

Conversion of a Spark-Ignited Aircraft Engine to JP-8 Heavy Fuel for Use in Unmanned Aerial Vehicles

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ABSTRACT

In order to satisfy a single-fuel mandate, the U.S. Department of Defense has a need for engines in the 20 to 50 hp range to power midsized Unmanned Aerial Vehicles (UAVs) and the ability to operate on JP-8 also known as “heavy” fuel. It is possible to convert two-stroke aircraft engines designed to operate on a gasoline-oil mixture to run on JP-8/oil using the Sonex Combustion System (SCS) developed by Sonex Research, Inc. Conversion of the engine involves replacing the cylinder heads with new components designed to accept a steel combustion ring insert. Also required are glow-plugs to preheat the cylinder head prior to engine start. The converted engine produces the same power output as the stock engine operating on gasoline. Conversion of both a 20 hp and 40 hp engine was successfully achieved using the SCS.

INTRODUCTION

The U.S. Department of Defense (DoD), in particular the U.S. Army, continues to pursue the implementation of JP-8 as the “Single Fuel on the Battlefield.” This principle was first advanced by DoD Directive 4130.43 [1], *Fuel Standardization*, issued in 1988. It has been reinforced by DoD Directive 4140.25[2], *DoD Management Policy for Energy Commodities and Related Services* (2004):

“Primary fuel support for land-based air and ground forces in all theaters (overseas and in the Continental United States) shall be accomplished using a single kerosene-based fuel, in order of precedence: JP-8, commercial jet fuel (with additive package), or commercial jet fuel (without additives.).... Fuel support for ground forces may also be accomplished using commercially available diesel fuel when supplying jet fuel is not practicable or cost effective.”

The Directive goes further in discouraging the acquisition of gasoline-powered equipment:

“To the maximum extent practical, no new combat support or combat service support equipment or vehicles requiring gasoline type fuels shall be acquired or developed unless the support concept is to supply fuel as a packaged product.”

With these mandates in force, the services have been mounting a sustained effort to reduce or eliminate gasoline-powered vehicles and equipment from their inventory. This task has not been an easy one, and the end is not yet in sight. One area in particular where progress has been slow is Unmanned Aerial Vehicle (UAV) systems.

The DoD UAV fleet is composed of a mixture of commercial, purpose-built, U.S. and foreign-designed systems. Large systems, such as the RQ-4A Global Hawk, were designed with turbofan engines that accept JP-8 fuel. Smaller systems operate on a range of fuels from motor gasoline to electricity. Across the DoD, there are efforts underway to convert the remaining gasoline-powered systems

to operation on JP-8, also known as “heavy fuel.” [3] The goal is to achieve the Single Fuel on the Battlefield, either through engine conversion programs or wholesale replacement. The DoD has repeatedly highlighted the critical need to develop small heavy fuel engines for its next generation and legacy UAV fleet.[4]

The purpose of the research described below is to investigate the feasibility of converting a 40 hp-class aircraft engine designed to operate on gasoline to instead operate on heavy fuel. The engine conversion focused on properly managing the waste energy from the combustion process. The energy management is accomplished using the Sonex Combustion System (SCS). The SCS uses geometry and material properties inside the combustion chamber to achieve the energy management required to enable heavy fuel operation. The SCS technology is scalable to a wide range of engine sizes making heavy fuel operation practical for all of the UAV platforms that currently operate on aviation gasoline.

CONSIDERATIONS FOR JP-8/S-8 HEAVY FUEL UAV ENGINES

Traditional DoD re-engine programs focus on upgrading existing power plants with improved models that offer higher thrust, increased altitude, improved reliability or ease of maintenance. Conversion of an existing engine coupled with the introduction of a new fuel requires significant analysis and testing to ensure the effectiveness and suitability of the new design. Once an engine design is selected, platform integration is almost as complex as the engine development process.

An additional consideration for UAV heavy fuel engine developers is that the U. S. military, in particular the Air Force, are developing synthetic substitutes for conventional JP-8 using the Fischer-Tropsch (F-T) process. The Air Force alternative is commonly referred to as S-8.[5] It is likely that deployed forces may have both fuels available to them with the next decade. Engine designs that are being adapted for JP-8 should also take into account operation on the S-8 fuel, as it has slightly different properties than JP-8.

Power plants for some UAVs and other compact applications rely on two-stroke engine technology due to their high power-to-weight ratio and high reliability. [6,7] UAVs require high power-to-weight ratios to maximize payload capacity, and the high value of UAV payloads demands a highly reliable power plant to ensure mission success. Compact applications such as auxiliary power units (APU) also require high power-to-weight ratios to ensure their footprint is minimized for easy transport.

