in figure 2 were chosen to exercise the four variables and to determine the possible range of values for the ratio of the average delivery radius for the conventional long-haul airplane (B_8) to the DLF

radius (B_7). It was found that for hub spacing (B_7) greater than about 4500 km (2430 n. mi.), the aforementioned ratio for the four systems of figure 2 varied from 1.003 to 1.012. For simplification and without causing significant influence in the study results,

$$B_8 = 1.01 B_7$$

(11)

STANDARD CASE

A "standard case" is defined to provide a reasonable representation of both hub/spoke and conventional freight distribution systems. Later evaluation of the influence of the system variables will depend in part on the use of the standard case as a reference. Table I lists both the dependent and independent variables and their values for the standard case. The rationale for the selection of the independent variables which define the standard case is given in the paragraphs to follow.

The long-haul aircraft selected for each system have recently been studied so that their economic performance is well documented. The characteristics of the DLF (D_D and W_D) were obtained from reference 4. The conventional airplane design used in the standard case is an advanced, fuselage-loaded airplane also obtained from the Boeing study (ref. 4); this design was used in that study as a reference in the comparison with the DLF. Figure 3 shows both of these long-haul (or line-haul) aircraft. The aircraft cost factors (D_C , D_D , D_F) are represented by the sum of the direct operating cost and aircraft investment cost. The investment cost is added because DOC does not adequately represent the influence of airplane first cost in an economic comparison between aircraft configurations (ref. 3). The costs for the feeder aircraft (D_F) were determined by a consideration of data from reference 8 and a nonreferenceable industry source. The truck cost input was obtained from reference 9. All cost data are based on 1976 dollars.

The literature containing data or projections on terminal and cargo handling costs exhibits a wide variation in values. From reference 9 through 11 and six nonreferenceable sources, these costs vary from about 18 to 40 \$/Mg for a typical wide-body operation using 8x8 containers. The values assigned to the terminal and handling costs (H_C , H_D , H_F) in Table I are a function of aircraft size and are a best estimate from these available sources. The sensitivity of these handling costs in the analysis will be shown later.

The traffic-gathering radius for the DLF (R_1) is an input variable and is selected from an examination of the traffic-gathering areas for current wide-body freighters. The value of 555 km for the truck traffic radius into the hub terminal (R_3) is based on the typical six to eight hour delivery time for trucks that is compatible with the proposed delivery system. All other traffic and delivery radii shown in figure 4(a) are calculated in the analysis.

RESULTS AND DISCUSSION

Discussion of Standard Case

An analysis and evaluation of the standard case is made in figure 4(b). On the left of the figure, the truck is shown to carry the bulk of the cargo into the conventional terminals (70 percent), whereas the feeder airplanes provide the major service to the DLF terminal in the hub/spoke system (75 percent). When all of the system costs are combined, the conventional system costs are marginally lower than for the hub/spoke system (\$145K vs \$149K respectively). The cost breakdown on the right of figure 4(b) shows how the costs are generated in each system. Even though the line haul costs of the DLF are significantly lower than for the smaller, more conventional airplane, the requirement to move a substantial tonnage into the DLF terminal by feeder aircraft is a great cost disadvantage. These small airplanes have operational costs 2 1/2 times that for the truck. A further cost is incurred when feeder airplanes are used in the system in that the cargo must change vehicles at both feeder and line-haul terminals. Thereby incurring an additional terminal and handling charge. It should be noted that the truck costs in figure 4(b) include the delivery charges for moving cargo both into the line-haul and feeder terminals.

This evaluation suggests that the hub/spoke system could show a greater advantage when fewer feeder aircraft are employed. That observation is clearly demonstrated in the analysis that follows.

Influence of DLF and Truck Traffic Radii

Both the DLF traffic radius (R_1) and the truck traffic radius into the hub terminal (R_3) will influence the percent of traffic carried by feeder aircraft in the two systems under evaluation. If the truck traffic radius (R_3) is held constant, then an increasingly greater share of feeder aircraft traffic will be generated as the DLF traffic radius (R_1) is extended beyond R_3 (of course when $R_1 = R_3$, all traffic is delivered to the line-haul terminals by trucks). This result is shown in figure 5(a) where the percent tonnage by feeder aircraft increases rapidly for the hub/spoke system as R_1 increases beyond R_3 . The use of feeders in the conventional system does not initiate until R_1 reaches about 960 km (518 n.mi.), then there is a rapid increase in tons carried by feeder aircraft. The vertical arrow on the abscissa on this and following figures indicates the standard case values of the variable. All variables have been assigned their standard case value except for the variable assigned to the abscissa. Except where noted differently, this format has been followed in figures 5 through 9.

The total transportation cost variation with the DLF traffic radius (R_1) is given in figure 5(b) where the influence of the feeder aircraft is clearly shown. The costs for the conventional system are relatively constant until feeder aircraft are introduced in that system, at which point the costs escalate. The hub/spoke systems shows a continuous cost increase with R_1 as an increasingly

larger percent of cargo into the DLF terminal is conveyed by feeder aircraft. The crossing point of these two curves where the costs for the two systems are equal occurs near $R_1 = 830$ km (450 n.mi.).

A similar result is found for the effect of the DLF truck traffic radius (R_3) on total costs. The total cost variation with R_3 is shown in figures 6(a) and 6(b) for the standard conventional aircraft payload (W_C) and for $W_C = 258$ Mg. The percent tons by feeder airplane into the line-haul terminal are indicated in figure 6(c) as a function of R_3 . By comparing 6(c) with either 6(a) or 6(b), the observation is made that the discontinuity in the conventional system cost curve occurs when the truck traffic radius has been increased sufficiently to carry all traffic into the conventional system terminal. This break point occurs when R_3 equals R_2 , the radius of the conventional aircraft traffic radius as indicated in figure 6. Fewer feeder aircraft are used in the hub/spoke system as R_3 increases, and the costs for that system consequently show a continuous decline with R_3 . The result in figure 6(a) then shows that the hub/spoke system is more cost-effective for low and high values of R_3 , with the middle range (490 km $< R_3 < 865$ km) indicating a cost benefit to the conventional system. When a larger design payload for the conventional aircraft is used in the calculation (fig. 6(a)), the hub/spoke system is more cost advantageous for all values of R_3 . (The full influence of W_C will be examined in later figures.) Figure 6(c) shows that as W_C is increased at a given value of R_3 , the conventional system with the larger payload aircraft requires a greater use of feeder aircraft. This result accounts for the cost disadvantage of the conventional system found in figure 6(a).

Influence of Design Payload Variation

Changing either DLF design payload (W_D) or the conventional airplane design payload (W_C) will alter the cost comparison between the hub/spoke and conventional systems. The variation of the DLF payload gives the cost relationship shown in figure 7. The hub/spoke system is economically more favorable for $W_D < 450$ Mg, but the largest cost differential between the two systems in figure 7 is only about 8 percent.

The influence of the conventional aircraft design payload W_C has a more significant impact as seen in figure 8. Figure 8(a) shows the results of design studies by Boeing (refs. 3 and 4) which indicate a bucket in the cost-payload curve. The minimum cost was selected as the design point. The total variation with W_C is shown in figure 8(b) for both the standard case (upper pair of curves) and for a condition in which no feeder aircraft are used in either system (lower pair of curves). Feeder aircraft have been eliminated by setting $R_1 = R_3$, which permits the trucks to deliver all cargo to the line-haul terminals. For this case, the hub/spoke operations shows substantial total cost advantages over the conventional system (the minimum cost differential still shows a 20 percent benefit to the hub/spoke system). Furthermore, the minimum aircraft cost (fig. 8(a)) and the minimum total transportation cost (fig. 8(b)) occur at approximately the same value of W_C .

In the standard case with feeder aircraft involved, the minimum total transportation cost occurs at a much lower payload value ($W_C = 110$ Mg) than the value of W_C which defines the minimum aircraft cost ($W_C = 135$ Mg). This result suggests that the total transportation system and operating environment should be considered in selecting design values for future cargo transports. As the percent of tons conveyed by feeder aircraft (fig. 8(d)) increase with W_C , the conventional system total transportation costs rise and finally exceed the hub/spoke costs (upper pair of curves in fig. 8(b)).

Aircraft Costs

The values assumed for aircraft costs (D_D , D_C , D_F) can be expected to greatly influence the transportation system evaluation. In figure 9, the conventional aircraft costs are seen to be a major determinant as to which system is more economical. The standard case value of the conventional aircraft costs (D_C) is seen to be quite near the intersection of the two curves defining the economic equivalence of the two systems.

Transportation Cost Sensitivity

The five primary variables examined so far in this study (W_C , W_D , D_C , R_3 and R_1) are compared in figure 10 along with the ratio of terminal handling costs (H_D/H_C) to determine individual variable influence on the ratio of hub/spoke costs to conventional system costs. Both cost and variable value of the normalized by standard case values in this presentation. For any value of the ordinate about -2.3 percent (obtained by setting $C = 1$, the hub/spoke system is more costly than the conventional system. The conventional airplane cost (D_C) has the highest leverage on the total cost comparison.

Effect of Line-Haul Range

The final cost comparison will be made on the basis of line-haul range. In this part of the analysis, two more line-haul aircraft are considered for the conventional distribution system (the Boeing double-lobe design of figure 3 has served as the line-haul vehicle in the study to this point). The first is the current 747-F (data obtained from ref. 5). The second addition is a twin-fuselage airplane obtained from a preliminary design analysis reported in reference 12. The aircraft acquisition costs on this design were kept low by using existing fuselages and wings from the 747. The design payload is 2.88 times that of the 747, yet the direct operating costs are 38 percent lower than for the existing wide-body. The three conventionally-designed aircraft are evaluated as candidate aircraft in the conventional system and compared to the hub/spoke operation in figure 11.

The distance between line-haul terminals (range) is presented in figure 11 as the line-haul distance from Chicago to several major international airports (fig. 12). Chicago is an appropriate choice since that airport already serves as a hub (see fig. 13), drawing traffic from a 650 km (350 n.mi.) radius which

includes the cities of St. Louis, Cincinnati, and Minneapolis. Even the Chicago to Tokyo distance of 10,450 km (6440 n.mi.) is not an unreasonable nonstop stage length. Pan American currently flies the 747-SP nonstop from New York to Tokyo, a distance of 11,200 km (6960 n.mi.).

The results in figure 11(a) are obtained assuming standard case values (Table I) for the DLF and Boeing double-lobe design. For ranges below about 7500 km, there is little advantage to the hub/spoke system in comparison with the conventional system with either the Boeing double-lobe or the twin body derivative of the 747 serving as the line-haul vehicle. The current 747-F is the most costly alternative for all ranges. For higher ranges (in excess of 9000 km), the hub/spoke system with the DLF airplane is economically more favorable. Even for the flight from Chicago to Buenos Aires, however, there is only a 7% advantage for the hub/spoke system with the DLF over the Boeing double-lobe airplane in the conventional system.

Since the analysis thus far has indicated that the hub/spoke operation without feeder aircraft is far superior in total transportation costs to be conventional system, a final range comparison is made in figure 11(b) assuming only truck delivery to the line-haul terminals. These results clearly show the superiority of the hub/spoke system for all ranges. Even for the shortest flight (Chicago to Anchorage) there is a 39% cost advantage for the hub/spoke and DLF over the conventional system using the Boeing double-lobe airplane.

CONCLUDING REMARKS

An elementary analysis of the hub/spoke air freight distribution system has been made in this study. This system would employ less than 15 hub centers worldwide and feeder aircraft terminals distributed along radial spokes from the hubs. The very large distributed-load freighter aircraft provide delivery between the hub terminals. This system is compared to a more conventional distribution system which can accept current wide-body or advanced, conventionally designed long-haul freighters.

