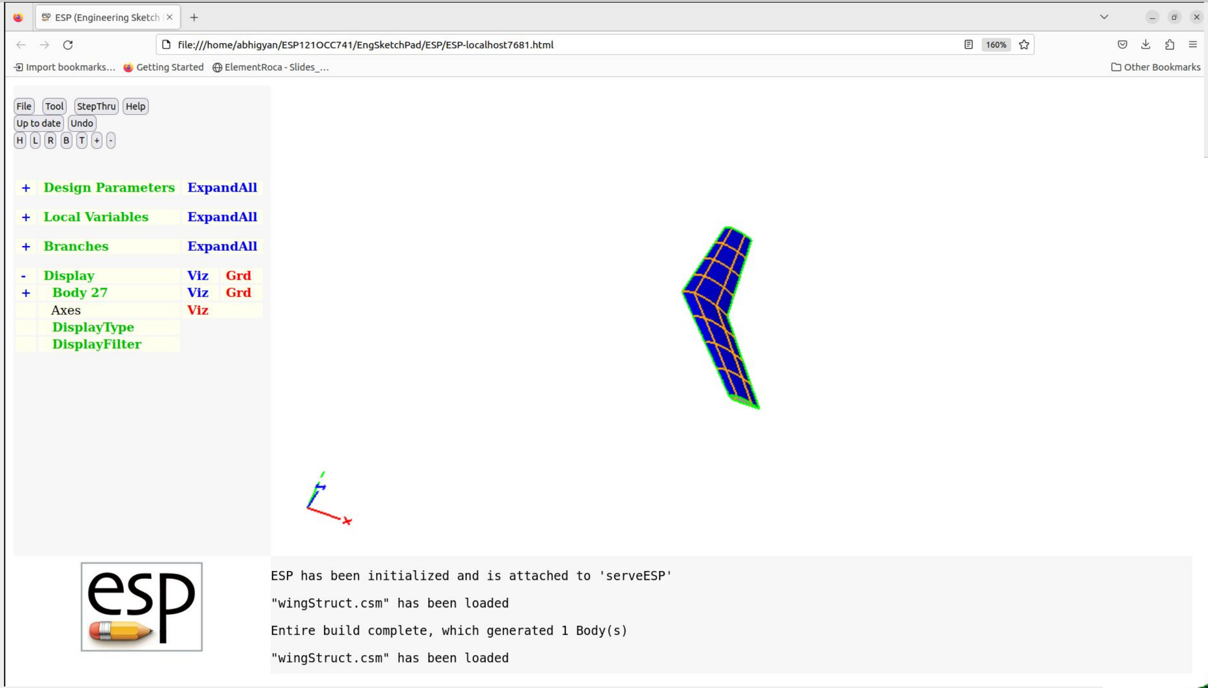
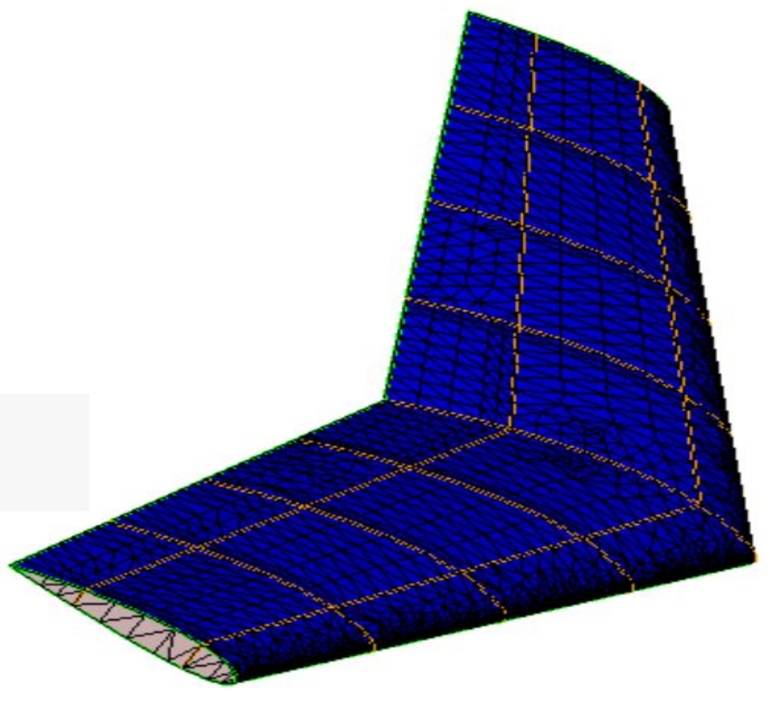
Engineering Sketch Pad





https://acdl.mit.edu/ESP/

Geometry in CFD

The current use of geometry in **design** processes is **ad hoc** and often consists of various tools. Conceptual Design tools **suggest** the shape but **do not realize** 3D geometry. Some disciplines have early-stage specialized tools that build 3D parametric models, but they do not consider the larger multidisciplinary design. Some disciplines remain "geometry free" during design, resulting in errors and a different final realized geometry.

A single, multidisciplinary geometry modeling system is needed to support complex geometric requirements in later stages. The system should generate geometries that do not need fixing or repair, and output the designed geometry seamlessly for commercial CAD systems to import the model without loss of accuracy in the shapes represented.

Relegating commercial CAD to the end of the design process may be surprising, but its focus has been, and is, manufacturing, not analysis. The current state of affairs is partly due to the focus on manufacturing rather than analysis.

Use of Geometry in Meshing

- A gap exists between creating geometry and analyzing geometry. This is due to the process first creating the geometry, then transferring the geometry information from a CAD-based geometry to a meshing tool, and then finally to the appropriate analysis tools.
- The usual connection between high-fidelity analysis codes and geometry is performed by a grid generator.
- 3D meshing software ultimately requires topological information to realize a closed “watertight” model.
- Each instance of the Master-Model/Feature tree is a BRep. Boundary Representations (BReps) are the standard data model that holds both the geometric and topological entities that supports the concept of a “solid”.
- The topology is directly related to both the design intent of the Feature Tree and the construction methods of the underlying CAD system.
- BReps have a tolerance that determines the meaning of “closure” for connected entities.
- To deal with gaps and overlaps without a program halt which then requires intervention, we can either “fix” the geometry or the Breps created.
- Currently, most BRep-based applications “fix” the geometry by representing the the geometry definition in a different manner. This causes various side effects like inconsistencies, errors, complexity and this process itself is not automatic, hence it needs to be done manually and thus, is time consuming.

A CAD-based Approach

There has been tremendous progress since early CAD softwares but there are still some drawbacks for its usage in the MDAO environment.

<u>Pros</u>

- Defeaturing for design progression and multi disciplinary process
- Consistency in design process (using same suite of parameters)
- Ability to take feedback to make corrections due to parameterisation

<u>Cons</u>

- Expensive CAD licenses
- Geometry files incompatible with mesh generators and must undergo tedious “CAD healing” during the meshing process
- Redesigned geometry alterations for different disciplinary analysis is likely to conflict with the definitions of the original geometry
- Proprietary formats that are hard to generate and modify externally
- Specialized construction not available as primitives are pre-defined (inability to create fully-parametric user-defined primitives)
- Incompatible parameterisation
- Very scarce training for using Parametric CAD in MDAO

<u>File Formats</u>

Each CAD system or geometry kernel uses a different mathematical formulation to represent the same types of surfaces, and also have different tolerances for closure. Therefore, while transferring data it may be found that the model may be open now again and need patching.

