AIRCRAFT POSSIBILITIES OF THE DIESEL ENGINE

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I. PREFACE

During the past few years the progress of air transportation has been so great that no one can deny the important part that all types of aircraft play in our present transportation system. It is reasonable to assume that the progress of the past will be used as a basis for even greater progress in the near future. Much remains to be done to make the aircraft power plant more reliable and safer. The writer contends that air transportation can reach new heights of safety, reliability, and economy through the use of the Diesel engine. This paper is an attempt to prove the preceding statement.

The writer wishes to express his appreciation to Prof. F. L. Wilkinson, Jr. for his valuable suggestions and the use of his aviation publications.

JAPANESE NAVY
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AIRCRAFT POSSIBILITIES OF THE DIESEL ENGINE

II. HISTORICAL BACKGROUND

Since the Wright brothers made their historic flight at Kitty Hawk in 1903 much progress has been made in aviation. The World War left us with a lasting impression of the importance of aviation, although the wildest dreams of that period have been surpassed today. The trans-Atlantic fever of 1927 did much to make the world air-minded, and in spite of the financial breakdown of 1929 and following years, aviation has marched steadily forward and is recognized today as a vital part of our complicated system of transportation.

Increased knowledge of the subject and better materials have doubled and redoubled engine sizes, passenger capacity, speed, and cruising range. Engine progress over the period since 1903 can be measured in terms of dead weight. The engine used by the Wright brothers weighed 21 lbs. per h.p., while the modern commercial air cooled engines have specific weights as low as 1.2 lbs. per h.p. A network of air routes have made traveling a matter of hours instead of days. South America, and now even the Orient, have become our neighbors. In the field of speed air travel has no serious rival, but much remains to be done to increase safety and capacity.

At the present time the spark-ignition or gasoline engine holds the field in aircraft power plants, but other sources of power may in the future become serious rivals. Discussion in this paper will be limited to the possibilities of the Diesel or compression-ignition engine.

III. REQUIREMENTS OF A SUITABLE AIRCRAFT ENGINE

1. Low specific weight.

The weight-horsepower ratio must be made as low as possible so that a large amount of dead weight will not be carried. A decrease in dead weight means an increase in pay load. A reduction in engine weight may be accomplished by increased use of aluminum and steel alloys and simpler designs.

2. Reliability.

The engine must be able to operate for a long period of time without need of repair or adjustment. Reliable performance in all kinds of weather conditions must be provided. Reliability can best be achieved by careful design. Fewer moving parts and simple shapes tend to promote reliability.

3. Low fuel consumption.

Low fuel consumption in an airplane is desirable because the weight of fuel carried and the cost of operation must be kept as low as possible for economical operation. Fuel consumption should not exceed 0.45 lbs. per h.p. hour when the engine is operating under load. Careful design and operation have a great bearing upon fuel consumption.

4. Compactness.

The engine should take up no more space than necessary, and should have a small frontal area and a shape that will conform with the natural contour of the aircraft. The use of the proper shape will greatly reduce head resistance.

The number and arrangement of cylinders largely determine the size of frontal area and the degree of compactness of an engine in proportion to its size.

5. Accessibility.

The engine should be designed and located so that necessary repairs and adjustments can be made quickly and easily. The modern radial engine is an illustration of a desirable type. If possible, the engine should be placed where it can receive continuous attention and necessary adjustments during flight. In an airplane this is best accomplished by placing water cooled engines inside a thick wing so that the mechanic can easily reach the engines.

6. Altitude performance.

There should be no great loss of power with increased altitude. The engine should be capable of good operation at an altitude of 15,000 feet without special accessories. By careful design and the use of superchargers good performance can be obtained at higher altitudes.

7. Quiet and smooth operation.

The engine should operate quietly and smoothly under all loads. A vibrating engine is likely to cause damage to itself, to connected wires and pipes, and to the airplane structure. Vibration can be remedied by careful design and balance, and by the use of shock-absorbing mountings and insulation.

8. Flexibility.

The engine should operate smoothly at all

speeds from the idling speed to the maximum. It must be able to accelerate and decelerate quickly and surely in response to movements of the throttle. A high degree of flexibility can best be obtained by careful design.

9. Reasonable cost.

It is highly desirable that the cost of the aircraft engine be made as low as possible without sacrificing the other desirable characteristics. The need for reliability and low weight requires the use of expensive materials and machining processes. Production in larger quantities and the use of better manufacturing methods will eventually reduce the cost per horsepower output.

IV. COMPARISON OF GASOLINE AND DIESEL ENGINES

	Gasoline	Diesel
1.	Uses 89% to 111% theoretical air.	Uses 120% to 250% theoretical air.
2.	Compression ratio of 5 - 1 to 8 - 1.	Compression ratio of 14 - 1 to 18 - 1.
3.	Ideal efficiency of 32% to 48%.	Ideal efficiency of 40% to 63%.
4.	Actual efficiency of 25% to 30%.	Actual efficiency of 30% to 40%.
5.	Fuel not equally distributed to all cylinders.	Fuel equally distributed to all cylinders.
6.	Fuel lost due to carburetor flooding, etc.	No fuel wasted. Positive injection system.
7.	Ignition fouled by excessive lubrication.	No fouling of ignition. Excess oil burned as fuel.
8.	Uses high priced gasoline.	Uses low priced fuel oil.
9.	Pay load is reduced due to weight and bulk of fuel.	Increased payload due to reduced weight and bulk of fuel.
10.	Fuel is source of fire hazard.	Non-explosive fuel eliminates fire hazard.
11.	Power output falls off sharply at higher altitudes.	Good performance at higher altitudes.
12.	Torque falls off for lower engine speeds.	Holds a high torque for lower engine speeds.

