This fuel can be mixed with gasoline or burned by itself. At the present time this fuel is not widely available.[2]

3.0 ENGINE OPERATION

The operation of UAV engines essentially lies in the classification of the engine. The most common types include two stroke, four stroke, and rotary, each with a varying number of cylinders, in addition to turbine engines.

3.1 Two Stroke Engines

Two stroke engines, like the one shown in Figure 1, typically have excellent power-to-weight ratios, while remaining relatively inexpensive. However, these engines tend to exhibit high vibration and noise levels, in addition to performing with low fuel efficiencies.[7] Historically, two stroke engines are either methanol or gasoline powered.

Many methanol powered engines, such as the ones produced by O.S. Engines, operate on "glow fuel," which is a gas-oil mixture containing methanol in addition to 5 – 15% nitromethane and a minimum of 16% synthetic castor oil lubricant.[8] These engines also tend to be small and compact in size, intended for small UAVs.[9]

FIGURE 1 - TWO STROKE ENGINE[10]

Combustion engine is the general term for those engines that can operate with fuels including the JP series, DF series, and Jet series. Engines designed for civil and military applications, such as those developed by Cosworth Engines, accept multiple fuels including JP5, JP8, DF1, and DF2.[11] Several of these engines contain single-cylinder direct-injection compression-ignition systems, using port and reed-valve induction. Engines such as the AE-1 provide high performance characteristic, as is desired for use in the US Navy's Small Tactical Unmanned Aerial System, Tier Two class UAV program.[12] A gas-oil mixture is commonly used in two stroke engines in ratios of 40:1 to 50:1, including those manufactured by Evolution Engines, with electric ignition and single or twin cylinders.[13]

3.2 Four Stroke Engines

Four stroke engines are the most fuel efficient of the various classes of internal combustion engines. When compared to two stroke engines, four stroke engines perform with lower vibration and noise levels; four stroke engines have a higher vibration than a Wankel engine. As a negative attribute, four stroke engines additionally exhibit a lower power-to-weight ratio than a two stroke engine of comparable power output.[14] While most four stroke engines operate on heavy fuels, some engines do utilize glow fuel, such as some of the models with air bleed carburetors produced by Enya Engines.[15] In some cases, it necessary to add a fuel injection system in order to enable low temperature starting and proper altitude mixture compensation, as well as to reduce the susceptibility to icing.[16] Four stroke engines are capable of outputting greater net thrust and are commonly used on larger UAVs including the turbocharged model, as produced by Rotax, used on the "Huron" and the "Predator". An example of a four stroke engine is shown in Figure 2.

FIGURE 2 - FOUR STROKE ENGINE[17]

3.3 Rotary (Wankel) Engines

Figure 3 shows a rotary (Wankel) engine. Rotary (Wankel) engines combine the rotating cylinder with the rotary valve in create a single component (RCV), which reduces the component count and is less complex to assemble. There is no valve bounce at over-speed operation, nor a cam chain or valve lash clearance to adjust, thus increasing its simplicity. The cylinder rotates around the piston at half of the crankshaft speed and provides continuous piston lubrication, which in turn reduces friction. No complex overhead valves, cams or electronic servo cartridges are needed, due to the implementation of a fixed timing ring.[18] Rotary engines operate with gasoline, methanol, diesel, and JP8 fuels, and possibly also with JP10 and JetA.[11] Due to the high internal turbulence levels and compact combustion chamber, these engines exhibit excellent JP5 and JP8 operating characteristics and are capable of generating the same power with heavy fuels as with gasoline.[18]

FIGURE 3 - ROTARY (WANKEL) ENGINE[19]

3.4 Turboprop Engines

Turboprop engines, like the one shown in Figure 4, are composed of a gas turbine driving a propeller. Essentially, when the turbine is functioning, the two-stage turbine section, which has an inner and outer shaft configuration, is driven by gas flow from the core engine. The output power of the engine is purely derived from the kinetic energy of the exhaust gas flow.[20] The inner shaft is connected to a gearbox which reduces the turbine speed to a rate appropriate for a propeller. An axial fan on the gearbox provides the critical cooling of components that are exposed to high engine operating temperatures.

FIGURE 4 - TURBINE ENGINE[21]

3.5 Diesel Engines

Diesel engines have no ignition systems. Instead, the engines use an electric or mechanic injection system, both of which are highly reliable. Diesel engines are more efficient and have lower specific fuel consumption than gasoline engines (a 20% reduction on average).[16] This positively increases the range and endurance of the aircraft, in addition to reducing weight due to a smaller required fuel tank size. Unlike gasoline engines, exact mixture control is not a requirement. These engines are also designed to operate for long periods of time without scheduled maintenance.

3.6 Engine Selection and Limitations

UAV engines vary in multiple physical attributes and performance characteristics: size and weight, fuel requirements, power output, flight time before refueling, maintainability, rebuild capacity, lifespan, and, often one of the forefront concerns, cost. Due to the variation in these properties and the limitations of per engine modifications that would need to be made to the ETS for testing, selection criteria were applied to a general list in order to isolate potential candidates that could be tested using the ETS. Several viable mid-sized two-stroke, four-stroke, and rotary engines were selected based on relative size, weight, and power output (due to the limitations of the dynamometers and controls). Table 1 includes several of the engines considered, with the specifications summarized from material that can be found Appendix C.

Engine Model	Engine Type	Weight [kg]	Max Power Output [hp]	Speed [RPM]	Application
Sachs SF 350	Two stroke		26	6800	*Pioneer*
Limbach L550E	Two stroke	16	50	7500	
Rotax 912 ULS/S	Four stroke	58	78	5500	*Predator*
Rotax 582 Mod 99	Four stroke	64	65	6500	
UEL AR801R	Rotary	29	52	6000	*Hermes*
UEL AR-741	Rotary	24	38	7800	*Shadow*

TABLE 1 - POTENTIAL ENGINE CANDIDATES FOR THE ETS

4.0 EFFECTS OF FUEL VARIATION ON ENGINE OPERATION

UAV engines are designed and constructed with the intent to operate using a specific fuel. While it may be possible to coax the engine to continue to run once the primary fuel has been substituted, a decrease in efficiency or performance may result. Several aspects can be considered areas of concern when analyzing the performance of an engine operating with an alternative fuel. These factors may include: fuel-air ratios required for operation, detonation due to the use of a lower octane fuel, an increase in exhaust particulates and other pollutants, and the need for additional maintenance.

The fuel-air ratio of an engine is the mass ratio of air to fuel during combustion. By operating at a ratio lower than the optimum, (operating rich), additional fuel is being forced into the airstream intended for combustion but complete combustion will not occur. The excess fuel, determined by the density of oversaturation, will simply continue to flow out of the engine with