

Energy Optimized Aircraft: What is it and how do we make one?

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ABSTRACT

Efforts are underway to develop technologies to create a more Energy Optimized Aircraft (EOA). The question becomes how should one define an Energy Optimized Aircraft and how should energy optimization be measured to determine what is optimal? This paper provides a top level point of view for the goal of an Energy Optimized Aircraft. It outlines how one should approach the design of such an aircraft, the relevant vehicle systems technologies to enable energy optimization for fighter aircraft, and potential aircraft level measurands for determining degrees of goodness associated with incorporating different technologies. The top-to-bottom approach is provided for traceability of technologies being developed to aircraft and mission level goals.

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INTRODUCTION

The Air Force is proud to be a leader in America's ongoing quest to use energy more efficiently through better procedures and new technologies while, at the same time, decreasing energy consumption and the nation's dependence on imported oil. Energy management is an evolving process that will require the systematic incorporation of new information, rigorous insertion of technological advancements, and continuous improvement of processes and practices. The Air Force Energy Plan, Reference 1, is built upon three pillars (reduce demand, increase supply, and culture change) that guide energy management within the Air Force. One of the key pillars of the Air Force Energy Plan is to reduce demand and is the basis for this paper. Precious supplies and transportation of military jet fuel to the area of responsibility are of concern. In addition, the demand of jet fuel will increase as more stealth fighter/attack aircraft are built and fielded. This increase in demand is based on stealth aircraft designs that rely upon (1) internally integrate weapons to increase survivability, (2) full mission fuel carried internally, and (3) advanced integrated avionics suites to conduct missions. The internal weapons bays, aircraft survivable aero designs, and maximized fuel load increase the cross sectional area of the aircraft thereby increasing the drag of the aircraft. This increased drag increases the fuel required

to meet the same mission radius as earlier generation aircraft. It also requires increased engine thrust to obtain the same maximum speed that require higher relative fuel burn at cruise conditions due to the bigger engine required for maximum speed. Today and in the future we will see more tenuous supplies and increased demand on military jet fuel. Thus it is beneficial to create and if possible retrofit energy optimization technologies and techniques for managing energy on an aircraft to reduce demand. Energy management is not only important to stealth fighter/attack aircraft, but should be considered for other types of aircraft as they are being designed. The questions become how should we look at energy and what do we mean by an energy optimized aircraft. This paper is intended to open the dialog and offer a point of view as to what an EOA is and how should the benefits of technology insertion be measured.

The Air Force Energy Plan highlights the need for reduced fuel demand, increased supply, and changing the culture. Subsequent documents, such as the Air Force Acquisition and Technology Energy Plan (Reference 2) and published papers (References 2, 3, 4, 5, 6) offering component and systems technologies that supposedly make an aircraft energy optimized do not show a traceable measurable way to quantify whether the aircraft is energy optimized. There may be a case that the aircraft is more

energy efficient than use of legacy component or system technologies, but how does one quantify whether an aircraft is energy optimized or not. This paper attempts to bridge the gap and offer quantifiable ways of defining and measuring whether and aircraft is energy optimized.

To start the dialog, a definition of an Energy Optimized Aircraft (EOA) is proposed and all subsequent discussion will use this definition as the goal of desirability that everything can trace back to. With this goal in mind, a fresh look at energy, power, and aircraft capability will be presented at a very top level. Follow on sections will suggest possible measurands for quantifying energy optimization and waste energy, followed by the identification of critical technologies required for making an EOA and near-term demonstrations required to start the transition of science and technology to make fighter/attack aircraft energy optimized.

Definition: An EOA is an aircraft that purposefully minimize fuels (energy) usage while performing the missions it was designed for.

The discussion that follows is meant to provide traceability of technology development and demonstration to top level warfighter goals. Component, system, and air vehicle architecture technologies should be able to trace their contribution to the end item goals. However, the proven benefits of integrated systems has made traceability of individual component technologies to end item goals a non-linear relationship. The following discussion will attempt to provide intermediate level metrics (measurands) that component, system, and architectures can be quantified against to provide a relevant measurand of goodness to assist in overcoming the non-linear relationships of integrated systems.

