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Achieving the Air Force's Energy Vision

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Achieving the Air Force's Energy Vision

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The US Air Force is the largest consumer of energy in the federal government, spending $9 billion in 2008 to fuel aircraft and ground vehicles as well as provide energy to installations.[1] In that same year, the Air Force's fuel bill of $7 billion amounted to more than half of the US government's total fuel cost.[2] Because of the critical and central role that energy plays in completion of the Air Force's mission, the secretary of the Air Force has developed an Air Force energy plan supported by three pillars—"Reduce Demand," "Increase Supply," and "Culture Change"—and guided by the energy vision "Make Energy a Consideration in All We Do" (fig. 1). In response to the Air Force's energy program and vision, Air Force Institute of Technology (AFIT) researchers are helping realize the first two pillars by developing a new academic specialization in alternative energy, designing hybrid-electric remotely piloted aircraft (RPA), testing synthetic fuels, creating a new course of study concentrating on managing fuels distribution, and conducting research on the storage, management, and distribution of fuel. The third pillar, "Culture Change," lies outside the scope of this article. Given the success of the academic programs and promising research results, the Air Force should continue to expand energy-related curricula and research at AFIT. Increased support would allow establishment of an energy-focused research center at AFIT that could help the Air Force tackle its energy-related challenges.

Figure 1. Three pillars of the Air Force energy plan. (Reprinted from *Air Force Energy Plan 2010* [Washington, DC: Assistant Secretary of the Air Force for Installations, Environment, and Logistics, 2010], 7, http://www.safie.hq.af.mil/shared/media/document/AFD-091208-027.pdf.)

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Academic Specialization in Alternative Energy

Researchers are investigating possibilities for alternative energy (e.g., hybrid-electric systems, fuel cells, biofuels, and solar power) in the United States to reduce our dependency on foreign oil. Most of this research has examined automotive transportation and ground-based facilities, but this article discusses the rising interest of and momentum from the military and industry in applying clean, renewable energy to air and space applications. The strategic plan of the American Institute of Aeronautics and Astronautics for 2009–13, which emphasizes energy as well as air and space, lists "Improve Aerospace Energy Efficiency and Advance New Energy Technologies" as a strategic imperative. According to this imperative, "AIAA must provide a collaborative, information-sharing environment to ensure that the best technical professionals and most creative innovators are focused on fuel efficiency challenges facing the aerospace industry and on emerging opportunities to contribute to future sources of clean, affordable energy."[3] The Air Force, defense contractors, and industry need researchers and engineers who have technical expertise in the fields of aerospace engineering and alternative energy. Many universities offer excellent programs in these disciplines, but very few emphasize merging the two. AFIT is bridging the gap in academia by enhancing its curriculum with energy-related courses, hiring faculty members with experience in both fields, and expanding its laboratory facilities.

In response to the Air Force's pressing need for engineers with educational backgrounds in alternative energy and aerospace engineering, AFIT has developed an academic specialization in alternative energy systems within its aeronautical engineering and astronautical engineering master's degrees. This specialization, an extension of the two current master's degrees, requires courses in energy, optimization, and air and space design. The specialization seeks to provide a coherent course of study for aerospace engineering students interested in pursuing research topics in alternative energy and advanced propulsion systems for micro air vehicles (MAV); small RPAs; and high-altitude, long-endurance aircraft. Two students completed the sequence in 2010, and six more are expected to do so in 2011.

Two other universities, Wright State University and the University of Dayton via the highly successful Dayton Area Graduate Studies Institute program, are contributing to academic specialization in alternative energy. The state of Ohio approved both universities' proposals to offer master's degrees in clean and renewable energy, and both have developed courses that AFIT students may take to fulfill requirements for this specialization. The collaboration allows them to receive instruction at local civilian schools and leverage research already begun at the other universities.

As part of the specialization, AFIT has developed an independent-study course to educate students on methods of analyzing the performance of small RPA propulsion system components such as electric motors, advanced batteries, internal combustion engines (ICE), and fuel cells. As interest in the new academic specialization increases, the institute plans to develop a laboratory course on the fundamentals of fuel cell technology, motors, advanced batteries, and ultracapacitors.

AFIT is playing a critical role in meeting Air Force and industry demand for more engineers trained in alternative energy and aerospace engineering. These new engineers will help the Air Force implement the energy plan's call for reducing demand by increasing the efficiency of propulsion systems and augmenting the supply of energy via alternate fuels. Its strategic location near the Air Force Research Laboratory (AFRL) at Wright-Patterson AFB and numerous air and space contractors allows students to obtain practical work experience without relocating. The fact that this new program offers students a "hybrid" degree in energy and aerospace disciplines makes it unique.

