

THE TECHNICAL AND ECONOMICAL FEASIBILITY OF PRODUCING
LIGHT WEIGHT PRIVATE VERTICAL TAKEOFF AND
LANDING (VTOL) AIRCRAFT

by

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of

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in

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Approved:

Head, Major Department

Chairman, Examining Committee

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VITA

John (Jack) Richard Venrick was born on July 20, 1943 in Trenton, New Jersey. His parents are John and Dorothy Venrick, presently residing at Bozeman, Montana. His father is now enjoying his first year of retirement from the U.S. Forest Service where he held the staff position in range and wildlife on the Gallatin National Forest. John Senior is a 1942 graduate from the University of Montana in the School of Forestry.

Jack attended the first two years of High School in Sheridan, Montana and received his high school diploma from the Bozeman Senior High School in Bozeman, Montana. Subsequently, he attended Montana State University in Bozeman, Montana and graduated in the field of Electrical Engineering in 1966.

Jack spent his summers during college working in various positions and locations. The summer of 1963 was spent working for the U. S. Forest Service on the Deerlodge National Forest; the following summer was spent in New Jersey working as a machinist's aid and doing social research. The summer break of 1965 brought an opportunity from San Francisco, California as an Engineering assistant for the U.S. Department of Interior in the National Park Service.

After graduating from MSU in 1966, Jack took a position as an associate engineer in the 707/720 electrical power project group for The Boeing Commercial Airplane Division in Seattle, Washington. In 1968, he married a Seattle girl, Mary J. Rosser, a stewardess for Alaska Airlines. They both enjoyed a trip to Nassau in the Bahama Islands and points north to Alaska.

In September of 1969, Jack and Mary took leave of Seattle, The Boeing Company, and Alaska Airlines to come back to God's country in pursuit of more schooling. Mary took a position with the Montana Travel Agency in Bozeman to help tide the finances. She is now continuing her education in Home Economics at MSU and working part time at the travel agency. In September of 1970, with the help of travel discounts, savings, and close friends in Germany, they traveled through western Europe for a month.

Jack will complete the requirements for a Master of Science in Applied Science, with a major and minor in Business and Industrial & Management Engineering respectively, this quarter (Winter, 1971). Thereafter, both of us would like to take a position abroad for several years and return to one of the Rocky Mountain States.

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ABSTRACT

The evolution of VTOL aircraft, from the late 1930's with the autogyro to today's turbine powered fan and prop-fan propulsor systems, has come about in great part with the gradual improvement in high strength and temperature materials. Of the several hundred early designs, funded in no small way by the military, as few as 30 models were actually build and flown (see front cover). The turbine and high strength materials have opened the doors for reducing the rotor diameter and subsequently the drag profile of the helicopter.

Rotor aircraft (helicopters) are still likely to play the major role in VTOL commercial operations for at least the next ten years; and the greater part of current research is directed at increasing the speed of these vehicles. City-to-city and city to airport markets are extremely large (up to 200 miles), and the one in which the airlines have made the smallest penetration--less than 3 percent in the USA. With increasing road congestion accompanied by a high degree of frustration and prolonged travel time, this market has tremendous potential for airlines and future private VTOL aircraft. Continued advances in helicopter design include Lockheed's AH-56A 250 kts./hour compound helicopter. Aircraft companies such as the Hughes Tool Co., Ryan Aeronautical Co., Bell Helicopter Co., and Sikorsky Aircraft Company are all working on designs of helicopters to push the maximum speed to 400--500 mph.

Private VTOL aircraft appear to be in a technical and economic stalemate. Economically, we can only push exorbitant initial prices down to automobile levels over equal or competitive production runs involving hundreds of thousands of units a year. At the same time, we can not expect to finance immediate technical realizations in all phases of VTOL aircraft in such a highly competitive low-priced market. Gas-turbine and propulsor system weights have been substantially reduced through-out the last decade to essentially null-out future major weight reductions. Now it is felt among many gas-turbine specialists, that effort will shift toward improvement of specific fuel consumption, not to mention initial cost of the turbine.

Though science has been known to make drastic progress in quantum steps, this writer can only foresee a gradual change over to mass VTOL media. It may well be that the consumer's first introduction to VTOL transportation will be a privately owned helicopter. Even with their complex, relative high cost rotor systems, today's helicopter may be purchased with a much cheaper piston engine with many more hours of reliable flight time than its turbine competitor. Double seat light helicopters with enclosed cabins can be purchased as low as \$28,000, double seat enclosed cabin gyrocopters may be purchased as low as \$16,000. No turbine powered VTOL vehicle can yet compete with these cost figures even with much improved cruise speed and mean time between overhauls.

The want of a private VTOL vehicle awaits a more sophisticated technology in the not to distant future, perhaps 10 years for private helicopters, and 20 to 30 years for turbine powered fan and prop-fan models.

INTRODUCTION

VTOL (Vertical Takeoff and Landing) has, heretofore, precluded the development of the powerplant to run it. With the advent of the gas turbine technology, we are on the frontier of having the power to lift, control and stabilize aircraft with greater weight/hp ratios without the use of extended rotating airfoils as in the helicopter. It is intended that this study will reveal the major problems VTOL designers have come up against in the last twenty or more years; the price of research and development the tax payer and many corporations have payed, and the design parameters present designers are working with. In brief, the state-of-the-art problems VTOL people are confronted with are the following:

(1) Cost Turbine and general aircraft prices are extremely high-priced to cover the cost of research and development, maintenance, and specialized demand.

(2) Fuel economy Present marketable turbines have a specific fuel consumption near .6 lbs. fuel per horsepower per hour (more advanced engines are approaching .4). For a 900 shaft horsepower turbine with a vertical lifting capability of approximately 3 to 5 times its power, say 5 times 900 shaft horsepower = 4500 lbs, at maximum power this turbine would consume 83 gallons of fuel per hour.

(3) Controllability Inherent in this design parameter lies much of the past and even present challenge of the VTOL field where conventional control surfaces are either partially or wholly replaced.

Oscillation characteristics become critical, necessitating formulation of mathematical models, scale models and proto-types to establish oscillation periods and moments in lieu of countering with effective controls.

The next several pages reveals only a small number of the multitude of possibilities, in the field of vertical flight, open to the designer. As of 1963 the number of VTOL projects were reported to run into three figures.¹ Techniques of VTOL include rotor, propeller, shrouded propeller, fan lift, and jet. Thrust direction may be governed by tilting the aircraft, tilting engines or wings, thrust or slipstream vectoring and separate lift and thrust units.² Every approach has been tried and financed in no small way by the tax dollar. The U.S. Army Transportation Research & Engineering Command (TRECOCM) has been behind a large majority of VTOL research. Aviation Week & Space Technology points out that:

"unless funding for VTOL is increased by the military, or some other government agency, such as the National Aeronautics and Space Administration, the future of a VTOL business aircraft remains indefinite."³

Piasecki Aircraft Corporation was awarded \$1,444,960 as of December 7, 1959 for their VZ-8P flying platform. It is interesting to note that 5 months after Piasecki made his announcement in March 1958 of his contract research with TRECOCM; he came out with the following announcements:

"We have definite plans to modify the Army design for civilian use as soon as we fill Army requirements.⁴ We have named our civilian design the "Sky Car"."

Piasecki goes on to explain his expectations of the "Sky Car". He was asked what the "Sky Car" would cost, and he replied that if they are mass-produced in the same number as automobiles, the "Sky Car" would cost little more than a high priced motor-car.⁵ He continues:

"As the first high-utility air-ground vehicle for public use, the "Sky Car" may have as powerful an impact on our future as did the first automobile."⁶

Certification procedures with the Civil Aeronautics Administration had already begun then. What happened? Piasecki's Aircraft Corporation later merged with The Boeing Company to form the Boeing Vertol Division. New management and the unfeasibility of the design led to the eventual phasing out of the "Aerial Jeep" in 1967. (see Figure 2, page 4)

CHAPTER I

PAST APPROACHES

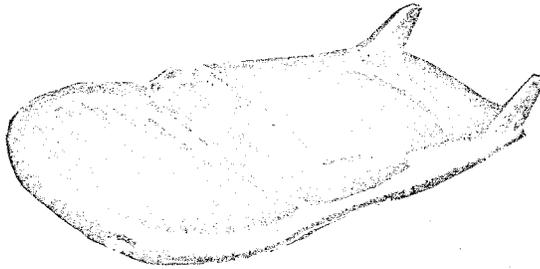


Figure 1
"Sky Car"

Piasecki's dream, the "Sky Car" above was to have no wings or conventional propellers. It was to be powered by two horizontal three-bladed rotor-props, one at the front and one at the rear, which will support the low craft on two columns of air. Want of more power for lift, horizontal speed and controlability, pushed the cost estimate over ten fold. Not even the Army and one and a half million dollars could buy the time that technology needed to bring out high temperature, and strengthen metals and production methods for turning out large numbers of these power plants. Evolution of the sky car's power system started with two 160 horsepower internal combustion engines, then to one 425 shaft horsepower turbine in 1959, and then to two 425 shp turbines sometime in 1960. The last report I have been able to find was in 1965, showing little change in design. I have inquired at Piasecki Aircraft Corp. as to what has become of the Sky Car but received no reply.

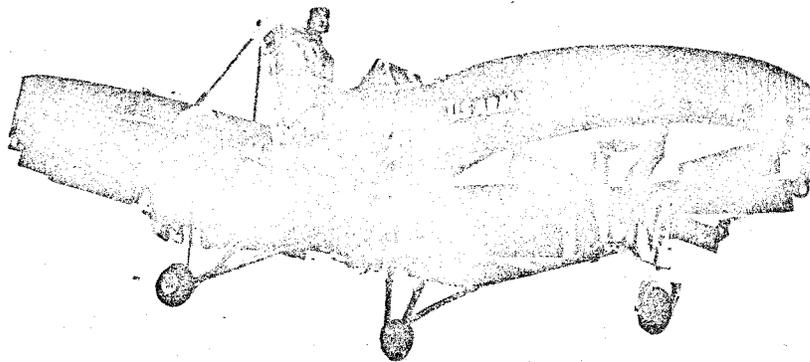


Figure 2
"Aerial Jeep" VZ-8P

Piasecki demonstrated steady hover capability of VZ-8P at altitudes from a few feet off the ground to about 20 feet. Army thus far has funded approximately \$1,444,960 on VZ-8P. (Aviation Week Dec. 1959)



Figure 5

Travois X-2 "One Man's Dream"

The Travois X-2 was designed by Leonard E. Mueller, Eau Claire, Wis., who reports that he has made successful flights of models of the configuration. Scale model, above places two men fore and two aft. Flying platform proposal to U.S. Army features use of coaxial ducts for optimum fairing. Specifications call for use of 245 hp. Franklin engine turning a large rotor of 10-ft. diameter and smaller rotor of 7-ft. diameter. Control system considers fore-and-aft wheel movement to change pitch of large blades differentially in a cyclic manner, rotation of wheel would cause large blades to change pitch cyclically for roll while simultaneously applying friction to brakes on small and large rotor shafts for yaw. Apparently, nothing more came of the Travois X-2 as no further articles have appeared since this date (Aviation Week, January 26, 1959, page 67). This is an example of a one man attempt to attract the much needed financial support from a government contract before pursuing such a venture.