	Gasoline	Diesel
13.	Requires a large cooling surface.	Requires 30% less cooling surface than gasoline engine.
14.	Electrical interference. Requires shielding.	No electrical interference. No shielding.
15.	Fuel consumption of 0.45 to 0.55 pounds per h.p. hour.	Fuel consumption of 0.35 to 0.45 pounds per h.p. hour.

V. PRINCIPLE OF THE DIESEL ENGINE

The Diesel-cycle principle is based on a law of nature that the more air is compressed the higher the temperature of this air becomes. Dry air with an original temperature of 60°F., if compressed into one-tenth of its original volume without heat loss through the cylinder walls, will reach a temperature of 825°F. If it is compressed to one-fifteenth of its original volume under the same conditions, it will reach a temperature of 1050°F. The greater the compression, the higher the resulting temperature. The compression-ignition engine makes use of this means to ignite the fuel instead of using an electric spark as in a conventional gasoline engine.

By using fuel-injection pumps and nozzles, fuel oil can be used instead of gasoline. The pumps raise the fuel to a very high pressure and force it through a relatively small opening, or openings, in the nozzles. This action atomizes or breaks the fuel into very fine particles in the form of mist and sprays this mist into the hot compressed air where it ignites and burns. Any oil, when subjected to a certain temperature, will ignite and burn. Various Diesel-fuel oils have different ignition temperatures, but practically all are well below 1050°F.

In extremely cold weather it is sometimes necessary to supply heat to the cylinder from an outside source, as the

cylinder wall may absorb enough heat from the compressed air to lower its temperature below the ignition temperature of the fuel oil. This artificial heat may be supplied by means of electrical glow plugs or heating the cooling water in the cooling jackets. Under most weather conditions, however, it is only necessary to crank the engine to start it. Hand cranking is sufficient for smaller engines, but large engines require the use of an inertia, a compressed air, or an electrical starter.

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VI. ADVANTAGES OF THE DIESEL AIRCRAFT ENGINE

The Diesel engine has a number of inherent advantages over the spark-ignition engine. These are listed and discussed below.

1. Fuel economy.

Using a compression ratio of between 14 to 1 and 18 to 1, the Diesel engine shows an ideal efficiency of 40% to 63% compared to 32% to 40% for the spark-ignition engine. Actual efficiency ranges between 30% and 40% for the Diesel, compared with 25% to 30% for the spark-ignition engine.

According to a chart published by a leading authority on airplane engines, the best specific fuel consumption figure for propeller load was 0.45 pounds per h.p. hour for a gasoline engine and 0.35 pounds per h.p. hour for the Diesel engine. This gives the Diesel a brake thermal efficiency 28% higher than that of the gasoline engine.

Because of its higher thermal efficiency and its ability to burn low priced fuels, the Diesel engine can effect a savings of 70% to 80% in fuel costs. The 1935 report of the Wright Aeronautical Corporation shows that the average fare received was 6¢ per mile, 1.52¢ of which was spent for gasoline. This represents a fuel expenditure amounting to 25% of the revenue. By using Diesel engines this fuel cost would have been reduced to 0.32¢ per mile or less. Besides the savings in fuel costs, it is estimated that an additional

saving of several million dollars would have been brought about by decreased repair and maintenance costs.

2. Fire hazard reduced.

Since the Diesel engine uses a fuel that is not easily exploded and carries no explosive mixture outside the cylinder itself, it is easily seen that the Diesel is much safer, both in normal operation and in case of a crash. An explosion in a Diesel crankcase is unlikely, for a piston cracked or broken enough to admit flame would drop the compression pressure instantly, and the Diesel engine is fired only by the heat of high compression.

The dangerous character of gasoline is due mostly to the combination of a high degree of volatility with inflamability. Most Diesel fuels have a lower ignition temperature than gasoline, but any fire started by fuel oil coming in contact with red-hot exhaust pipes in case of a crash would merely be a shower of sparks and no explosion could result.

3. Less weight and bulk of fuel and tanks.

Because of the higher heating value of Diesel fuel, less weight and bulk must be carried for the same amount of power and distance. Specific fuel consumption is reduced 20% or more by using the Diesel engine. There is also a noticeable reduction in the size and weight of fuel tanks. This advantage of the Diesel increases possible weight and bulk of payload as much as 100% in some cases, as well as increasing the cruising range.

4. Easier to start in cold weather.

Since there are no complicated adjustments for the air-fuel mixture in the Diesel engine, starting is quicker and more certain. The use of glow plugs and an inertia starter offer additional ease of starting. It is only necessary to inject the fuel and rotate the engine. No choking is necessary as is the case of the gasoline engine.