Disadvantages of two-stroke engines, as compared to four-stroke engines, include shorter service life, greater emissions, and lower fuel efficiency. Although these disadvantages have

reduced the use of two-stroke engines in many commercial applications, they have not been major roadblocks to their implementation for military applications such as UAVs and APUs because the advantages outweigh the shortcomings. [8,9]

THE SONEX COMBUSTION SYSTEM

The heart of the research project is the conversion of two aircraft engines using the SCS, a patented technology developed by Sonex Research Inc. a developer of spark ignited heavy fuel engines for military applications. The SCS has been used successfully to convert small engines to heavy fuel, for example the 1.9 hp engine that powers the *ScanEagle* UAV system. The focus of this research project is to determine the feasibility of converting two larger engines, in the 20 hp and 40 hp range, to operate on heavy fuel using the SCS.

The SCS achieves in-cylinder control of ignition and combustion of heavy fuel through chemical and turbulent enhancement using patented combustion chamber designs. [10] In two-stroke Spark-Ignition (SI) engines the SCS achieves ignition of the heavy fuel by vaporizing the fuel near the spark plug late in the compression stroke. The fuel is vaporized by energy retained from the previous combustion cycle.

The energy management required to vaporize the fuel around the spark plug is achieved through careful use of geometry and materials. A bowl in the head of the cylinder surrounds the spark plug. The bowl accommodates a fraction of the incoming charge to be segregated from the bulk of the charge. Since the segregated portion of the charge has a low mass it is quickly vaporized in the high temperature environment of the cylinder. In addition, the vaporized portion of the charge surrounds the electrode of the spark plug so it will ignite when the spark plug is energized.

Aluminum and mild steel are the materials used in the SCS; mild steel is used to form the bowl around the sparkplug and aluminum is used for the remainder of the cylinder. Mild steel is used for the bowl around the sparkplug because the thermal capacity of mild steel enables sufficient energy from the previous combustion event to be stored in the cylinder head to vaporize the incoming fuel. In a traditional engine design the energy used to vaporize the incoming charge in the SCS would need to be transferred out of the cylinder either by engine coolant or air, depending on the cooling scheme.

Aluminum is used in the remainder of the cylinder because it is light weight, strong, and an effective heat transfer material that is commonly used in air cooled engines. A typical embodiment of the SCS consists of a mild steel cylinder head, or insert, encased in an aluminum cylinder. [Figure 1](#)

shows an exploded view of a typical cylinder design used in an SCS.

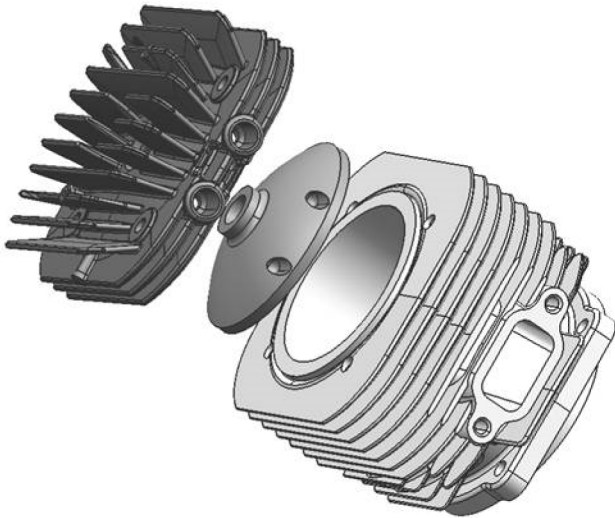


Figure 1. Exploded View of a Typical Cylinder Design Used in the SCS.

A feature of two-stroke engines that aids the SCS in enabling an SI engine to be operated on heavy fuel is the exhaust products that are retained in the cylinder after the expansion stroke. Energy in the hot exhaust products help to heat and vaporize the incoming charge. Also, the exhaust products contains vaporized unburned hydrocarbons that rapidly combust and energize the combustion reaction.

These features of the SCS combine to effectively manage the waste energy and products of the previous combustion event to enable the effective use of heavy fuel in an SI engine. The result of these features is a heavy fuel powered two-stroke engine that has equivalent performance and fuel consumption as a gasoline fueled two-stroke engine of equivalent size.

ENGINE CONVERSION USING THE SCS SYSTEM

A typical engine conversion to heavy fuel using the SCS maintains the gasoline engine's stock carburetion or fuel injection system, intake and exhaust systems, spark ignition system, and compression ratio. No modifications are made to the moving parts, including the piston. Two-stroke engines converted with the SCS running on JP-5, JP-8 and D-2 diesel (with lubricant additive) retain the ignition precision of the SI process and provide knock-free combustion.[11,12]

Specifically for this project, a design was implemented that replaced the existing cylinder head with a new cast aluminum head assembly. This new casting was designed with a “pocket” or cavity that would accept a steel insert. The insert fits inside the head and maintain the compression ratio of the

stock engines. A picture of the aluminum head is shown in [Figure 2](#) and the steel insert is pictured in [Figure 3](#). Installation of these new components required the head of the existing cylinder jug be removed. A ridge was machined into the top of the resulting cylinder to aid in sealing the aluminum head casting/steel insert/cylinder assembly. The volume of the new cylinder assembly is modified by removing additional material from the top of the cylinder until it matches the volume of the original cylinder jug. This is done to maintain the same compression ratio as the original engine design.