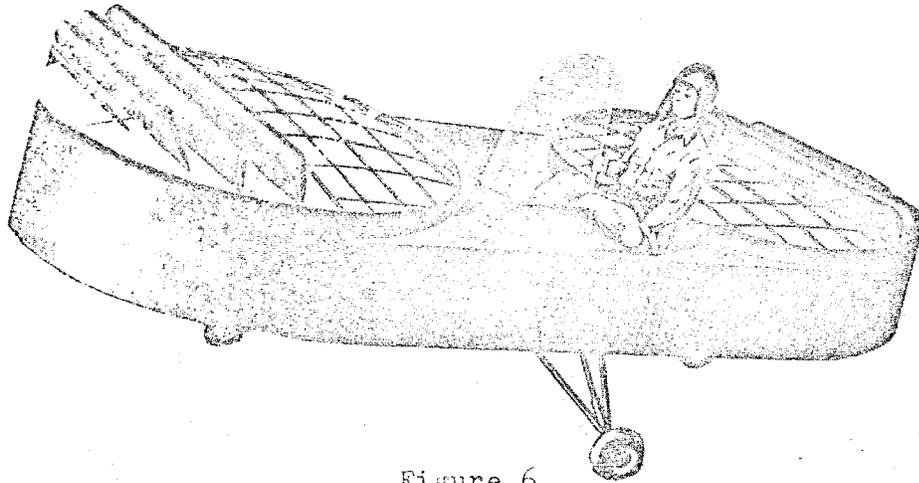


Figure 6

Before the Crash

Chrysler aerial platform, was scheduled for rollout sometime in February 1959, (Aviation Week, January 26, 1959, page 56) has complex system of vanes and cascades to provide forward thrust, cancel-out nose pitchup phenomena. Chrysler Corporation canceled this project after the vehicle crashed, this was reported in September 28, 1959, some 9 months from the drawing board. This design resembles that of Piasecki Aircraft Corporation. Chrysler also started with an internal combustion engine rated at 380 hp but did not even attempt a change over to a turbine power plant.

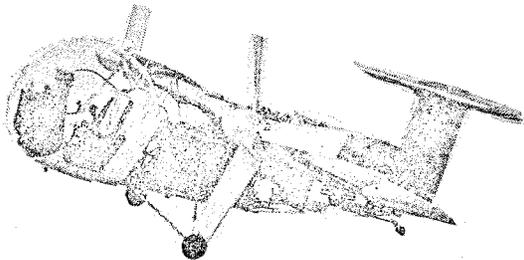


Figure 7

Model 76

The Vertol Aircraft Corporation now a division of The Boeing Co. came out with a Model 76 in 1956-57. The design incorporated a basic helicopter frame and cab; the tail and wing sections added for the necessary control and increased lift. The wing and the rotor-propellers tilt together through a 90 degree arc from a control in the cab. (American Helicopter June 1957, page 4)

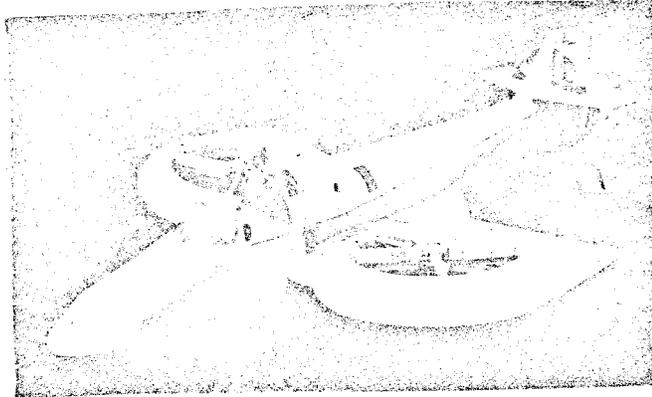


Figure 8

Vanguard "2C Fan-Wing"

Vanguard Air & Marine Corporation plant at Paoli, Pa. has completed 12 hours of ground test of the 2C fan-wing, vertical takeoff and land aircraft. (Aviation Week, October 19, 1959, page 129) It is powered by a single Lycoming O540-A1A piston mounted behind the cockpit; wing rotors are three bladed. Engine transmits ducted pusher propeller via a shaft about 10 feet long. Tail duct is 5 feet in diameter. Ironically, President Edward Vanderlip, of the Vanguard Air & Marine Corporation was the former vice-president and treasurer of Piasecki Aircraft Corporation. He and a five man engineering staff attempted to do what Piasecki could not. Again starting out with a 380 hp piston engine with a tentative base price of \$38,500 and a top speed of 260 mph. They later changed to a 850 shp turbine powerplant. Funds came from the sale of stock, there were 180 shareholders at this time, 24 of them were presidents of Philadelphia area corporations. This company has gone into bankruptcy and all of its assets have been sold by the trustee.

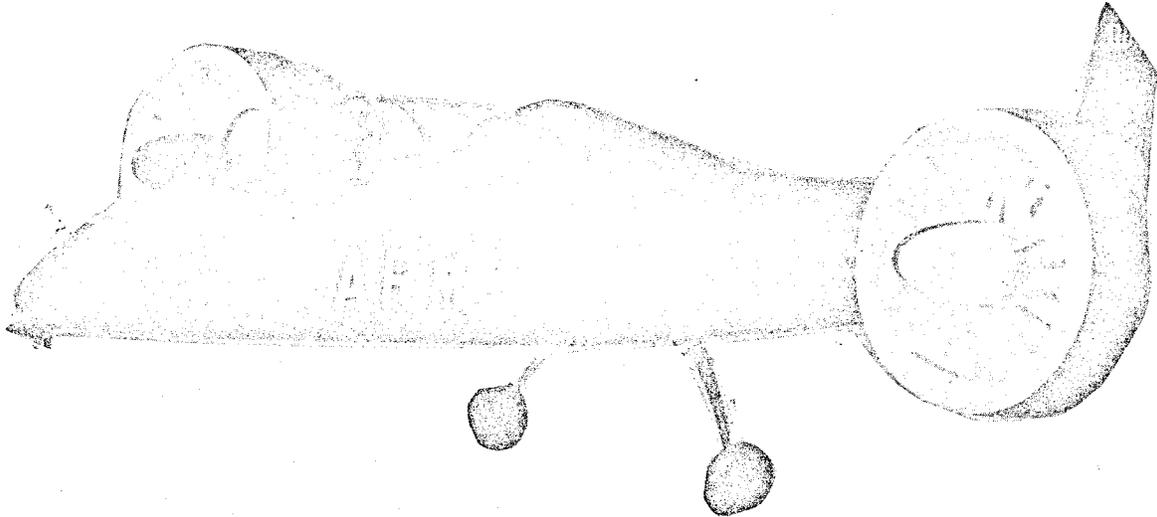


Figure 9

"The Doak 16"

The Doak Aircraft Company through the U.S. Army Transportation Research & Engineering Command (TRECOCM), financed the first prototype of the Doak 16, Army designation VZ-4DA. It is powered by a 840 shp Lycoming T53-L-1. The flight test program began October, 1958. The wing-tip ducts are rotatable through 92 degrees for hovering and cruising. The turbine engine is housed in the fuselage behind the intake duct with the shafts passing through the wing quarter section into a gear box in the hub of the duct. Each ducted fan assembly contains eight plastic fixed-pitch blades with 14 inlet guide vanes upstream of the blades and nine straightening stators downstream. Pitch and yaw control vanes are located in the exhaust efflux at the rear of the aircraft. Roll control in hover is obtained by differential variation in the pitch of the individual propellers; in forward conventional controls are used through actuating elevators, ailerons and rudder. Gross weight is 2700 pounds. President of the Doak Aircraft Company predicts use of his plane as big troop transports and airport "taxi" service to urban areas. (Science News Letter, October 24, 1959, page 271)

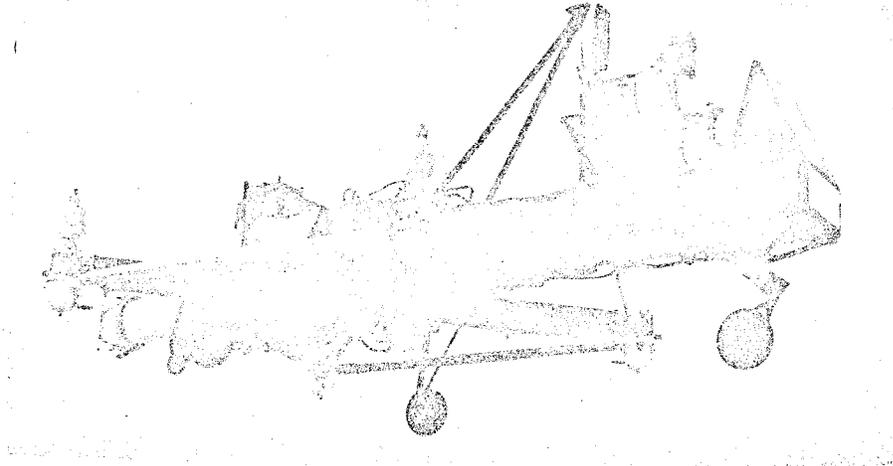


Figure 10
Curtiss VZ-7AP

Curtiss-Wright Army-sponsored VTOL test vehicle, VZ-7AP, flies during its initial public showing. Pilot Rodger Gardner flew the four-propeller research vehicle four separate times during the demonstration, for a total flight time of more than 15 minutes. During the demonstration the vehicle was flown forward, in the hover, and to left and right laterally. It also was flown to approximately 12 ft. above the surface of the ground (from wheels to ground), but only about 10 mph. in forward speed. The vehicle so far has approximately two hours in actual flight time, although running time of the engine, gear box, and propellers at operational speeds exceeds 14 hours. Flight time on these components is counted by helicopter rotor system standards; that is, all rotating time is counted rather than actual off-the-ground flight time. Curtiss-Wright also demonstrated its Skydart target, Turbomite turbine and Demon missile checkout system. (Aviation Week, November 16, 1959 page 93) The Army Transportation Research and Engineering Command (TRECOC) shows its persistence by funding Curtiss-Wright in mid-1957 to build the "aerial jeep" VZ-7AP. Funding ended in September 1959 with a statement that would be no more from TRECOC unless the program could be carried further on its own. The last report was found in 1963.

