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EFFECT OF PRESENT TECHNOLOGY ON AIRSHIP CAPABILITIES

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ABSTRACT: This paper presents the effect of updating past airship designs using current materials and propulsion systems to determine new airship performance and productivity capabilities. New materials and power plants permit reductions in the empty weights and increases in the useful load capabilities of past airship designs. The increased useful load capability results in increased productivity for a given range, i. e., either increased payload at the same operating speed or increased operating speed for the same payload weight or combinations of both.

Estimated investment costs and operating costs are presented to indicate the significant cost paraments in estimating transportation costs of payloads in cents per ton mile. Investment costs are presented considering production lots of 1, 10 and 100 units. Operating costs are presented considering flight speeds and ranges.

INTRODUCTION

As the result of many inquiries, Goodyear Aerospace Corporation (GAC) conducted studies relative to the projected costs for operating basic airships as transportation system vehicles. Past designs, a larger size of past designs, and the direct substitution of present materials and propulsion systems for past materials and propulsion systems were considered in the studies. The studies attempted to be conservative by not considering heavy take-offs in calculating useful load capabilities or redesigns of the airship to obtain: lower empty weights, aerodynamic lift, or greater flight speeds. Background on past GAC airship designs, the effect of substituting present technology on airship performance capability, and a simplified cost analysis considering investment costs and operating costs of airships as transportation vehicles are presented.

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SUMMARY OF UNITED STATES AIRSHIPS

As part of the studies GAC reviewed past airship designs and their characteristics. Goodyear has been involved with design, construction, testing and operation of most of the United States non-rigid and rigid airships. A listing of these airships is presented in Table I.

Table I - U. S. Navy/GAC Airships*

Dates In Use	Airship Class	Number Produced	Mission
1931-33**	Akron/Macon	2	U.S. Navy Patrol And Aircraft Carrier
1931-45	K Class	135	Patrol And Escort
1955	ZPG-5K	18	Patrol And Escort
1951-58	ZPG-2(2W)	17	ASW And AEW Patrols
1956-61	ZPG-3W	4	AEW Patrols
1941-47	L Class	150	Convoy/Escort
1947-1972	GZ-(L) Class	10	Goodyear Advertising

*Above listing represents about 75 percent of all U. S. airships built
**Rigids - others are non-rigid or pressurized structures

Goodyear's non-rigid airship production experience versus the characteristic airship length is presented in Figure 1.

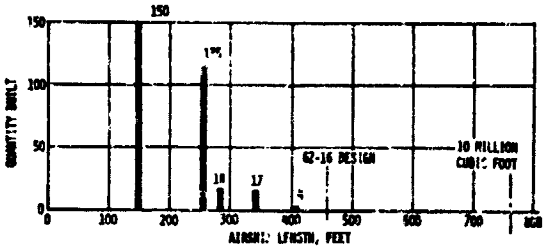


Figure 1
GAC Non-Rigid Airship Experience

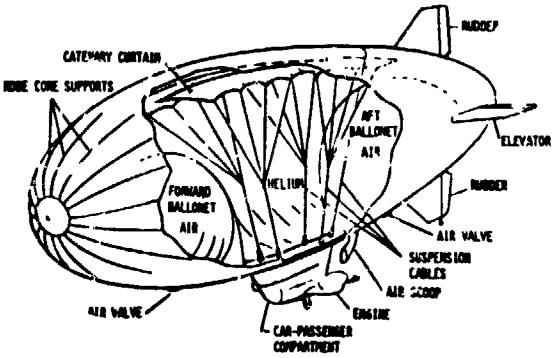


Figure 2
Typical Airship Design

The quantities of each size built indicates that most of the experience is with airships 150 to 260 feet in length. The GZ-16 design represents one of the large non-rigid designs completed by Goodyear for government consideration. Also indicated is the length of an airship with a volume of 10 million cubic feet. A typical non-rigid airship design is presented in Figure 2. The airship envelope group is basically a foldable assembly including the basic envelope, catenary attachments, cables and ballonet. Components and subassemblies, such as, the nose cone supports, valves and fans are rigid structures attached to the envelope. The car group is a rigid assembly of such items as the car structure, engines, controls, pilot station, cargo bay, etc. The car group is attached to the envelope through use of external and internal catenary curtains. Assembly of the airship-car to envelope, etc. - is accomplished in a hangar. The envelope is inflated with helium and a weighted net placed over the envelope controls the envelope distance above the floor. The rigid structures are attached to the envelope and corresponding cable adjustments are made while the lifting envelope is restrained. Once the car is attached and the ballonet filled with air, the net can be removed. The functions of the ballonet are shown in Figure 3.