This study indicates the following conclusions:

1. The economics of the hub/spoke system are severely comprised by extensive use of feeder aircraft to delivery cargo into and from the large, distributed-load freighter terminals. The conventional system uses far fewer feeder airplanes, and in many cases, none at all. This results occurs because the traffic-gathering area for the large capacity aircraft is much greater than for the smaller, conventional line-haul airplanes. The pickup and delivery radius of the truck is quickly exceeded in the hub/spoke system with all traffic beyond that limit gathered by feeder aircraft. Not only are the higher costs for the smaller feeder airplane disadvantageous, but their use requires an additional exchange of the cargo between modes compared to the truck delivery.

2. When feeder aircraft are eliminated from the hub/spoke system, that system is universally more economical than any conventional system employing smaller, conventionally-designed airplanes.

3. In selecting values for the parameters to initiate cargo transport design, the total transportation system in which that vehicle will operate could influence the selection process. For example, in this study the payload value defining the minimum operating cost for the conventional line-haul airplane does not coincide with the payload value providing the minimum total transportation cost.

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TABLE I. - STANDARD CASE

(1976 Dollars)

Independent Variables

$D_C = 3.91$ cents/Mg-km	(5.70 cents/ton-statute mile)
$D_D = 2.95$ cents/Mg-km	(4.30 cents/ton-statute mile)
$D_F = 5.82$ cents/Mg-km	(8.50 cents/ton-statute mile)
$D_T = 2.33$ cents/Mg-km	(3.40 cents/ton-statute mile)
$H_C = 16.54$ \$/Mg	(15 dollars per ton)
$H_D = 13.23$ \$/Mg	(12 dollars per ton)
$H_F = 19.85$ \$/Mg	(18 dollars per ton)
$W_C = 195$ Mg	(215 tons)
$W_D = 544$ Mg	(600 tons)
$W_F = 18$ Mg	(20 tons)
$B_7 = 5556$ km	(3000 nautical miles)
$B_8 = 5611$ km	(3030 nautical miles)
$R_1 = 1111$ km	(600 nautical miles)
$R_3 = 555$ km	(300 nautical miles)

Dependent Variables

$B_1 = 878$ km	(474 nautical miles)
$B_2 = 613$ km	(331 nautical miles)
$B_3 = 393$ km	(212 nautical miles)
$B_4 = 393$ km	(212 nautical miles)
$B_5 = 143$ km	(77 nautical miles)
$B_6 = 143$ km	(77 nautical miles)

TABLE I -STANDARD CASE concluded.

Dependent Variables (continued)

$R_2 = 665$ km

(359 nautical miles)

$R_4 = 555$ km

(300 nautical miles)

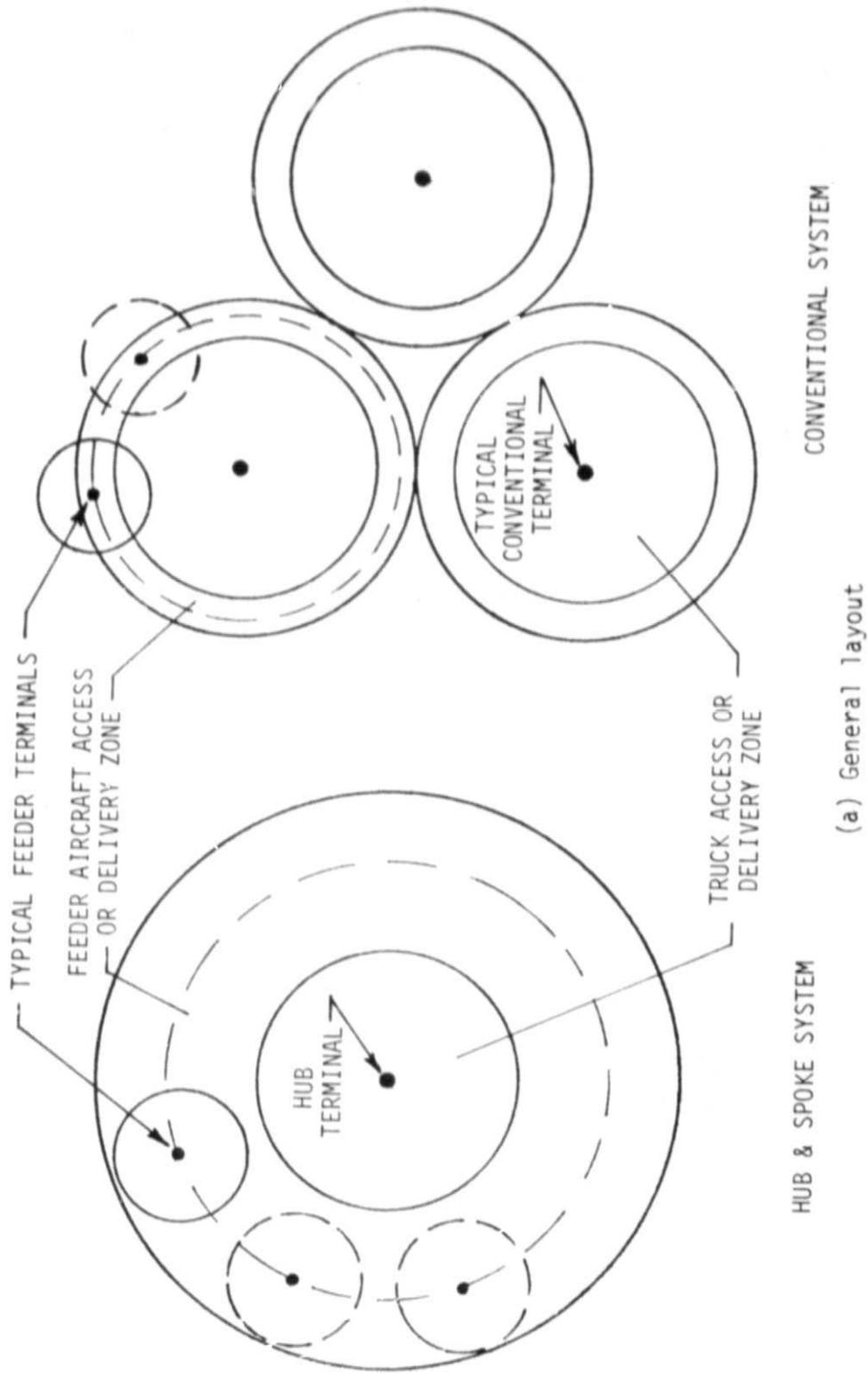
$R_5 = 203$ km

(110 nautical miles)

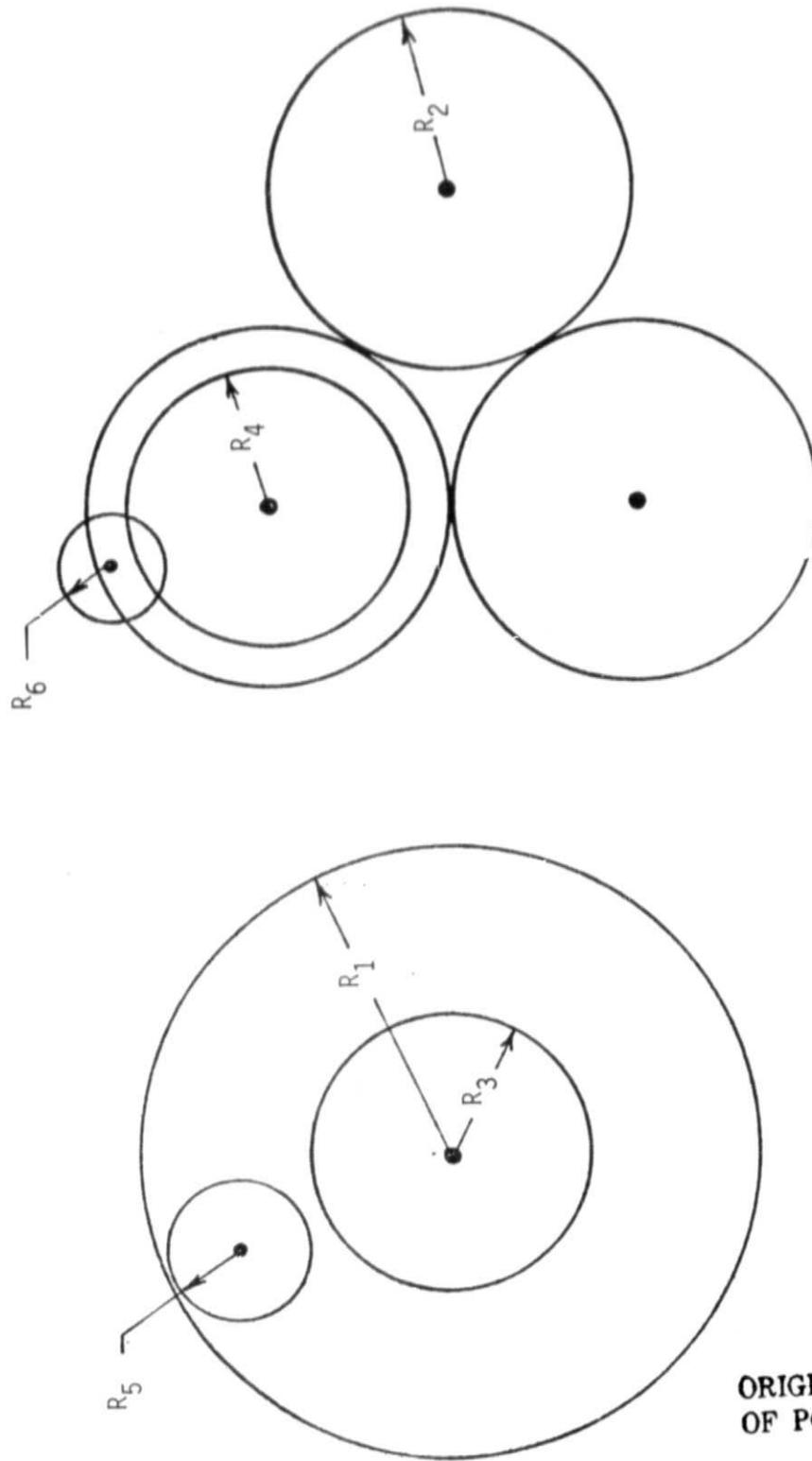
$R_6 = 203$ km

(110 nautical miles)

