Aircraft Electric Propulsion…The Future

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ABSTRACT

Electric Propulsion brings high flexibility in moving power around the flight vehicle. It is becoming a key enabler to integrate propulsion into the aircraft and permits to reduce the energy consumption for specific missions. It permits the incorporation of distributed propulsion as well as Boundary Layer Ingestion to improve the efficiency. The presentation summarizes the recommendation of the National Academy of Engineering (2016) to achieve a significant reduction in fuel burn for large commercial aircraft with a Turbo Electric Architecture.

The NAE report outlines the challenges and opportunities. NASA funded a 5 year program which includes 5 other Universities led by The Ohio State University to address these challenges. Optimization of systems are described as well as high energy storage, high power density electronics and high power electrical motors. The thermal management of these high power systems are discussed. The testing of the developed products will take place at NASA's NEAT facility at Plum Brook in Sandusky, Ohio.

Application of this pioneering work to military UAV and PAV's are discussed as well as the go forward plans into industry and the government for the years ahead. Multiple opportunities available from small unmanned aircraft to long endurance systems. Significant potential benefits in fuel burn, range, acoustic signatures and emissions valuable to the war fighter. A considerable amount of work is needed to make this happen and in house research is outlined in many fields. In summary a challenging and high perspective future.

1.0 INTRODUCTION

Electric Propulsion offers a new power source for aviation in both the commercial and military fields. This paper describes the activities of the U.S. National Academy of Engineering and its recommendations for future research, the challenges and opportunities for electric propulsion. It discusses the NASA University Led Initiative (ULI) to address these challenges as well as the program given to The Ohio State University (OSU) and its team. The preliminary results of this work show great possibilities for commercial aircraft.

In parallel, the plans for the U.S. Air Force are outlined. The possibilities and goals for different weapon systems are discussed. The technology portfolios for the U.S. Air Force Research Laboratories are impressive and the potential for future Hybrid Electric Propulsion Power Systems are far-reaching and are getting explored.

2.0 MAIN SECTION

2.1 NATIONAL ACADEMY STUDY

The U.S. National Academy set up a committee to examine several means to reduce carbon emissions and fuel burn from aircraft. The conclusion of this 2 year study was that a deduction of 20% in CO2 could be achieved with electric propulsion but the challenges need to be addressed, namely:

- System Integration
- Ultra High Power Density Electric Machines
- Energy Storage
- Advanced Controls
- Research Facilities

These challenges are being addressed.

2.2 NASA UNIVERSITY LED INITIATIVE (ULI)

NASA asked The Ohio State University to lead a team of 5 Universities to address these challenges.

The Team:

- The Ohio State University
  - Center for Automotive Research (CAR) – Batteries
  - Center for High Power Performance Electronics (CHPPE) – Power Electronics
- University of Wisconsin-Madison
  - Electric Machines
- University of Maryland, College Park
  - Thermal Management
- North Carolina A&T State University
  - Thermal Management
- Georgia Institute of Technology
  - System Integration
- Case Western Reserve
  - Batteries
- NASA
  - NEAT Test Facility

The team above has been set in place. Power electronics research and batteries are led by the Center of High Performance Electronics and the Center of Automotive Research at The Ohio State University. University of Wisconsin is focused on electric machines. University of Maryland and University of North Carolina A&T State University are investigating and researching thermal management. Advanced battery work is being done at Case Western Reserve University. The system integration work is being carried out by Georgia Tech in cooperation with the Center for Automotive Research (CAR).

A 1 MW motor drive with a power density of 25 kW/kg is being developed – See **figure 2-1** (Power Electronics). It is being designed to operate a 2000 dc voltage at low pressure. Particular attention is being focused on system stability on the airplane. In parallel, a 1 MW motor is being developed with a power density of 14 kW/kg by the University of Wisconsin – See **figure 2-2** (Electric Motor).