- IGES file format contains data that is defined as disjoint and unconnected surfaces and curves, with no explicit notion of topology.
- STEP file format supports topology as well as geometry. This format is seldom used in practice as constructing a STEP reader is complex and requires a complete solid modeling geometry kernel to deal with the data.
- STL combines a discretized view of the Brep as well as its geometry and topology can provide a complete, and easier to use, access point. (Needs further study why its not used in flow analysis)
- EGADS
- NMB

Objectives

- To support the entire Multi-Disciplinary Analysis and Optimization (MDAO) process from conceptual to detail design in a seamless manner, as well as multi fidelity analysis.
- To make the process user-friendly and support for automation to minimize unnecessary or repetitive human effort.

Current methods to achieve these objectives is Constructive Solid Geometry (CSG) using Conceptual Design tools; this is the natural foundation on which the modelling techniques are based, allowing flexibility in creating complex structures from simple components.
Next, a combination of 2 approaches is used - CAD systems and their “feature” based view of construction, and Bottom-Up methods which generate solid “components”.
To realise the MDAO objectives via the Bottom-Up approach, EGADS, a new software suite is built as well as entire ESP architecture, which is explained next.

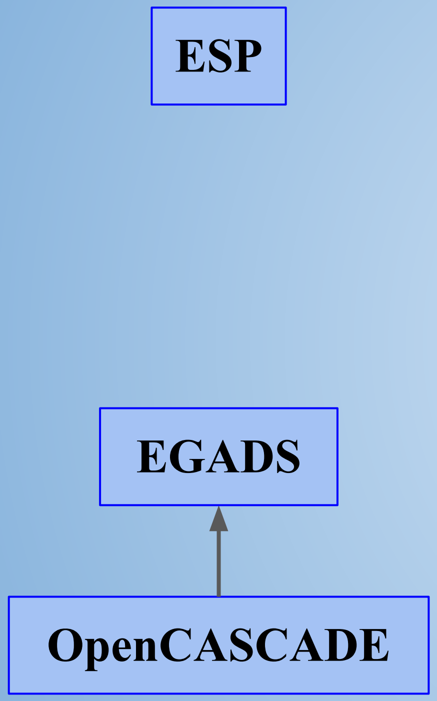
Parts of ESP Architecture

ESP

OpenCASCADE

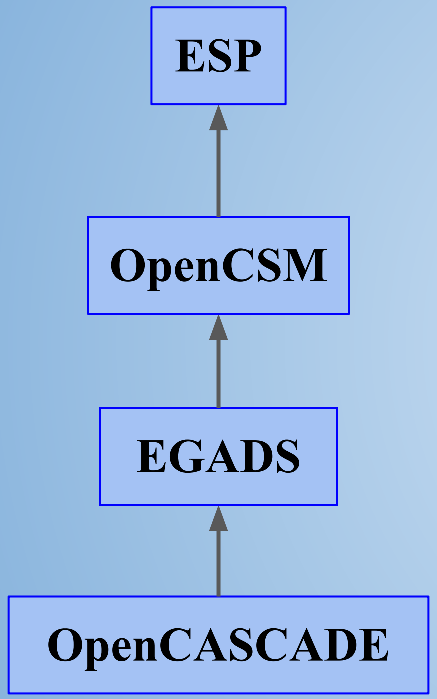
- OpenCASCADE
  - Fully functional Open-Source Solid modeling geometry kernel
  - Creates geometry primitives and generates BRep model
  - Performs Bottom-Up construction and CSG operations
  - Fully Object-Oriented C++ API

Parts of ESP Architecture



- EGADS (Electronic Geometry Aircraft Design System)
    - Open source, object-Based software built on top of OpenCASCADE
    - procedural-based API reducing the level of programming complexity and the huge suite of methods of OpenCASCADE
    - Full support for current platforms and can be driven by multiple user applications
    - outputs STEP file as well as native EGADS format

Parts of ESP Architecture



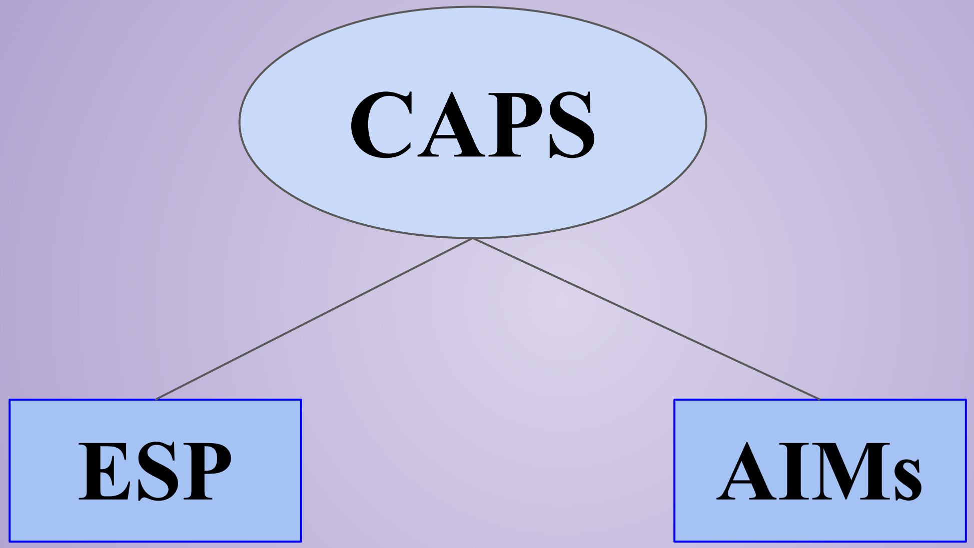
- OpenCSM is built on EGADS
  - Parameters each having unique names are all stored as two-dimensional arrays of floating point numbers (parameters can either be external or internal)
  - Feature trees are defined in terms of a binary-like tree of branches. Each branch has an associated type which describes the operation to be performed. Branches can have zero to two parents.
  - While not strictly object-oriented, the API has been designed in an object-based manner, making it directly interfacable with object-oriented systems
  - Extensible via user-defined primitives and directly provides sensitivities

ESP

ESP is a browser-based system at the top of the architecture which provides the user the ability to interact with a configuration by building and/or modifying the design parameters and feature tree that define the configuration.

