High Altitude Long Endurance Aircraft Configurations

Aaron F. Botwick[1]
Department of Mechanical and Aerospace Engineering, University of Virginia, Charlottesville, VA 22902

High altitude long endurance unmanned aerial vehicles or HALE UAVs are emerging as solutions to difficult aircraft operation challenges such as atmospheric research and large-area intelligence, surveillance and reconnaissance (ISR). HALE aircraft typically operate at an altitude of at least 60,000 feet for durations of twenty-four hours or more. These altitudes and endurances are the upper-extremes for horizontal winged flight. Such operation requires high-performance solutions in numerous areas such as configuration, propulsion efficiency, and weight and drag reduction. Creative solutions must be developed in these areas in order to overcome the difficulties associated with HALE aircraft operation. Previous HALE aircraft designs will be considered in order to determine the types of solutions that have been effective for high altitude long endurance flight in the past.

I. Introduction

The examples considered in this paper include aircraft that are currently in use as well as some that have been used as demonstrations or prototypes, and a few that are in the conceptual stage. Below are the notable examples of HALE unmanned aircraft along with the maximum endurance, service ceiling, payload and a brief description of the propulsion system used. Some of the following platforms have performance data that is impressive in one area, but lacks capability in other areas that are required for the design competition. Such platforms are still of interest because the subsystems that enable high performance in one area can potentially be integrated into another platform. Other platforms do not have exceedingly high performance in any one area, but showed potential by achieving high performance without the use of next-generation engines or at a small aircraft size. These platforms can potentially be scaled up or upgraded in order to achieve the goals of the design competition.

II. Existing HALE UAV platforms

A. Table of Selected Aircraft Performance Data

Platform	Endurance	Service Ceiling (feet)	Method of propulsion	Maximum Payload
QinetiQ Zephyr	336 hours	70,000+	2 brushless DC electric motors	5 lbs
NASA Helios	100+ hours	96,000	14 brushless DC electric motors	626 lbs
NASA Altus	24 hours	65,000	Rotax TC 4-cylinder engine	330 lbs
Boeing Phantom Eye	100+ hours	65,000	Liquid hydrogen engine	450 lbs
Boeing Condor	58 hours	67,000	2 LC, FI 6-cylinder engines	N/A
Aurora Flight Sciences Theseus	30 hours	70,000+	2 TC piston engines	700 lbs
General Atomics RQ-4 Global Hawk	33 hours	60,000	Single turbofan engine	3000 lbs
Scaled Composites Raptor	48 + hours	65,000	Two-stage "highly modified" Rotax	150 lbs

B. Description of Selected Aircraft

1. QinteQ Zephyr

The QinetiQ Zephyr is a relatively small solar-electric powered UAV. It is powered by two brushless DC electric motors. During the day the solar panels power the electric motors and charge secondary lithium-sulfur batteries. At night the batteries supply the power to the motors. It can only operate at partial power with the batteries, so the aircraft can lose up to 20,000 feet in altitude each night. The Zephyr holds the endurance record for unmanned flight at 336 hours 22 minutes, which is almost exactly two weeks. This is the only example of a UAV reaching the goal endurance of the design project.

Figure 1 QinetiQ Zephyr

2. NASA Helios

The NASA Helios is a massive flying wing aircraft powered by 14 brushless DC electric motors. It has a wingspan of 247 feet and an aspect ratio of 31. The aircraft is constructed from lightweight materials such as carbon fiber, graphite epoxy, Styrofoam and Kevlar. The trailing edge elevators are the only control surfaces, so differential power supply is used to control pitch and yaw. Because the engines towards the edges of the wings are higher during flight due to the crescent shape of the aircraft during flight, supplying more power to those engines will decrease the pitch angle. Supplying more power to the engines on one side or the other of the aircraft will control the yaw. The Helios proved to be a fragile design, and ended up breaking apart violently and crashing into the ocean during a flight. It encountered turbulence and subsequently encountered catastrophic problems when the aircraft began to warp and change configuration. The purpose of the aircraft was to demonstrate the potential use of atmospheric satellites, or high altitude long endurance aircraft used as semi-permanent communications-relay stations.

