Accelerated Aircraft Prototyping Leveraging CNN's

MIT MANAGEMENT SLOAN SCHOOL

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MIT LINCOLN LABORATORY | OPERATIONS RESEARCH CENTER

1. Background: Lincoln Lab's Flight Test Facility

Designs	Evaluates	Tests
• State-of-the-art airborne sensors • Aircraft modifications	• Aerodynamic performance • In-Flight forces (Drag and Lift)	• Fly new sensors • Improve current aircraft • Validate prototypes


2. Problem: Aerodynamic Analysis is Expensive

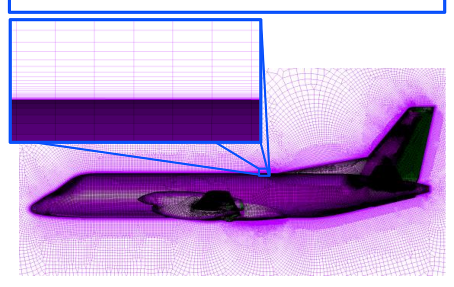
Problem Statement

The time and resources required to assess the aerodynamic properties of new aircraft prototypes is a significant hurdle during the conceptual design phase when design parameters are rapidly changing and the opportunity for design impact is highest

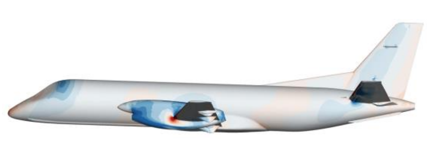
Traditional workflow is labor-, computational-, and time-intensive

Step 1: Simplify outer mold from complex CAD geometry in O(hrs)	Step 2: Build high-quality, watertight mesh in O(days)	Step 3: Run aerodynamic analysis on super-computer aerodynamics in O(days)

Base geometry



O(10) million cell mesh



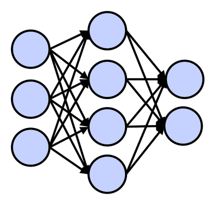
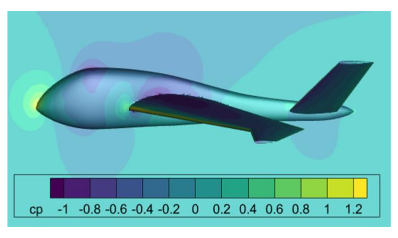
Drag obtained by integrating forces over the aircraft

3. Goal: Accelerate Aerodynamic Analysis

Objective

Improve aerodynamic analysis through an automated workflow, leveraging a machine learning framework and expanding the current 3D aircraft model training dataset

Dataset of 3D Aircraft → Machine Learning Framework → Predict Flow Field → Derive Quantities:

