

Power & Thermal Systems Integration Techniques for High Performance Jet Aircraft

Clarence Lui, Matthew Dooley and Jacquelyn Duchene
Northrop Grumman Corp.

ABSTRACT

The high electrical power demand and heat rejection characteristics of a high energy laser pose new challenges to airframe power and thermal system designers. Typically, the power demand requires additional power storage devices and electrical generator upsizing which will adversely impact the engine performance and installation envelope. The thermal system is complicated by an already limited onboard heat sink, resulting in a bulkier system. Utilizing conventional approaches, the aircraft will suffer from additional weight, less available installation volume, and lower overall performance. This paper presents a potential integrated power and thermal system with attributes to minimize aircraft penalty. The system is a collection of various integration techniques that will be discussed individually for potential standalone application.

CITATION: Lui, C., Dooley, M. and Duchene, J., "Power & Thermal Systems Integration Techniques for High Performance Jet Aircraft," *SAE Int. J. Aerosp.* 5(2):2012, doi:10.4271/2012-01-2164.

INTRODUCTION

The emphasis on electronic warfare in the post cold war era has drastically escalated the power and thermal demand on contemporary military aircraft designs and their subsystems needed to support systems such as active array radars, electronic countermeasure devices, and power electronics. This trend will be further heightened as the military prepares for the operation of high energy lasers onboard aircraft platforms. The principle of the high energy laser systems is based on the conversion of electrical energy into lasing power. The technology in these types of systems is evolving, with the projected efficiencies of the entry level systems (solid state) to be about 10% to 15%. At these efficiencies, the high energy laser (HEL) system will create an unprecedented scale of power demand and will further challenge the modern thermal system design as these inefficiencies turn the energy into heat. Fundamentally, the power can be simply supplied directly from the aircraft power generation system and/or from electrical storage devices such as batteries and capacitors. On the thermal management side, the solid state electronic components in the lasing weapon system necessitate operating in narrow operating bands (ranging from $\pm 1^{\circ}\text{C}$ to $\pm 3^{\circ}\text{C}$). This, in addition to the massive heat sink demand, leads to a new design scenario. One of the design approaches being explored by the industry is to apply a thermal storage concept (such as phase change materials) to contain the narrow operating bands. The thermal

storage devices can also reduce the rates of the heat sink demand and, as a result, significantly minimize the impact on the airframe thermal management system. [Figure 1](#) illustrates concepts related to conventional means of handling the integration of a HEL system onboard. In this conventional approach, the thermal management of the HEL utilizes phase change material heat exchangers which are cooled via a dedicated vapor cycle system or air cycle machine while the power distribution aspect revolves around batteries and an APU which only provides power as needed through bleed air consumption.

CHALLENGES & POTENTIAL SYSTEM CANDIDATE

The implementation of a directed energy system onto an aircraft platform presents considerable challenges in regards to handling the power and thermal demands. The HEL power system must provide fast power recharge to allow for multiple firings, in addition to handling the standard aircraft power loads, all within a package that can be easily installed within the aircraft envelope. As there are multiple options for handling this, the goal is to meet the challenges in the lightest weight, smallest package available in order to minimize the weight penalties to the aircraft and the loss of potential fuel volume. Thermal challenges associated with a directed energy system are largely associated with the need to reject a much larger heat load.