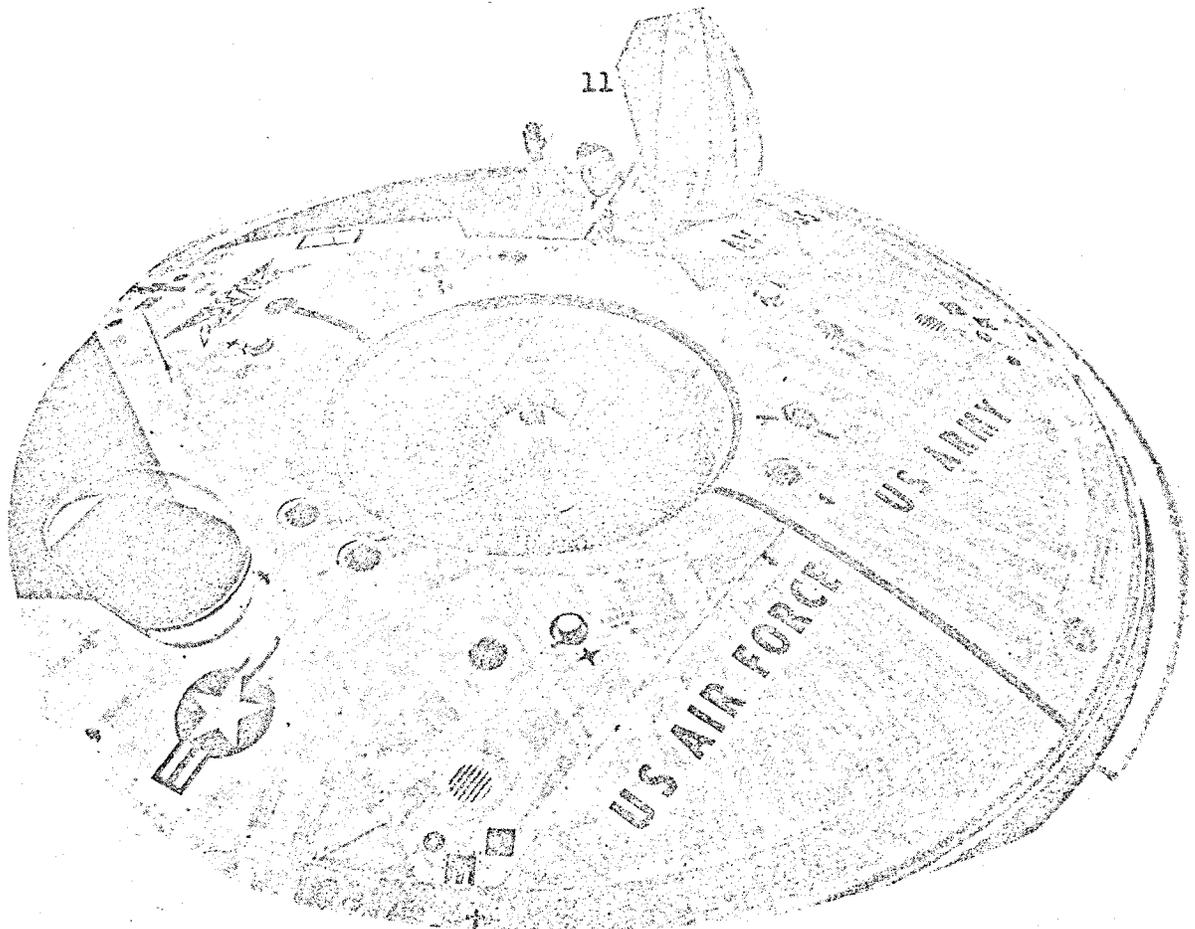


Figure 11

A Disk-Shaped Research Vehicle

Avro Aircraft, Ltd. of Canada was able to proceed to several months of wind tunnel tests at Ames Research Center with the financial support combined from the U.S. Air Force and Army. The Avro "Saucer" is powered by 3 Continental J69 turbojets driving a tip turbine forcing air to the circumference of the craft for vertical. Horizontal flight is achieved by deflecting some of the annular jet rearward; the jet cannot be turned through a 90 degree angle allowing a continuous vertical support. The Army views this model as a possible replacement for current liaison aircraft. Supersonic version was being considered with sharper wing edges and a modified inlet system for annular jet augmentation flow. Circular aircraft are relatively inefficient below 500 mph, and with an aspect ratio (wing span to mean chord) of only 1.28-drag due to lift is very high. As of the date of this report, test work was not completely successful, but there were indications that the stability and transition problems are not insurmountable.

(Aviation Week August 8, 1960 page 31)

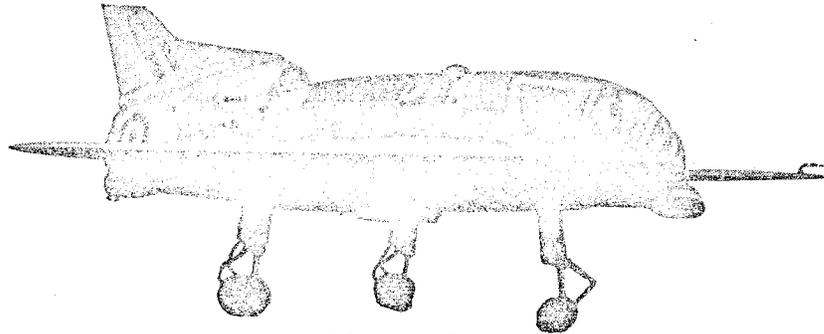


Figure 12

SC.1 a Research Aircraft

Short Brothers & Marland Ltd. of Great Britain have developed the SC.1 as a research aircraft employing 4 RB. 108 Rolls-Royce engines for vertical lift (2,130 lbs. each) and 1 RB. 108 for horizontal thrust. High thrust to weight ratios are obtainable with lift jets at the sacrifice of fuel consumption. One Rolls-Royce lift jet has been able to reach a thrust/weight ratio of 16 as of the date of this article. Controllability and stability are reached through slightly rotatable lift engines and variable nose and tail forced air outlets. (Interavia Feb. 1963 page 171)

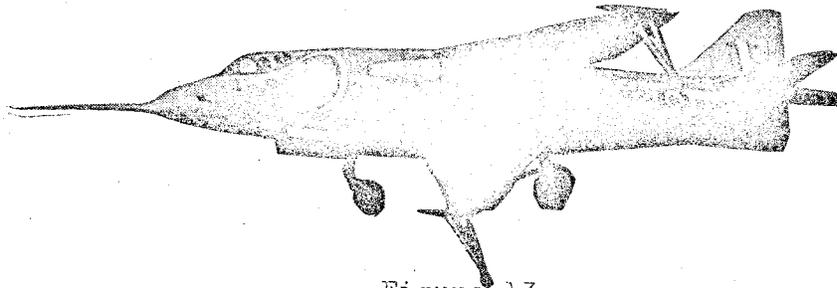


Figure 13

The Hawker-Siddeley venture

Hawker Aircraft Ltd. of England with the Bristol Siddeley Engines Limited came up with a relative revolutionary VTOL during this year with variable exhaust outlets on a turbofan engine. Thrust capability ranges from 15,000 to 20,000 pounds depending on the model of engine. The origin of the Hawker P.1127 goes back to early 1957 and has been designed as a single-seat tactical strike reconnaissance aircraft capable of supersonic speeds at high altitude plus high subsonic cruising speeds in low-level strike roles. This venture was interestingly enough started as a private risk before a government contract was issued 12 months later. (Interavia 1963)

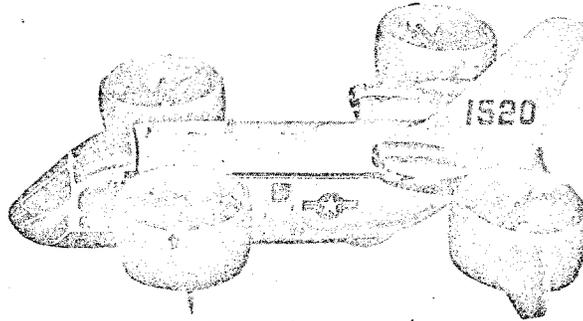


Figure 14

The Bell X-22A

Bell Aerosystems Company, division of Bell Aerospace Corporation, designed two Bell X-22A under a contract from the U.S. Navy in late 1962. Specifications called for speeds up to 350 mph, carrying 6 passengers and a crew of two yielding a 15,000 pound gross take-off weight. Four turbo-shaft jet engines (1,250 shaft horsepower) power the rotatable ducted fans. Stabilization and control are brought about by differential variation in the pitch of the individual propellers. (Interavia February 1963 page 166)

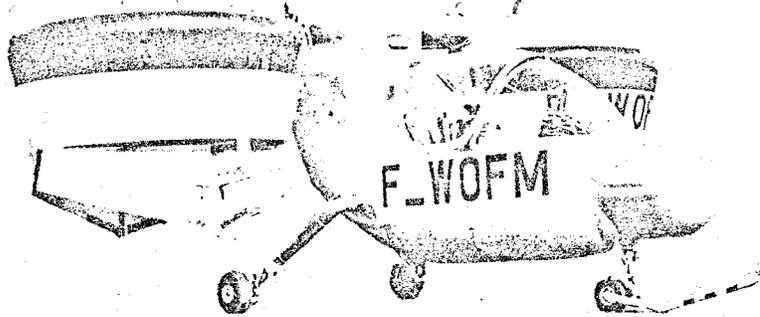


Figure 15

The Nord 500 Experimental

Nord Aviation recently started flight testing the Nord 500 experimental VTOL aircraft. Two three-bladed ducted tilting propellers are driven by linked shafts connected to two 317 shp Allison T63-A-5A turbines. The engines are installed above the main fuselage. Control in yaw and pitch is by differential and by collective propeller-tilt respectively; roll control is achieved by thrust modulation. (Interavia, Feb. 1969, page 146)

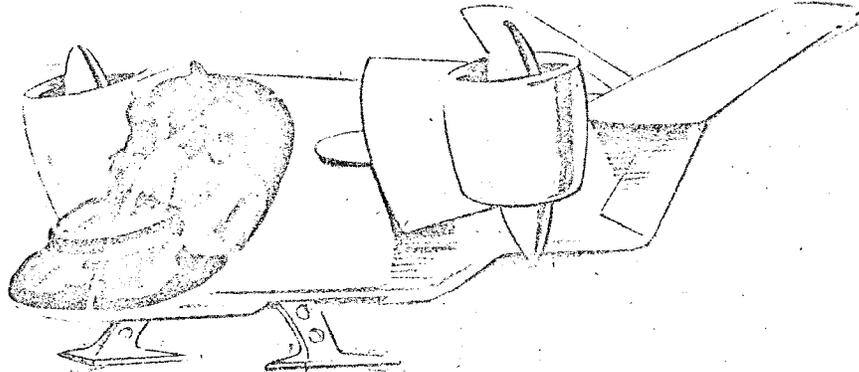


Figure 16

A Futuristic Design

Beech Aircraft is considering the two-place turbofan vertical takeoff and landing (VTOL) aircraft with a high cruise speed. The power plant size would probably run near 850 to 900 shaft horsepower with present technology; at \$50 per horsepower the turbine alone would be at least \$42,500. A senior engineer in the Bell Helicopter Co. VTOL program estimates the company would consider \$300 per horsepower per unit on a new helicopter program to amortize an investment of \$30,000 in development, certification and production tooling cost. This assumes one sale per month. The above model could go to some \$240,000 using the above rule-of-thumb method.

According to the Bell engineer, few if any companies can gamble on an investment of this magnitude considering the return over such a long period. This seems highly conservative and of course dependent on estimate market demand. The above figures are more in line with Bell Helicopter Company's commercial VTOL where gross weight starts at 12,400 lbs. with a passenger capacity of 14 plus a crew of two.