Figure 2-1 (Power Electronics)

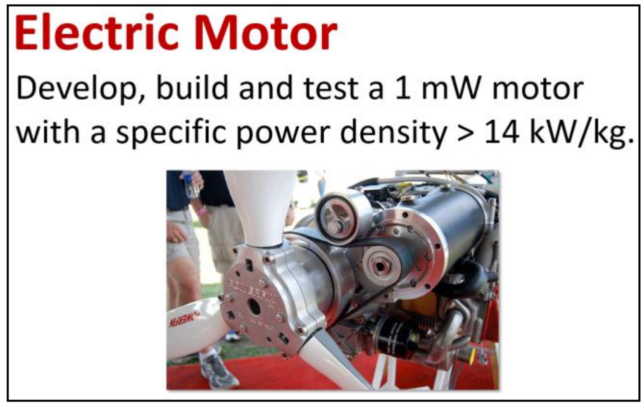

Figure 2-2 (Electric Motor)

While Turbo Electric Propulsion was the system architecture chosen for the study by the National Academy, the team research identified a distinct advantage offered by a Hybrid Electric System - See **figure 2-3** (System Architecture).

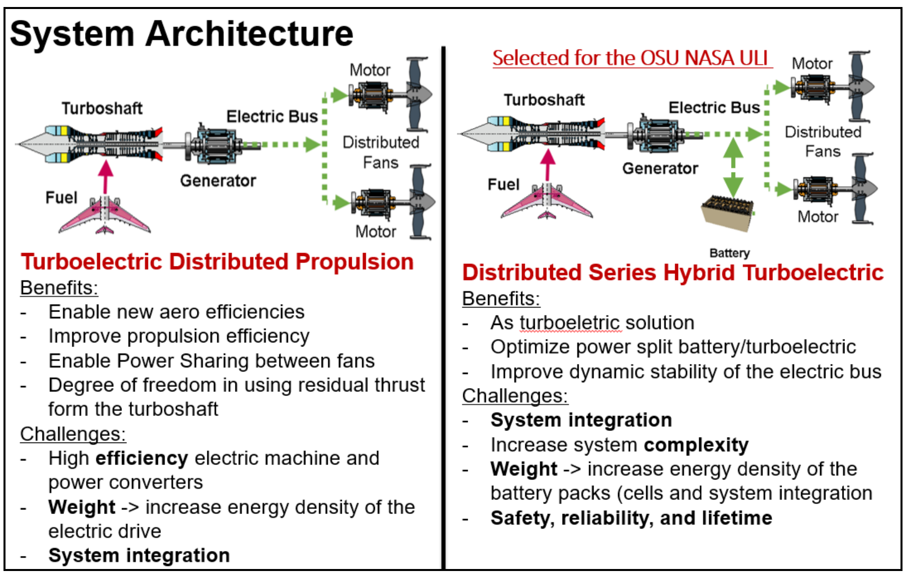

Figure 2-3 (System Architecture)

The team's analysis indicates that the following technology benefits can be obtain in a regional aircraft by the incorporation of a hybrid electric system – see **figure 2-4** (Power Consumption Profile).

- Distributed Propulsion 9%
- Hybrid Propulsion (incorporation of batteries) 6%
- Boundary Layer Ingestion/Optimized Power Management 5%