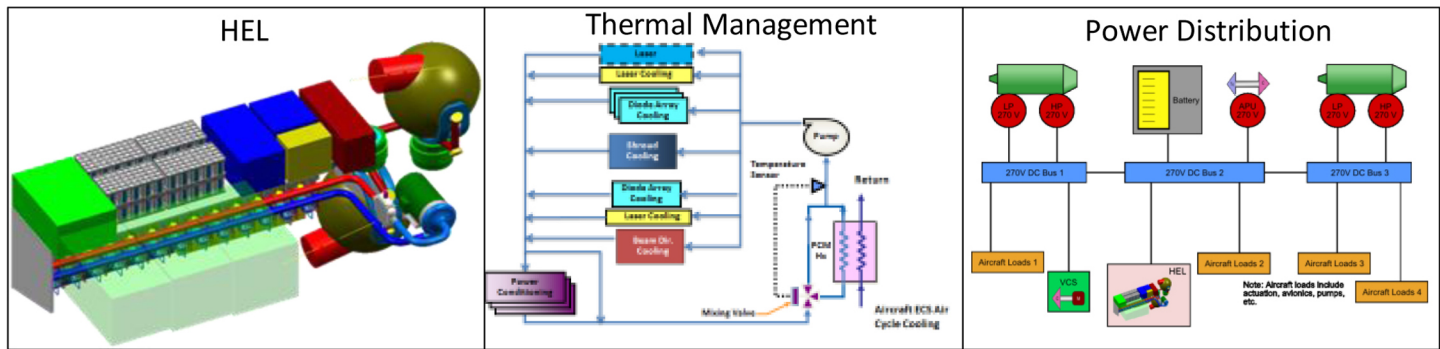


Figure 1. High Power Laser Thermal and Power Management

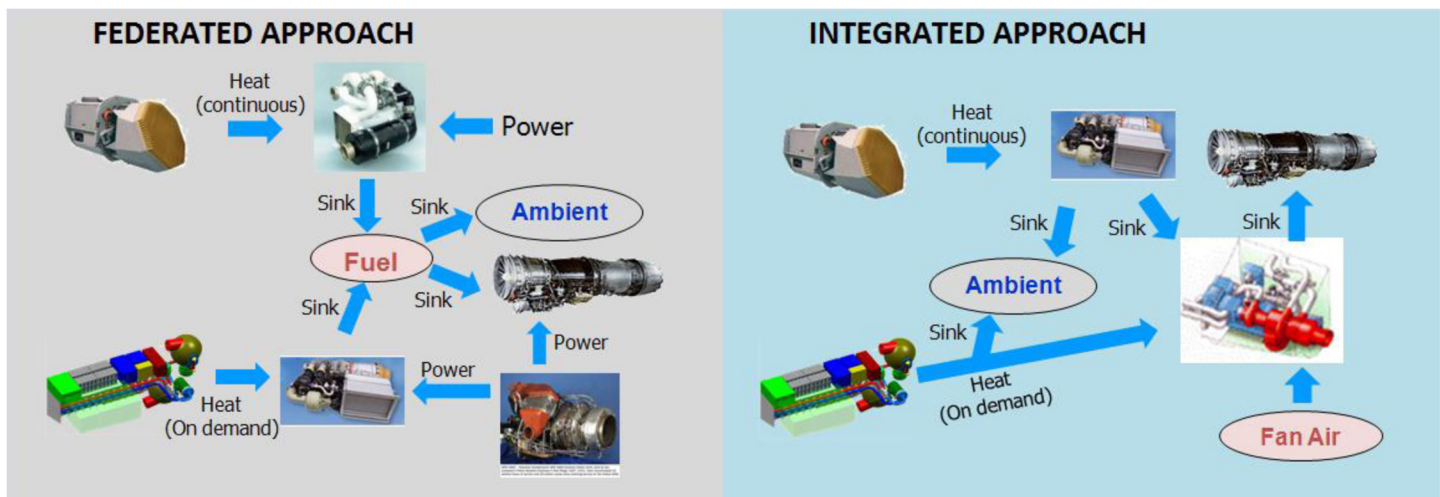


Figure 2. Federated vs Integrated Design

Figure 2 suggests an integrated approach to maximize the utilization of onboard equipment while eliminating that which isn't necessary. As illustrated, the eliminated equipment is replaced by advanced components which can provide support for the HEL system demands in a smaller overall package. Low pressure loss heat exchangers and highly conductive materials constructed integrally with aircraft structure are particularly critical to this concept. The architecture also suggests adapting an energy efficient vapor cycle cooling system to manage the continuous mission system heat load. This will free up the integrated power and cooling unit (IPCU) to provide a heat sink for the HEL system and allow for thermal storage system recharging. The IPCU compressor is adaptable to engine bleed conditions to provide the additional capability to match the HEL system thermal recharging demand. The IPCU is envisioned to operate at extreme subfreezing temperatures, helped by recuperating the HEL system's low temperature return fluid and using it as a heat sink. This allows the IPCU to utilize bleed air from the mid to low stage engine compressor stages. Also, the HEL system is operated on-demand, further minimizing the overall bleed penalty. This approach will

maximize the equipment utilization for lowest weight and lowest cost design. Critical technologies that enable extreme subfreezing operation and efficient vapor cycle cooling system integration are required to implement this candidate system concept. The concept is schematically illustrated in Figure 3.

POWER INTEGRATION

The incorporation of a high energy laser (HEL) onto an aircraft platform poses major challenges in terms of handling the immense power demand without decreasing aircraft performance. Traditional means of handling the increased power demand revolve around upsizing the engine generators. In an attempt to counter this negative impact, the integrated approach looks to move the load off the engines by utilizing a rechargeable power storage option. This option can satisfy the peak demands of the HEL system during periods of lasing, and then be recharged to handle multiple engagements. Sizing criteria for the power storage system largely depends on the duty cycle of the HEL system. Power storage system sizing to support a kilowatt HEL, based on existing battery technologies, is estimated to weigh

