LIGHTWEIGHT DIESEL AIRCRAFT ENGINES FOR GENERAL AVIATION

Steven G. Berenyi
Teledyne Continental Motors
General Products Division

Although we refer to it as a diesel engine, the compression-ignition engine runs well on Jet A, JP-5, and even on JP-4 with limitations because of cetane considerations. While this presentation is based strictly on our paper study, and describes the two engines indicated by the other speakers, I would like to point out that we have a single cylinder version of this engine running as of last week.

This study was initiated for Ed Willis' group. We looked at two different engines; one a far-out design and the other a less advanced one. What are the advantages of a diesel to general aviation? As we saw it, the incentives were reduced fuel consumption, reduced operating costs and reduced fire and explosion hazard. There are no ignition mixture control or inlet icing problems. There are fewer controls and no electrical interference problems.

Figure 1 is a schematic of the proposed engine. It has an independent turbocharger loop that can operate with its own starter, and has a combustor independent of the main engine. The engine itself has a radial configuration and employs the two-stroke cycle principle. The idea is to start up the turbocharger independently. This provides high pressure air in the lightweight engine which is designed to a maximum of 1500 psi firing pressure. Actually our engine design produces 1400 psi, with the balance of the pressure being made up by the independent turbocharger.

Why two stroke? Here are some of the advantages as we see them: weight reduction, fewer parts, improved reliability, and no valves. The absence of valves is a key advantage if we go to an uncooled, ceramic version, in which valves would present a problem in such an uncooled configuration. Further, the two stroke gives us reduced frontal area, particularly by eliminating the overhead valve mechanism and its associated frontal area.

Why uncooled? To go uncooled, we would have to go with ceramic piston tops and ceramic cylinder liners. These are pretty far out ideas for aircraft application at this point, but these are ideas that are being tried on engines for the Army right now (not airborne engines). Some of the cooling loss can be converted to useful energy, reducing cooling drag.

Why the independent turbo loop? Here are some of the features as we see them. The engine can be cranked indefinitely. As long as the turbo is running, it provides air and an assured start. There is plenty of high pressure (hot) compressed air for cold starting, and the turbo loop can be operated independently as an auxillary power unit (APU) when the main engine is not required.

Figure 2 shows a cutaway of the uncooled engine. No cylinder cooling is provided. Visible on the right at the rear of the engine are the combustor and turbo. Individual injectors are on the front. Figure 3a is a side view and Figure 3b is a frontal projection. The engine is about 30 inches in diameter overall. The oil cooler and after cooler are below at the rear of the engines.

Our projections are that the cost is about 20% over that of a current aircraft engine of the same horsepower. Our weight projections are very favorable: 457 lbs. vs a comparable 578 lbs. The reason for this is the radial configuration which provides a compact engine with two main bearings. The crank case is very short and light.

Figure 4 is a comparison of operating characteristics of the diesel and a conventional six-cylinder gasoline engine. Figure 5 shows comparisons for BSFC on takeoff, full-power cruise and 65% cruise. These figures are for the uncooled ceramic version of the engine. Later on I will show some projections for the minicooled version in which cooling is provided in the combustion area only with no cooling lower on the base. Figure 6 is a dimension comparison with the 520 H gasoline engine. Results are favorable for the diesel. Figure 7 shows a comparison of dimensions for the two engines.

The installation study and airplane performance projections were made by Beech. Two comparisons were made of the computer-predicted airplane performance. One was for a fixed airplane with a variable performance (Figure 8A), and the other a fixed performance with variable airplane size (Figure 8B). Diesel characteristics are indicated by solid bars, and gasoline by stripes. The important points here are payload --1600 vs 1479, and range 1400 vs 932. In the second comparison (Figure 8B), we see that to fly the same range of 1400 nautical miles would take an airplane with a wing area of 322 square feet for the gasoline powered version vs 241 square feet for a diesel allowing a much smaller airplane of about 11,000 lbs. vs. 8000 lbs.