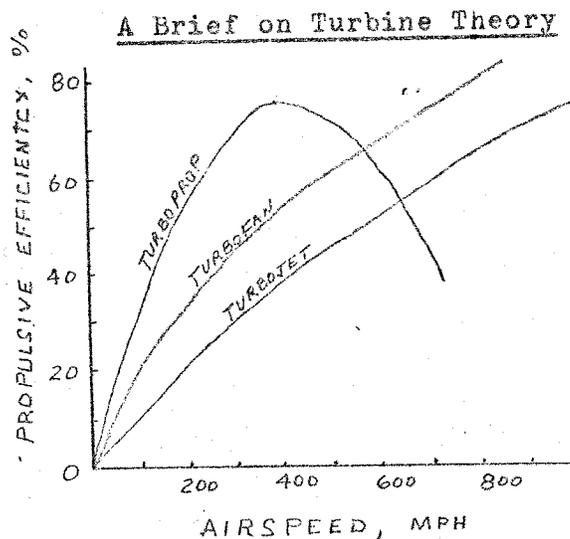
CHAPTER II

TECHNICAL FEASIBILITY

We have seen in the past few pages a few of the hundreds of machines which have been attempted to fill the VTOL vacuum over some twenty years. It can be appreciated now the risk a manufacturer takes on in every new field where research and development goes hand in hand with the capital investment. Some of the many problem areas new products face are successfully predicting market demands, pricing production, and selling costs, meeting estimated time scales, building with today's technology, at the same time keeping your fingers on tomorrow's pulse. At least half of the models illustrated started unsuccessfully with piston engines, grossly underestimating the need for power in lift, controllability and stability systems. The technology of the 1930's was not sufficiently advanced to build power plants with relative high power to weight ratio, and the helicopter was only conceivable through the use of its extended rotating airfoil.⁷

The 1940's brought in the turboshaft engine and at last offered the possibility of developing sufficient thrust with highly loaded propellers to sustain weight in hovering and horizontal flight. However, the price we still pay is very high relative to the piston engine in both money, fuel, and maintenance. It is interesting to note that in 1904 when the first Ford's came out they were selling at \$850; (this would compare to some \$3400 today) and only a well-heeled physician could lay down the cash for one. There were 1708 Fords sold the first year. It seems we are much more ahead of the present technology with the turbine today than the piston engine was in 1904. A 500 shp turbine may well run near \$50 per horsepower or some \$25,000; in terms of 1904, we could say \$6,000 and were just talking about one engine!

Today much of the VTOL research and development and purchasing comes through government contracts. So the helicopter and the car still exists today with the piston engine powering these modes of transportation, through some twenty years for the helicopter, and seventy years for the automobile. The helicopter's development was successful through the combination of adequate power plants available in the late 1930's and the application of the rotary wing brought about by the autogyro.⁸ Now many of the larger helicopters have gone to gas turbine power plants due to lower operation cost per mile.



Graph 1

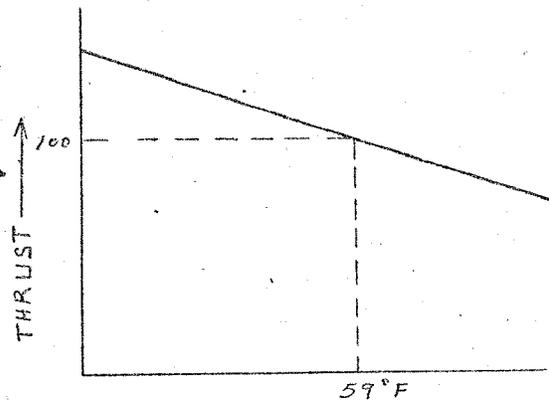
Comparison of propulsive efficiency of the turbojet, turbofan, and turboprop with changing airspeed.⁹

There are many factors that effect the efficiency of a turbine engine. Some of these are listed below:

1. Engine rpm
2. Size of nozzle area
3. Weight of fuel flow
4. Amount of air bled from the compressor
5. Turbine inlet temperature

6. Speed of the aircraft
7. Temperature of the air
8. Pressure of the air
9. Amount of humidity

Turbines do not idle at 7 or 8 percent of total power as a piston engine, but at 65% rpm on the ground, even higher in the air. The first 5 factors above can be controlled by design and 6 through 9 are non-design factors. As an example of how critical these design factors are, an increase of some 800 degrees in the turbine inlet temperature can increase output power 130% plus reduce the specific fuel consumption. Inlet temperature is of course limited to present high temperature material technology. The gas turbine is also sensitive to the temperature of its environment. (see Graph 1) All engines are rated at the same standard temperature of 59 degrees F.

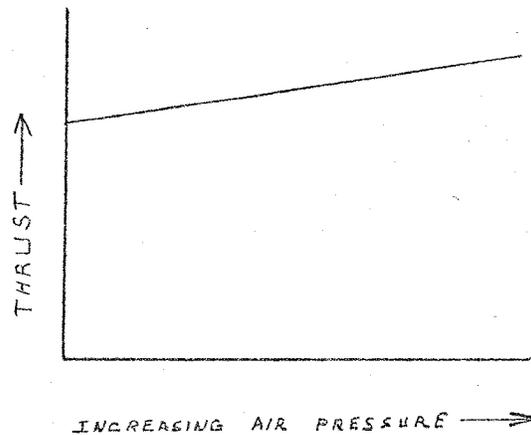


INCREASING AIR TEMPERATURE →

Effect of air temperature
on thrust

Graph 2

Thrust may vary as much as 20% from the specified rating on cold or hot days.¹⁰



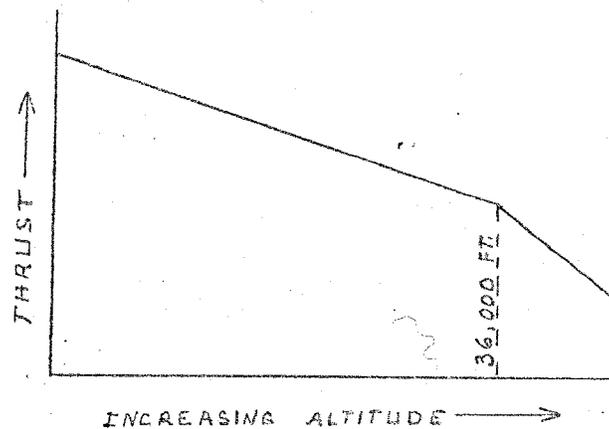
INCREASING AIR PRESSURE →

Effect of air pressure
on thrust

Graph 3

Air pressure drops as altitude is gained.¹¹

We can see from Graph 2 that air temperatures hotter than standard effect less thrust, and conversely, temperatures colder than 59 degrees F. produce large thrusts. Graph 3 shows us the common problem that all air breathing aircraft come up against. High altitudes bring less dense air and consequently less thrust, that is, when the pressure goes up, density goes up and when temperature goes up, density goes down. After 36,000 ft atmospheric temperature remains constant at some -55 degrees F. The thrust gained, due to this decrease in temperature before 36,000 feet, cannot be traded off for the loss of thrust due to the decrease in air pressure.



Effect of altitude on thrust

Graph 4

Combining thrust loss due to pressure decrease with altitude, and thrust gain due to temperature decrease with altitude.¹²

The Future of the Turbine

The operational corridor of the turbine has been reviewed in the last four graphs and we face these guide lines:

1. Maximum propulsive efficiency near 350 mph
2. Maximum percent thrust near and below temperatures of 59 degrees fahrenheit
3. Optimum thrust under altitudes of 36,000 feet

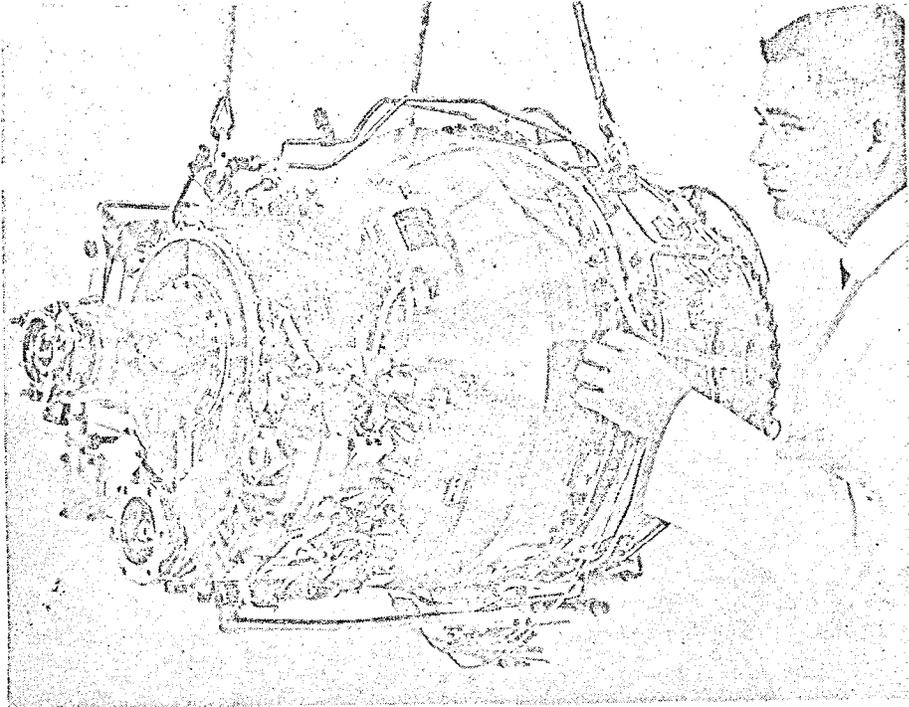


Figure 17

Pratt & Whitney's ST9

Pratt & Whitney's ST9 advanced technology, turboshaft demonstrator engine is designed to produce 1,500 shp. at significant savings in weight and fuel consumption compared to current comparable engines. The engine is being built and tested at P&W's Florida facility under contract from the Army Aviation Materiel Laboratories. Potential applications for the engine include UTTAS and other advanced Army V/STOL aircraft. (Aviation Week & Space Tech., November 17, 1969, page 32)

Perhaps no other engine in history can claim the specifications of Pratt & Whitney's ST9 and General Electric's GE 12. Both engines are expected to offer a 25 to 30 percent decrease in specific fuel consumption compared to those offered in the previous generation. Also a 40 percent decrease in weight from the last generation is expected. This would mean a decrease in weight from

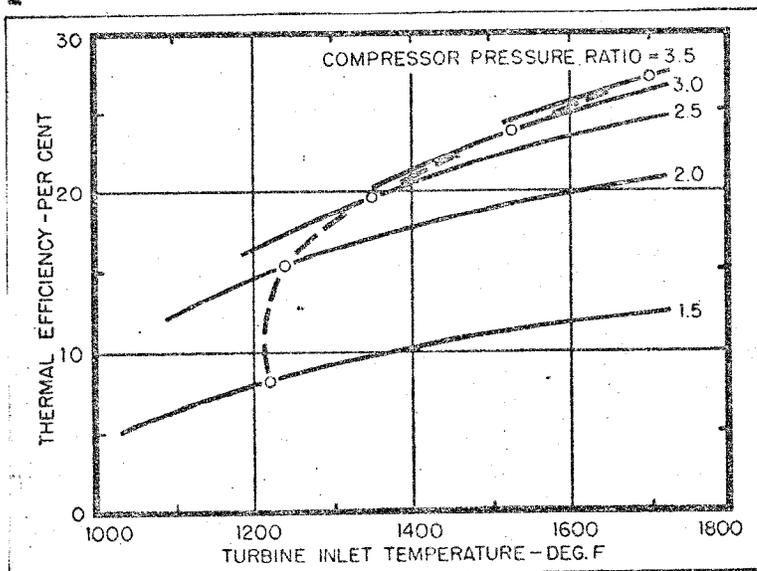
335 lbs. for the T58-GE 5, 1500 shp turbine to 201 lbs. and a decrease in the SFC (specific fuel consumption) from .61 to .46 lbs. of fuel per hp per hour. A savings of approximately 35 gallons of fuel per hour. This contract was provided by the Army Aviation Materiel Lab. which extended this particular contract to both companies through April 30, 1970. The Army claims this turbine offers the highest pressure ratio of any small engine ever built.

