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An experimental and analytical investigation of a multi-fuel stepped piston engine

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ABSTRACT

This paper presents results of computational modelling of a stepped piston engine using one dimensional CFD code. The analysis builds upon the experimental work performed on a four-cylinder stepped piston engine for Unmanned Air-Vehicle (UAV) application. A range of variables in terms of fuels, fuelling methods and core engine parameters have been modelled and compared with actual test data. The maximum power recorded from experimental testing was 30.47 kW at 5250 RPM using kerosene JET A-1. The correlation between theoretical and experimental data is in general agreement within the bounds of the uncertainties of experimental errors and the assumptions within the numerical models. Simulation has allowed an assessment of potential for direct injection fuelling predicting minimum specific fuel consumption (SFC) of 0.273 g/kWh using indolene and 0.310 kg/kWh using simulated JET A-1.

1. Introduction

The need for low mass engines capable of operating efficiently on low volatility fuels has been a NATO objective for quite some time [1]. The requirement remains to this day largely unfulfilled [2] except for a number of small volume exploratory applications for unmanned air-vehicle (UAV) systems. The high volatility of gasoline and therefore its deployment in theatre and onboard Navy vessels poses a very hazardous safety risk. Furthermore due to the fact that the majority of military aircraft and ground based vehicles operate on kerosene based (AVTUR, NATO F34, JP5, JP8) and diesel fuels, the logistical supply and support challenges of moving and storing AVGAS and AVGAS/oil mixed fuels for conventional two-stroke engine powerplants presents significant problems.

UAVs by their very nature have to meet very stringent targets in order to achieve low overall vehicle mass objectives. All of the onboard systems, notably air-frame, avionics, electronic surveillance payload, propulsion system and fuel payload must be designed to meet these minimum mass requirements. The powerplant normally represents one of the highest mass assemblies within the overall UAV system. In the case of the propulsion system, the most efficient method of combustion of low volatility fuels is achieved using compression ignition. Thermal efficiencies in excess of 50% [3] have been demonstrated using two-stroke cycle diesel engines. Unfortunately these are high mass engines achieving very high power levels but at a power:mass ratio of only around 0.035 kW/kg. Automotive four-stroke diesel engines are capable of achieving typical levels of 0.8 kW/kg. Unfortunately these also present too high a mass penalty for UAV application. For medium and short range applications turbine powerplants are largely unsuitable. For fixed wing UAVs the minimum cruise speed or loitering speed of small turbine powerplants is normally too high for practical surveillance missions unless rotary wing UAVs are adopted [4].

A means of overcoming this problem was identified via experimentation [5] with low mass spark ignition engine combustion of kerosene JET A-1. Successful operation of such a system based upon an engine not required to sustain the high pressure required for compression ignition, offers a means to meet this conflicting need. The two-stroke cycle engine has been the subject of research and development for low emission automotive applications via results observed using direct injection. Notable examples demonstrated by Schlunke [6], Duret [7] and most recently by Turner et al. [8]. The highest thermal efficiency levels with a two-stroke cycle engine are therefore likely to be achieved with direct injection of heavy fuels.

During the experimental phases of the research forming the subject of this study a range of tests were conducted to assess the effects on the performance of a stepped piston engine designed and developed at Bernard Hooper Engineering Ltd (BHE) under Ministry of Defence contract. The work included

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