There is no warming-up period, for the heat of compression warms the engine as soon as it is started. A Diesel engine will carry its full load almost immediately after starting, while a gasoline engine requires a considerable time to warm up. This feature of the Diesel should prove to be a great advantage, as many accidents occur just after the take-off because of engine failure resulting from a cold engine.

5. No radio interference.

Since there is no electrical ignition system on the Diesel engine, there can be no electrical interference with radio. Actual tests have proved this fact. Radio shieldling for the gasoline engine adds to the cost and weight of the installation and reduces the reliability of the ignition system, as it adds to the chance of leakage of the high-tension current.

6. High torque developed at comparatively low speeds.

Down to about 30% of full engine speed the torque of the Diesel engine decreases but slightly as the r.p.m. is lowered. On the other hand, the torque of the gasoline engine decreases almost proportionately to the r.p.m. The Diesel engine maintains a higher average torque at all engine speeds.

The torque is an important factor in engine performance.

7. Simpler in construction.

Expense and weight due to carburetors and magnetos are saved when the Diesel engine is used. Also, the valve mechanism of the Diesel is much simpler than that of the gasoline engine. The carburetor and ignition equipment for a 700 h.p. single-row radial gasoline engine costs about $600, which should more than cover the cost of oil-injection equipment for a Diesel of the same power output. A built-in compressed air starter should save a large part of the $500 necessary for an inertia starter, besides giving a substantial reduction in weight.

The two-stroke principle, although inefficient for spark-ignition use, is well adapted for efficient Diesel operation. With the two-stroke Diesel a greater output can be obtained with fewer cylinders, a feature that reduces weight and expense. With the reduction in the number of cylinders comes a reduction of the number of injection pumps and valves. The two-stroke principle also means higher thermal efficiency, as the cylinders do not have a chance to cool off between the power strokes. The two-stroke Diesel is well adapted to super-charging without additional complications, as it is only necessary to increase the capacity of the scavenging pumps. The two-stroke engine also has a smaller jacket loss per horsepower. This means a lighter and simpler cooling system.

8. Smaller cooling surface necessary.

In the Diesel engine a larger part of the heat is used to produce power due to the higher thermal efficiency. The heat loss to the cooling medium is less because a greater excess of air is used and higher degree of expansion exists. This inherent advantage of the Diesel reduces the necessary cooling surface by 30%. Due to smaller cooling surface required, air cooled Diesels up to 1500 h.p. can be built.

9. Fewer instruments and controls.

Since the process of fuel mixing is automatic in the Diesel, no complicated controls, such as carburetor and ignition adjusting devices, are needed. The lack of an electrical ignition system banishes one very prolific source of trouble. The fuel pumps and injectors of the Diesel engine are much simpler than the carburetors, magnetos, and spark plugs of the gasoline engine and less trouble should be experienced with them.

10. Ignition not fouled by excessive lubrication.

When lubricating oil enters the combustion chamber of the gasoline engine, fouling of the spark plugs is likely to result. This is not true with the Diesel engine, for any lubricating oil entering the combustion chamber will burn as fuel and there will be little or no carbon deposit. This feature adds to the safety and reliability of the Diesel engine.

11. Not affected by heavy rains or ice.

With the Diesel there can be no trouble due to a wet carburetor or to a water-soaked ignition system. A plane equipped with a Diesel engine can encounter a heavy rain without chance of engine trouble.

There is less danger of ice formation at the air intake with the Diesel than with the gasoline engine. Also, vapor locks will not occur, due to the nature of the fuel.

12. No great loss in power with increased altitude.

In the Diesel engine the amount of fuel taken into the cylinder does not depend upon the density of the air used. Fuel is injected by a pump and air is drawn in through the valve opening. Tests have shown that the Diesel can be successfully operated at 20,000 feet without special accessories. Extra altitude power is obtained at the sacrifice of specific fuel consumption, because the fuel-air ratio rises as the air density decreases. A limit is reached when the Diesel engine begins to smoke, and from then up the throttle is partly closed and acts as an altitude mixture-control as well as throttle. Supercharging provides good altitude performance without sacrificing fuel economy.

13. Ability to operate in any position.

The Diesel engine is practically unaffected by the position of the plane in flight, whereas the gasoline engine must use a special floatless carburetor if maneuvers are to be made safely.

14. Exhaust less hot and noisy.

Due to the higher ratio of expansion and the fact that the Diesel engine operates on a considerable proportion of excess air, the pressure at the time the exhaust valve opens is much lower than that of the gasoline engine. This reduces the noise and the flame of the Diesel exhaust.

15. Easily accessible.

One of the chief disadvantages of the present airplane engine is inaccessibility during flight. German engineers have successfully overcome this disadvantage by mounting a liquid cooled Diesel engine inside the wing for continuous attention and necessary adjustments during flight. This could not be done with as much success using the gasoline engine, due to danger of fire and explosion.

