AIAA Design Competition: Hybrid Electric Regional Turboprop RFP

Analysis of the Effects of Visual Aesthetics on Aircraft Designs

A Thesis Prospectus
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By
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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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General Research Problem: Designing a Successful Hybrid Electric Turboprop Aircraft

How to design a more efficient and marketable hybrid electric turboprop aircraft for airlines?

With the development of a globalized economy comes the growing need for energy. For the transportation industry, this means the use of fossil fuels due to their high energy density and ease of access as a result of the widespread fuel distribution network across the globe. However, the substantial consumption of fossil fuels by human activities has resulted in the increase of greenhouse gas concentration in the atmosphere causing global warming. Furthermore, the cost of fossil fuel has also been rising over the years, and it is expected to rise as low-extraction-cost reservoirs are being depleted at a rapid rate. Therefore, regional airlines are facing growing demand for more efficient turboprop aircraft to be used for short-haul domestic routes.

With the implementation of hybrid-electric technology, it is speculated that this can bring down the emission and fuel consumption levels drastically in the next decade. The 2022 American Institute of Aeronautics and Astronautics (AIAA) Design Competition Request for Proposal (RFP) calls for a hybrid electric turboprop design with a significant block fuel reduction on a typical mission, and a projected entry into service time by the year 2035. I am on a nine-person technical team, and we will design such a hybrid aircraft to meet the design requirements set out by the competition rules. This would serve as the technical portion of my thesis paper.

While reading the RFP, hidden among other technical requirements, one line in the design objective caught my attention. It reads: "Make the aircraft visually appealing so it will be marketable" (AIAA, 2023). This sparked my interest and led me to ask: "What role, if any, does visual aesthetics play in the design and marketability of aircraft?" This is the STS portion.

The technical and STS portion connects well together. By understanding the effect on an aircraft’s aesthetics on its performance and marketability, I hope to make the best choices when designing an hybrid-electric turboprop aircraft to compete in the AIAA design competition.

AIAA Design Competition: Hybrid Electric Regional Turboprop Request for Proposal

How can an hybrid electric architecture improve the efficiency of a regional turboprop aircraft?

Turboprops are aircraft that are powered by propellers driven by turbine engines. With flexible passenger capacity, modern turboprop aircraft such as the ATR72 and De Havilland Canada Dash 8 Q400 are widely used by a variety of regional airlines. Many of those regional airlines also partner with major national and international carriers to fulfill the short-haul flight market for passengers traveling to and from smaller and remote airports. The AIAA design competitions specify 50 seat capacity hybrid-electric turboprop with a 20%+ reduction in fuel on a 500 nautical mile mission compared to current turboprops, as well as a reduction in emissions ($CO2$, NOX, soot, etc.) In addition, the airplane must have a projected entry into the service year of 2035. At the same time, the airplane must have over 1000 nautical miles of range with maximum payload and passenger capacity, have a minimum cruise speed of 275 knots, similarly sized cabin and wings as the existing traditional turboprop aircraft, be equipped with autopilot and IFR instruments, have acceptable take-off and landing performances when compared to existing products, and meet all FAA 14 CFR Part 25 requirements for certification. To meet such an extensive list of aircraft performance requirements in such a short time, design decisions must be based on today's technology, especially regarding the capability of the battery technology.

Current lithium-ion batteries has relatively low energy density (0.72MJ/kg) when compared with Jet-A fuel (43MJ/kg). Unlike automobiles, adding weight to an airplane significantly decreases its efficiency and operational range. Nonetheless, electric motors have a much higher propulsive efficiency when compared to turboshaft engines, making it potentially worthwhile to integrate into the design. We will utilize electric motors and batteries to design a more efficient turboprop.

With limited space and weight capacity available on an aircraft, where and how to store the sizable and heavy batteries would major constraints for the design. It is entirely possible that an unconventional looking aircraft would be the end product to satisfy those technical constraints. To the passengers, the new design could mean an different seating arrangement, a different boarding and deboarding sequence, or a change in checked/carry-on baggage allowances.

Nonetheless, this technical project is important because short-haul regional flights have great potential to reduce emissions, especially when compared to long-haul flights that have a stricter requirement for the fuel's energy density which makes hybrid-electric architecture less suitable. This project shall lay down the building blocks of the sustainable aviation, which would have great benefit to the reduction of carbon emissions and the slowdown of climate change.

Analysis of the Effects of Visual Aesthetics in Aircraft Designs

What role, if any, does visual aesthetics play in the design and marketability of an aircraft?

In this section, aircraft aesthetics is generally defined by proportion. In summary, to be of good aesthetics means to be of proper proportion when compared to existing state-of-the-art designs.

