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

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NASA is involved in a research and technology program related to improved and advanced general aviation engines. The overall goals of the program are to develop the technology to improve fuel economy, reduce engine weights and installation drag, and provide for broad-specification fuel or multifuel usage. Its two major technical thrust are directed at the near-term improvement of conventional air-cooled spark-ignition piston engines and at future alternative engine systems based on all-new spark-ignition piston engines, lightweight diesels, and rotary combustion engines that show potential for meeting program goals in the midterm and long-term future.

The conventional piston engine activities involve efforts on applying existing technology to improve fuel economy, investigation of key processes to permit leaner operation and reduce drag, and the development of cost effective technology to permit flight at high-altitudes where fuel economy and safety are improved.

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

NEAR-TERM IMPROVEMENT OF CONVENTIONAL ENGINES

The objective of the ongoing near-term improvement of conventional engine effort is to identify and foster the near-term technology base to reduce fuel consumption by 20 percent, extend the cruise altitude capability and decrease emissions.

The program addresses several specific technology elements through a combination of contract and in-house projects. The most significant are

(1) An investigation of using existing technology to modify a piston engine for the purpose of improving fuel economy and reducing exhaust emissions.
(2) An effort to improve cooling and reduce installation drag.
(3) An effort to improve understanding of the combustion process to allow leaner burn operation.
(4) Research to determine improved fuel-injection system characteristics.
(5) A contractual effort to define the benefits and optimum design requirements of an advanced, cost-effective general-aviation high-altitude turbocharger.

Each of these elements will now be discussed in more detail.

Near-Term Modifications

Teledyne Continental Motors Aircraft Product Division, under a NASA cost sharing contract, is researching and developing methods to improve the fuel economy and reduce the exhaust emissions of its aircraft piston engines. Their research has resulted in the development of four concepts which, when applied to such an engine, permit leaner operation and thus improved fuel economy and simultaneously reduced exhaust emissions of hydrocarbons and carbon monoxide. The four chosen concepts as shown in figure 1 are

(1) A timed, air-density-compensated fuel-injection system, which replaces the familiar low-pressure continuous-flow system.

(2) A thermal barrier exhaust port liner for improved cylinder head cooling.

(3) Air injection which in combination with the exhaust port liners reduces the exhaust valve stem temperatures to levels below the baseline engine while increasing CO and HC oxidation in the exhaust.

(4) Variable spark timing to maintain best power spark timing over a broader operating range.

A comparison of the emissions and fuel economy for the standard IO-520 engine configuration and the engine with these four concepts integrated is presented in table I. Emissions are shown as percentages of the proposed 1980 standards. EPA has announced its intention to withdraw these but have not yet done so. Note that the modified engine meets all of the standards and in addition demonstrates a 10 percent improvement in the high performance cruise fuel economy. It also exhibited a 22 to 30 percent improvement in the LTO fuel economy.

The final round of tests are presently being conducted with a flightworthy engine, and the contract is being extended to include an flight test phase in early 1980.

Cooling Drag Reduction

The objective of the cooling drag reduction program, a joint effort of the Lewis and Langley, is to develop and demonstrate the technology to improve the performance and economy of 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 for which few data on the heat-rejection patterns are known. It has been estimated that the cooling drag for current designs ranges from 5 to 27 percent of the total airplane cruise drag. Recently completed tests in the Ames Research Center 40 by 80 ft wind tunnel have shown a cooling drag of 14 percent of total airplane cruise drag for one configuration. An integrated approach to engine cooling that includes reduced cylinder cooling requirements and improved internal and external aerodynamics can reduce this drag by at least 50 percent.

This cooling study is strongly encouraged by the industry because many turbocharged installations now operate near detonation or cooling limits. This problem, which affects both safety and economy, will be greatly aggravated by efforts to fly higher through use of improved turbochargers.

NASA Lewis will award a contract by the end of 1979 for the first portion of the cooling program. This part of the program will determine the current practice and actual minimum cooling requirements for representative, present-day cylinder-head and barrel assemblies. Using these baseline results, various cooling concepts will be evaluated on their ability to reduce the cooling requirements. At least two of the most promising concepts will be selected, designed, integrated, and tested on the cylinder-head and barrel assemblies. To extend these experimental results to other cases, an analytical computer simulation model on the cylinder head/barrel assemblies will be developed in a joint effort of Lewis and the contractor.