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VII. DISADVANTAGES OF THE DIESEL ENGINE, WITH SUGGESTED IMPROVEMENTS

1. Initial cost is too high.

As is true with any new product, the cost is higher at first because of experimental and other special costs. When the engine becomes more popular and production increases, the cost to the buyer can be reduced to the level of the gasoline engine. One of the biggest factors now is the cost of the injection pumps. By the use of a simplified pump combined with the injector, the cost of production of these necessary parts can be reduced below that of magnetos, carburetors, and spark plugs.

2. High weight-power ratio.

The lowest weight-power ratio attained thus far is 1.6 pounds per h.p. for the water cooled Diesel engine, compared with 1.32 pounds per h.p. for the radial air cooled gasoline engines used by the leading airlines of this country. The specific weight of the Diesel can be further reduced by the use of new materials and by intense development of the two-stroke design.

3. Greater crank torque and higher rotative speeds necessary for starting.

Greater power is necessary to crank the Diesel engine because of the high compression ratio. The use of a mechanical starter to crank the engine almost completely eliminates the starting problem. A special valve for partly

releasing the compression pressure at the beginning is a great aid if hand cranking is to be used.

4. Engine runs harder.

Vibration is very undesirable in an aircraft engine. The wide pressure range used causes the Diesel to run hard. By careful balancing, lower peak pressures, and the use of two opposed pistons per cylinder, a very smooth running Diesel can be built. Rough running at idling speeds can be eliminated by using an injector control to regulate the amount of fuel fed to the engine.

5. Greater stroke-bore ratio.

The higher compression ratio of the Diesel is the cause of the high stroke-bore ratio. This undesirable feature results in higher piston speeds and greater cylinder wear. Wider use of long wearing alloys should eliminate most trouble arising from this source.

VIII. SPECIFICATIONS FOR THE FUTURE DIESEL AIRCRAFT ENGINE

1. Two-stroke operation.
2. Adaptability of design to 1500 h.p. or more.
3. Flexibility of cylinder arrangement.
4. Maximum fuel consumption:

	Lbs./h.p. hr.
Clear exhaust, rated b.h.p.	0.40
75% of rated b.h.p.	0.35
Cruising, 50% of rated b.h.p.	0.36
Take-off, 125% of rated b.h.p.	0.50

5. Gears for proper propeller speed.
6. Must be capable of being supercharged to rated h.p. at 15,000 feet altitude.
7. Maximum dry weight of 1.5 pounds per rated h.p.
8. Peak cylinder pressure of 800 pounds per square inch.
9. Air cooling for smaller engines.
10. Starting without glow plugs.
11. Either individual cylinder injection-pumps or dual unit-pumps.
12. Minimum service intervals:
    - 50 hours, routine inspection of nozzles.
    - 350 hours, top overhaul.
    - 1000 hours, major overhaul of bearings, pistons, etc.
13. Minimum engine life of 4000 hours.
14. Freedom from torsional vibration in operating range.

IX. PRESENT DEVELOPMENTS

A. American Diesel progress

1. The Packard Diesel.

In 1929 Packard introduced a nine cylinder radial Diesel, which had been developed under the direction of Captain Woolson. The engine develops 225 h.p. at 1950 r.p.m. and has a specific weight of 2.26 pounds per h.p.

Characteristics:

Dynamometer test of 500 hours without overhaul.

Temperatures of 17°F. met in flight tests without difficulty.

Individual fuel pumps built as unit with spray nozzle.

Altitudes of 18,000 feet without special accessories.

Single valve serves for both intake and exhaust.

Maximum cylinder pressures over 1200 lbs. per sq. inch. Compression ratio of 16 to 1.

Below is a comparison of the performance of two planes, identical except for engines.

A. Packard, 225 h.p.

	Ground Level	5000'	8000'	Ceiling 20,000'
M.P.H.	116	118.4	118.6	82
R.P.M.	1980	2110	2015	1750

Time to reach ceiling: 42.9 min.

B. Gasoline, 225 h.p.

	Ground Level	5000'	8000'	Ceiling 14,270'
M.P.H.	103	99.5	-	64
R.P.M.	1990	1970	-	1745

Time to reach ceiling: 90.2 min.

2. Lambert (Deschamps), 12 cylinder, water cooled, two-stroke, 30° inverted V-type, 1200 h.p. at 1600 r.p.m., B.M.E.P. of 98 lbs. per sq. inch. Supercharged. Specific weight of 2.00 pounds per h.p.

3. Guiberson, 9 cylinder radial, single valve, 240 h.p. at 2020 r.p.m. Specific weight of 2.25 lbs. per h.p. Specific fuel consumption of 0.48 pounds per h.p. hr.

4. Aviation Diesel, 7 cylinder radial, four-stroke, 400 h.p. at 1500 r.p.m. Compression ratio of 14 to 1. Specific weight of 3 pounds per h.p. Specific fuel consumption of 0.40 pounds per h.p. hr.

5. Sterling crankless Diesel.

Thus far this engine has only been used for stationary power purposes, but its simplicity of design, compactness and possibilities of low specific weight should soon bring it into aviation use. The engine has its cylinders grouped in barrel or revolver form, with two pistons per cylinder. Straightline motion is changed into rotary motion by means of a swash plate at each end. The engine has few moving parts and a mechanical efficiency of 85%. Operation is on the two-stroke principle and built-in scavenger pumps are used.