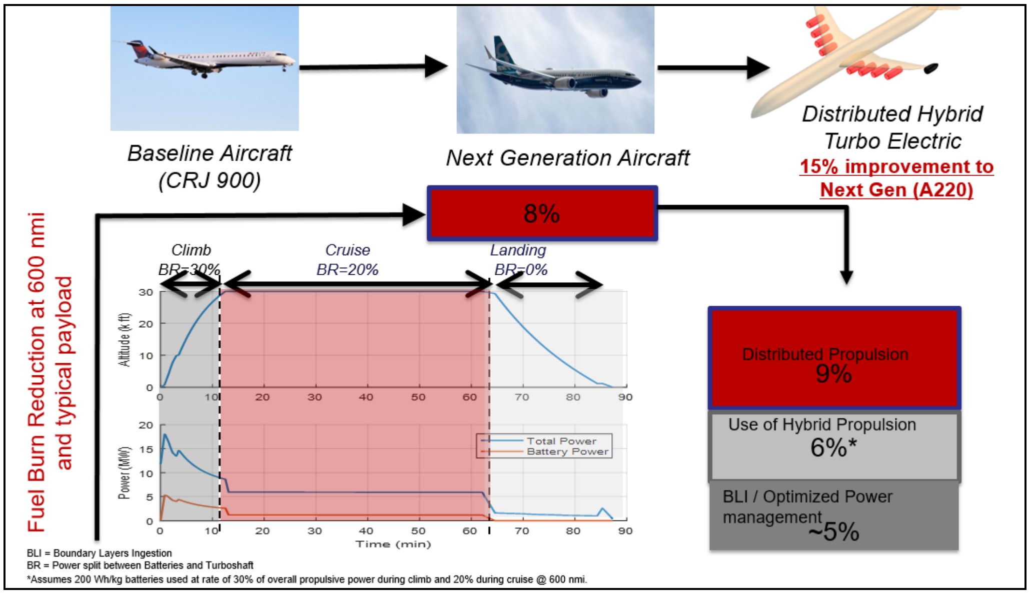

Figure 2-4 (Power Consumption Profile)

The distributed propulsion architecture shown in **figure 2-5** (Energy and Propulsion Configurations) offers a benefit of 20% in fuel burn and CO2 to the system. This requires a significant focus in thermal management as shown in **figure 2-6** (Thermal Management). As high megawatt systems are being introduced in both the commercial and military fields, the thermal management is key to the cooling needed for successful operation of these vehicles.

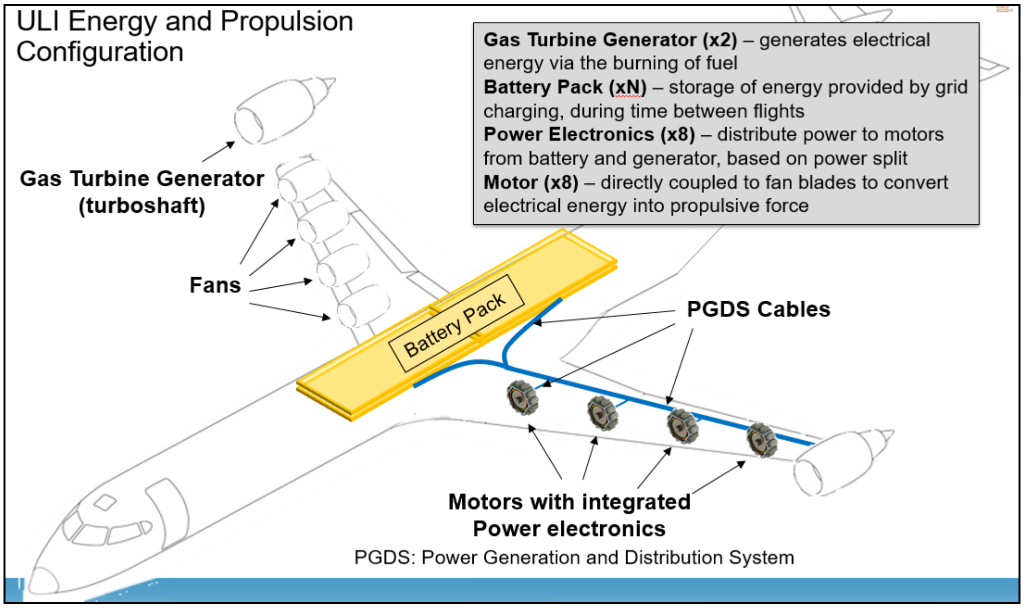

Figure 2-5 (Energy and Propulsion Configurations)