- Captures the design intent in a simple, easy to read, nonproprietary text file (ASCII) that is **easily modifiable** by any other component in an MDAO environment, *viewed in a web-based GUI.*
- Supports **easy integration** into a larger process by *allowing geometry import/export using file standards* (either discrete or analytic) and **direct connections** to a number of 3D grid generators, *preventing loss of critical information when the standard does not support the data in the current available systems.*
- The ability to easily add **customized features** to the system. (UDPs)

- Provides **attribution at all levels**, which is an *essential capability when one wants to connect (in a multi-disciplinary way) the various parts of the various representations.*
- Supports the generation of **multiple models from the same parameterization** and provides for **Backward compatibility** *due to non-sequential design workflow (**Phase**).*
- **Open-source** and is not encumbered with any licensing restrictions. **CAPS** libraries through **AIM** plugins enables an MDAO environment freely.
- Provides **analytic parameter sensitivity** (for much of the build), making it *suitable for the gradient-based optimization processes that are frequently used in MDAO* environments. The sensitivity of any part of a configuration with respect to any design parameter.



CAPS stands for "Computational Aircraft Prototype Syntheses". It is an infrastructure for multifidelity, multidisciplinary modeling that can be integrated within a framework. CAPS enables physics-based design by analysis and manages the flow of information between the geometry subsystem, various analysis interface modules (AIMs), and the environment driven by an external design process.

CAPS API

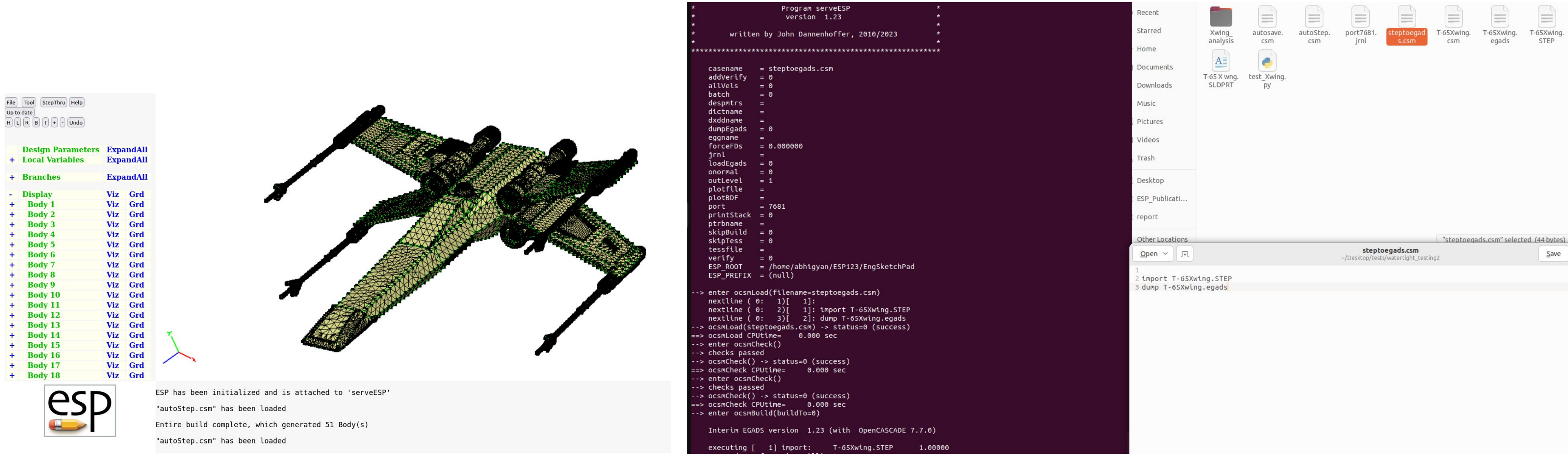
- Enhances automation by tightly coupling analysis with geometry and allow interdisciplinary analysis with “field” data transfer and also does not replacing optimization algorithms
- Provides the tools and techniques for generalizing analysis coupling like in multidisciplinary coupling and multi-fidelity coupling
- Provides the tools for rigorously dealing with geometry (single and multi-fidelity) in a design process where OpenCSM connects design parameters to geometry and CAPS itself connects geometry to analysis tools.
- It hides all of the individual analysis details but **does not** make analysis tool a “black box”
- Intends to input and attribution driven automated (not automatic) meshing

Analysis Interface Module (AIM) is used to interface between CAPS framework and analysis tools

Low Fidelity	**Structural Analysis**	**Meshing**	**3D CFD**
- AWAVE - FRICTION - AVL - XFoil	- Masstran - MYSTRAN - NASTRAN - ASTROS - TACS	*Surface* Native EGADS AFLR4 *Volume* TetGen AFLR3 Pointwise	Cart3D Fun3D SU2

- Supports **easy integration** into a larger process by *allowing geometry import/export using file standards* (either discrete or analytic) and **direct connections** to a number of 3D grid generators, *preventing loss of critical information when the standard does not support the data in the current available systems.*

model is watertight after importing from external sources



Step by Step Process of a Designing a Wing in ESP Integrated Environment

Including CFD Simulation

Each step is a Phase.