If we don't go with the totally uncooled version, what are alternate possibilities? One is limited cooling, where the combustion chamber only is cooled. The penalties with this design are increased fuel consumption, although it is still lower than current gasoline engines. If we eliminated the high speed alternator that would be associated with the APU type turbocharger, the conventional alternator would be employed. The penalties would be a larger, heavier alternator and larger batteries.

The engine for which hardware has been constructed is the 250 cruise horsepower engine with limited cooling and conventional materials. We have a single cylinder version which has been run up to about 25 horsepower in a "green" run. Our goal is 90 horsepower per cylinder for the takeoff rating. Projected BSFC of this particular engine would be 0.36 at cruise. The 250 horsepower engine combines the best features of the 400 and the 200 without the risk of introducing ceramics. It would be a low compression ratio radial engine, geared, two-stroke, four cylinder with the independent turbocharger. We would go with a conventional combustor with a high pressure turbocharger on the order of 8:1 pressure ratio.

This is one area where the NASA-sponsored turbocharger would work well. Although it is 8:1 on a single stage, it's not really that far out. We have turbochargers on other engines right now that are running 6:1.

If we project this engine program to the year 1995, or 2000, what are some things we could add to it? We could go to the high temperature materials; airbearings, plus turbocharging and turbocompounding. All would improve its performance.

The key technologies required to make this project successful are: the combustion and scavenging system in a two-cycle loop, and the high pressure, high efficiency turbocharger. We do need a very high pressure injection system as well. And if we go to the independent turbocharger loop, we need the high speed starter/alternator. If we want to carry it further, we will need all of the above plus the ceramic components, advanced lubricant solids and airbearings.

SCHEMATIC TWO STROKE ENGINE WITH INDEPENDENT TURBO LOOP

Hot Engine Configuration—No Cooling/Low Compression Ratio Piston

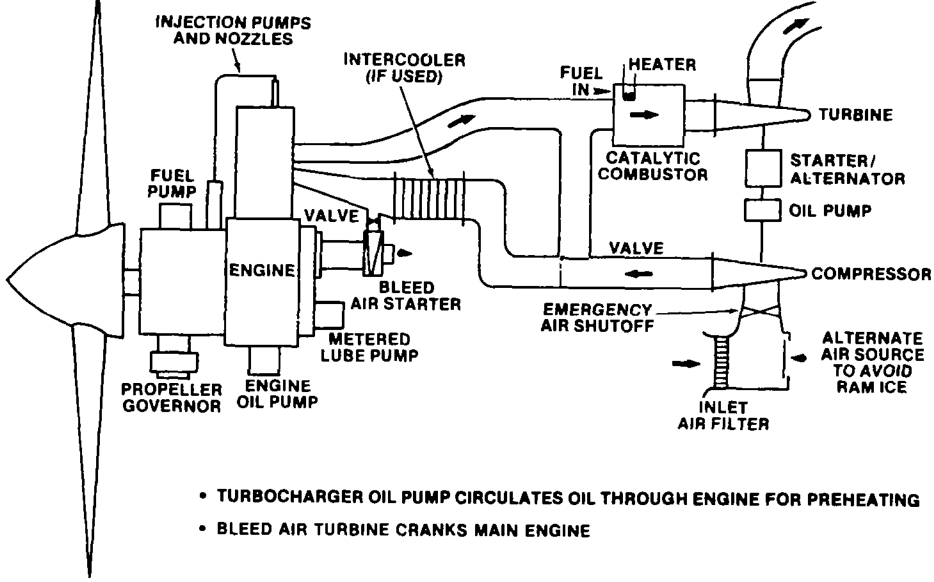

Figure 1.