B. German Diesel progress

Outstanding among all European Diesel developments are the vertical six cylinder Junkers engines built in Germany. Two pistons per cylinder are used and operation is on the two-stroke principle. A built-in supercharger also serves as a scavenger pump. Fuel is sprayed tangentially from four nozzles located at the center of the cylinder. The upper and lower crankshafts are connected by gears which also reduce the propeller speed. Simplicity of design and the use of magnesium - aluminum alloys have made possible extremely low specific weight. Fuel consumption has reached the low level of 0.375 pounds per h.p. hour.

The output of the Junkers Jumo 205 engine has been increased to 700 h.p., which is equivalent to 1.6 pounds per h.p. This figure compares very favorably with gasoline engines of similar size. Now under construction are the eight cylinder Junkers Jumo 206 engines, ranging in size from 1,000 to 1,500 h.p. The same producers are now carrying on experimental work with extremely compact Diesel engines of the 1,500 to 2,000 h.p. class.

The Junkers G-38, the largest Diesel-engined plane in the world, is powered with four Junkers Jumo 204 engines of 750 h.p. The plane carries 34 passengers, has a wing span of 144 feet, and weighs 27 tons.

The Mercedes-Benz 1100 h.p. LOF-6 engines have proved highly successful in the trans-Atlantic flights of the

airship Hindenburg. The reduction in the weight of fuel carried has made possible greater pay loads, as well as greatly reduced operating costs. Sometime this year the Zeppelin LZ-130 will be placed in trans-oceanic service, using similar engines.

In the airplane field, the huge Dornier Do-20 flying boat, powered by eight Diesel engines, will soon be placed in trans-Atlantic service. In the near future sea-planes built by Blohm and Voss and powered by four Junkers Jumo 205 Diesel engines will be used to carry the mails from Europe via Lisbon and the Azores to New York.

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X. CONCLUSIONS

Leading European aviation authorities were alert to grasp the Diesel as a forward step in air transportation. American experts are now giving it serious consideration.

The 1936 annual report of the National Advisory Committee for Aeronautics contains a section on compression-ignition engines from which the following statement is summarized: "The low fuel consumption and reduction in fire hazard obtained by the use of the compression-ignition engine should be of particular interest to operators of long-range transport aircraft."

Trans-Pacific example.

During 1936 the world hailed the successful flights of the China Clipper across the Pacific, but few people stopped to consider the fact that the expensive and excessive load of gasoline caused the great ship to operate at a loss. The use of Diesel engines of the same size would have reduced the weight of fuel carried by approximately 30%. This would have meant an increase in payload of 100% and a reduction in operating costs of 75%.

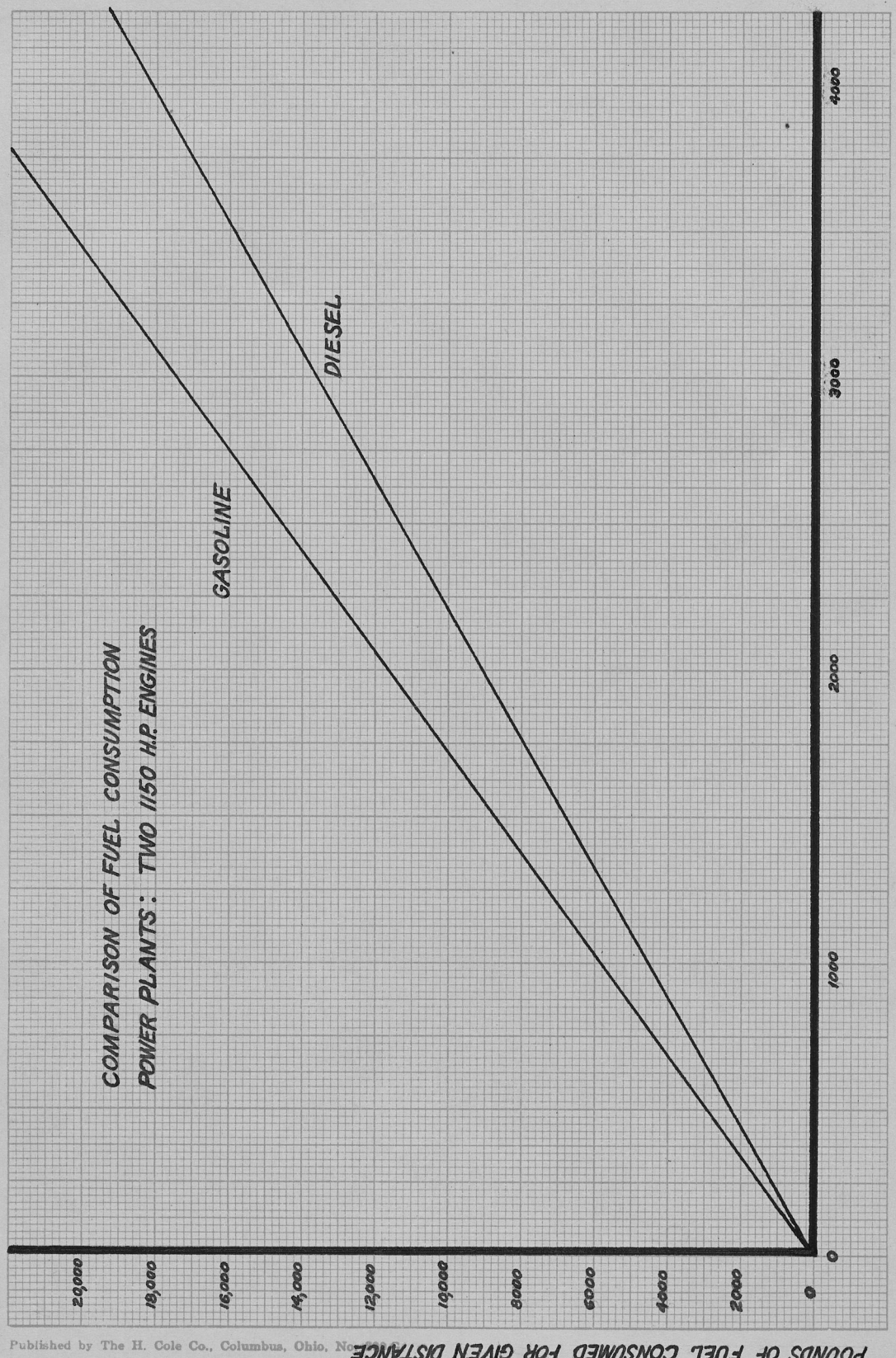
Application to U. S. air routes.