Geometry Creation

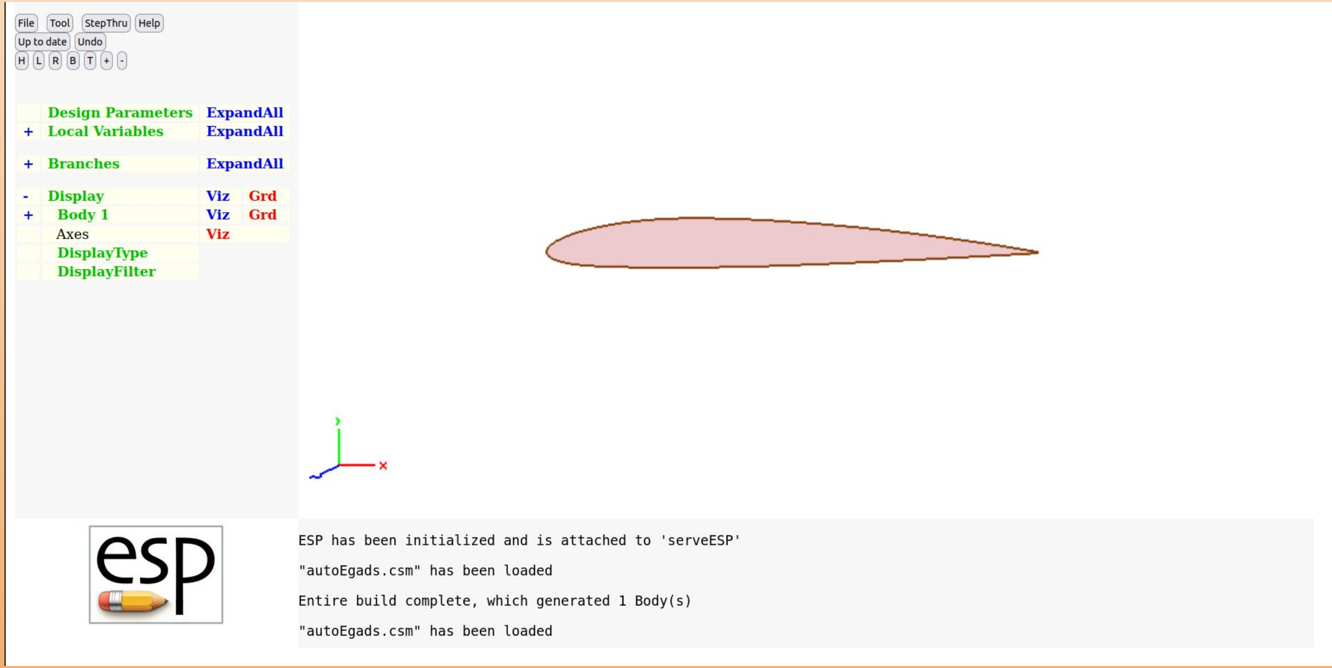
using Low Fidelity Analysis tools

Attribution

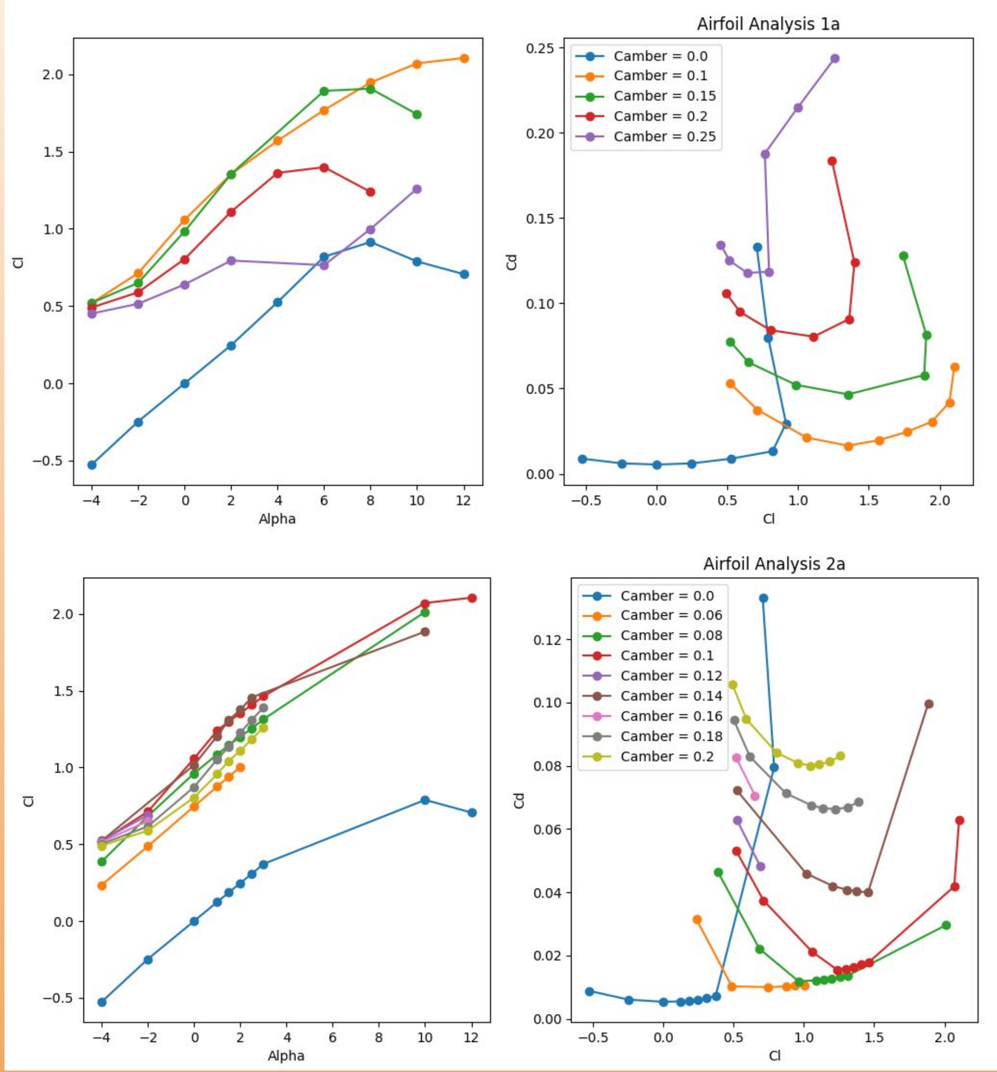
I. Airfoil Section

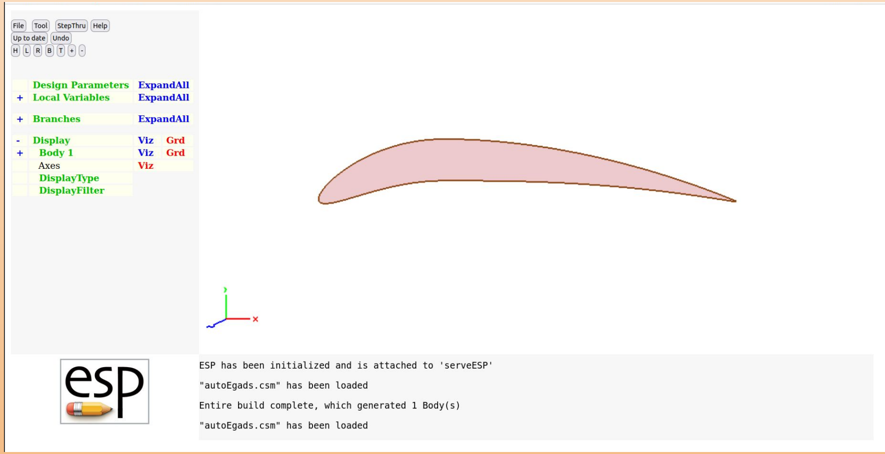
https://web.mit.edu/drela/Public/web/xfoil/

Using **Xfoil**, to generate naca airfoil of appropriate characteristics optimised with respect to Cl/Cd values