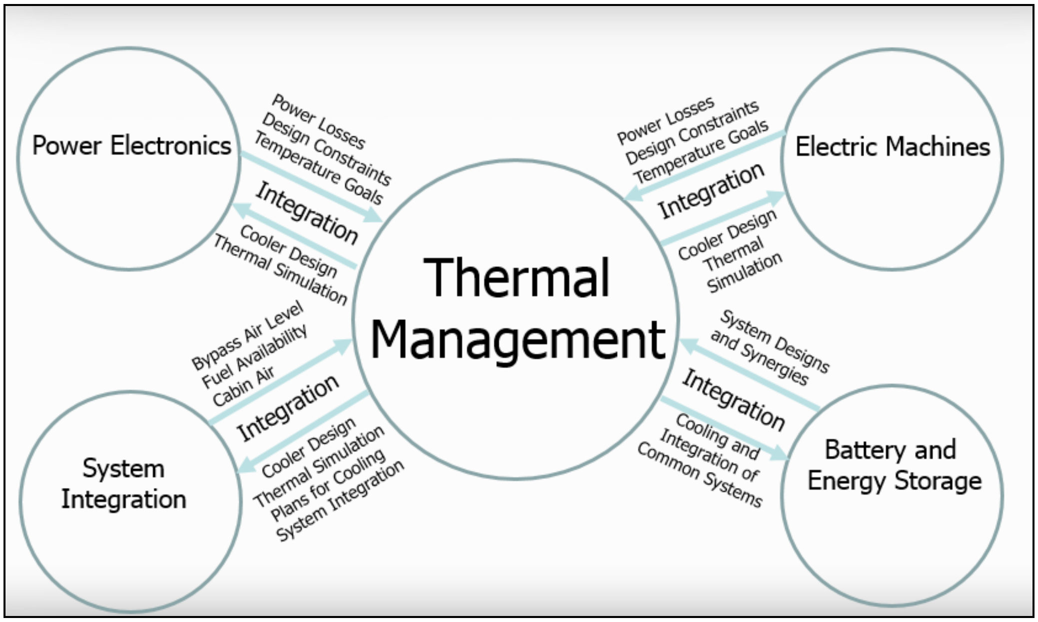

Figure 2-6 (Thermal Management)

An absolute requirement to the successful development of hybrid electric vehicles is the availability of a high MW facility with altitude capability. The NASA NEAT facility created by the NASA Glenn Research Center – see **figure 2-7** (NEAT NASA Electric Aircraft Test Bed) is a key element of the ULI research effort. The plan is to test a 1 MW machine at different altitudes over complete operational maps.

Figure 2-7 (NEAT NASA Electric Aircraft Test Bed)

In summary, further optimization of aircraft energy management system will be needed to optimize fuel consumption, vehicle weight, and capital cost. In addition, continual storage, electric motors and thermal management. As of today it looks like commercial hybrid electric aircraft is becoming a reality and will have a profound effect on the military hybrid electric propulsion development.

2.3 U.S. SMALL UNMANNED POWER AND CONTROL

The U.S. Air Force's vision is to deliver an affordable and integrated small unmanned aircraft system (SUAS) with the following attributes:

- Exponential Force Multiplier
    - Cross domain integration across mission sets
- Easily Integrated Asset
    - Deployable by a variety of means, providing flexibility, reach, penetration, and integration with joint forces
- Cost Savings Enabler
    - Employing low cost SUAS with increased functionality improves combat effectiveness and efficiency

The approach is to:

- Leverage unique expertise in hybrid power and flight control technologies to address current and future UAS requirements
- Explore hybrid propulsion system architectures and control strategies
- Foster critical industry / Govt partnerships to develop, demonstrate and transition technologies into next generation UASs
- Perform integration of UAS ground/flight testing to validate technology predictions
- Coordination of R&D Across DoD / Govt Agencies, and International Partners

The challenge resides with the breadth of the requirements – see **figure 2-8** (SUAS Power/Propulsion: Key Challenges)**,** which shows that we are looking at group 1 with a weight of 0-20 lbs to groups going to 1,320 ton. These five different groups go from handheld UAV's to Global Hawk and Reaper with transcontinental missions. For all of them the leadership is looking for propulsion systems offering increased play loads, quiet operation and increased system reliability.