The increase in payload made possible by the low fuel consumption of the Diesel is more apparent in non-stop runs of 1000 miles or more. The resulting increase in

revenue, together with the marked decrease in operation and maintenance costs, will certainly be no small figure on the books at the end of the year. Below in Figures 1 and 2 is a comparison of the fuel consumption of the gasoline and Diesel engines, showing the net increase in payload made possible by the Diesel. Figure 3 shows a comparison of fuel cost for the two engines on the passenger mile basis. Figure 4 is an airway map of the United States, showing some principal long distance flights. Figure 5 names these flights and states the distance and possible increase in payload with the Diesel.

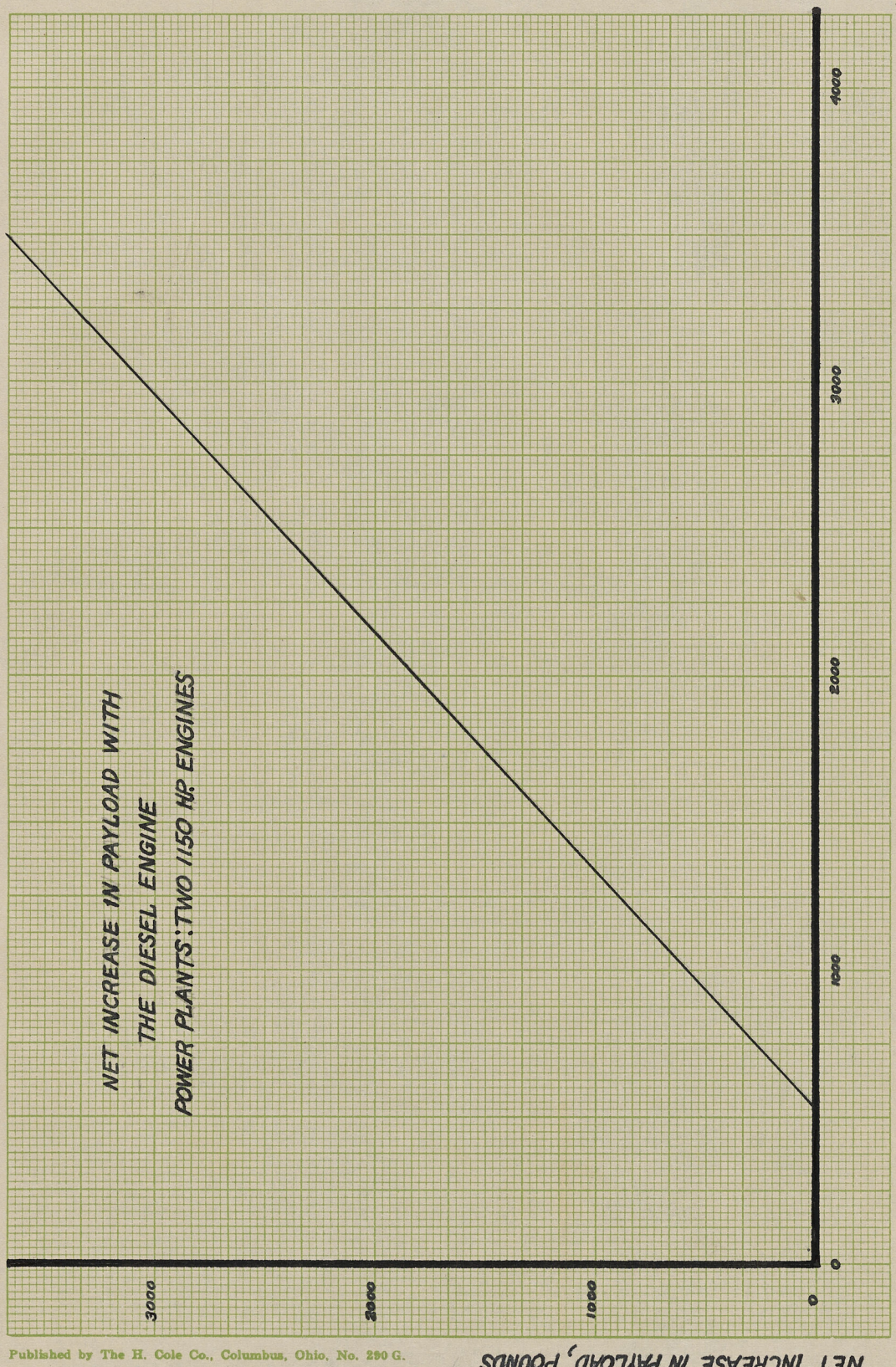
All data is based on two 1150 h.p. engines. The gasoline engines have a specific weight of 1.32 pounds per h.p. and consume 0.48 pounds of fuel per h.p. hour. The Diesel engines weigh 1.60 pounds per h.p. and use 0.375 pounds of fuel per h.p. hour.