Hybrid-Electric Remotely Piloted Aircraft

Industry members and university researchers are exploring new propulsion means such as hybrid-electric systems for air and space applications. Some hybrid-electric designs use an ICE and electric drive system whereas others are based on fuel cells. At the 2009 Experimental Aircraft Association's AirVenture Oshkosh, German aircraft designer and builder Flight Design displayed a parallel hybrid-electric propulsion system with an ICE and electric motor (fig. 2) for a general aviation aircraft. A battery-powered 30 kilowatt (kW) electric motor provides boost power to a downsized 86 kW Rotax 914 engine for takeoff and climbing.[4] The power-assist parallel hybrid configuration allows the pilot to stretch a glide with electric power in the event of engine failure. For large RPAs, AeroVironment is hybridizing a hydrogen-burning piston engine with an electric drive system on its high-altitude, long-endurance Global Observer aircraft.[5] Previously, three researchers at the University of California–Davis developed a conceptual design of a small hybrid-electric RPA that laid the foundation for a prototype of such an aircraft currently in development at AFIT.[6]

Figure 2. Flight Design's hybrid-electric propulsion system. (Reprinted by permission from Jason Paur, "Hybrid Power Comes to Aviation," *Wired.com*, 28 July 2009, http://www.wired.com/autopia/2009/07/hybrid-aviation.)

Former AFIT student Ryan Hiserote compared three distinct parallel hybrid-electric conceptual designs for a small RPA, each with three battery-discharging profiles, for a total of nine configurations.[7] His analysis determined that a configuration using an ICE, an electric motor, and a clutch to disengage the engine during electric-only quiet operation was the most suitable for a typical five-hour intelligence, surveillance, and reconnaissance (ISR) mission. The engine is shut off during the ISR mission segment to reduce the aircraft's acoustic signature. Military and civilian students at AFIT in the Aeronautics and Astronautics Department, under the direction of Assistant Professor Fred Harmon, are designing a prototype of the hybrid-electric RPA based on the two-point conceptual design, which includes an ICE sized for cruise speed as well as an electric motor and a battery pack sized for a slower endurance speed (i.e., loiter). The parallel hybrid-electric design gives the vehicle longer time on station and greater range than electric-powered vehicles, together with smaller acoustic and thermal signatures than gasoline-powered vehicles. The resulting design takes the form of a 13.6 kilogram RPA that uses 40 percent less fuel than a conventional ICE-powered aircraft and that includes enhanced capability supplied by a "quiet" mode during ISR operations, utilizing only the electric system. These efforts illustrate the growing interest in applying hybrid-electric technology to air and space systems and the benefits that those systems can offer war fighters.

In addition to hybrid-electric systems with hydrocarbon-powered engines, numerous companies and universities are researching fuel-cell-based systems for aviation applications. Boeing recently flew a manned aircraft (two-seat Dimona motor-glider with a 16.3-meter wingspan) powered by a proton-exchange-membrane fuel cell/lithium-ion-battery hybrid propulsion system.[8] The company's researchers believe this type of fuel cell technology could power small manned and remotely piloted vehicles. For large commercial aircraft, designers could apply solid-oxide fuel cells to secondary power-generating systems, such as auxiliary power units. The Georgia Institute of Technology has designed, built, and flown a fuel-cell-powered RPA.[9] The Navy recently flew a small RPA, the Ion Tiger, powered by a 500-watt fuel cell.[10] The AFRL has flown a fuel-cell-based system on a Puma RPA. Under a small-business-innovation research contract with the AFRL, modification of the original battery-only-powered Puma with a fuel cell hybrid system expanded its mission capabilities by tripling flight endurance time from three to nine hours.[11] In July 2009, the experimental Antares DLR-H2 became the world's first manned vehicle to take off under fuel cell power.[12] Not long ago, AFIT initiated an effort to develop a conceptual design tool to better understand the advantages and tradeoffs of using fuel cells in MAVs.[13] The tool integrates precise analyses of aerodynamics, propulsion, power management, and power sources to determine the endurance capability of a given mission for an MAV.

These hybrid-electric system efforts, whether based on ICEs or fuel cells, clearly reflect the interest in applying alternative-energy concepts to aircraft applications. The previously mentioned designs will prove useful, depending on mission requirements as well as size and type of aircraft. For example, as described earlier, AFIT researchers are testing a prototype of a hybrid-electric system for a small RPA to demonstrate its usefulness during a typical ISR mission. Furthermore, a current AFIT student's work on a conceptual design of a hybrid-electric system for a trainer aircraft will determine how much fuel and energy it can save during a typical training mission. The Air Force should support the expansion of AFIT's research on fuel-cell-based systems to ascertain the improvement in range and endurance for small RPAs and MAVs. For larger aircraft, such systems may be useful for auxiliary power units. Hybrid-electric systems will contribute to the first pillar of the energy plan by helping lessen the demand for energy.

