Composite Re-Design for a Small-Scale Supersonic UAV

T. Chang, B. Dezall, R. Fyfe, M. Mina, K. Pieper and K. Powell

Department of Mechanical & Manufacturing Engineering

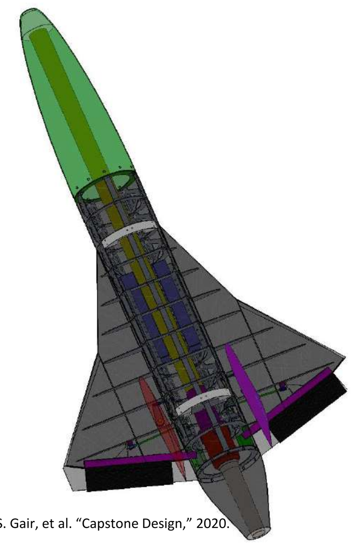
University of Calgary

April 2022

Introduction / Abstract

Small-scale unmanned aerial vehicle (UAV) platforms are becoming an increasingly viable solution for conducting flight and fluid mechanics research in the transonic and supersonic regimes. The Aerospace and Compressible Flow Research Group at the University of Calgary (AERO-CORE), in partnership with Atlantis Research Labs (ARL), has developed low-drag UAV designs as a baseline for a supersonic-capable end product. This project encapsulates a high-level composite re-design of the structure to elevate its capabilities to theoretically achieve supersonic flight, and serves as a stepping stone for the future full-scale prototypes.

Previous versions include a primarily aluminum structure capable of subsonic flight, supported by a thesis investigating conceptual airframe designs [2]. In order to reduce weight and improve aerodynamics in future prototypes, AERO-CORE and ARL initiated this capstone to re-design the external shell and internal structural supports given composite materials. Re-design was completed in SolidWorks, ANSYS Mechanical and ANSYS Composite Prep-Post, as well as a python-based aerospace conceptual design environment (SUAVE) for performance verification.



[1] S. Gair, et al. "Capstone Design," 2020.

Methods

Structural Re-Design

1) Upgrade the planned propulsion system to support supersonic speeds given a theoretical range of aircraft weight.
2) Scale the existing airframe to fit the selected engine.
3) Replace the external shell with a chosen carbon fiber-epoxy matrix composite design supported with material property results from ANSYS Composite Prep-Post.
4) Iterate the design of internal aluminum structural supports to reduce weight and create space for fuel and instrumentation.

Computer-Based Verification

1) Verify theoretical flight performance of the external airframe in the SUAVE aerospace conceptual design environment.
2) Verify static/structural performance of the full-body structure to failure loading scenarios in ANSYS Mechanical.

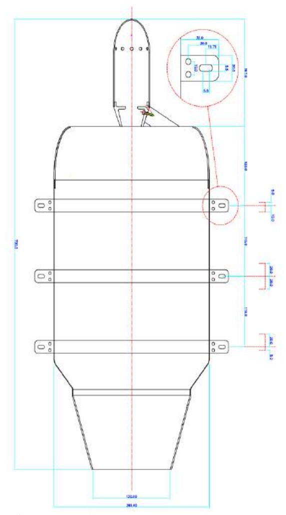
Carbon Fiber Test Layups

1) Select a viable composite carbon fiber-epoxy layup method based on the final material design, time constraints and cost.
2) Select an appropriate mold material for use on a CNC router.
3) Create ¼- and ½-scale negative models in Fusion 360 with thought given to the cutting tool and surface finish.
4) Employ an affiliated specialist to demonstrate best practices.
5) Produce first-round layups on sub-full-scale models.

Process / Materials / Discussion

Design Scaling

Previous versions of the aircraft employed a much smaller engine that was not practical for supersonic flight. Selection of the AMT Lynx Jet Engine[3] was approved for its ability to deliver 1569N of thrust, subject to scaling of the full body by a factor of 1.6 and conservation of an aspect ratio of 1.7.



[4] AMT Jets. "AMT Lynx Jet Engine," 2022.

SUAVE Setup and Verification

Developed by Stanford University, SUAVE[4] is an open-source python-based aerospace conceptual design environment used throughout this project to asses aerodynamic performance. Specifically, it was adapted to perform theoretical, low-fidelity flight analyses in the transonic and supersonic regimes, cross-referenced with manual calculation and verification in ANSYS Mechanical. It successfully computed flight characteristics for the airframe including stall speeds, lift distributions, and flight time for weight optimization.