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 and barrel assembly and to conduct experimental verification tests on a single-cylinder engine. Parallel efforts in aerodynamics methodology will improve nacelle internal flow paths, inlets, and exits. Following the verification testing, a full-scale engine and nacelle will be built for wind tunnel and flight tests.

Combustion Process Studies

Spark-ignition combustion process studies are being conducted to provide the data base from which predictions of flow process and chemical reactions in homogeneous and stratified charge engines can be made. Included in this activity are efforts in developing diagnostic instrumentation, conducting experimental studies, and developing sophisticated computer models.

Combustion-Diagnostic Instrumentation

Instrumentation has been designed at Lewis that will determine on a per cycle, per cylinder basis, real-time measurements of the indicated mean effective pressure and percent mass of charge burned as a function of crank angle. Today, our systems are being used by both the aircraft and automotive industry.

We also have a good design for ionization probes, which are placed in the cylinder head to measure flame position and thickness as a function of crank angle.

Laser Doppler velocimetry (LDV) measurements of the velocities and turbulence levels for cold flow within the combustion chamber have been undertaken through a grant to Carnegie-Mellon University.

A contractual study with Barnes Engineering Co. has indicated that a laser can extend the usefulness of an infrared spectral radiometer. The study concluded that spacial resolution could be improved by using a high-energy laser to change the energy state of the specie of interest at the measurement point within the chamber. It can then be detected by the infrared device at a different wavelength than the surrounding carbon monoxide in the chamber.

A unique charge sampling system has been developed at Lewis 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 crank angle up to the start of combustion. The sample valve (fig. 2), which was developed from a General Motor's design, is shown installed in the cylinder head of a V-8 engine used for some of our combustion studies. 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 fuel-air ratio.

All of the above instrumentation has proven to be extremly 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 equation which includes engine air-fuel ratio, speed, and torque. This result is important in Otto cycle modeling where until now the mass fraction burned curve was assumed to have a simple cosine relation.

Otto Cycle Computer Model

For the past 5 years Lewis has had a zero-dimension Otto cycle code effort. And since 1977 we have supported a program on internal combustion engine flame propagation and emissions at Princton University (and now Carnegie-Mellon) with Dr. William A. Sirignano as the Principal Investigator. The major goal of the grant program remains the development of a theory and multidimension computer code for flows and combustion in a reciprocating engine. The variables to be considered are details of engine geometry and operating conditions and fuel chemistry. Predictions will include engine performance, fuel consumption, heat transfer, exhaust composition, and local flow velocities. The code will also predict the effect of turbulence intensity and scale effects, the effects of manifold and valve flow, and the chemical composition of the flow close to the walls. The basic approach includes not only developing the computer program, but also the experimental valildation of key hydrodynamical features of the flow model. The status of this effort is as follows:

(1) The code predicts the flow field for axisymmetric, unsteady, moving boundary, compressible, turbulent (scale and intensity) piston-cylinder flows.

(2) 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.

(3) The predicted flow field includes the boundary layers and hence surface effects.

(4) The predicted flow field is sensitive to both large and small scale turbulence conditions.

(5) Measurements of the axial and tangential components of mean flow and the rms of velocity fluctuations for two different operating conditons have been made.

(6) Comparisons with the theoretical predictions are being made. The first examples are the low speed, open orifice, and turbulent nonreacting 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, but the predicted velocity profile gradients are larger than the measured gradients. Good agreement occurs with the location and magnitude of the flow reversal region.

Fuel Injection

Research is being conducted to improve the inlet-port fuel-injection system by extending the lean limit. To accomplish this requires a more complete understanding of the relationship of the fuel-air mixture preparation before 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. Various investigations have been conducted which tend to support this theory. However, these results are in conflict with the recent work of General Motor's researchers 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 vaporizatin yeilds 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.

Spectron Development Laboratories, Inc., under a NASA contract is using a laser visibility method to obtain particle field measurements of different injectors under simulated engine manifold conditions.