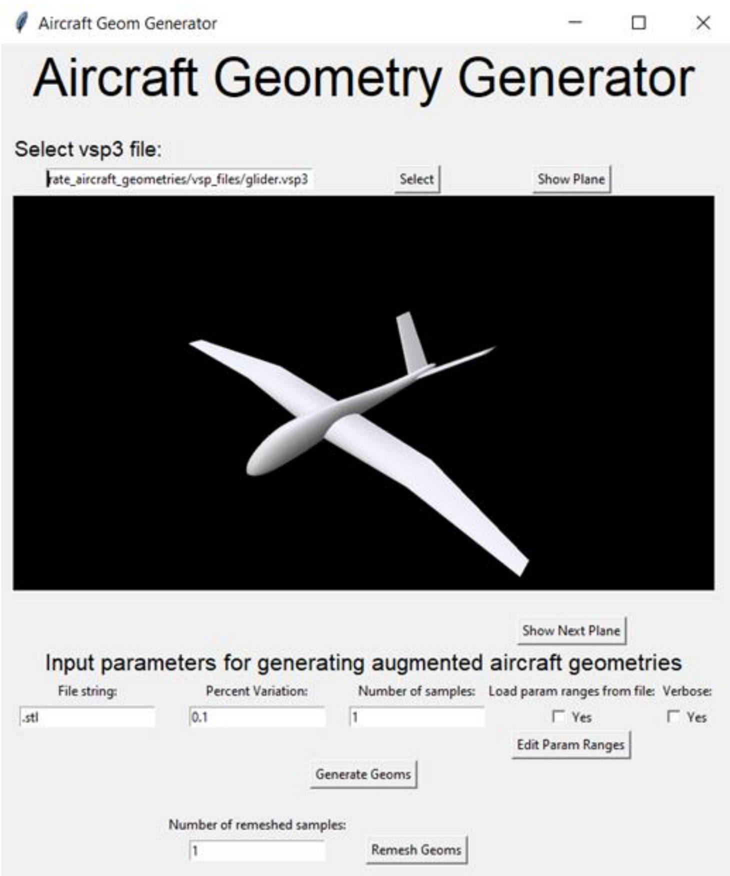




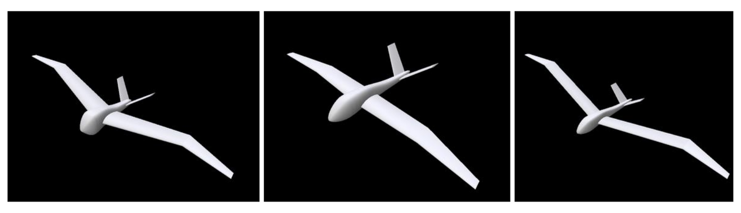
Derive Quantities: $C_D = 0.75$, $C_L = 15$

4. Solution Part I: Aircraft Data Generation Tool

The Need for a Diverse 3D Aircraft Dataset

- A diverse dataset of aircraft models is necessary to train a generalizable fluids model
- Lincoln Laboratory requires a database representative of most Air Force aircraft
- Certain design parameters are more important to aerospace engineers than others





Aircraft Geometry Generation Tool

- Takes in any aircraft model (OpenVSP)
- Can generate 1000's of new geometries
- Latin hypercube sampling of design parameters
- Can leverage open source community

User Specifications

- GUI and command line functionality
- Input ranges or a percent variation for critical aerodynamic parameters
- Remeshing feature enables flexibility in defining object granularity

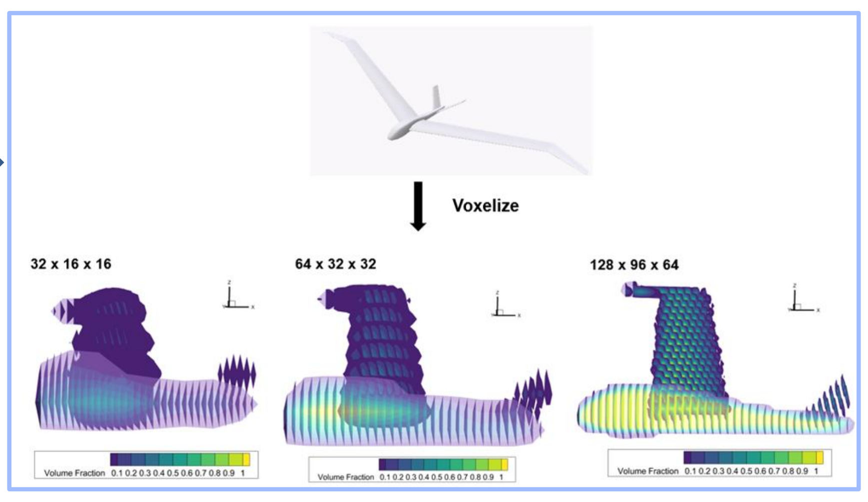
Editable Parameter Ranges

1. Fuselage length to average diameter ratio
2. Fuselage cross-section shape
3. Wing and stabilizer
   4. Aspect ratio
   5. Taper ratio
   6. Airfoil thickness
   7. Dihedral angle
   8. Twist angle