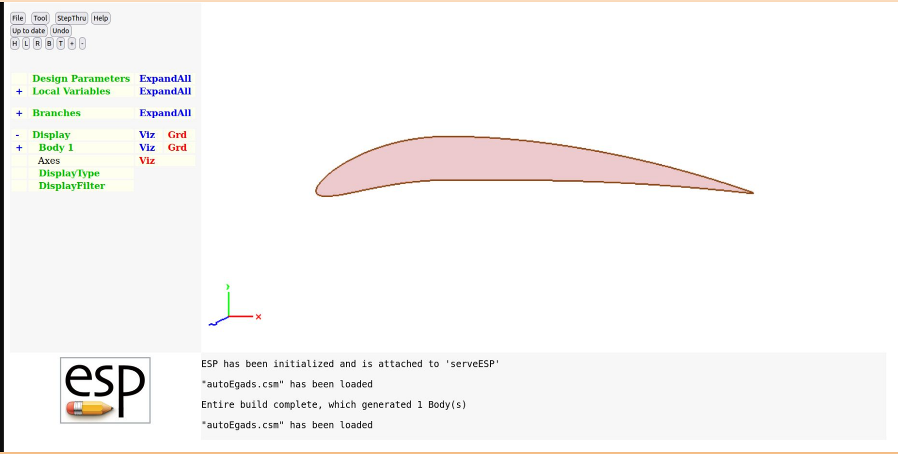


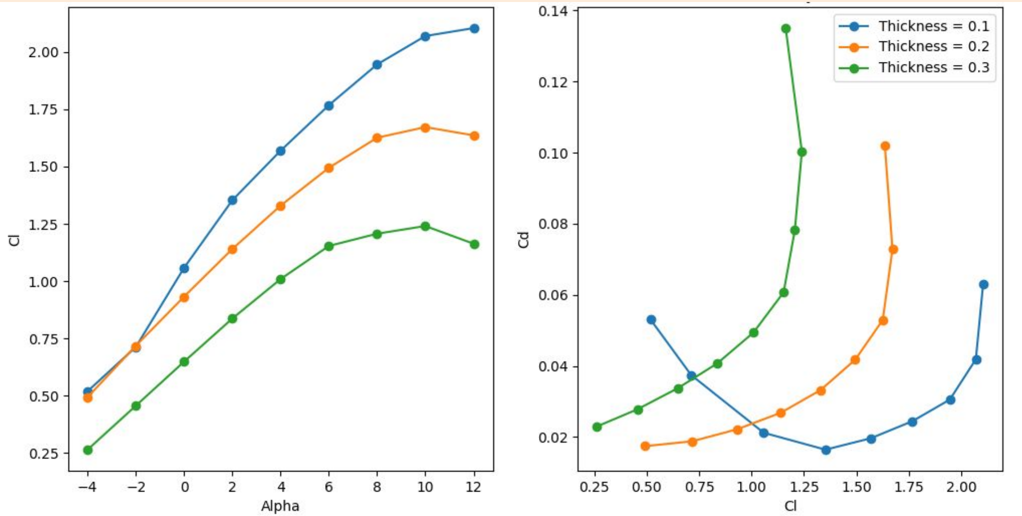
Camber Calculations

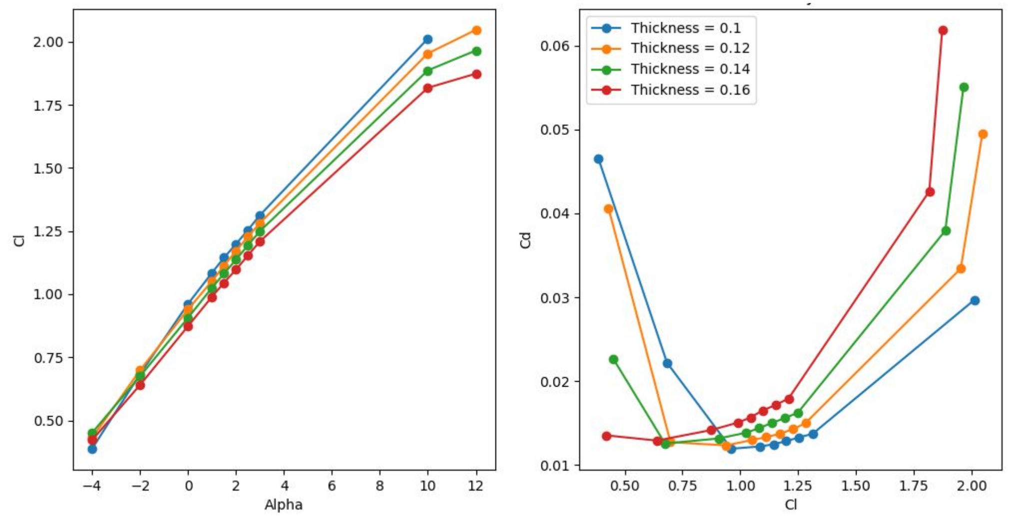


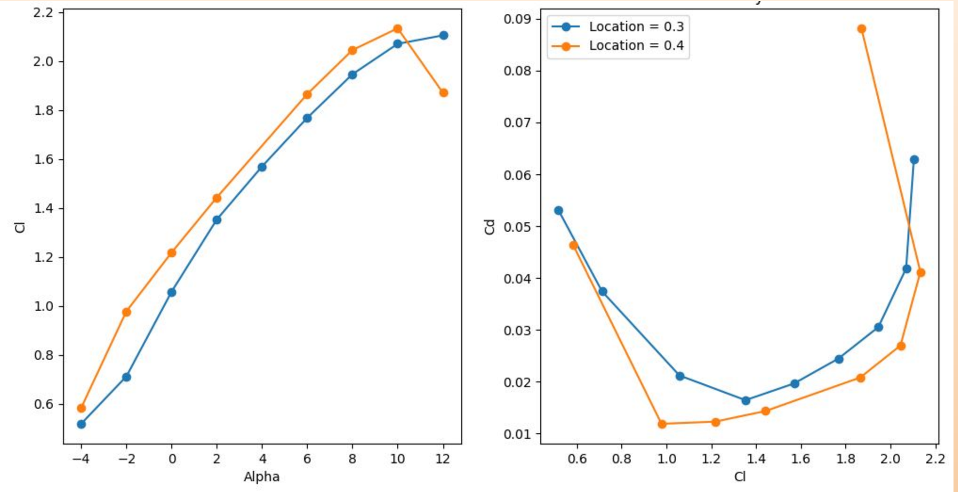


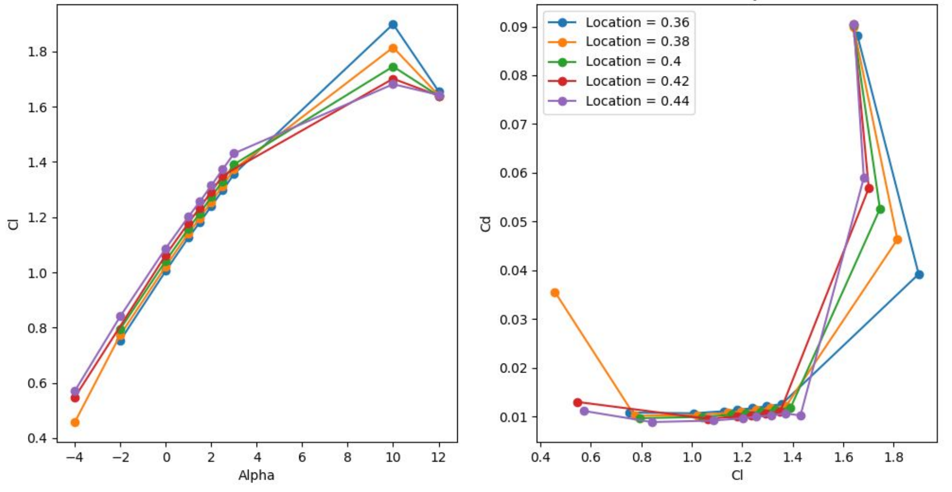
Maximum thickness Calculations

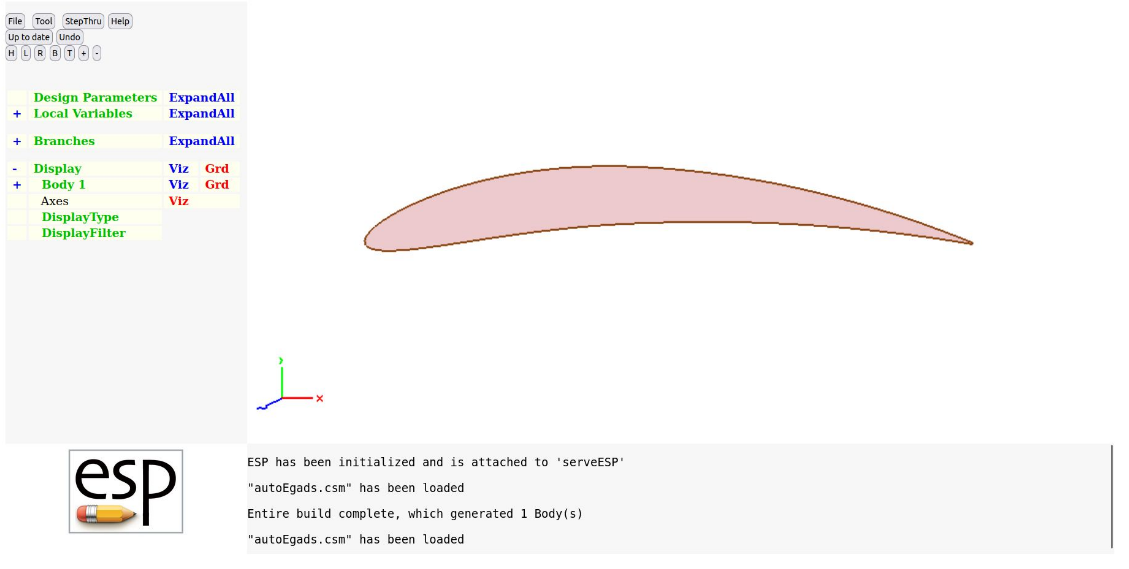












Location of Maximum camber Calculations

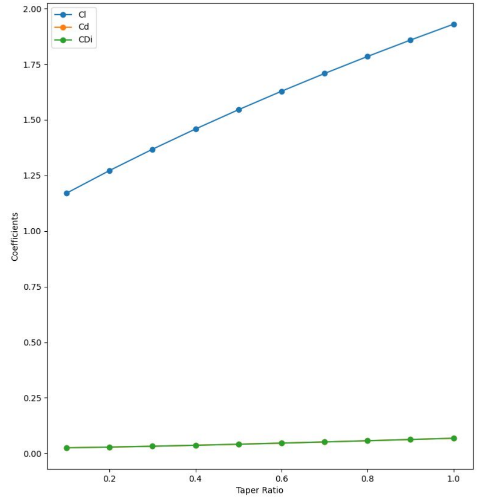
MSES code could be used for shape optimisation after Xfoil analysis.

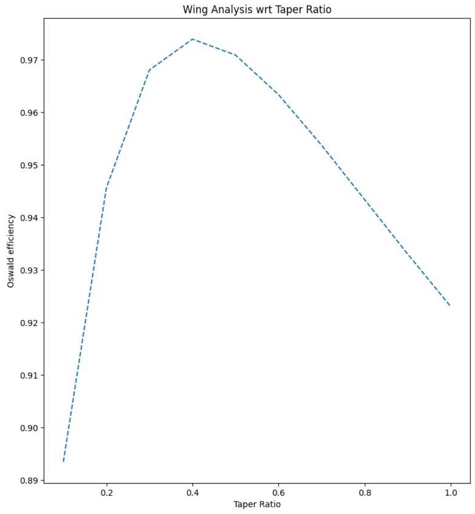
II. Wing

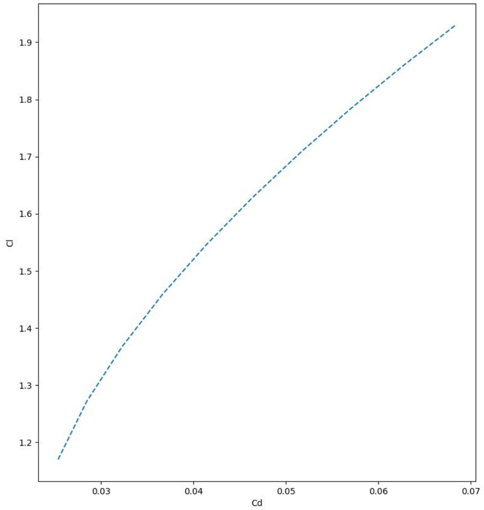
https://web.mit.edu/drela/Public/web/avl/