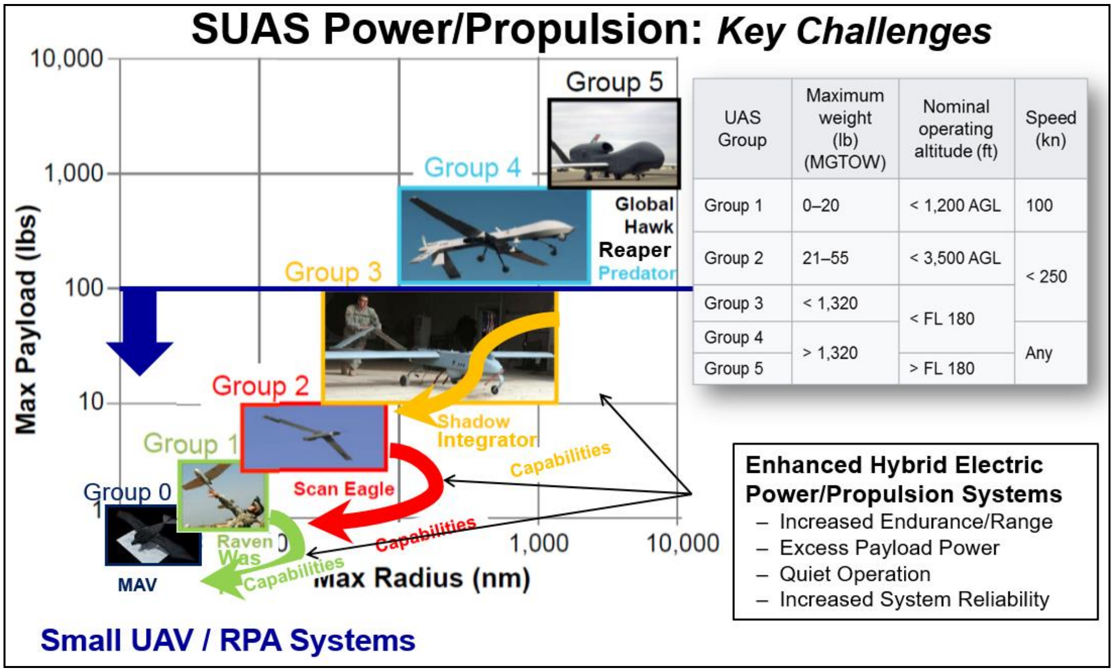

Figure 2-8 (SUAS Power/Propulsion: Key Challenges)

The goals for these Hybrid Electric Propulsion Systems are outlined in **figure 2-9** (SUAS Power/Propulsion Goals) below.

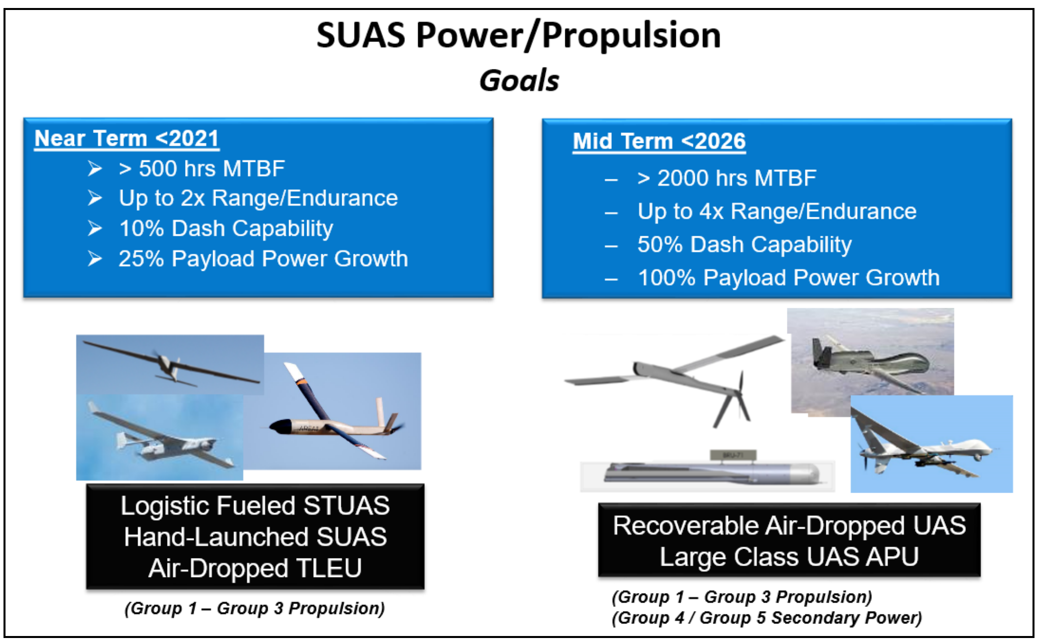

Figure 2-9 (SUAS Power/Propulsion Goals)

To accomplish these goals the U.S. Air Force put together some significant power and control technology portfolios – see **figure 2-10** (Power Technology Portfolios) below.