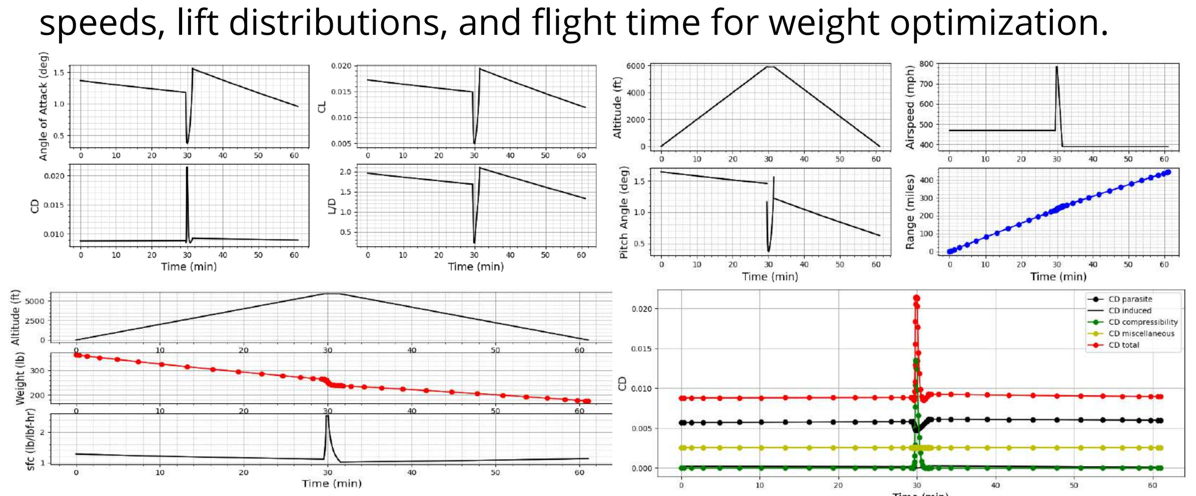


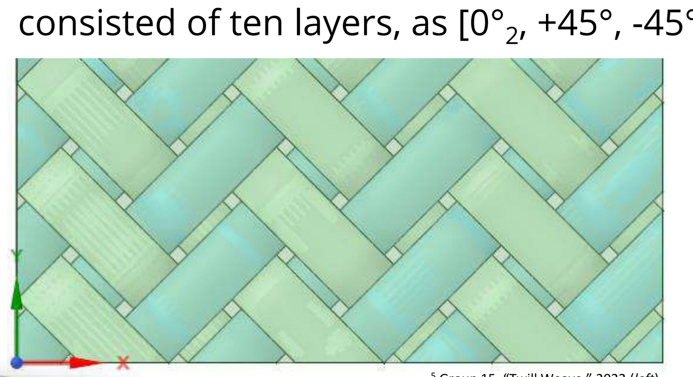
Figure 1: Airframe Flight Characteristics Computed in SUAVE [5]

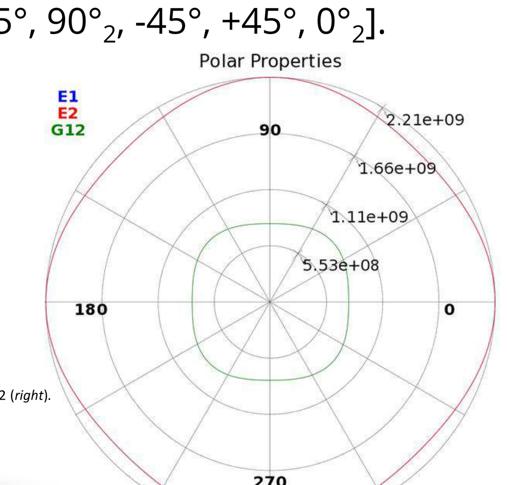
Simulation was able to prove that, with scaling, the airframe is capable of supersonic flight at 165 kg with the AMT Lynx engine.

ANSYS Composite Prep-Post (ACP)

To assess the behavior of a carbon fiber-epoxy matrix under appropriate failure loading, ACP was used to incorporate the selected materials with their various strength and elastic properties, and then used to set up ply layering. The carbon fiber was integrated into the material designer module where a twill weave pattern was selected for its high manufacturability. The carbon fiber-epoxy design was deemed acceptable for full-scale prototyping.

The carbon fiber laminate was placed during fabrication such that it closely resembled the quasi-isotropic design, where strength and stiffness are equal in all directions within a plane. The set of ply orientations found to best satisfy the desired material parameters consisted of ten layers, as [$0°_2$, +45°, -45°, $90°_2$, -45°, +45°, $0°_2$].