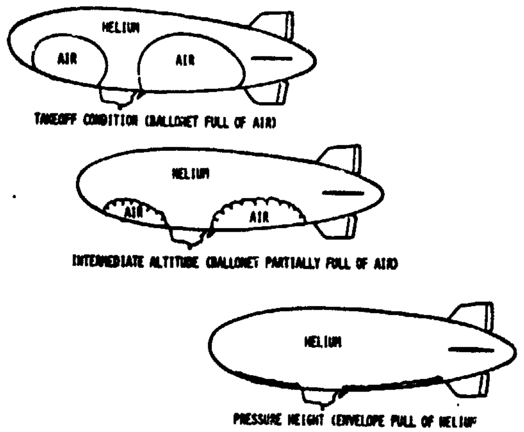


Figure 3
Airship Ballonet Operation During Flight

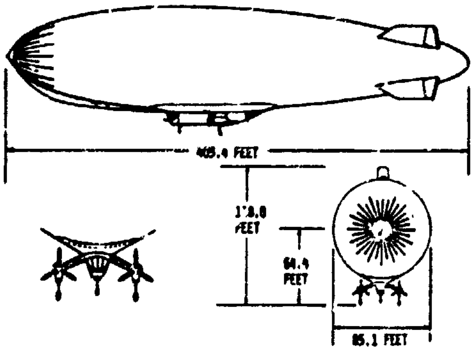


Figure 4
Goodyear ZPG-3W Airship

The ballonet controls the buoyancy and attitude of the airship from takeoff to pressure height or maximum flight altitude. The air in the ballonet is discharged automatically as the airship ascends to allow expansion of the helium gas and the ballonet maintains a constant envelope pressure during flight. The ballonet is essentially empty at the pressure height altitude condition. Flying higher than pressure height results in envelope pressures above design conditions. The ballonet can also provide static trim in pitch during operations of the airship.

The largest non-rigid airship to become operational with the Navy is presented in Figure 4. Exceptional performance was attained by the U.S. Navy using the Goodyear ZPG-3W despite bad weather during long endurance station keeping/reconnaissance missions. Advanced ground handling equipment and methods were developed for the ZPG-3W airship that reduced ground crew manpower requirements during landing, takeoff and mooring. Goodyear believes that large non-rigid airships should be considered for cargo transportation. The rationale includes:

o Rigids had to be used initially for large sizes because high strength envelope fabric did not exist for non-rigids.

o New and efficient envelope materials are available for large non-rigid airships.

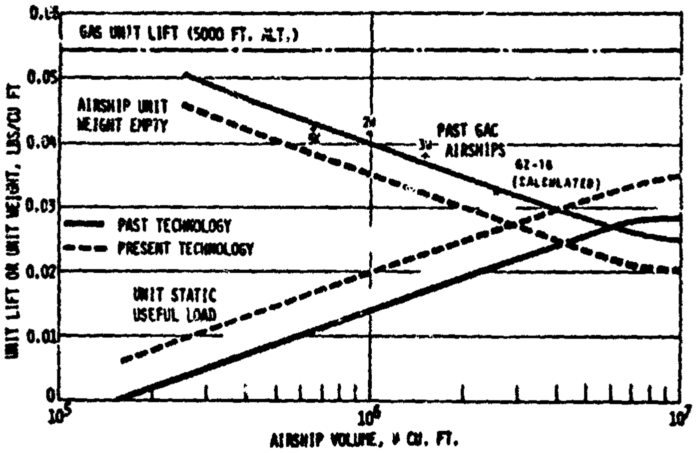
o New materials are:

  . Twice as strong as steel for same thickness.
  . Six times as strong as steel for same weight.

o Not one non-rigid airship has been lost due to structure or mechanical failure.

