

PRANDTL-M: Designing a New Mars Glider

NATHAN SAM | EATHAN DEVINE | MANI BHUMA | CODE 530

MENTORS: DAVE BERGER AND OSCAR MURILLO



Table of Contents

- Our Backgrounds
- Project History/Purpose
- Approach
- Aerodynamic Analysis for PRANDTL-M
- XFLR5
- OpenVSP and VSPaero
- Nathan's Conclusion
- Mechanical and Mold Design for PRANDTL-M
- Eathan's Conclusion
- Open Flight Simulation for PRANDTL-M
- Mani's Conclusion
- Extra Slides

Manikrishnakumar (Mani) Bhuma

Iowa State University
Aerospace Engineering
Rising Senior

Previous Roles:

- Physics research intern at WashU
- Aerospace Student Council President
- Events Director of Society of Ethical Engineers



Hobbies:

- Photography
- Tennis/Table Tennis
- Music
- Travel



Other Projects:

- CySat (Make 2 Innovate)
- Senior Design Project
- Matlab code using Low Pass Filter to predict stock prices

Photo Credit: Mani Bhuma

Eathan Devine

John Brown University
Mechanical Engineering
Rising Senior

Previous Work:

- Process Engineering Intern at 3M
- Lego Robotics Mentor

Other Projects:

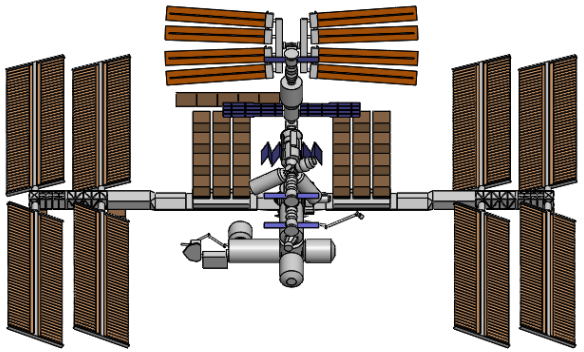
- Upcoming Senior Design Project
- Junior Design Project – Solar-Powered Automated Deer Feeder
- Digital Electronics State Machine Coffee Maker

Hobbies:

- Cross Country/Track
- Hiking/Camping
- Board/Card Games
- RC Cars
- Piano

Eathan Devine

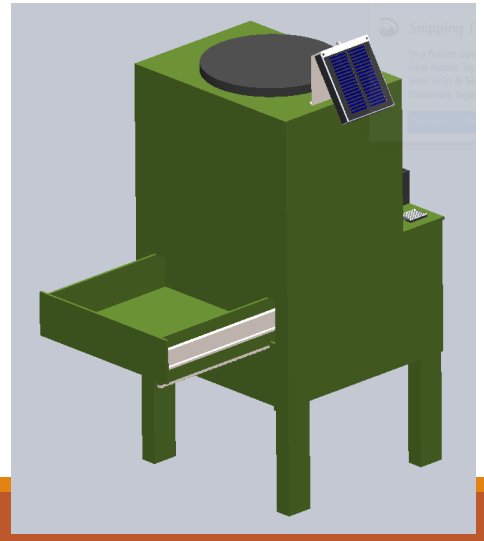
John Brown University
Mechanical Engineering
Rising Senior



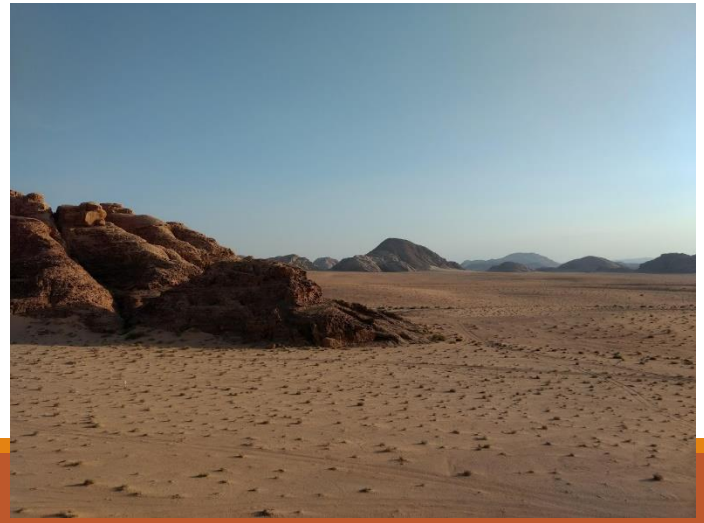












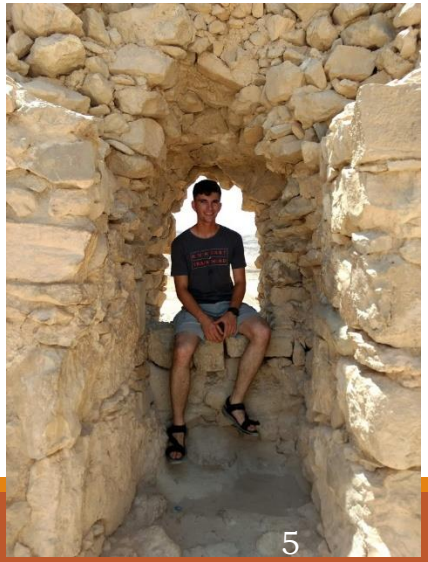


Photo Credit: Eathan Devine, John Brown University

Nathan Sam

California State Polytechnic University, Pomona
Mechanical Engineering
Sophomore

Previous Experience

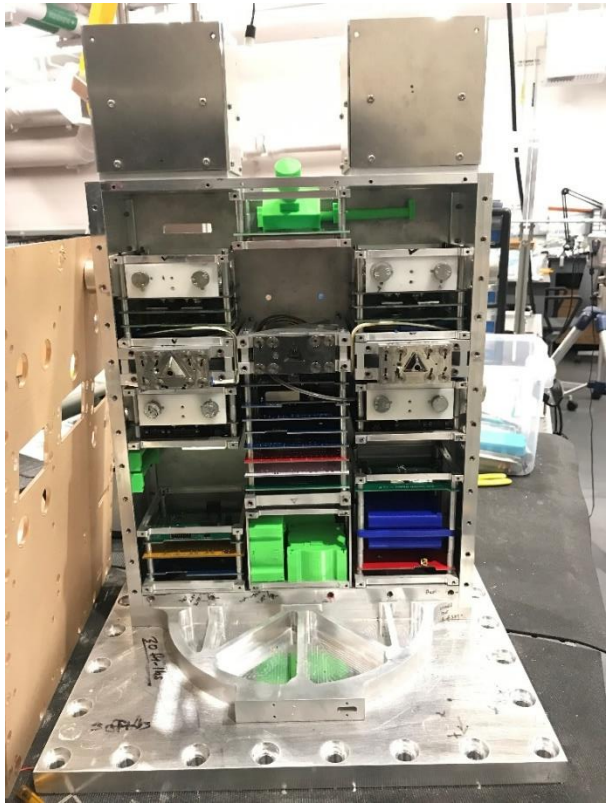
- Cal Poly Small Unmanned Ground Vehicle
- Lab Assistant at Caltech
- NASA Community College Aerospace Scholars
- NASA L'SPACE Academy

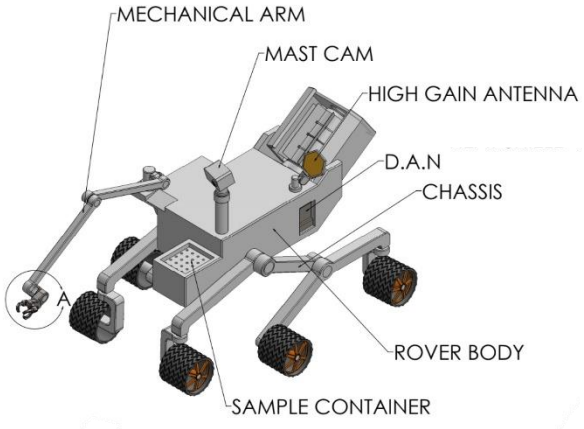
Interest

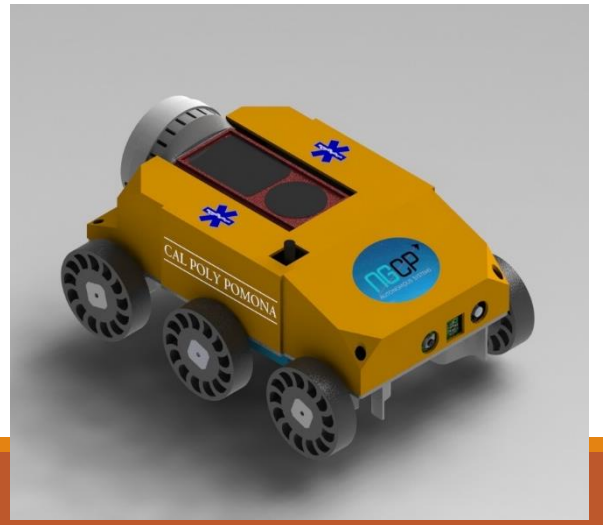
- Hiking
- Board games
- CAD/ 3D printing
- Basketball

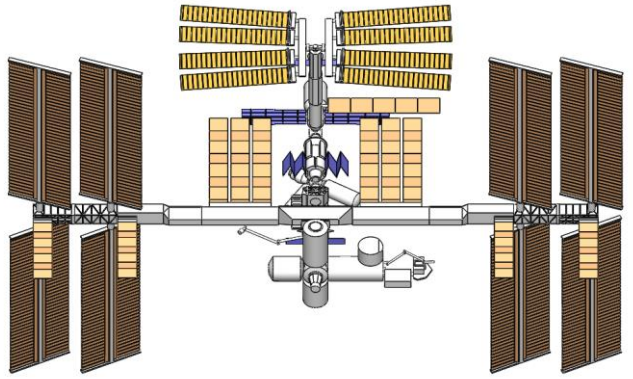
Nathan Sam

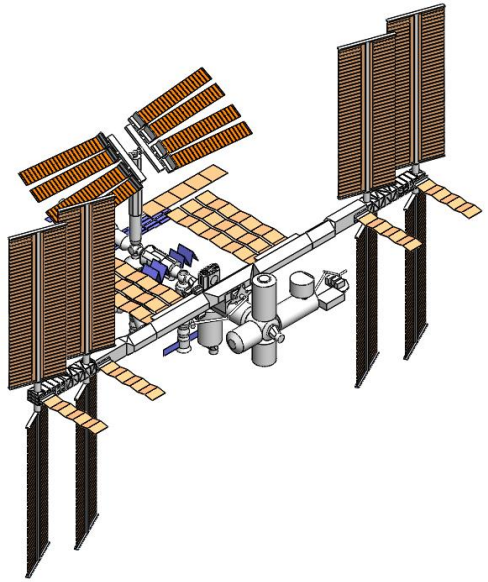
California State Polytechnic University, Pomona
Mechanical Engineering
Sophomore











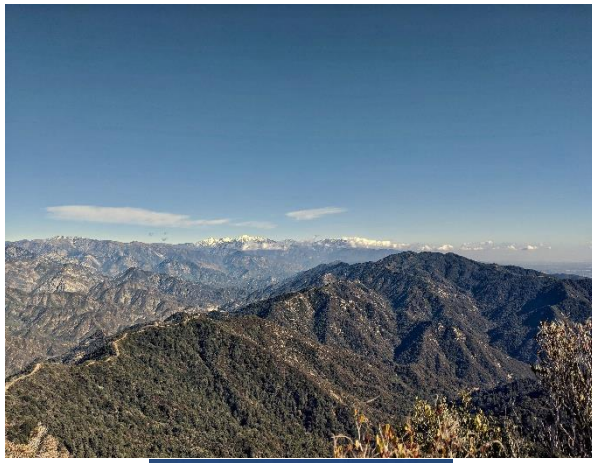
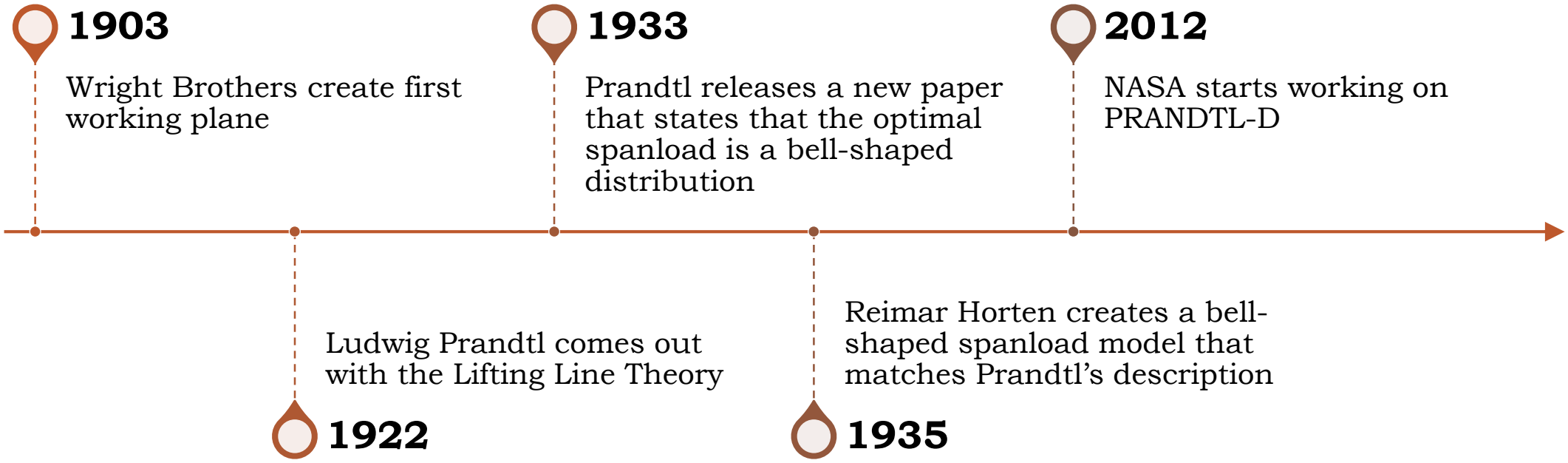