ENERGY, POWER, AND AIRCRAFT

The term “energy” is used by many different disciplines in aircraft design. The terms energy and power are sometimes used synonymously, however there is a major difference. Energy is a potential state, whereas power is the rate at which energy is transferred, used, or transformed. It is important to recognize all the forms of energy on an aircraft are based on one source, [Figure 1](#). That source is the chemical energy stored in jet fuel. The first law of thermodynamics states that energy can neither be created nor destroyed, it just changes form. Chemical energy of jet fuel is burned in the engine combustor as part of a Brayton power cycle that produces heat (thermal energy potential). The Brayton cycle uses a compressor and turbine to compress ambient air, heat it, and then expand it through a turbine resulting in a hot air/combustion by-product mixture used for thrust to push the aircraft through the air. Thrust produced from high-temperature, high-speed air is the primary purpose of the engine, but the engine provides a source of secondary energy and power for other aircraft functions besides thrust. One source is the turbine compressor coupling shaft that is an

energy source that if used produces useful power and some energy waste (heat) due to friction in the drive train and bearings. Gears attached to the turbine and compressor shaft are connected to gear boxes that drive other aircraft systems such as: generators, fuel pumps, hydraulic pumps, and lube oil pumps. Each of these systems provides useful energy/power to other aircraft components, with inefficiencies manifesting itself in heat. The other energy power source is compressed high temperature air (thermal energy potential), which is also available at various stages in the compressor. The pressurized thermal energy is used to drive other air vehicle system turbines (such as an environmental control system cooling turbine) or as a source of pressurized air for other systems such as: Environmental Control System (ECS), On-Board Oxygen Generating System (OBOGS), On-Board Inert Gas Generating System (OBIGGS), and a variety of other minor systems that require a pressurized air source to enable their function. In most cases

Chemical Energy Transitioned into

- Kinetic Energy (Thrust)
- Potential Energy (spinning gears/shaft, compressed high temperature air)

equipment requiring pressurize air cannot use the compressor discharge air at the temperature and pressure exiting the engine and must be cooled to some level to be of use and/or regulating the pressure of the air to an acceptable level. The cooling of the compressor discharge air wastes the thermal energy from compression and the pressure regulation also waste energy/power. Some efforts have been made to select compressor/fan discharge air at various stages in the compression cycle to better match the pressure and temperature requirements and minimize waste. Thus, there are two major forms of wasted energy, those consisting of various forms of friction (mechanical, windage losses in rotating equipment, pump case leakage, magnetic/eddy current/resistive losses in electrical machines) and cooling of pressurized air.

As we can see in [Figure 1](#), chemical energy (fuel) is changed into a variety of other energy sources that have multiple layers. As the chemical energy changes form it provides a direct energy usage by something else, or it produces waste heat. So when we discuss an energy optimized aircraft we should be focusing on (1) how to transition chemical energy into other forms that are the most useful, [Figure 2](#), and (2) reduce the waste heat produced while making the transition, [Figures 3](#) and [4](#). Efforts in the past usually focus on reducing waste heat, which is the efficiency of a system. This two pronged approach not only focuses on the usual efficiency of energy usage, but it also opens the question of effectiveness-are you using the right form of energy and the right heat sink.

This discussion will be limited to fighter/attack aircraft, but the approach can be used for air mobility, surveillance, Uninhabited Combat Air Vehicles (UCAVs), Unmanned Air Vehicles (UAVs), Tankers, long endurance sensor aircraft,