400 HORSEPOWER AIRCRAFT DIESEL

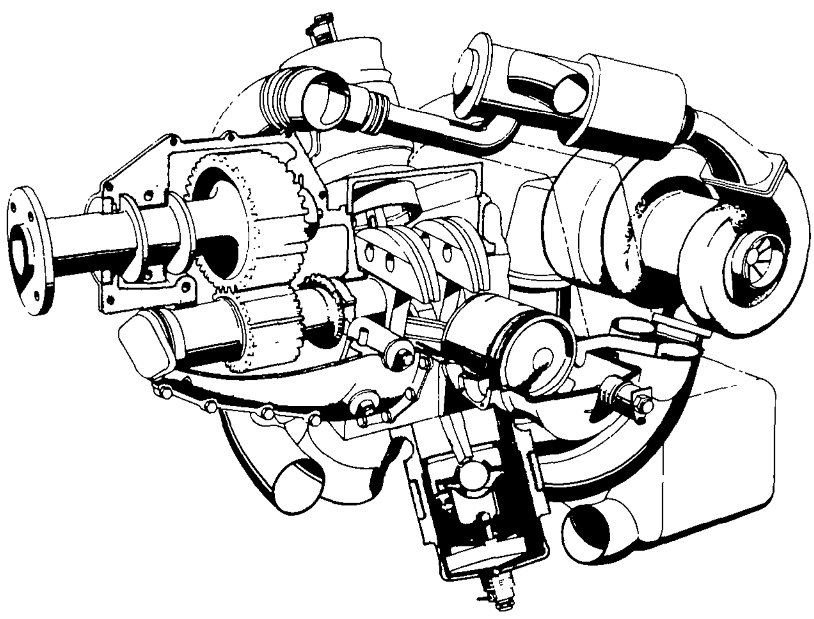

Figure 2.