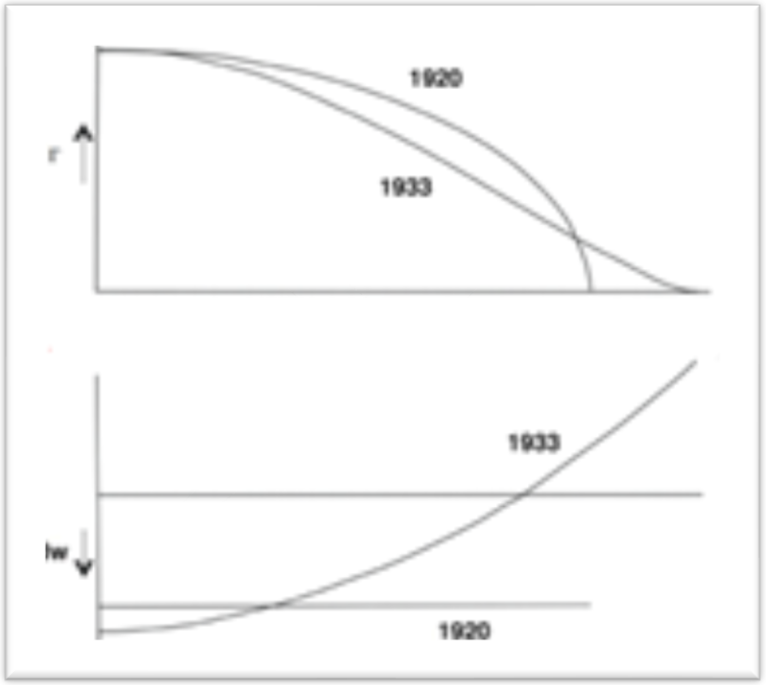


Photo Credit: Nathan Sam

Project Timeline



Theory



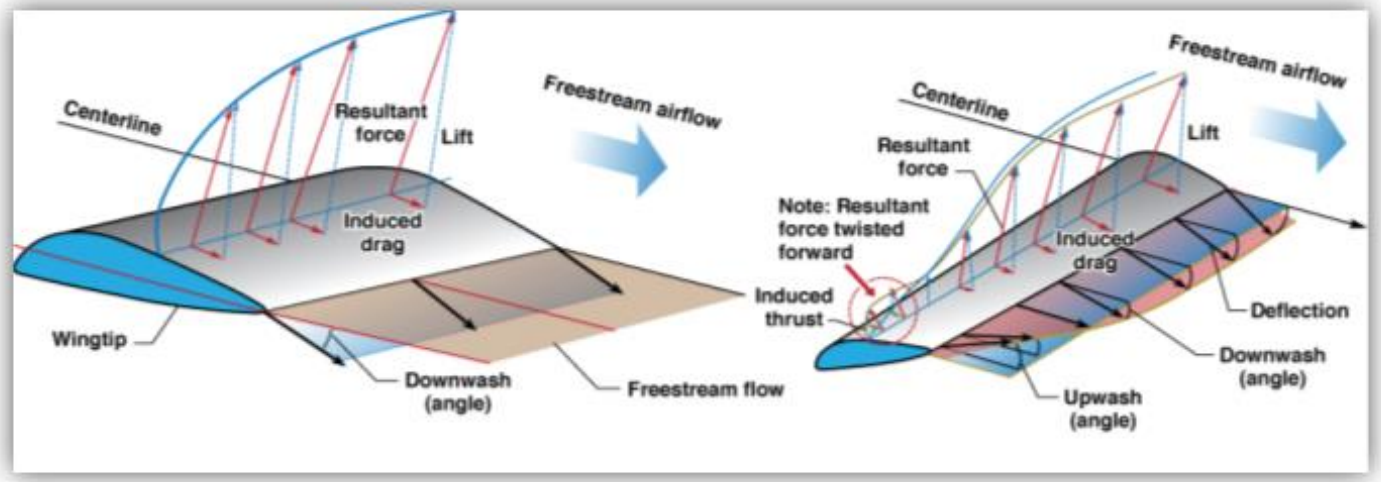


Photo Credit: NASA

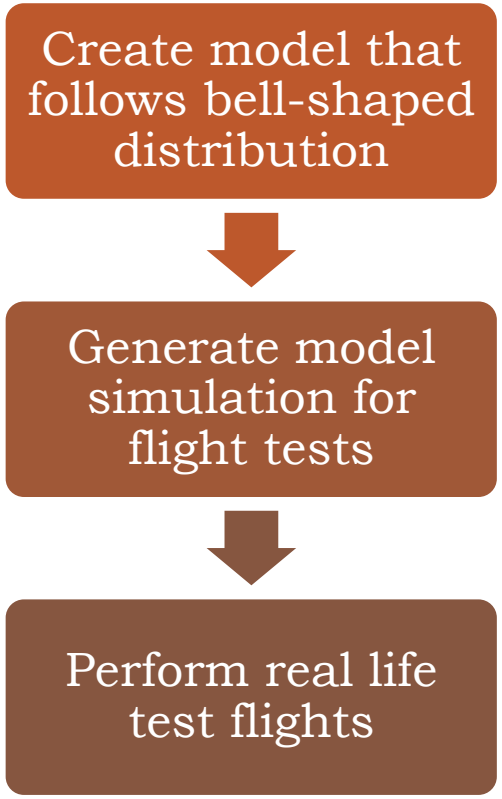


Courtesy of NASA | Dennis Calaba

PRANDTL-M's Goals and Significance

- Use Prandtl's theory to create glider swarm
- Gather atmospheric data on Mars
- Pinpoint appropriate human landing spots for Mars missions

Our Approach





Aerodynamic Analysis for PRANDTL-M

NATHAN SAM | SUMMER 2020 INTERN

MENTORS: DAVE BERGER AND OSCAR MURILLO

Objective

Challenge: During Spring of 2020, the first flight test of PRANDTL-M 6.0 was conducted. The aircraft was able to fly for a brief second but not stably.

Task:

- Determine what aerodynamic tool can predict both a bell-shaped lift distribution and proverse yaw (roll and yaw moment are in the same direction)
- Run analysis on PRANDTL-M to observe what change in geometric properties can increase stability
  - Increase yaw stability to enable proverse yaw



XFLR5

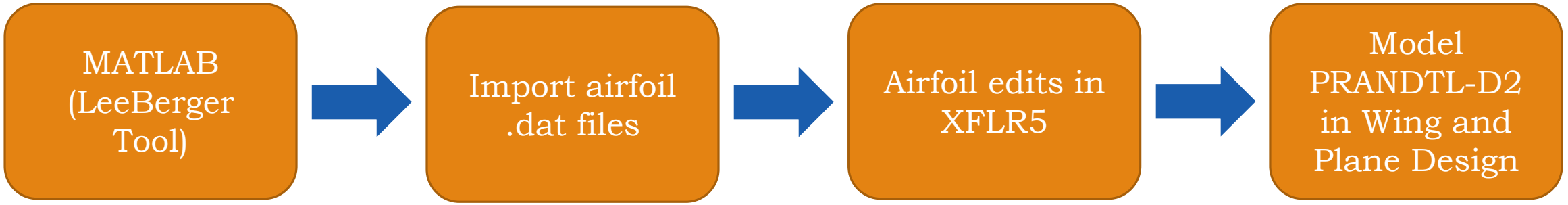
Verifying XFLR5

Using PRANDTL-D2 experimental data as a standard:

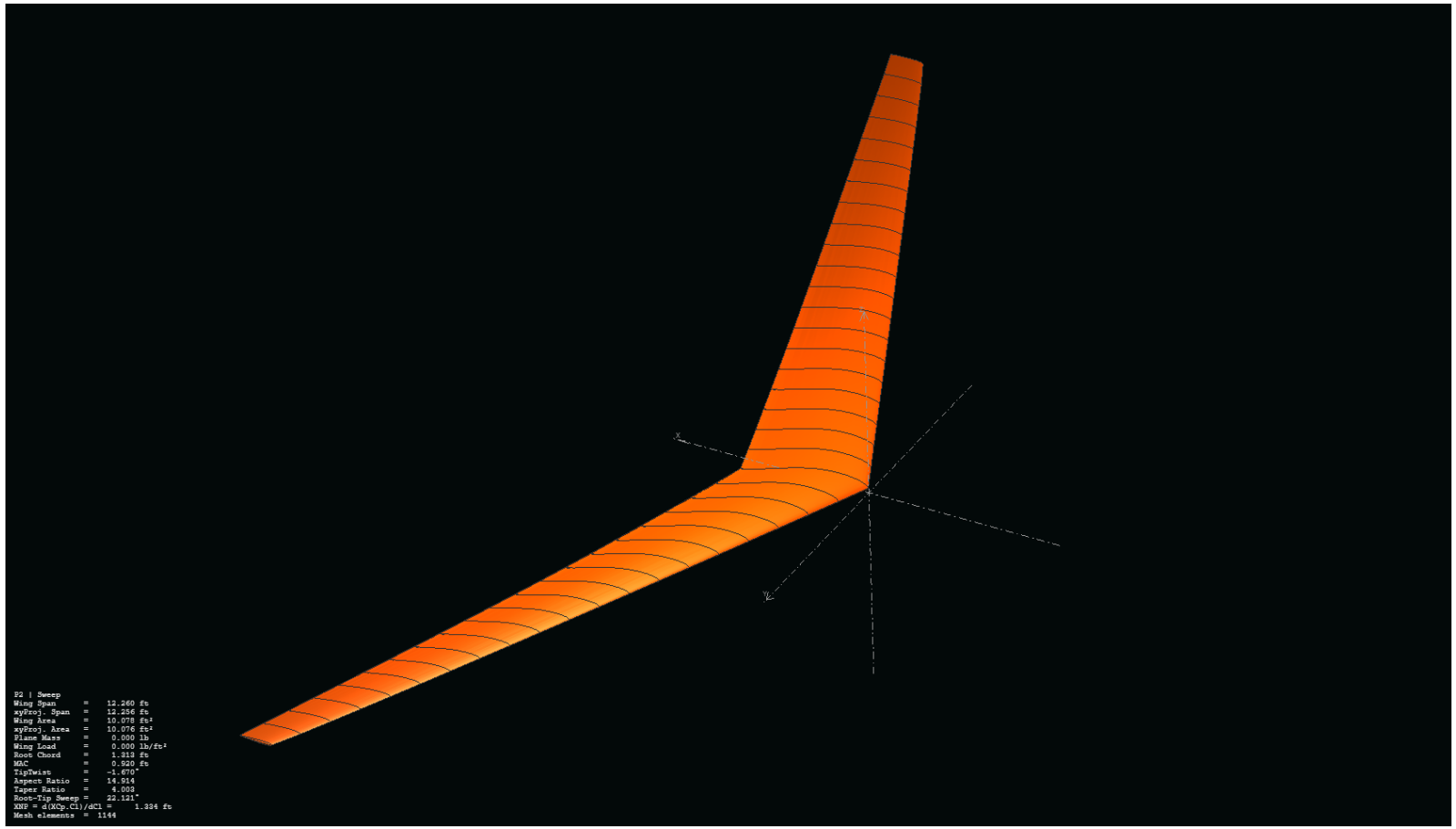
- Determine if XFLR5 shows a bell-shaped lift distribution
- Compare calculated Cnda vs CL results

Run analysis for PRANDTL-M 6.0

Modeling PRANDTL-D2 in XFLR5



PRANDTL-D2 in XFL5



CAD Credit: Nathan Sam

PRANDTL-D2: Lift Distribution in XFLR5

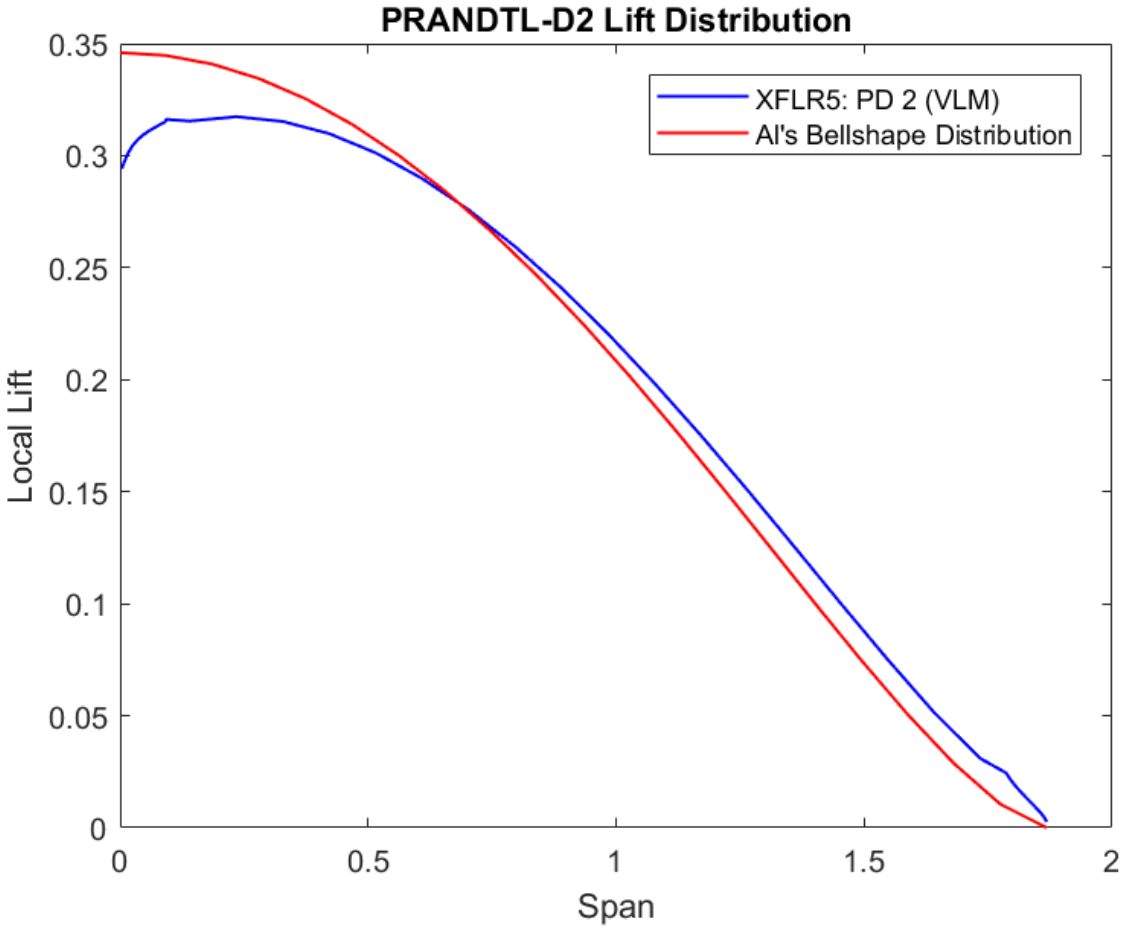


Image Credit: Nathan Sam

PRANDTL-D2: Cnda vs CL

Objective:

- Determine if XFLR5 shows yaw moment due to change in aileron deflection (Cnda) increasing as coefficient of lift (CL) is increasing
- Compare XFLR5 results with flight data

Procedure:

- Run aileron deflection analysis from 0° – 15° to get Cn results
- Combine data sets with respect to angle of attack
  - i.e Alpha = 0, CL ~ 0.2, what are the respected Cn values with deflection angles 0° – 15°
- Find best fit for the data set (Cnda)
- Graph Cnda vs CL

For Alpha = 0, CL = 0.2			For Alpha = 1, CL = 0.3			For Alpha = 2, CL = 0.4	
Aileron	Cn		Aileron	Cn		Aileron	Cn
0	0.711658585		0	0.2894917		0	0.985967008
1	0.46560896		1	0.14058201		1	0.374874213
2	0.889678098		2	0.53961604		2	0.470059252
3	0.067093855		3	0.19173774		3	0.644863193
4	0.598806926		4	0.96390211		4	0.106900912
5	0.038795589		5	0.84012906		5	0.8000076
6	0.472018345		6	0.092241		6	0.052471503
7	0.398146378		7	0.9951383		7	0.350769839
8	0.195221805		8	0.42754168		8	0.789721672
9	0.823127436		9	0.23859305		9	0.208799481
10	0.839145772		10	0.10015268		10	0.471690329
11	0.390771215		11	0.12869668		11	0.905014133
12	0.151896709		12	0.36518838		12	0.406218841
13	0.759236891		13	0.36412356		13	0.478556423
14	0.818541694		14	0.68756467		14	0.358962944
15	0.222868695		15	0.11898251		15	0.209841274
m	2		m	3		m	4

CL	m = Cnda
0.2	2
0.3	3
0.4	4

Image Credit: Nathan Sam

PRANDTL-D2: Cnda vs CL

Results:

- Flight data
  - Cnda at design CL ~ 0.6 is positive
  - Slope of trend is positive
  - Therefore proverse yaw is achieved
- XFLR5
  - Cnda at design CL is negative
  - Positive trend of Cnda increasing as CL increases
  - Slope is flat compared to the flight data

