NASA Technical Memorandum 79254

AN OVERVIEW OF NASA RESEARCH ON POSITIVE DISPLACEMENT TYPE GENERAL AVIATION ENGINES

(NASA-TM-79254) AN OVERVIEW OF NASA RESEARCH ON POSITIVE DISPLACEMENT TYPE GENERAL AVIATION ENGINES (NASA) 40 p HC A03/MF A01 CSCL 21E

N79-31210

Unclas
G3/07 35768

E. E. Kempke and E. A. Willis
Lewis Research Center
Cleveland, Ohio

Prepared for the
Aircraft Systems and Technology Meeting
sponsored by the American Institute of
Aeronautics and Astronautics
New York, New York, August 20-22, 1979

An Overview of NASA Research on Positive Displacement
Type General Aviation Engines
AIAA Paper No. 79-1824

E. E. Kempke & E. A. Willis

ABSTRACT

An update is presented of the general aviation positive displacement engine programs underway at the NASA Lewis Research Center in Cleveland, Ohio. The program encompasses conventional, lightweight diesel, and rotary combustion engines. Its two major technical thrusts are directed at lean operation of current production type spark ignition engines and advanced alternative engine concepts. Recent developments in these areas are described.

INTRODUCTION

The NASA Lewis Research Center is involved in a research and technology program related to improved and advanced general aviation engines. As indicated in a recent overview[1], the total program contains elements which address both turbine-type engines and positive-displacement engines including conventional recips., diesels and Wankel rotaries. In last year's review of the positive-displacement engine program[2], we reviewed its objectives and rationale and surveyed the early results. The purpose of this discussion is to provide an update on recent developments and to review selected research areas in greater depth.

The overall goals of the NASA sponsored positive displacement engine program are to develop technology to improve fuel economy, reduce engine weights and installation drag, and provide for broad-specification fuel or multifuel usage. Its two major technical thrusts are directed at lean operation of conventional air cooled spark-ignition piston engines; and advanced alternative engine concepts such as all-new spark-ignition piston engines, lightweight diesels and rotary combustion engine concepts that show potential for general aviation in the mid-term and long-term future.

The conventional piston engine activities involve efforts on improved fuel injection, improved cooling, and experimental and theoretical combustion studies.

The advanced engine concepts activities include engine conceptual design studies and enabling technology efforts on the critical or key technology items.

In each area, the basic approach includes theoretical studies supported (to the extent practicable) by experimental research and by continuing improvements to our facilities, instrumentation and combustion diagnostic capabilities.

FACILITIES

The leading features of the three currently active facilities are given in Table I.

In the diesel facility ("SE-6"), the news is that the AVL single-cylinder research engine/dynamometer test rig is now operational and is producing data to support the diesel design study which will be discussed later.

In the "SE-11" facility, an ambitious instrumentation development task using a 1975 Chevrolet V-8 engine as a "workhorse", was completed early this year. (Some results from this work will be discussed in a later section.) The Chevrolet has now been replaced by a 1978 Mazda rotary engine, non-emissions model #12-B. The completed installation is illustrated in Figure 1. Facility shakedown running is in progress currently, with data production hopefully following shortly. The basic objectives of the Mazda program (which will not be further discussed herein) are, firstly, to adapt the combustion diagnostic instrumentation to rotary engines; and secondly, to evaluate the suitability (for aircraft propulsion) of mass produced rotary engines or components thereof.

This year's modifications to the aircraft engine facility ("SE-17") consist primarily of adding a transparent inlet port for flow visualization studies as will be more fully discussed in the section on "Fuel Injection".

CONVENTIONAL ENGINE ACTIVITIES

Current-Production Type Engine Improvment

Teledyne Continental Motors, Aircraft Products Division under a NASA Contract is engaged in research aimed at improving the fuel economy and reducing exhaust emissions of its General Aviation aircraft piston engines[3]. The investigation has resulted in the development of four concepts which, when applied to an aircraft piston engine; provide reductions in exhaust emissions of hydrocarbons and carbon monoxide while simultaneously improving fuel economy. The four chosen concepts as shown in figure 2 are (1) an improved fuel injection system (2) an improved cooling cylinder head, (3) exhaust air injection, and (4) variable spark timing. The combination illustrated here has already demonstrated a 7% high performance cruise fuel economy improvement with emissions reduced significantly below the EPA levels.

Cooling Drag Reduction

The objective of the General Aviation Cooling Drag Reduction program is to develop and demonstrate technology to improve the performance and economy of general aviation piston engine aircraft via reduced cooling and installation drag. Contemporary engine cooling and installation designs are based in part on technology and data developed for radial engines. These data and technology are not adequate for precise design of an engine installation using a horizontally-opposed engine. It has been estimated that the cooling drag for current designs ranges from 5 to 27% of the total airplane cruise drag. Recently-completed tests in the Ames Research Center 40' X 80' wind tunnel have shown a cooling drag of 14% of total airplane cruise drag for one configuration[4]. An integrated approach to engine cooling that includes reduced cylinder cooling requirements together with improved internal and external aerodynamics associated with the installation and nacelle design, can reduce this drag by at least 50%.

This is translatable into a potential 2-14% improvement in the airplane's fuel economy, which is a substantial economic benefit to the individual owner/operator and, eventually perhaps, to the national economy as well. In addition, individual owner/operators will enjoy noticeable improvements in range, speed, rate-of-climb, ceiling, engine-out capability, and other similar areas of traditional concern to General Aviation.

NASA-Lewis has already issued an RFP for the first portion of the Piston Engine Improved Cooling Program. This part of the program will establish the current practice and actual minimum cooling requirements for representative present-day cylinder head/barrel assemblies. Using these results, various cooling concepts will be evaluated on their ability to further reduce the cooling requirements below the present-day minimum values. At least two of the most promising concepts will be selected, designed, integrated, and tested on the cylinder head/barrel assemblies. In order to extend these experimental results to other cases, an analytical computer simulation model on the cylinder head/barrel assemblies will be developed. This will make the above results accessible and useful to the entire industry regardless of which contractor is selected.

A planned but as-yet unfunded follow-on contracted effort will use the above improved technology base and design information to design an optimized cylinder head/barrel assembly and to conduct experimental verification tests on a single cylinder engine. Parallel efforts will result in improved aerodynamics methodology for improved inlets, exits and cowling internal flow paths. Following the verification testing, a full scale engine and nacelle will be built-up for subsequent full scale wind tunnel and flight tests.

Fuel Injection

A research effort is being conducted to determine and demonstrate the potential of an optimized inlet-port fuel injection system to reduce fuel consumption and exhaust emissions via an extension of the lean limit. To accomplish this requires a more complete understanding of the relationship between the fuel-air mixture preparation prior to induction into the combustion chamber and overall engine performance. The extent to which the microscopic and macroscopic degree of homogenity of the mixture entering the combustion chamber affects performance is not well known. The classical theory concerning mixture preparation has been that a well mixed, homogeneous charge was necessary for lean operation. The reasoning behind this theory was that erratic fuel-air ratios may have patches of very lean mixtures that prevent ignition or impede propagation. Various investigations have been conducted which support this theory[5,6,7]. However, these results are in conflict with the recent work of Matthes and McGill[8] as well as Peters and Quader[9] who concluded that some form of heterogeneous intake charge "wetted" with fuel droplets and possibly with bulk stratification may be optimum for lean combustion. Accordingly, the NASA investigation is designed to provide additional information on this important aspect without assuming that complete vaporization yields optimum heat engine performance.