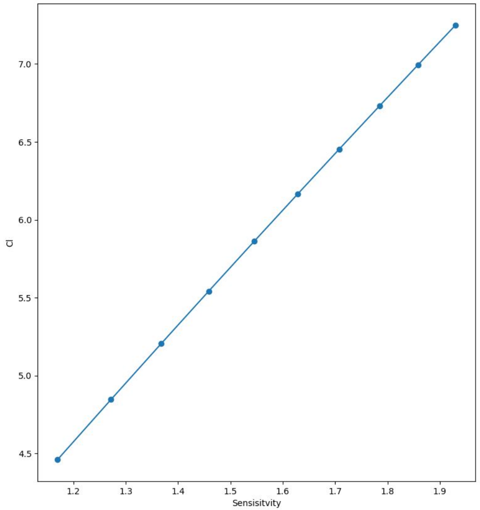
Using **AVL**, to generate wing of appropriate characteristics optimised with respect to taper ratio

Wing Optimisation









Structural Analysis

Various software analysis suites like masstran and MYSTRAN can be used to optimise the material composition, integrity as well as other structural characteristics of the model, especially the fuselage.

Sensitivities

What is sensitivity? Why is it important?

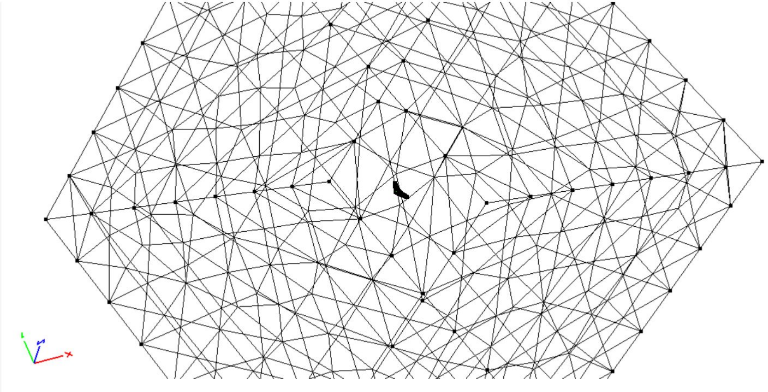
Sensitivity is the gradient of the objective and constraint functions with respect to variables of the environment (like design).