This brings to point four major developments we can hope to look forward to in the future evolution of turbine technology.¹³

1. Higher turbine inlet temperatures

There are two approaches that may be used to obtain this objective. We must improve the materials to withstand higher temperatures or make them run cooler through design improvement. While advanced turbines employ individual blades, those in the hottest gas are complicated by internal cooling passages though automotive turbines enjoy one-piece cast turbine rotors.

2. Turbine temperature control at part-load



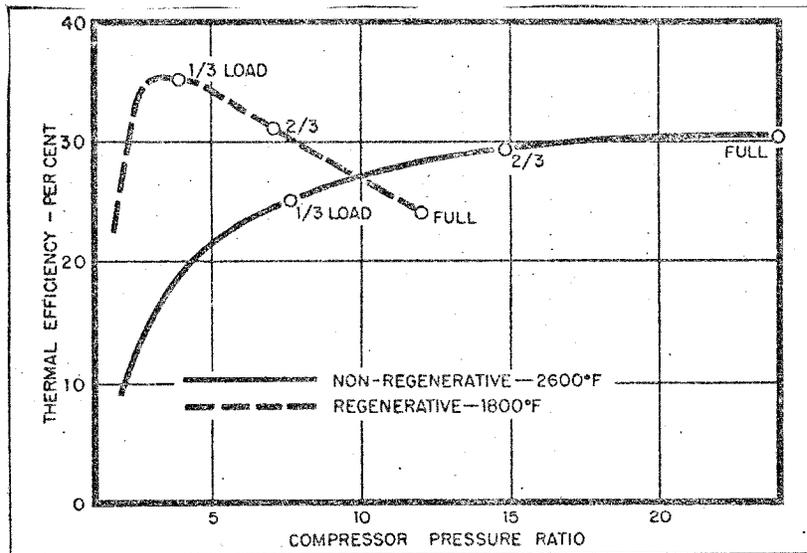
The solid lines in Graph 5 are curves of constant compressor pressure ratio. We see the increase in thermal efficiency as the turbine inlet temperature increases over a constant pressure ratio. (Gas Turbine International, Jan-Feb 1969, page 49) The dashed line represents the temperature and thermal efficiency drop as fuel flow is reduced to decrease power output effecting

Graph 5

compressor slow down and a decrease in the pressure ratio. If we look at the constant pressure ratio of 2.0 and at the dot indicating 1250 degrees Fahrenheit; the thermal efficiency at this part-load point could be increased from 16 to 21 percent by raising the temperature from 1250 degrees F to 1700 degrees F at the turbine inlet. Many methods have been devised to try to accomplish this specification. To mention a few would include variable power turbine nozzles. This would transfer more turbine pressure to the power turbine increasing the turbine inlet temperature necessary to run the compressor.

3. Use of regenerator for part-load fuel economy

Approximately 6 percent advantage can be had in thermal efficiency with the use of a regenerator, even with a futuristic pre-turbine temperature of 2600 degrees F. The superior part-load economy of the regenerative engine even at lower inlet temperatures can be seen in Graph 6 below. (Gas Turbine International, Jan-Feb 1969, page 49)



Graph 6

4. Higher compressor ratios

Ideal maximum compressor pressure ratios are being sought near 12 and 24 for regenerative and non-regenerative turbines respectively. This is, however, limited to cost, aerodynamic efficiency, and regenerator leakage.

Turbine Engines in Automobiles

The Ford Motor Company has been doing turbine research and development work for the past 20 years. They have come up with three problem areas in the application of turbine engines to passenger cars;¹⁴ fuel economy, car performance, and cost. The cost factor will be reviewed in a later section.

Fuel economy - In automobile application the acceleration requirements for a car may require 200 hp, yet use only 10 horsepower to drive steadily on a level road at 30 mph. Obtaining good fuel economy becomes a problem of reducing idle fuel consumption. For turbines this can be done by increasing the cycle pressure ratio or turbine inlet temperature but this would have to be accomplished at very low cost. Also reduction of idle speed and/or use of compressor variable geometry can substantially improve idle fuel flow. Control of parasitic losses such as bearing losses, heat and leakage losses, etc. can have an effect.

Car Performance - The most difficult design criteria to meet with a turbine car is competing with the initial acceleration of the piston engine. It becomes important to (1) design the high speed rotating components to have minimum inertia, (2) optimize idle speed with acceptable idle fuel consumption, and (3) provide excess torque to the compressor spool during acceleration by using high gas temperatures and/or variable geometry devices. A turbine powered car may have a shorter 4-second distance but a longer 10-second distance than an equivalent piston powered car.

Other factors - Ceramic materials were used in a rotary regenerator in the early 1960's, made by the Corning Glass Works. This material

known as "Cerocr" showed potential of tolerating high temperatures and high thermal gradients with little distortion plus being feasible at automotive prices. Surprisingly, market studies indicated the logical application for initial introduction of a vehicular turbine was in the extra-heavy truck field.

These large vehicles would be in the 80,000 lb. GCW class with speeds up to 70 mph. The initial purchasing and operating costs of a diesel engine were studied, and the fuel cost was found to be over 9 times that of the amortized initial engine cost. (see table I below)

Table I

Diesel Engine Cost Breakdown
(over 600,000 mile operating period)

amortized initial engine cost.....	\$ 6,300
fuel cost.....	57,420
lube oil.....	2,400
service and repair.....	5,520
overhaul.....	2,760
	<u>\$ 74,440</u>

It is essential therefore that a truck turbine powerplant be competitive in fuel economy with the diesel. A Detroit to Pittsburgh route was simulated on the computer, using some 16 gas turbine cycle arrangements compared with equivalent diesel powered trucks. The resulting route fuel economy was projected to be at least equal to that of the best equivalent over-the--road diesel.

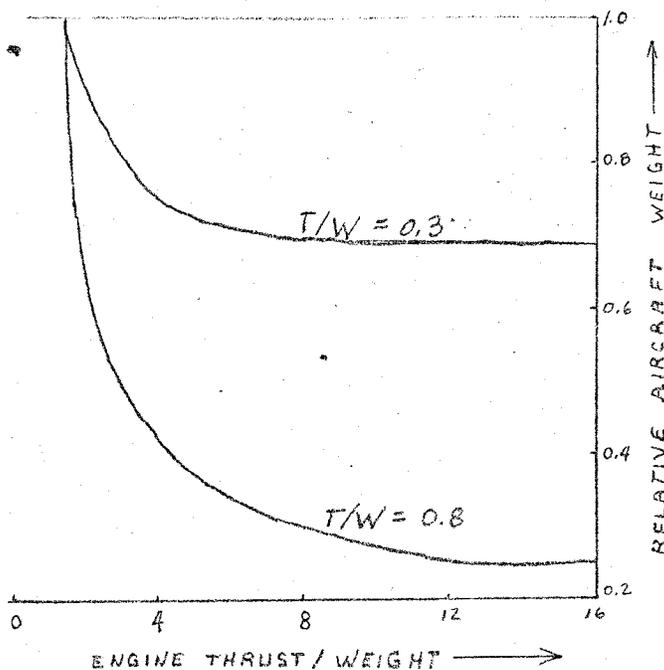
As mentioned before ceramic turbine components are being studied and with encouraging results. Ceramic exhaust plenums and production models of a turbine nozzle ring made of silicon nitride are starters for Corning's possibilities in the turbing field. Silicon nitride has a modulus of rupture of 20,000 psi, excellent

thermal shock properties that can withstand temperatures to 2500 degrees Fahrenheit with little oxidation. Ceramics opens up new areas and hopes for turbine design to produce low-cost high-temperature turbine engines.

The Turbine - The State of the Art

"With additional gains of approximately 30 percent in reduced fuel consumption, 50 percent in weight and 6 db (decibel) in noise level over and above the large improvements already accomplished, these programs promise that V/Stol propulsion is about to take off dramatically." - George Rosen, Chief, Propeller R&D, Hamilton Standard Corporation.¹⁵

During the 60's thrust/weight ratios of turbines increased remarkably. At the present ratios, it becomes less profitable in terms of total aircraft weight as the power-plant may only represent 10 or 20 percent of the gross weight. (see Graph 7)¹⁶



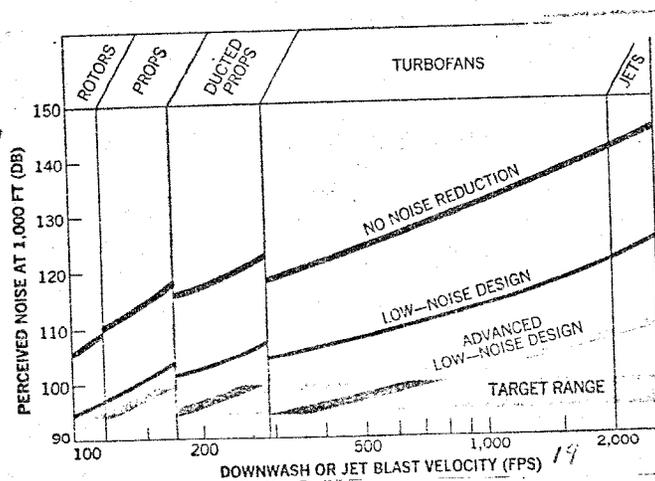
Graph 7

The next logical step for the engine designer is to improve the specific fuel consumption. Such parameters as bypass ratio, pressure ratio turbine inlet temperature, and afterburner temperature, can be effectively varied and combined and matched with the appropriate mission for minimum cost. For years the effort to raise inlet temperatures progressed slowly,

however in the late 1950's and early 1960's this was changed by the general adoption of blade cooling techniques. In 1950 the mean turbine inlet temperature was 1050 K (Kelvin); by 1960 it had increased by 100 K, but in the following 10 years the inlet temperature increased by 300 K.¹⁷

To foresee the most significant future changes in the gas turbine engine is most difficult. The continued trend to very high pressure ratios, opens speculation that the gas turbine may take over certain prime movers in non-aerospace applications such as very high pressure ratio diesel engines, and highly sophisticated high temperature steam turbines, just as it once took over within aerospace.

The Noise Corridor



The Noise Corridor

Graph 8

shows the relative advantage of five types of propulsors with the inherent gradual increase of downwash velocity and noise. Compound helicopters with large rotors are advantages over other VTOL shown above due to the low jet velocity. Moderate applications of

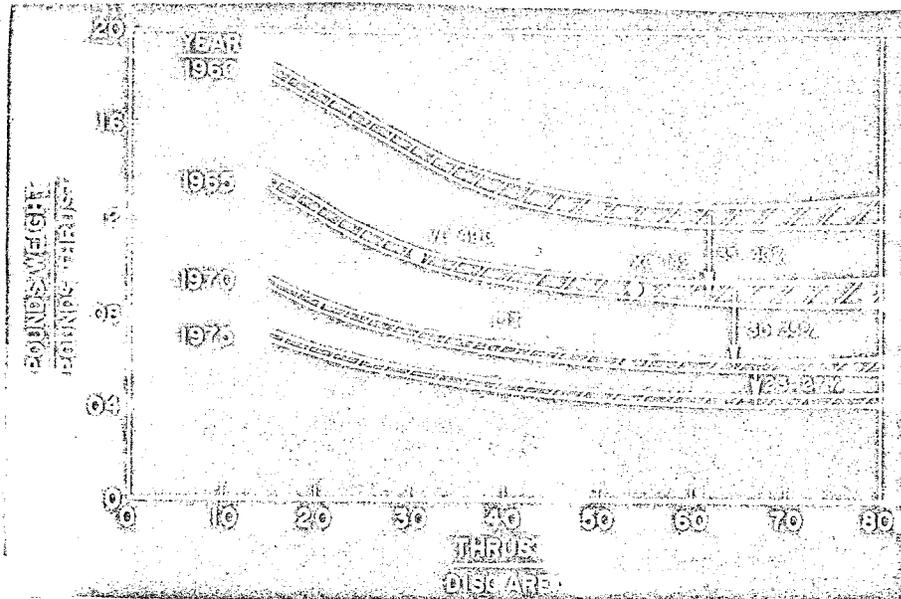
Large commercial V/Stol projects ironically, have chosen 95 db (decibel) as the standard noise level since this is also the normal level for city traffic and as yet, there is no official FAA noise standard.¹⁸ This figure is also accepted by a number of American and European cities. Graph 8

acoustic engineering should enable both rotor and propeller craft to stay in the noise corridor. Turbofans will require modifications in the engine design plus acoustic treatment and noise abatement procedures. It appears that jet powerplants will not make the noise limit even with the advanced suppression methods. Table II below is provided to give the reader a clearer picture of noise intensity relative to some older common carriers.