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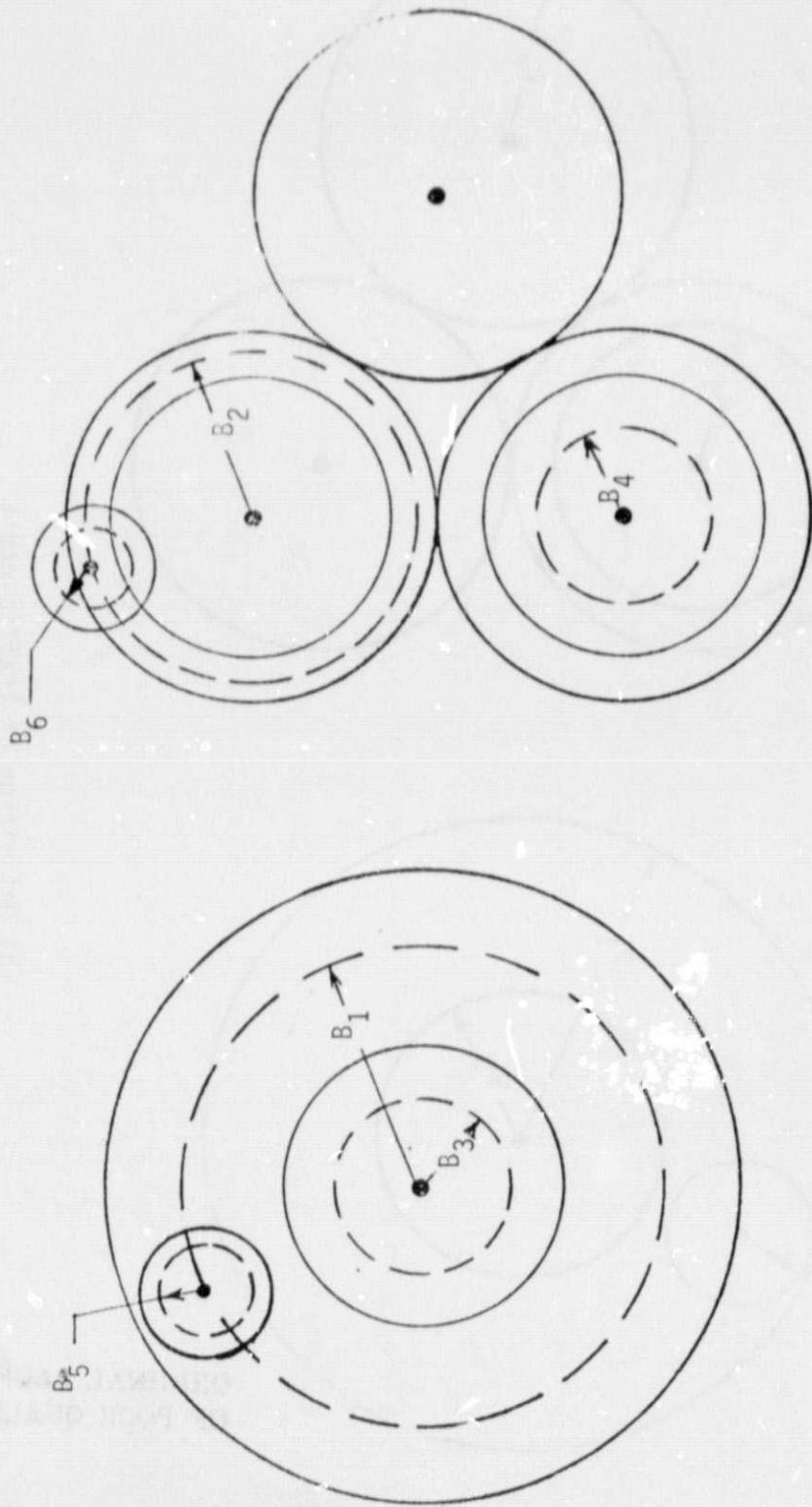
(a) General layout
Fig. 1 - Model for hub/spoke and conventional distribution system



(b) Definition of traffic radii

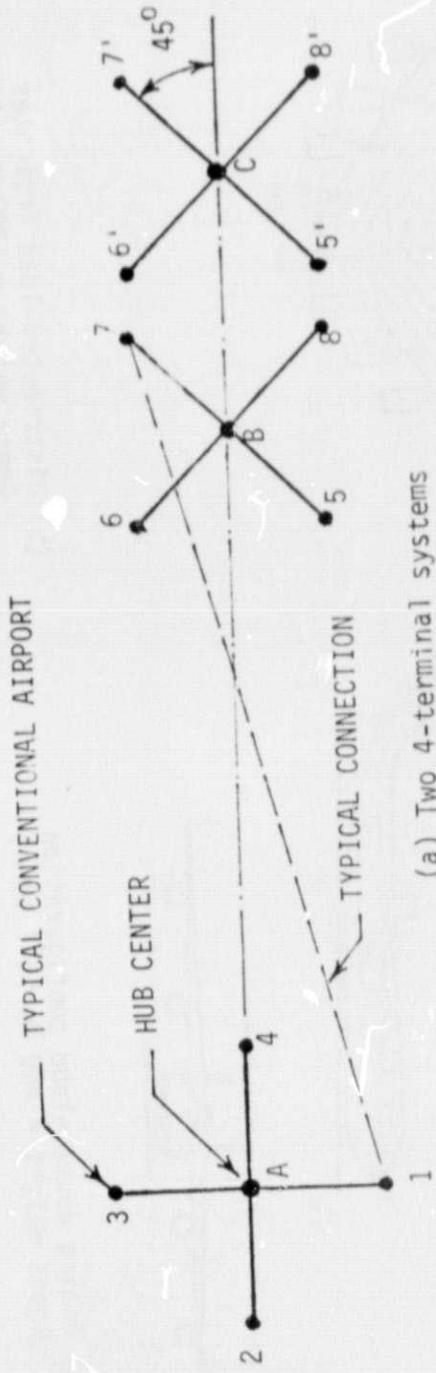
Fig. 1. - Continued

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(c) Definition of effective delivery radii

Fig. 1.- Concluded.

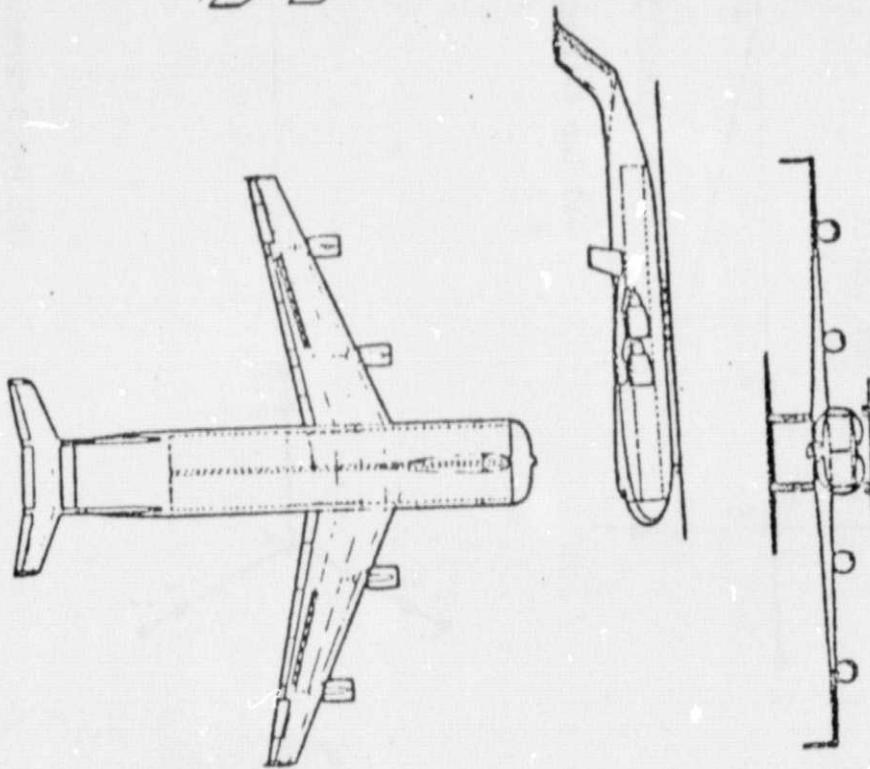


(a) Two 4-terminal systems



(b) Two 3-terminal systems

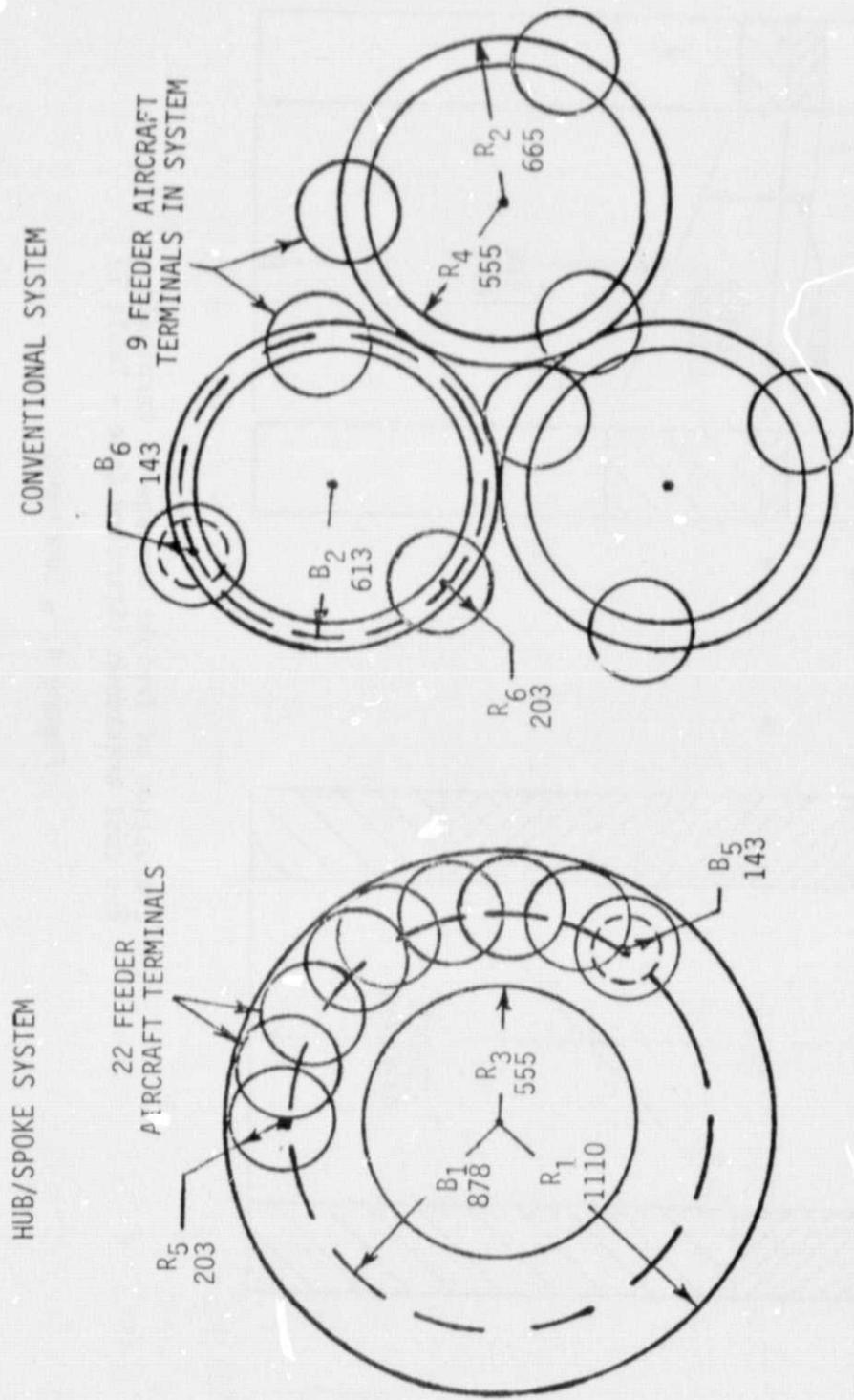
Fig. 2.- Determination of average distance between Conventional airport terminals.