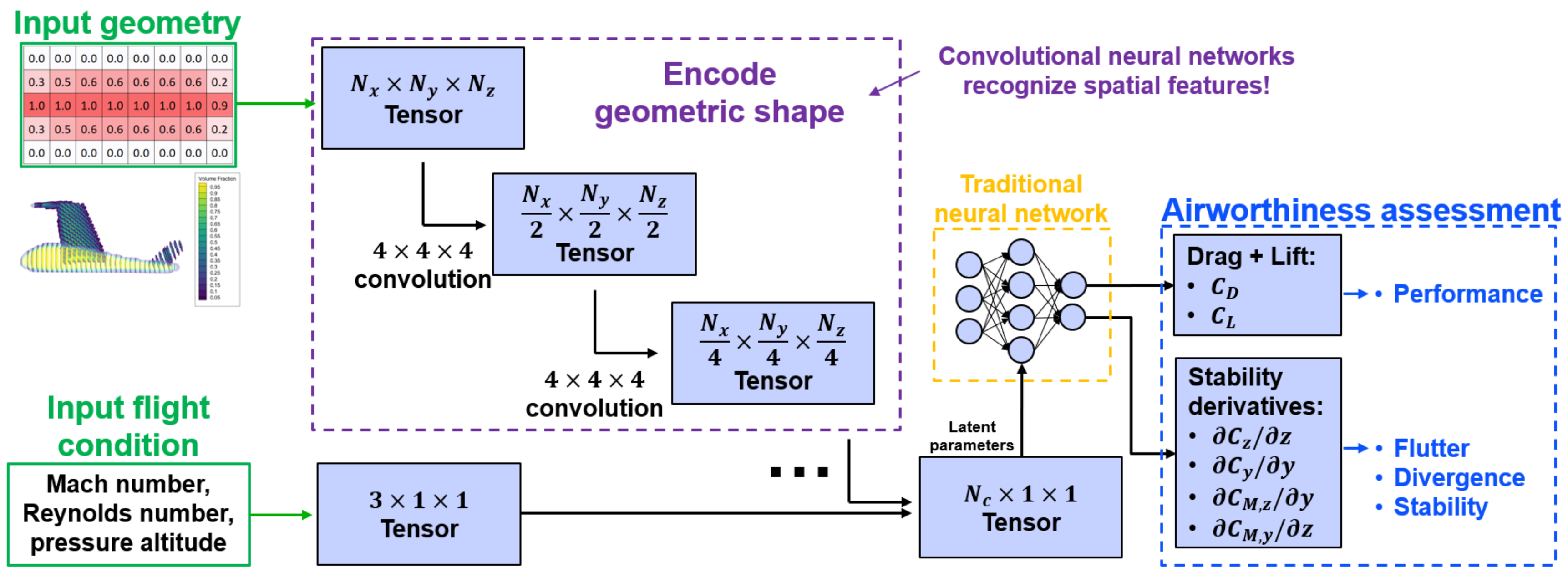
5. Solution Part II: Using Convolutional Neural Networks to Predict Aerodynamic Values

Methodology

- Voxelize geometry into 3D volume tensor
- Different resolutions impact input data
- Concatenate with flight conditions to predict aerodynamic quantities