400 HORSEPOWER AIRCRAFT DIESEL

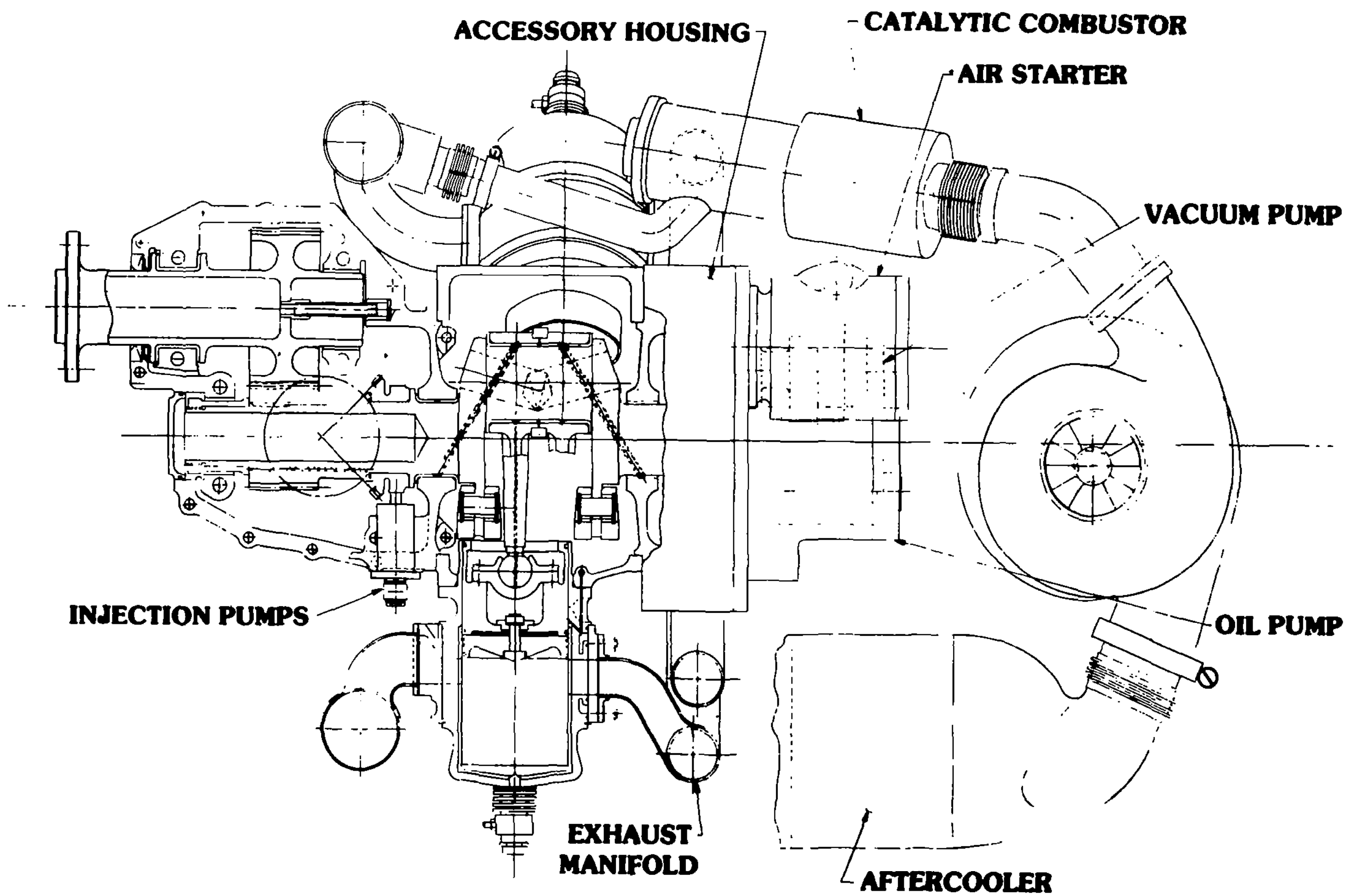

Figure 3a

400 HORSEPOWER DIESEL AIRCRAFT ENGINE

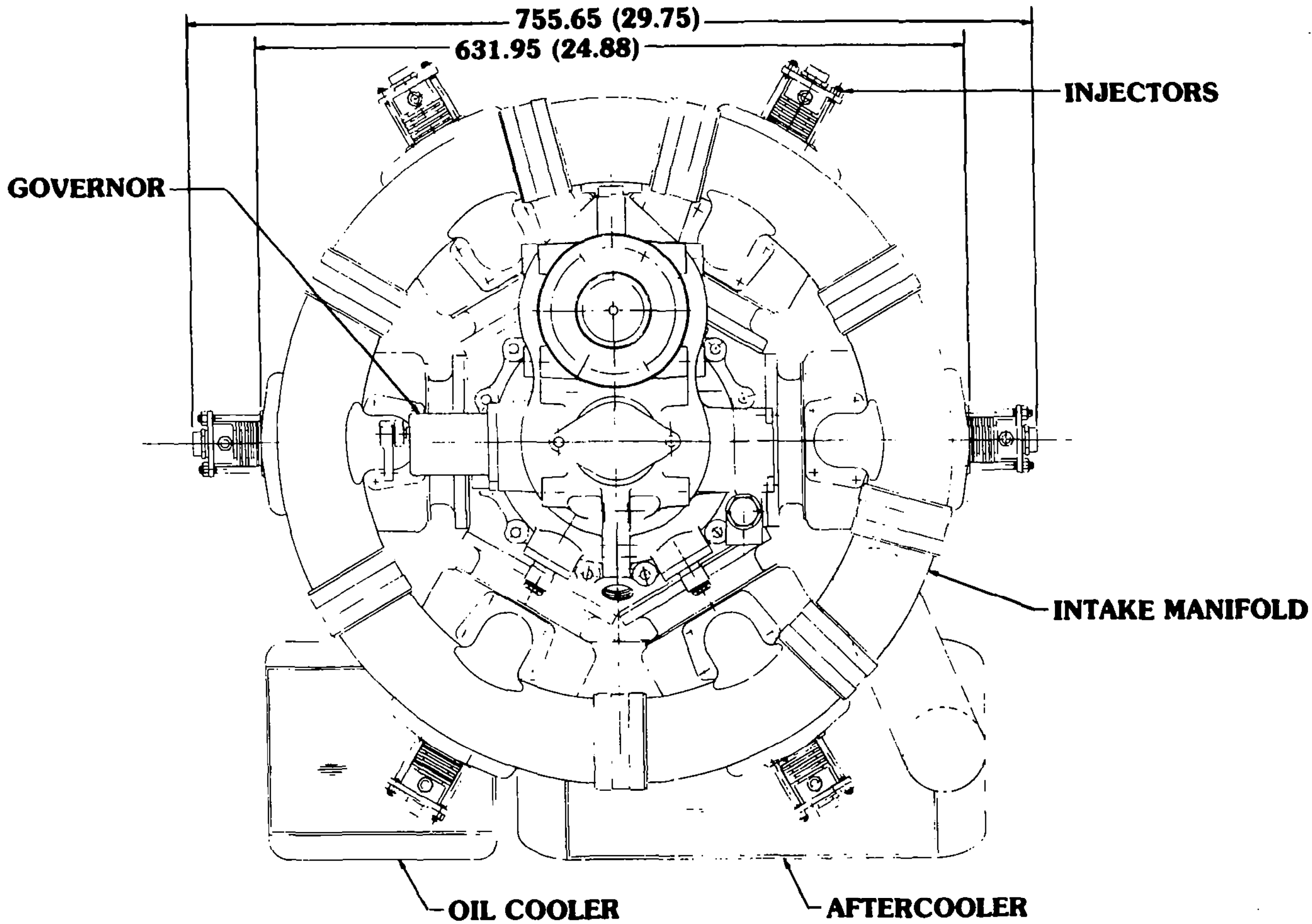

Figure 3b

COMPARISON GTSIO-520-H GASOLINE ENGINE AND GTDR-290 AIRCRAFT DIESEL

CONFIGURATION	GTSIO-520-H 6 CYL. OPPOSED	GTDR-290 6 CYL. RADIAL
DISPLACEMENT IN^3	520	289
TAKE-OFF RPM	3400	3500
RATED MAX. TAKE-OFF HP	375	400
RATED MAX. FOR CRUISING	282	400

Figure 4.

COMPARISON GTSIO-520-H GASOLINE ENGINE AND GTDR-290 AIRCRAFT DIESEL

CONFIGURATION	GTSIO-520-H 6 CYL. OPPOSED	GTDR-290 6 CYL. RADIAL
BSFC LB/HP-HR:		
TAKE-OFF	.70	.37
FULL POWER CRUISE	–	.35
65% POWER CRUISE	.45	.32

Figure 5.

COMPARISON GTSIO-520-H GASOLINE ENGINE AND GTDR-290 AIRCRAFT DIESEL

	GTSIO-520-H	GTDR-290
CONFIGURATION	6 CYL. OPPOSED	6 CYL. RADIAL
DIMENSIONS:		
LENGTH (INCHES)	64.25	43.50
WIDTH (INCHES)	34.04	24.88
HEIGHT (INCHES)	26.78	26.00
ENGINE WEIGHT DRY (LBS)	578	457

Figure 6.