(a) Boeing double-lobe configuration
Gross weight = 469 Mg (517 tons)

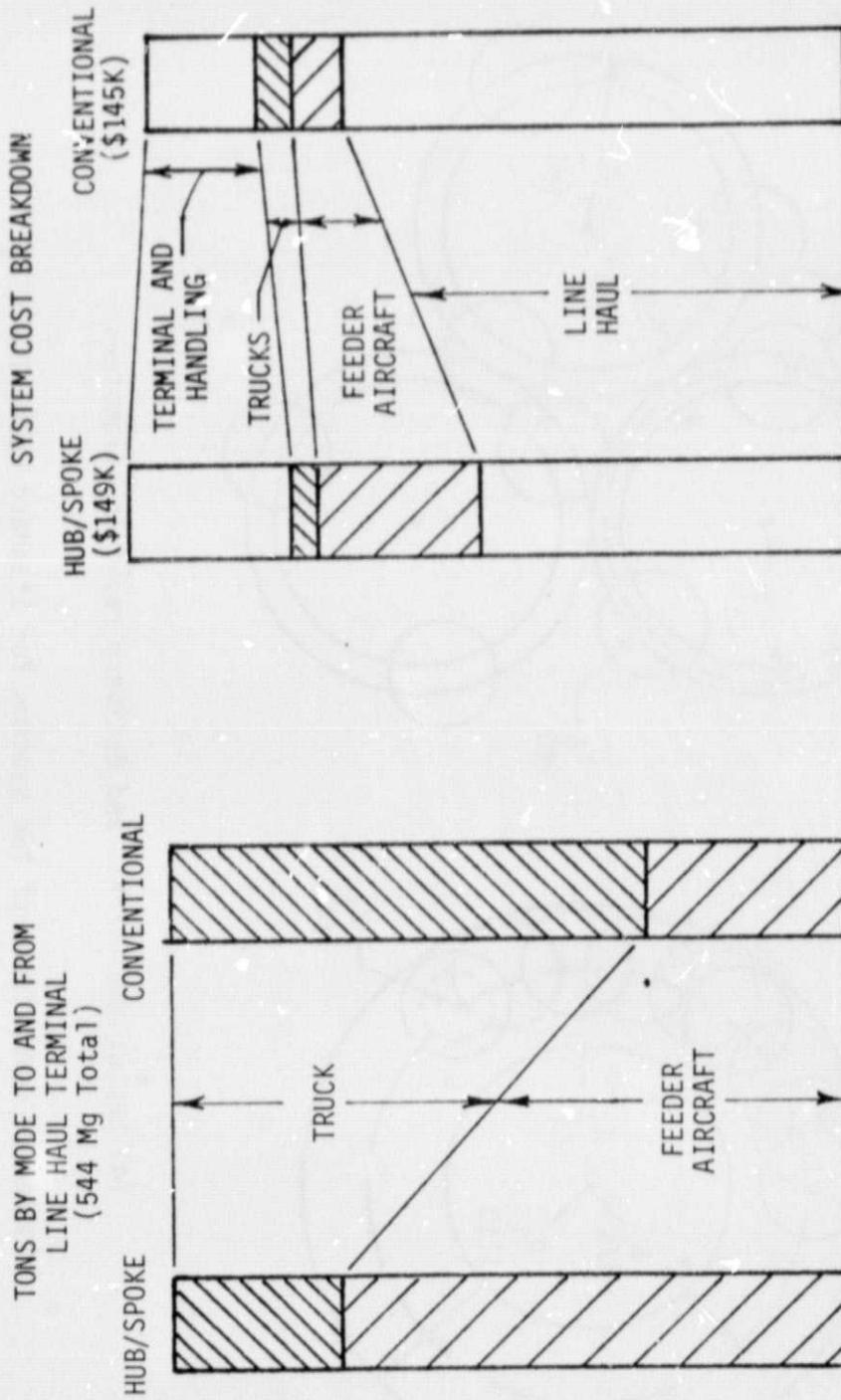
(b) Distributed-load freighter
Gross weight = 1283 Mg (1414 tons)

Fig. 3.- Line-haul aircraft for standard case (Table I).



(a) Layout and traffic and delivery radii in kilometers

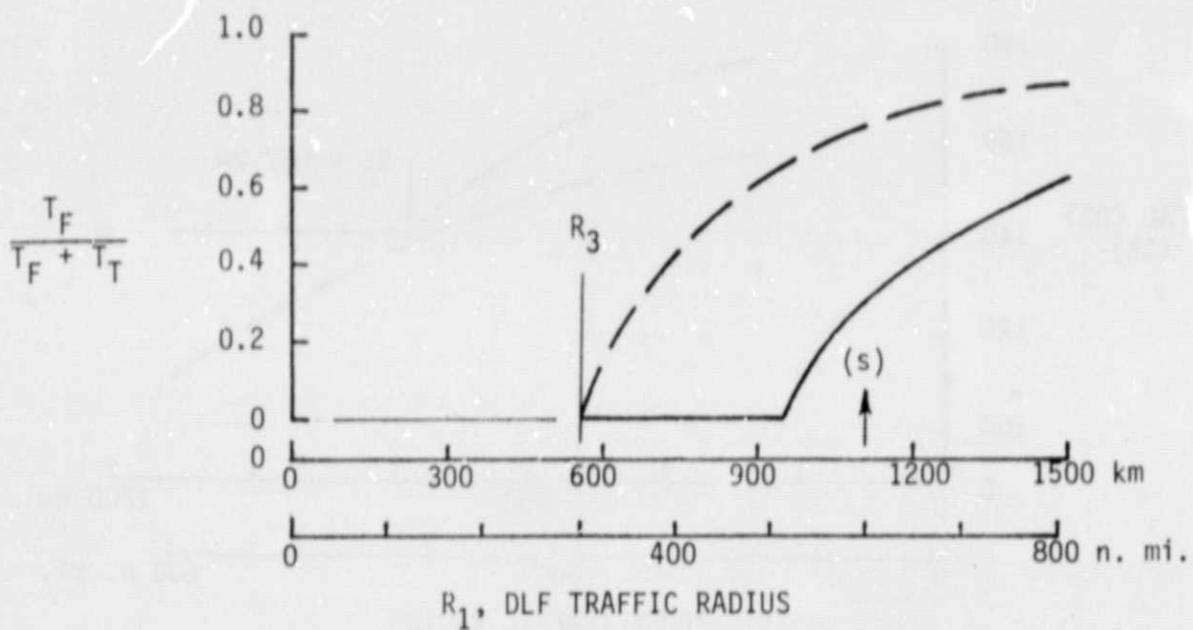
Figure 4.- Comparisons of two systems for Standard Case (Table I).



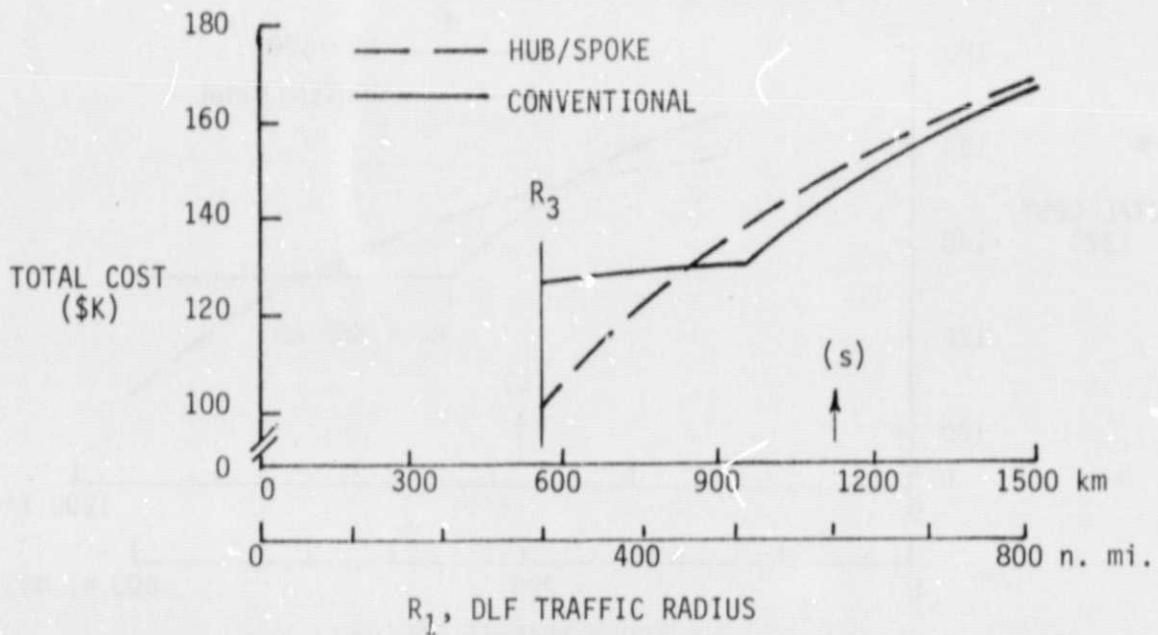
(b) Evaluation of freight tonnage to terminals and cost breakdown (Standard Case - Table I)

Figure 4. - Concluded.

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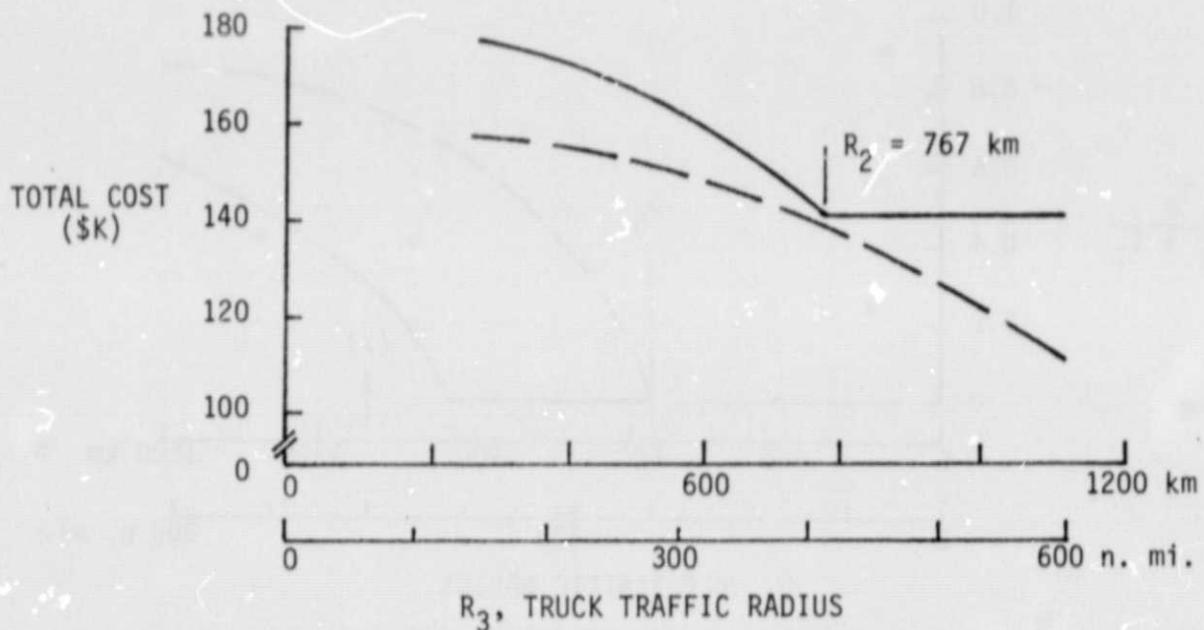


