

ENGINEERING ANALYSES OF BASIC CONSIDERATIONS
OF THE DEVELOPMENT OF THE FIEDLER HIGH SPEED
OPPOSED CYLINDER INJECTION ENGINE.

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HISTORY OF THE DEVELOPMENT OF THE J F #4-130, 2 CYCLE DIESEL

The original development was started in 1938 for the Lawrence Engineering and Research Corp., Linden, N.J. who had a development contract from the Navy Department for a diesel aircraft engine. After using various different configurations including overhead valves, sleeve valves, air cooled and water cooled modifications the Fiedler principle was finally adopted on a single cylinder test engine.

After six years of development work and an expenditure of close to \$1,000,000. the single cylinder was demonstrated to the Navy and in various tests proven to be better than anything known at that time in fuel consumption, combustion, peak pressures, continuous BMEP and simplicity of design.

Unfortunately the plan for a radial multiple bank configuration did not meet the projected power since the single cylinder was only rated at 120 HP, and a two bank radial therefore, would only give a total of 1500 HP while the Navy was looking forward to engines which would develop 3000 HP or more.

It therefore was decided to use the single cylinder development and incorporate it into a light weight opposed cylinder marine engine.

A contract was given to the Fiedler Sellers Corp. and three engines were built, developed and tested in the years 1944 to 1947. Due to the cessation of the armed conflict the Navy discontinued this program while the Fiedler Sellers Corp. used the information to develop a smaller high speed engine which is the J F #2-33.

The J F #2-33 is operational up to 12,000 RPM. It has been tested extensively at 8,000 with a conservative rating of 65 BMEP which gives the two cylinder unit a rating of 50 HP. Since the two cylinder engine due to its configuration (Lanchester System) is

in complete balance and the crankshaft is designed heavy enough it can be built in units of 2, 4, 6, and 8 cylinders or for the same rating of 65 BMEP at 8,000 would give units of 50, 100, 150 and 200 HP.

The same, of course, holds true for the J F #2-130. The two cylinder configuration being in complete balance would give 150 HP minimum at 3600 although the top speed of this engines is estimated to be in the neighborhood of 6,000.

The advantages of this engine development are not only light weight, but great reliability and exceptional fuel economy.

The reliability is due to simplicity and elimination of parts that in other engines cause failure as for instance:

1. No valves.
2. No valve springs.
3. No tappets.
4. No cam shafts.
5. No gearing whatsoever.
6. No load on housing or main bearings.
7. No oil pump.

The only bearings that are loaded in this engine are the connecting rod and wrist pin bearing and these are both roller bearings. The main crankshaft bearings are also roller bearings but are not loaded and act only as steady rests.

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1. SCAVENGING CONSIDERATIONS

Extensive study of scavenging problems in high speed two cycle engines was conducted by the author in 1921 to 1924 in the laboratory of Professor Becker, head of the Mechanical Engineering Department of Technische Hochschule, Berlin-Charlottenberg.

During these tests the volumetric efficiency of the three cylinder Fiedler engine was investigated and it was determined that an 80% volumetric efficiency of the total displacement is possible at a mean piston speed of 1000 feet per minute involving a stroke loss of 20% due to porting and using half the circumference for exhaust and half for scavenging. The port area was reduced by the necessary bridging by approximately 40%. The compression ratio of the crank case resulted in indicated maximum pressure of 5 pounds at a bore stroke ratio of 1.5 to 1.

The mechanical efficiency of this particular engine in question ranged from 96% at 1000 to 86% at 2800 (see page 24 of the Franklin Institute lecture, Jan. 1942.)

This three cylinder engine was so outstanding in its performance that Professor Becker published the results and comparisons to other engines that he had tested in technical papers in Germany, a reprint of which is on page 25, Figure #3 of the Franklin Institute lecture, January 1942.

In all future engine development which range from small high speed to locomotive type of 10" bore and 12" stroke as well as six years development work on two cycle aircraft injection engines with Charles Lawrence these basic figures

have been confirmed again and again and found reliable
and substantially correct.

2. NEW METHODS OF PORTING

In the years 1938 to 1942 the author cooperated in the development of a 100% supercharged high speed injection engine with Mr. Charles Lawrence, the inventor of the Wright Whirlwind engine.

During this period some of the porting investigations of previous years were repeated to determine if excess scavenging air which could be made available in a blower type scavenged engine would increase the cycle efficiency. It has been the author's opinion proven by previous tests and contrary to the accepted theories that the cycle efficiency improves almost at the same rate as the scavenging efficiency declines. As proof of this the author again calls attention to the University of Pennsylvania test report on Page 24, Figure 4 of the January 1942 issue of the Franklin Institute Journal. The full load fuel consumption which is equal to maximum scavenging efficiency is in this particular case between .6 and 1. pound per H.P. hour. At half throttle the fuel consumption decreases from .8 to .6 pounds per H.P. hour.