A logical first step in this investigation is the careful characterization of fuel injection spray nozzles. The physical state of the fuel-air mixture inducted into the cylinder is influenced by the properties of the spray emitted from the injector. Hence, key variables such as droplet size, velocity, and spatial distributions must be known as a function of nozzle design and operating parameters.

Qualitative comparisons of manifold port fuel injectors were conducted using photographic data of fully developed fuel sprays into quiescent air in order to screen injectors[10]. Mechanically and electronically operated pintle injectors exhibited the best atomization characteristics. Plain-orifice injectors currently in use on the general aviation engines imparted low atomization to the fuel under the conditions tested.

Spectron Development Laboratories, Inc. under a NASA contract is using a laser visibility method (particle sizing interferometry with off-axis light collection) to obtain particle field measurements of different injectors under simulated engine manifold conditions. Particle size and velocity are measured simultaneously, spatial distribution is determined directly and data analysis and management is automated. With this method (Figs. 3 & 4), the size and velocity of each particle is measured as it passes through an interference fringe pattern formed by the intersection of two focused laser beams.

The size is determined by the relative modulation of the signal and the velocity is accurately determined by measurement of the signal period.

The second phase of the investigation which consists of establishing the disposition of fuel-air mixture in the aircraft engine will be conducted at Lewis. One cylinder head of the TSIO-360-C engine has been modified to include a transparent acrylic intake section as shown in fig. 5. Under a wide range of motored engine operation, high speed photography and in-cylinder fuel-air measurements using a sampling valve will be used to correlate the injector spray and position with the fuel-air mixture characteristics in the intake port, and cylinder during the intake and compression stroke to more fully understand the precombustion process.

The next phase will consist of single-cylinder performance and emissions tests.

Experimental and Theoretical Combustion Studies

The objective of the spark ignition combustion studies is to establish fundamental knowledge and predictions of the flow process and chemical reactions in homogeneous and direct injection stratified charge engines.

Diagnostic instrumentation has been developed by NASA to acquire fundamental information about the governing subscale combustion process. The generated information is also used to support the development of an Otto cycle computer model (to be discussed in the next section).

Instrumentation already designed will determine on a per-cycle, per cylinder basis, real-time measurements of:

1. Indicated mean effective pressure.

2. Percent mass of charge burned vs. crank angle.

3. Combustion interval and ignition lag.

4. Pressure-volume diagram.

5. Average and standard deviations of imep, combustion.

6. Ignition energy, secondary voltage and current.

Very briefly the above is accomplished as follows: a piezoelectric transducer measures pressure at each moment within the engine cylinder. Gas volume is computed from the measured shaft angle and engine geometry. From pressure, thermodynamic relations and adiabatic assumptions we compute the fraction of charge fuel burned at every given moment, and by integration of pressure vs. volume we determine the indicated mean effective pressure. From these results we infer the ignition lag and the combustion interval.

In addition, ionization probes are placed in the cylinder head to measure flame position and thickness as a function of crank angle. Figure 6 shows an arrangement of three probes in a wedge shaped head.

The probes extend radially on a common line, which is offset by approximately 0.6 cm and on the exhaust valve side of the spark plug. Several interesting measurements of flame propagation have been made with this arrangement. Figure 7 is an oscilloscope photograph, taken in real time, of the 3 ionization probe signals and mass fraction burned with crank angle for two successive cycles. We can establish the fraction of charge burned with flame location and the relative speed of flame propagation with rate of energy release. Also, we can determine the combustion interval and ignition lag from these photographs for different timing, equivalence ratio, and power settings. An important result from these photographs is the difference in radial and axial flame propagation rates for different cylinder head geometries. Refering to figure 7 we see that the flame has moved to within 1 cm. of the cylinder wall and only about 50% of the charge was burned. This indicates the strong effect of squish as resulting from a particular head geometry and the relatively slow penetration of the flame towards the piston. This display, along with our real time ignition secondary or spark plug voltage and current display is used to show the effect of turbulence and local variations in air fuel ratio on ignition source stability, flame kernel development and finally flame propagation for several consecutive engine cycles. A principal assumption employed in combustion modelling is the concept of a spherical flame with small thickness. The validity of this assumption is checked over a wide variation in engine conditions using the ionization probe and mass fraction burned versus crank angle display.

More recently, a unique charge sampling system has been developed which measures the local fuel air ratio. The information provided by the system is used to establish the cyclic and spacial variation of fuel/air ratio within the combustion chamber at selected times in the cycle of an operating engine.

Briefly, the sampling system works as follows: a very small volume of gas is sampled by a fast acting valve at any selected crankangle up to the start of combustion. The sample enters a high vacuum chamber and is analyzed by a mass spectrometer for fuel and air concentration. A digital electronic instrument was designed by NASA to control the sample valve, measure the output from the mass spectrometer, and perform the calculation to determine the equivalence ratio. Figure 8 shows the sample valve installed in the head of a Chevrolet V-8 engine. A typical spectrum output from the mass spectrometer is shown in figure 9. Mass 14 and 43 is used as air and fuel signatures which in turn are electronically ratioed to give air/fuel ratio to characterize the quantity of air and fuel, respectively.

All of the above instrumentation has proven to be extremely valuable in studying the role of turbulence and gas motions in combustion chambers. A principal goal is to formulate a general mass of charge burned relationship which includes air fuel ratio, engine RPM, and torque. This result is again important in Otto cycle modelling where until now the mass fraction burned curved was assumed to have a simple cosine relation.

Otto Cycle Computer Model

Since December 1977, the National Aeronautics and Space Administration has supported a program on internal combustion engine flame propagation and emissions at Princeton University with Dr. William A. Sirignano as the Principal Investigator. The major goal of the program remains the development of a theory and a computer code which predicts (temporally and spatially-resolved) hydrodynamic and thermochemical properties in the reciprocating combustion chamber together with power, heat transfer losses, and emissions-at-the-exhaust-port. The basic approach includes not only developing the computer program[11], but also the experimental validation of key hydrodynamical features of the flow model.

Theoretical Program. A major effort has been placed into developing a computer code which can be employed for the calculation of two-dimensional, unsteady, reacting and nonreacting turbulent (as well as laminar) compressible flows with moving boundaries and with scalar transport. The decision was made to begin with an existing two-dimensional steady incompressible code ("TEACH") and develop it to account for unsteadiness, moving boundaries, and variable density. That decision was implemented early in the program and the documentation for that code has been completed. The code has been exercised for the laminar (very low rpm) case and the turbulent case with highly-idealized representations of the intake and exhaust valve. Presently, the efforts are concentrated upon the development of more realistic valve geometries, the addition of a swirling motion, and the addition of chemical reaction and mass transfer.

In summary the status of the Otto cycle code is as follows:

* The code predicts the flow field for axi-symmetric, unsteady, moving boundary, compressible, turbulent (scale & intensity) piston-cylinder flows.