Figure 2 NASA Helios

3. NASA Altus

The NASA Altus is a small UAV that has been successfully used for atmospheric research. It was designed as a test-bed for conceptual propulsion and performance systems. These systems included engines, lightweight structures, scientific payloads and flight operations techniques (altus ss). The power plant is a four-cylinder Rotax engine with a two-stage turbocharger. It has achieved endurances of over 24 hours and altitudes of 65,000 feet. It is designed as a somewhat modular system capable of integrating newer systems to achieve higher performance.

Figure 3 NASA Altus I

4. Boeing Phantom Eye

The Boeing Phantom Eye is perhaps the best existing platform when considering both payload and endurance. This design features two 2.3 liter turbocharged liquid hydrogen internal combustion engines mounted on either side of the fuselage along the 150-foot wingspan of the aircraft. Boeing is considering designs for an even larger HALE UAV similar to the Phantom Eye that could potentially carry a payload of over 2000 pounds and stay aloft for over a week. Those are the threshold values for the NASA design competition, so it is clear that the Phantom Eye design has a lot of potential.

Figure 4 Boeing Phantom Eye

5. Boeing Condor

The Boeing Condor is a very interesting HALE UAV example because it was completing test flights in 1988. The Condor operated at altitudes of 67,000 feet and stayed aloft for 58 hours. The project never found a customer though. It was considered too vulnerable for military operations and too expensive for any civil or research applications. Therefore, the project did not progress any further. The engineers claim that the aircraft wasn't able to reach its full potential and could have reached 73,000 feet and endurances of over a week.

Figure 5 Boeing Condor

6. Aurora Flight Sciences Theseus

The Aurora Flight Sciences Theseus is apparently a very capable aircraft, but performance information is largely unavailable. The company claims that the aircraft reached altitudes over 70,000 feet. Aurora Flight Sciences got experience from working on human-powered flight projects, which are relevant due to the high L/D ratios and lightweight frames required for such projects. They also produce a model called the Perseus, which set an altitude record of 62,000 feet for a single engine propeller-driven aircraft. The Perseus uses a closed loop triple turbocharged Rotax engine that burns gasoline; cryogenically stored oxygen and re-circulated engine exhaust gas

Figure 6 Aurora Flight Sciences Theseus

7. Scaled Composites Raptor

The Scaled Composites Raptor was built as a demonstrator vehicle. A single highly modified Rotax engine powers the Raptor. The aircraft reached 65,000 feet and was successfully tested at an equivalent of 70,000 feet with altitude chambers. The Raptor is now flown by NASA as a test bed for applicable technologies for high altitude UAVs and atmospheric research.

Figure 7 Scaled Composites Raptor

8. General Atomics Global Hawk

The General Atomics Global Hawk is of significant relevance as the current aircraft being used in the role of NASA's atmospheric research. The Global Hawk has the highest payload capacity of any of the aircraft considered in this paper. It can carry a payload of 3,000 pounds, which is the goal for the design competition. It has achieved an endurance of 33.1 hours and reached altitudes of 60,000 feet. A single Rolls-Royce AE3007H turbofan engine with 7,600 pounds of thrust powers the Global Hawk.

Figure 8 The NASA version of the General Atomics Global Hawk

C. Conclusions Drawn from Aircraft Examples

A few conclusions can be reached from assessing the performance data of these aircraft. The aircraft with the highest endurance have achieved such goals with solar power and electric motors. Unfortunately, these types of designs do not allow for much payload capacity. The rest of the designs utilize consumable fuel sources. The consumable-fuel-based designs offer much better engine power and are able to carry larger payloads, especially relative to size. The configurations of these designs all feature high aspect ratio wings and minimalistic frames, a style that points towards the propulsion system as the focal point of the design.

III. Implications of Method of Propulsion

Perhaps the most important factor in this design challenge is the choice of propulsion system. Several other subsystems play a role in maximizing efficiency by reducing drag, maximizing lift and reducing weight; but the propulsion system ultimately is the most directly responsible for the endurance of the aircraft. Minimizing the fuel consumption of the engines will maximize the endurance of the aircraft and possibly lead to weight reduction by decreasing the required amount of fuel carried by the craft. The configuration of the aircraft is dependent on the method of propulsion that is utilized. Investigating examples of HALE UAVs gives some degree of insight into the effectiveness of a few of the existing propulsion systems. The propulsion system solutions that have been investigated in this paper fall into the two main categories of either solar powered electric engines or liquid fuel-burning engines.