Figure 1



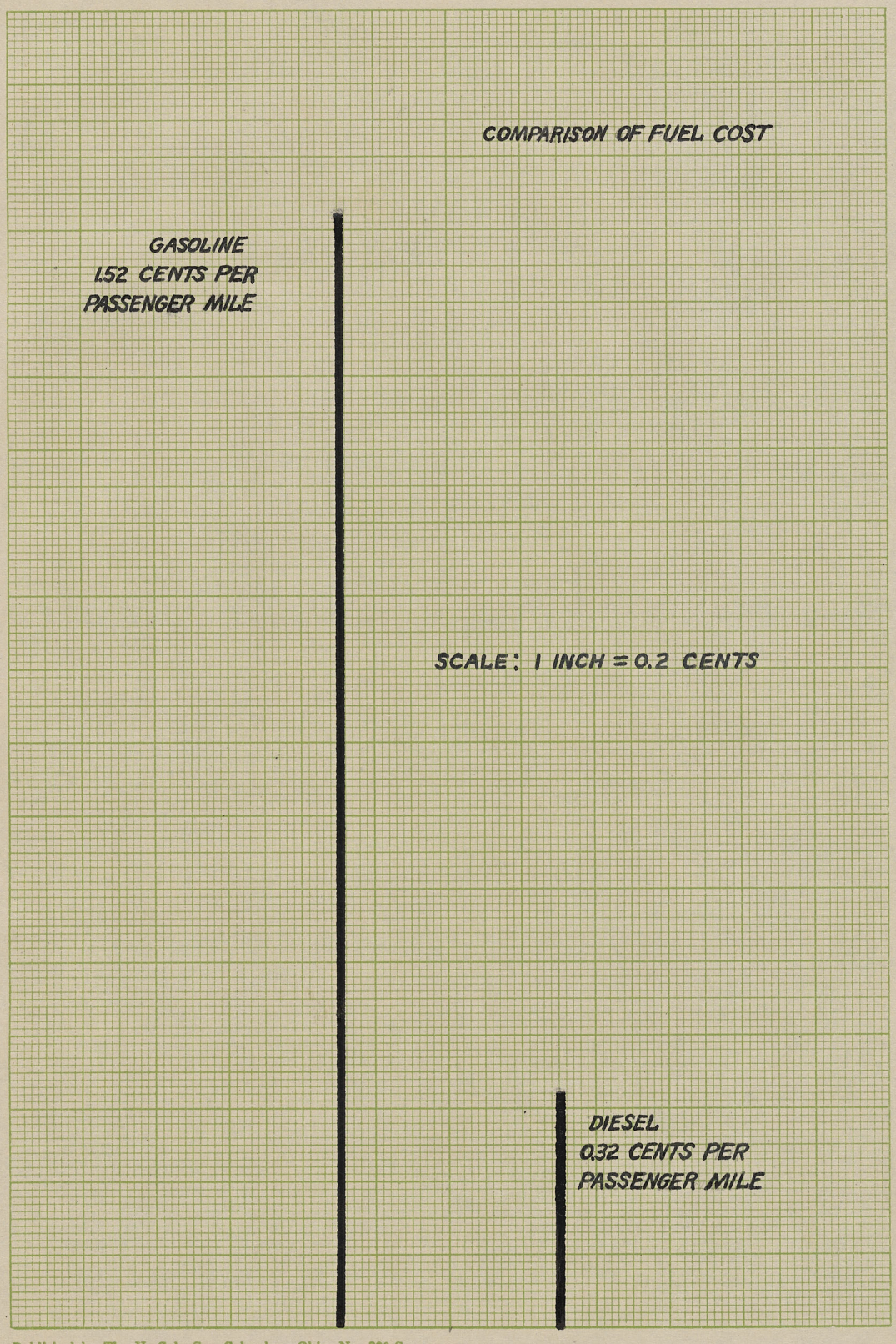
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Figure 2