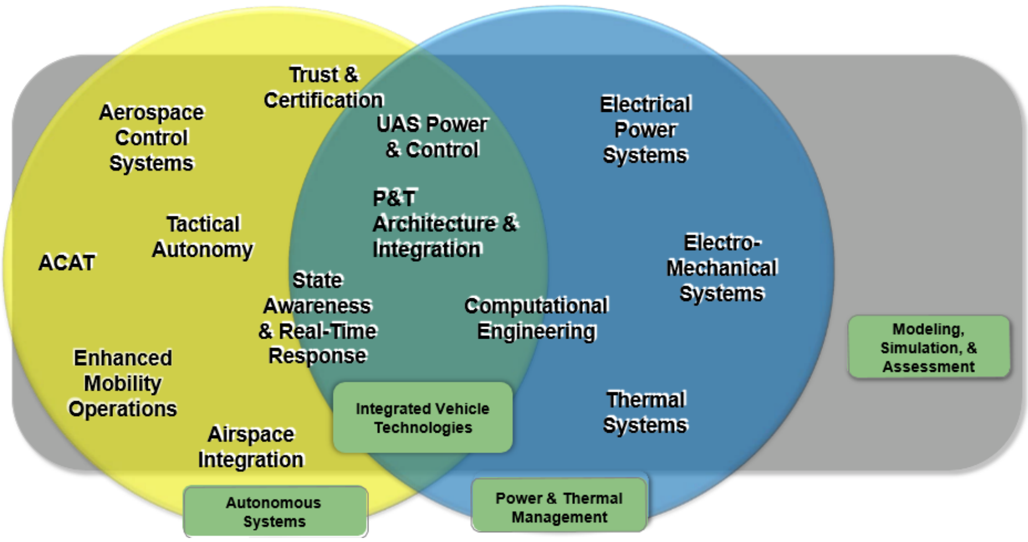

Figure 2-10 (Power Technology Portfolios)

They cover a variety of disciplines from computational engineering, electric power systems to power and thermal management to mobile simulation and assessment. Very ambitious program. Some of the technology portfolios are shown in **figure 2-11** (Program Focus Area and Technology Goals) aimed on extending range and endurance and mission flexibility.

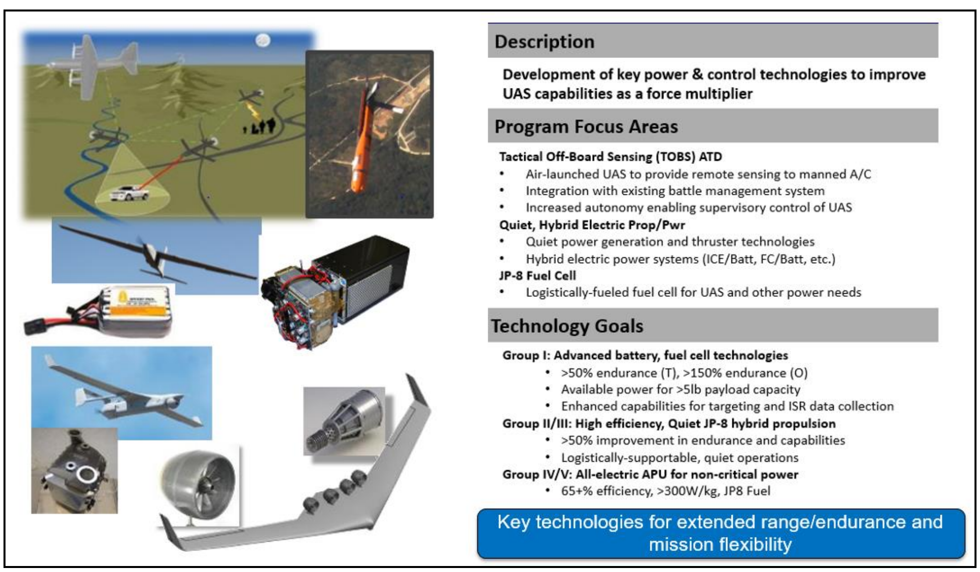

Figure 2-11 (Program Focus Area and Technology Goals)

The in-house power and thermal management and in-house R&D programs summarized in **figure 2-12** (Power Technology Program). The electric chemical development and characterization are outlined in **figure 2-13** (In-House R&D Program Product Areas).