Concurrently, manifold flow-visualization tests to establish the disposition of fuel-air mixture are being conducted at Lewis. One cylinder head of the TSIO-360 engine has been modified to include a transparent acrylic intake section (fig. 3). Under a wide range of motored engine conditions, high-speed photographs are taken through fiber optics located at the right side of the intake section. The previously discussed sampling valve will be installed to measure the fuel-air ratio within the cylinder. From this information a correlation of the injector spray and position with the fuel-air mixture in the intake port and cylinder can be established.

After these flow visualization tests, single cylinder hot performance and emission tests will be conducted.

High Altitude Turbocharger Technology Program

Turbochargers have served General Aviation well, improving comfort, economy, safety, and performance by providing higher takeoff power and high-altitude capability at reasonable cost. The trend is toward even higher altitude capability for all size aircraft engines. Thus, an aircraft could safely fly over the weather and at the same time improve its flight efficiency. In response to a suggestion by its advisory committee, NASA has initiated an effort to identify, develop, and demonstrate the technology for a family of advanced but cost-effective turbochargers applicable to a spectrum of conventional and alternative engines. The projected program, which will emphasize near-term improved spark-ignition engines as the baseline, has three phases: system performance analysis and conceptual design study (phase I); reference configuration design and component verification testing (phase II); and final design and verification testing (phase III). Phase I has been funded and, depending on the results, funds for the remainder of the program will be considered.

ALTERNATIVE PROPULSION SYSTEMS

Although current aircraft engines operate at high levels of efficiency and reliability, changing requirements in terms of fuel economy, fuel availability, and environmental concerns have brought about the consideration of significantly improved or completely new types of engines for future aircraft. NASA has addressed this issue through a series of conceptual design study contracts with engine manufacturers.

The conceptual engine candidates under study are (1) improved/advanced spark-ignition piston engines, (2) lightweight diesel engines, (3) stratified-charge rotary engines, and (4) advanced turboprop engines which were in the preceeding presentation.

The above-mentioned activities typically include several technical tasks, such as (1) technology evaluation and configuration selection, (2) conceptual design, (3) a preliminary airframe integration study, and (4) program recommendations to address each candidate's key technology requirements. The status and results of the three internal combustion engine candidates will be presented following this overview.

The preliminary airframe integration study portions of this work will assess the apparent advantages of that particular concept compared with current engines.

Contractual studies will also be conducted to obtain from two general-aviation airplane manufacturers (Cessna Aircraft Co. and Beech Aircraft Corp.) a comparative evaluation of the four candidates in airplanes and on missions that are representative of the manufacturer's expected market share. The evaluations will be conducted on a consistent basis; that is, to the greatest extent practicable, the same or equivalent airplane and engine technology will be used for all direct comparisons.

In all cases, the airframe will be tailored to take maximum advantage of the candidate engine's unique features, or to minimize the adverse effect of its less-desirable features. The criteria of comparison will include airplane size, economics, and flight performance; fuel consumption and fuel tolerance; business factors; and an assessment of relative technological risks.

In the above comparative studies two types of aircraft will be used - a high-performance, pressurized single and a pressurized twin. The nominal engine size is 250 bhp (net, installed cruise power at 25 000 ft altitude). It is expected that results of these two contracts will allow a rational selection of one or more candidates for a contemplated NASA engine technology development and demonstration program.

Broader in-house studies are being conducted to evaluate additional types of aircraft and missions. Longer term supporting research and technology efforts are being conducted at Lewis. These efforts are aimed at evaluating selected key technology areas in order to verify concept potential and to enlarge the overall technology base. The diesel and rotary engine test cells are now operational, with baseline mapping complete. The buildup of the stratified-charge, single-cylinder facility is under way.

Table I

EMISSIONS AND FUEL ECONOMY COMPARISON

	BASELINE	COMBINED MODS
	EMISSIONS, % EPA 1980 LEVELS	
CO	185	28
HC	122	11
NO_X	10	86
	BSFC, % CHANGE	
LTO	0	-30%
CRUISE	0	-10%