* The code extends beyond the valve into the manifold and consequently the initial conditions do not use assumed velocity and turbulence profiles but real engine variables such as valve diameter to cylinder bore ratios, valve lift curves, and entrance and exhaust flow angles and swirl.

* The predicted flow field includes the boundary layers and hence surface effects.

* The predicted flow field is sensitive to both large and small scale turbulence conditions.

Experimental Program. In order to validate the turbulence model, a cold flow configuration has been designed and fabricated which simulates the essential hydrodynamic features of the combustion chamber in a reciprocating engine. In particular, laser doppler velocimetry (LDV) measurements have been undertaken; mean flow velocity and velocity correlations have been determined for the experimental configuration. Special calculations pertaining to the cold flow configuration have been made with the above-mentioned computer code and compared to the experimental results. Some reacting flow cases have also been calculated but further development is required here.

The measuring LDV system employs a 15 mW He-Ne Spectra Physics laser (Model 124A) with λ = 633 nm, couples with Thermo System Series 900 LDV optics. Cigar smoke is used as the seeding agent. A dual beam forward scattering method for measuring single flow velocity component is used. A Bragg cell (frequency shifter) TSI Model 980 with electronic down-mixer has been incorporated in the transmitting optics to resolve directional ambiguity in the flow, since flow reversal zones exist inside the cylinder. Since the engine operation is periodic and the data are taken over a number of cycles, a zero reset of the electronic clock is triggered by a signal from a top-dead-center indicator which was built and installed early this year. This enables us to relate each data point taken to the appropriate crank angle and also allows for identification of individual cycles. The data signals are transmitted to the on-line computer (HP 21MX) as Doppler frequency-time pairs and converted by a computer code to velocity-crank angle pairs. A data collection rate of 100 to 1000 signals per second is typical.

Measurements of both axial and tangential velocity components have been taken (separately) for various operating conditions (e.g., open-orifice and open-valve at 31 rpm). A complete mapping of velocity distribution in the motor includes 4 to 5 axial positions; at each of them, measurements at 20 to 25 different radial locations have been taken. Measurements on both sides of the cylinder axis have proved that the flow is practically axisymmetric. Each individual test consists of about 10,000 data points, taken over a number of motor cycles.

Two significant test series have been accomplished: experiments with open orifice and experiments with permanently open-valve, both at one rpm level (31 rpm) and one compression ratio (7:1). It is expected that by the end of the research activity at Princeton, similar tests for higher rpm (approx. 260 rpm) will be made, and the engine will also be tested in operating-valve conditions (such tests require special treatment of the data, since the engine cycle consists of four strokes rather than the two strokes of the open-orifice or open-valve conditions).

Figure 10 shows the typical experimental axial velocity distributions at one axial position (2.54 cm) and various crank angles for both open-orifice and open-valve conditions. The mean flow field variations with time during a cycle can be learned. In the open-orifice case, the intake flow takes the shape of a jet with a diameter roughly equal to the orifice diameter, and a peak axial velocity exceeding the piston velocity by an approximate factor of cylinder-to-orifice area ratio. Maximum piston velocity at 31 rpm is about 12 cm/s. In the open-valve case, the intake flow is aimed approx. 45° from the centerline. A flow reversal region near the wall can be identified during the intake stroke for both cases. However, with the open-valve, there is another flow reversal region, behind the valve. The exhaust axial velocity is relatively uniform in the two cases and is of the order of the piston velocity.

In summary, the following experimental results have been obtained:

* Measurements of two flow velocity components: axial and tangential; apparently for the first time in a similar system. Thus, significant additional information on the mean velocity and turbulence intensity in the engine cylinder could be obtained.

* Comparison of different cycles which suggests that cycle-to-cycle variations are generally insignificant in this motored design.

* Results of axial and tangential components of mean flow and rms of velocity fluctuations have been accomplished for two different operating conditions: Open-orifice and open-valve, both at 31 rpm and compression ratio of 7:1.

Similar measurements at higher rpm (approx. 260) and measurements with an operating valve (4 strokes) conditions will be made during the next three months. Lower compression ratio measurements will be made before the end of the grant year. Also, by redesign of the cylinder head, access for radial velocity measurements will be allowed.

Comparisons with the theoretical predictions are being made. The first examples are the low RPM, open orifice, and turbulent non-reacting flows. The velocity profiles agree in shape and good matching occurs in the vicinity of the orifice jet or in the region near the jet. Comparisons near the wall agree in shape, however the predicted velocity profile gradients are larger than the measured gradients. Good agreement occurs with the location and magnitude of the flow reversal region.

ADVANCED ENGINE CONCEPTS

Background

The effort on advanced engine concepts for General Aviation is continuing. This effort includes the study and evalution of lighweight diesel, rotary combustion, and advanced spark ignition piston engine concepts that show potential for aircraft application in the mid-term and long-term future. The design studies are at different stages of progress, therefore only the results of the completed diesel study will be discussed in detail.

Lightweight Diesel

Teledyne Continental Motors, General Products Division has completed a study to arrive at diesel engine configurations and applicable advanced technologies which offer potential benefits to a general aviation aircraft engine.

The engine concept design for high level technology is shown in figure 11. The cylinders are arranged in two offset banks of three cylinders each, acting on a single crankpin. The rotating and reciprocating inertias are 100% balanced by counterweights on the crank cheeks. The pendulum dampers are mounted to the counterweights and will be tuned for the 4-1/2 and 6th orders. The cylinders are uncooled and provided with ceramic liners. The intake ports and the intake manifold are located at the front side -- the cool side of the engine. The exhaust ports and exhaust manifolds are located at the backside -- the hot side of the engine. Two exhaust manifolds are required to prevent the exhaust pulse of one cylinder to interfere with the Curtiss loop scavenging of the previous cylinder in the firing sequence. The piston tops are ceramic.

The small end of the connecting rods is designed to allow free rotation of the piston to reduce the wear rate of the piston rings. The big end of the connecting rods is designed as a slipper, i.e., each rod contacts only 1/3 of the circumference of the crankpin. This is possible for 2-stroke cycle engines because the combined load of gas pressure and inertia is always directed toward the crankpin. The bearing material will initially be conventional, but a study could be conducted later of self-lubricating and gas bearings to eliminate the need for oil in the crankcase. The oil to be used initially is a synthetic oil which can take higher temperatures and requires fewer changes than conventional petroleum based oils.

Immediately in front of the 1st main bearing are 6 individual injection pumps, operated by a single lobed cam ring. Individual pumps were chosen to improve engine reliability -- failure of one pump still leaves 5 cylinders operable. Also, all fuel lines can have the same length resulting in the same injection timing for all cylinders.

A bevel gear in front of the cam ring drives the prop governor and the fuel priming pump.

A gear reduction reduces the crankshaft speed of 3500 rpm at take-off down to 2300 rpm propeller speed.

At the back of the crankcase is an accessory housing which contains the gearing for the engine oil pump, the vacuum pump, and the bleed air starter. The air starter drive is provided with a slip clutch to prevent engine damage in the case of a hydrostatic lock in one of the cylinders (accumulation of fuel due to the leakage of a fuel injector). Four engine mounting points are provided on the accessory housing. Above the accessory case is the catalytic combustor assembly. Leading to it are the two exhaust manifolds and the air bypass for operation the the APU mode.