There is a common saying in the field of aerospace engineering: "If it looks right, it flies right". It is an intuitive philosophy that the design aesthetics of the aircraft often reflects its performance and handling characteristics in the air. For example, A sleek jetliner's retractable landing gears and smooth polished skin not only look aesthetically pleasing to its pilots and passengers but also serves to reduce its aerodynamic drag and increase its cruise speed and fuel efficiency. A stealth fighter's trapezoidal-shaped vertical stabilizers and bubble canopy not only look modern when parked on the ramp, but it also served to reduce its radar signature and improve its pilot visibility. A bush plane with its high-mounted wings and large diameter tires not only makes it look heavy-duty but also allows its propeller and wings to clear obstacles when landing on improvised runways in remote areas. The list of examples can go on and on, even outside of the field of aerospace: In most of automobiles, exterior mirrors are fitted inside of a rounded housing not only because of the aesthetic values, but because of the reduced aerodynamic drag and therefore better fuel economy. After all, when a good design is successful, it tends to stick around and becomes the norm, and aircraft is no exception to this rule.

When it comes to the marketability of two competing aircraft capable of fulfilling the same mission, if all else is equal, good aesthetics and geometric ratio can be the deciding factor. One of the more famous examples of this happening is during the selection of the Joint Strike Fight (JSF) program, in which teams at 4 companies (McDonnell Douglas, Northrop Grumman, Lockheed Martin, and Boeing) competed against one another for the lucrative contract which would replace various tactical aircraft operated by the United States and its allies. The design requirements were difficult: The new single-engine supersonic multi-role fighter aircraft needed to be stealthy and provide robust situational awareness to the pilot during both air-to-ground and air-to-air engagements. It also needed to meet the specifications of the U.S. Air Force, U.S. Navy, and U.S. Marine Corps as well as allied partners. Eventually, only two companies remained Boeing and Lockheed Martin. Both companies received $750 million in grants from the Department of Defense to build a prototype. The Boeing team built the X-32 prototype on the left in Figure 1, while the team at Lockheed Martin built the X-35 prototype parked on the right.

Figure 1. JSF Prototypes Parked Side by Side on the Ramp (Boeing)

In the end, the Department of Defense chose Lockheed Martin's X-35, which would eventually lead to the production of the F-35 Lightning II. While the exact reason why Lockheed Martin's prototype was chosen was never officially disclosed to the public, stories told by a test pilot during a recent interview provide some information on this rather secret competition at the time.

That test pilot is now-retired Commander Phillip "Rowdy" Yates, a former Naval aviator. The testing of the prototype was very limited due to the limited capabilities of the demonstrator aircraft. There were no extensive requirements for high-G maneuvers or top speeds. "The designs were not meant for those types of evaluation", Yates said, "This was not a fly-off". Each contractor designed its flight test program, what they wished to show beyond the requirements, and just let the evaluation occur back at the program office with the proposals.

Even though prototypes from both teams could take off and land vertically, they use different mechanisms and therefore have drastically different appearances. Boeing's X-32 utilizes a more traditional thrust-vectoring nozzle to redirect the exhaust air downwards to achieve limited vertical thrust as in Figure 2, it needed a much larger engine inlet to have enough airflow to generate enough thrust needed for the mission. However, even with the significantly larger inlet, Boeing's X-32 prototype cannot generate enough vertical thrust. According to Yates, "They would need to get their STOVL aircraft to Pax River where the air was a little thicker at sea level to create more thrust and have enough safety margin to ensure that aircraft could hover."

