Vapor

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Georgia Institute of Technology

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TEAM PICTURE

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ABSTRACT

This paper presents the design and development of a four-seat electric general-aviation (GA) aircraft for 2020 entry into service in response to NASA's request for proposal. The threshold aircraft requirements exceed any capability demonstrated by manned electric aircraft to date, while the goal requirements are competitive with modern combustion-powered GA aircraft. The main challenge for electric aircraft is the weight and volume of energy storage devices (ESD) such as batteries and fuel-cells. Another barrier is modifications to airport infrastructure needed to support electric flight. Nevertheless, electric aircraft offer potential benefits in operating cost, energy consumption, noise and emissions.

Selecting an ESD depended on its feasibility in meeting the requirements. The need to quantify and understand the effects of the requirements and the aircraft design drove the creation of a custom electric aircraft modeling environment. Detailed weight, drag, performance, and electric system analyses were included in the model. Performance levels of several types of ESDs were collected from literature. Specific-energy (energy per unit mass) and specific-power (power per unit mass) were treated as the constraint space for the design. Aircraft power and weight constraints stemming from the analysis indicated no ESD could meet all the goal requirements. The main constraint was the specific-energy required for aircraft with practical weight and cost.

The first approach to minimizing specific-energy was optimizing the vehicle and flight profile because these do not require major technological changes. Analysis revealed that a Cirrus SR22-like vehicle was already well-optimized, and there was little room for improvement.

The next approach was conducting requirements tradeoffs to reduce the specific-energy demand. This was guided by quantitative sensitivity analysis and qualitative GA market analysis. The goal payload of 800 pounds had the smallest impact on specific-energy demand and was well-matched to the four-seat requirement, so the goal was retained. A survey of six combustion-powered GA aircraft revealed that range was consistent near 800 nautical miles, while cruise speed was much more variable. It was determined that meeting the 800 nmi goal range while relaxing cruise speed from the 175 kts goal to 150 kts would result in a competitive design.

The final approach to minimizing specific-energy was adding aircraft technologies. The most significant benefits could be realized with improvements in parasitic drag and propeller efficiency. A key enabler to the technologies was using electric motors, which are more flexible than combustion engines in terms of size and placement. Detailed drag modeling and propeller analysis in XROTOR led to a unique configuration named *Vapor*. The design included twin 8-foot tail-mounted propellers, a laminar flow fuselage, and retractable gear, and achieved 92% propeller efficiency and a 25% parasitic drag reduction compared to the Cirrus SR22.

Aircraft specific-energy demand was reduced by 40% at the conclusion of the process, and the only feasible ESD was a proton exchange membrane fuel-cell (PEMFC). Fuel-cell and hydrogen storage performance levels were benchmarked to systems in the automotive and aerospace sectors. A fuel-cell system was modeled in detail and achieved a specific-energy of 800 Wh/kg and 55% efficiency (compared to 400 Wh/kg for batteries and 25% efficiency for combustion). This allowed designing an aircraft with a gross weight of 3,450 lbs and a competitive cost of $547,500. *Vapor* is 16 dB quieter and consumes 3.8 times less energy per mission than the SR22. Lower lifecycle cost than the SR22 was determined by a probabilistic analysis of future avgas and hydrogen fuel costs. Hydrogen fueling stations were modeled, and analysis revealed that modest infrastructure investment can enable fuel-cell powered flight. The *Vapor* concept was shown to be a technically feasible, economically viable, and competitive electric aircraft.