The turbocharger is located behind the accessory housing. Figure 11 shows the turbine to the left and the compressor in the center. To the right is gear housing with the high speed alternator and turbo oil pump drives.

The turbocharger can run independent of the engine. For that purpose a high-speed starter/alternator and an oil pump are mounted on the turbocharger. A 2-way valve is placed in the intake manifold. To start the engine this valve is in the vertical position of the schematic (Fig. 12) which results in a turbocharger loop independent of the engine. Combustor fuel is ignited by the heater. This heater can be turned off as soon as the catalyst becomes sufficiently hot. The cycle will become self-sustaining at approximately 1/3 of maximum turbo speed, and the starter now runs as an alternator. Hot, high pressure air will flow to the engine when the 2-way valve is partially opened. The cylinder intake ports are opened during approximately 120 crank-degrees, so hot air can flow through two cylinders for preheating on an extreme cold day. The high pressure air will next be admitted to the engine-mounted bleed air starter to crank the engine. The whole sequence would be automatic on a production engine.

This system offers many advantages:

1. The availability of hot induction air at start reduces the need for a high compression ratio. The engine will start and idle at a 10:1 compression ratio provided this hot high pressure air is available to it. Thus, with this low compression ratio, the firing pressures are held down to 9650 kPa at full load resulting in low engine weight.

2. The engine will start easily under extreme cold conditions, a problem with current gasoline engines.

3. Hot start problems are eliminated.

4. Easy restart while airborne.

5. The engine can be shut-off and the turbocharger kept running when the aircraft is on the ground for some period. Meanwhile, electric power, cabin heat or air conditioning remain available. This in effect converts the turbocharger into an APU.

6. The battery requirement is greatly reduced since engine

cranking is accomplished by air pressure.

The study indicates that the diesel promises to be an attractive powerplant for general aviation aircraft. A comparison of the diesel with a comparable gasoline aircraft engine (Table II) shows a reduction of fuel flow (24%), a smaller package and reduced engine weight (21%).

The characteristics of the diesel engine results in an improved aircraft performance. The results of engine-aircraft integration study performed by subcontractor Beech Aircraft to determine the performance of a twin engine aircraft equipped with gasoline engines or the diesel (Table III) shows that the diesel powered aircraft had a 8% greater payload and simultaneously had a 50% greater range.

The engine-aircraft integration study also disclosed that the diesel powered airplane has a considerable overall cost advantage. Gasoline airplanes of equivalent size cost less initially, but this advantage is offset by reduced mission capability and higher operating costs. In addition, the diesel engine presents no installation problems. Although the radial configuration is different than current gasoline engines, the mounting to the airframe is essentially the same and requires no major modifications.

The technologies which result in this high level of performance are, although advanced, not untried. The adiabatic engine, the catalytic combustor and the high-speed alternator are currently under development under various contracts. It should be noted here that, although the concept engine proposes the use of ceramic combustion system components, the use of such materials for "man rated" aircraft may be 20 years away. These were incorporated primarily to show what may be ultimately possible. However, alternate approaches available are given which will result in some degradation of performance but nevertheless will result in a powerplant which outperforms the gasoline aircraft engine. A substantiation of this potential will be provided in a study extension now underway. The additional effort will cover a design, performance, and cost study of a 300 HP diesel engine applicable to single and twin engine aircraft.

The lower risk technologies approach involves a) the substitution of limited cylinder cooling and elimination of ceramic components, b) the substitution of a conventional combustor for the catalytic combustor.

Rotary Combustion Engine

As reported in a recent SAE Business Aircraft Meeting, the Curtiss-Wright program with NASA to improve the RC2-75 cruise fuel economy has resulted in a BSFC decrease from 0.54 lbs/bhp-hr originally to 0.475 currently.[12] It is anticipated that the BSFC will be reduced further as the effort continues. Engine modifications made thus far involve a compression ratio increase to 8.5:1 from 7.5:1 and spark plug repositioning closer to the trochoid surface, both contributing to improved firing regularity at low power.

A second NASA contract to Curtiss-Wright was awarded in June 1979 to perform a more advanced rotary combustion engine design study. Based on the above-mentioned experimental progress and developments in relevant automotive and military rotary engine programs, it is felt that the rather ambitious goals illustrated in Figure 13 should be achievable. Curtiss-Wright has selected Cessna Aircraft as a subcontractor to perform the airplane/engine integration and mission studies. Various design approaches will be identified and evaluated consistent with the basic approach of a turbocharged stratified charge rotary combustion engine. Some examples of the new design approach candidates are:

Thermal barrier materials

Lightweight rotors

High speed, high pressure small fuel injection pump

Silicon Nitride apex seals

Advanced Turbocharging

Turbocompounding

High-BMEP operation

<u>Advanced Spark Ignition Piston Engine</u>

Figure 14 summarizes NASA's long term goals for an advanced spark-ignition engine relative to the near-term objectives for improved current-production type engines. A study is underway at Teledyne-Continental Motors, Aircraft Product Division to characterize and define the technology requirements of an advanced engine to meet these goals. The study includes the generation of conceptual design(s) incorporating these technologies and an engine/aircraft integration effort which will be conducted by Beech Aircraft to determine the performance improvement of an airplane powered by the advanced engine(s).

CONCLUDING REMARKS

In conclusion, the past year has seen progress on numerous fronts. We have continued to upgrade and modify our in-house experimental facilities and instrumentation to reflect changing program requirements. An ambitious experimental program to develop advanced combustion diagnostic techniques has been completed in-house, and new programs involving rotary engine technology, improved cooling techniques and fuel injection technology have been established. The Princeton grant program to develop and verify a realistic Otto cycle computer model shows significant progress at only the 50% complete point. The contract with TCM for near-term engine improvements has resulted in several concepts which together yield significant gains in economy and cooling efficiency. As a final step in this contract, a complete engine incorporating all the improvements is now being built up for a brief flight demonstration later this year. We expect this engine to demonstrate the technology to meet our original near term goal of 10% improved cruise fuel economy2.

Let's now look a little farther into the future and consider the alternative engines. We feel that the advanced, all-new spark-ignition piston engine, the lightweight diesel engine, and the stratified-charge rotary engine are all viable candidates. They have the potential of improving significantly on the present situation in terms of fuel economy, fuel tolerance and other characteristics. Study contracts have been let in each area. The diesel study has been completed with encouraging results, and it is clear that at least this candidate has the potential to meet our long term goal of 30% to 50% reduction in life-cycle fuel costs[2]. But we are also optimistic about the other candidates and would not wish to draw final conclusions before all the results are in.

REFERENCES

1. Stewart, W. L., Weber, R. J., Willis, E. A., and Sievers, G. K., "NASA Research on General Aviation Powerplant," NASA TM-79031, 1978.

2. Willis, E. A., "General Aviation Internal-Combustion Engine Research Programs at NASA-Lewis Research Center," NASA TM-78891, 1978.

3. Rezy, B. J., Stuckas, K. J., Tucker, R. J., and Meyers, J. E., "Concepts for Reducing Exhaust Emissions and Fuel Consumption of the Aircraft Piston Engine," SAE Paper 790605, Apr. 1979.