On the single cylinder 100% supercharged blower scavenged air craft engine extensive tests were conducted which included measuring the volumetric efficiency for various port areas, port timing, and air quantities (charts of these investigations are attached.) The following major conclusions were reached:

- a. The length of the exhaust port around the circumference of the cylinder should be as large as physically possible to give maximum opening areas at highest pressure

which makes it possible to move the exhaust port opening down towards bottom center permitting a larger expansion ratio, lower exhaust temperatures, and resulting in smaller discharge volume.

b. Restriction of the exhaust port in relation to the scavenging port to avoid blow through and waste of air during the time that both ports are open.

c. That extension of the exhaust port towards bottom center beyond the point where the scavenging port opens is detrimental since it promotes blow through, causes cooling of the combustion chamber and wastes power for air delivered detrimental to cycle efficiency.

d. Best cycle efficiency is attained when scavenging air delivered is less than the swept volume so that portions of the exhaust products from previous cycle are retained and recompressed. (Single engine under test at full load with the compression pressure of 720 pounds gauge could be stopped from firing if enough scavenging air was blown through the engine.)

The author therefore came to the conclusion to design an engine with a new type of porting arrangement which uses the whole circumference of the cylinder for the exhaust port, this port only extending down to the height of the necessary scavenging port. This system not only fulfills all the requirements previously mentioned but also has the advantage of an even temperature distribution for the piston and liner. The exhaust is discharged symmetrically around the whole circumference while the scavenging air is introduced,

counter flow to the exhaust flow, over the flat piston top forming a column in the center directing the new charge upwards toward the centrally located combustion chamber (comparative diagram of timing and scavenging areas is attached.)

3. COMBUSTION ANALYSES

The new combustion theory advanced by the author has been analyzed in the lecture held at the Franklin Institute on May 4, 1939. Since that time further tests not only during the period that he worked with Charles Lawrence but also during the time he was associated with Princeton University Jet Propulsion Laboratory (project Squid) have proven the correctness of the advanced theory.

To summarize these findings, good combustion in injection engines can only be realized if the following is achieved:

a. Mixing of the hydro carbon with the air at temperatures below 400 degrees F. This can be achieved if the hydro carbon is kept in a liquid state during the mixing period. Large individual widely separated drops are preferable to achieve this since the latent heat of evaporation of the core of the individual droplet prevents vapor formation which leads to cracking and subsequent detonation of the hydrogen air mixture.

b. The reason for this phenomenon seems easiest explained if one visualizes two molecules of different weight bonded together by a rubber band. If this combination is accelerated to the point where the band is broken, the means of accelerating the carbon molecules to the point where it will oxidize is lost. The result is the dropping out and non participation of the carbon in the combustion process. The hydrogen molecule relieved of its burden will accelerate at a much greater rate especially if it enters the oxidation process on the lean side or at the mixture point where oxidation can first be sustained. Calculations, however, have

shown that the mechanics of molecular acceleration can not reach a speed or temperatures which by its bombardment would cause relatively cold metals, as for instance piston tops, to disintegrate. The only plausible explanation for this phenomenon seems to be that the molecular acceleration of the hydrogen molecules is so great that its own bond is broken resulting in $2H$ or atomic hydrogen. At the point of necessary deceleration the atomic hydrogen reverts back to molecular hydrogen and the heat release at this time is twice that of an H_2O reaction.

The author some ten years ago suggested a research program to various universities which would mean a spectrographic investigation of the combustion reaction at time of detonation. Observations through quartz openings into the combustion chamber during detonation indicate that at time of the reaction the flame is brilliantly white. Non-detonating reactions are yellow, over rich mixtures are red.

To summarize, combustion can only be initiated if a stoichiometric ratio in some form exists. Hydro carbon injected into high temperature air does not initiate a combustion reaction but promotes cracking of the hydrocarbon. The rate of cracking is determined by the size of the droplets. The easiest structure that is cracked is vapor. For orderly combustion all fuel should be injected into the corresponding air mass before it reaches oxidation temperatures. From a thermodynamic standpoint a compression ratio which is equal to the reaction temperature is the most efficient. For practical purposes the larger the droplets and the faster the introduction (less

exposure of the hydrocarbon to acceleration) the higher the compression ratio and the higher the thermal efficiency.

However, one phase should not be overlooked and that is that if temperatures exceed 2000 degrees F. a CO₂ reaction can not be sustained. Calculation and tests on single cylinder experimental engines seem to indicate that a compression pressure of 950 to 1000 pounds represents the most efficient compression ratio and with the proper fuel introduction the maximum pressure should not exceed 1000 or 1100 pounds, which for the first time would produce an engine which is operating under the true diesel cycle instead of present so-called diesel injection engines which work on an Otto cycle.

The author has made long studies on the recent engine to substantiate the above. The difficulty encountered, however, is that there is no instrumentation available at the present time which will not increase the compression chamber volume to such an extent that the proper compression ratio can not be maintained (compression space .60 cubic inches.) All indications are, however, that the engine does for all practical purposes operate on a diesel cycle.

