

# Aerodynamic & Structural Optimization of Additive Manufactured Rocket Fins

*Lattice-Based Topology Optimization for Lightweight Aerospace Structures*

Venu Jangam, Ramson Nyamukondiwa

International Space University, Illkirch-Graffenstaden, 67400, France

Email: [venu.jangam@community.isunet.edu](mailto:venu.jangam@community.isunet.edu), [ramson.nyamukondiwa@isunet.edu](mailto:ramson.nyamukondiwa@isunet.edu)



## INTRODUCTION

In modern aerospace engineering, the need of maximum payload capacity and fuel efficiency demands ultralight, structurally robust rocket fins capable of enduring extreme flight regimes. While Additive Manufacturing (AM) facilitates the integration of high-performance internal lattice structures, this study employs Truss Topology Optimization (TTO) integrated with real-time Fluid-Thermal-Structure Interaction (FTSI). This approach ensures the design achieves critical hypersonic survivability while adhering to strict manufacturability constraints.

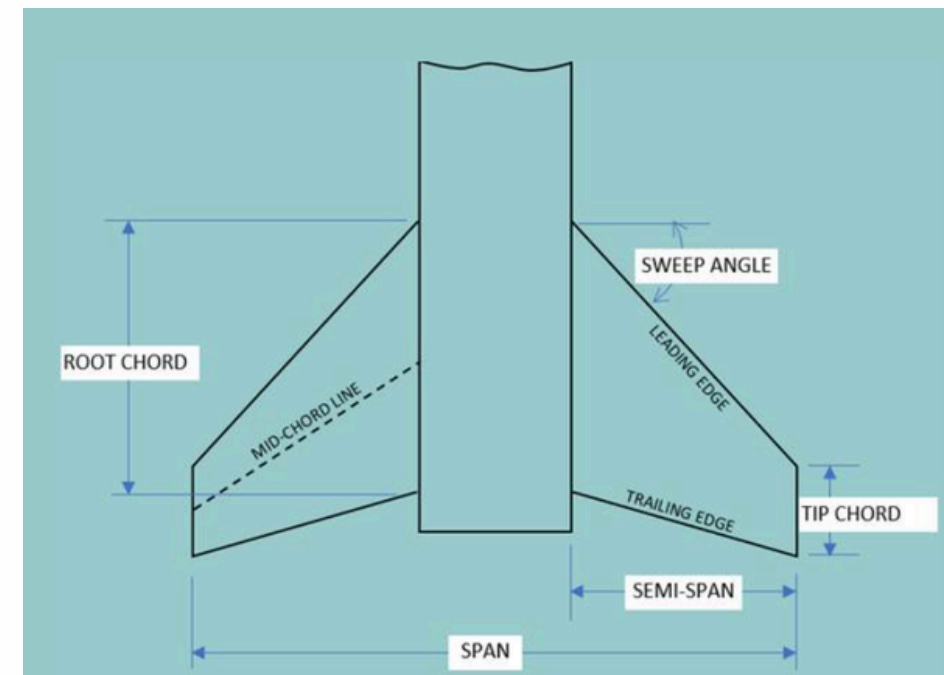


FIG: NOMENCLATURE OF FIN. SOURCE: NAKKA (2024)

## OBJECTIVES

To propose a unified Design for Additive Manufacturing (DfAM) framework that integrates optimization mathematics, aerodynamic heating, and manufacturing constraints into one continuous loop.

## METHODOLOGY

The research integrates four systematic steps to improve control surface design:

- **Aerodynamics Baseline:** It first studies conventional fin behavior and stability requirements, focusing on planform shape, span-to-chord effects, and Computational Fluid Dynamics (CFD)
- **Lattice & AM Evaluation:** Classifying internal structures into strut-based and Triply Periodic Minimal Surfaces (TPMS) while defining 3D printer geometric limitations.
- **Optimization Algorithm Comparison:** Evaluating density-based algorithms (like SIMP) against Truss Topology Optimization (TTO) for ultralight aerospace applications.
- **Multi-Physics Integration:** Applying Fluid-Thermal-Structure Interaction (FTSI) to account for aerodynamic heating and aeroelastic tailoring to mitigate destructive vibrations (flutter)

## GAPS & CHALLENGES

- **No unified framework yet:** Current work on aerodynamics, topology optimization, and additive manufacturing is not well connected.
- **Optimization-method mismatch:** Density-based methods create non-physical gray regions, while TTO can struggle with kinematic compatibility and local buckling in complex structures
- **The "Cold Simulation" Error:** Cold models can underestimate deformation and stiffness loss at high speed
- **Manufacturing constraints are not fully handled:** Self-supporting angles, minimum strut limits, surface roughness, porosity, fatigue reduction, and missing certification standards still make the mathematically optimal design different from the actually manufacturable one.