4. Corsiglia, V. C., Katz, and Kroeger, R. A., "Full-Scale Wind Tunnel Study of Nacelle Shape on Cooling Drag," AIAA Paper 79-1820, Aug. 1979.

5. Robison, J. A. and Brehob, W. M., "The Influence of Improved Mixture Quality on Engine Exhaust Emissions and Performance," Air Pollution Control Association, Journal, Vol. 17, No. 7, July 1967, pp. 446-453.

6. Lindsay, R., Thomas, A., Woodworth, J. A., and Zeschmann, E. G., "Influence of Homogeneous Charge on the Exhaust Emissions of Hydrocarbons, Carbon Monoxide and Nitric Oxide from a Multicylinder Engine," SAE Paper 710588, June 1971.

7 Dodd, A. E. and Wisdom, J. W., "Effect of Mixture Quality on Exhaust Emissions from Single-Cylinder Engines," Proceedings of the Institution f Mechanical Engineers, London, Vol. 183, Part 3E, 1969, pp. 117-132.

8. Matthes, W. R. and McGill, R. N., "Effects of the Degree of Fuel Atomization on Single Cylinder Engine Performance," SAE Paper 760117, 1976.

9. Peters, B. D. and Quader, A. A., "'Wetting' the Appetite of Spark Ignition Engines for Lean Combustion," SAE Paper 780234, 1978.

10. Evanich, P. L., "Photographic Characterization of Spark-Ignition Engine Fuel Injectors," NASA TM-78830, 1978.

11. Ramos, J. I., Humphrey, J. A. C., and Sirignano, W. A., Numerical Prediction of Axisymmetric Laminar and Turbulent Flows in Motored Reciprocating Internal Combustion Engines," SAE Paper 790356, Feb. 1979.

12. Jones, C., "A Review of Curtiss-Wright Rotary Engine Developments with Respect to General Aviation Potential," SAE Paper 790621, Apr. 1979.

TABLE I

NASA-LeRC POSITIVE DISPLACEMENT ENGINE RESEARCH FACILITIES - STATUS AS OF AUGUST, 1979

FACILITY	ENGINE	DYNAMOMETER	FEATURES	STATUS
SE-6	DIESEL, SINGLE CYL, AVL MODEL 521	125 bhp/ 5000 rpm MOTORING CAP.	SIM HIGH TURBOCHARGING; IMEP & GASEOUS EMISSIONS INSTRUMENTATION; VARIABLE INJECTION TIMING.	OPERATIONAL & CURRENTLY ACTIVE
SE-11	MAZDA ROTARY, MODEL 12-B (NONEMISSIONS)	300 bhp/ 5000 rpm	IMEP; COMBUSTION DIAG & GASEOUS EMISSIONS INSTR.	OPERATIONAL & CURRENTLY ACTIVE
SE-17	CONTINENTAL MODEL TSIO-360	300 bhp/ 5000 rpm	IMEP & GASEOUS EMISSIONS INSTR; INLET FLOW VISUALIZATION; TEMP/HUMID. CONTROLLED INLET AIR.	CHECKOUT IN PROGRESS

CS-79-3284

TABLE II

DIESEL VS GASOLINE ENGINE

		4-CYCLE GTSIO-520-H	2-CYCLE DIESEL
CONFIGURATION		6-CYL OPPOSED	6-CYL RADIAL
BORE x STROKE	mm	133.35 x 101.60	100 x 100
DISPLACEMENT	LITER	8.514	4.712
TAKEOFF POWER	kW	279.64	298.28
RPM AT TAKEOFF		3400	3500
FUEL FLOW AT TAKEOFF	kg/hr	119.07	67.13
65% CRUISE POWER	kW	181.76	193.88
FUEL FLOW AT CRUISE	kg/hr	49.75	37.74
DIMENSIONS:			
LENGTH	mm	1657	1105
WIDTH	mm	865	632
HEIGHT	mm	680	660
DRY WEIGHT	kg	262	207

CS-79-3283

TABLE III

AIRCRAFT PERFORMANCE

		GASOLINE POWERED	DIESEL POWERED
RATED POWER	kW	298	298
MAX TAKEOFF WEIGHT	kg	3671	3671
STD EMPTY WEIGHT	kg	2380	2294
USEFUL LOAD	kg	1291	1377
USEABLE FUEL	kg	609	652
PAYLOAD	kg	683	726
MAX CRUISE SPEED	km/hr	454	472
RANGE	km	1805	2592

CS-79-3282

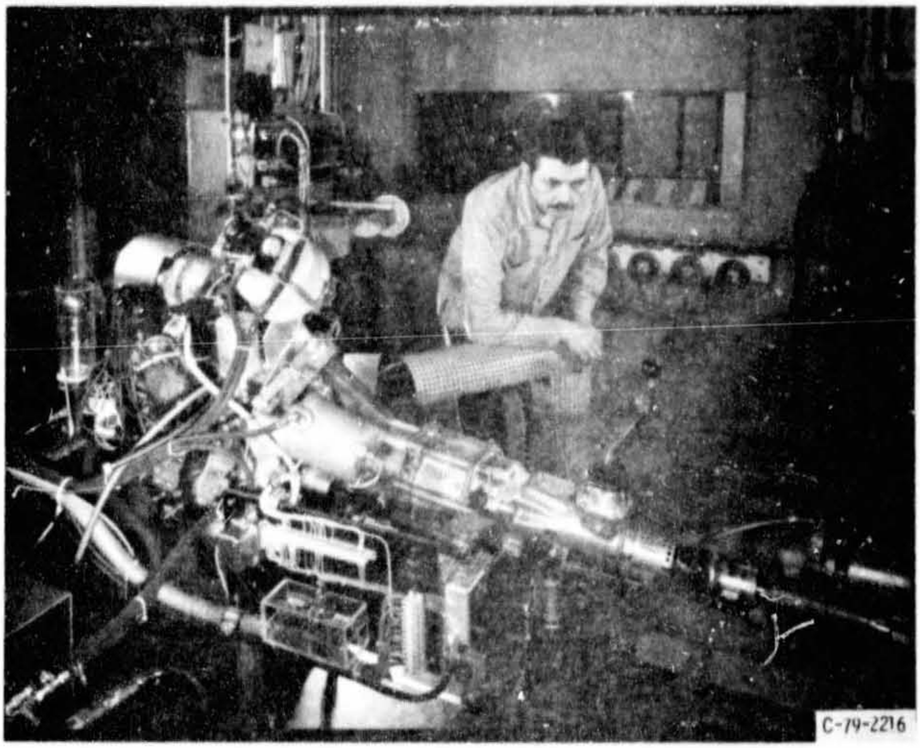


Figure 1. - Rotory test cell.