Table II
Commercial Aircraft Noise¹⁹

Douglas DC-3 (1936)	
Takeoff.....	98 db
Landing.....	94
Douglas DC-6B (1951)	
Takeoff.....	105
Landing.....	104
Boeing 707-120 (1959)	
Takeoff.....	131
Landing.....	115
Boeing 707-320B (1963)	
Takeoff.....	130
Landing.....	117

The techniques of noise suppression vary with the type of propulsion and include engine inlet and exhaust muffling, reduced tip speeds, refined aerodynamic blade shaping, proper location and configuration of vanes, and sound absorptive liners.²⁰ Moderate V/Stol aircraft sizes currently under consideration are approaching the 95 db (decibel) at 500 feet. Past efforts to decrease propulsor disk area loading to decrease noise was met with an adverse trade-off with weight. However, with the more advanced turbine, weight reduction up to 40% of the original power-plant size has made new compromises possible between disk loading (gross weight) and noise. Larger diameter with reduced tip speed propulsors are possible to reduce noise. Future reductions in weight and noise are very promising stemming from continuing research and development programs. (see Graph 9 on next page)

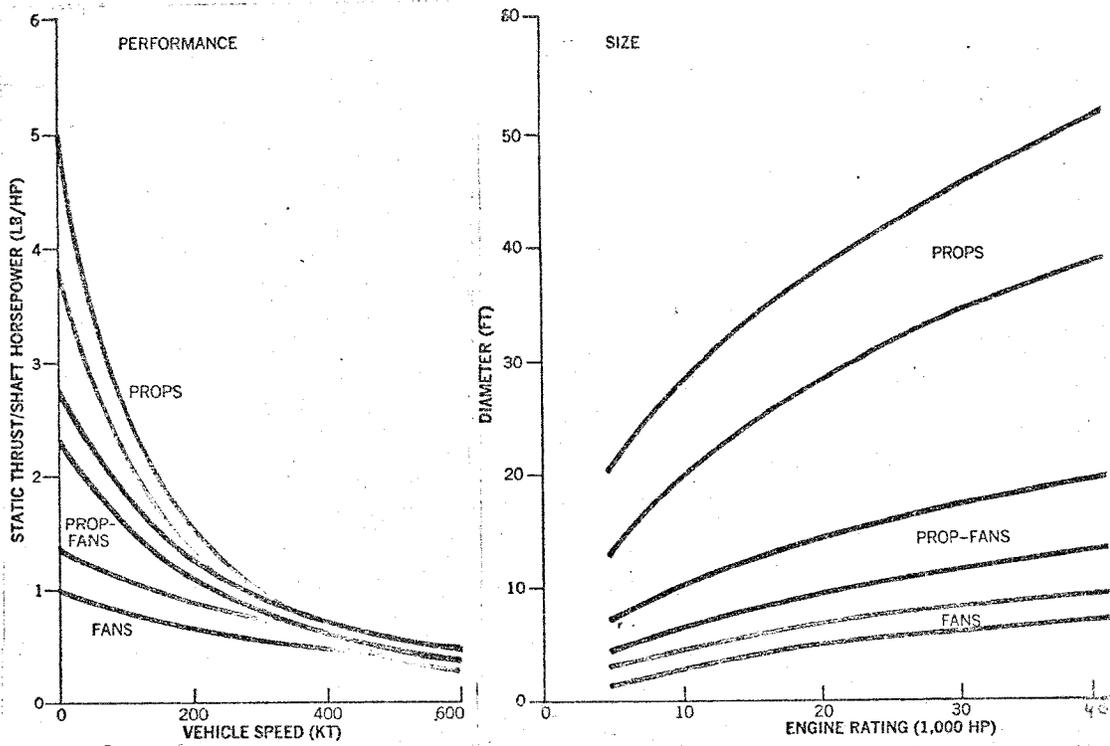


Graph 9

Downward trend in propeller system weights is shown. Bands for second generation (1970) and third (1975) are considered realistic goals by Hamilton Standard. (Aviation Week & Space Technology, Nov. 24, 1969, pg. 62)

The Propulsor System

Looking at Graph 9, we can approximate a propeller system weight by assuming a thrust/disc area ratio. We will choose 25 and this could be approximately the ratio for a 3200 pound craft with two 9 foot diameter propellers. This would yield a .08 weight/thrust ratio or about 256 pounds for the propulsor system; half the weight of the same thrust/weight ratio ten years ago. Here again, the propeller as the turbine is approaching a small percentage of vehicle gross weight--where further weight reductions programs is financially questionable compared to the weight saved. The role of the type of propulsor can be seen from Graph 10 on page 28, where trade off characteristics may be observed with increasing diameter, and thrust and bypass ratios opposed by increases in drag. The propeller-fan or propfan (typically between 8 and 12 blades) can be seen to bridge the gap in the thrust disc loading between present



Graph 10

(Space/Aeronautics May 1970, page 35)

propellers and fans.²¹ This gap in thrust disc loading is spread from a 100 pounds/foot² maximum for props to 800 pounds/foot² for fans; this report gives the most attractive load ranges for prop-fans between 200 and 400 pounds/foot². Controllable pitch blades have shown design feasibility in the prop-fan, increasing off-design performance, reducing engine-out drag, and improving reverse thrust performance.²² The additional weight cost and complexity are showing a good trade off with large, costly and less efficient flow reversers. Beginning aerodynamic wind tunnel performance testing of prop-fan models has confirmed predictions. Preliminary design studies have indicated that blade retention and pitch change mechanism are feasible. Research and Development work is scheduled for the immediate future along the propfan models.

CHAPTER III

ECONOMIC FEASIBILITY

Turbine technology in its present state can only be appreciated in corporate and military machines. Costs of turbine power plants run from \$50 per horsepower and up. The Allison Division of General Motors will presently produce several models in the 400 to 600 shp (shaft horsepower) that run between \$79 and \$87 per horsepower; that is around \$25,000 each rated at 317 shaft horsepower, and 2.27 shp/pound of engine. They are also working with other companies in conversion kit designs for "on the field" piston to turbine engine changes. Mr. D. G. Robinson, supervisor of Small Shaft Engine Sales for Allison, has stated in a letter and I quote:

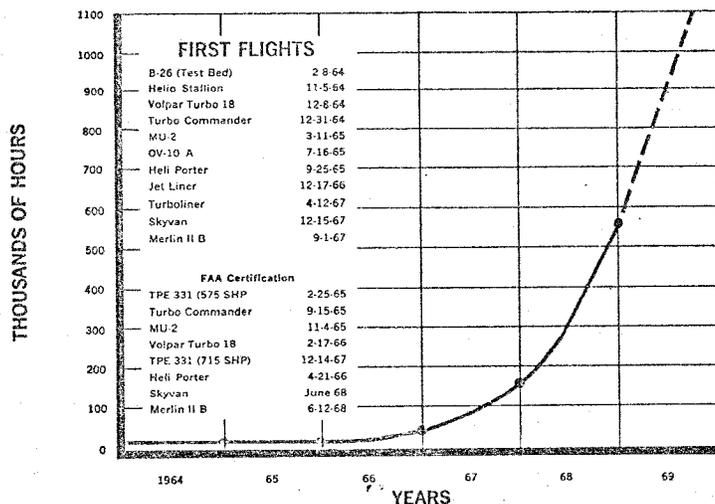
"We have every reason to believe that conversion of many existing aircraft to Allison turboprop power will prove economically practical and that this method of improving aircraft performance will become popular."

The Allison Division of GM gives in their sales booklet the following reasons for a "sweeping new turn" in the powering of light business and commercial aircraft.

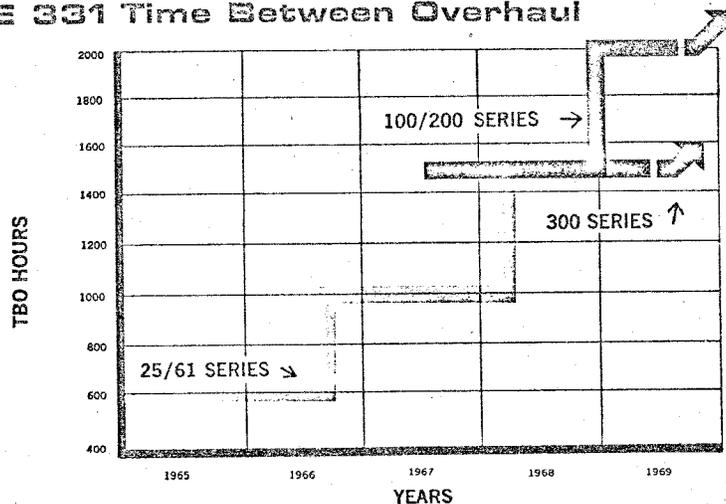
1. Improved performance characteristics
2. Potent maintenance economies
3. More scheduling dependability
4. Higher aircraft utilization and attendant lower operating costs
5. Greater design latitude for the airframe manufacturer

It is of course not surprising that such turbine manufactures as General Motors, The Garrett Corporation, General Electric, Pratt & Whitney should be optimistic about their sales, but it is interesting to look at the tremendous increase in engine flight operating hours and the time between overhaul. As can be seen in