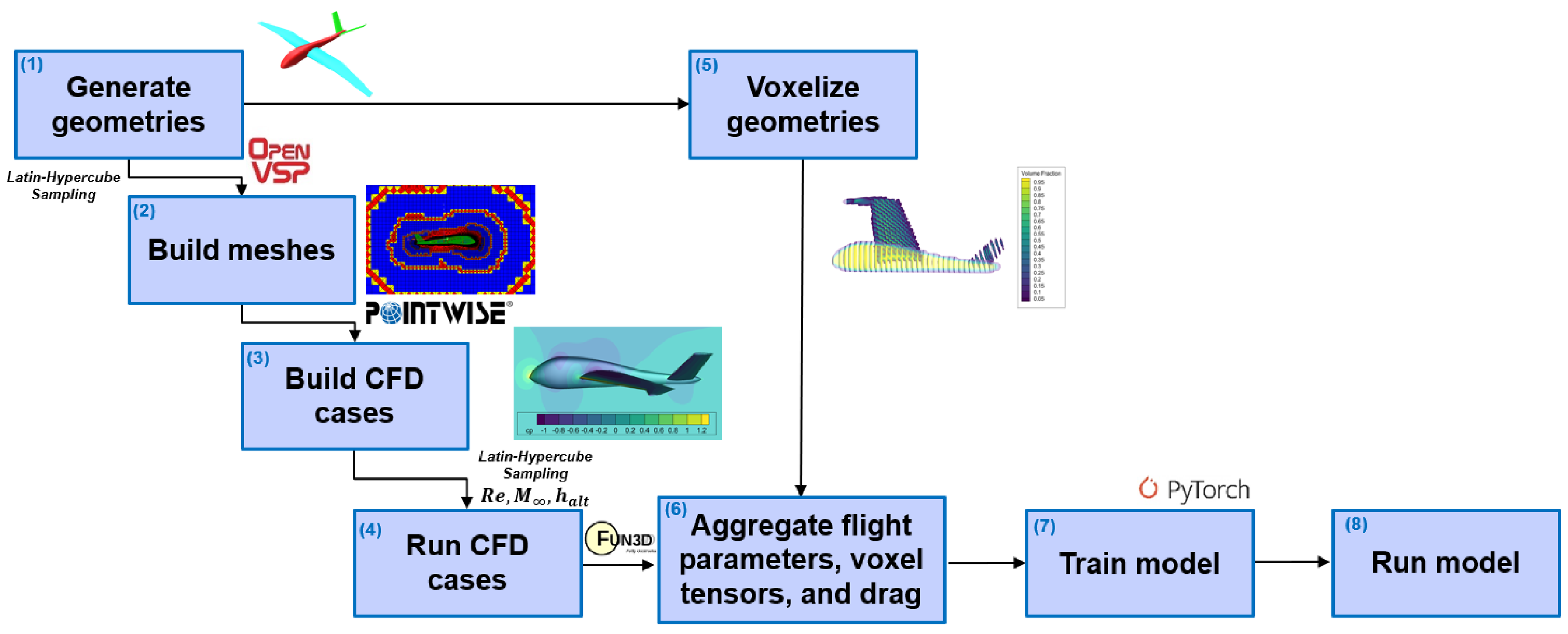


Example Neural Network Architecture



Convolutional Neural Network learns nonlinear relationship between drag for a given geometry and Mach, Reynolds number, and altitude

Training Process Overview



**Ground truth aerodynamic values are obtained from simulations on the GPU accelerated laboratory super computer (90 min each) that require computational meshes (4 min each)*

Experiments

- Trained and evaluated models for numerous volume fraction resolutions
- Tested model performance and documented results at different case turbulence tolerances
- Extensive hyper-parameter tuning over various network architectures

6. Impact: Efficient Aerodynamic Analysis

Aircraft Augmentation Tool	Aerodynamic Analysis Predictions	Accelerated Aircraft Prototyping
Time savings: O(hrs) ⟶ O(sec)	Time savings: O(days) ⟶ O(sec)	Fuel savings
User friendly & deployable	**5000x** speed up for analysis	Greater time-on-station
Exploration into previously unconsidered configurations	Enables more efficient designs	**98%** reduction in computational cost

7. Multidisciplinary Innovation

Lincoln Laboratory

- Potential for design optimization
- Approach can be expanded to other disciplines
- Digital aircraft dataset is widely desirable

Engineering Community

- Planning to open source aircraft augmentation tool
- Interest from multiple research efforts