

Executive Summary

- ❑ The main objective of this poster is to demonstrate a **low fidelity thermal protection system (TPS) sizing and analysis tool** for preliminary TPS thickness estimation.
- ❑ Emphasize the importance of TPS and the need to understand its role in high-speed flight vehicle design
- ❑ Present verification of the tool using a well-characterized vehicle.

Background & Motivation

- ❑ Recent vehicles such as SpaceX's Starship and NASA's Orion call for the **fundamental understanding of aerodynamic heating** and the materials that withstand it.
- ❑ With the need to push the envelope quickly, high-fidelity **computational fluid dynamics (CFD)** tools **might not be fast enough**.
- ❑ With this need to move forward quickly, a quick low fidelity tool that only requires simple inputs is needed to save time, energy, and most importantly money.



Figure 1. SpaceX's Starship Reentry [1]

Experimental Setup

- ❑ The analysis requires user-defined inputs for **vehicle geometry, flight trajectory, and TPS material properties**.
- ❑ Trajectory inputs consist of Mach number, angle of attack (AOA), and altitude over time.
- ❑ Vehicle geometry may be modeled using either a **fuselage or wing cross-section**. The X-15 wing cross-section was used in this analysis.
- ❑ Material inputs include density, emittance, and specific heat, with Inconel X selected for the present analysis.
- ❑ The current aerothermal modal **assumes flow in chemical equilibrium**.

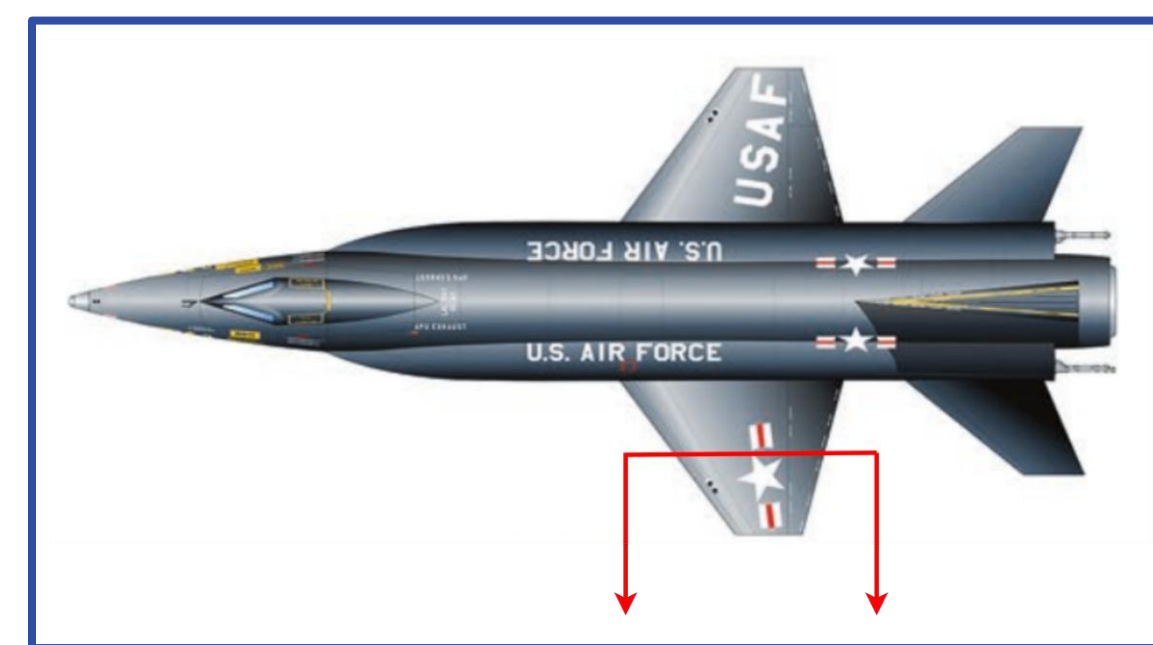


Figure 2. Top View of the X-15 with mid-semispan highlighted [2]