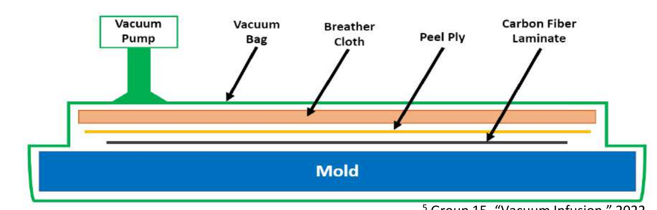




[5] Group 15. "Twill Weave," 2022 (left).
[5] Group 15. "ACP Polar Properties," 2022 (right).

Composite Carbon Fiber-Epoxy Matrix Manufacturing

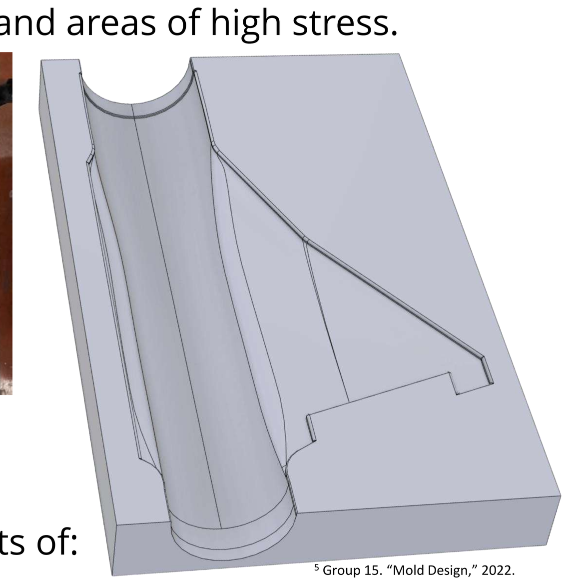
In consultation with affiliated industry professionals, it was decided that a wet layup and vacuum bag infusion process was the most effective solution for the airframe geometry and desired fiber characteristics. A 3k 2x2 twill weave provided appropriate fabric stability, workability, and strength. The ¼- and ½-scale molds were stabilized with an epoxy and smoothly sanded, then buffed with five coats of mold release wax. During layup, the carbon fiber was cut to shape, saturated with epoxy in layers, and laid into the mold without affecting the desired weave and ply orientations. A peel ply layer was applied on top, followed by breather cloth to soak up excess resin during the vacuum infusion process.



[5] Group 15. "Vacuum Infusion," 2022.

Selection of the mold material was crucial from a surface finish, machineability and cost standpoint. A 40 PSI rigid foam was selected for its ability to be quickly and cleanly machined on a CNC router, while remaining cheap and locally available. A sample mold from the upper half of the fuselage and wing was chosen to demonstrate challenging geometries and areas of high stress.

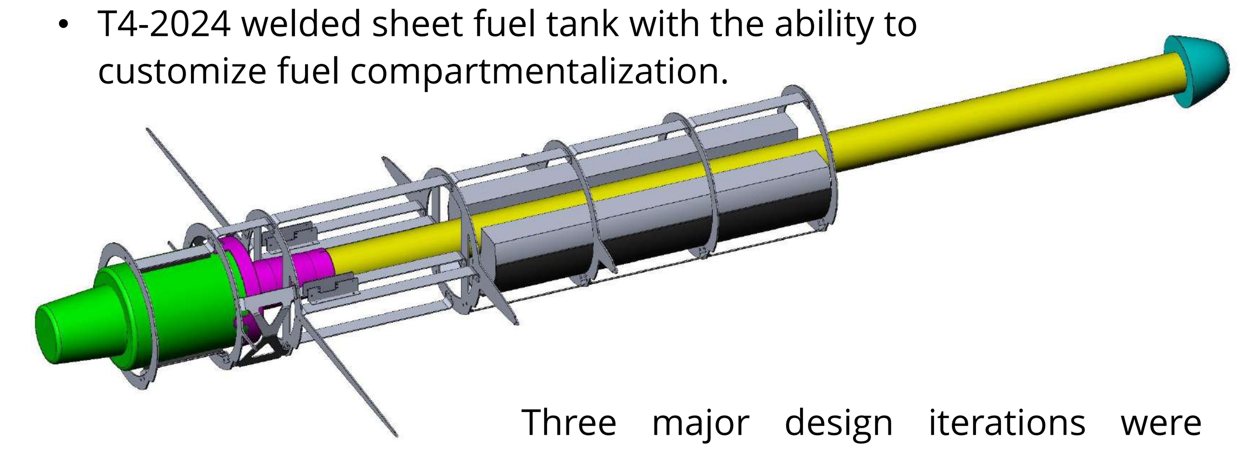
[5] Group 15. "1/4-Scale Carbon Fiber Layup," 2022.