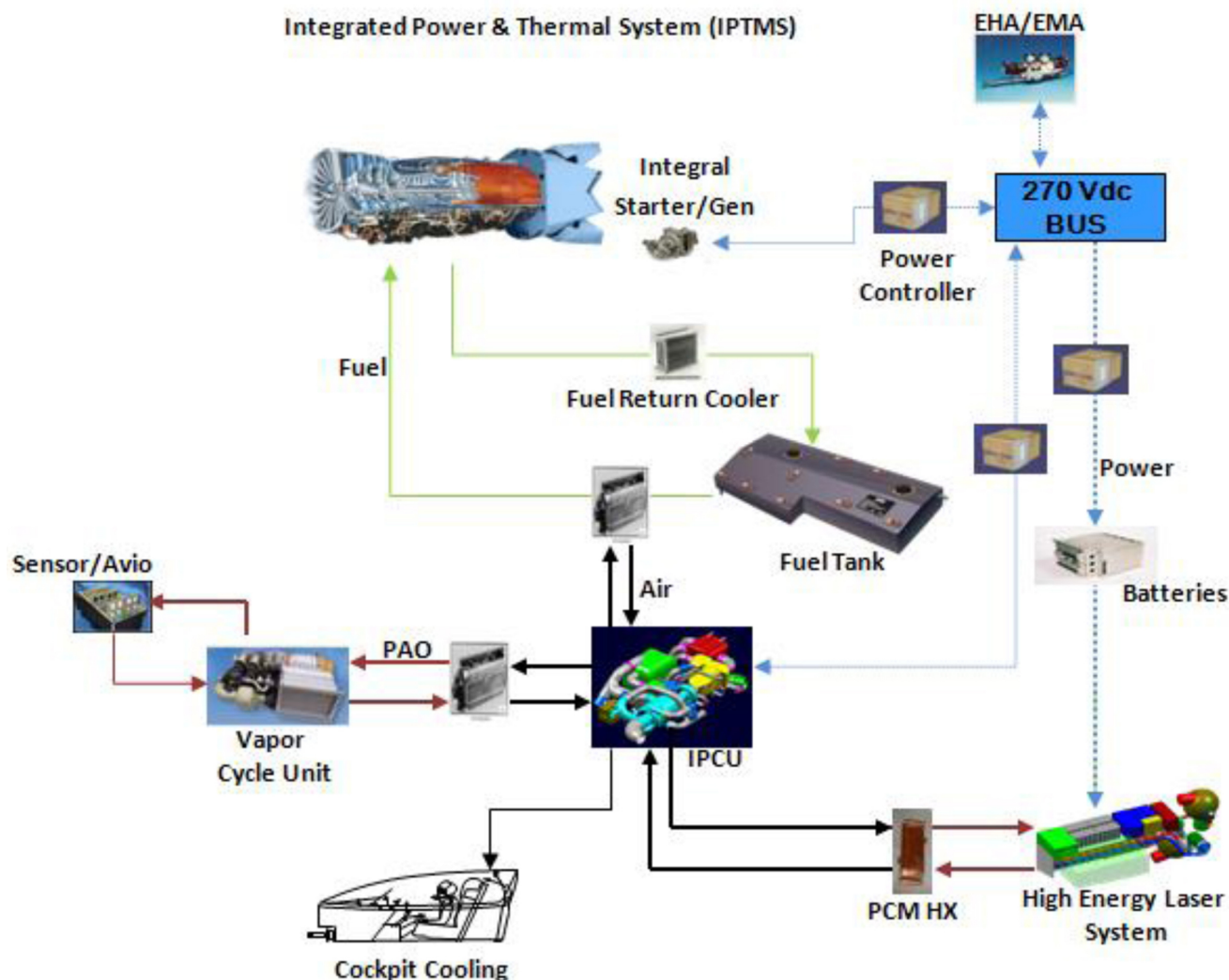


Figure 3. Candidate Integrated Propulsion & Power/Thermal System

approximately 1000 lbs in an envelope of 15 cubic feet. While these impacts are certainly not insignificant in terms of weight gain and fuel volume loss, the impact to the overall aircraft's performance is much less than when handled by upsizing of the engine generators. With advances in power storage technologies such as ultra-capacitors and/or compact flywheel systems, these impacts can be potentially reduced even further. The power recharge aspect of the power storage system is envisioned to be accomplished via power extraction from the engine generators.

THERMAL INTEGRATION

Thermally Integrated Structure (THIS)

The favorable weight and strength characteristics makes honeycomb structures using composite materials a popular choice for the airframe designers. Unlike aluminum, the composite honeycomb structures have low conductivity behavior that lead to a significant loss of thermal heat

rejection capability. The THIS concept attempts to recover some of the thermal losses. The critical steps are a) to improve the conductivity of the composite honeycomb structures; b) the increase the thermal convection rates from the fluid to the structure and c) integrating the fluid cooling channels into outer moldline structure to reduce aerodynamic drag.

Figure 4 depicts some of the potential designs and materials to recover the thermal conductivity. As shown, from a material standpoint, diamond has the potential to significantly exceed aluminum's thermal conductivity. Although it has been applied in some special designs in space applications, it is unlikely from a cost and practicality standpoints for aircraft applications. The relative ease of implementation of Thermal Conductive Composites makes them a good starting candidate for technology development, versus the carbon-carbon composites which have a higher conductivity but present manufacturing challenges.