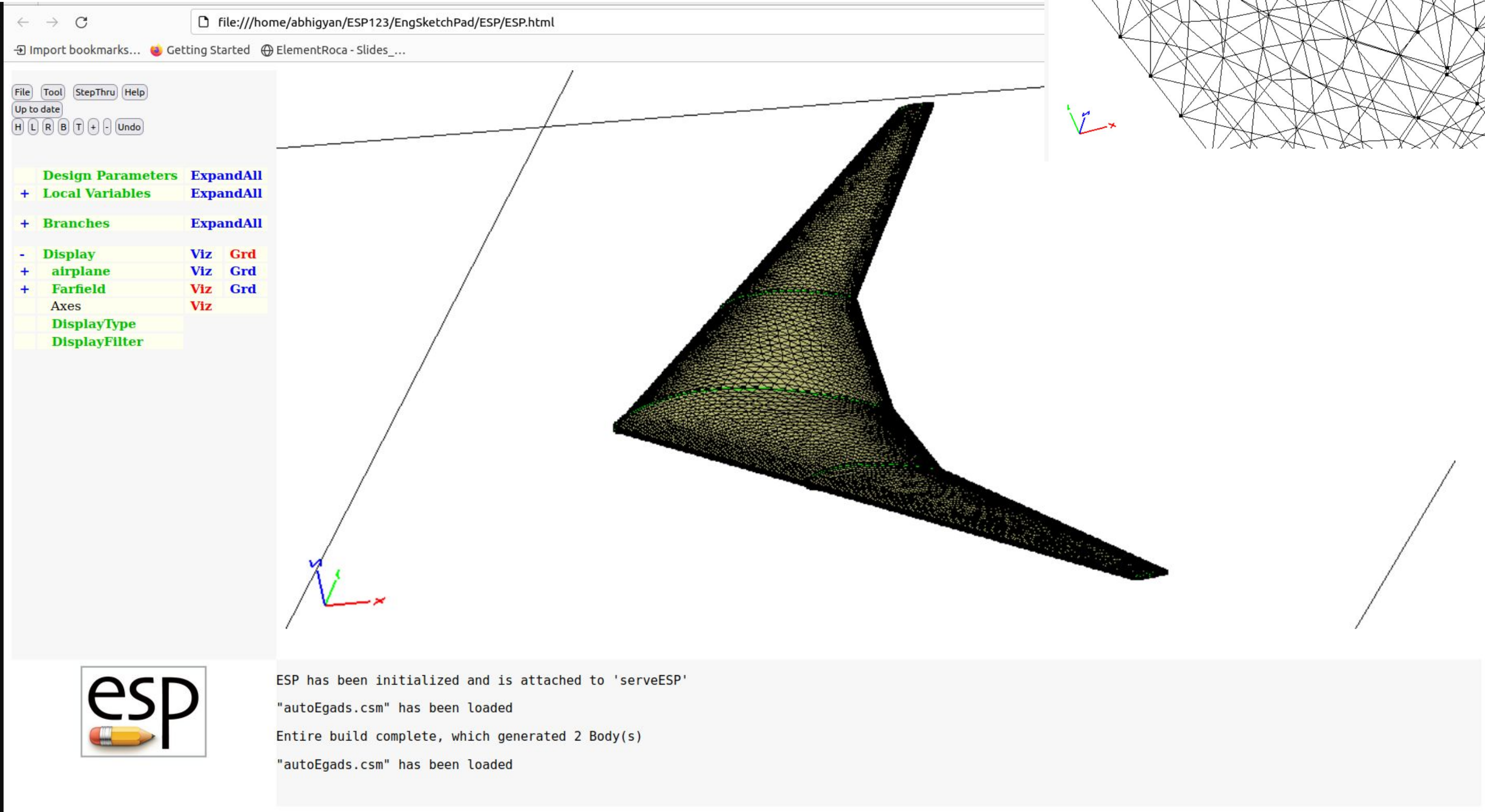
It is important so that we can verify the accuracy our results (like to reduce spatial discretization errors).

One major goal is obtaining sensitivities of output functionals to CAD design parameters. Among the various proposed methods, the Computational Aircraft Prototype Syntheses (CAPS), shipped with Engineering Sketch Pad (ESP), caught the interest of the researches due to its demonstrated capability to construct solid geometry from CAD-like parameters, calculate parametric sensitivities, and handle geometric constraints efficiently. In addition, this framework includes APIs to flow solvers like SU2 and meshing packages, allowing efficient field data communication among the geometry builder, meshing software, and SU2 solver to calculate parametric sensitivities.