TPE 331/T76 Flight Operating Hours



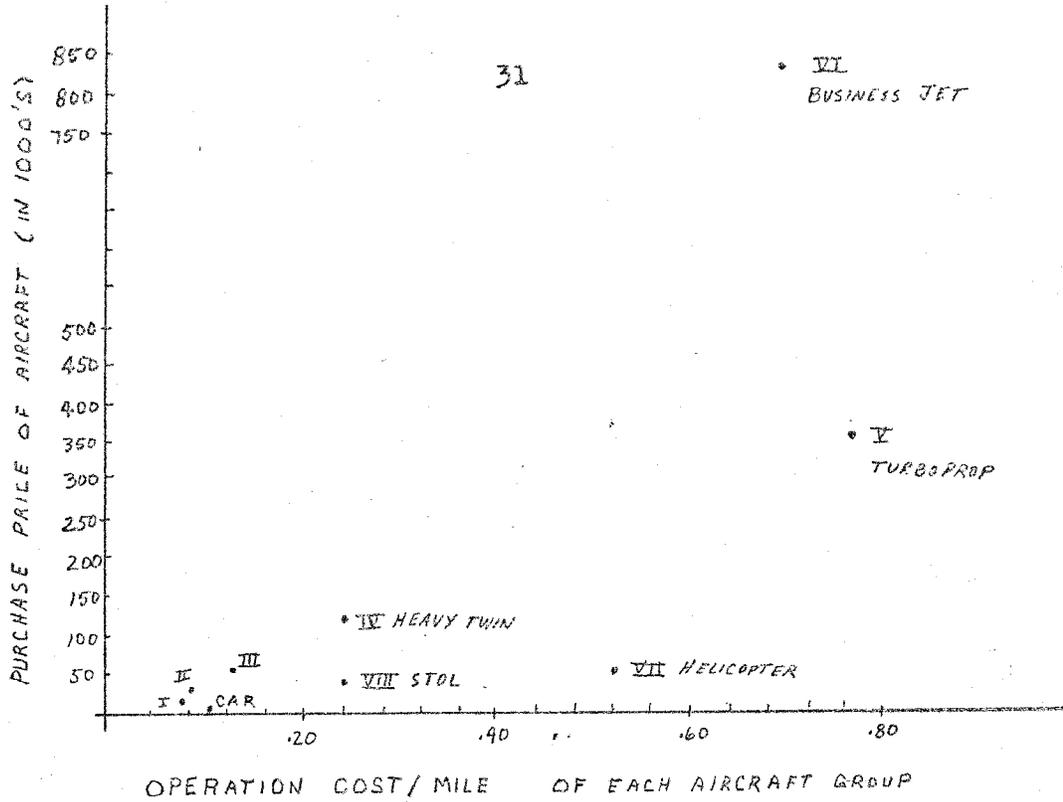
TPE 331 Time Between Overhaul



Graph 11

"Allison 250 Series Gas Turbine Engine Sales Booklet"

Graph 11, the projections of the AiResearch TPE 331/T76, TPE being a turboprop engine, of model number 331 having a military designation T76, are even now outdated with the General Electric, GE: 12 claiming 5000 hours time between overhauls!



Graph 12

Table III

AIRPLANE BUYER'S GUIDE

	Category	Seats	Speed	Range	Cost	*Annual Operation Cost (500 hrs.)
GROUP I	Single-engine, fixed gear	4	130 mph	700 mi.	\$13,500	65,000 miles \$4,800
GROUP II	Single-engine, retractable	4	185 mph	900 mi.	\$27,500	87,500 miles \$7,200
GROUP III	Light twin	4-5	200 mph	900 mi.	\$52,000	100,000 miles \$13,200
GROUP IV	Heavy twin	6-8	230 mph	1,100 mi.	\$135,000	105,000 miles \$26,000
GROUP V	Turboprop	6-8	270 mph	1,500 mi.	\$375,000	135,000 miles \$102,000
GROUP VI	Jet	6-10	500 mph	1,750 mi.	\$850,000	220,000 miles \$155,000
GROUP VII	Helicopter	3	90 mph	250 mi.	\$50,000	45,000 miles \$25,000
GROUP VIII	STOL	4-6	160 mph	750 mi.	\$45,000	80,000 miles \$20,000

*Operation costs do not take into account depreciation or pilot salaries.

Table III

Graph 12 (on page 31) compares the annual operation costs for 7 categories of aircraft; these costs reveal that to effect minimum cost the aircraft must be utilized to its fullest capability. That is, it must be used for the purpose it was designed for, whether long distance, high altitude cruising, inter-city and airport-city transportation. A business jet could no more compete economically in inter-city transportation than a helicopter could in international flights. A commercial jet flight may run the passenger 6 to 15 cents per mile depending on the distance, class of service, and the time of year. Yet, helicopter charter flights from airport to downtown areas may run near \$1 per mile for the passenger.

What are We Looking For?

Turbine engines or components to these engines have never been mass produced unfortunately; so it becomes quite speculative estimating manufacturing costs. Project facility and tooling costs to undertake mass production are even more difficult not to mention servicing networks and related training programs. It is necessary to obtain fairly reliable projections of the above costs to foresee any economic advantage of the venture.

Today, all production aircraft from 400 horsepower and up are turbined powered.²³ It seems probable that light weight VTOL aircraft will require at least twice this much power depending on the propulsor system used. Referring to Graph 10, page 28, static thrust/shp (lb/hp) for props run near 3 for speed of 100 knots and near 2 for prop-fans. If we consider a vehicle weight of 3000 pounds for example, power plant size would be 1000 to 1500 horsepower for vertical lift. Maximum speeds have ranged up to

300 mph for most VTOL aircraft; this compares favorably to the maximum propulsive efficiency at 350 mph shown on graph I, page 16, for turboprop engines. While altitude and air temperature do have an effect on the turbine and propeller performance, these do not seem to be insurmountable see page 17. Temperatures near and below 60 degrees Fahrenheit appear ideal while altitudes near 10,000 feet take a thrust loss of approximately 10 to 15 percent.

As mentioned under "The Turbine - The state of the art", the next hopeful step for the engine designer is in reduction of the gas turbine specific fuel consumption. Our imaginary VTOL above with a 1000 shp engine could have a SFC of .46 pounds of fuel per hp per hour similar to the GE 12 or ST9 shown on page 19, figure 17. This would yield 460 pounds of fuel per hour at maximum thrust, in other words, 71 gallons per hour. With aviation fuel and no refund on the tax for the private pilot, the cost per gallon is 45 cents or \$32 per hour of VTOL flight. However, as we mentioned before, this must be considered in the light of the vehicle's design which would be at speeds of 200-300 mph. Fuel cost per mile would be approximately 10 cents, however, if we look at graph 12 operation costs for a single engined turboprop may run at 76 cents a mile including maintenance, engine overhaul, and spare parts. The turbine powered Bell 205A shows figures of \$78 an hour with \$45 of that going for airframe spare parts and engine overhaul. This is for a time between overhaul (TBO) of 1,600 hours compared to the futuristic 5000 hours of the GE 12 turbine. Scheduled maintenance is light for the Bell 205A calling for one-hour-a-day overseeing examination plus nine hours for the 100 hour inspection.

The Light Turbine Helicopter

Insurance and Safety - Insurance rates are excessive, hull rates are 13.8 percent of base price which for the small two-seater turbine helicopter like Hughes 500, or Bell JetRangers and Fairchild-Hiller FH-1100's running at \$100,000 would be \$13,800 annually, and this is without liability!²⁴ Mr. John Ryan, executive director of the Helicopter Association of America, has denounced the manufacturers and insurance companies because of the "engine-failure rate of alarming proportions in new turbine models and the exorbitant insurance rates". Manufactures response to these accusations have been from flat denial to little concern. Service letters have been issued by the Allison people to cover problems with various stages of the compressor and with a main shaft bearing failure from coking of the oil lines; consequently some brands of oil were taken off the recommended list. In the two years that the Bell JetRangers and Fairchild-Hiller FH-1100 have been in service, Mr. Ryan disclosed that 54 have been forced into autorotations, due to their Allison turbine engines failure in flight. Of the 312 JetRangers with 76,000 flight hours, there had been 50 inflight engine failures and 13 airframes damaged from emergency autorotations.²⁵ Compare this to 167 Fairchild-Hiller FH-100's with 37,800 flight hours logged, and only four had inflight engine failures, and 3 damaged in emergency autorotations. This appears to be more favorable even with half the flight time taken into consideration.

This history of inflight engine failures leads us to install a back-up system. With prop, prop-fan, and fan configurations, propulsor system cannot take advantage of autorotation, at least, to the effect of a controlled emergency landing. Therefore,

alternate power plants with cross-shafting and/or aerodynamic support will add to the cost of the basic system. It also seems imperative that, at the present and in the near future, aerodynamic surfaces will have to supplement lift to reduce fuel consumption. This point seems especially pertinent to private aircraft where operational costs cannot be necessarily spread over a large number of passenger miles. We saw in Graph 12 and Table III page 31, the various annual operational costs for different aircraft and Group I of the single-engine, fixed gear category, considered the least expensive; which is twice the cost of a high priced car though operationally competitive if you spread it over 65,000 miles annually. This is quite discouraging to some, however, the elite have a funny habit of introducing the expensive toys first. Even the bicycle sold in the hundreds of dollars in the 1800's and the rich were pooh-poohed whilst riding through the park.

The Market - With no where to turn for comparison of the light VTOL acceptance, we may look toward the light turbine powered 2 or 3 seater helicopter. The Bell Helicopter Corporation reports that the entire light turbine helicopter field is booming and they have sold more Jet-Rangers (4 seater model) in a single year than anyone in history.²⁶ A notable price change in this class of helicopters has been brought out by the Enstrom Company (merged with the Purex Corporation in 1968). The T-28, powered by a 240-shp Garrett-AiResearch turbine is priced around \$62,000 with a useful load of 1400 pounds.²⁷

This is encouraging to see the turbine powered light helicopter approach the piston version - a light piston helicopter may run from \$30,000 to \$50,000. Though it is indeed hard to foresee a mass market for private VTOL even at half this price, you can

rest assured this has been seen by many others and resulted in the refinement and sales push of the gyrocopter on the public market. The gyrocopter does not have a powered rotor and is not capable of complete VTOL operation - usually requiring 75 to 100 feet for landing and takeoff. The gyrocopter's low cost, relative to the helicopter, is achieved by doing away with the complex transmission, gear boxes, and tail rotor used in applying power to the main rotor and counteracting torque; not to mention the ability to use low cost, low powered piston engines with non-variable pitch props etc. A picture (Figure 18) is shown below of the McCulloch Aircraft Company's J-2 Gyroplane, designed by Jovanovich and later sold to McCulloch. For \$15,950, McCulloch hopes to attract city-suburb, city-country commuters with its relative low cost, and 120 mph speed and short landing and takeoff features. Flight certification was granted May 6, 1970 by the Federal Aviation Administration and national dealerships were being planned to receive demonstrator models.²⁸

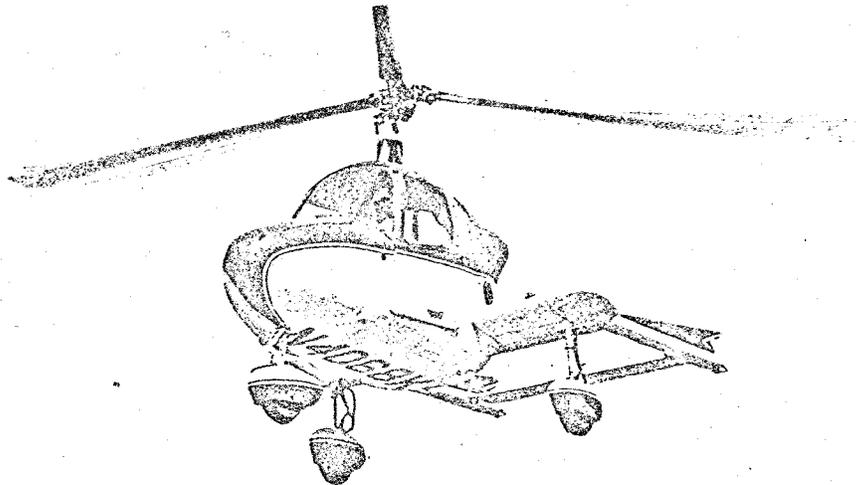


Figure 18

"J-2 Gyroplane"

McCulloch Aircraft Corporation's new J-2 Gyroplane
is now being manufactured in Lake Havasu City.