[5] Group 15. "Mold Design," 2022.

Minimalistic Interior Structure

The finalized internal structure consists of:
- AMT Lynx Jet Engine[3];
- T6-6061 aluminum engine connector and air intake with ABS cap;
- Minimized T6-6061 sheet structural ribbing;
- Landing gear compartment with stainless steel anchors;
- EPDM rubber supports for the engine and fuel tank; and
- T4-2024 welded sheet fuel tank with the ability to customize fuel compartmentalization.



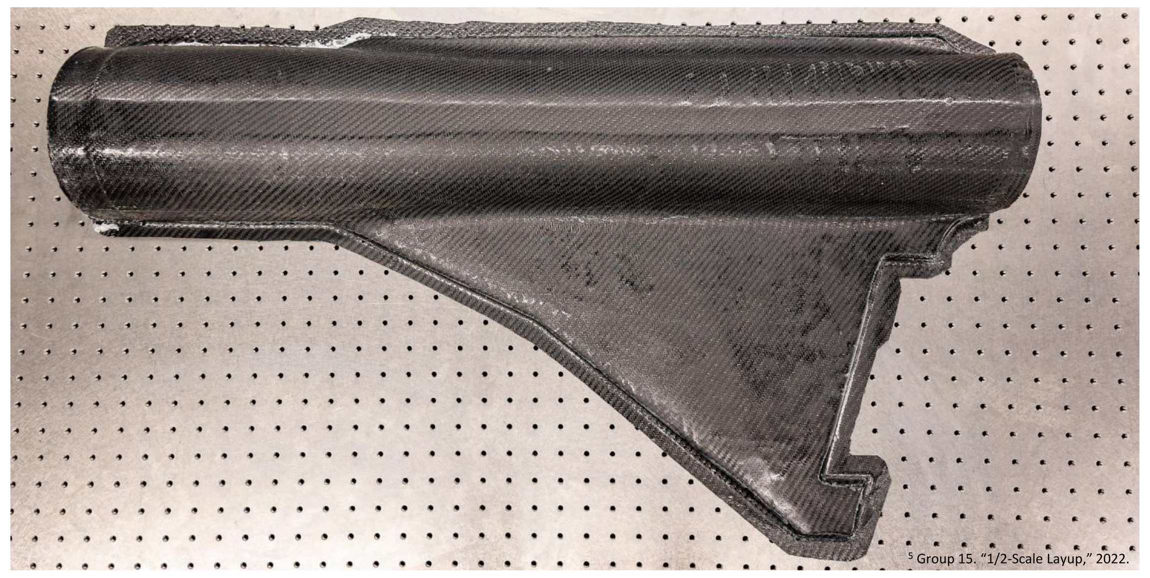
[5] Group 15. "Internal Structure," 2022.

Three major design iterations were completed, each consecutively verified in ANSYS, culminating in a weight reduction from 220 kg to 165 kg.

ANSYS Mechanical Verification

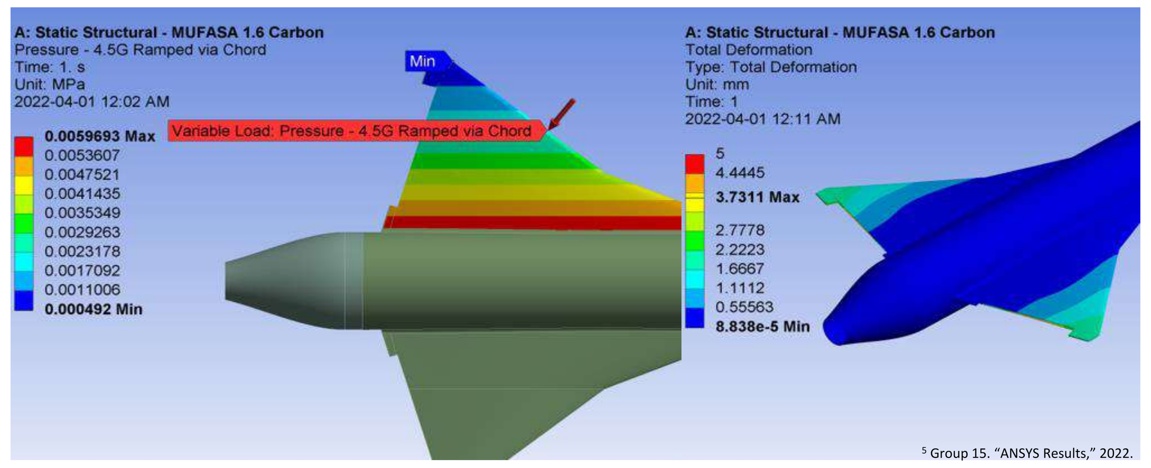
The full-body structure was imported into a static/structural module and approximated using a tetrahedral element mesh subject to quadratic solutions. Following a literature review and consultation with ARL engineers, structural performance was verified under the theoretical failure loading scenarios below, and a safety factor of 1.5:
- +4.5/-3 Gs of distributed pressure;
- +4.5/-3 Gs of ramped pressure (via the chord profile); and
- a cantilevered 25.7 kg engine mass acting directly on supports.