Mesh Generation

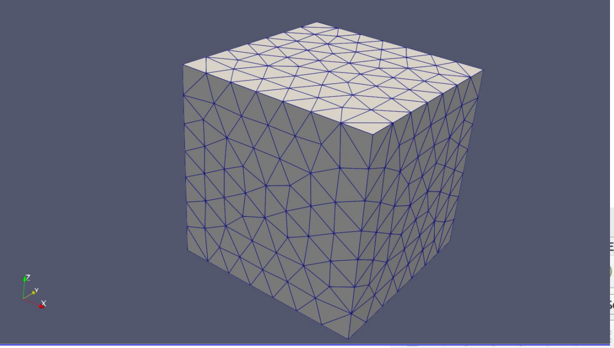
I. Surface Meshing



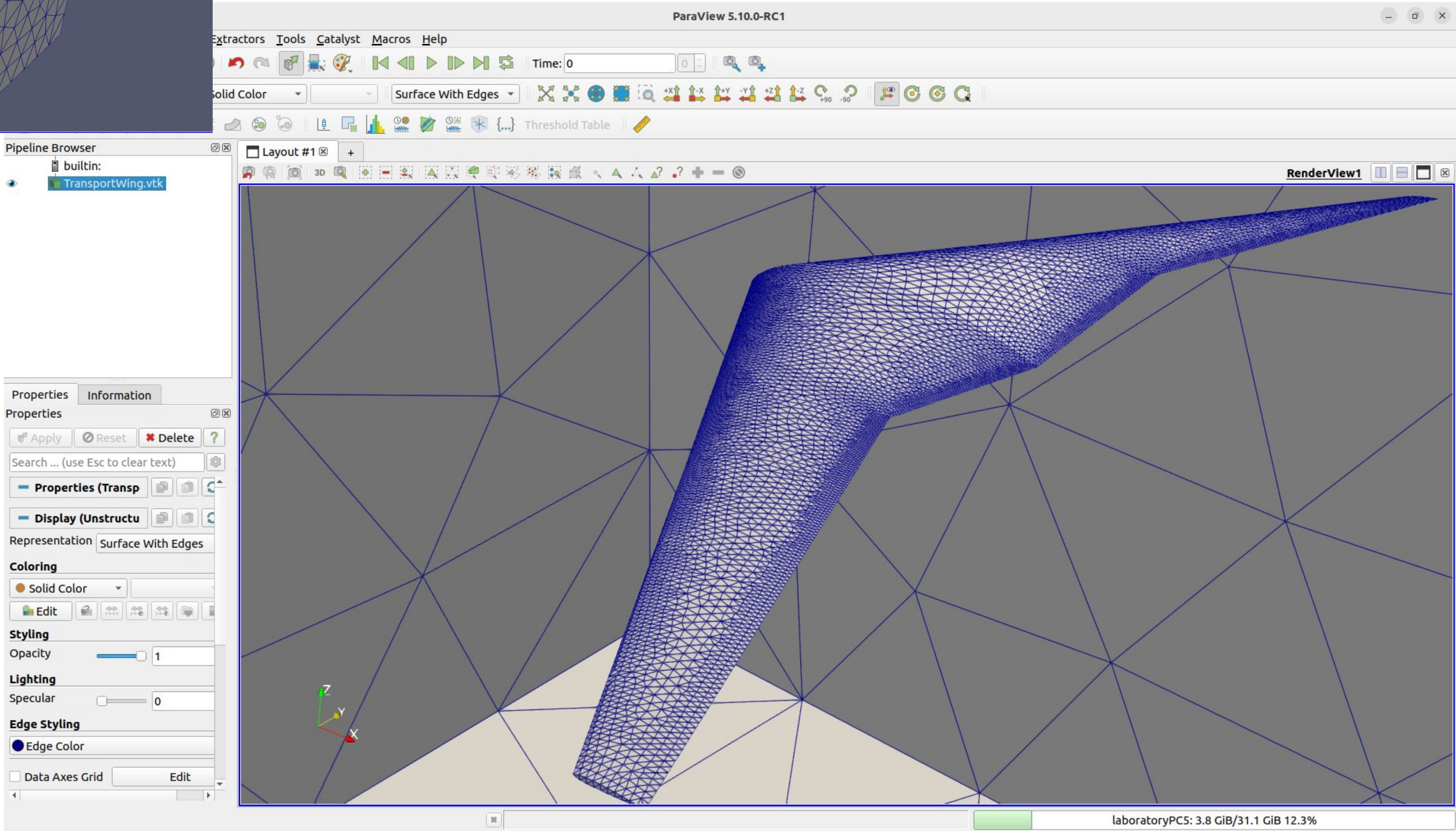


AFLR4

I. Volume Meshing



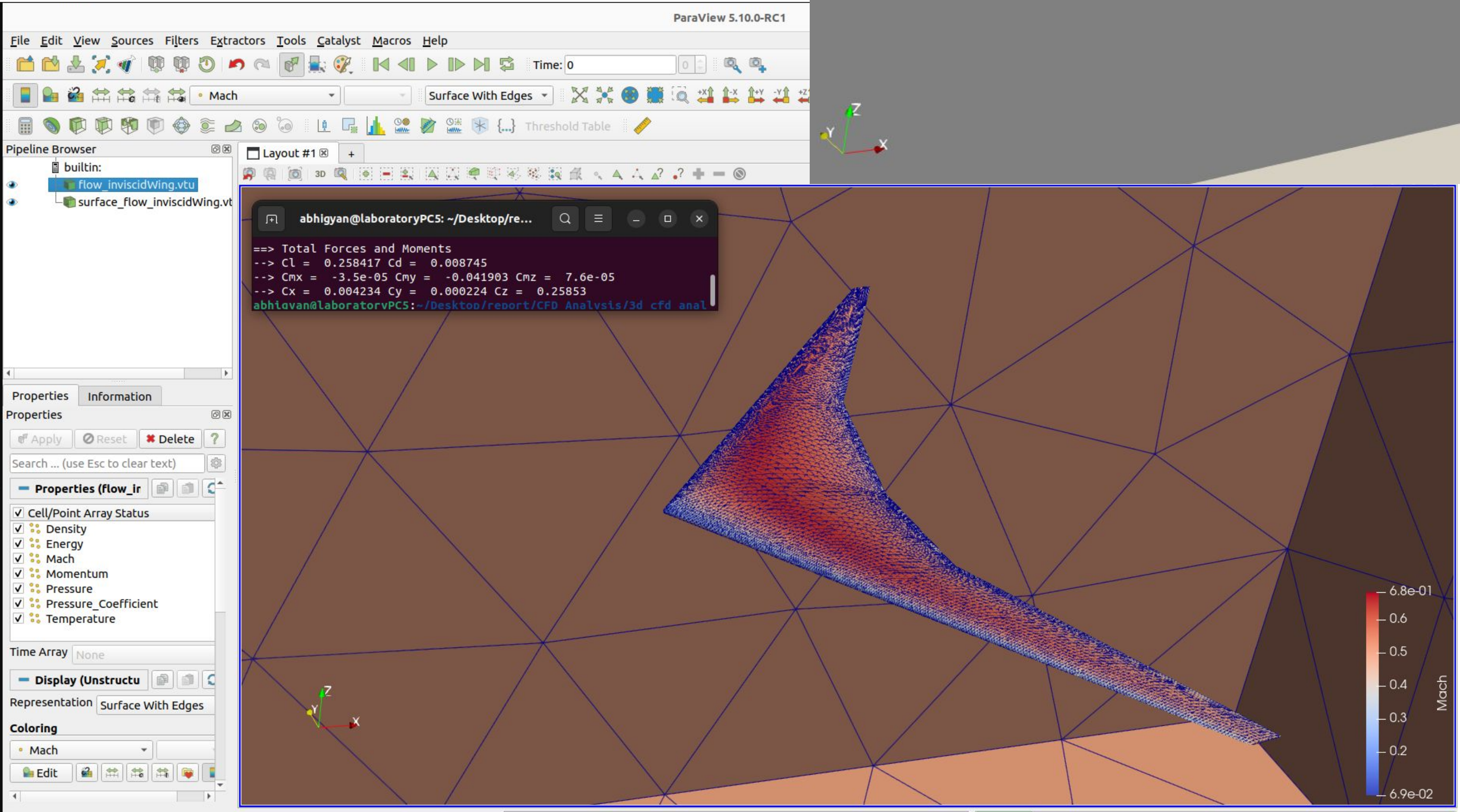
AFLR3



3D CFD Analysis

SU2


Z
Y
X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Coloring
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6.9e-02
Mach

All ESP Publications are available at this site.

https://acdl.mit.edu/ESP/Publications/?C=D;O=A

Using Design-Parameter Sensitivities in Adjoint-Based Design Environments

Geometric Sketch Constraint Solving with User Feedback

- better than AutoCAD like systems

Research Paper topics which research deeply into specific kind of sketching tools and design methods

- Conservative Fitting for Multi-Disciplinary Analysis
- Design Sensitivity Calculations Directly on CAD-based Geometry
- Generation of Parametric Aircraft Models from a Cloud of Points
- The Creation of a Static BRep Model Given a Cloud of Points
- Using Design-Parameter Sensitivities in Adjoint-Based Design Environments
- Flends: Generalized Fillets via B-splines
- Towards Fully Regular Quad Mesh Generation
- Extension of local cavity operators to 3d + t spacetime mesh adaptation
- Hybrid Shell Model for Aeroelastic Modeling
- Shape Continuum Sensitivity Analysis using ASTROS and CAPS
- Boundary Representation Tolerance Impacts on Mesh Generation and Adaptation
- Exploring Tie Constraints for Structural Analysis Problems
- Parallelization Strategies for Efficiently Computing CAD-based Sensitivities for Design Optimization
- A Parametric G1-continuous Rounded Wing Tip Treatment for Preliminary Aircraft Design
- On Analysis Driven Shape Design Using B-Splines

Much of the Objectives established -
https://acdl.mit.edu/ESP/Publications/AIAApaper2012-0683.pdf