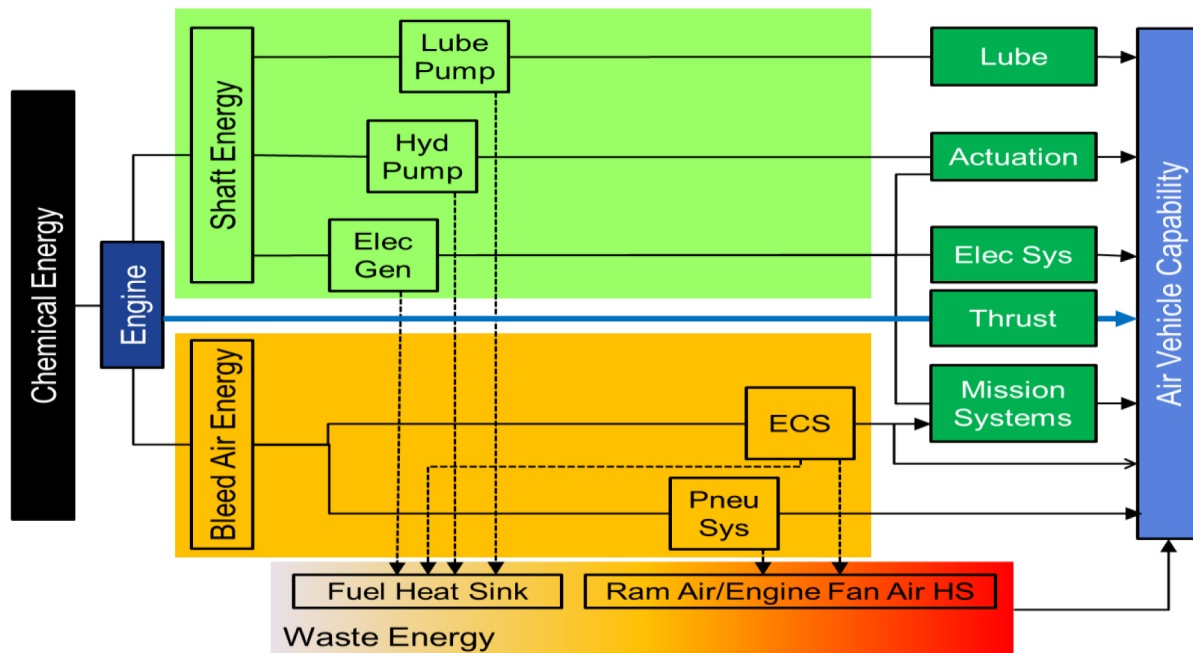


Figure 1. Aircraft capability is traceable to chemical energy of jet fuel

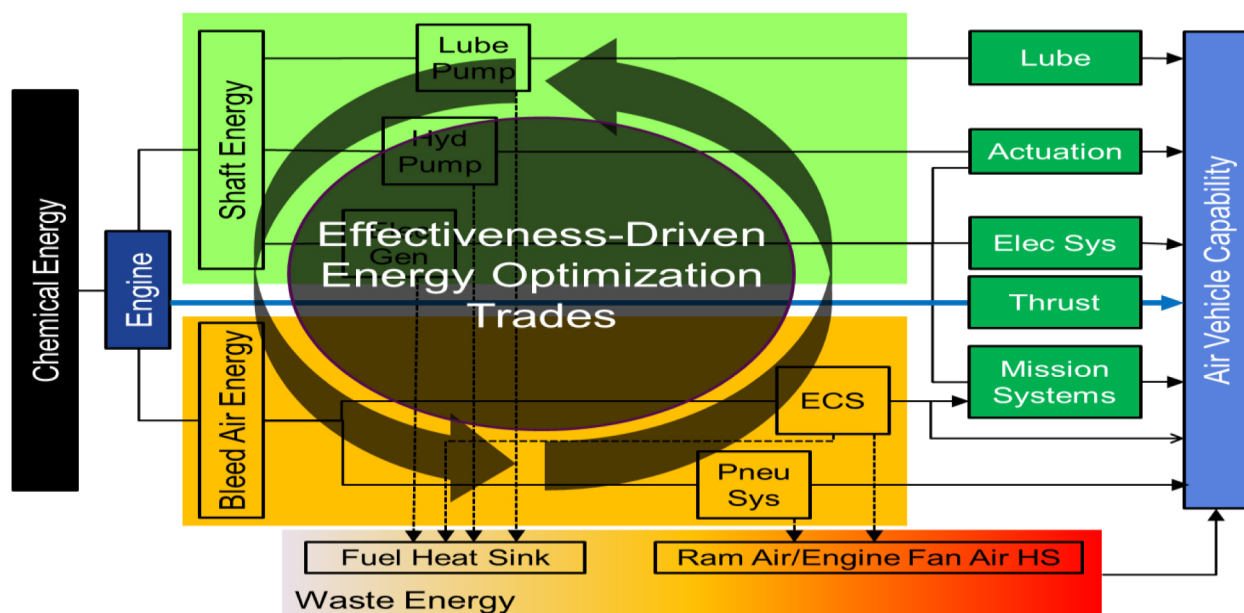


Figure 2. EOA Energy Effectiveness can be obtained by proper selection of energy source to provide warfighter capability

and hypersonic aircraft. The use of energy by these aircraft to meet mission needs is different than fighter/attack aircraft. As such, the conversion of chemical energy into other forms of energy will have different magnitudes and ratios than fighter/attack aircraft. So it is important to recognize that the technology solutions for an EOA fighter/attack aircraft may be different than that of other aircraft types. However, for any type of aircraft the following is true.

An EOA

- Effectively changes chemical energy (fuel) into other useful forms of energy to meet mission needs
- Efficiently uses energy to reduce waste