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Figure 3



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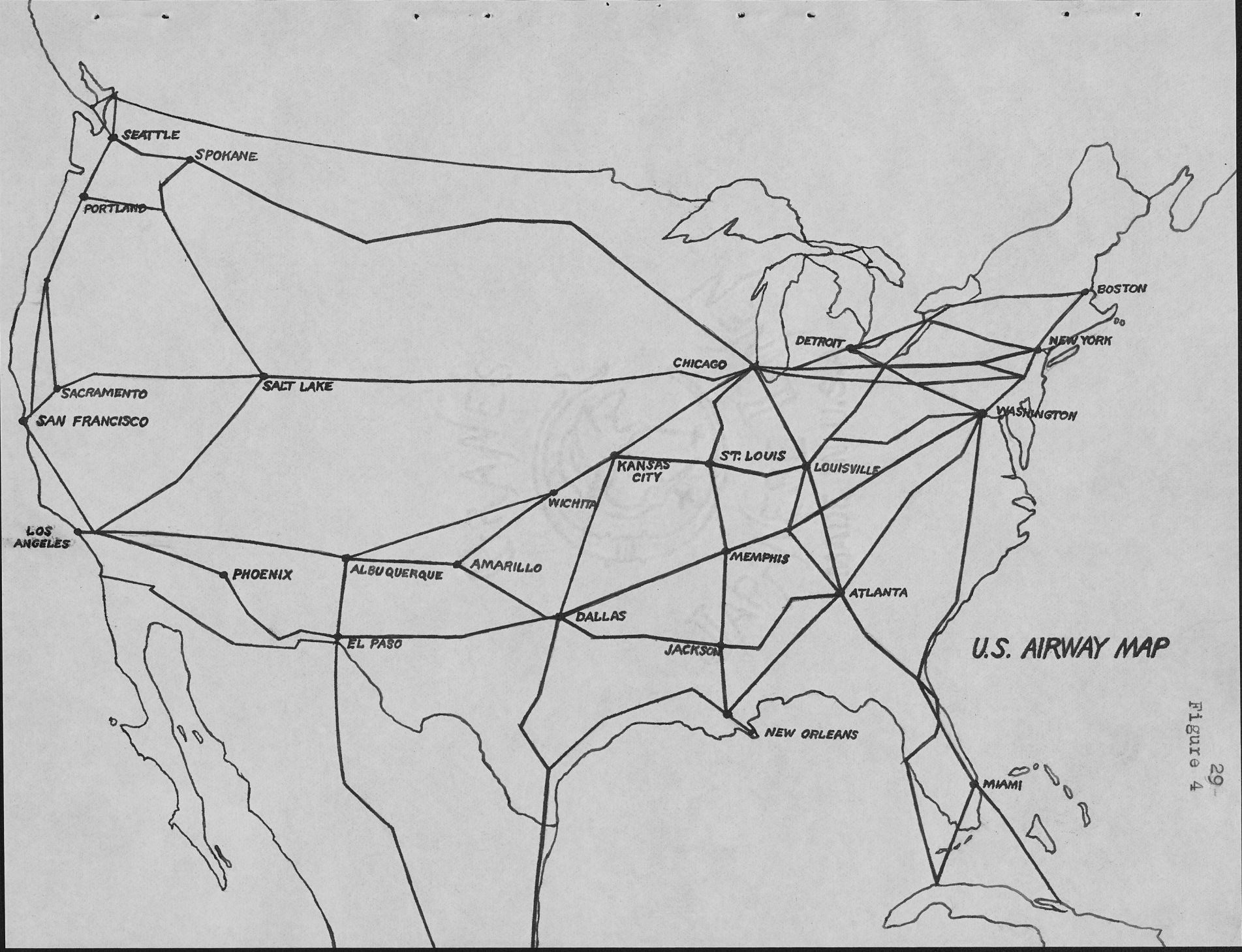

SEATTLE
SPOKANE
PORTLAND
SACRAMENTO
SAN FRANCISCO
SALT LAKE
CHICAGO
DETROIT
BOSTON
NEW YORK
WASHINGTON
ST. LOUIS
KANSAS CITY
LOUISVILLE
WICHITA
LOS ANGELES
PHOENIX
ALBUQUERQUE
AMARILLO
MEMPHIS
ATLANTA
DALLAS
EL PASO
JACKSON
NEW ORLEANS
MIAMI
U.S. AIRWAY MAP

Figure 4

FIGURE 5

FLIGHT	DISTANCE	PAYLOAD INCREASE
NEW YORK TO CHICAGO	727 MILES	234 LBS.
CHICAGO TO SALT LAKE	1115 "	720 "
NEW YORK TO " "	1842 "	1620 "
" " TO SAN FRANCISCO	2517 "	2460 "
" " TO PORTLAND, ORE.	2417 "	2330 "
" " TO LOS ANGELES	2292 "	2180 "
" " TO NEW ORLEANS	1345 "	1000 "
" " TO DALLAS	1440 "	1125 "
" " TO MIAMI	1245 "	880 "
DALLAS TO LOS ANGELES	995 "	560 "
CHICAGO TO " "	1565 "	1270 "
" TO NEW ORLEANS	1045 "	625 "

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XII. APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it has been submitted.

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