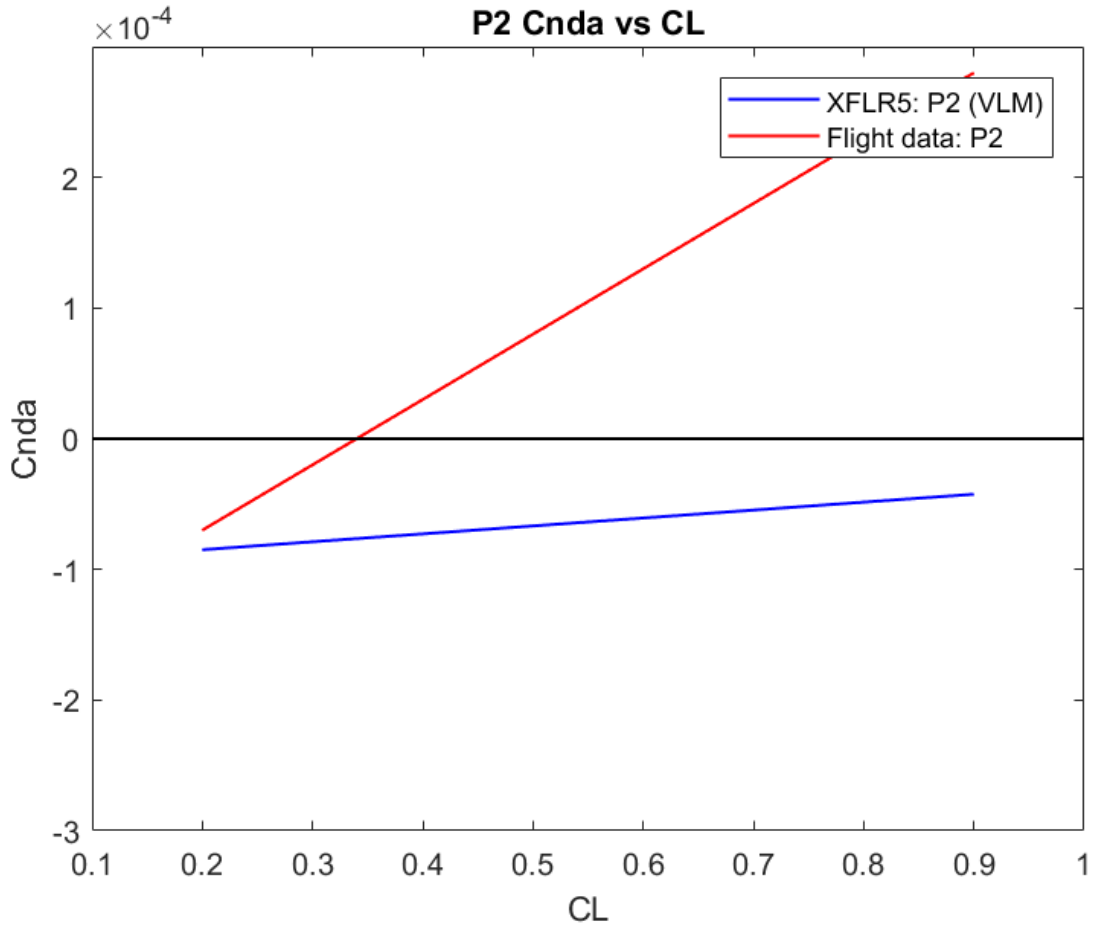


Image Credit: Nathan Sam



OpenVSP and VSPaero

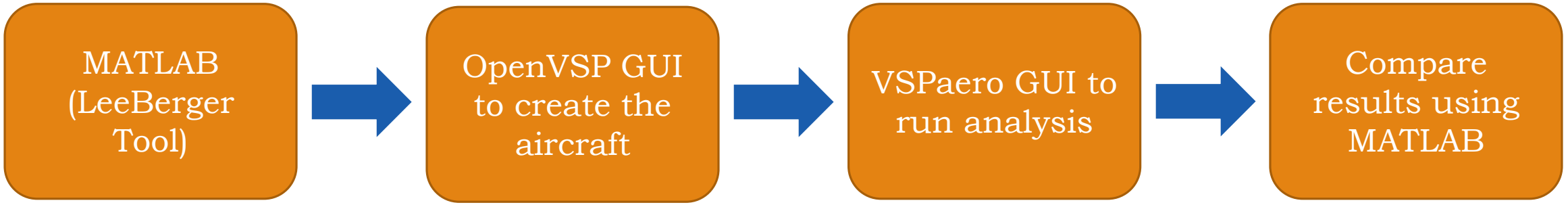
Verifying VSPaero

Using PRANDTL-D2 experimental data as a standard:

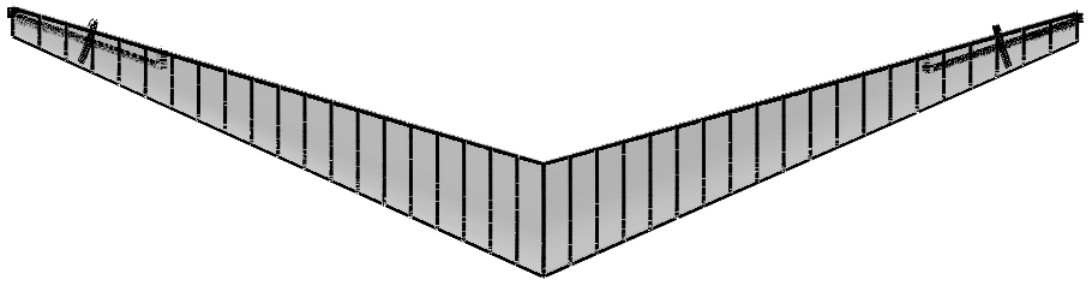
- Determine if VSPaero shows a bell-shaped lift distribution
- Compare calculated Cnda vs CL result

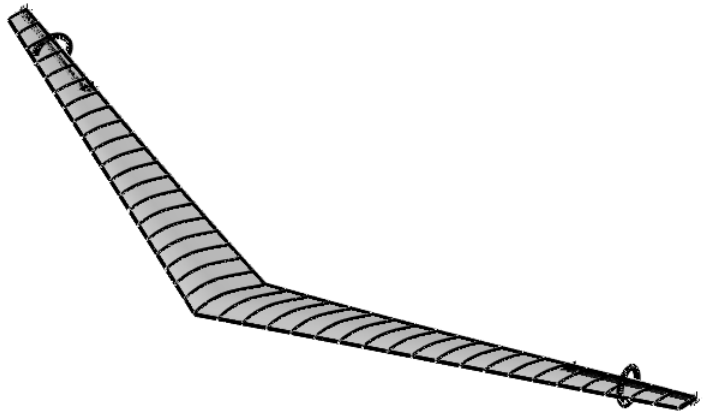
Run analysis for PRANDTL-M 6.0

Modeling PRANDTL-D2 in OpenVSP



PRANDTL-D2 in OpenVSP









CAD Credit: Nathan Sam

PRANDTL-D2: Lift Distribution in VSPaero

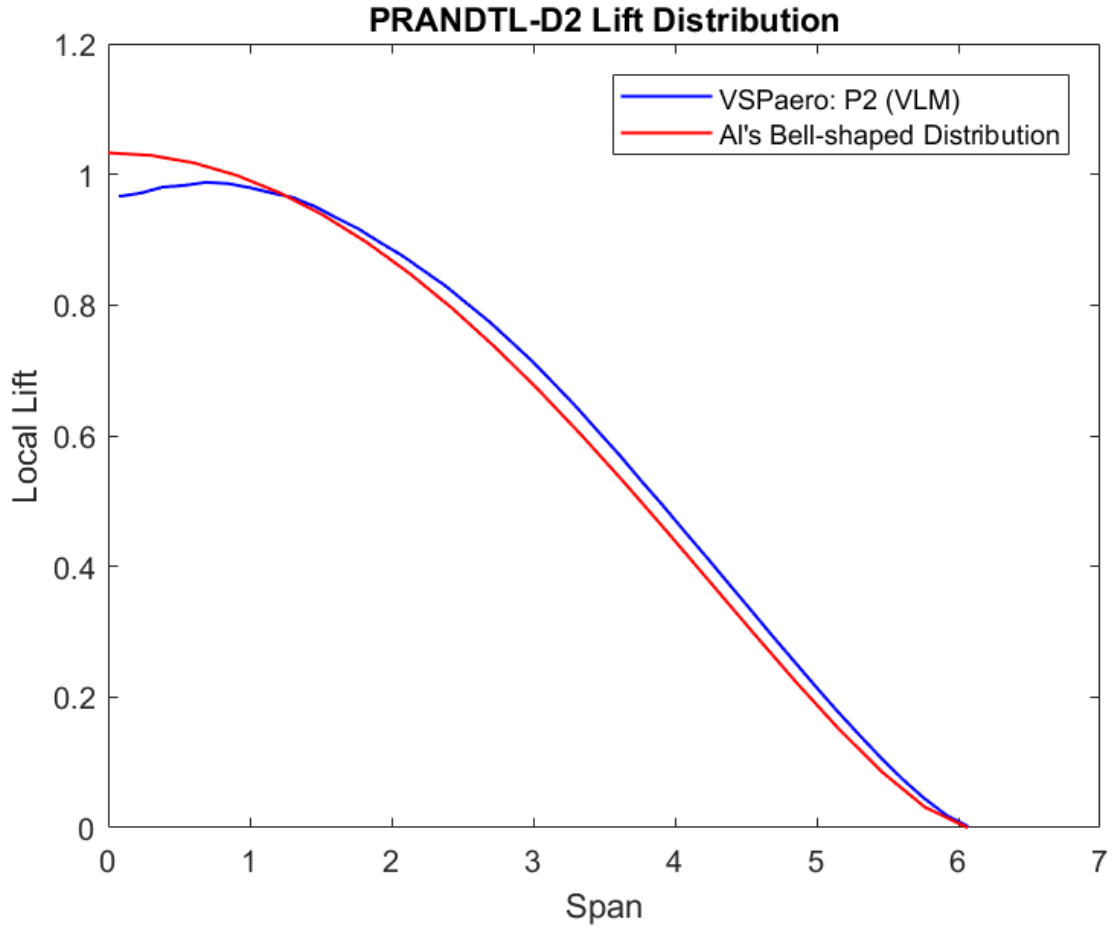


Image Credit: Nathan Sam

PRANDTL-D2: Cnda vs CL

Objective:

- Determine if VSPaero shows yaw moment due to change in aileron deflection (Cnda) increasing as coefficient of lift (CL) is increasing
- Compare VSPaero results with flight data

Procedure:

- Run aileron deflection analysis from 0° – 15° to get Cn results
- Combine data sets with respect to angle of attack
  - i.e Alpha = 0, CL ~ 0.2, what are the respected Cn values with deflection angles 0° – 15°
- Find best fit for the data set (Cnda)
- Graph Cnda vs CL

For Alpha = 0, CL = 0.2			For Alpha = 1, CL = 0.3			For Alpha = 2, CL = 0.4	
Aileron	Cn		Aileron	Cn		Aileron	Cn
0	0.711658585		0	0.2894917		0	0.985967008
1	0.46560896		1	0.14058201		1	0.374874213
2	0.889678098		2	0.53961604		2	0.470059252
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4	0.598806926		4	0.96390211		4	0.106900912
5	0.038795589		5	0.84012906		5	0.8000076
6	0.472018345		6	0.092241		6	0.052471503
7	0.398146378		7	0.9951383		7	0.350769839
8	0.195221805		8	0.42754168		8	0.789721672
9	0.823127436		9	0.23859305		9	0.208799481
10	0.839145772		10	0.10015268		10	0.471690329
11	0.390771215		11	0.12869668		11	0.905014133
12	0.151896709		12	0.36518838		12	0.406218841
13	0.759236891		13	0.36412356		13	0.478556423
14	0.818541694		14	0.68756467		14	0.358962944
15	0.222868695		15	0.11898251		15	0.209841274
m	2		m	3		m	4

CL	m = Cnda
0.2	2
0.3	3
0.4	4

Image Credit: Nathan Sam

PRANDTL-D2: Cnda vs CL

Results:

- Flight data
  - Cnda at design CL ~ 0.6 is positive
  - Slope of trend is positive
  - Therefore proverse yaw is achieved
- VSPaero
  - Cnda at design CL is negative
  - Slope of trend is identical and positive
  - Unsure of the scaling issue happening
    - A PRANDTL-M intern will be using Langley's AVL to compare results with VSPaero