SIZE COMPARISON GTSIO-520-H AND AIRCRAFT DIESEL GTDR-290 –400 BHP–

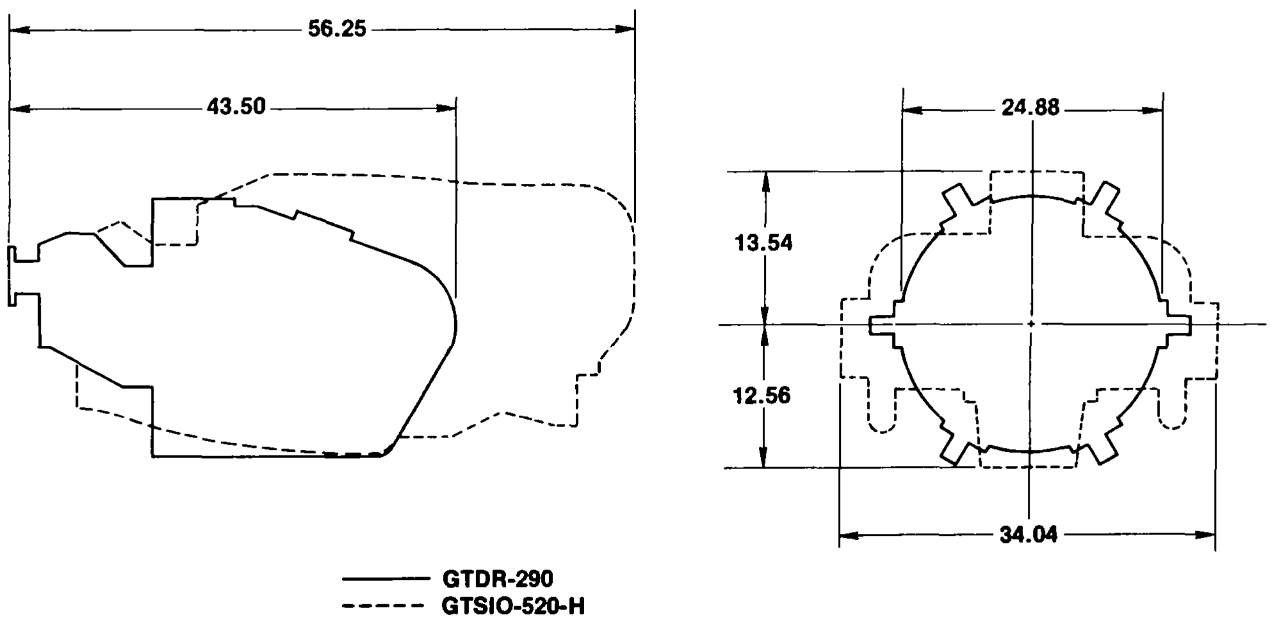

Figure 7.

COMPARISON
DIESEL AND GASOLINE POWERED AIRCRAFT ENGINES
400 HORSEPOWER • TWIN ENGINES

[A] FIXED AIRPLANE SIZE; VARIABLE PERFORMANCE

DIESEL / GASOLINE

		Diesel	Gasoline
RATED HORSEPOWER	(HP/RPM)	400/2300	400/2267
MAX. TAKEOFF WEIGHT	(LBS)	8055	8055
MAX. LANDING WEIGHT	(LBS)	8055	8055
• STD. EMPTY WEIGHT	(LBS)	5016	5258
• USEFUL LOAD	(LBS)	3039	2797
• USABLE FUEL	(LBS/GAL)	1439/240	1318/220
• PAYLOAD–W/FULL FUEL	(LBS)	1600	1479
• ALTITUDE	(FEET/ PERCENT POWER)	25000/82%	25000/75%
• MAX. CRUISE SPEED	(KNOTS)	256	242
• RANGE	(NAUTICAL MILES)	1400	932
TAKEOFF DISTANCE	(FT)	2300	2300
LANDING DISTANCE	(FT)	2220	2220
STALL (LANDING) SPEED	(KNOTS)	73	73
WING AREA	(SQ. FT)	241	241

•VARIABLE PARAMETERS

[B] FIXED PERFORMANCE; VARIABLE AIRPLANE SIZE

DIESEL / GASOLINE

		Diesel	Gasoline
• RATED HORSEPOWER	(HP)	400	555
• MAX. TAKEOFF WEIGHT	(LBS)	8055	10982
• MAX. LANDING WEIGHT	(LBS)	8055	10982
• STD. EMPTY WEIGHT	(LBS)	5016	6922
• USEFUL LOAD	(LBS)	3039	4060
• USABLE FUEL	(LBS/GAL)	1439/240	2460/410
PAYLOAD–W/FULL LOAD	(LBS)	1600	1600
• ALTITUDE	(FEET/ PERCENT POWER)	25000/82%	25000/75%
MAX. CRUISE SPEED	(KNOTS)	256	256
RANGE	(NAUTICAL MILES)	1400	1400
TAKEOFF DISTANCE	(FT)	2300	2300
LANDING DISTANCE	(FT)	2220	2260
STALL (LANDING) SPEED	(KNOTS)	73	73
• WING AREA	(SQ. FT)	241	322

•VARIABLE PARAMETERS

Figure 8.