

A Hybrid Economy Bleed, Electric Drive Adaptive Power and Thermal Management System for More Electric Aircraft

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ABSTRACT

Minimizing energy use on more electric aircraft (MEA) requires examining in detail the important decision of whether and when to use engine bleed air, ram air, electric, hydraulic, or other sources of power. Further, due to the large variance in mission segments, it is unlikely that a single energy source is the most efficient over an entire mission. Thus, hybrid combinations of sources must be considered.

An important system in an advanced MEA is the adaptive power and thermal management system (APTMS), which is designed to provide main engine start, auxiliary and emergency power, and vehicle thermal management including environmental cooling. Additionally, peak and regenerative power management capabilities can be achieved with appropriate control. The APTMS is intended to be adaptive, adjusting its operation in order to serve its function in the most efficient and least costly way to the aircraft as a whole.

This paper presents a hybrid APTMS, which balances the use of economy bleed air and electric drive in a single architecture that automatically adapts to changing aircraft conditions to optimally regulate its function. Bleed air is used when it is relatively “cheap” (i.e. requires the lowest fuel consumption compared to other available power sources), but is reduced and supplemented with electric power from the main engine generator when bleed air becomes more

expensive and electric power becomes cheaper. Through proper control, this strategy can find the most efficient balance of bleed air and electric power, increasing aircraft range and capability. This architecture, abbreviated “e²”, is presented, describing its components, functionality, and features. Comparisons to more traditional systems highlight the potential for energy savings afforded by the e² system. The analysis shows that the e² architecture has the potential to significantly reduce energy use compared to previous systems, without upsizing the primary generating system (PGS). Additional anticipated benefits include the ability to provide both cooling and supplemental power growth without upsizing the turbomachinery.

INTRODUCTION

In support of MEA initiatives, several recent advancements in aircraft thermal management systems have been made. The Power and Thermal Management System (PTMS) developed by Honeywell for aircraft combines the functions of the auxiliary power unit (APU), emergency power unit (EPU), environmental control system (ECS) and thermal management system (TMS) [1]. In the PTMS, these previously federated systems are combined into an integrated system which allows the turbomachinery to be used for both power and cooling functions. This integrated approach significantly reduces the weight penalties traditionally associated with having multiple units on the aircraft, none of which is active during the whole flight profile. The PTMS

lays the groundwork for the APTMS, and its e^2 variant, which is described here.

The APTMS is designed to provide main engine start, auxiliary and emergency power, and vehicle thermal management including environmental cooling. Its goals are to reduce fuel burn, weight, and cost, and to increase aircraft power and cooling capabilities. It is a derivative concept from the JSF / Integrated Subsystems Technology (J/IST) demonstration program, which spawned the PTMS. As its name suggests, the key feature of the new system is that it is adaptive, adjusting its operation dynamically in order to operate as efficiently as possible during each flight segment. The new approach is abbreviated “ e^2 ” to highlight that it utilizes both economy engine bleed air and electric drive. This architecture also eliminates the exclusive reliance on engine fan air and fuel as the primary heat sinks for thermal management, these sinks having proven to be costly contributors to excessive energy extraction. It does this by providing the flexibility to accommodate third-stream air (lower pressure, and therefore lower energy intensive, engine air) and low-observable ram air as additional heat sinks. This presents a favorable combination for a more efficient energy approach.

One particular feature of MEA that has proven to be a challenge is the presence of significant regenerative and peak electric power imposed on the electrical system by the electric actuators during transient flight maneuvers. Traditional aircraft have utilized hydraulic actuation, which does not regenerate electrical power, and thus the electrical specifications for aircraft systems have not allowed for regeneration onto the electrical system [2, 3]. This restriction has led to large resistors being used to burn off regenerated actuator power locally, adding significant heat loads to the aircraft TMS. As described in [2], allowing the regenerative power to flow on the electrical bus would alleviate this burden, greatly reducing TMS equipment weight. However, the regenerated power must be processed somehow, which requires advanced bi-directional electrical drives [4] and either rotating machinery [5] or other electric storage devices such as electrical accumulator units (EAU's) [6] capable of handling bidirectional power flow. The e^2 architecture offers a possible solution to this, by utilizing its advanced electric drive and rotating machinery to transfer regenerated power to the APTMS shaft inertia in the form of rotational energy. In essence, the APTMS can utilize its shaft as a flywheel during actuator transients, an idea that has been examined and found to be viable [7]. During peak events, the stored energy can then be resupplied to the bus, relieving the burden on the main engine and providing stability.

This paper describes the e^2 APTMS, and its remaining sections are organized as follows. First, the e^2 architecture is presented and described in detail. Next, an analysis of the

performance of a notional system is given, with comparisons to existing architectures. Finally, concluding remarks are made.

ARCHITECTURE DESCRIPTION

A generalized APTMS architecture is shown in Figure 1. The turbomachinery consists of the cooling turbine (CT), starter/generator (S/G), compressor (C), and power turbine (PT), all co-mounted on a rotating shaft. Cold air exits the CT and is sent to the aircraft both for environmental control, and for the cooling of heat loads. After cooling the aircraft loads, the air passes through a regeneration heat exchanger (HX) where some of the aircraft heat is reclaimed in order to drive the CT. The hot air is then compressed in the turbomachinery compressor so that it can better reject heat to the main aircraft heat sink, shown here as either the main engine fan air or aircraft ram air. Once the air has rejected its heat, it returns to the CT, but not after first possibly cooling fuel and then reclaiming some heat as described above. The air is expanded in the CT, which provides shaft power to drive the turbomachine's compressor, and also provides the cool air for the aircraft. The turbomachine shaft can also be driven by either the S/G or the PT, which uses engine bleed air. A burner can be used in the case of engine failure (no pressurized bleed air available) or to supply supplemental power to the APTMS. The hot pressurized air is expanded across the PT, and after its energy has been extracted by the turbomachine shaft, the air is exhausted. Many variations exist on the architecture described here; however the e^2 concepts can be applied generally to any APTMS architecture that is capable of being powered with either bleed air or electric power.

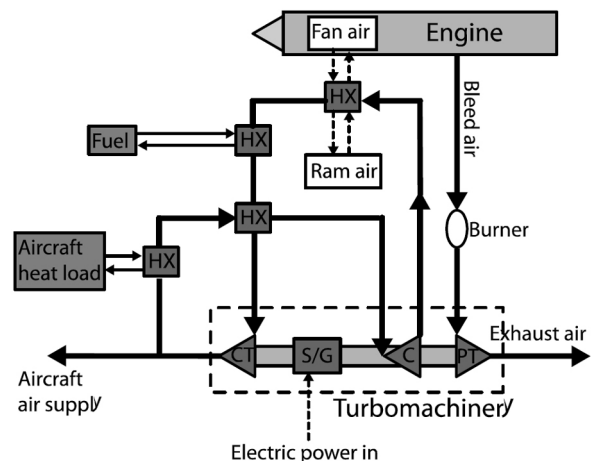


Figure 1. Generic APTMS architecture

A key feature of the e^2 architecture is that it allows the APTMS shaft to be driven electrically, utilizing the existing S/G in motor mode. The electric power for this comes from the main engine generator during periods of low electric load