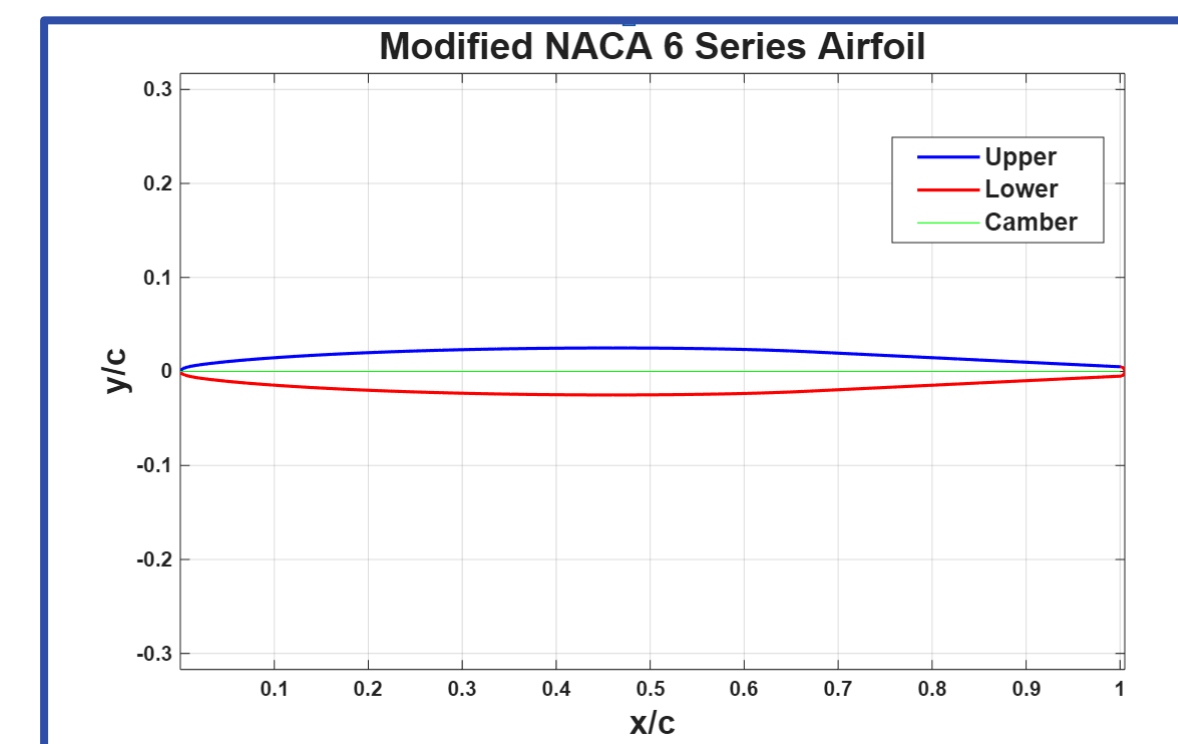


Figure 3. X-15 Airfoil

Experimental Test Plan

- ❑ The user will input the vehicle's established geometry, trajectory, and material properties.
- ❑ The analysis will be run for the selected section with **wall temperature** as the output.
- ❑ The designer will compare the result against the material's allowed temperature.
- ❑ If the material is **within the allowable temperature range**, the thickness is kept and sent to higher fidelity analysis for refinement. If not, **the thickness is reselected** and the **process repeats**.
- ❑ The presented analysis utilizes the known Inconel X thickness values of the X-15's wing [3].