Testing Synthetic Fuel

AFIT is contributing to the second pillar—increasing the supply of energy—by conducting research into alternate fuels. Aviation fuel is a substantial expense for both the Air Force and commercial airlines. In 2006 fuel became the largest element of operating costs for US airline carriers for the first time in history.[14] As the most prolific consumer of aviation fuel in the federal government, the Air Force uses approximately 2.5 billion gallons per year.[15] The service can reduce fuel costs by using alternate fuels (e.g., Fischer-Tropsch [FT] fuels), designing more efficient engines or new propulsion systems, or designing more aerodynamic configurations and lighter structures.[16]

Commercial industry and the government have both established organizations to research and certify the use of alternate fuels. A coalition known as the Commercial Aviation Alternative Fuels Initiative strives to enhance energy security and environmental sustainability for aviation by engaging the emerging alternative jet fuels industry to use those fuels in commercial aviation.[17] Bill Harrison, technical adviser for fuels and energy for the Propulsion Directorate at the AFRL, also stresses the need to increase the supply of domestic fuels by researching, testing, and certifying new alternative/domestic fuels.[18] Alternative fuels could replace many traditional ones such as JP-5, JP-7, and JP-8. For example, in August 2007 the B-52 aircraft was certified for a 50/50 blend of a synthetic fuel and JP-8.[19] The Air Force also stood up the Alternative Fuels Certification Office in 2007 with a charter from the secretary of the Air Force to manage certification of all Air Force platforms (over 40 types), support equipment, and base infrastructure on a 50/50 blend of FT fuel and JP-8.[20] Nearly the entire Air Force fleet has been certified to fly on a synthetic fuel blend.

AFIT actively researches the replacement of traditional jet fuels with alternatives. Jet fuels fall into the broad class of hydrocarbon materials referred to as kerosene fuels.[21] Compared to traditional jet fuels produced from petroleum (e.g., JP-8), FT fuels are synthetically derived from other sources such as coal, natural gas, or biomass—the product of a catalyzed chemical process that initially converts feed fuels into carbon monoxide and hydrogen and then combines those chemicals into longer-chain hydrocarbon molecules. Theoretically, the energy content of these fuels is sufficient to replace traditional ones, but we need more research on their use in devices originally designed for traditional jet fuels.[22] AFIT is researching the use of FT fuels in an ultracompact combustor in the Combustion Optimization and Analysis Laser laboratory, which has several diagnostic techniques available (e.g., measuring the amount of unburned hydrocarbon and nitrogen oxides) to analyze the performance of these new fuels. Initial results show promise and demonstrate that FT fuels can substitute for traditional jet fuels.

Academic Course of Study in Petroleum Management and Research into Fuels Distribution

Recently, AFIT developed a specialized fuels-management track in its master of science program in logistics and supply chain management. In the fall of 2010, five Air Force fuels officers began this new course of study, which encompasses inventory models, demand forecasting, supply-chain resiliency, alternative fuels, environmental issues, and the transportation, distribution, and storage of petroleum. Graduates of this program will be assigned to the Air Force Petroleum Agency, the Defense Logistics Agency, and other petroleum-management positions on major command staffs.

Students, both domestic and international, from AFIT's Department of Operational Sciences have conducted numerous in-depth, cutting-edge studies on fuels. For example, Maj David Mazzara did a cost-benefit analysis of air refueling of RPA systems.[23] Maj James Nicholson investigated the cost-effectiveness of replacing petroleum-based diesel-like fuels with biodiesel fuels in Air Mobility Command, determining the price needed to offset the cost of producing biodiesel if the price of traditional fuel increases.[24] Lt Col Juan Salaverry developed a model for forecasting jet fuel prices in his home country of Argentina.[25] Maj Murat Toydas developed two nonlinear optimization models that examined the trade-off between departure fuel weight and loaded cargo for a given origin, destination, and tanker base location.[26] And Lt Evren Kiymaz conducted a study that measured airlift fuel efficiency.[27] All of these studies illustrate methods either to decrease fuel demand or to increase its supply.