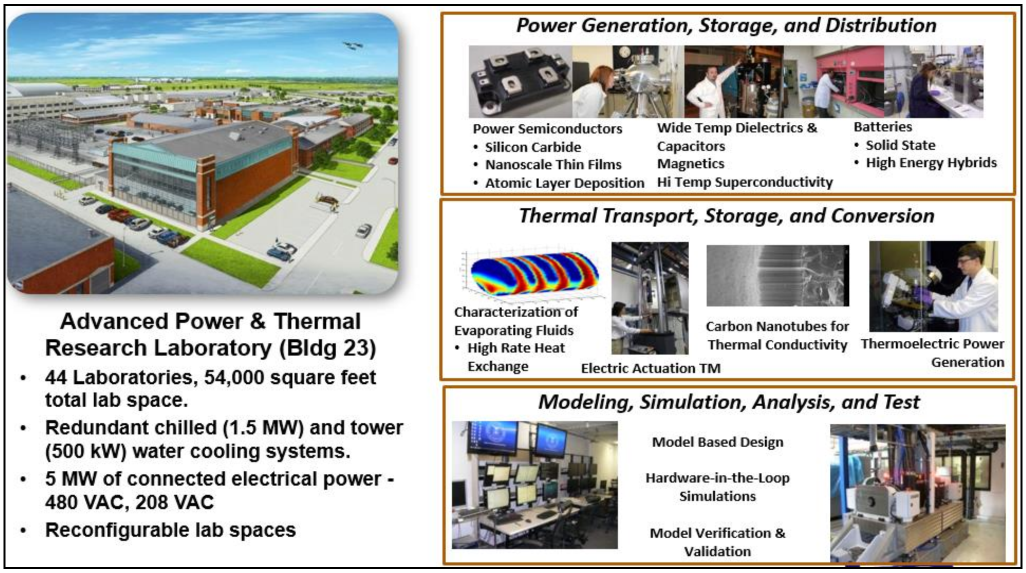

Figure 2-12 (Power Technology Program)

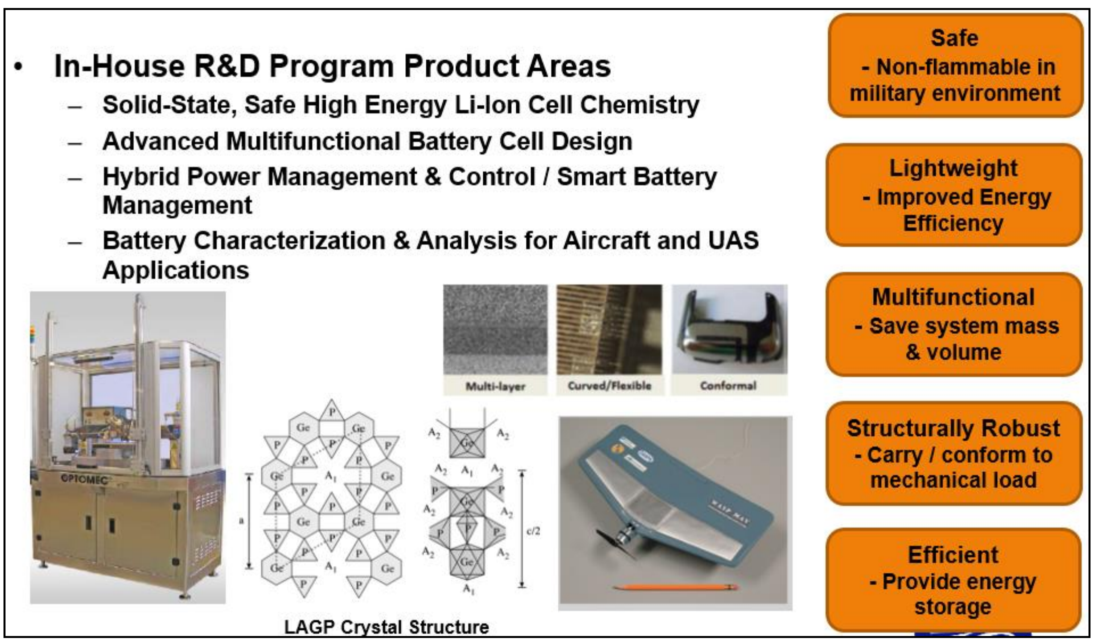

Figure 2-13 (In-House R&D Program Product Areas)