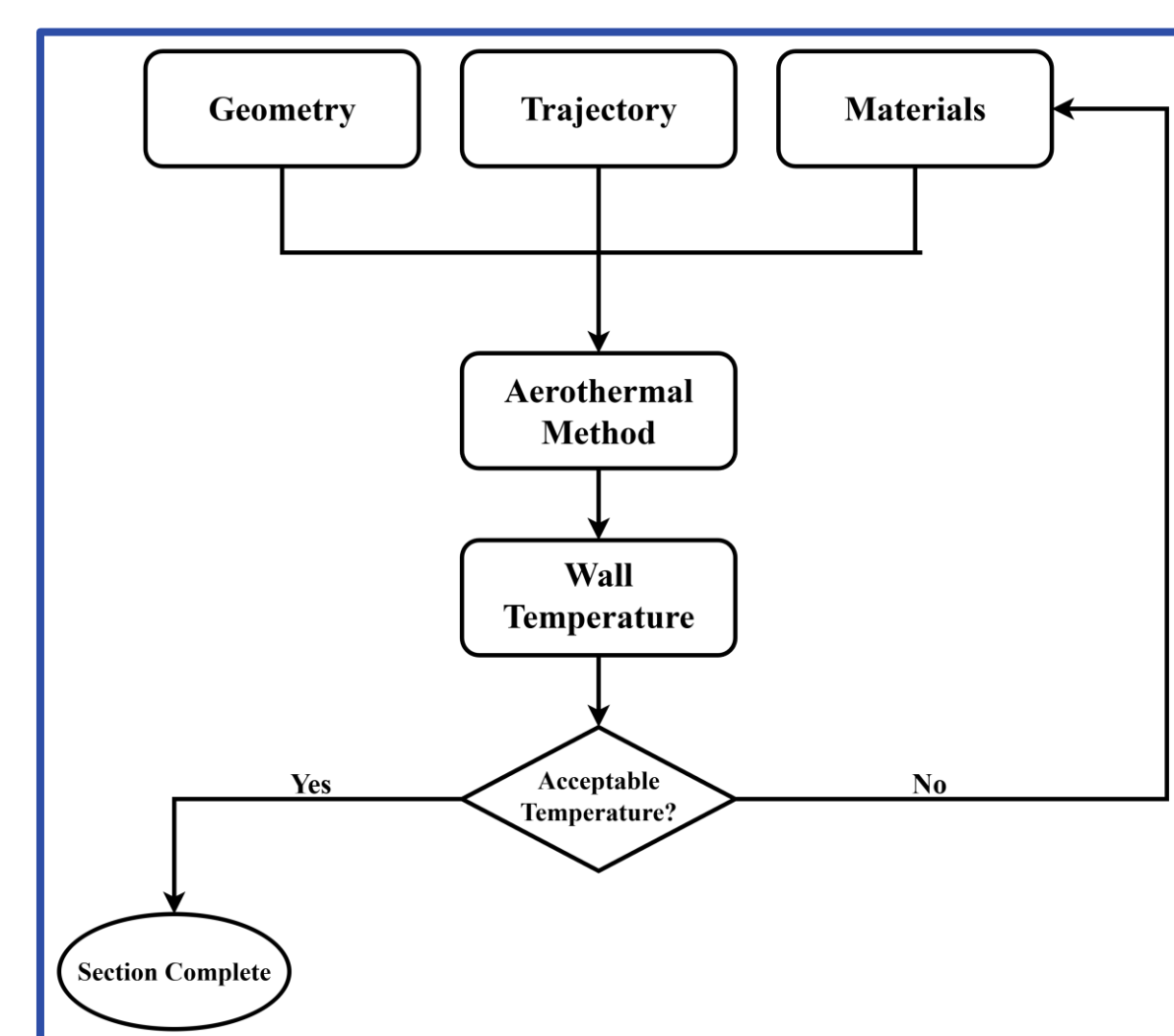


Figure 4. Aerothermal Analysis Program

Wing Station	Thickness [ft]	Material
Stagnation Pt.	0.0053	Inconel X
4% Chord	0.0049	Inconel X
10% Chord	0.0049	Inconel X
20% Chord	0.0045	Inconel X
46% Chord	0.0045	Inconel X

Table 1. Inconel X Thickness on X-15 [3]

Experimental Results

- ❑ X-15 validation results are shown below for **stagnation wall temperature** at the wing tip and multiple locations along the **lower wing surface**.
- ❑ The model demonstrates **good agreement** with the X-15 data [3], capturing the heating trends at the **leading edge, 4% chord, 20% chord, and 46% chord stations**.
- ❑ At the **10% chord station**, the measured trend does not match either the laminar or turbulent prediction, suggesting a possible **transition region** that requires further investigation.