## RESULTS

- **Truss topology optimization gives the best lightweight solution:** The approach is shown to produce clean, strut-based structures that are easier to manufacture than gray, intermediate-density designs.
- **Kinematic compatibility and local buckling control matter:** When these are included, the optimized lattice is not only lighter but also more stable under compressive loading.
- **Thermal effects change the structural response:** High-speed aerodynamic heating can reduce stiffness significantly, so cold-condition predictions are not reliable for fast flight.
- **Aeroelastic tailoring improves flutter resistance:** Tuning the internal lattice layout can raise flutter speed by about 15%

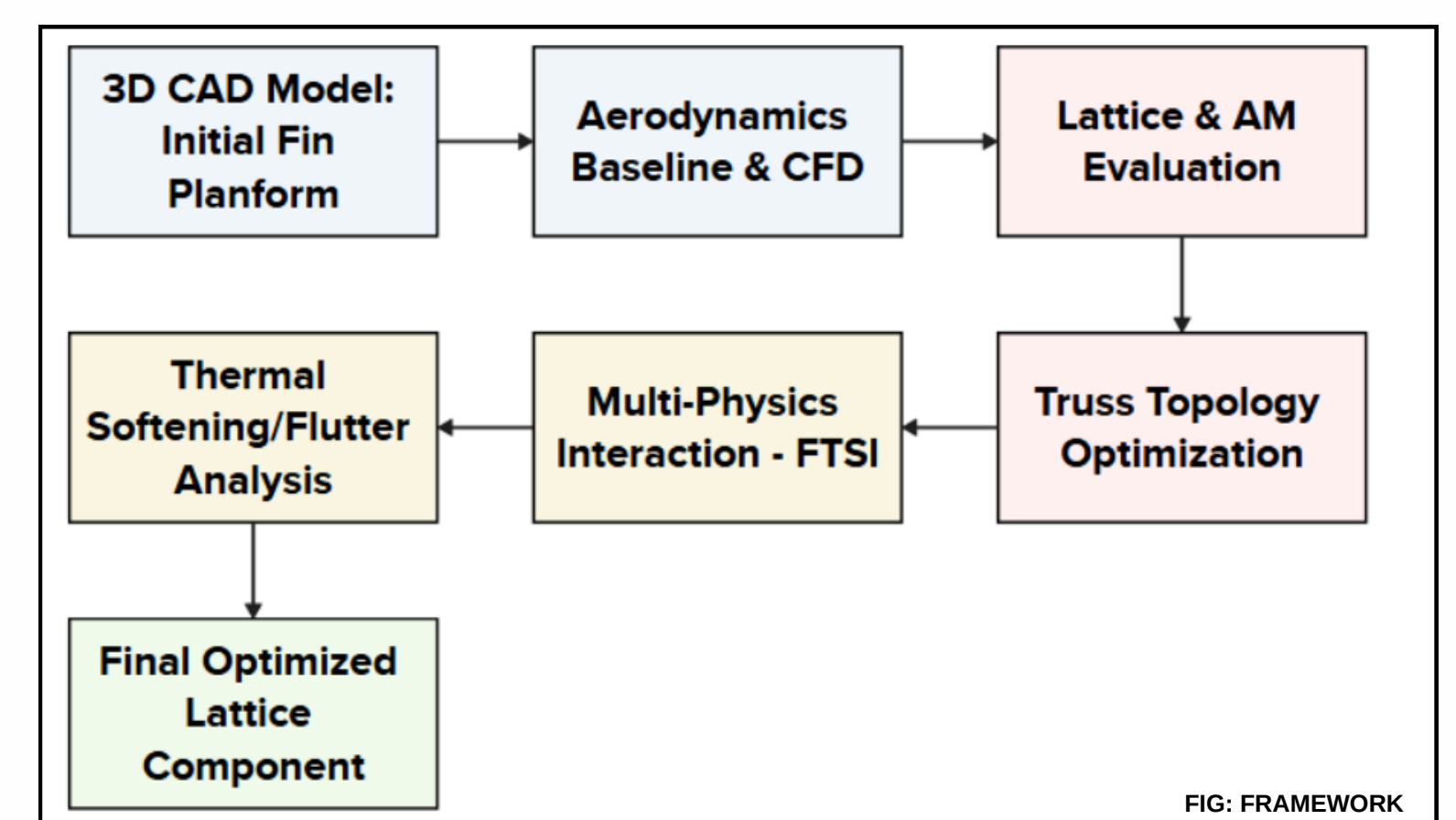


FIG: FRAMEWORK

## FUTURE WORK

- Extend the study to more realistic and diverse test conditions on different aerospace components
- Improve the model or framework to increase accuracy and robustness.
- Include uncertainty analysis or sensitivity testing where relevant.

## CONCLUSIONS

This work demonstrates that Truss Topology Optimization (TTO), when combined with kinematic compatibility constraints and local buckling limits, produces manufacturable strut-based lattice fins that outperform density-based methods in weight savings and structural clarity. Fluid-Thermal-Structure Interaction (FTSI) must be included to correct cold-model errors, as aerodynamic heating at Mach 4+ can increase tip deflections by over 120% due to material softening. The proposed DfAM framework successfully integrates self-supporting angle restrictions ( $<30^\circ$ ), aeroelastic tailoring for 15% flutter margin gains, and defect compensation for AM surface roughness and porosity. This approach creates modular, high-performance rocket fins ready for hypersonic certification and next-generation launch systems.

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