This shows the width and breadth of the research effort needed to move the United States Air Force Hybrid Electric forward. Numerous opportunities for collaboration exist across all product areas.

- Group 1 SUAS Long Endurance, Off-Board Sensing
  - Development of advanced long endurance SUAS technology providing remote sensing for off-board OPS
  - Addressing UAS requirements for stand-off and under weather off-board sensing
- Logistics Fuelled (JP-8) Quiet Hybrid-Electric Drive
  - Development of next gen hybrid electric power & propulsion solutions for extended endurance/range, reduced acoustic signatures, and modular/scalable to different SUASs
  - Addressing UAS needs and requirements for long endurance, quiet operations
- Extended Reach Cooperative ISR and Targeting
  - Design/develop long endurance Group 3 recoverable air-launched SUAS with integrated flight controls enabling supervisory management of UAS and cooperative control of unmanned teams
  - Addressing UAS needs and requirements for extending operational reach and signature reduction
- High Efficiency, Fuel Flexible (JP-8, Jet-A, Diesel) Electric APU
  - Develop and demonstrate a high efficiency all-electric on-board aircraft APU for high-altitude, long-range unmanned aerial system (UAS) operations
  - Addressing needs and requirements for more on-board power to support adv. payloads and other subsystems

This is a very ambitious program. It relies on the development of multiple technologies. The challenges will be; 1) successful technical realization of these different technologies in a timely fashion 2) the financial support of the different phases of these individual projects in a sustained fashion. Technical as well as financial problems will occur and work around plans will have to be developed. It is recommended that contingency measures be taken both technical and financial to ensure the viability of the program. A program management review needs to be put in place with quarterly WebEx reviews as well as a face to face reviews on an annual basis to keep the program on track and take remedial actions as needed.

3.0 CONCLUSION

In conclusion we can see that hybrid electric propulsion brings multiple opportunities in the military field. One can look at hand held systems to large vehicles powered electronically in the future. Enormous benefits are on the horizon; extended range, improved endurance, reduced acoustic signature. Considerable lower pollutants and pollution, etc. It is obvious that considerable work remains to be done. The U.S. Air Force is addressing the technology needs vigorously. One can look at strong cooperation between academia, government and industry to take this forward. It’s an exciting world.

4.0 REFERENCES

[1] Thole, K. et al. (2016), Commercial Aircraft Propulsion and Energy Systems Research, Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions, The National Academies Press, Washington, DC: doi:10.17226/23490, available at https://www.nae.edu/154518/Commercial-Aircraft-Propulsion-and-Energy-Systems-Research- (assessed 22 July 2019)

[2] Harrop, P. (2016), Hybrid and electric systems R&D at the U.S.-DOE IDTechEx Research Article, No Copyright, available at https://www.idtechex.com/en/research-article/hybrid-and-electric-systems-r-d-at-the-u-s-doe/9676 (assessed on 22 July 2019)

[3] Felder, J. (2015), NASA Electric Propulsion System Studies, No Copyright, available at https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160009274.pdf (assessed 22 July 2019)

[4] Rippl, M. (2011), Sizing Analysis for Aircraft Utilizing Hybrid-Electric Propulsion Systems, Thesis presented at Wright-Patterson Air Force Base, March 2011, available at https://apps.dtic.mil/dtic/tr/fulltext/u2/a540143.pdf (assessed on 22 July 2019)

[5] Rottmayer, M. (2017) USA Hybrid Electric Power and Power Propulsion, available at http://www.ndia.org/-/media/sites/ndia/divisions/manufacturing/documents/afrl-uashybridpower.ashx?la=en (assessed 22 July 2019)