EFFECT OF TECHNOLOGY ON AIRSHIP PERFORMANCE CAPABILITIES

The cargo capacity of airships is based on the amount of air they displace, their empty weight, the propulsion requirements for cruising speed, and the fuel requirements for the operating distances and speeds. One approach for indicating their capability is the gas unit-static lift per cubic foot as presented by the horizontal upper curve in Figure 5.



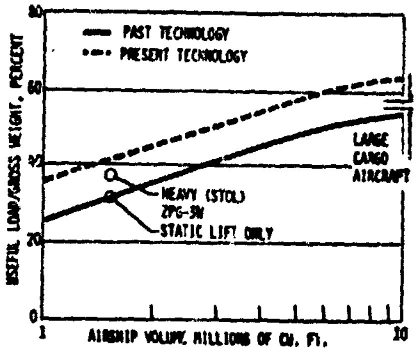


Figure 5
Airship Unit Weight And Static Lift Characteristics

Figure 6
Airship Useful Load Efficiency

Its value is the difference between air and helium weights at a nominal helium purity value at 5,000 feet (0.0545 lbs/cu. ft.). The next lower solid curve presents the calculated empty unit weight (weight of airship empty/volume of air displaced by airship) of airships using past materials and engines. Past and present operational GAC airships are indicated on the curve for reference. The lowest solid curve is the difference between the gas unit lift and the airship unit empty weight. This difference is useful load for a neutrally buoyant airship and is available for fuel and cargo. The dashed curves present the same information for airships using present envelope materials and turboprop engines. These newer materials and power plants offer a significant increase in useful load compared to past materials and engines.

Another method of presenting vehicle efficiency is to plot the percentage of useful load to gross vehicle weight. Values of this parameter are presented for airships displacing 1 to 10 million cubic feet of air in Figure 6. The solid curve represents airships made using past materials and engines. The dashed curves represent the same designs using present materials and engines. Both curves are based on take-off with a neutrally buoyant airship. The ZPG-3W Airship value and that for a large cargo aircraft are presented for reference. The effect of "taking off" heavy (STOL) also can increase the value of the parameter. For example the value increased from 31 to 38.6 percent as indicated by symbols on the figure when the ZPG-3W Airship operated in the heavy condition.

From the useful load values, the payload can be calculated versus range for the different size airships. Payload values at 75 knots cruising speed and 5,000 feet altitude were calculated for airships ranging in size from 1.5 to 10 million cubic feet. The results are presented in Figure 7 using past and present technology considering only static lift.

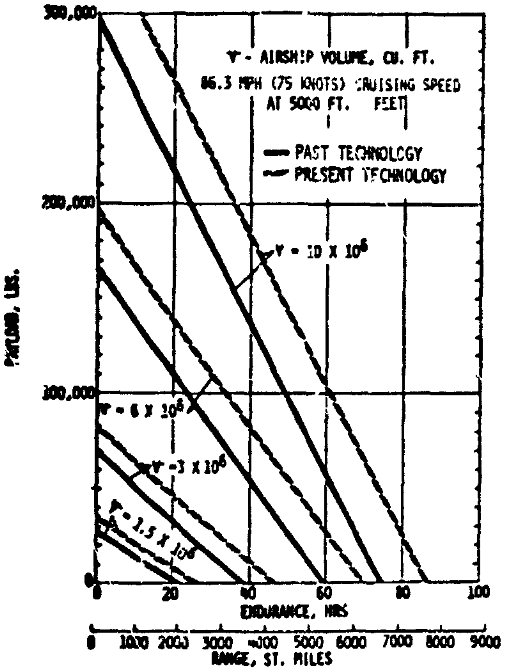


Figure 7
Payload Weight Capabilities Versus Range For Airships Cruising At 75 Knots

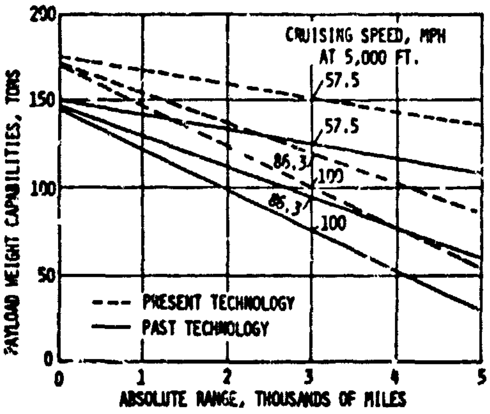


Figure 8
Payload Weight Capabilities Versus Range For 10 Million Cu. Ft. Airships At Different Cruising Speeds