In one very successful study, Maj Phil Morrison, a recent graduate of AFIT's Advanced Study of Air Mobility program, completed research on reballasting the KC-135.[28] He hypothesized that shifting ballast fuel out of the forward-body fuel tank and compensating by adding weight (such as armor) elsewhere on the plane would yield two significant benefits: (1) tankers could off-load more fuel to receiver aircraft, and (2) the Air Force would reap significant savings through improved fuel economy of its KC-135 tanker fleet. Major Morrison's research indicated that, if implemented, his proposal would pay for itself in less than two years and mitigate an additional $14 million in fuel cost each year thereafter. The Air Force recently committed funds to make the ballasting change in the KC-135.

Conclusion and Recommendations

The Air Force is striving to lower its energy expenditures and raise energy security by reducing demand, increasing supply, and changing its culture. AFIT researchers are contributing to the first two pillars of the energy plan by developing new curricula that concentrate on alternative energy and fuels, designing hybrid-electric propulsion systems, testing synthetic fuels to replace traditional fuels, and advancing research in the area of fuel distribution and management. AFIT military and civilian graduates who have backgrounds in aerospace engineering, alternative energy, and fuel management will assume technical leadership positions and possess the knowledge to leverage technologies and tools for critical air and space applications to help the Air Force carry out its energy plan.

The Air Force needs to fully support AFIT in this endeavor. AFIT should expand its curricula to incorporate more courses on energy and fuels as well as construct laboratories to test hybrid-electric systems, fuel cells, and synthetic fuels. Conceptual design tools need improvement in order to analyze options for future Air Force aircraft such as hybrid-electric trainers and RPAs. AFIT also needs to conduct further research on fuel-cell-based systems to determine the enhancement in range and endurance for small RPAs and MAVs. For larger aircraft, AFIT should conduct more research into how fuel-cell-based systems may prove useful for auxiliary power units. Additionally, if the institute received appropriate support, it could establish an energy-focused interdisciplinary research center. Clearly, AFIT has a vital role to play in helping the Air Force achieve its energy vision. ✪

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Notes

1. *Air Force Energy Plan 2010* (Washington, DC: Assistant Secretary of the Air Force for Installations, Environment, and Logistics, 2010), 4, accessed 14 January 2011, http://www.safie.hq.af.mil/shared/media/document/AFD-091208-027.pdf.

2. Mark J. Lewis, "Military Aviation Goes Green," *Aerospace America* 47, no. 8 (September 2009): 25, accessed 14 January 2011, http://www.aerospaceamerica.org/Documents/Aerospace%20America%20PDFs%20(2009)/Aerospace%20America_SEP2009.pdf.

3. American Institute of Aeronautics and Astronautics (AIAA), "2009–2013 Strategic Plan: Sections I and II" (Reston, VA: AIAA, 2009), 1, accessed 15 November 2010, http://www.aiaa.org/pdf/industry/Strat_Plan_ShortVersion_March09.pdf.

4. Jason Paur, "Hybrid Power Comes to Aviation," *Wired.com*, 28 July 2009, http://www.wired.com/autopia/2009/07/hybrid-aviation.

5. "Stratospheric Persistent UAS: Global Observer," AeroVironment, http://www.avinc.com/uas/stratospheric/global_observer.

6. Frederick G. Harmon, Andrew A. Frank, and Jean-Jacques Chattot, "Conceptual Design and Simulation of a Small Hybrid-Electric Unmanned Aerial Vehicle," *Journal of Aircraft* 43, no. 5 (September–October 2006): 1490–98, accessed 14 January 2011, http://www.dodsbir.net/sitis/view_pdf.asp?id=REF%203%20AF103_209.pdf; Frederick G. Harmon, Andrew A. Frank, and Jean-Jacques Chattot, "Parallel Hybrid-Electric Propulsion System for an Unmanned Aerial Vehicle" (presentation, Association for Unmanned Vehicle Systems International Unmanned Systems North America 2004 Symposium, Anaheim, CA, 3–5 August 2004); Frederick G. Harmon, Andrew A. Frank, and Sanjay S. Joshi, "Application of a CMAC Neural Network to the Control of a Parallel Hybrid-Electric Propulsion System for a Small Unmanned Aerial Vehicle" (presentation, Institute of Electrical and Electronics Engineers International Joint Conference on Neural Networks, Montreal, Canada, 31 July–4 August 2005); and Frederick G. Harmon, Andrew A. Frank, and Sanjay S. Joshi, "The Control of a Parallel Hybrid-Electric Propul-

sion System for a Small Unmanned Aerial Vehicle Using a CMAC Neural Network" *Neural Networks* 18 (2005): 772–80.

7. Ryan M. Hiserote and Frederick G. Harmon, "Analysis of Hybrid-Electric Propulsion System Designs for Small Unmanned Aircraft Systems" (presentation AIAA-2010-6687, 8th Annual International Energy Conversion Engineering Conference, Nashville, TN, 25–28 July 2010).

