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On parallel hybrid-electric propulsion system for unmanned aerial vehicles

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ABSTRACT

This paper presents a review of existing and current developments and the analysis of Hybrid-Electric Propulsion Systems (HEPS) for small fixed-wing Unmanned Aerial Vehicles (UAVs). Efficient energy utilisation on an UAV is essential to its functioning, often to achieve the operational goals of range, endurance and other specific mission requirements. Due to the limitations of the space available and the mass budget on the UAV, it is often a delicate balance between the onboard energy available (i.e. fuel) and achieving the operational goals. One technology with potential in this area is with the use of HEPS.

In this paper, information on the state-of-art technology in this field of research is provided. A description and simulation of a parallel HEPS for a small fixed-wing UAV by incorporating an Ideal Operating Line (IOL) control strategy is described. Simulation models of the components in a HEPS were designed in the MATLAB Simulink environment. An IOL analysis of an UAV piston engine was used to determine the most efficient points of operation for this engine. The results show that an UAV equipped with this HEPS configuration is capable of achieving a fuel saving of 6.5%, compared to the engine-only configuration.

Contents

1. Introduction . . . 2
2. Hybrid-electric propulsion system . . . 2
3. HEPS configurations . . . 3
   3.1. Series configuration . . . 3
   3.2. Parallel configuration . . . 3
   3.3. Power-split configuration . . . 4
4. HEPS control strategies . . . 4
   4.1. Intelligent controllers . . . 4
   4.2. Rule-based controllers . . . 5
5. HEPS model . . . 5
6. Ideal operating line analysis of an UAV ICE . . . 5
   6.1. ICE torque calculations . . . 5
   6.2. ICE BSFC calculations . . . 6
   6.3. Engine map . . . 6
   6.4. Determining the IOL . . . 7
7. HEPS Powertrain . . . 7
   7.1. Piston engine model . . . 7
   7.2. Electric motor model . . . 8
   7.3. Generator model . . . 8
   7.4. Battery model . . . 8
   7.5. CVT Dynamics model . . . 8
   7.6. Charge Battery Now (CBN) module . . . 9
   7.7. Powertrain Output Allocation module . . . 9

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8. HEPS IOL controller . . . 9
8.1. Operating mode module . . . 9
8.2. Power Demand module . . . 10
8.3. Engine Operating module . . . 11
8.4. Engine Throttle Command module . . . 11
8.5. Rate of Change of Ratio Command module. . . . 11
8.6. Torque difference calculation module . . . 11
9. UAV Simulation Model . . . 11
9.1. Flight Planner Module . . . 11
9.2. Aircraft Control Module . . . 13
9.3. Mission scenario. . . . 13
10. Integrated HEPS model . . . 14
11. Conclusions . . . 17
References . . . 17

1. Introduction

An Unmanned Aerial Vehicle (UAV) is a "remotely piloted or self-piloted aircraft that can carry cameras, sensors, communications equipment or other payloads" [1]. UAVs have emerged as a viable platform to operate in regions where the presence of onboard human pilots is either too risky or unnecessary, in a diverse range of applications, from reconnaissance and surveillance tasks for the military, to civilian uses such as aid relief and monitoring tasks [2]. Their lower operation costs (as compared to manned aircraft and satellites) and availability in a great variety of sizes and capabilities have contributed towards the surging interest in UAVs from both the military and civilian sectors.

The focus of UAV applications has hitherto been predominantly in the military domain, but there has been increasing global interest in civilian and commercial UAV applications over the last decade, especially the use of small UAVs. Examples of these smaller cousins of the military UAVs, e.g. MQ-1 Predator or RQ-4 Global Hawk, include the Shadow, the Aerosonde, the Global Observer, the Bell Eagle Eye, the SkySeer, the ARCAA Flamingo UAV and the KillerBee 4 UAVs. The lower-cost factor of these small UAVs, much of which is due to the increase in the availability and quality of commercially off-the-shelf (COTS) components, and rapid increases in their capabilities as a result of technological advances, present attractive incentives [3] for non-military and amateur UAV operators and developers, who are generally under more strict cost budgets when compared to their military counterparts.

Trade-offs between payload capability and aircraft endurance is always a problem that needs to be solved in the development and construction of UAVs, regardless of their size. As with all aircraft, there are mass and space limitations on UAVs for all onboard systems, including electronics, powerplant(s), fuel storage and payloads. However, these limitations are stricter for a small UAV due to their already smaller sizes.

The miniaturisation of avionics equipment and an increase in their capabilities have seen significant reductions in size, weight and power usage for small UAV components [4]. On the other hand, the use of COTS aeromodelling powerplants on a large proportion of emergent propeller-driven UAV platforms can be significantly disadvantageous in the aspects of operational utility and energy efficiency, when compared to traditional aircraft powerplants [5]. While some UAV developers have successfully modified COTS aeromodel powerplants to achieve excellent efficiency, the utilisation of COTS components that are not sized ideally for the UAVs is still a common practice amongst civilian UAV developers, mostly due to cost issues. Consequently, the associated weight and space penalties contribute to limits on onboard fuel and/or energy resources (e.g. battery). This in turn brings about the problem of how to efficiently utilise the available energy resources on a small UAV.

One approach used in the research in the area of efficient energy usage on a small UAV is by developing and implementing alternative energy technology. Examples of these include fuel cells, solar cells and hybrid propulsion systems. In this paper, the utilisation of a Hybrid-Electric Propulsion System (HEPS) on the UAV is investigated.

The rest of this paper is organised as follows: Section 2 presents a brief background on HEPS, followed by Section 3 with a description of the main Hybrid-Electric (HE) powertrain configurations that are most commonly in use today, and an analysis of control methods for HEPS is given in Section 4. Section 5 presents a HEPS model which uses a Continuously Variable Transmission (CVT) and an Ideal Operating Line (IOL) control strategy, with the IOL analysis of the UAV internal combustion engine (ICE) described in Section 6. The component models of the HEPS powertrain are described in Section 7, and the HEPS controller in Section 8. A UAV Simulation Model (UAVSM) is described in Section 9, and its integration and simulation results are presented in Section 10.

2. Hybrid-electric propulsion system

Traditionally, small civilian UAVs are mostly powered by internal combustion engines (ICEs). But, as ICEs have a thermal efficiency of at most 40% [6] and, despite the high energy density of the liquid hydrocarbon fuels used by ICEs, with energy preservation issues on the rise, more efficient powerplant configurations have been sought.

A popular alternative powerplant is the electric motor (EM), which is capable of operating with an efficiency of close to 100% [7]. However, EM's high efficiency is negated by the necessary use of a power storage system which drives the EM in order to power the UAV. This power storage system, in most cases a battery, is often the largest component by weight in an UAV, representing a large weight penalty. Also, it has a limited operating duration and relatively long period of time required to replenish its charge. Despite recent advances in power storage technology which have reduced the impact these drawbacks have had on the use of EM in civilian UAVs in the past, the sizes and relative inefficiencies of power storage systems still hold back the development of purely electrically powered UAVs.

A way of overcoming the shortcomings of both powerplants is to integrate an ICE with an EM to form a Hybrid-Electric Propulsion System (HEPS). Hybrid propulsion technology has been an area of intense research, particularly by the automotive industry, and results have shown significant increases in fuel efficiency. In contrast, the study of utilising hybrid propulsion in aircraft had only begun in recent years, and there has been little investigation on the various control methods for HEPS and their effects on