From the useful load capabilities of the airships, presented in the past curves, the payload capacities of 10 million cubic feet displacement airships were calculated for 3 different cruising speeds and for ranges to 5,000 miles. The results are presented in Figure 8. Zero range represents a zero fuel condition. The reduction in payload weight capability with increasing range is directly related to increasing fuel weight requirements. For ranges of approximately 2,500 miles and a reserve of 500 miles, the payload capability can be determined from the 3,000 mile absolute range values. Payload capabilities from 75 to 150 tons are available, depending on the cruising speed and whether past or present technologies are used in the airship's construction. For ranges of approximately 1,500 miles and a 500 mile reserve, the payload capability can be determined from the 2,000 mile absolute range values. Payload capabilities of nearly 100 to 160 tons are available.

The value of payload transported in ton-miles per gallon of fuel is of interest from a fuel conservation standpoint. The values for several cruising speeds were calculated for a single size airship. The results are presented in Figure 9.

Values from 10 to 50 ton-miles per gallon are available on flights with an absolute range of 3,000 miles. Values from 13 to 62 ton-miles per gallon are available on flights with an absolute range of 2,000 miles. The values are greatest at the lowest speeds and shortest ranges.

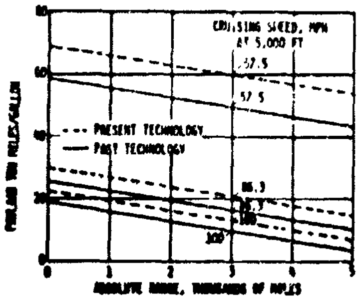


Figure 9
Payload Ton Miles/Gallon Vs Range And Speed For 10 Million Cu. Ft. Airships

SIMPLIFIED COST ANALYSIS

A simplified cost analysis was made to determine the costs per ton-mile for delivering cargo 2,500 and 1,500 miles using airships of 10 million cubic feet displacement flying at 5,000 feet altitude.

The characteristic dimensions for the 10 million cubic feet displacement airship based on design considerations used with the ZPG-3W and GZ-16 Airships are presented in Figure 10. No new design innovations and only proven fabrication, dimensional and operational practices using present day materials and engines were considered for calculating performance and costs. The costs are grouped as investment and direct operating costs in Table II. The annual investment costs are presented as a portion of initial airship costs for ease of presentation. The direct operating costs are grouped into labor and material costs per hour of flight

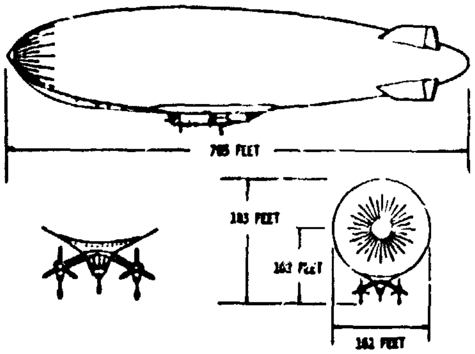


Figure 10
Typical 10 Million Cubic Feet
Displacement Airship

Table II - Preliminary Airship Transportation Cost Model

- Investment Costs
  - Annual Costs
    - Depreciation Of Investment
    - Interest On Investment
    - Insurance
  - Initial Investment Costs
    - Non-Recurring - 1st Unit, 10 Units, 100 Units

- Direct Operating Costs
  - Labor Costs/Flight Hour
    - Flight Crew
    - Maintenance Technicians
    - Ground Service Crew
  - Material Dollars/Flight Hour
    - Fuel/Oil
    - Helium
    - Spares/Equipment

User investment costs are presented in Table III.