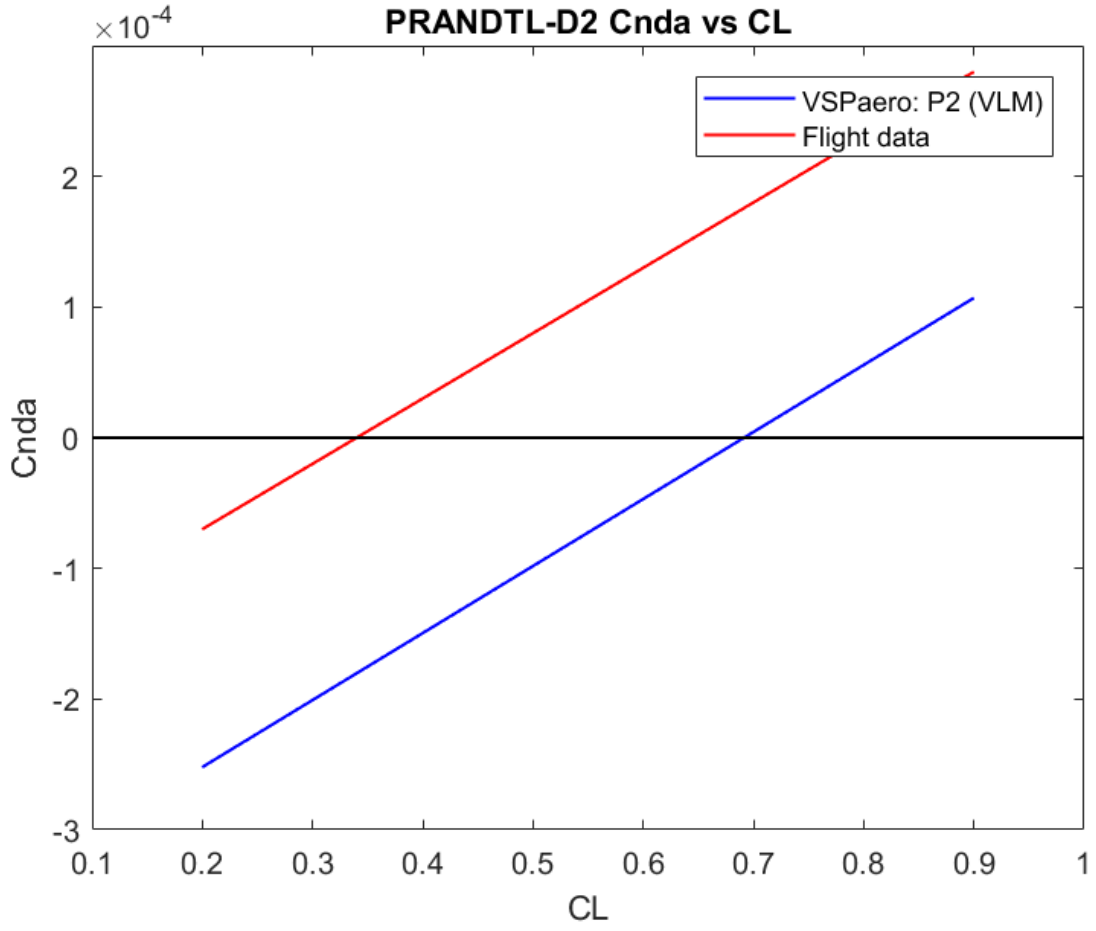


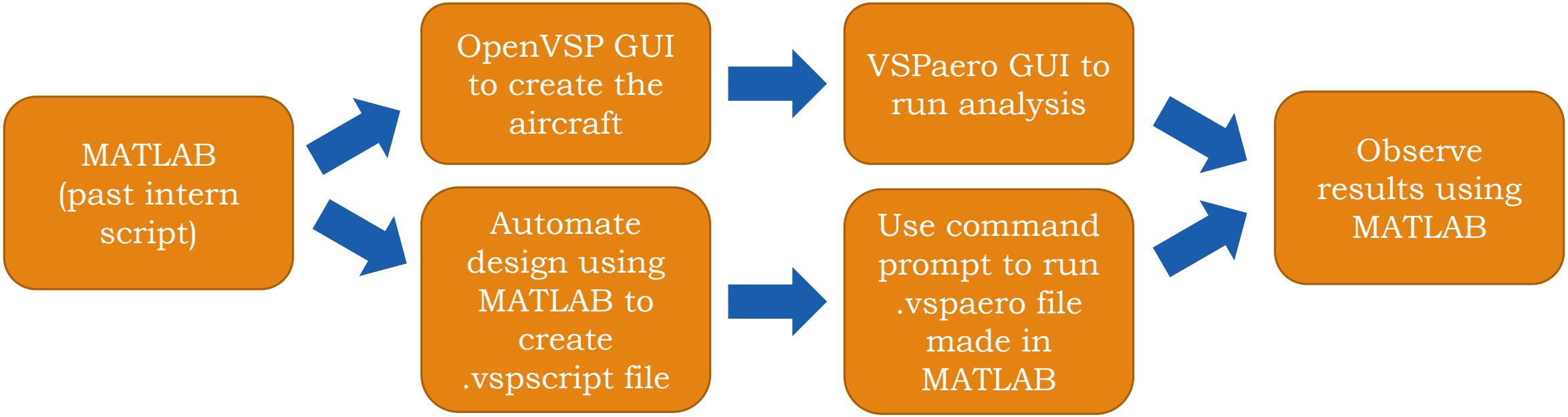
Image Credit: Nathan Sam

Analysis of PRANDTL-M 6.0

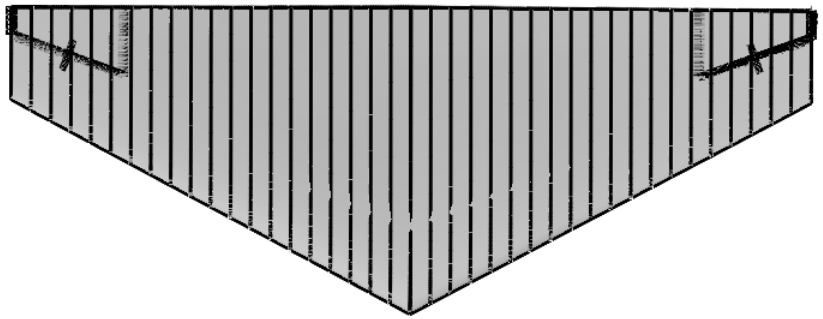
- Observe if PM 6.0 has a bell-shaped lift distribution
- Cnda vs CL:
  - Analyze if Cnda vs CL has a positive slope
  - At design CL ~ 0.3, see if Cnda is positive
- What properties to change to increase proverse yaw to increase efficiency

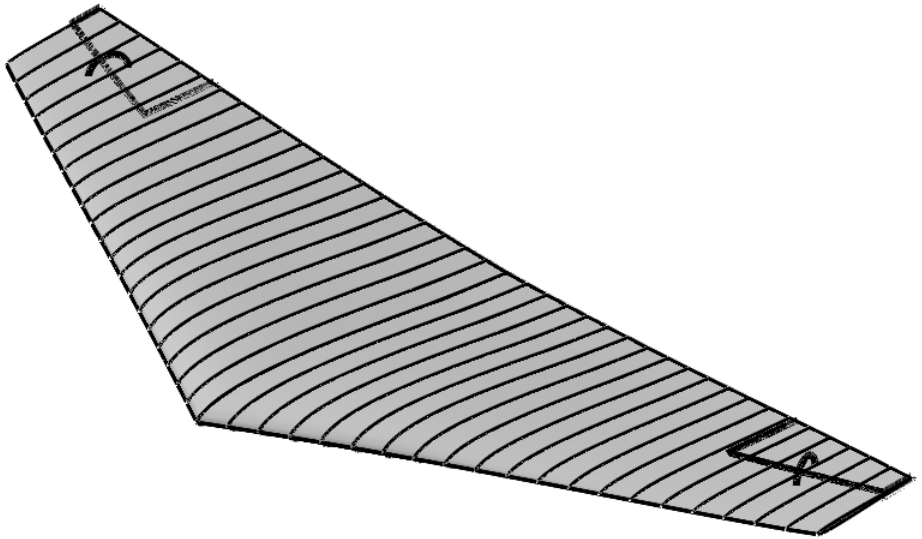
Creating PRANDTL-M

Now knowing that VSP can detect both bell-shaped lift distribution and proverse yaw, analysis for PRANDTL-M can start.



PRANDTL-M 6.0 in OpenVSP









CAD Credit: Nathan Sam

PRANDTL-M 6.0: Lift Distribution in VSPaero

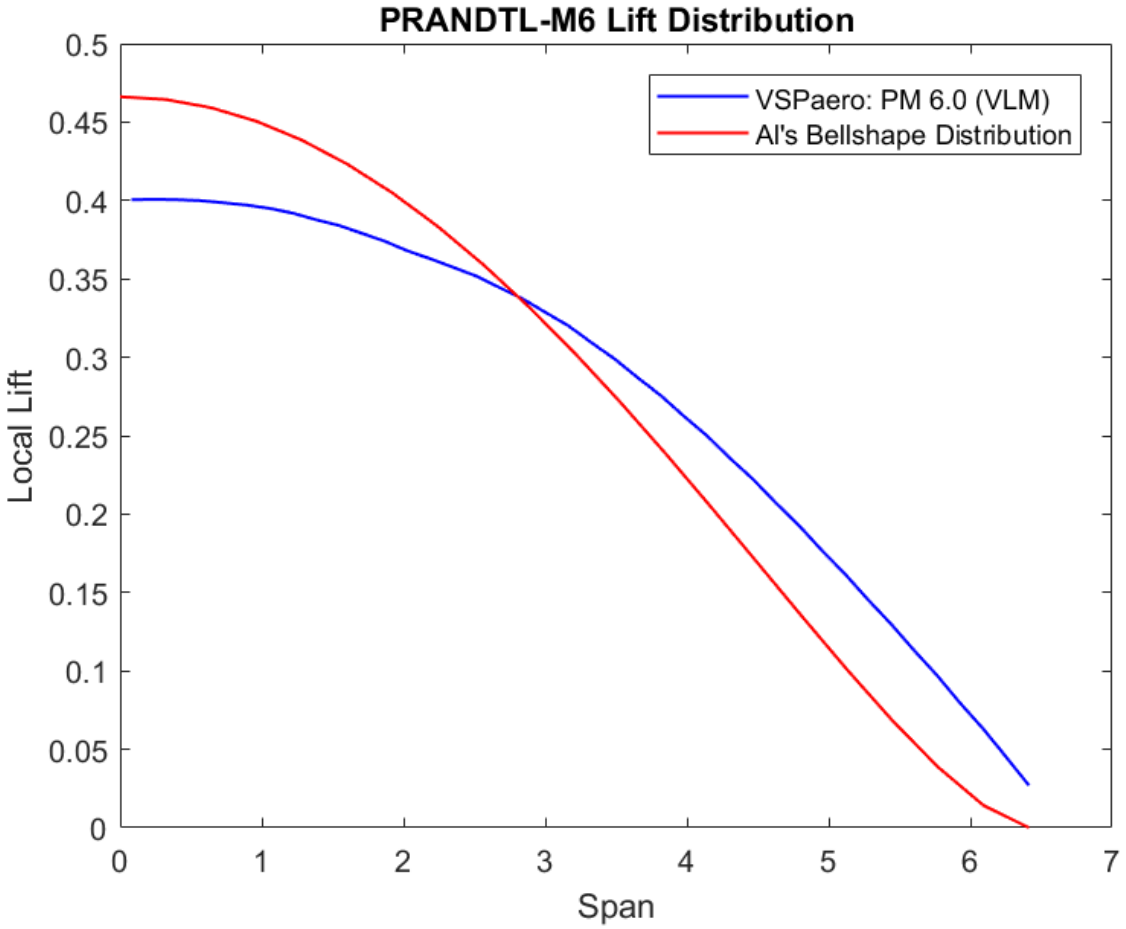


Image Credit: Nathan Sam

PRANDTL-M 6.0: Cnda vs CL

Objective:

- Determine if VSPaero shows yaw moment due to change in aileron deflection (Cnda) increasing as coefficient of lift (CL) is increasing
- At the design CL, observe the calculated Cnda

Procedure:

- Run aileron deflection analysis from 0° – 15° to get Cn results
- Combine data sets with respect to angle of attack
  - i.e at Alpha = 0, CL ~ 0.2, what are the respected Cn values with deflection angles 0° – 15°
- Find best fit for the data set (Cnda)
- Graph Cnda vs CL

For Alpha = 0, CL = 0.2	
Aileron	Cn
0	0.711658585
1	0.46560896
2	0.889678098
3	0.067093855
4	0.598806926
5	0.038795589
6	0.472018345
7	0.398146378
8	0.195221805
9	0.823127436
10	0.839145772
11	0.390771215
12	0.151896709
13	0.759236891
14	0.818541694
15	0.222868695
m	2

For Alpha = 1, CL = 0.3	
Aileron	Cn
0	0.2894917
1	0.14058201
2	0.53961604
3	0.19173774
4	0.96390211
5	0.84012906
6	0.092241
7	0.9951383
8	0.42754168
9	0.23859305
10	0.10015268
11	0.12869668
12	0.36518838
13	0.36412356
14	0.68756467
15	0.11898251
m	3

For Alpha = 2, CL = 0.4	
Aileron	Cn
0	0.985967008
1	0.374874213
2	0.470059252
3	0.644863193
4	0.106900912
5	0.8000076
6	0.052471503
7	0.350769839
8	0.789721672
9	0.208799481
10	0.471690329
11	0.905014133
12	0.406218841
13	0.478556423
14	0.358962944
15	0.209841274
m	4

CL	m = Cnda
0.2	2
0.3	3
0.4	4

Image Credit: Nathan Sam

PRANDTL-M 6.0: Cnda vs CL

Results:

- VSPaero
  - Slope of trend is and positive
  - Cnda at design CL ~ 0.3 is negative
    - Recalling that VSPaero results had a scaling issue when comparing data for PRANDTL-D2

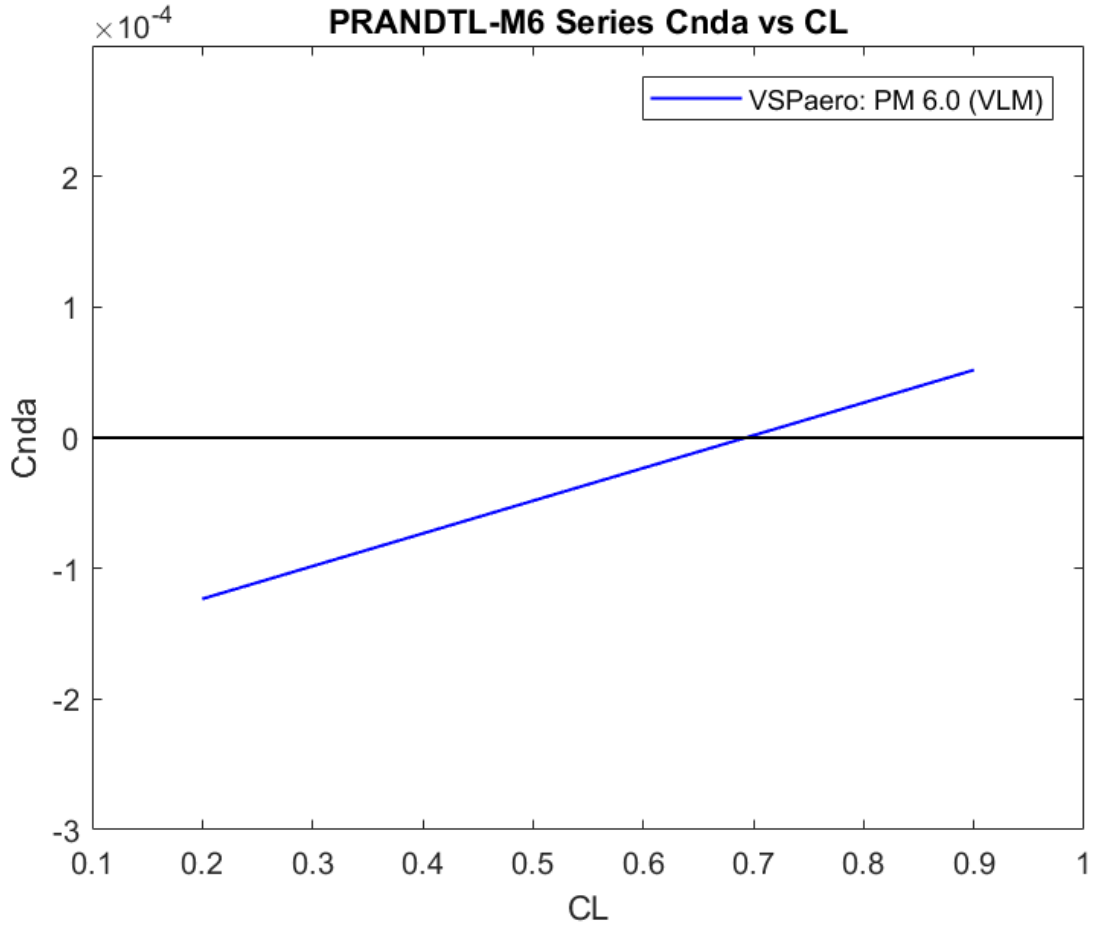


Image Credit: Nathan Sam

Changing Twist Distribution

Due to PRANDTL-M 6.0 lift distribution being more elliptical than bell-shaped:

- Change twist distribution to have bell-shaped lift distribution
- Observe if this will increase Cnda