A. Solar-Electric Propulsion Systems

The electric systems rely on solar power for energy. This drastically reduces the fuel weight by replacing liquid fuels with batteries or fuel cells. The QinetiQ Zephyr utilized this approach to successfully complete a two-week long continuous flight; setting the world endurance record for a winged aircraft. The solar-electric approach to propulsion has a major disadvantage in the area of maximum power. The electric motors do not produce enough thrust to carry a large payload. The Zephyr, for instance, is only able to carry a five-pound payload, making it useless for the types of research operations considered in this design project. The highest payload capacity of a solar-electric HALE UAV is 600 pounds, belonging to the NASA Helios. That is still well below the 2000-pound payload threshold of the design project. An additional setback is the fact that the solar-electric powered UAVs depend on battery power at night and cannot operate at full power during this time. The lightweight design of solar-electric-powered HALE UAVs has also proved to be fragile. The NASA Helios was torn to pieces when it encountered complications from turbulence while flying over the Pacific Ocean.

B. Consumable Fuel Propulsion Systems

Several different types of fuel burning engines have been considered for HALE UAV designs. These engines are modified versions of common four or six cylinder piston or rotary engines. Using such engines, aircraft such as the Aurora Flight Sciences Theseus and Scaled Composites Raptor have achieved HALE flight goals. In 1988, the Boeing Condor achieved an endurance of 58 hours and reached an altitude of 67,000 feet. It should be noted that the piston and rotary engines used in the aforementioned aircraft are relatively inefficient compared to emerging technology such as the liquid hydrogen engines used in the Boeing Phantom Eye. The relatively simple configurations of aforementioned aircraft could be coupled with next-generation engines in order to achieve the goals of this design project.

C. Next-Generation Propulsion Systems

According to a recent NASA study written on the subject of HALE UAVs, the next-generation engines being considered for HALE UAVs are liquid hydrogen internal combustion engines, liquid hydrogen gas turbines, liquid hydrogen proton exchange membrane (PEM) fuel cells, and liquid hydrogen Stirling Cycle heat engines.[3] The study concluded that the liquid hydrogen internal combustion engine would provide the highest endurance of the engines considered. Performance data on these engines is not readily available, but may be attainable through industry contacts.

IV. Conclusions

In conclusion, it seems that the traditional configuration of a fuselage with high aspect ratio wings and a consumable fuel propulsion system is potentially the best approach to the proposed design challenge. Consumable fuel configurations are sturdier and carry much larger payloads that configurations with solar-electric power regeneration. Payload capacity is of notable importance to this design competition, due to the large amount of instrumentation required for atmospheric research missions. The consumable fuel platforms can easily integrate various types of advanced technology to further increase its endurance and reduce its weight. Various options exist in the area of propulsion systems and more are currently being developed. The platform should be designed to be able to incorporate these new systems as the technology matures and becomes available. The platform should also be able to incorporate the numerous other subsystems, devices and features that maximize efficiency. These include winglets and small turbines that harvest incoming airspeed to generate secondary power. Considering the subsystems from previous HALE aircraft can lead to a better understanding of the various small challenges that can be addressed in order to contribute to an overall improvement in the efficiency of the final aircraft platform. The example HALE aircraft may not contain literal applications to the design competition, but rather conceptual clues as to the important areas to improve on in the design. In the case of this particular design competition, it seems that the most critical goals are to maximize Lift-Drag ratio and minimize Thrust Specific Fuel Consumption. Relatively basic configurations have been able to achieve impressive altitudes. The Boeing Phantom Eye seems to take a large step forward in performance (when considering endurance and payload capacity) from the other designs by taking advantage of advanced liquid hydrogen engines. Creative, next-generation solutions to propulsion will need to be identified in order to begin the process of choosing the best configuration and overall design concept for the desired HALE UAV platform.

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