Table III - Annual Investment Costs

Annual Costs (As A Portion Of Initial Investment Costs)

1. Depreciation = $\frac{\text{Initial Cost - 0.20 Initial Cost}}{\text{10 Years}}$ = 0.080 Initial Investment Costs Per Year
2. Interest - (Average Over 10 Years = 0.040 Initial Investment Costs Per Year
3. Insurance = 0.03 (Average Depreciated Cost For 10 Years) = 0.018 Initial Investment Costs Per Year

Total = 0.138 Initial Investment Costs Per Year

Initial Investment Costs - Single, Average Of 10, Average Of 100 Units - 2500 Mile Operating Range

Airship Performance* Operating Characteristics Speed, MPH	Range, Miles	Cargo Tons	Unit Costs** Millions 1st Unit	Average For 10	Average For 100
57.5	2500	151	27.6	19.7	13.8
86.3	2500	120	28.1	20.1	14.0
100	2500	101	28.6	20.4	14.3

*Differences In Cargo Capacity Reflect Propulsion System And Fuel Weights For The Same Size Airship At Operating Flight Speeds To A Maximum Range Of 3,000 Miles.

**Differences In Costs Reflects Propulsion System Costs For The Operating Flight Speeds.

Annual Investment Costs Per Ton Mile - 2500 Mile Operating Range

Airship Performance Operating Characteristics Speed, MPH	Range, Miles	Cargo Tons	Productivity* Ton Miles Each Year	Costs/Ton Mile, Cents Average For 10 Airships	Average For 100 Airships
57.5	2500	151	3.47×10^7	7.84¢	5.5¢
86.3	2500	120	4.15×10^7	6.68¢	4.65¢
100.0	2500	101	4.04×10^7	6.98¢	4.88¢

*Productivity Based On 4,000 Flight Hours Per Year.

Annual investment costs consider depreciation, interest and insurance costs. Taxes on the user's investment, profit on the user's investment, or initial non-recurring costs to build and certify the first airships were omitted. The initial investment costs are dependent, mostly on the airship costs. The average recurring costs for 10 airships (based on 1973 dollars) were used to determine the recurring costs of the first production unit and for the average costs of 100 production units. The differences in price between airships with different cruising speeds are related to the differences in propulsion systems and nose stiffening costs. The investment costs per ton-mile were determined from the annual investment costs and airship productivity in ton-miles for 4, 000 flight hours per year. The flight period is similar to that used for commercial airplanes. Productivity ranges from 30 million to 40 million ton-miles per year per airship for flights of 2, 500 miles. The investment costs per ton-mile range from approximately 4. 65 to 7. 84 cents per ton-mile depending on the airship's cruising speed and the number of airships produced.

Direct operating costs are further defined in Table IV and are based on the costs of labor and materials. The cost of labor is calculated from the labor hours per trip and the hourly rate for the three general classes of labor. The labor costs per ton-mile are obtained by dividing the labor costs per trip by the ton-miles of cargo carried per trip. The direct operating labor costs run from 1. 87 cents to 2. 16 cents per ton-mile.

The direct operating costs for materials consumed by the airship include: the fuel and oil, based on the horsepower required for the cruising speed, the cost of replacing helium lost due to operations and some leakage, and the cost of spares based on the hours of flight per year and the airship's initial cost. The costs of materials per ton-mile are from 3. 03 to 5. 75 cents. The lowest value is related to the lowest speed airship which requires the least fuel and also has the greatest payload capacity.

The totals of investment and direct costs per ton-mile for 2, 500 mile and 1, 500 mile flights are presented as total operating costs in ton-mile in Table V. The investment costs are approximately one-half the total costs per ton-mile at the lowest cruising speed. Increasing the cruising speed reduces the investment costs per ton-mile and increases the direct operating costs per ton-mile. The optimum cruising speed for least cost per ton-mile appears to be between 57. 5 and 100 MPH as the value for 86. 3 MPH is less than either. The total costs per ton-mile run between 10. 5 cents and 14. 7 cents depending on how many airships are produced and their cruising speeds for trips of 2500 miles. The total costs per ton-mile run between 9. 27 and 13 cents depending on how many airships are produced and their flight speeds for trips of 1500 miles.

A similar study was conducted using past airship designs including their original materials and engines. Their costs are presented as solid lines in Figure 11 in cents per ton mile versus their productivity per year. Both single airships and fleets of ten airships are presented. The curves indicate the desirability of selecting airships of increasing size over selecting many airships of the same size for increasing productivity. The operating costs presented earlier of the single airships using present materials and propulsion systems also are indicated for reference by the dashed curve.