TEST RESULTS

	BASELINE	COMBINED CONCEPTS
EMISSIONS, % EPA 1980 LEVELS		
CO	185	45
HC	122	25
NO_x	20	62
BSFC, % CHANGE		
LTO	0	-27%
CRUISE	0	-7%

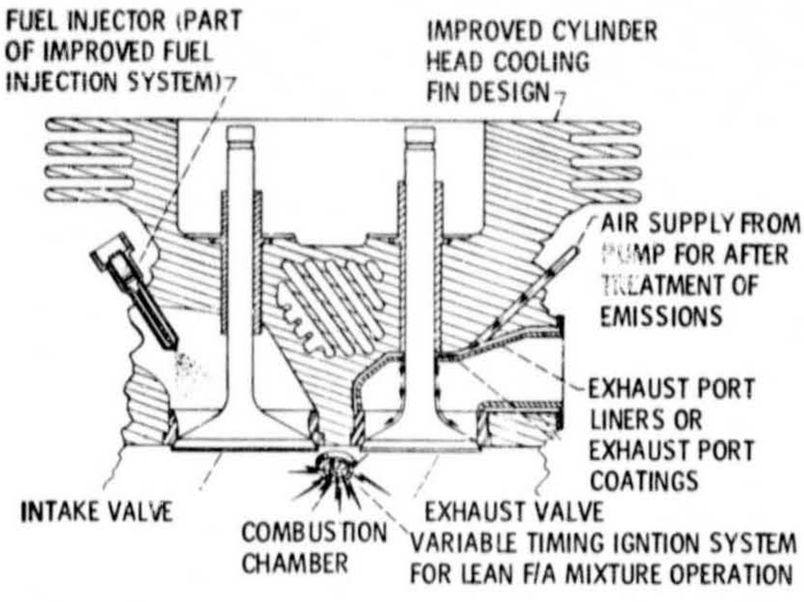


Figure 2. - Advanced cylinder head concept integration. CS-79-3286

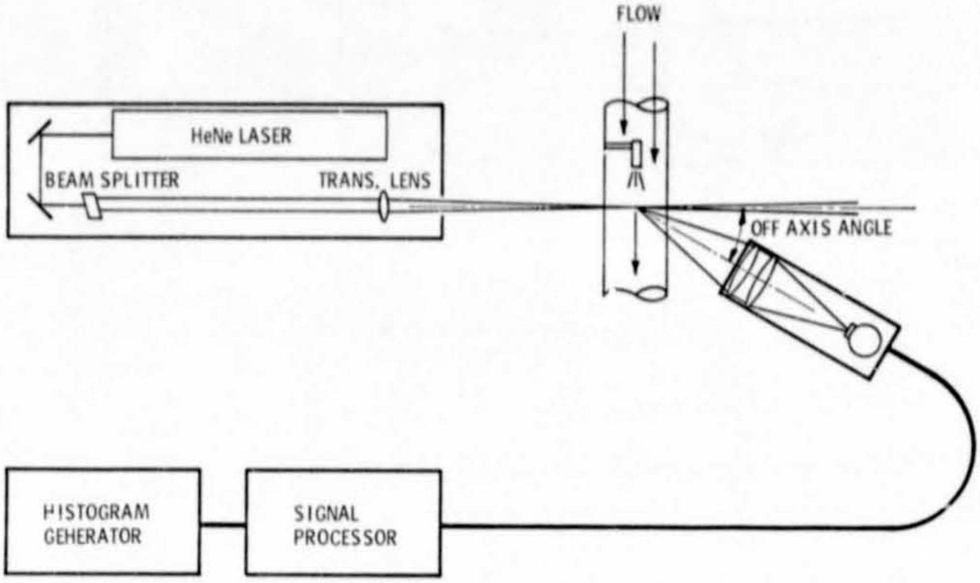


Figure 3. - Laser doppler velocimeter and particle sizing system schematic.

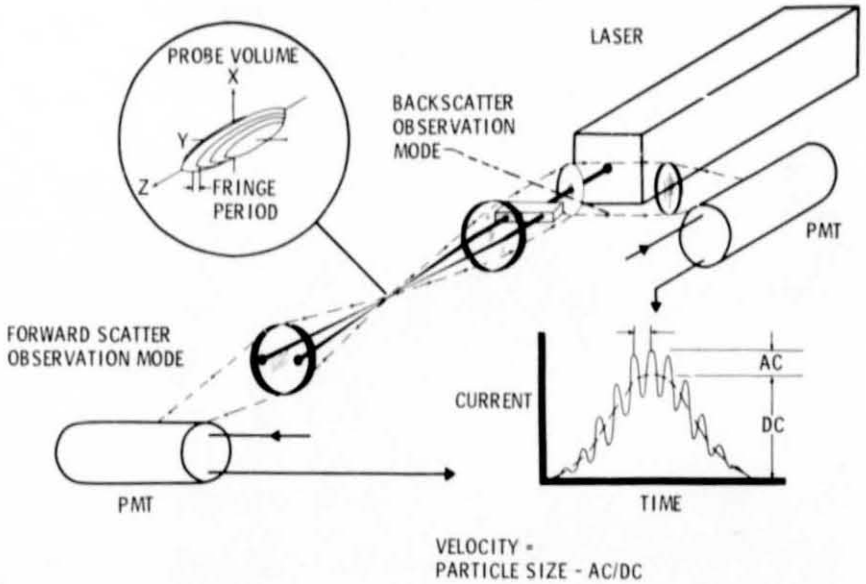


Figure 4. - Optical arrangement for a particle sizing interferometer using off-axis light collection.

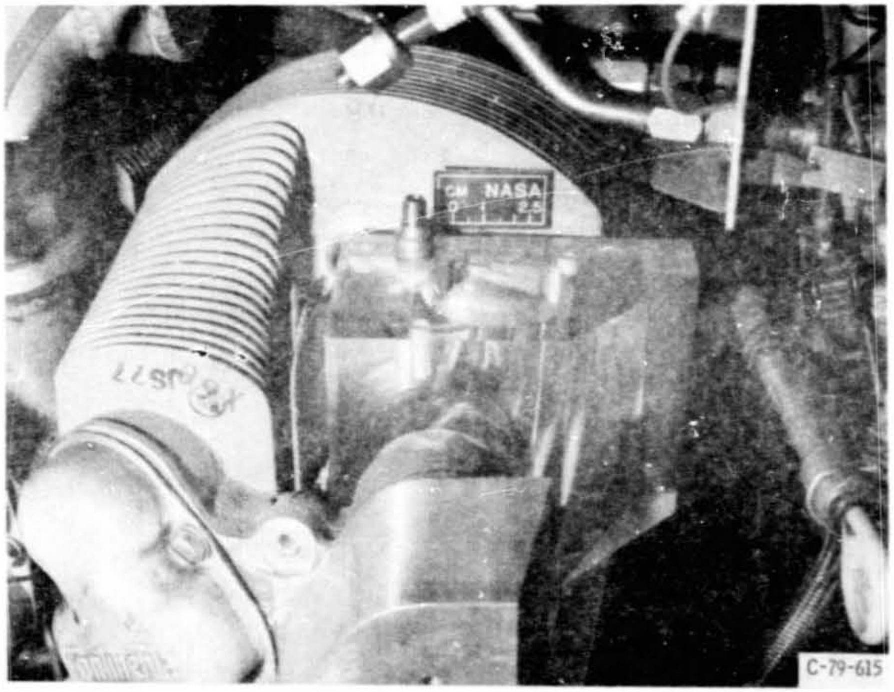
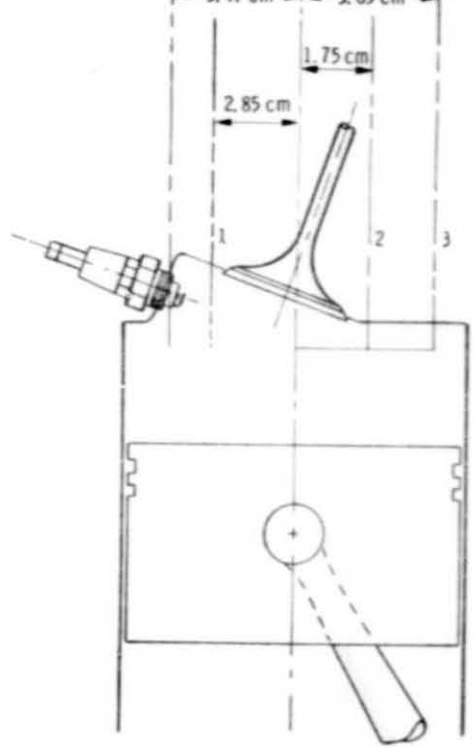