Seattle P-I, Feb. 21, 1971

Civilian & Military Helicopters Market

Civilian helicopter markets have been slow to develop because of the complex rotor systems and resulting operating costs.²⁹ About 500 were predicted to be sold in 1970 of the civilian version, while some 1251 military helicopters had been appropriated for a major weapon system for fiscal 1970. Light turbine powerplants and the Vietnam war developments have improved the outlook for business helicopter economics. Lear Jet has also entered into the light turbine helicopter field against Bell, Fairchild Hiller, and Hughes; they are forecasting sales of 2,500 in the 1970's of its 8-14 place helicopter.³⁰

Sikorsky and Boeing Vertol are predicting a market for up to 200 heavy-lift helicopter for construction, petroleum, and utility line work in the next 10 years. Ironically, the main competition comes from Russia which has two versions with a heavier payload capability than the U.S. helicopter. In fact, the Soviet Union has claimed a world's record with an even larger model which will lift a 34 ton payload to an altitude of 9,378 feet.

The military helicopter market is predicted to decline considerably from its Vietnam peak. Extremely high rates of combat losses, plus operational attrition, were responsible for the increased production of all service models during 1965-68. Bell Helicopter division of Textron has been the major supplier of military helicopters and the Army is planning a replacement for this model in the mid 1970's and they have already started funding small engine development for it with GE and Pratt & Whitney. (See pg 19, Figure 17)

V/STOL Compact Aircraft Market

The determination of the military people to develop a feasible VTOL aircraft brings up the next case in point. The reader will recall Figure 13, page 12, where a picture and brief description of the Hawker-Siddeley was shown. The first appearance of this type of aircraft in the U.S. (inventory will be made in 1971) coming from an approval in the fiscal 1970 budget of \$42 million, for the U.S. Marines to purchase 12 of these aircraft. Another 18 Hawker-Siddeley's for \$118 million has also been requested. The Pegasus engine for this VTOL was based on French patents, engineered by the British and heavily financed through its development stages by the U.S.³¹ This project is a good example of the growing international business. The Marines will perform operational testing of this craft in Vietnam and pending its successful completion, there will be an eventual buy of 100 or more. The Hawker-Siddeley's aircraft will be built by McDonnell Douglas under license. It is predicted this could develop into a major program for the Douglas Division.

Business Aircraft Market

To help us foresee possible markets and trends in VTOL aircraft, we shall look at the fast-growing plane market business. Sales of U.S. business and personal aircraft in 1969 hit more than \$700 million and are headed toward the \$1 billion annual level by 1975.³² The number of business and personal aircraft have ranged from 13,000 to 16,000 annually for the previous 5 years. Unit deliveries have remained steady or decreased slightly while dollar totals increased steadily. This is because of the larger proportion of twin engine piston, and turbine aircraft dollars in the sales mix-aircraft with higher unit price tags but lower unit sales.

Private aircraft marketing has some of the features of the automotive field. Distributor-dealer networks are vital for after-sales service; the private aircraft owner usually has to depend on the dealer network for this support. Each company usually supplies a wide range of models for a variety of prices, and performances, classes, and annual model over-hauls have become traditional for the lower-price ranges.

High-performance, jet-powered, corporate aircraft have been the largest contributor toward the \$1 billion annual sales level. Ten business jet manufactures (5 outside the U.S.) are in this competition. The market for some of the small business jets is expected to grow, especially in Europe, and the market for them in the 1970's is forecasted to top 1,000 aircraft. The three major small light private airplane manufactures, Beech, Cessna, and Piper capture 90 percent of the piston-engine business aircraft market.³³

Risk vs. Reward

As mentioned at the beginning of this report, many companies cannot, on such research programs with VTOL crafts, financially shoulder the burden of R & D. They are up against a technical and economical risk. Also we mentioned before the necessity of government sponsored programs of development. However, with the rising anti-military tide today, financing becomes one of the toughest problems facing any company at any stage in VTOL development.³⁴

Taking a lesson from the commercial aircraft companies, development costs used to be charged against the first few aircraft produced and sold, as few as 20, and the book losses incurred were then recovered from profits on every subsequent aircraft sold. This was ideal in situations where the particular market did not

continue to grow, then there were no unamortized costs to absorb later. However, as R & D costs became too large to charge against small blocks of initial production aircraft, write-off of costs had to be spread over a longer production run. This encouraged pricing based on expected orders as well as those in hand, consequently accurate estimates of potential market became vital!

The commercial aircraft builder has to make well-judged trade-offs between aircraft size, speed, price, operating cost, and passenger preference, and judge the airline willingness to pay for them. Equally important, he must have timed his market entry correctly. His ability to deliver what he has guaranteed to the airlines in a reliable aircraft is the proof of the pudding. Unless he has conceived and designed his product in tune with the tempo of the airline market, there will be no allotment for learning curves and no chance to produce a profit.³⁵

CONCLUSION

Something to hope for - As this page is being typed Williams Research Corporation, under a contract by New York City's Department of Air Resources, has developed a relative low emission gas-turbine for \$240,000 to be used as a demonstrator model in an American Motors compact Hornet car.³⁶ The turbine is only part of the program which includes a number of other power plants such as the conventional piston engines converted to liquified petroleum gas, compressed natural gas, and liquified natural gas. What has this to do with VTOL aircraft? First, the head of Ford Motor Company's turbine division has stated that a mass produced gas turbine is very unlikely to come about in the near future unless environmental factors demand it. According to a company spokesman

of Williams Research Company, cost figures for engine production indicate that the turbine will in fact be cheaper to produce than a piston engine with emission devices; that is, if they are given the same production run on gas turbines as on piston engines, and assuming that the piston engine can be brought down to turbine emission levels.³⁷ Second, this would greatly speed up present turbine technology to enable modifications to an air-worthy mass production model.

Another leading case in the near future is brought out by this same company. A one-man flying platform would have a flight duration of 20 to 30 minutes and a top speed of more than 60 mph.³⁸ Appearing like the "magnetic-car" out of the cartoon series of Dick Tracy, the Williams Aerial Systems Platform (WASP) is powered by an uprated version of the company's 430 pound thrust WR19 turbofan engine that is used in the Bell Aerospace jet flying belt. A full scale mock-up of the flying platform was displayed at the recent Air Force Exposition in Washington, D.C. An excellent case in point is the recognition of a need for individual mobility in the third dimension, plus the conviction to stand behind such an idea with company funds. It hopes to interest the military for starters and enjoys foreseeing civilian applications.

It is interesting to note that the company plans the WASP for police use in 3 to 5 years and the general public in 10 years. Why do you suppose the company president, Sam Williams has said that it will take as long as 3 to 10 years to have the flying platform on the market when they have an existing engine? This writer believes the company is hoping to foresee substantial fuel and cost improvements in their own engine, enough so, to provide police with more than 20 to 30 minutes of flight and less initial

cost. The 10 year figure would indicate Mr. Williams may be pre-supposing initial cost figures dropping to around \$10,000 with flight duration times of several hours.

Commercial VTOL-STOL service now - "The Civil Aeronautics Board has decided service with VTOL and STOL aircraft between major metropolitan areas of the Northeast is feasible, both technically and economically." ("The Stars & Stripes" September 14, 1970) The week this announcement came out the CAB moved into the second phase in which specific routes may be awarded and carriers selected. The board has approved the finding of Examiner, E. Robert Seaver that VTOL-STOL flights are necessary and feasible between the metropolitan areas of Boston, Hartford, Conn., New York, Trenton, New Jersey., Philadelphia, Wilmington, Delaware, and Washington.

A chief obstacle to the progress toward metro-flights has been a "cycle of inaction" with these factors:

1. Local authorities lack incentive to develop landing sites in the absence of some assurance that suitable VTOL-STOL aircraft will be available.
2. Manufacturers are reluctant to start active production of V/STOL aircraft until they have sufficient orders.
3. Carriers-aircraft operators are unwilling to order shipment unless they can look forward to suitable landing sites.

The CAB added that while fully developed city-center-to-city-center flights may demand equipment and landing sites not yet available, a more modest level of suburban V/STOL service is already possible with existing aircraft and can be started without delay.

Private VTOL aircraft later - With the advent of the gas-turbine, private and commercial VTOL transportation has become technically feasible with small diameter rotating airfoils. Relative high engine horsepower-to-weight ratios have enabled technology to attempt to improve the inter-urban transportation problems, and military mobile air support functions. There are still problems in the VTOL field, the major ones currently economic with initial cost and fuel economy. We have seen what it will take to solve this in previous articles, that is an ecological calling to mass produce the turbine engine and/or time to overcome fuel and high-temperature material cost. It seems inevitable to the writer that a mass mode of private air transportation will significantly add to and largely replace many forms of ground travel.

Already commercial air travel is exponentially climbing toward 200 billion passenger miles for the year 1977 compared to the 90 billion mark to date. The turbine engine manufactures are profiting from a monopoly on all production aircraft over 400 shaft horsepower. It is not surprising to hear that Ford's attorney after a frightening ride through town in the early 1900's exclaim that he was afraid the automobile would not sell because it frightened too many people, and horses, not to mention running over chickens. Imagine a \$1500 machine competing with a good horse! But today we enjoy the evolution of both of these machines and the rich have their own private airplanes, business jets and helicopters.

Human factors in future VTOL aircraft - What then is the effect of this mode of transportation, how can we conceive of flying at several hundred miles an hour, at 20,000 to 30,000 feet in a machine that starts out at near 10 times the cost of a high priced

car? Man and machine has been and will always be in a state of evolution toward adapting to the environment. The Radio Corporation of America (RCA) recently published an advertisement in the Scientific American entitled "Is New York Really Necessary?" Paraphrasing what the people from RCA mentioned that 80 percent of the American people live on less than 10 percent of the land area, and of course it was for a good reason back in the 1800's. At the time of the industrial revolution, it was necessary to live in cities for the sources of energy like coal, water and electricity, also for the very limited communication network to maintain our social and business purposes.

There is also one other deficiency not brought out by RCA, that we lacked the transportation to travel any great distance to and from our homes. According to RCA now that communication and power are technology advanced away from the urban cities, there remains some question of transportation. How far do you want to go on bumper to bumper freeways under 60 to 70 mph speed limits? RCA says, "No more. There are no longer any good reasons to continue this hopelessly outmoded life style." Industrial areas will become hubs, rural areas will disperse several hundred miles from these centers as transportation systems and modes complement outward moving communication, power, and water systems. Transportation has been outdated and with it the piston engine has become prehistoric.

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FOOTNOTES

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|-----|----------------------|-----|----------|
| 1. | 11 - 170 | 27. | 7 - 49 |
| 2. | 11 - 168 & 169 | 28. | 12 |
| 3. | 4 - 55 & 56 | 29. | 10 - A19 |
| 4. | 3 - 15 | 30. | 10 - A19 |
| 5. | 3 - 15 | 31. | 10 - A25 |
| 6. | 3 - 15 | 32. | 10 - A18 |
| 7. | 1 - 170 | 33. | 10 - A19 |
| 8. | 1 - 170 | 34. | 10 - A42 |
| 9. | 1 - 74 (figure 3-9) | 35. | 10 - A42 |
| 10. | 1 - 74 (figure 3-12) | 36. | 9 - 39 |
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| 25. | 6 - 68 & 69 | | |
| 26. | 6 - 68 & 69 | | |

note: Above footnotes indicates number and page of bibliography referred to on page 45.