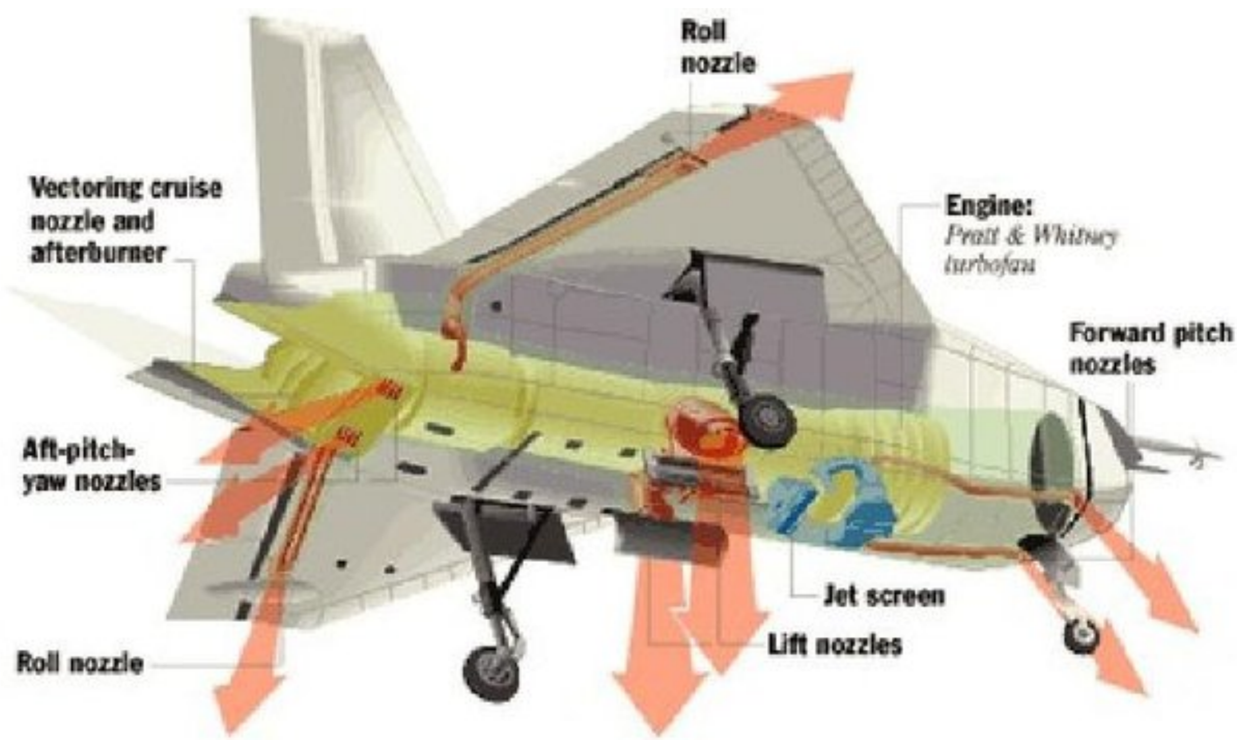

Figure 2. Boeing X-32 Schematics (Majoor, A.)

Lockheed Martin's prototype uses a much more advanced system. For vertical lift, the X-35 featured a separate 48-inch lift fan fed by an intake behind the cockpit that redirected cool air from above the aircraft to below it. The X-35 also included a swiveling exhaust system that redirected the exhaust from the main engine into the vertical lift system. Both of these systems work in tandem to produce vertical thrust as illustrated in Figure 3 so that the main engine inlets of Lockheed Martin's X-35 prototype are not as big as that of the X-32 by Boeing.

Of course, there is also what many test pilots called the other "unspoken sense" of why the X-35 won the JSF competition: It looked more proportional. "The X-35 looked more like a fighter than the X-32", Yates said, "Boeing knew they had a problem with that if you will, and to address it, they had a little mantra that said 'look, you're taking it to war, not to the senior prom.'" However, in the end, Boeing lost. Lockheed Martin won the JSF contract with the X-35 prototype because its more aesthetically-pleasing lift fan design also increased its VTOL performance, which is an important metrics in the JSF competition, and Boeing confirmed the same (Defense Daily, 2001).

We didn't lose, but Lockheed Martin clearly won," Jerry Daniels, then president of Boeing's Military Aircraft and Missile Systems, told reporters during a conference on October 30th, 2001. "(Boeing) emphasized direct lift with tremendous commonality. Lockheed had a very innovative lift fan and at the end of the day demonstrated it worked. The lift fan opened the door for performance improvements we didn't get staying within the parameters of a direct lift approach." Another liability was that Boeing, in its STOVL design, had to run its engine in "high temp" mode, increasing wear and support costs on the engine, a trait the Lockheed lift-fan approach did not share.