Getting new twist distribution:

$$\Delta Alpha = \frac{(Al's\ Local\ Lift\ - Current\ VSPaero\ Local\ Lift)}{0.106}$$

$$New\ Twist = Initial\ Twist\ Configuration + \Delta Alpha$$

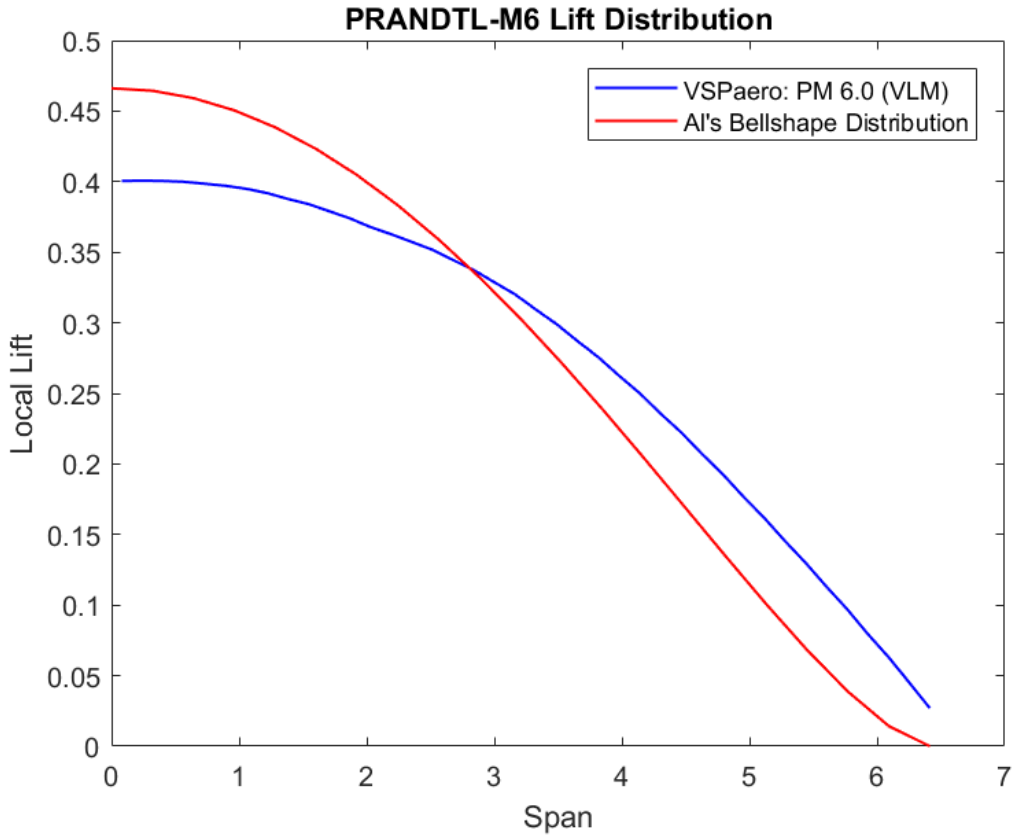
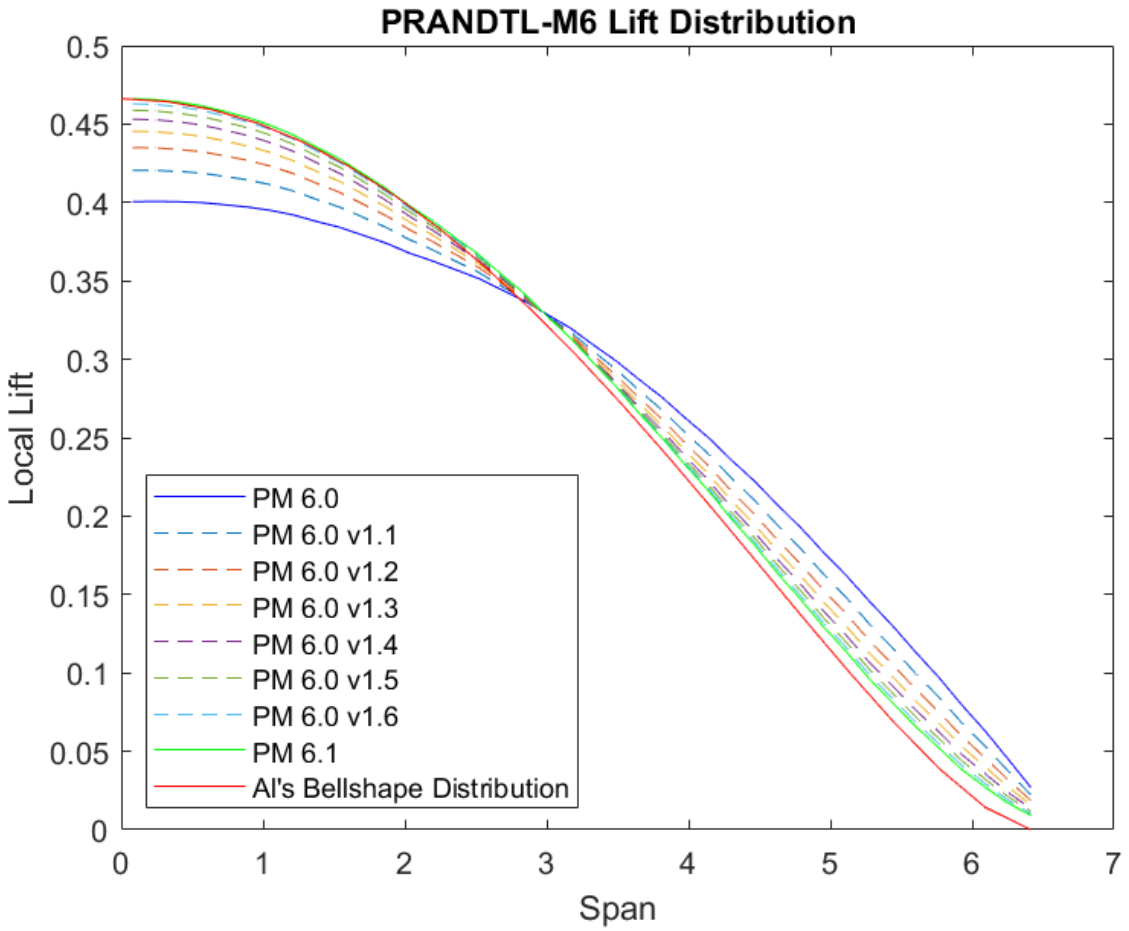


Image Credit: Nathan Sam

Changing Twist Distribution



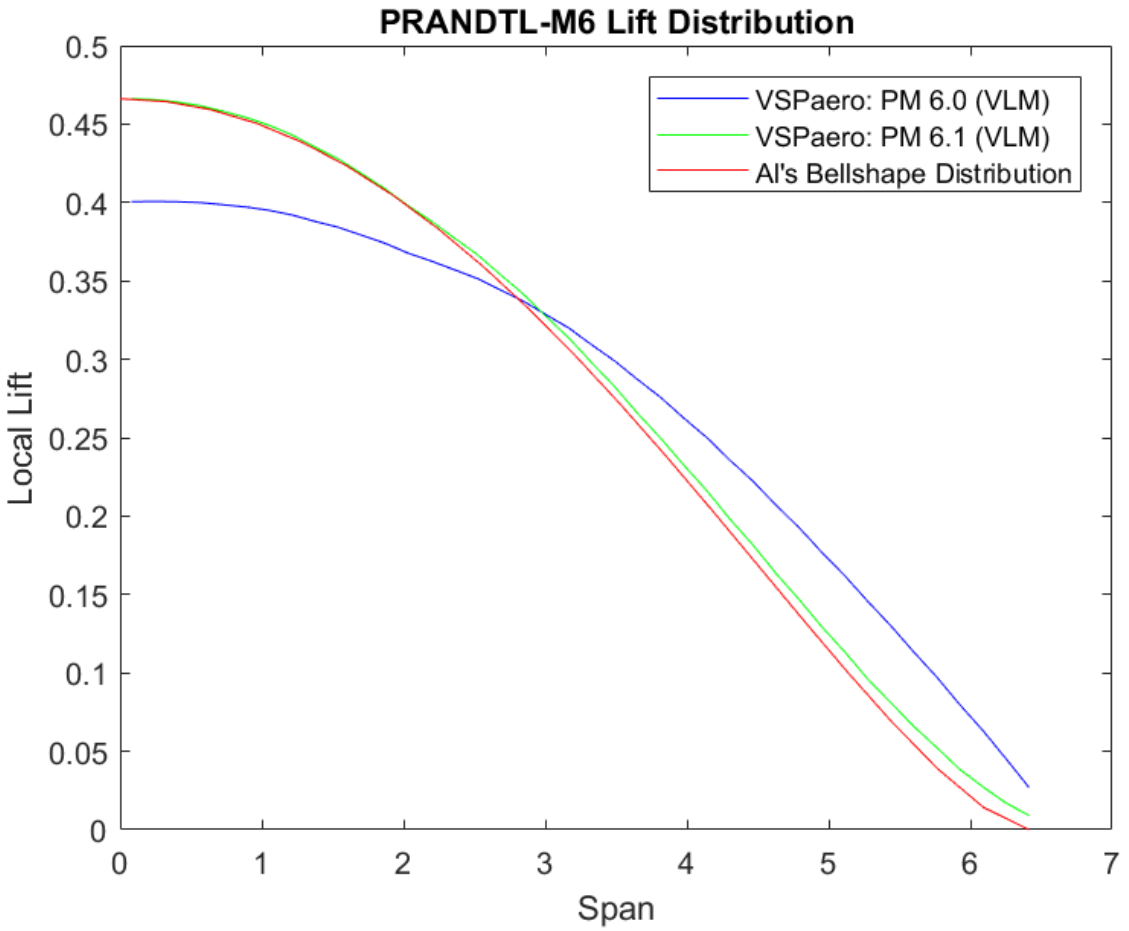
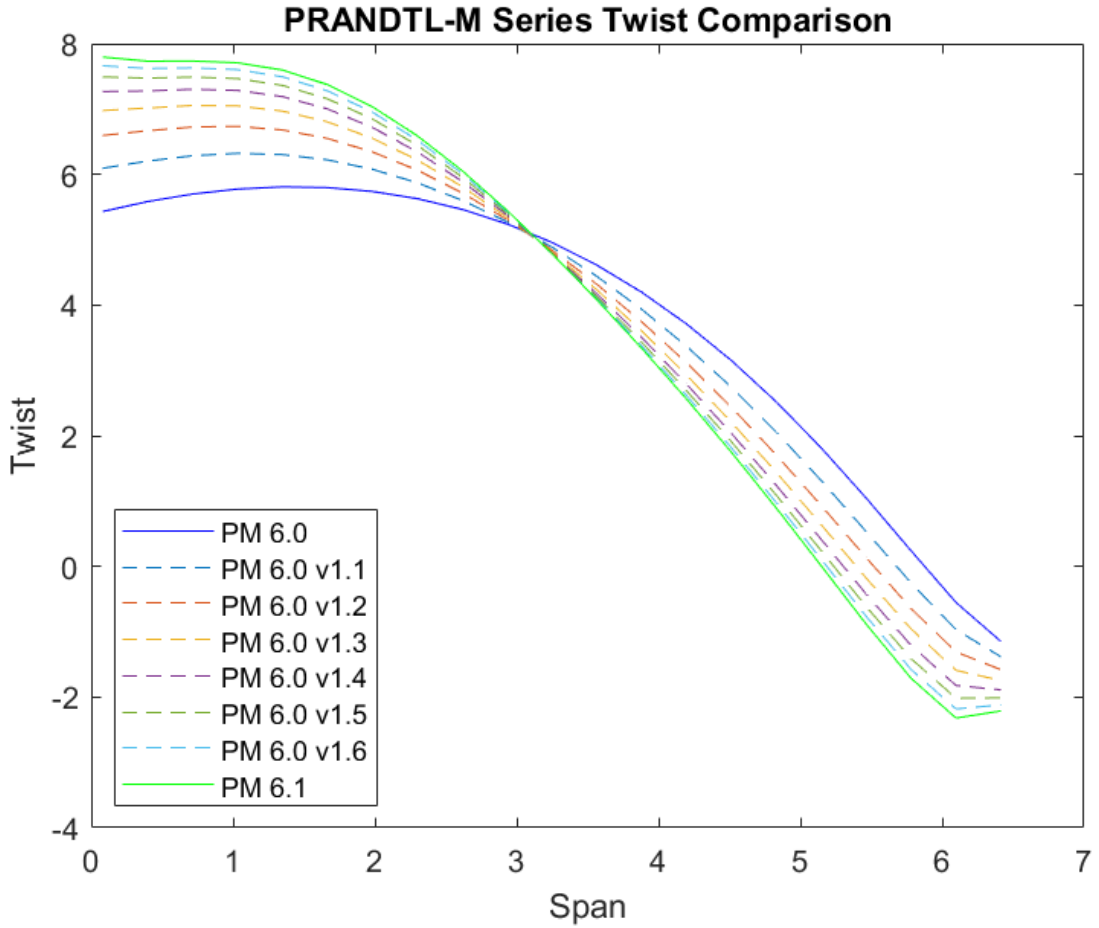


Image Credit: Nathan Sam

Changing Twist Distribution



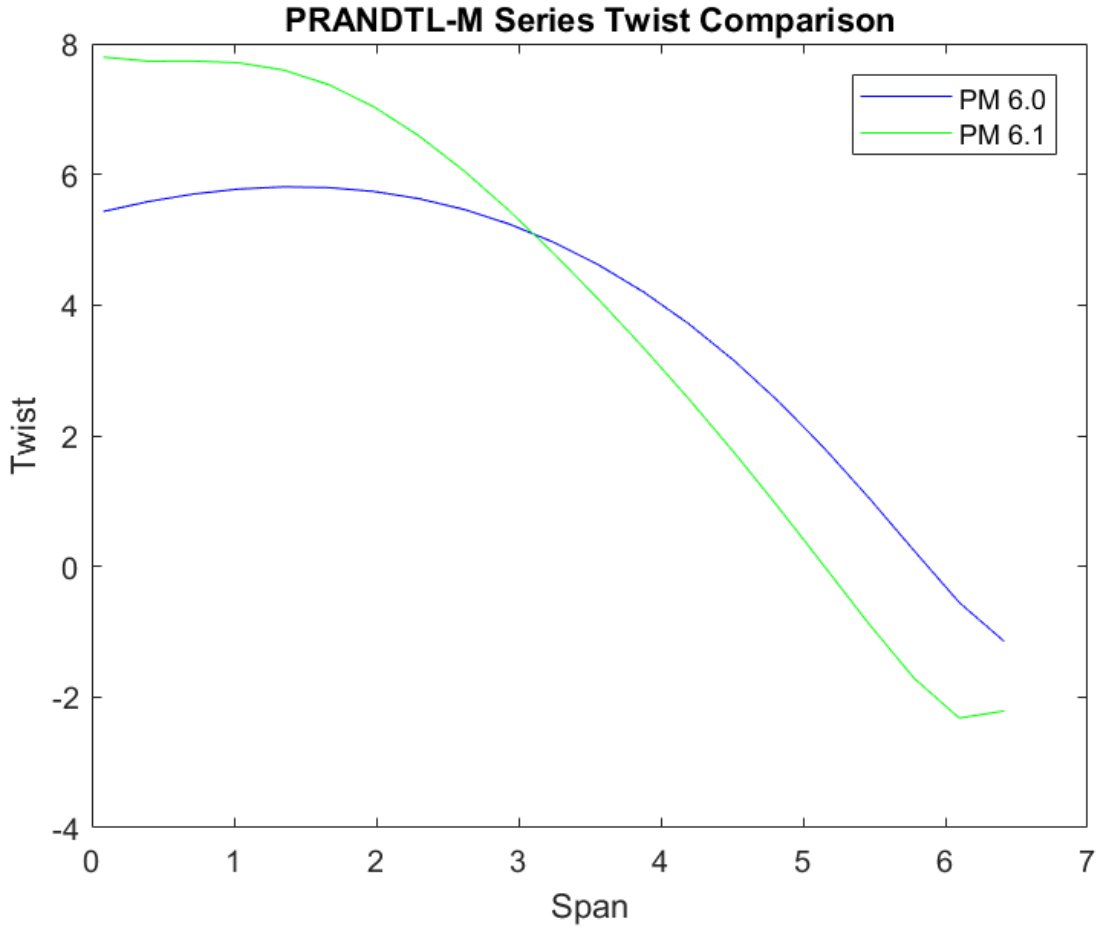


Image Credit: Nathan Sam

PRANDTL-M 6.1: Cnda vs CL

Results:

- VSPaero
  - Slope of trend is identical and positive with PM 6.0
  - Cnda at design CL ~ 0.3:
    - Still negative but showed an increase of 18%