(a) Fraction of cargo transported by feeder aircraft into line-haul terminal

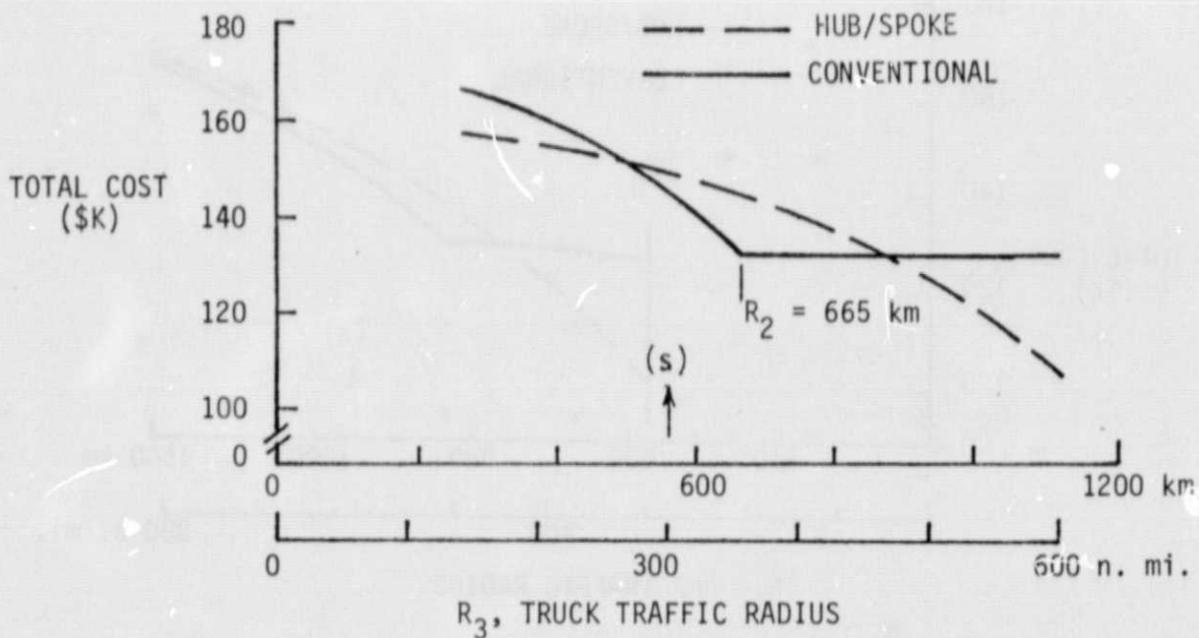


(b) Total cost

Fig. 5.- Effect of DLF traffic radius (R_1).

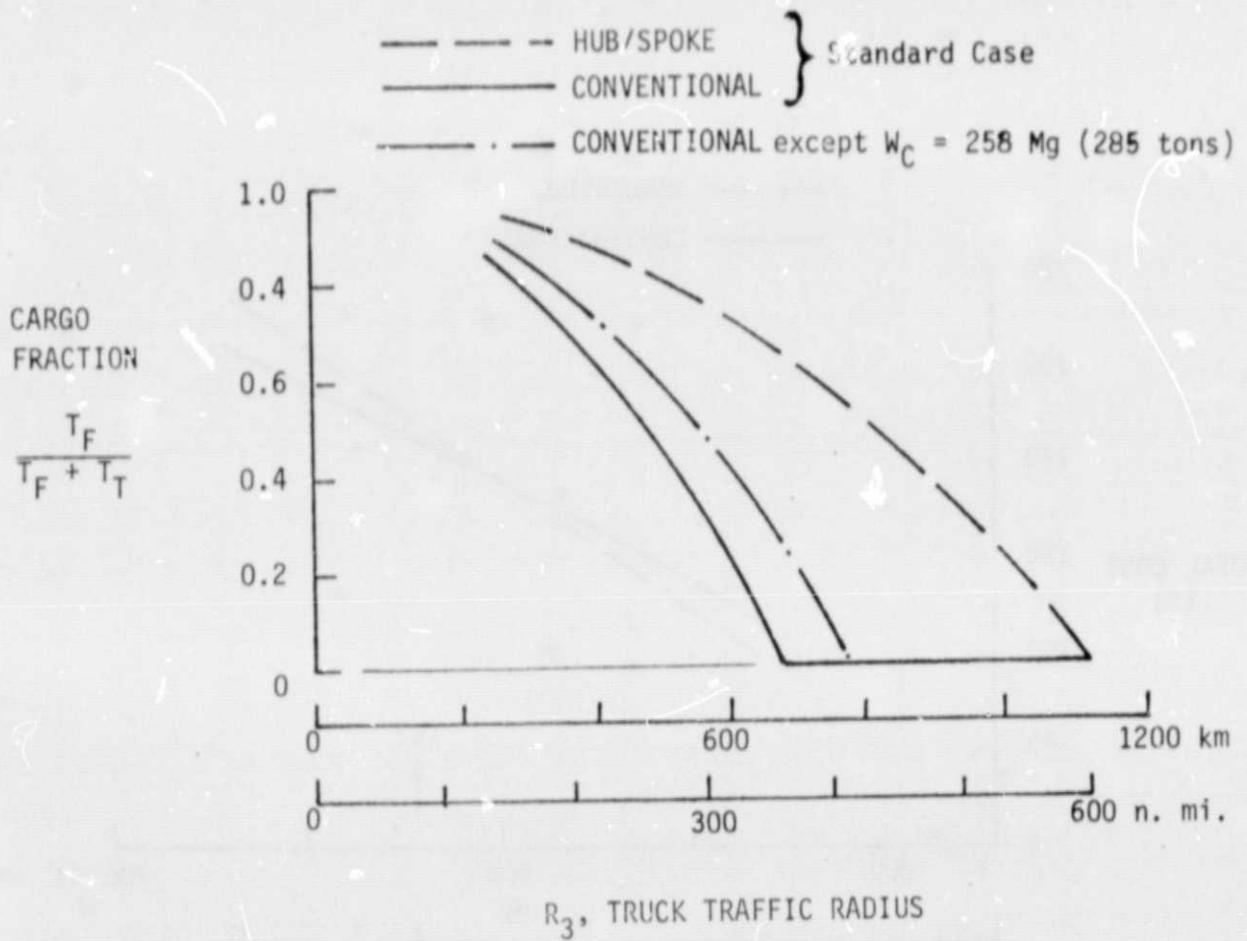


(a) Total cost variation for $W_C = 258$ Mg (285 tons)



(b) Total cost variation for standard case

Fig. 6.- Effect of truck traffic radius, R_3



(c) Fraction of cargo transported by feeder aircraft into line-haul terminal

Fig. 6.- Concluded.

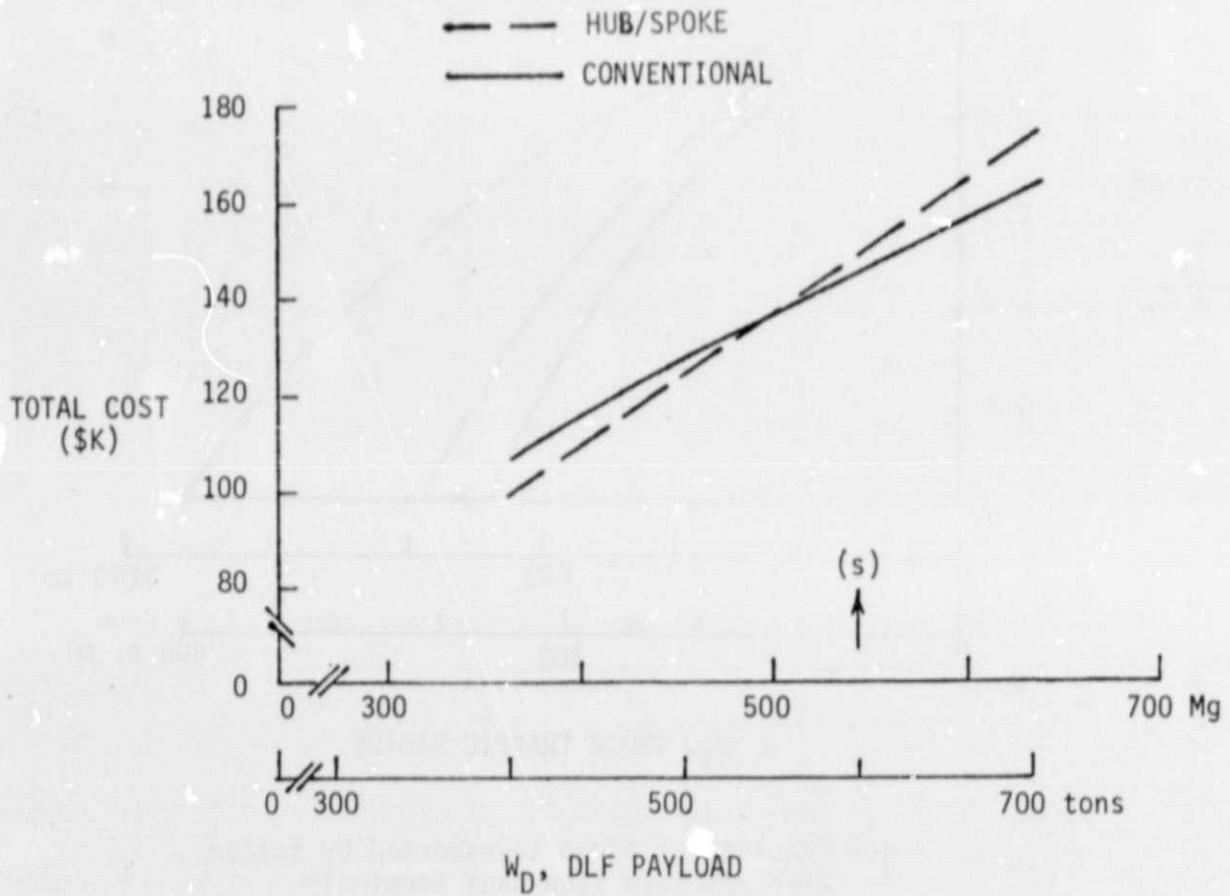
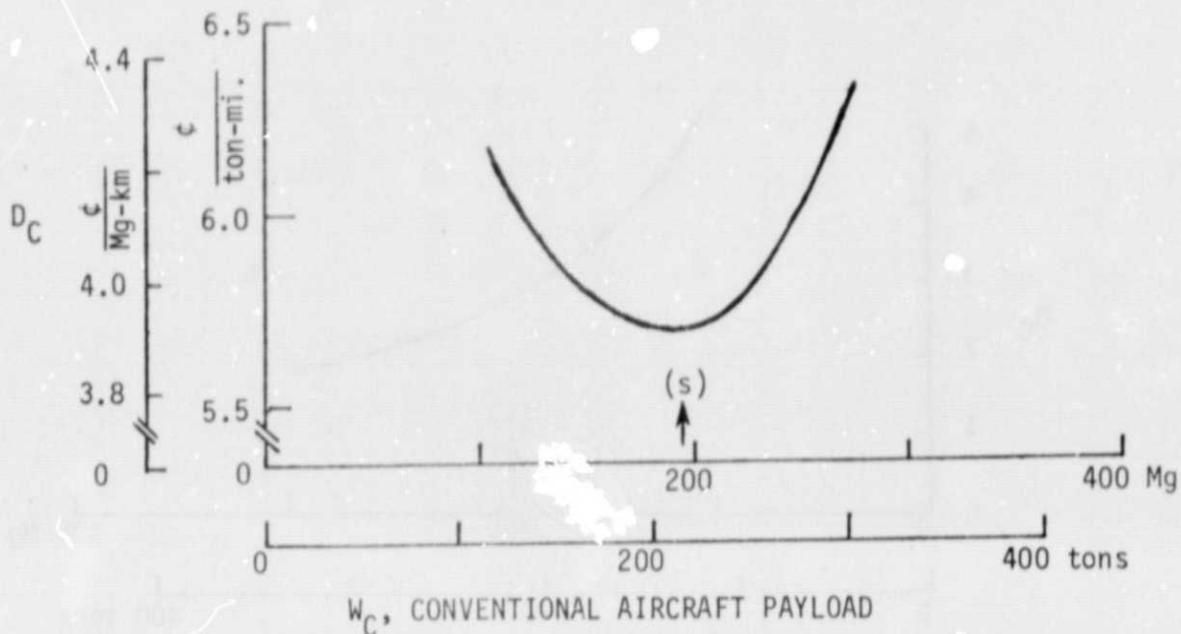
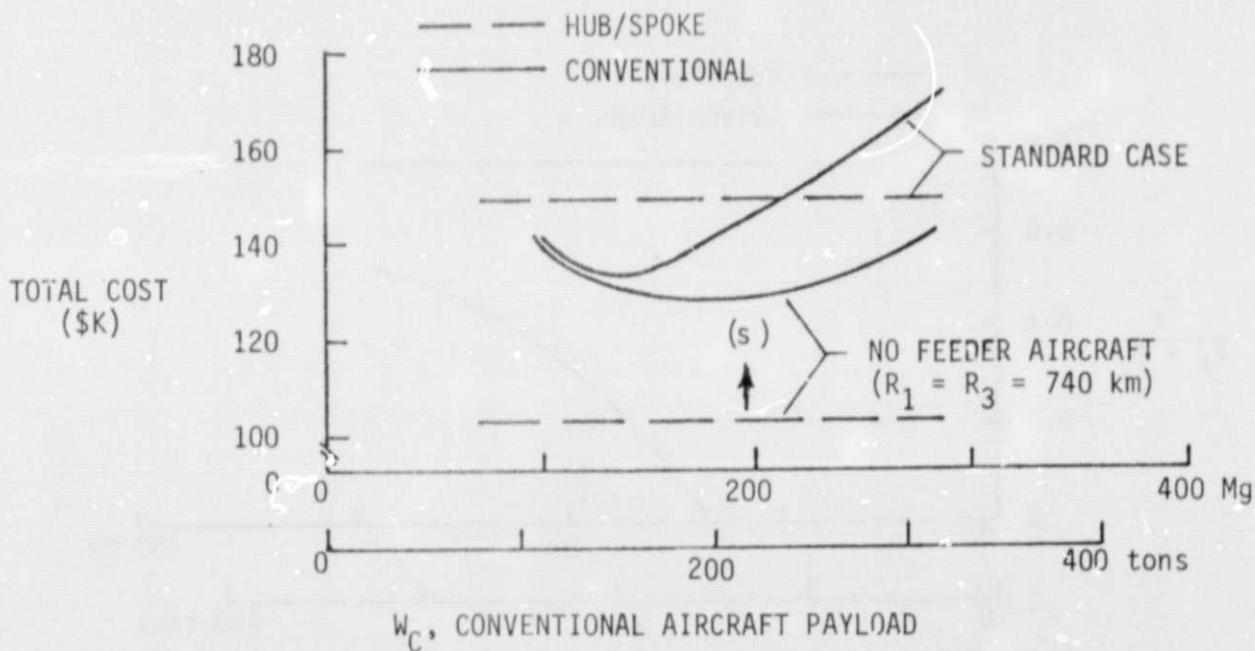


