COMPUTATIONAL AND ANALYTICAL METHODS IN THE AIRCRAFT DESIGN CURRICULUM

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Abstract

Traditional and new approaches in aircraft preliminary design have been analyzed in order to review the curriculum, introduce new "prerequisite" courses in the Mechanical Engineering & Aerospace programs, and motivate students to solve challenging design problems. Several computational and analytical methods and tools ("Predictors" of Vehicle Trajectories, Operational Envelopes, Probe Aerothermodynamics, and Engine-Fuselage Configuration Solutions) have been successfully used by students in the design practice. Their projects covered different aeronautical areas: the alternatives to the NASP and X-33 projects of hypersonic vehicles, a replacement to the current U.S. Air Force primary training jet, a transonic military V/STOL personnel transport, a remote controlled military surveillance and scout plane, and others.

1 Introduction

Planetary exploration programs [1] made new requirements [2] to future engineers and researchers in hypersonic high-temperature gas dynamics and aircraft design. A preliminary design of a hypersonic vehicle has become a real challenge for students in my *Aircraft Design* classes with the University of New Hampshire and Worcester Polytechnic Institute [3]. In "traditional" courses of the Aerospace & Mechanical Engineering curriculum (applied aerodynamics, gas dynamics, fluid mechanics, heat transfer, combustion, and hypersonic flows), which are prerequisites for the *Aircraft Design* course, students develop new software and analytical tools that have been successfully used in predicting vehicle trajectories [1, 4], operational envelopes [5], aerothermodynamics of probes [4], engine-fuselage configuration solutions [6], and trust evaluation for supersonic combustion regimes [7].

2 New Foundation Courses

The introduction of new foundation courses, namely, *Hypersonic and High-Temperature Gas Dynamics* and *Computational Fluid Dynamics*, has enriched the traditional curriculum of the Aerospace Program. New topics have been added to the course studies, such as perspectives on hypersonic viscous flow research, similitude in hypersonic aerodynamics and probe design [8], tendencies in aerospace vehicle design, supersonic combustion [7, 9], transport phenomena at high temperature conditions [10], and rarefied gas-dynamics research.

The non-equilibrium thermodynamics approach has been considered in detail in the classroom. Students have creatively used these skills in studies of real physical processes at high temperatures, as well as in modeling and simulating flow conditions in nozzles, engines, and underexpanded jets [11].

Students formulated new physical ideas and developed new numerical algorithms and applications. A team of graduate students and researchers was asked to study segmented projectile aerodynamics [12] in hypersonic viscous flow. One of the students did a mistake in a body-shape approximation generating the cylinder-plate configuration. After fruitful discussions of plate aerodynamics in hypersonic flow, we made a decision to continue the study. The drag reduction effect and the absence of the Reynolds analogy between heat flux and skin friction were found in the case of a plate located behind a cylinder [13].

3 Aircraft Design Course

The objectives of the aircraft design course are to help students in conducting their individual design of an aircraft, which should meet specifications, present the design via a report, substantiate that the design meets specifications, and demonstrate the specified mission using simulation.

Specifications [5, 6, 14] must be unique for each project and should include *payload* (passengers, baggage, cargo, etc.), *crew* (pilots, attendants, baggage, etc.), *range* (including loiter and alternate), *altitude, cruise speed*, *climb*, *take-off* and *landing parameters*, *powerplants*, *pressurization*, *certification issues*, and *mission profile*. The report includes specifications, projection and isometrics views, calculations and analyses demonstrating that specifications are met, and results of simulation demonstrating that mission was met. Drawings should indicate materials, subsystems, propulsion and fuel systems, etc. Students calculate all aircraft characteristics [15, 16] (empty weight, center of gravity, maximum speed, cruise speed, maximum maneuvering speed, range, stall speeds, rate of climb, ground and landing rolls, maximum gross weight, wing loading, power loading, and fuel capacity).