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INTEGRATED NEAR TERM MODS

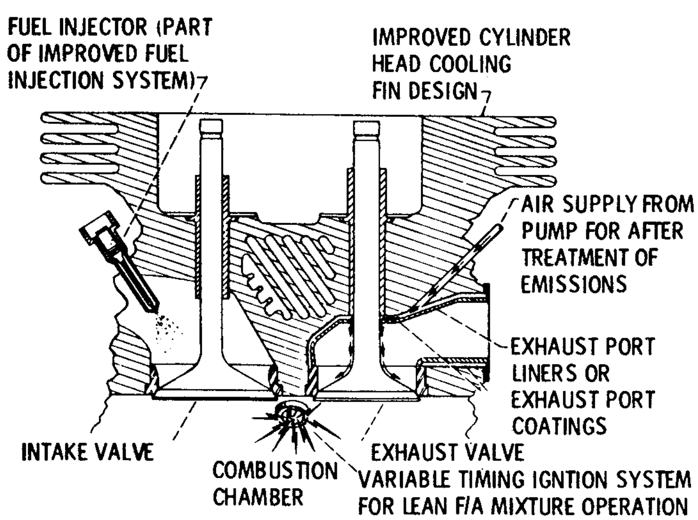

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Figure 1

GAS SAMPLING VALVE
INSTALLED IN CYLINDER HEAD

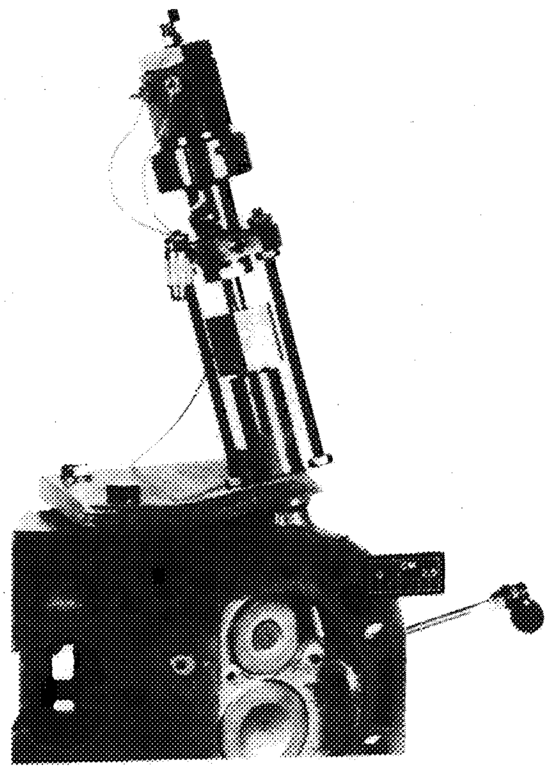

Figure 2 CS-79-4289

CYLINDER HEAD WITH TRANSPARENT INTAKE SECTION

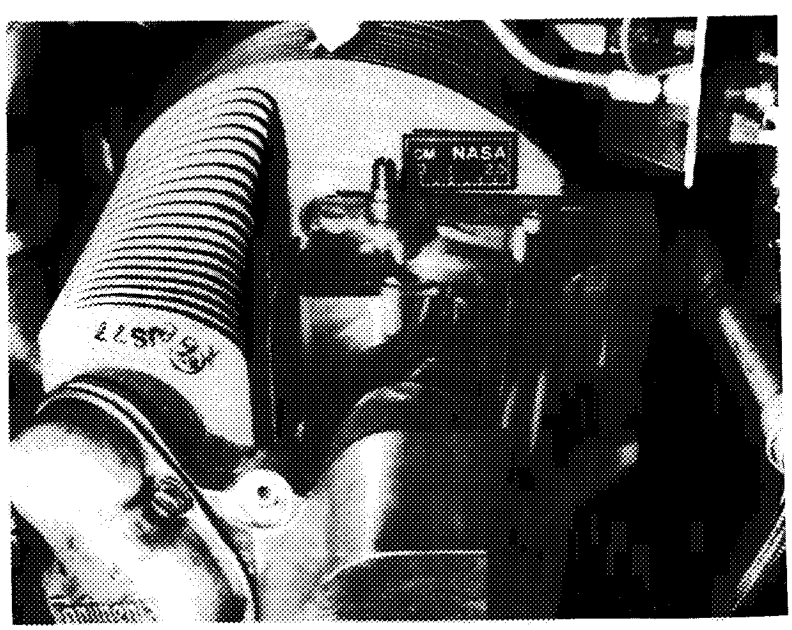

Figure 3 CS-79-4288