Figure 5. - Cylinder head with transparent intake section.



BORE = 10.16 cm
STROKE = 8.83 cm

Figure 6. - Location of three ionization probes installed combustion chamber.

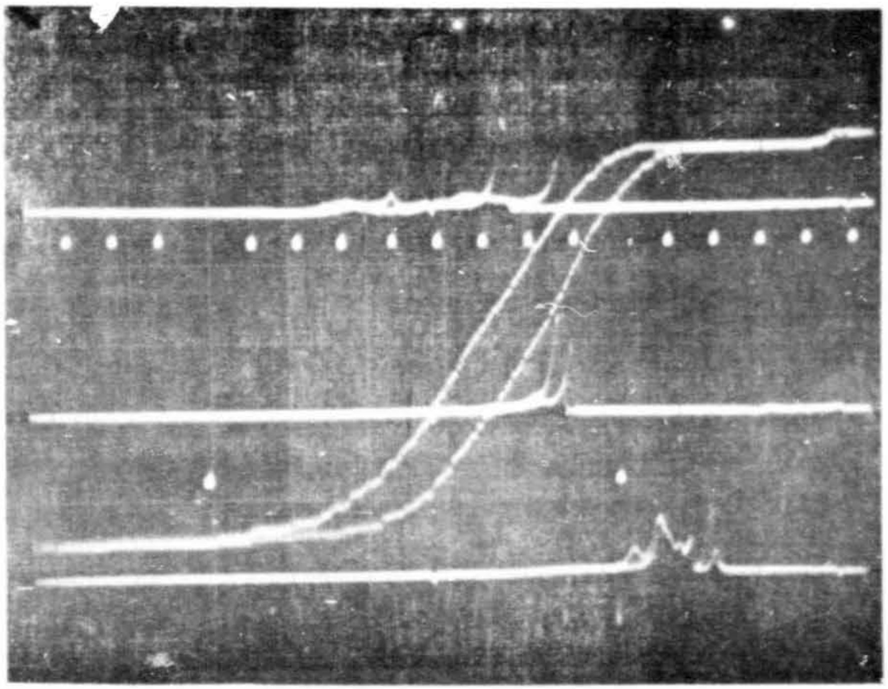


Figure 7. - Oscilloscope photograph of mass fraction burned curves and three ionization probe signals.

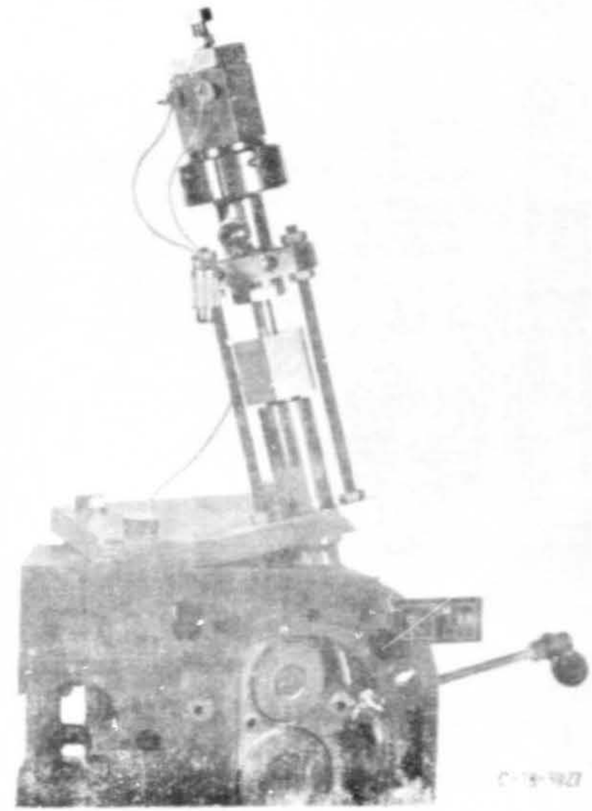


Figure 8. - Sampling valve installed on engine cylinder head.

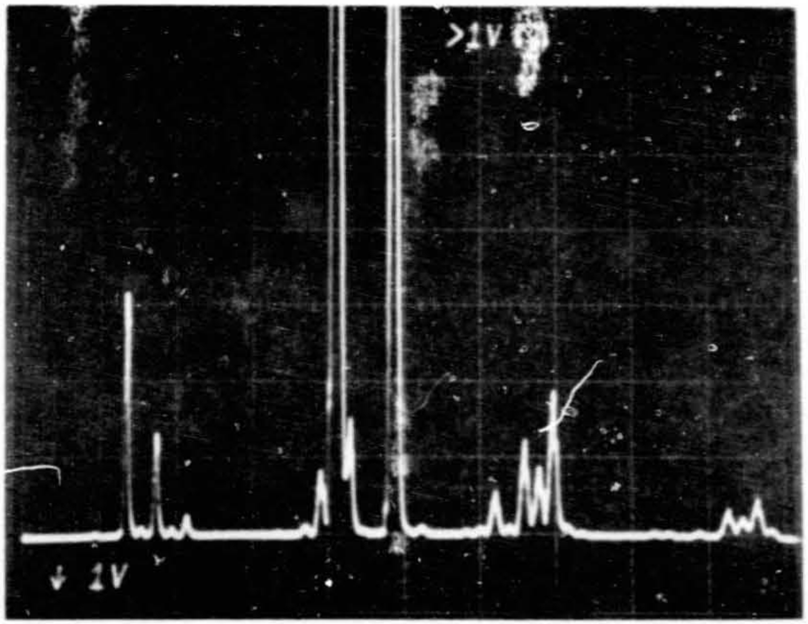


Figure 9. - Typical spectrum output from mass spectrometer.