Fig. 7.- Effect of DLF payload, W_D .

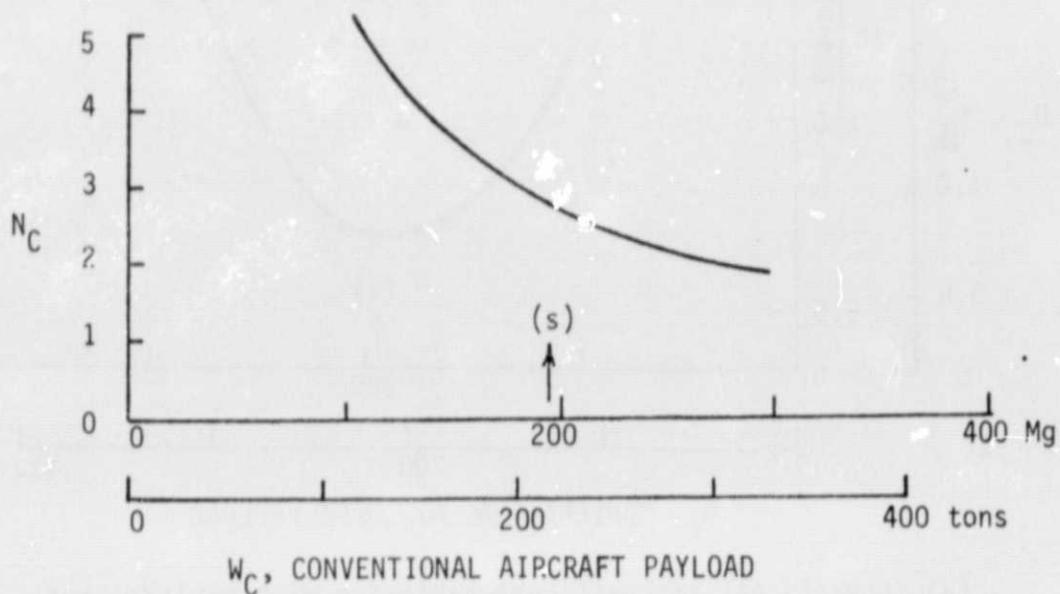


(a) Conventional aircraft cost variation with payload (refs. 3 and 4)

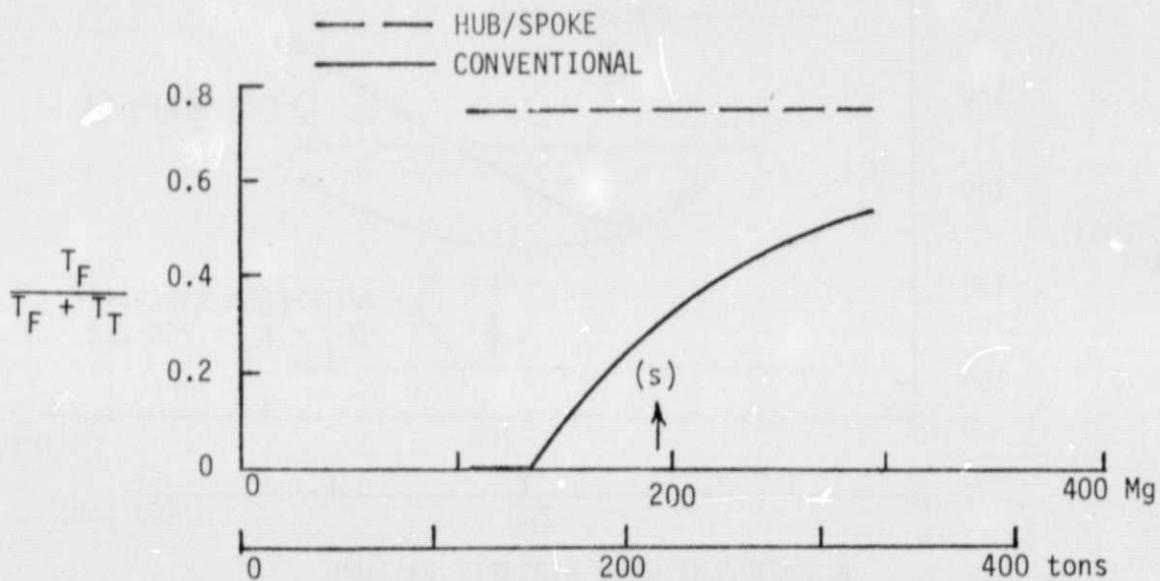


(b) Total cost

Fig. 8.- Effect of conventional aircraft payload, W_C



(c) Number of conventional aircraft terminals. Standard Case



(d) Fraction of cargo transported by feeder aircraft into line-haul terminal. Standard Case.

Fig. 8.- Concluded.

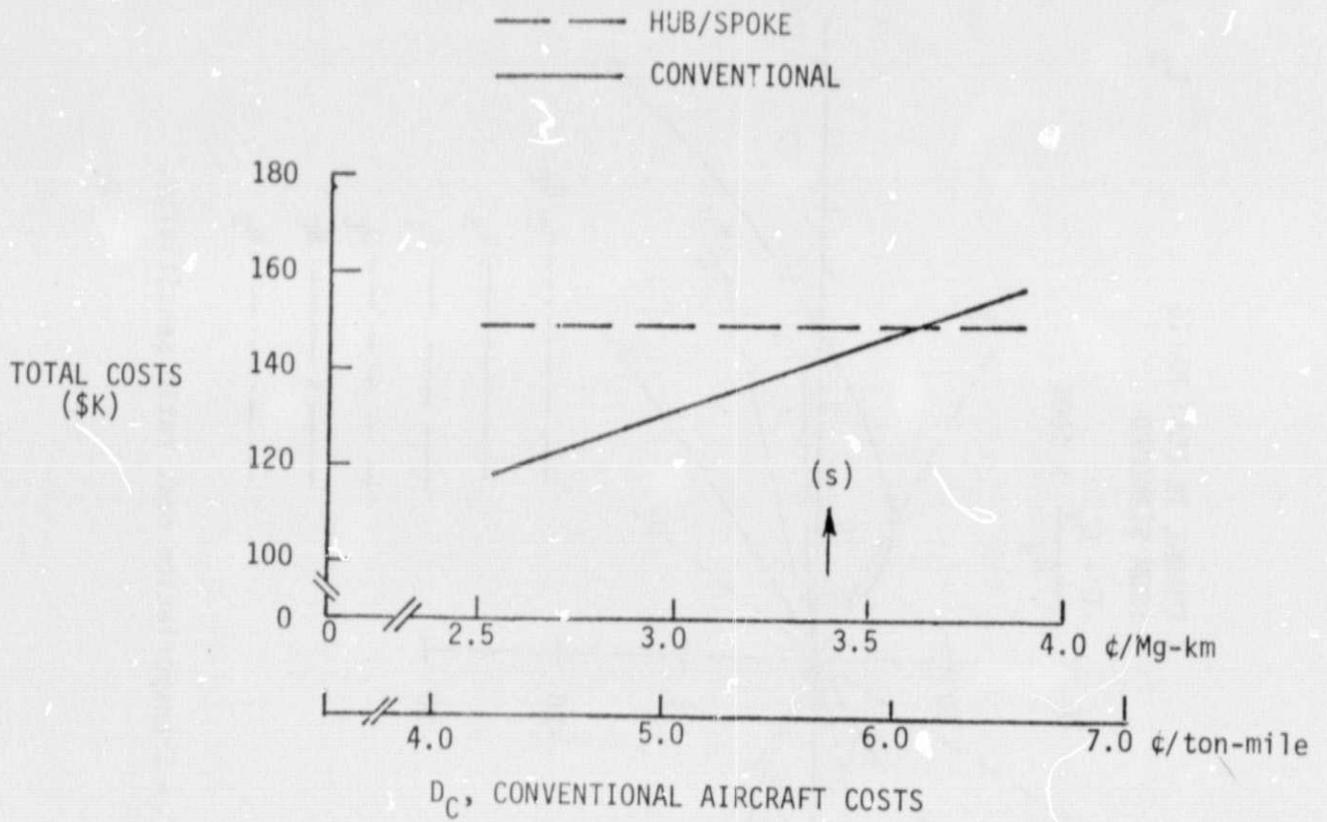


Fig. 9.- Effect of conventional aircraft economics

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$$C_s = \frac{DLF \$}{CONV. A/C \$} = 1.024$$