(P.S.) Combustion investigations on a ram jet at Princeton proved that combustion efficiency can be increased substantially and combustion chamber lengths substantially reduced if the hydro carbon is introduced upstream in the large loosely bonded droplets. At the same time this type of approach eliminates the so-called flame holder.

These findings should be of great value in the field of Turbo jet engines.

4. INJECTION EQUIPMENT

To design the proper injection equipment which fulfills all the requirements of good combustion the author has spent over 25 years in testing available injection equipment, modifying the same and finally designing and building his own equipment. This equipment consists of two important components, namely the pump and the fuel valve. The fundamental difference between the present day fuel valves and the one developed by the author is:

- A. Large and long orifices (diameter to length ratio 4 to 1)
- B. Large valve seat with a maximum lift of .003 inches
- C. A heavy spring with very steep characteristics and low pre-load so that the injection pressure does not exceed 1800 pounds per square inch.

A valve of this type produces a spray of widely dispersed droplets and the superimposed orifice determines the spray pattern. The orifices have to be chosen large enough so that under no condition for maximum fuel delivered and maximum speed the area is smaller than the lift area of the valve. In this way the orifice will never offer any restriction to the fuel flow.

As far as the pump is concerned its design is based on the following observations:

- a. On a plunger type port controlled pump, regardless of speed and diameter of plunger and regardless of cam contour that operated the plunger, the duration of injection is constant within .060 of an inch of plunger stroke after port closing.

The author's analyses is that within that period the plunger imparts an impact blow on the fuel column which if the reservoir between the plunger (fuel line) is properly selected will create a wave which in turn opens the injection valve and there is not enough time available to have the wave oscillate in the system to cause secondary injections. The period of injection remains constant within limits of 10 to 12 degrees shaft angle and this is regardless of the cam contour. To utilize this effect a pump would have to be designed so that the plunger diameter times .060" stroke is within the maximum capacity required for the engine.

To develop a high speed pump it was found that for long time operation a cam and flat spring loaded tappet is inadequate. The investigation finally resulted in the adaptation of a roller cam where the roller is supported and rolling on the outer diameter of a needle bearing. (See attached drawing). The roller in turn actuates a lever which operated the fuel plunger. The quantity discharged is determined by the amount the plunger is allowed to override the ports. In this way the port closing velocity is varied which results in the more or less efficient impact blow which in turn determines the fuel quantity discharged on the other end of the fuel column through the injection valve. This latest pump produces correct injections up to 12,000 injections per minute with a duration of 7 to 8 degrees pump shaft angle. Other design features are that the reciprocating masses are kept to a minimum allowing high speed operation.

5. BASIC DESIGN FEATURES OF THE FIEDLER ENGINE

The possibility of operating injection equipment at speeds up to 10,000 R.P.M. opened a new field for light weight engine design. The author had many years of experience with high speed engines, one of which he flew in his own plane during the years 1925 and 1926. This particular engine had a 4 1/4 inch stroke and an operating speed of 3000 R.P.M. Based on this experience the new engine was designed to operate at 3000 R.P.M. continuously. To do this a mechanical system had to be chosen that was in perfect balance. The only system that fulfills these requirements without counter weighting and special balancing shafts is the Lancashire system of two opposed cylinders with three connecting rods operating on "B" crank, the center rod operating one piston while the two side rods operate the opposite piston. In this system all masses of the two units are opposing each other.

The displacement per cylinder of 19.6 cubic inches was chosen because it is approximately the same displacement per cylinder as the previously mentioned three cylinder engine for which all test data have been available. This happens to match with the minimum fuel quantities that have been successfully injected with the proper dispersion characteristics through a single hole orifice and at speeds up to 10,000 injections per minute.

To have the necessary scavenging pressure available for high speed operation and to bring the piston speeds down into commercial limits a two inch stroke was chosen.

To keep the engine weight down the motor block and crank case were made out of aluminum which were held in compression by four bolts connecting the cylinder heads so that the crank case actually was not exposed to any firing pressures. Under this system it should be remembered also there is no load on the main crankshaft bearings, since they act only as steady rests.

The connecting rod and wrist pin bearings are roller bearings which are lubricated by small quantities of fuel oil which is introduced into the scavenging air. This lubrication is also sufficient to lubricate the pistons and rings. The author conducted numerous tests to determine if traces of fuel oil in the scavenging air affects the combustion characteristics. It was found that within limits the combustion efficiency increases and that at the same time it facilitates cold starting (Indicator cards of these tests and data are available).

To summarize the latest Fiedler engine is possible:

- a. Due to the new scavenging system
- b. Due to new combustion system and injection equipment development.
- c. Due to the general configuration which eliminates high stresses on the engine structure itself and only imposes loads on the connecting rod bearings which can be held to dimensions so that they can easily operate under the required load conditions.