Results



[5] Group 15. "1/2-Scale Layup," 2022.

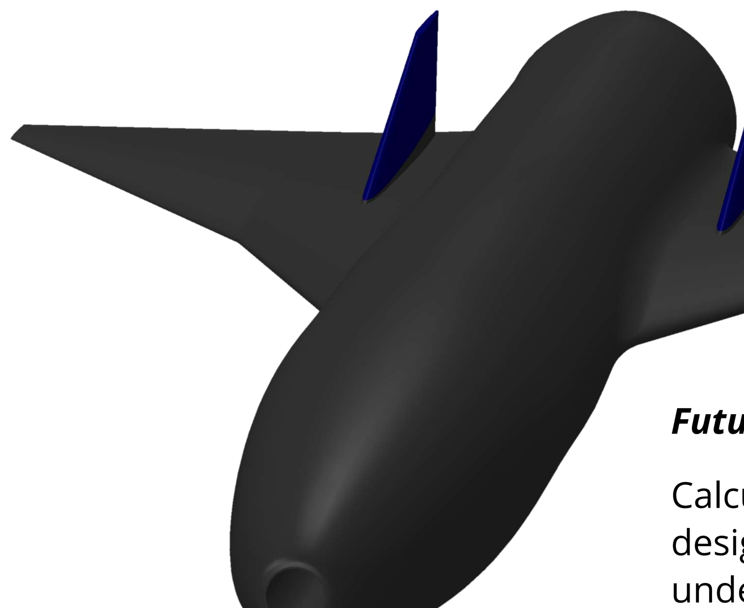
Applied Pressure [MPa]	Max. Shell Deformation [mm]	Max. Internal Deformation [mm]	Max. Shell Equivalent Stress [MPa]	Max. Internal Equivalent Stress [MPa]
4.5G Distributed	3.73	1.92	127.86	131.43
-3G Distributed	2.49	1.28	85.24	87.62
4.5G Ramped	1.43	0.50	56.76	24.86
-3G Ramped	0.94	0.33	37.28	16.18



[5] Group 15. "ANSYS Results," 2022.

Conclusions

The project produced a viable composite carbon fiber-epoxy matrix external shell re-design, and successful vacuum infusion layups at partial ¼- and ½-scales. These layups provide crucial planning information for future full-scale prototyping. A high-level material reduction and re-design of the aluminum structural components was also completed to support the inclusion of a supersonic-capable engine, more fuel and landing gear while reducing overall scaled weight by over 55 kg. Verification was performed on material designs at a safety factor of 1.5.



[5] Group 15. "Composite Shell," 2022.

Future Considerations

Calculations and significant design for landing gear were undertaken, though future work will need to explore fit, braking and manufacturability. Control systems were selected for previous versions and will need to be adapted to this airframe. Finally, a decision regarding the placement of vertical stabilizers requires engineering considerations from ARL.

References
[1] S. Gair, et al. "Design, Fabrication, and Subsonic Flight Testing of a UAV Designed for Supersonic Flight." University of Calgary, 2020.
[2] B. Dalman. "Conceptual Design Methods for Small-Scale Supersonic Uncrewed Aerial Vehicles." University of Calgary, 2021.
[3] "Amtjets.com," AMT Netherland, 2019. [Online]. Available: http://amtjets.com/pdf/lynx_specifications.pdf.
[4] "SUAVE 2.5: Design Dreams Come Alive," SUAVE, 2021. [Online]. Available: https://suave.stanford.edu/.
[5] Group 15. "Various ENME 501/502 Capstone Design Project Results and Figures." University of Calgary, 2021-2022.