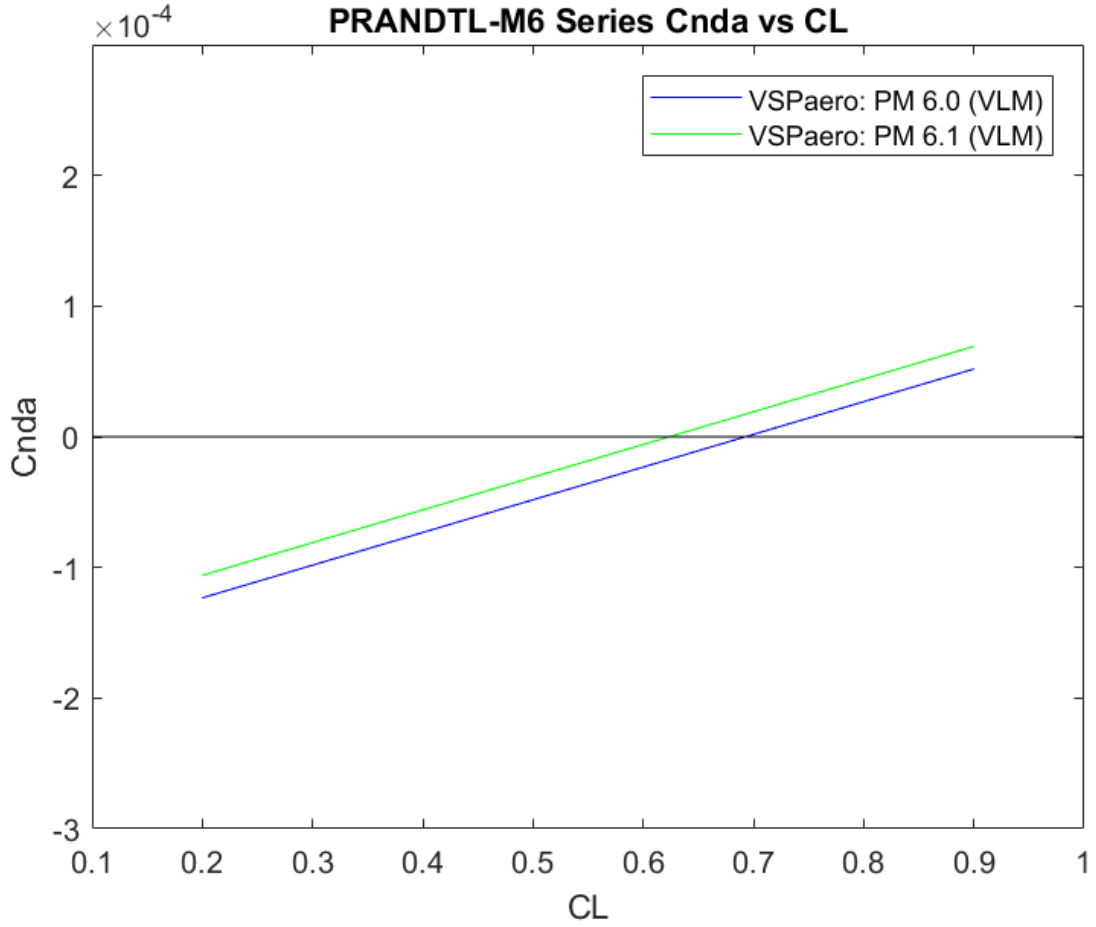


Image Credit: Nathan Sam

Changing Dihedral for PRANDTL-M 6.1

Analysis:

- See how changing dihedral angle will affect the Cnda vs CL results
- Modeled PM 6.1 with different anhedral and dihedrals of: -2°, 0°, 2° (original), 5°, 10°

Results:

- Change in dihedral:
  - Decreasing dihedral, increases Cnda
  - PM 6.1 will have no dihedral
    - Cnda increased by 29%
    - Will reduce roll stability, but can use control surfaces to stabilize

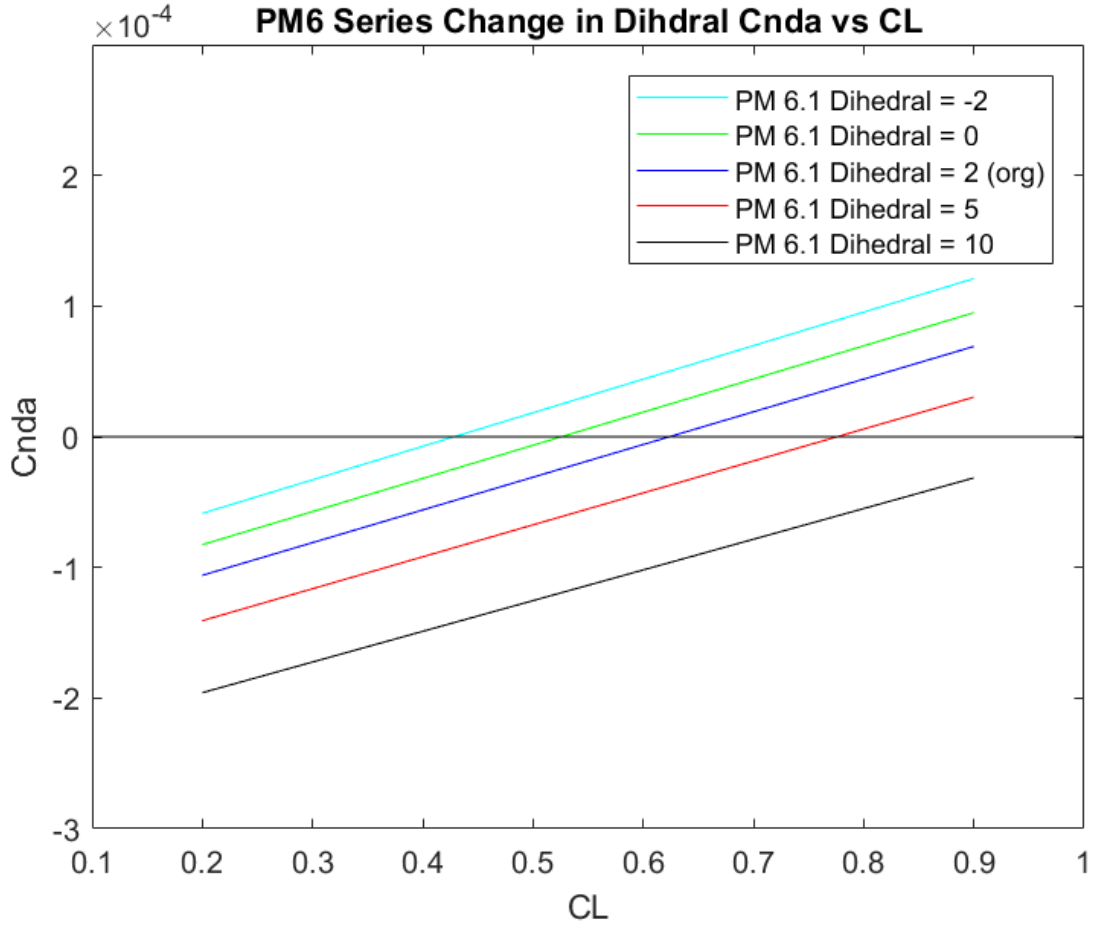


Image Credit: Nathan Sam

Conclusion

- VSPaero is able to detect both bell-shaped lift distribution and estimate proverse yaw
- PRANDTL-M 6.0 initially had more of a elliptical lift distribution
- By changing the twist distribution to have the lift distribution match Al's lift distribution, it increased Cnda by 18%
- When decreasing dihedral, it will increase Cnda
  - PM 6.1 will have a dihedral angle of 0° which increased Cnda by 29%

Pandemic Impact

Cons:

- Was not able to perform initial task
- Could not hang out with the awesome PRANDTL-M team in person
- No more random sonic booms

Pros:

- Working on aerodynamic related topic
- Virtual internship

Lessons Learned

- Communication is key
- Basic understanding of aerodynamics
- NASA employees are very humble and willing to help
- Enjoying analysis type work
- Conflicted between aviation and space

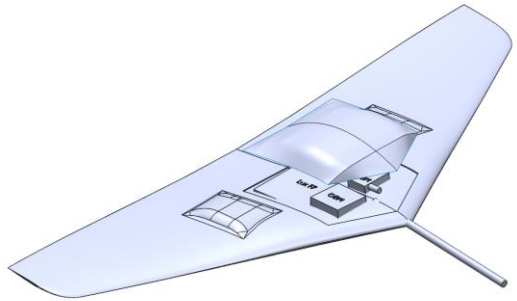
Future Work

Project:

- Start fabrication for PRANDTL-M 6.1
- Perform flight test for PRANDTL-M 6.1
  - Compare experimental data with calculated data
- Run analysis on change in aspect ratio to see affect in Cnda

As for me:

- Continue my education towards a B.S. in Mechanical Engineering
- Hopefully more AFRC internships!
  - Look into Pathways
- Climb Mt. Whitney



CAD Credit: Nathan Sam

Acknowledgements

PRANDTL-M Team:

- Dave Berger (mentor)
- Oscar Murillo (mentor)
- Michael Butros
- Red Jensen
- Derek Abramson
- Justin Hall
- Logan Shaw
- Eathan Devine
- Mani Bhuma
- Jared Quillen
- Bradley Arias

AFRC Employees:

- Lisa Illowsky
- Ciera Knabe
- Jay Levine
- Mark Smith
- Emily Glover
- Jason Lechniak
- Summer 2020 AFRC Interns



Mechanical and Mold Design for PRANDTL-M

EATHAN DEVINE

SUMMER 2020 INTERN

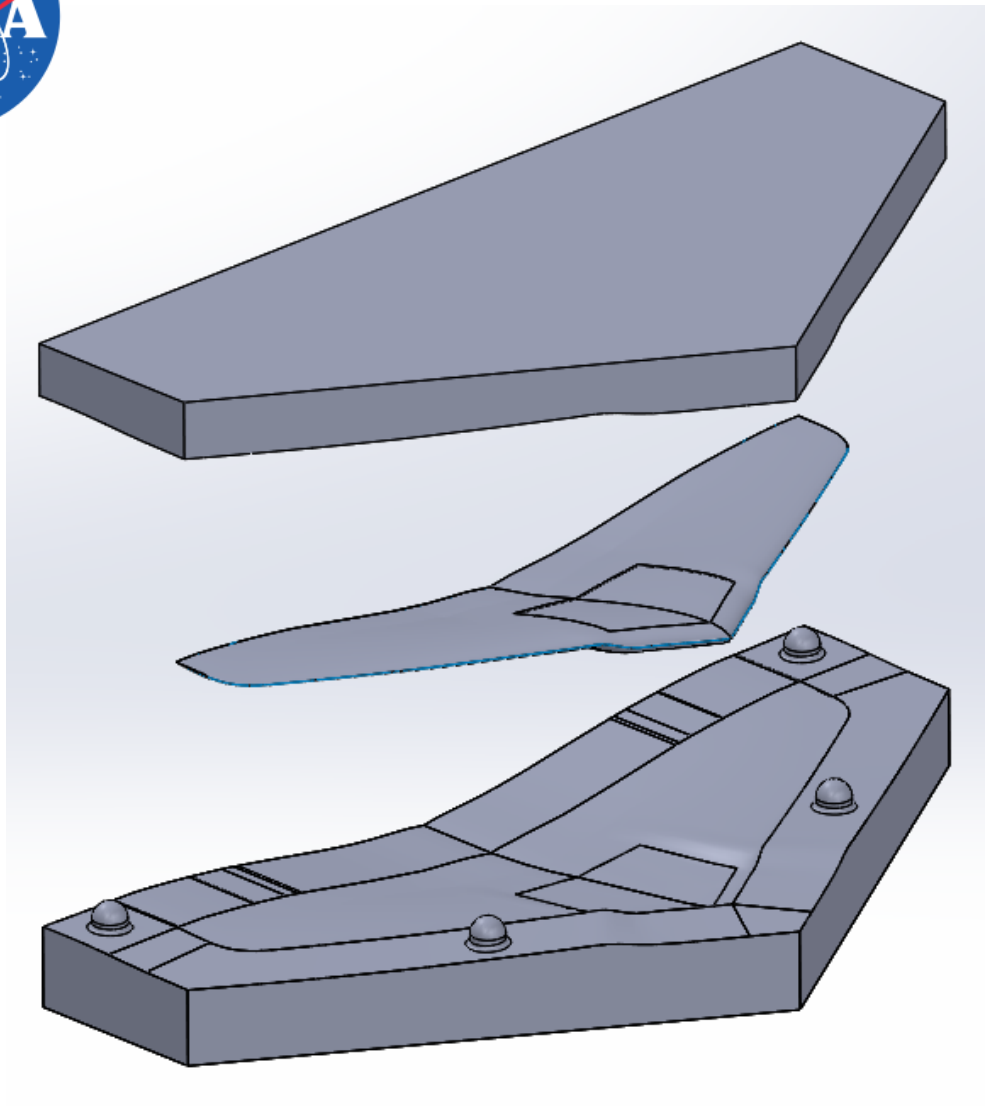
MENTOR: DAVE BERGER

Objective

Challenge: It was determined that the PM 7.0 wing design needed to be edited for smoother geometry will still maintaining desirable aerodynamic properties. There is a need for a new modular release mechanism for flight testing.

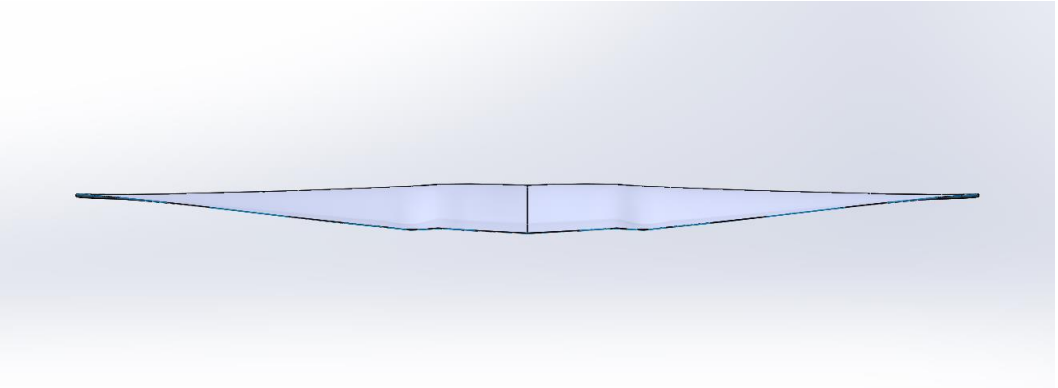
Task:

- Create design tools to edit/redesign PM 7.0 wing to complete the fabrication mold
- Design a modular release mechanism for flight testing



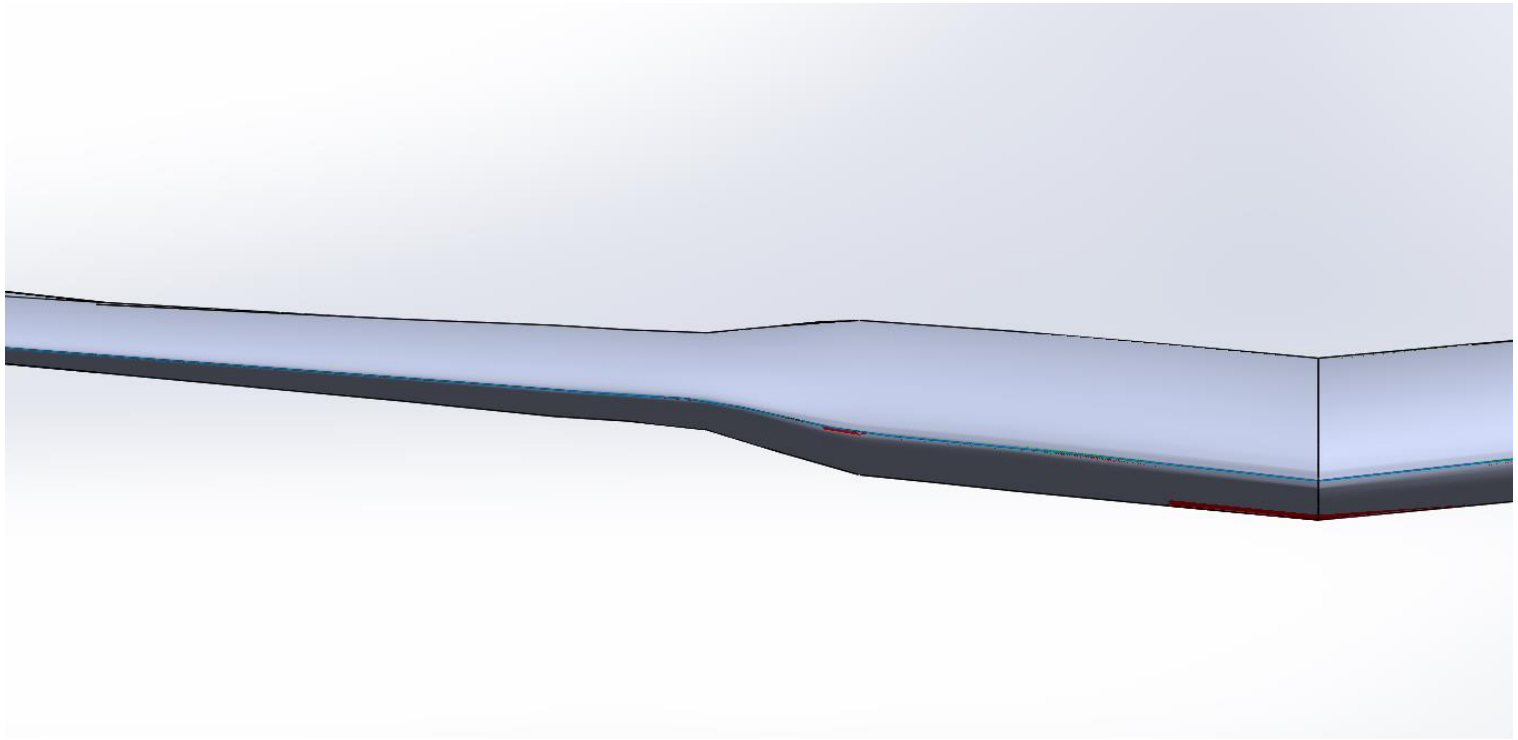
Mold Design

- Tasked with developing a fabrication mold design for PM 7.0 Series glider
- Encountered problems with the discontinuous shape of the trailing edge