(STANDARD CASE)

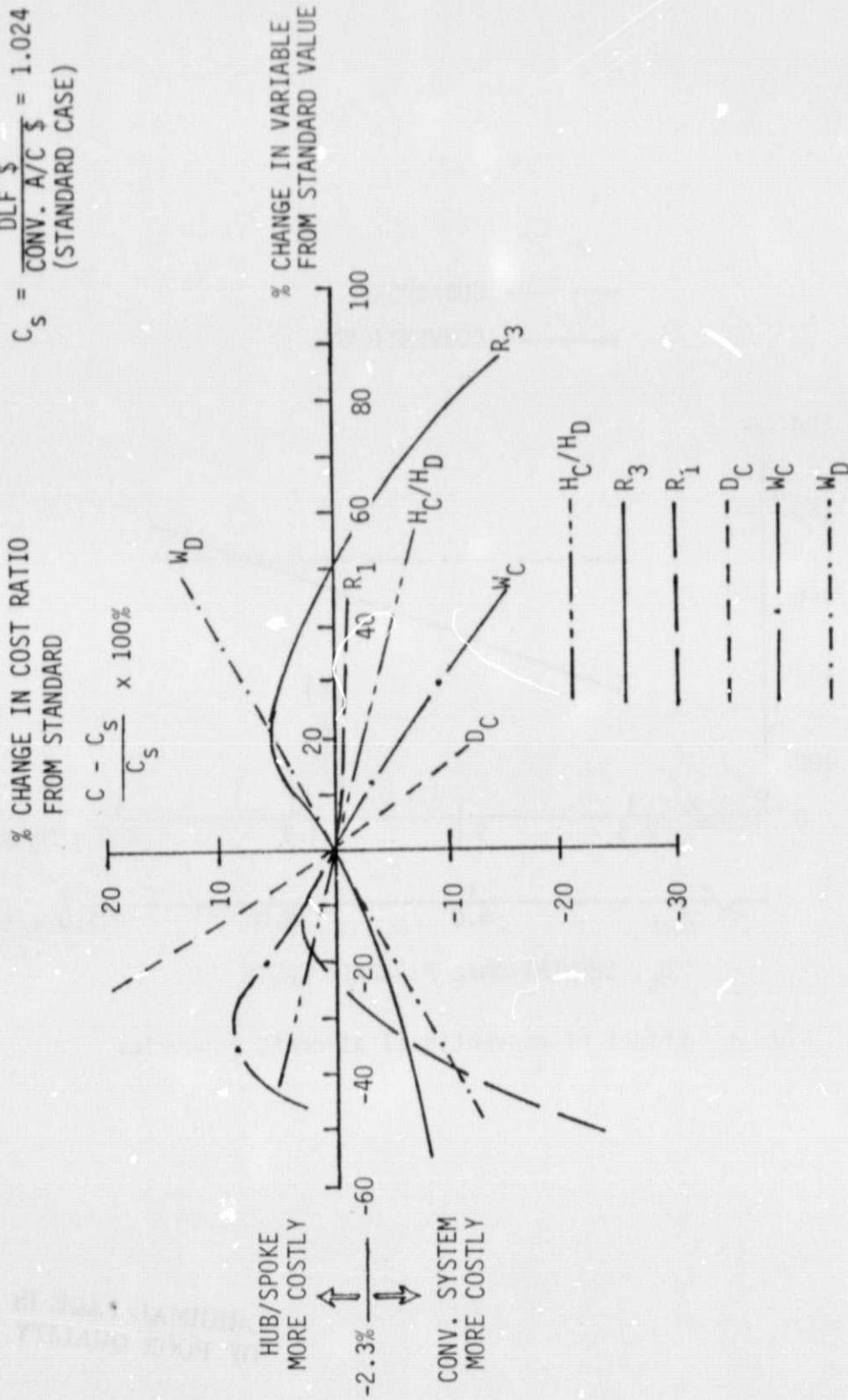
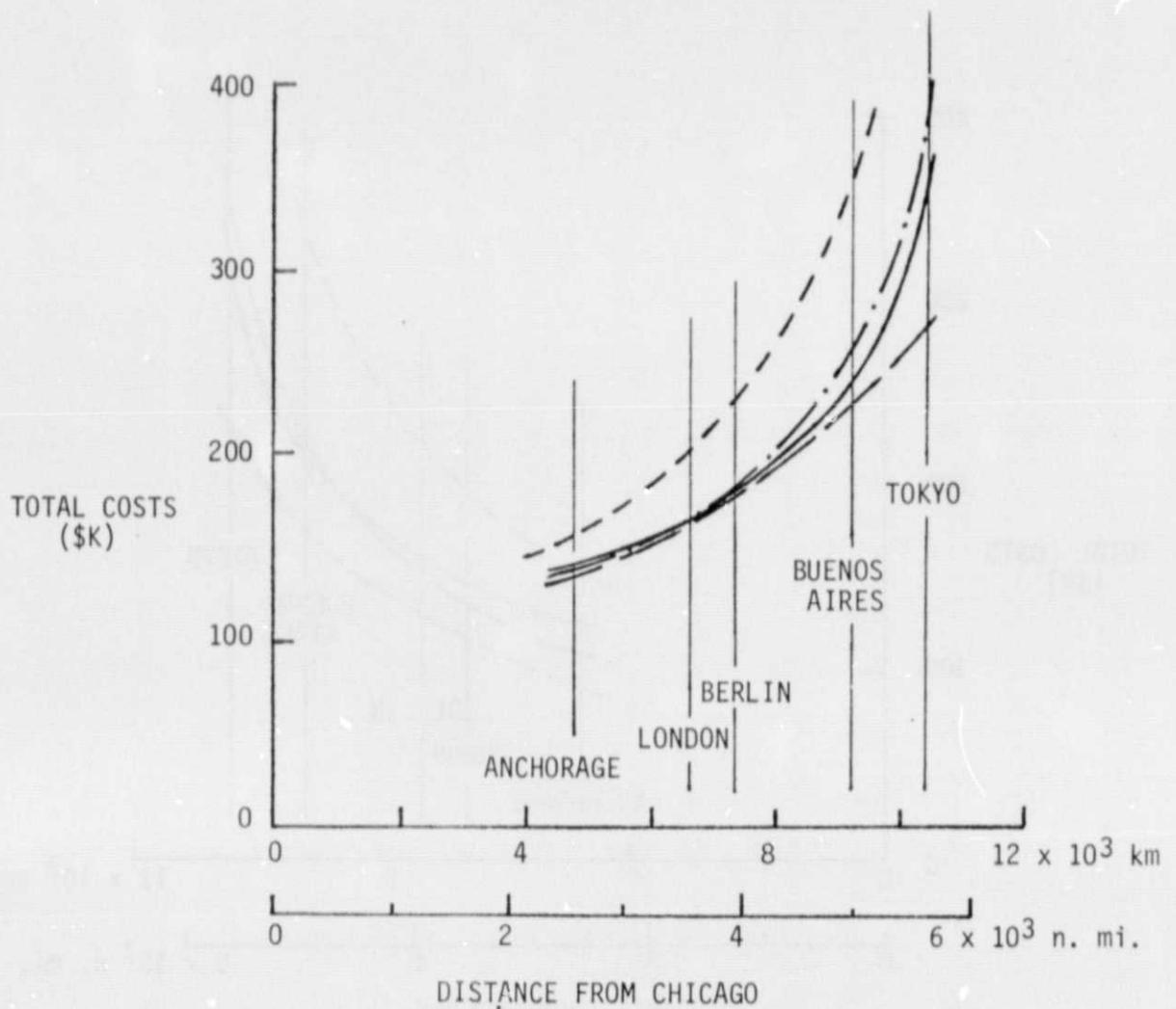
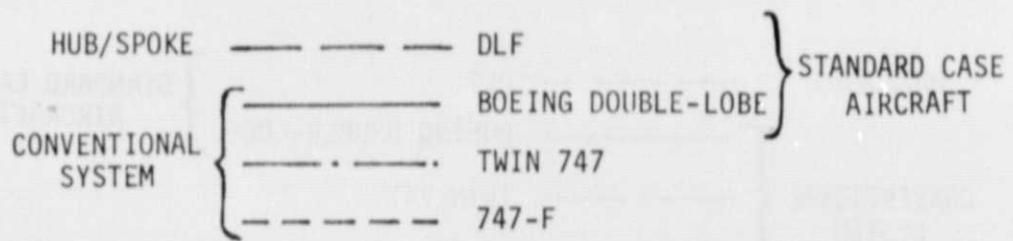


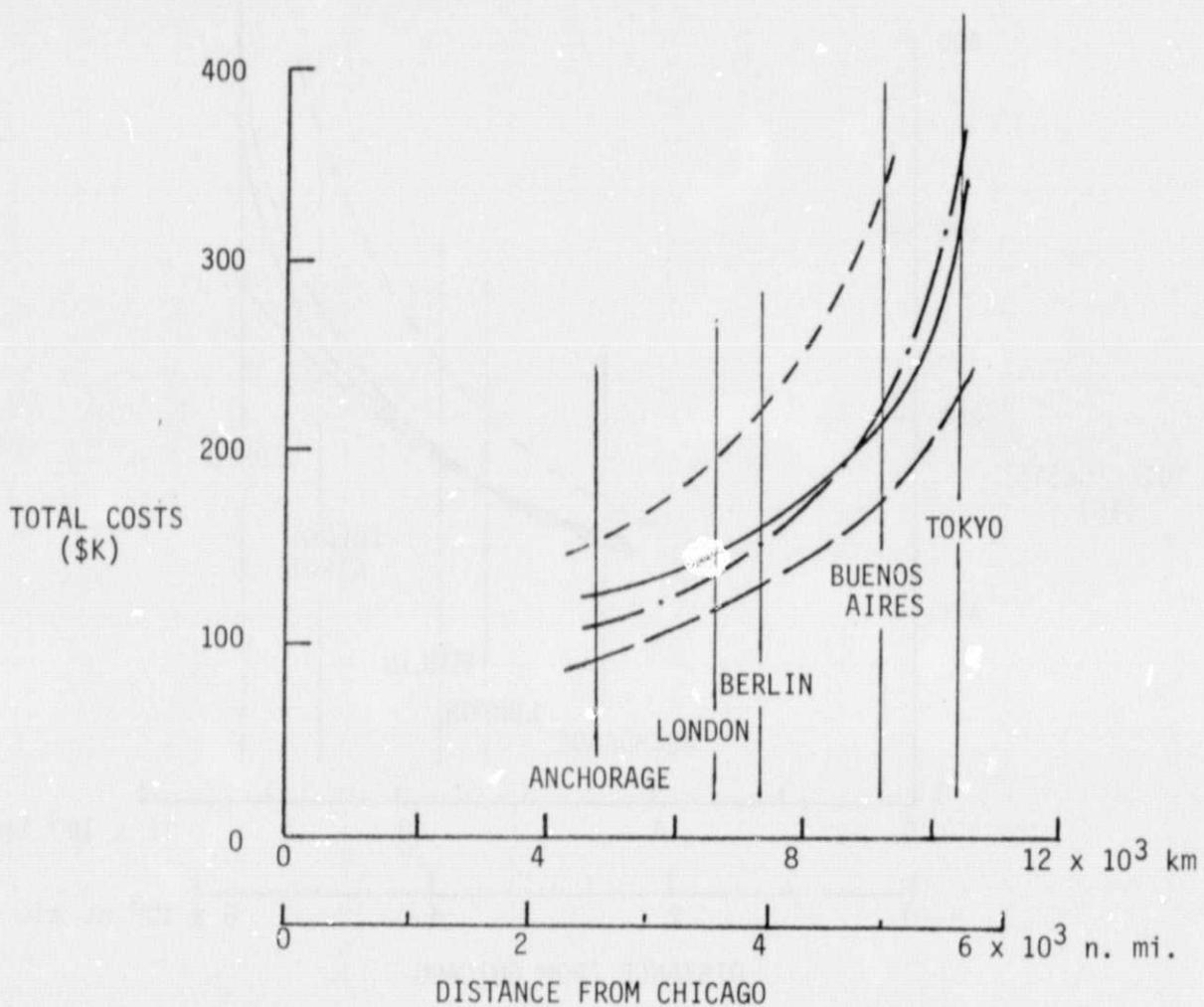
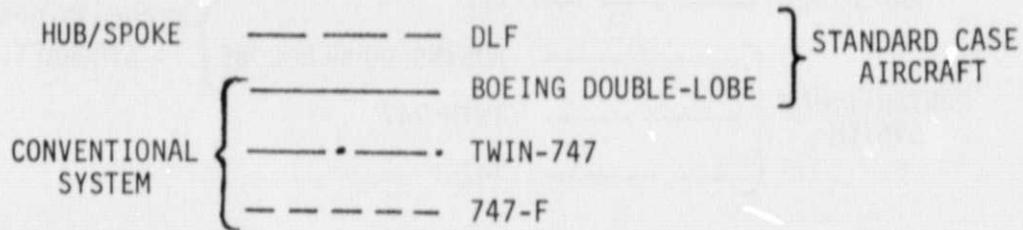
Fig. 10.- Transportation cost ratio sensitivity.