8. "Boeing Successfully Flies Fuel Cell-Powered Airplane," Boeing, 3 April 2008, http://www.boeing.com/news/releases/2008/q2/080403a_nr.html.

9. Thomas H. Bradley et al., "Flight Test Results for a Fuel Cell Unmanned Aerial Vehicle" (presentation AIAA-2007-32, 45th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, 8–11 January 2007); and Blake A. Moffitt et al., "Design and Performance Validation of a Fuel Cell Unmanned Aerial Vehicle" (presentation AIAA-2006-823, 44th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, 9–12 January 2006).

10. "Surveillance Vehicles Take Flight Using Alternative Energy," Public Affairs, Office of Naval Research, 2009, accessed 14 January 2011, http://www.onr.navy.mil/Media-Center/Press-Releases/2009/Surveillance-Vehicles-Alternative-Energy.aspx.

11. "UAS Advanced Development: Fuel Cell Puma," AeroVironment, http://www.avinc.com/uas/adc/fuel_cell_puma.

12. Pat Toensmier, "The Cutting Edge: Fuel Cell Powers Manned Flight," *Defense Technology International*, September 2009, 60.

13. Paul M. Hrad and Frederick G. Harmon, "Conceptual Design Tool for Micro Air Vehicles with Hybrid Power Systems" (presentation AIAA-2010-6688, 8th Annual International Energy Conversion Engineering Conference, Nashville, TN, 25–28 July 2010).

14. Frank Sietzen, "Growing Fuels for Greener Skies," *Aerospace America*, September 2009, 32.

15. *Air Force Energy Plan 2010*, 4.

16. Lewis, "Military Aviation Goes Green," 24.

17. "Commercial Aviation Alternative Fuels Initiative" (CAAFI brochure), caafi.org, 17 August 2010, http://www.caafi.org/about/pdf/CAAFI_brochure_August_2010.pdf.

18. William E. Harrison, "Alternative Energy for Aerospace Applications" (presentation, 4th Annual Dayton Engineering Sciences Symposium, Dayton, OH, 27 October 2009).

19. Lewis, "Military Aviation Goes Green," 24.

20. Beatriz Rodriquez and Thomas M. Bartsch, "The United States Air Force's Process for Alternative Fuels Certification" (presentation AIAA-2008-6412, 26th AIAA Applied Aerodynamics Conference, Honolulu, HI, 18–21 August 2008).

21. Tim Edwards, "Kerosene Fuels for Aerospace Propulsion-Composition and Properties" (presentation AIAA-2002-3874, 38th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Indianapolis, IN, 7–10 July 2002).

22. M. A. Mawid, "Development of a Detailed Chemical Kinetic Mechanism for JP-8 and Fisher-Tropsch-Derived Synthetic Jet Fuels" (presentation AIAA-2007-5668, 43rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Sacramento, CA, 8–11 July 2007); and Tim Edwards et al., "Fuel Composition Influence on Deposition in Endothermic Fuels" (presentation AIAA-2006-7973, 14th AIAA/AHI Space Plane and Hypersonic Systems and Technologies Conference, Canberra, Australia, 6–9 November 2006).

23. Maj David J. Mazzara, "Autonomous Air Refueling for Unmanned Aircraft Systems: A Cost/Benefit Analysis," graduate research paper AFIT/IMO/ENS/09-08 (Wright-Patterson AFB, OH: Air Force Institute of Technology, 2009).

24. Maj James B. Nicholson, "Bio-Diesel for Air Mobility Command Assets: The Way Ahead," graduate research paper AFIT/IMO/ENS/09-10 (Wright-Patterson AFB, OH: Air Force Institute of Technology, 2009).

25. Lt Col Juan A. Salaverry, "Predicting Argentine Jet Fuel Prices," AFIT/GLM/ENC/07M-01 (thesis, Air Force Institute of Technology, Wright-Patterson AFB, OH, 2007).

26. Maj Murat Toydas, "Fuel Savings Opportunities from Air Refueling," AFIT/LSCM/ENS/10-12 (thesis, Air Force Institute of Technology, Wright-Patterson AFB, OH, 2010).

27. Lt Evren Kiymaz, "Fuel Efficiency Assessment with DEA," AFIT/LSCM/ENS/10-07 (thesis, Air Force Institute of Technology, Wright-Patterson AFB, OH, 2010).

28. Maj Phil G. Morrison, "Reballasting the KC-135 Fleet for Fuel Efficiency," graduate research paper AFIT/IMO/ENS/10-10 (Wright-Patterson AFB, OH: Air Force Institute of Technology, 2010).