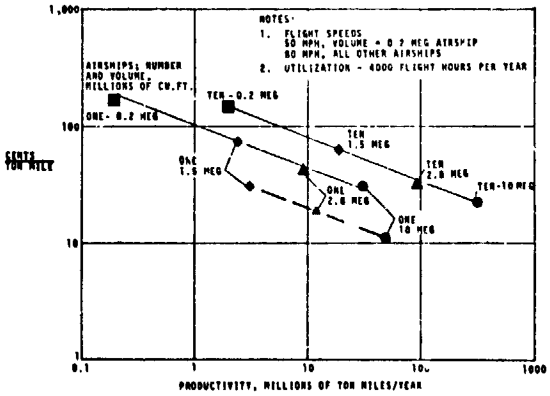


Figure 11
Effect Of Airship Size On Ton-Mile Costs

Table IV - Direct Operating Costs - 2500 Mile Trip

Labor Hours And Labor Costs

Labor Hours Per Trip
Flight Crew (5) = 5 (Flight Hours + 2 Hours)
Maintenance Technicians = 10 (Flight Hours)
Ground Service Crew = 60 Man Hours, Loading-Unloading - Services

Labor Costs Per Trip And Per Ton Mile

Operating Speed MPH	Flight Crew @$15/hr. av.	Maintenance @$10/hr. av.	Ground Service @ $7/hr. av.	Total $ per trip	Ton Mi. per trip	Cost/Ton Mile'	Cents
57.5	3410	4350	420	8180	378,000	2.16	¢
86.3	2320	2900	420	5640	300,000	1.87	¢
100	2020	2500	420	4940	252,500	1.95	¢

Material Dollars - Average For 10 Units

Flight Speed MPH	Fuel Costs*, ¢ ton mile	Helium Costs**¢ ton mile	Spares Costs***¢ ton mile	Total Materials, ton mile
57.5	0.71 ¢	1.0 ¢	1.89 ¢	3.6 ¢
86.3	2.00 ¢	0.85 ¢	1.62 ¢	4.47 ¢
100.0	3.20 ¢	0.87 ¢	1.68 ¢	5.75 ¢

Material Dollars - Average For 100 Units

Flight Speed MPH	Fuel Costs, ¢ ton mile	Helium Costs, ¢ ton mile	Spares Costs, ¢ ton mile	Total Materials, ton mile
57.5	0.71 ¢	1.00 ¢	1.32 ¢	3.03 ¢
86.3	2.00 ¢	0.85 ¢	1.13 ¢	3.98 ¢
100.0	3.20 ¢	0.87 ¢	1.18 ¢	5.25 ¢

*Fuel & Oil = 42¢/gallon. **Helium = 1 Volume/Yr. At $35 Per 1000 Cu. Ft. ***Spares Per Hr. = X 10^{-5} Initial Cost

Table V - Total Costs Per Ton Mile

2500 Mile Trips
Average Based On 10 Units

Flight Speed MPH	Investment Costs, ¢ Ton Mile	Direct Costs Ton Mile, ¢		Total Costs, ¢ Ton Mile
		Labor	Material	
57.5	7.84 ¢	2.16¢	3.60¢	13.6 ¢
86.3	6.68 ¢	1.87¢	4.47¢	13.02¢
100.0	6.98 ¢	1.95¢	5.75¢	14.7 ¢

Average Based On 100 Units

Flight Speed MPH	Investment Costs, ¢ Ton Mile	Direct Costs Ton Mile, ¢		Total Costs, ¢ Ton Mile
		Labor	Material	
57.5	5.5 ¢	2.16¢	3.03¢	10.7¢
86.3	4.65¢	1.87¢	3.98¢	10.5¢
100.0	4.88¢	1.95¢	5.25¢	12.0¢

1500 Mile Trips
Average Based On 10 Units

Flight Speed MPH	Investment Costs, ¢ Ton Mile	Direct Costs Ton Mile, ¢		Total Costs, ¢ Ton Mile
		Labor	Material	
57.5	7.40¢	2.16¢	3.41¢	12.97¢
86.3	5.84¢	1.75¢	3.89¢	11.48¢
100.0	5.69¢	1.72¢	4.48¢	11.89¢

Average Based On 100 Units

Flight Speed MPH	Investment Costs, ¢ Ton Mile	Direct Costs Ton Mile, ¢		Total Costs, ¢ Ton Mile
		Labor	Material	
57.5	5.20¢	2.16¢	2.87¢	10.23¢
86.3	4.06¢	1.75¢	3.46¢	9.27¢
100.0	3.98¢	1.72¢	4.07¢	9.77¢