Figure 2. Cast Aluminum Head and Steel Insert



Figure 3. Aluminum Head and Steel Insert Assembled and Ready for Installation on Engine Cylinder

To start the converted engines, glow plugs were employed to heat the cylinder assembly to a sufficient temperature to ignite the heavy fuel. Mounting provisions were designed into the aluminum casting for two glow plugs to be installed

in each cylinder. Two Bosch glow plugs were installed in each cylinder assembly.

ENGINE SELECTION FOR THE CONVERSION PROGRAM

The objective of the RIT research program was to obtain a heavy fuel engine suitable for integration into a medium-sized UAV platform. Currently a number of platforms use gasoline engines, but heavy fuel engine capability is required. A suitable production ready heavy fuel engine could not be identified after an extensive search. Therefore, the decision was made to convert an engine in conjunction with Sonex Research, an industrial partner.

The Limbach L275E/550E engine series was selected as the candidate platform to install the SCS. The 275E is a horizontally-opposed two-cylinder two-stroke offering 20hp. The L550E is a four-cylinder version of the two-cylinder L275E, and is rated at 40 hp. It has twice the displacement as the L275E.

Both engines are currently in production by Limbach Flugmotoren GmbH and are certified in Europe as “man-rated” engines. In addition, the Seeker II UAV built by Denel Dynamics in South Africa uses the L550E gasoline version. Seeker II variants have been in operational service with the South African military since 1991. The Seeker II variants were certified for use in South African civil airspace in 1994. [13] The use of a man-rated engine currently used in UAV applications reduced the risk that the resulting converted engine would experience reliability failures not related to the fuel conversion modifications. Both engines are relatively simple, straightforward two-stroke designs which permitted a rapid conversion.

The L275E engine was the “proof of concept” platform to prototype the SCS heavy fuel conversion system on the Limbach series engines. Once the L275E was successfully run on heavy fuel, the conversion design, with minimal changes, was migrated to the L550E engine. The primary difference of the cylinder configuration of the L275E as compared to the L550E cylinder configuration is the orientation of the cooling fins of the cylinder heads. The cylinder heads of the L275E are horizontal to make the most use of the wind from the propeller. By contrast, the side-by-side configuration of the L550E cylinders requires the cooling air to pass around the cylinders vertically to maintain temperature uniformity of all cylinders. Therefore, the fins on the cylinder heads must be vertical as well. The Limbach L275E is shown in [Figure 4](#) and the L550E is shown in [Figure 5](#). In summary, these were the modifications made to the stock engines:

- The existing cylinder jugs were modified to accept the SCS cylinder head assemblies that consist of a cast aluminum head with a mild steel insert.

- Bosch glow plugs were installed in the cast aluminum heads to heat the cylinder heads for cold start above 75 °C. The glow plugs were connected to an independent battery.

- A choke system was fabricated and installed on each carburetor to assist in starting. An independent carburetor is mounted to each cylinder of the original engine.

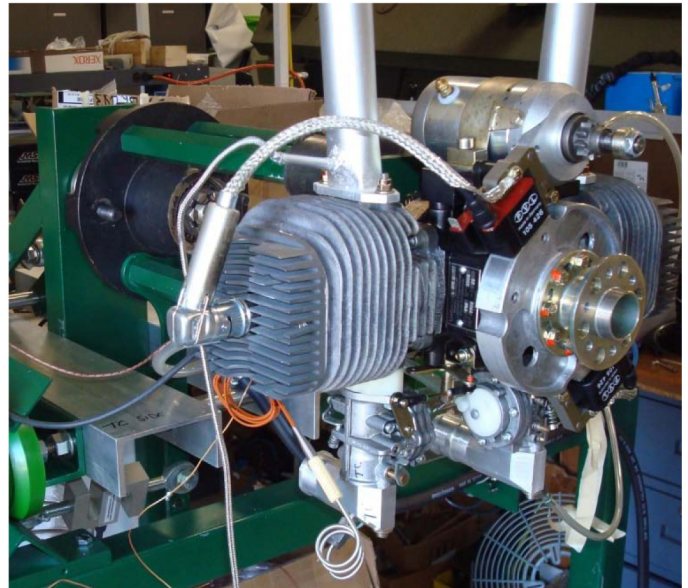


Figure 4. Limbach L275E 20 hp Air Cooled Two-Stroke Engine, (Note the orientation of the cooling fins on piston heads)



Figure 5. Limbach L550E 40 hp Air Cooled Two-Stroke Engine, (Note the orientation of the cooling fins on piston heads)