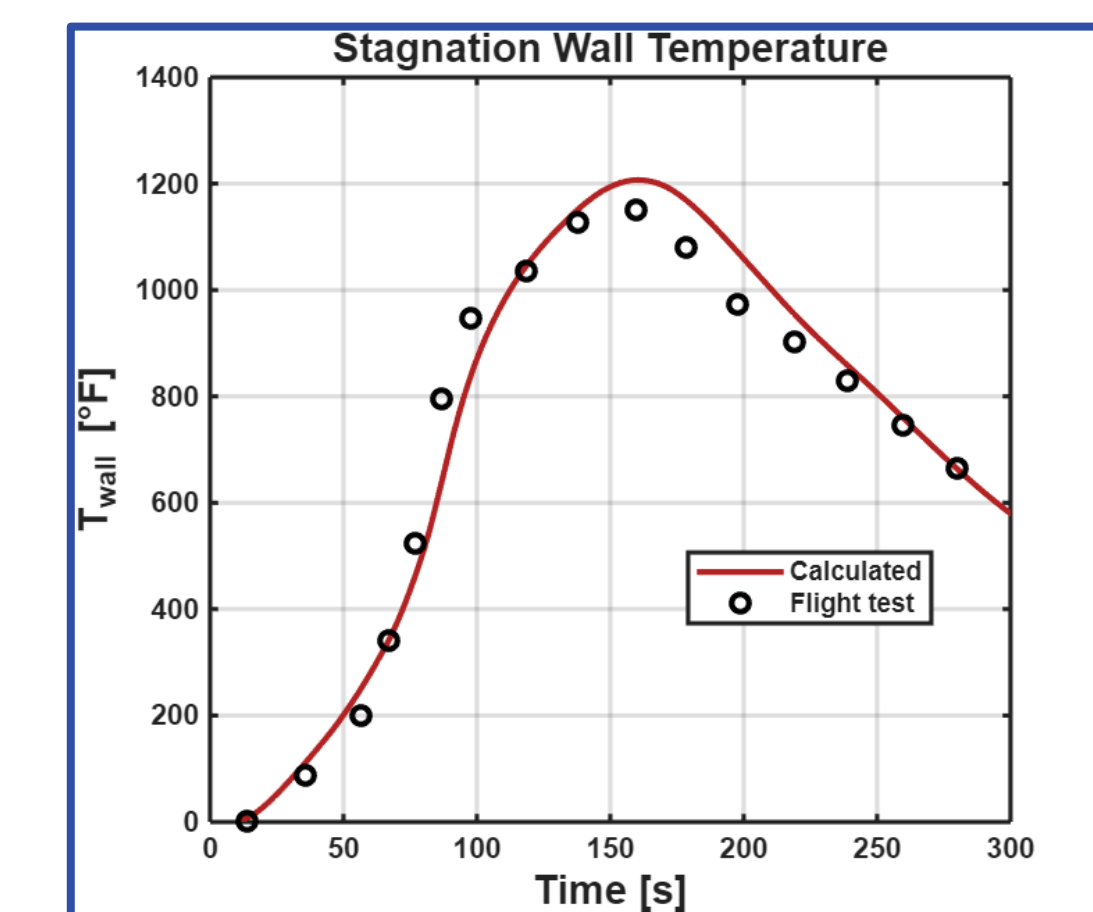


Figure 5. Stagnation Wall Temperature vs. Time

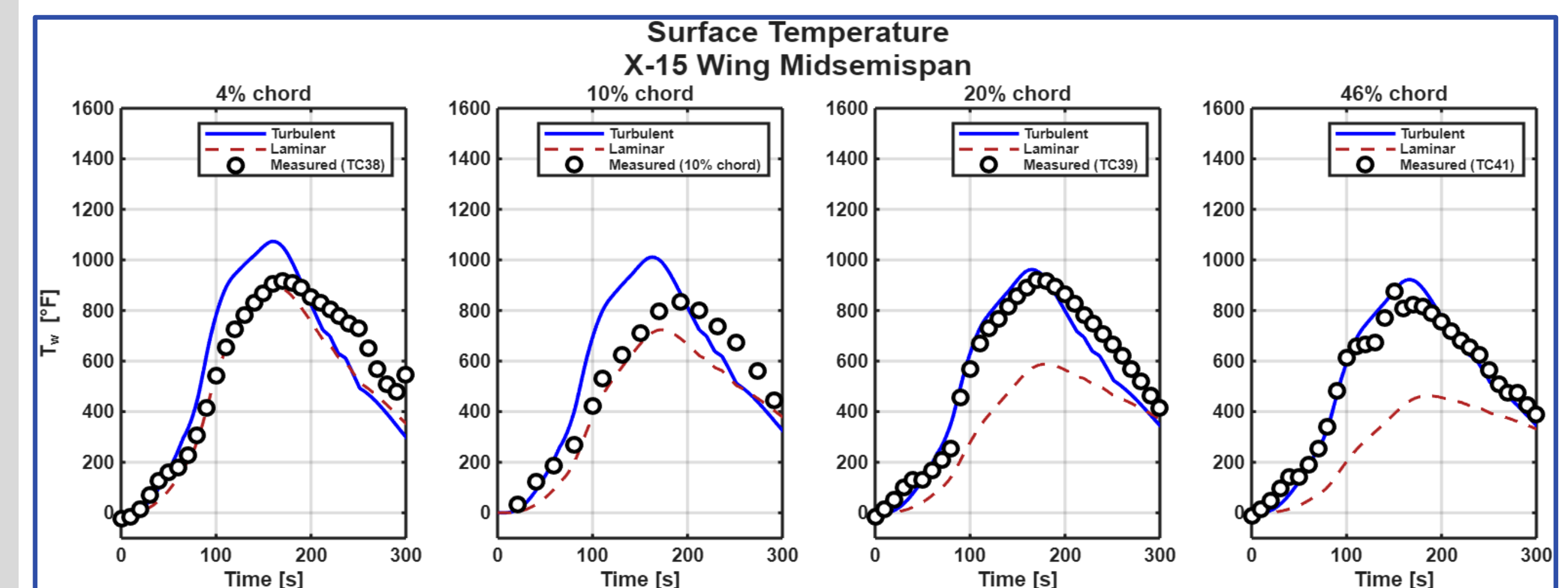


Figure 6. X-15 Wing Bottom Section Wall Temperature vs. Time

Conclusions

- ❑ A **low-fidelity aerothermal/TPS analysis and sizing tool** was developed for preliminary analysis using simple geometric, trajectory, and material inputs.
- ❑ Validation against the X-15 wing showed encouraging agreement at several stations, while remaining discrepancies indicate areas for continued refinement.
- ❑ **Future work** will extend the method to **reentry vehicles** and **capsule geometries** and improve the model physics for broader hypersonic applications.

References

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