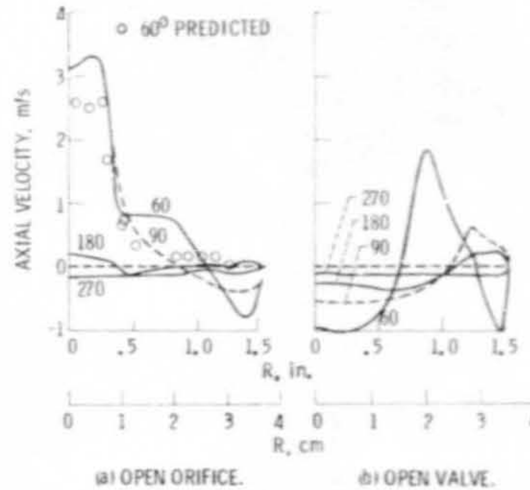


Figure 10. - Experimental results on mean axial velocity distribution at various crank angles. Z = 2.54 cm, 31 rpm, compression ratio 7:1.

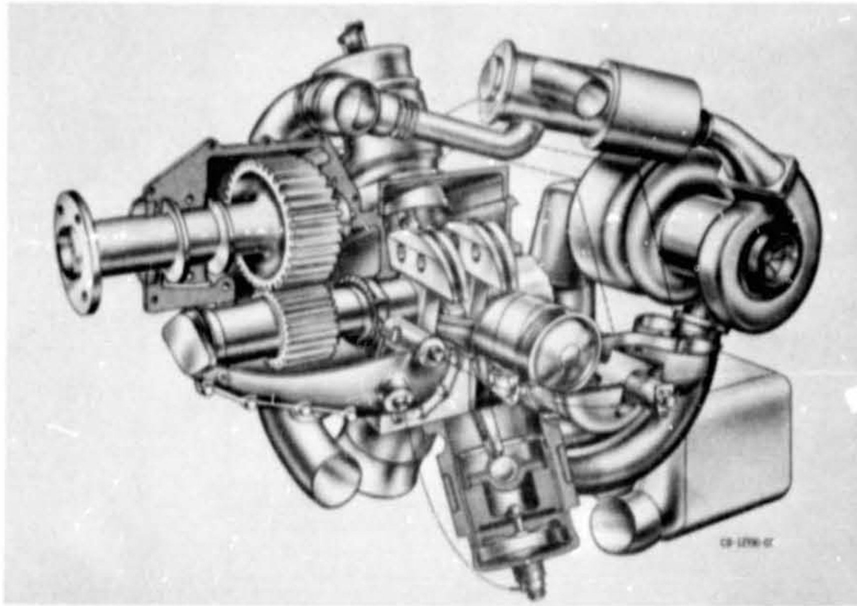


Figure 11. - 298 kW diesel aircraft engine.

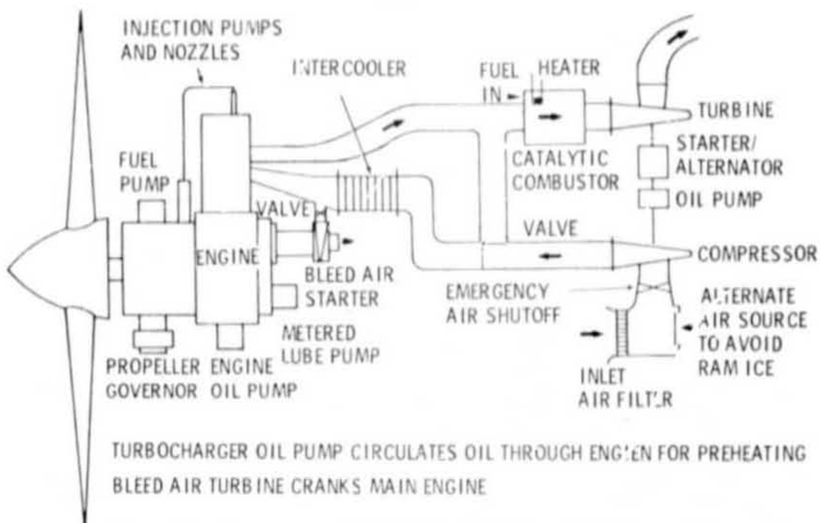
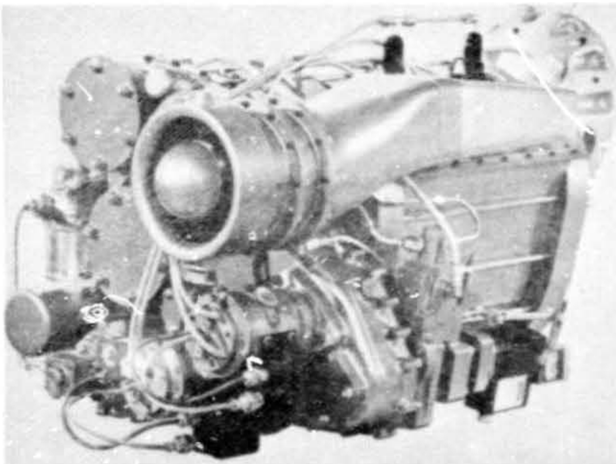


Figure 12. - Schematic 2-stroke engine with independent turbo loop/hot engine

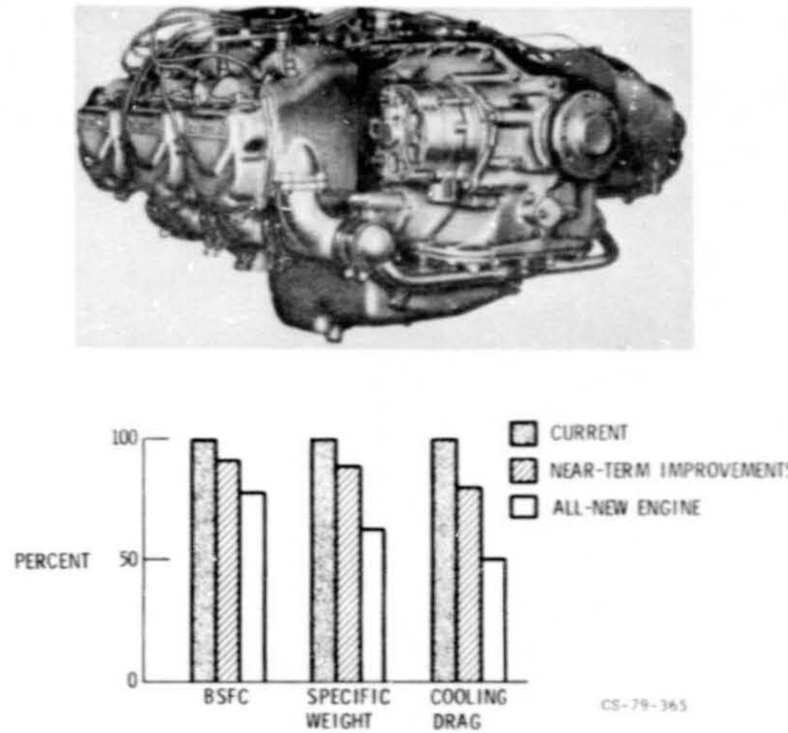


LONG TERM TECHNOLOGY GOALS (1988)

BSFC: 0.38-0.40 lb/bhp-hr
SP. WT: <0.75 lb/bhp
EMISSIONS: MEET EPA '80
FUEL: MULTI-FUEL
COOLING: LIQUID, LOW DRAG INST'L

CS-79-364

Figure 13. - Rotary engine research.



CS-79-365

Figure 14. - Piston engine research.