One method of determining whether a vehicle is competitive for transporting cargo in a new region is to compare its transportation costs versus the costs of developing an all weather highway and using standard highway vehicles. A short road, 100 kilometers, was chosen for comparison. All the costs for the road were charged against the transportation system. As can be seen by the curves in Figure 12 the annual investment costs for the road alone exceed the vehicle associated costs until 100 million ton-miles of cargo are transported per year. Airship costs using past and present materials and engines are indicated by solid and dashed curves respectively. For productivity rates of less than 100 million ton miles per year the airship is candidate transportation vehicle because of the annual road costs.

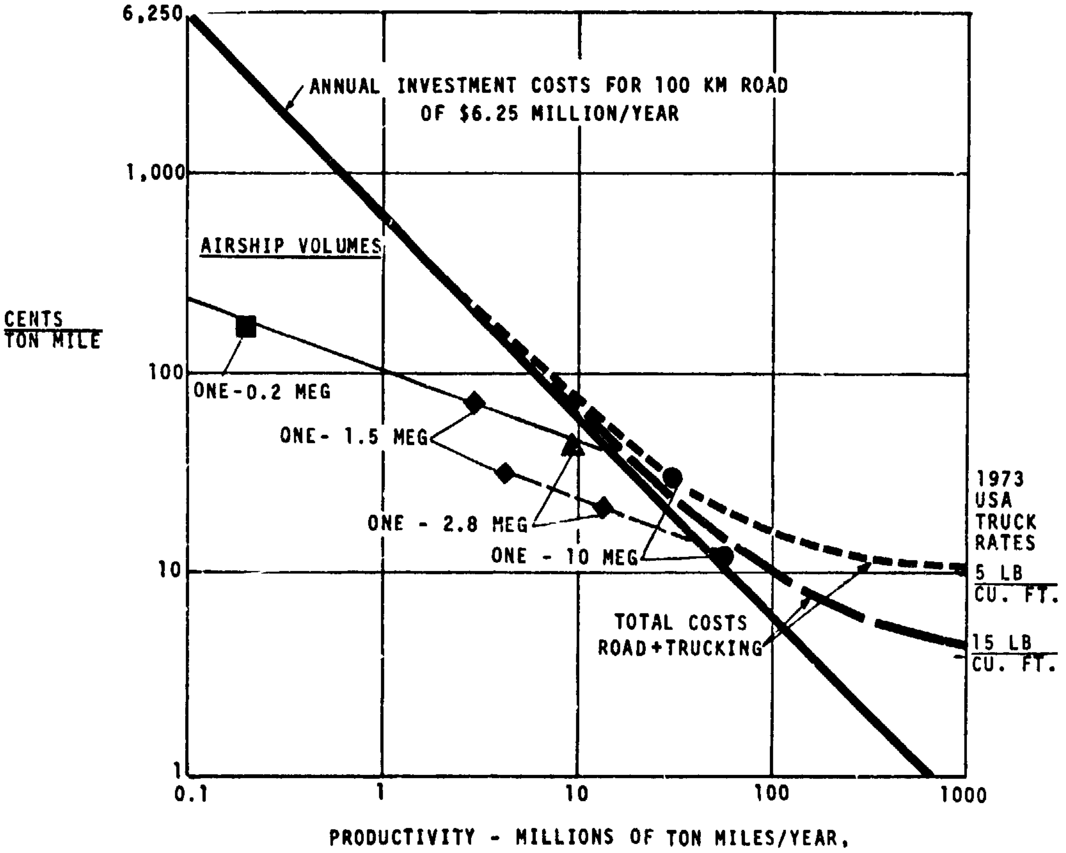


Figure 12
Comparison Of Transportation Costs Considering Investment Costs

CONCLUSIONS

The following conclusions were drawn from the results of the studies:

1. Present materials and propulsion systems can meet the requirements of all the basic airship designs investigated.

2. Use of present materials and power plants in these conventional airship designs increases their productivity and makes them attractive candidates for transportation missions, i. e.,

    - all sizes are attractive where the regions infrastructure is undeveloped

    - the largest size airship is attractive for transporting low density cargo even where the regions infrastructure is developed