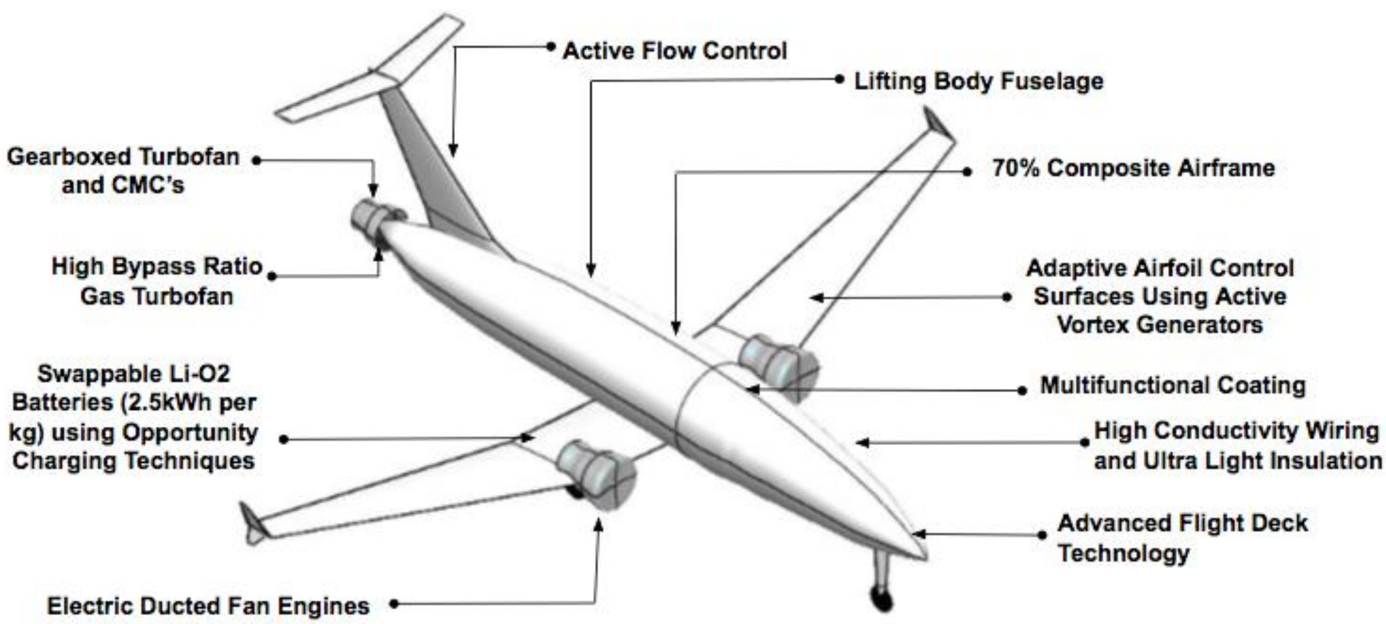
NASA Advanced Air Vehicles Subsonic Commercial Transport Design Challenge

Project INDRA

Emily Flaherty-Woods, Gautam Bhayani, Casey Graves,
Nils Herbert, Mike Kobyra, Garron Scoon(Team Lead)
All students are seniors in the School of Aeronautics and Astronautics

Faculty Adviser: John Sullivan
Purdue University, West Lafayette, IN 47906
Undergraduates
6/12/2017



Abstract

The NASA Advanced Air Vehicles Subsonic Commercial Transport Design Challenge is a university competition to design a 200+ passenger airliner expected to enter service in 2035 that meets NASA's Mid-Term goals for reduced fuel consumption, emissions, and noise. Specifically, the next generation airliner should include advanced vehicle concepts and technologies to reduce fuel consumption by 50-60% (relative to the 2005 best in class design), cruise NOx emissions by 80% (relative to the 2005 best in class design), LTO NOx emissions by 80% below CAEP 6 standards, and noise by 32-42 dB below Stage 4 standards.

This study seeks to assess the feasibility, technical risks, and benefits of a single aisle, short range, hybrid electric aircraft to enter service in 2035 which incorporates a variety of advanced technologies to meet NASA's design requirements stated above. This study begins with an assessment of the air transportation market predictions, the results of which are used to frame the context of the proposed design and concept of operations. Next, an initial design concept generation and down-selection method is discussed. Further, a detailed drag, sizing, stability, and structural analysis is performed to provide initial design estimates and basic performance calculations.

Based on the predicted market growth of the Asia-Pacific region over the next 20 years, a 200 passenger aircraft with a design range of 3500 nmi was determined to be the most valuable and cost effective aircraft for Asian airline operators looking to provide point-to-point services to their customers. Using concept generation and down selection techniques, and trade studies, a single aisle, narrow, lifting body, hybrid-electric aircraft that uses advanced propulsion, structures, and weight reduction technologies is proposed, hereinafter referred to as INDRA. Specifically, the INDRA incorporates a hybrid electric propulsion system using gear-boxed turbofan engines with CMC turbine blades and a high bypass ratio to reduce fuel consumption, noise, and emissions. Additionally, the design includes composite structures, split scimitar winglets, a multi-functional coating, adaptive airfoil control surfaces, active flow control, high conductivity wiring, and advanced flight deck technology to meet the design requirements.

The results of this system design study reveal that the proposed hybrid-electric aircraft design is capable of transporting 204 passengers 3,500nmi operating at a cruise mach of 0.728. Two over-the-wing mounted electric fans are used for taxi, takeoff, and landing, and one small aft mounted turbofan is tailored for cruise. Using sizing algorithms, which incorporate the proposed advanced technologies, the INDRA gross weight is found to be 161,433 lbs, with a fuel weight of 12,637 lbs, a payload weight of 47,250 lbs, and an empty weight (which includes 30,165 lbs of Li-Air batteries, the weight two electric motors, and the weight of the small gas turbofan) of 104370 lbs. The thrust required from the electric propulsion system for takeoff and climb at a rate of 90 ft/s is 61,344 lbs, and the thrust required from the small gas turbofan engine for cruise is 7,775 lbs. Further, the initial drag study reveals INDRA has a total drag coefficient of 0.0204 and a L/D ratio of 21.18. These design characteristics are comparable to aircraft of similar size such as the Boeing 737-800.

Additional analyses were made to ensure stability, structural, and safety requirements were satisfied. Further, a low fidelity cost analysis projected for 2035 provides a cost per unit of 36 million dollars and an airplane market price per unit of 86 million dollars; however, with the additional technologies proposed for this aircraft, the team believes the cost will be closer to 100 million dollar. When compared to the current list price of the 737-800 of 72 million dollars, the cost for the Indra aircraft is feasible. With a gradually increasing production rate, the team predicts the break even point to be 6 to 7 years into production. Additionally, a cumulative net present value examination was conducted with a lower and upper bound discount rates. The forecasted profits are 10 to 25 billion dollar. Based on the results presented in this paper, it is concluded that a short range, narrow body hybrid electric aircraft is both technically and economically feasible to enter service in 2035 and meet NASA's Midterm Goals regarding reduced fuel consumption, emissions, and noise. Future work is necessary to investigate opportunity charging techniques, battery storage facilities and battery swapping tooling, and the use of biofuels. Further, detailed analyses are needed to determine the carbon offset from manufacturing and charging the Li-Air batteries and to provide higher fidelity noise estimations.