(a) Standard case with feeder aircraft

Fig. 11.- Effect of line-haul range on total cost comparison.

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(b) No feeder aircraft. $R_1 = R_3 = 741 \text{ km (400 n. mi.)}$

Fig. 11.- Concluded.

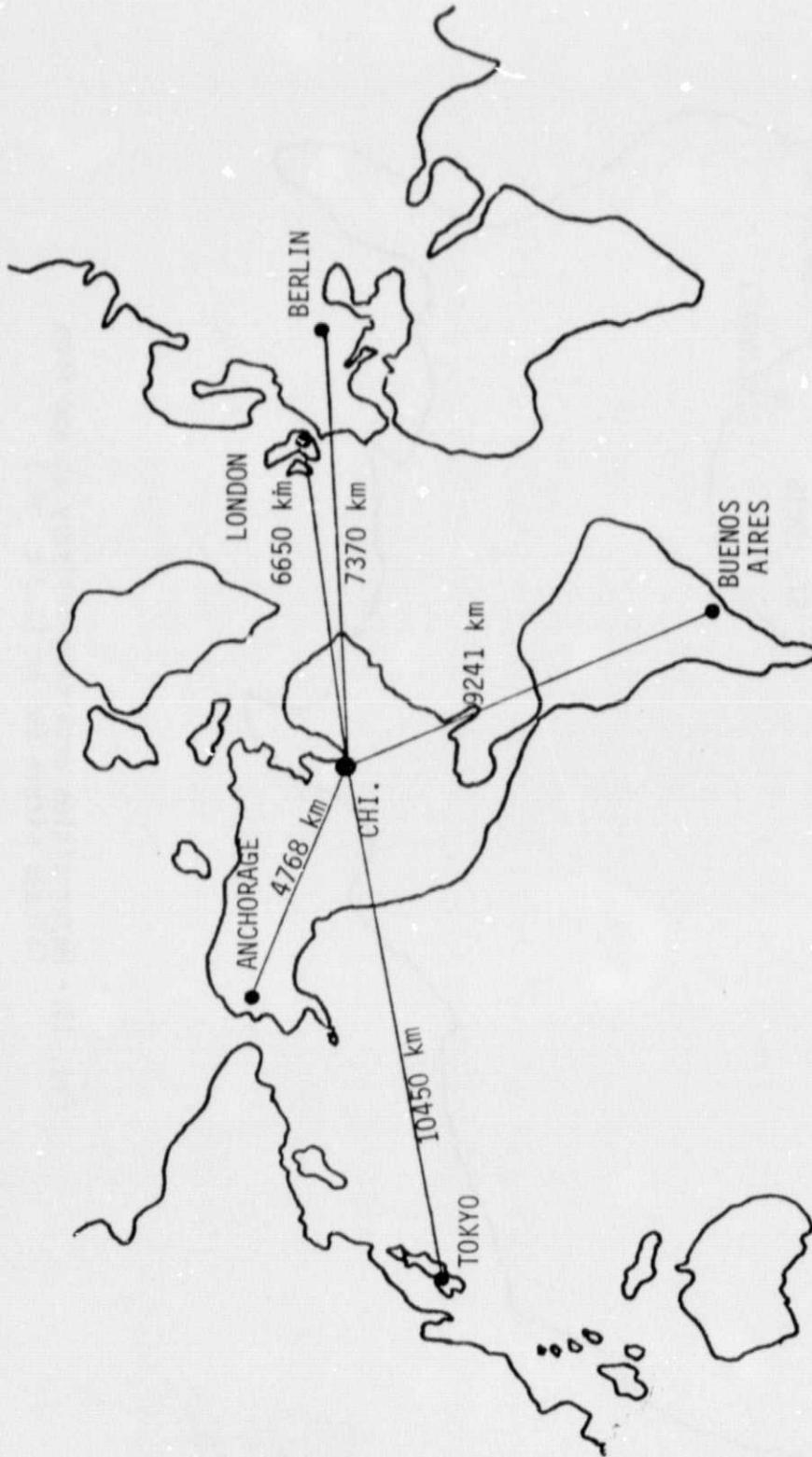


Fig. 12.- Line haul delivery system with Chicago as hub origin.

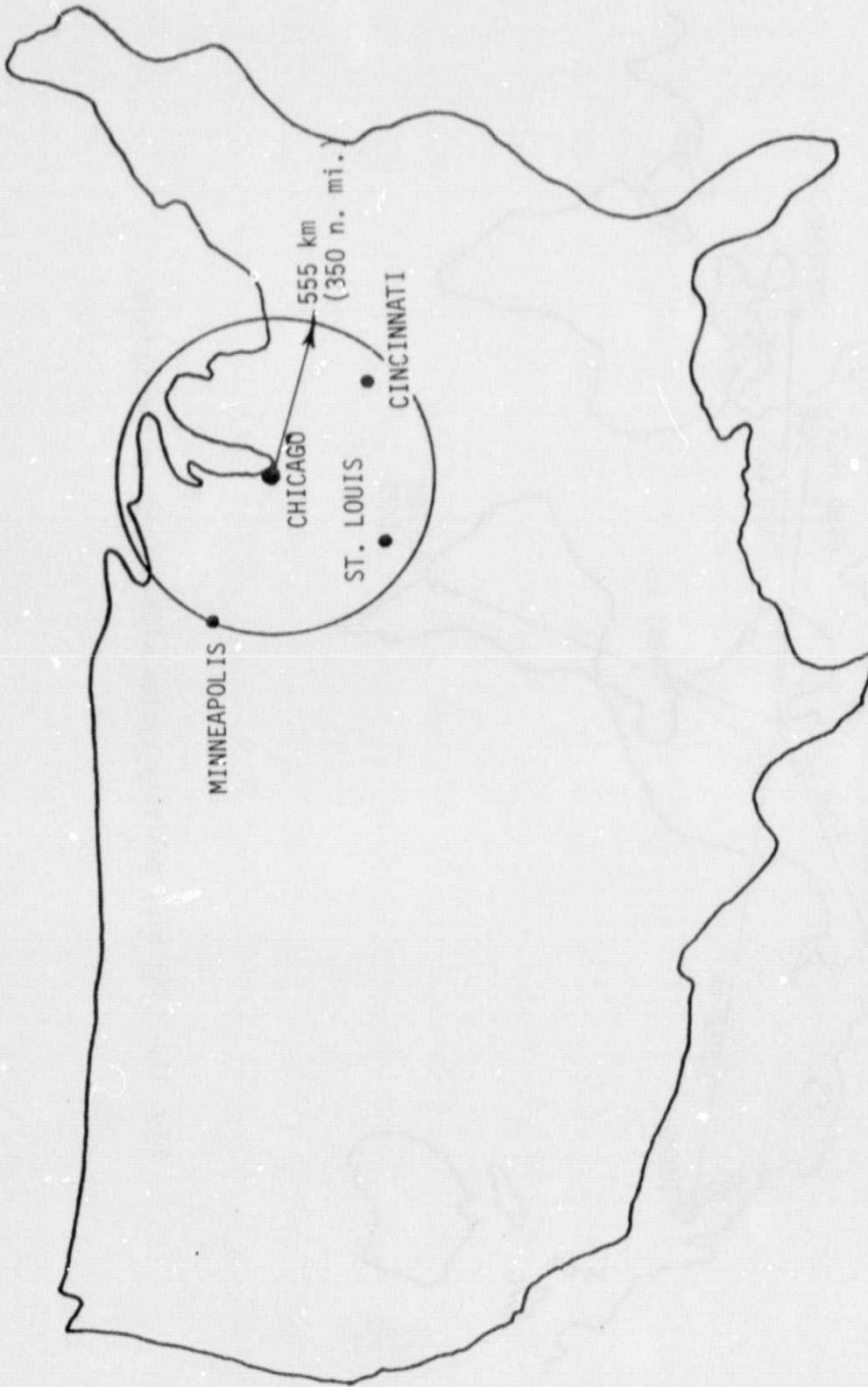


Fig. 13.- Major cities providing delivery to and from Chicago within 555 km (350 n. mi.)

1. Report No. NASA TM-72656		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle PRELIMINARY ANALYSIS OF HUB AND SPOKE AIR FREIGHT DISTRIBUTION SYSTEM				5. Report Date April 1978	
				6. Performing Organization Code 31.400	
7. Author(s) Allen H. Whitehead, Jr.				8. Performing Organization Report No.	
9. Performing Organization Name and Address NASA Langley Research Center Hampton, Virginia 23665				10. Work Unit No. 791-40-13-01	
				11. Contract or Grant No.	
12. Sponsoring Agency Name and Address National Aeronautics & Space Administration Washington, DC 20546				13. Type of Report and Period Covered Technical Memorandum	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract A brief analysis is made of the hub and spoke air freight distribution system which would employ less than 15 hub centers worldwide with very large advanced distributed-load freighters providing the line-haul delivery between hubs. This system is compared to a more conventional network using conventionally-designed long-haul freighters which travel between numerous major airports (typical of today's 747-F operation). Both trucks and short haul, "feeder" aircraft are used to deliver cargo to the airports. The analysis calculates all of the transportation costs, including handling charges and pickup and delivery costs. The results show that the economics of the hub/spoke system are severely compromised by the extensive use of feeder aircraft to deliver cargo into and from the large freighter terminals. Not only are the higher costs for the smaller feeder airplane disadvantageous, but their use implies an additional exchange of cargo between modes compared to truck delivery. The conventional system uses far fewer feeder airplanes, and in many cases, none at all. When feeder aircraft are eliminated from the hub/spoke system, however, that system is universally more economical than any conventional system employing smaller line-haul aircraft.					
17. Key Words (Suggested by Author(s)) Air Freight Hub/spoke Cargo aircraft Freight Distribution System			18. Distribution Statement Unclassified - Unlimited Subject Category 03		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 35	22. Price* \$4.50