Students are required to conduct at least one detailed design analysis from aerodynamics, structure, propulsion, stability, maneuvers, or controls. The aircraft mission should be demonstrated using flight simulation software [17]. The reports are evaluated by grading the attainment of specifications, substantiation by calculation or analysis, clarity and quality of the materials, and creativity of the design.

4 Examples of Students' Design Projects

Students love the challenge of the aircraft design class. As an alternative to the NASP and X-33 projects, Alan Bernat studied a preliminary design of a Hypersonic Transport (*The "Star Sprite"*), which can carry passengers to long distances in very short time, launch satellites into low elliptic orbits around the Earth, and deliver astronauts to the International Space Station. The flight range reaches a maximum by entering orbit cruising until entry then landing. The aerospace aircraft would service long distance trips at a cruise velocity of 16,750 ft/s, and the average Mach number M = 2.4 during atmospheric flight for short distances and climb. The design specifications included up to 80 passengers, two pilots, 6 technical and 2 steward personnel, and 10,000 lbs of shipping cargo. Powerplants are two GE90 airbreathing gas turbines and two DF/DX engines.

Sven Backlund has reviewed in his project report *"Military Trainer"* the detailed design process for a replacement to the current U.S. Air Force primary jet. The design specifications included a flight range of 500 miles, maximum speed of 500 mph (Mach number M = 0.67), pilot and trainee as crewmembers. The aircraft has a take-off weight of 7000 lbs. Its wing has the following characteristics: W_o/S ratio = 109.9 lb/ft^2, aspect ratio of 7, swept angle 0 deg, and NACA 2415 wing profile. He has found that the stability parameters are critical in the design implementation.

A transonic military V/STOL personnel transport (*"The Hawk"*) was designed by Corinne Kachler as aircraft with vertical take-off and landing capacities, which would allow it to be used with naval vessels. This aircraft could also be used for transport to areas, which are inaccessible to most other aircraft. Because of its high maneuverability and speed, it could be used during times of combat if personnel transport is necessary. The range is 1,500 mi, service ceiling – 55,000 ft, and maximum speed – M = 0.8. A detailed analysis of the aerodynamic characteristics was based on the examination of aspect ratio (9.5), sweep angle (60 deg), span (35 ft), and the airfoil (NACA 23015). The specific fuel consumption, C, has been evaluated by using approximations from Ref. 14 for two different points of the mission profile, cruise (C = 0.5) and loiter (C = 0.4).

Both the endurance and range were determined by using the data and recommendations of Roskam [6] and Nicolai [5].

Marvin Ng designed a remote controlled military surveillance and scout plane. This is a small, lightweight aircraft intended to fly over enemy activity or hostile territory to scout out and monitor the situation. It uses inferred and real-time video with night vision equipment for flight and surveillance. Being launched from a mobile platform and using a parachute for landing, this airplane will be versatile, because it does not require a runway for liftoff or landing, and can be easily transported to the front-line. The mission specifications include range (400 miles), speed (maximum – 250 mph, cruise – 188 mph), endurance (3 hours), field length (66 ft), and low cost.

Reviewing modern U.S. land-based long-range heavy strike aircraft (A-6E *Intruder* and F-111F *Aardvark*), Chad Wemyss found that his version of Heavy Attack Aircraft (*HAX*) can fruitfully compete with the predecessors. He designed *HAX*, which is capable of flying above 2000 miles, delivering a large bomb-load with a high degree of precision, and returning to its home base un-fuelled. It is designed with stealth technology, and is capable of operations from a short, semi-prepared airstrip. The design specifications include combat radius (2215 nm), maximum Mach number M_{max} = 1.6 (with afterburner), M = 1.3 (dry thrust at altitude of 35,000 ft), and M = 1.3 (with afterburner at 500 ft); payload (12 heavy weapons in 2 internal weapon bays and 4 advanced self-defense anti-radar missiles) and 2 crewmembers.

Totally 62 aircraft design projects were developed by students during the 1993-2001 academic years. The computational and analytical methods developed by students and the instructor were successfully used by students in the aircraft design projects.

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