CAD Credit: Eathan Devine

Discreet Change in Airfoil Thickness



CAD Credit: Eathan Devine

Optimizing the Airfoils

Possible solutions:

- Editing the reflex angles
- Translating the airfoils downward in the *z*-direction
- Designing and implementing a cosine curve fit to the body of the wing to smooth out the wing body

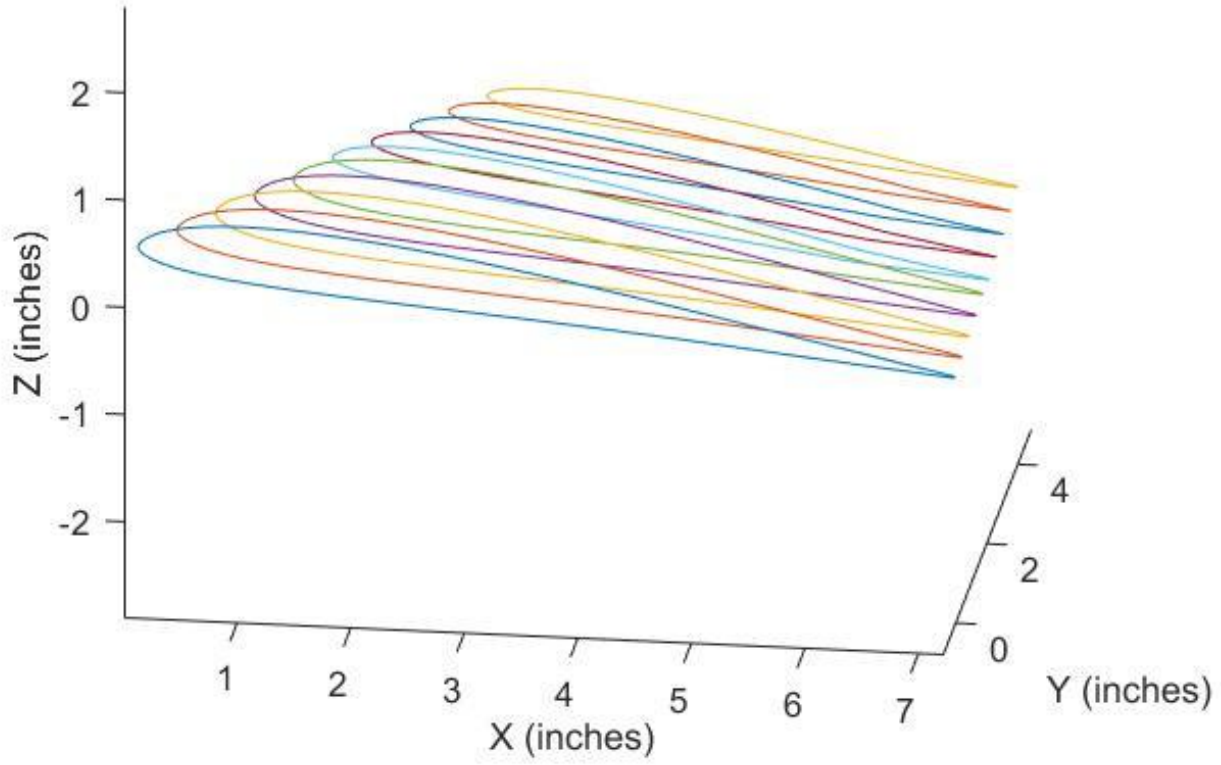
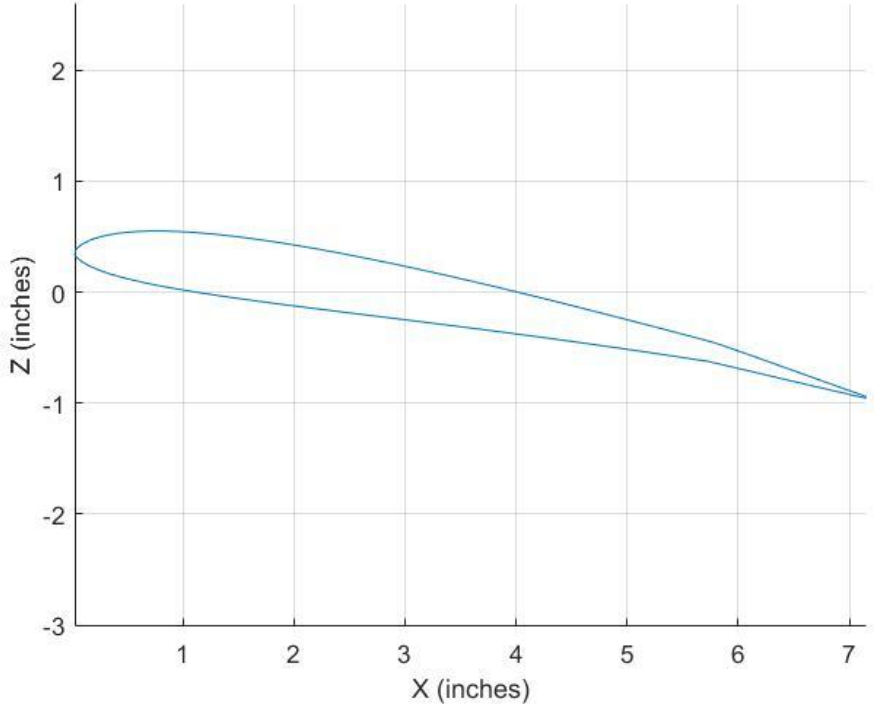


Image Credit: Eathan Devine

Editing the Reflex Angle

The airfoil curve data is edited using a new MATLAB tool I created. Editing the reflex angle changes the shape of the trailing edge but it also affects pitching moment and lift distribution.



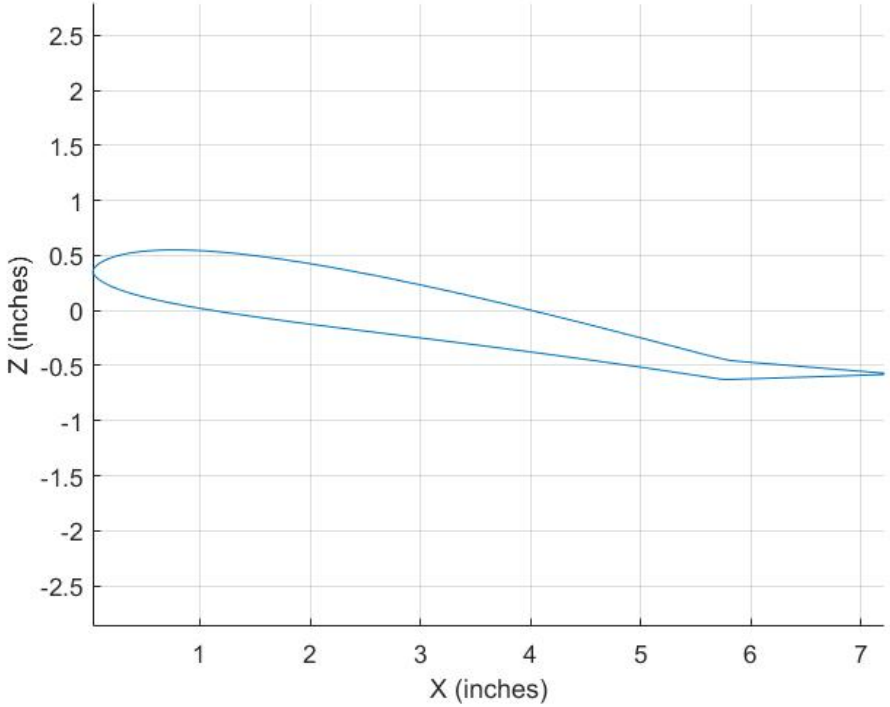
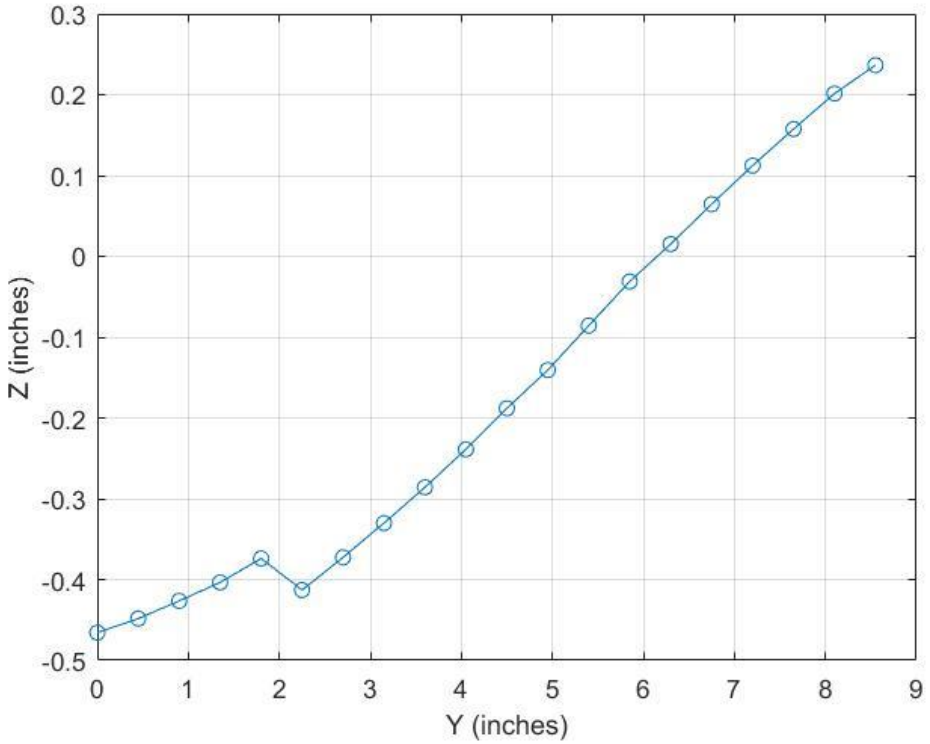


Image Credit: Eathan Devine

Editing the Reflex Angle

Below are images of the original and corrected trailing edge in PM 7.0 due to change in reflex.



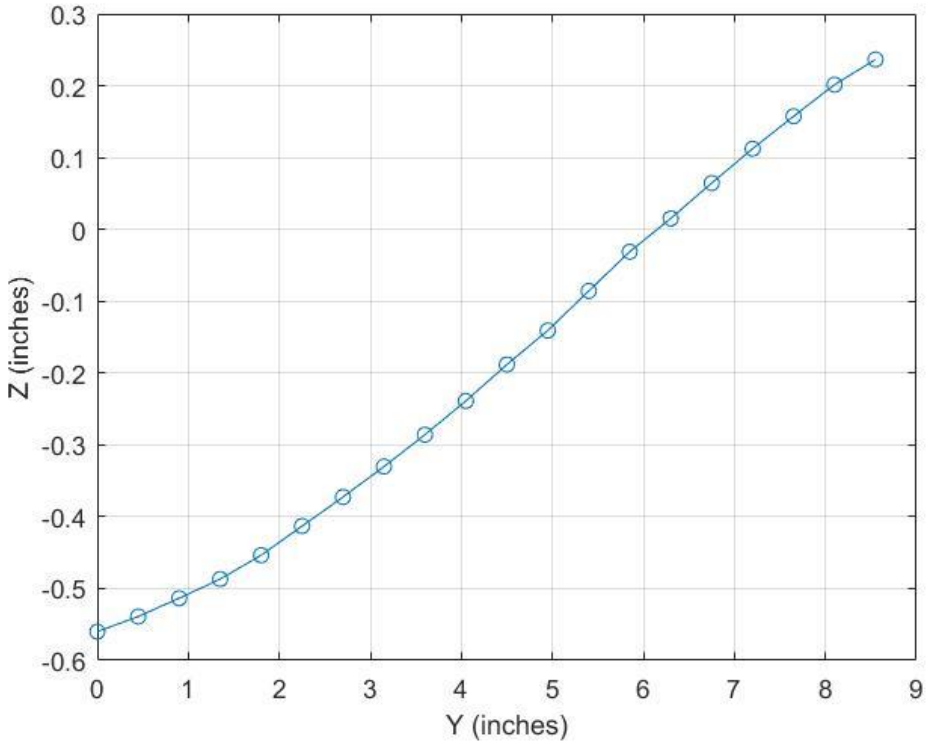


Image Credit: Eathan Devine

Translating the Airfoils

Translating the airfoils is another way to edit the trailing edge, however, this can cause changes in aerodynamic properties as well.