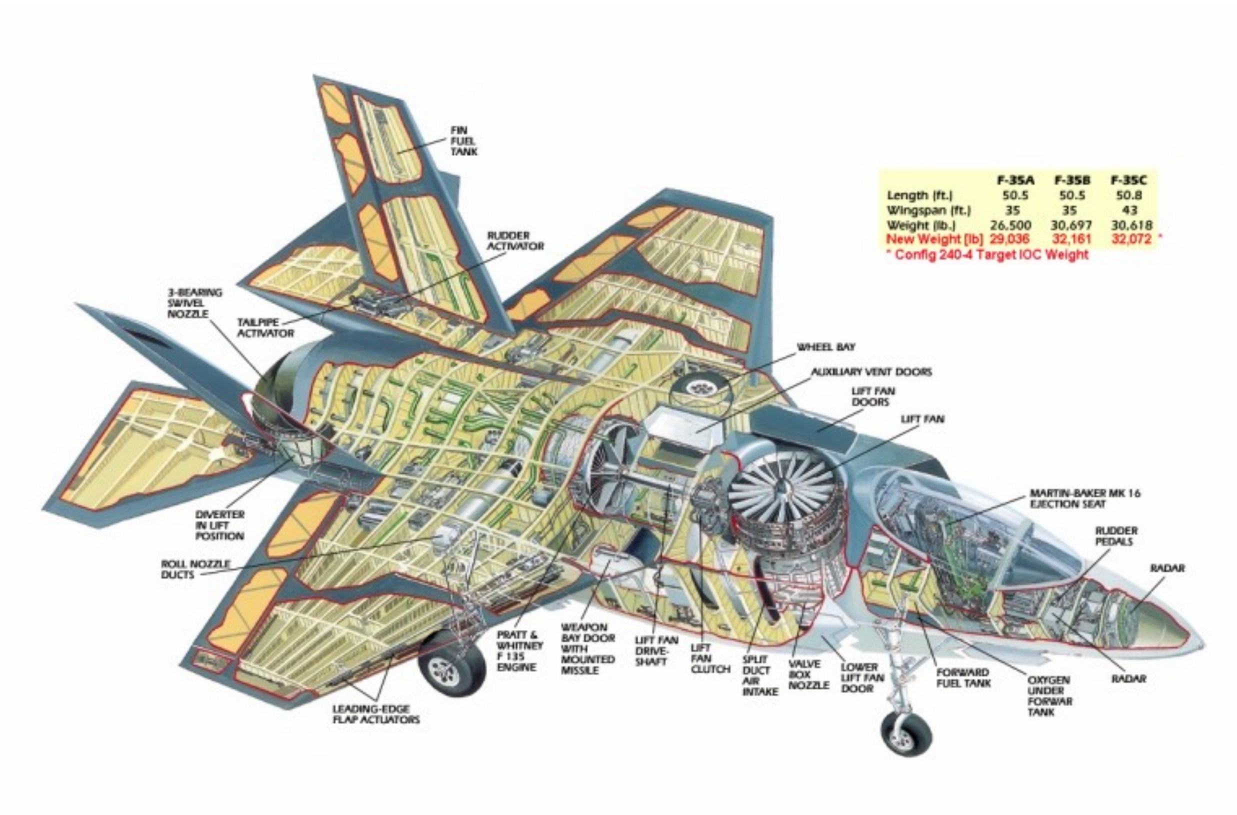

Figure 3. Lockheed Martin F-35 Schematics (Kopp, C.)

While it may be tempting to state that a good design will inherently look good, it is not always the case, especially when it comes to innovations that are designed to serve a unconventional purpose. Such is the case of NASA's Super Guppy (Figure 4) - a cargo plane designed to transport rocket parts for the space program. At a first glance, it may seem out of proportion and weird-looking due to its large-diameter fuselage diameter , but it does its mission incredibly well, so well that other aircraft manufacturers such as Boeing (Figure 5) and Airbus (Figure 6) built their versions to transport airplane parts from factories around the world. Though it is an unconventional design, it is incredibly successful.

Figure 4. NASA Super Guppy (Beason, C.)

Figure 5. Boeing Dreamlifter (Boeing)

Figure 6. Airbus Beluga XL (O'Hare, M.)

So why does the aerospace industry still emphasize the aesthetics of an aircraft when it has been proven that an out-of-proportion design can still be successful at its mission? Does the airline care about the "looks" of the airplane? How about the pilots, the passengers, or the engineers? I plan on diving deeper into this topic by analyzing additional examples in aviation. I am curious as to what role, if any, human perception of aesthetics has in the process of aerospace engineering design and the ultimate success of the final product which is an airplane.

My next steps of this investigation would be to:

- Begin searching for innovative aircraft designs examples with questionable aesthetics.
- Find more resources on such aircraft's technical background and market performance.
- Reference studies from other industries to bolster the strength of my arguments.
- Cite other scholarly articles that have looked into the effects of aesthetics in design.
- Incorporate all information into a concise and coherent thesis during the spring semester.

The research I gather will hopefully contribute to a deeper understanding in the decision making process during aircraft design when it comes to aesthetics, and aid in my team's on-going aircraft design project. In the end, if better-looking (proportional and conventional) aircraft really sell and/or perform better than an ugly-looking (disproportional and unconventional) aircraft, then our team should obviously take aesthetics into considerations during the design process. If the collected data suggests otherwise, I would want to find out exactly why is the aircraft aesthetics requirement is specifically mentioned in the RFP issued by the AIAA for the design competition.

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