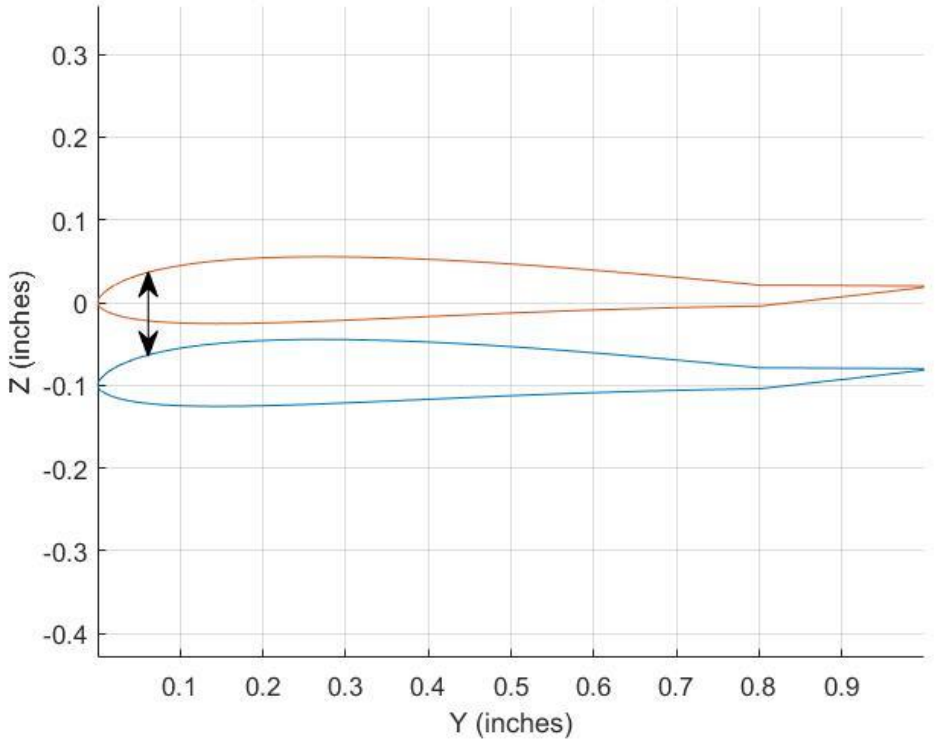
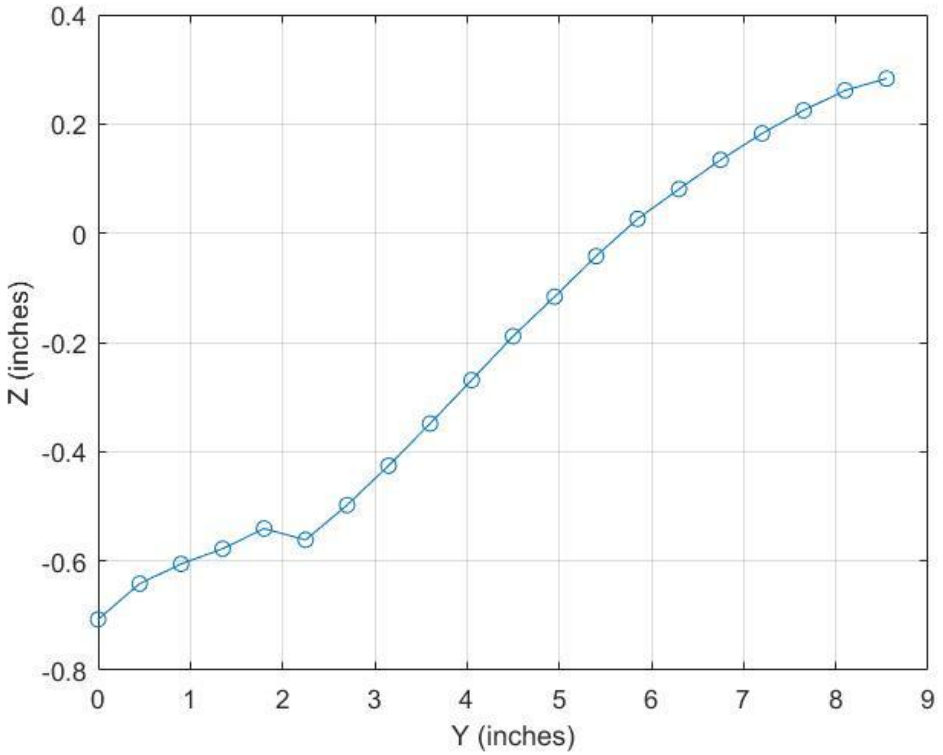


Image Credit: Eathan Devine

Translating the Airfoils

Below are images of the original and corrected trailing edge in PM 7.1 due to change in airfoil position.



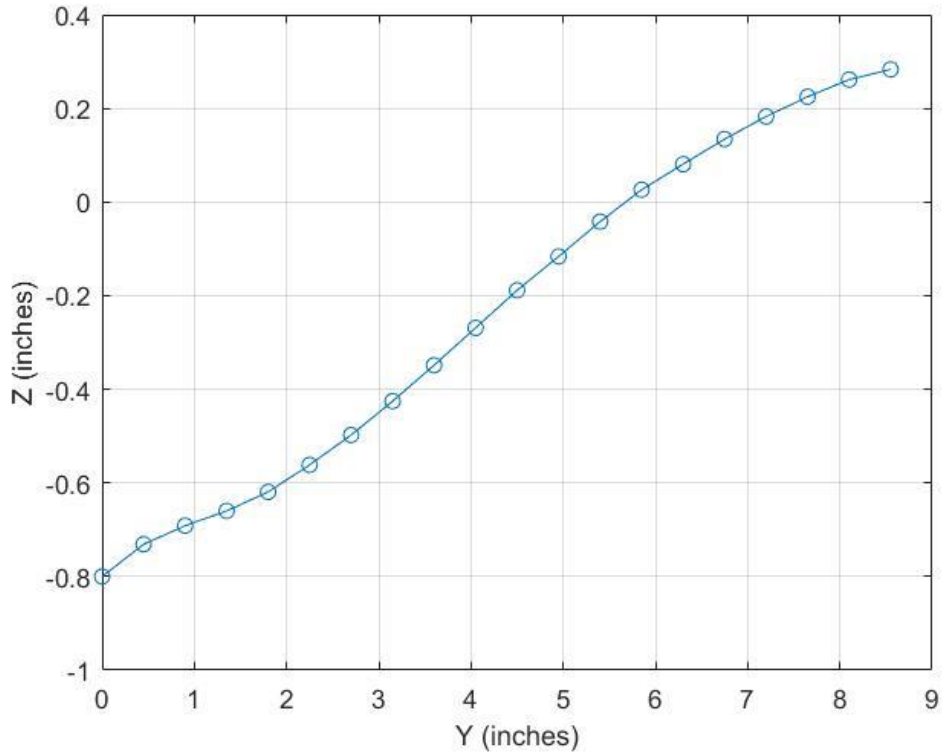
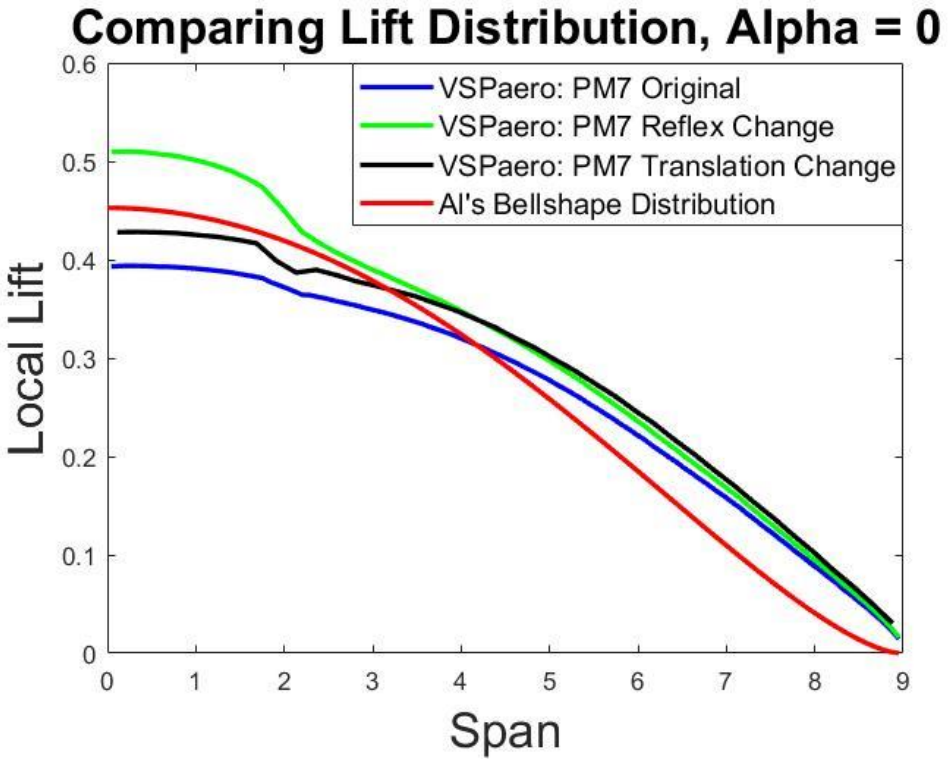


Image Credit: Eathan Devine

Results

The following plots were created using VSPaero to see how the changes affected lift distribution and pitching moment.



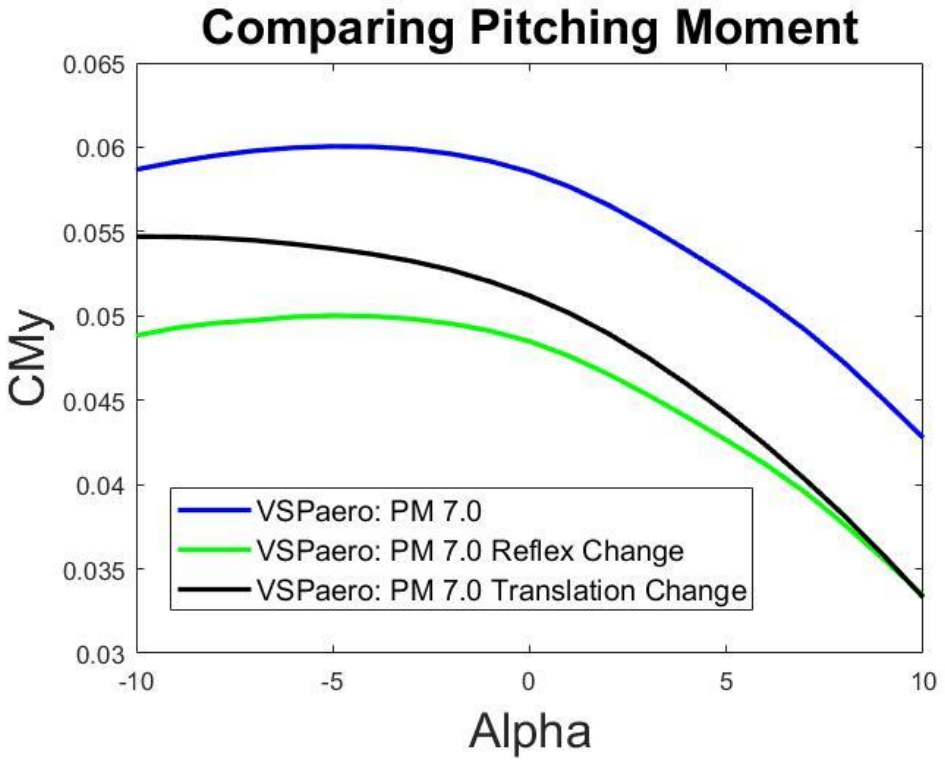
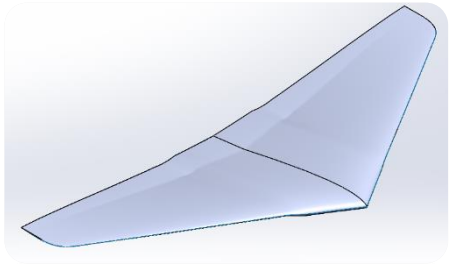


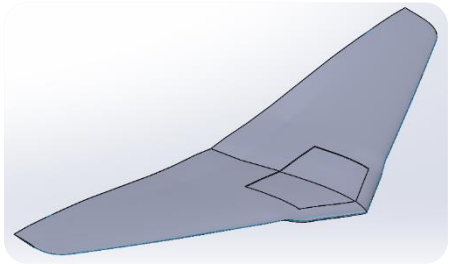
Image Credit: Nathan Sam

PM 7.1 and 7.2 Designs

This data paired with Nathan Sam's improved twist distribution led to the PM 7.1 and 7.2 design iterations. PM 7.2 will be designed with a cosine function thickness sweep.

PM 7.0 → PM 7.1 → PM 7.2



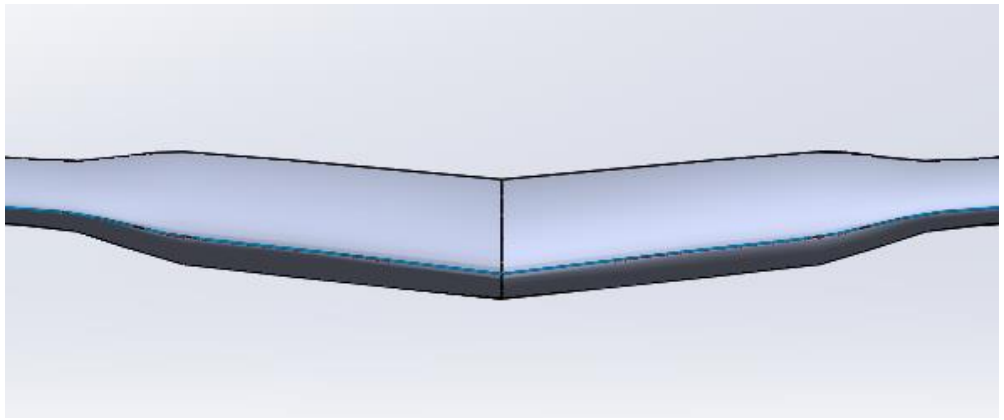


Coming Soon . . .

CAD Credit: Eathan Devine

Implementing a Cosine Curve

Because the lift distribution still showed the discontinuous effect of the discreet change in airfoil thickness, it was determined that implementing a smoother airfoil body with a cosine function could solve this problem.



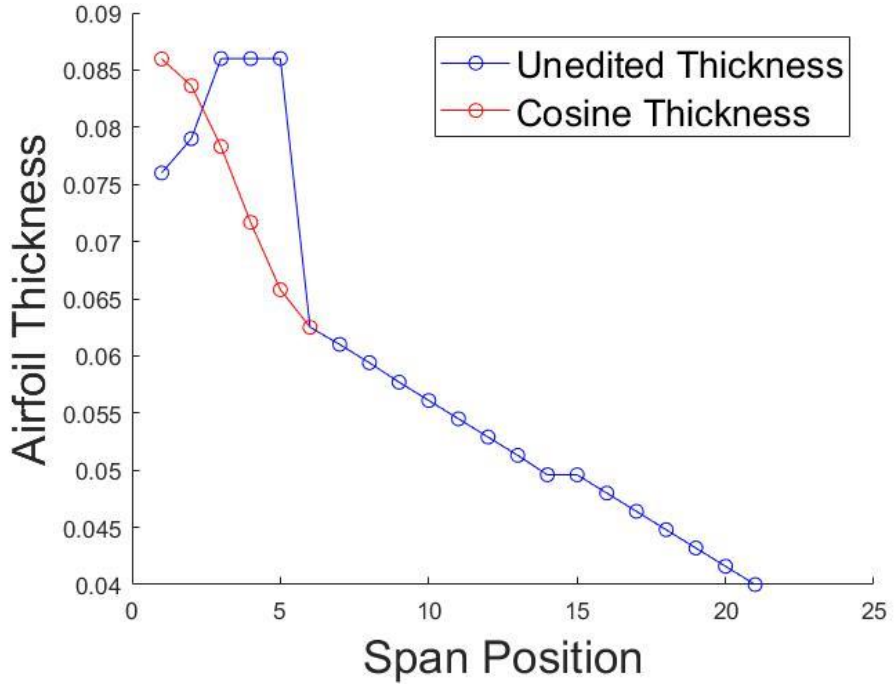
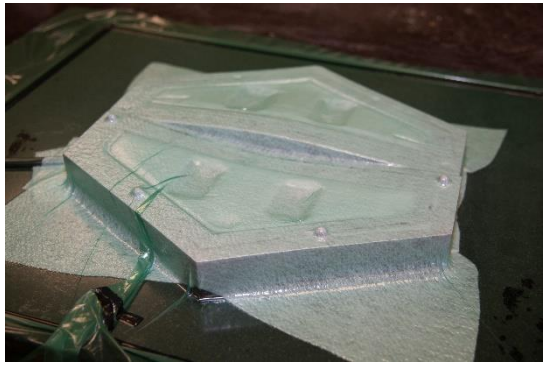


Image Credit: Eathan Devine, Nathan Sam and Bradley Arias

Fabrication

The next phase would be fabrication and test flights. These are images of PM 6.0 during fabrication.







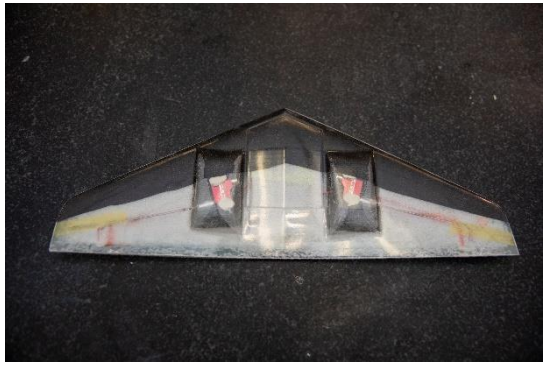


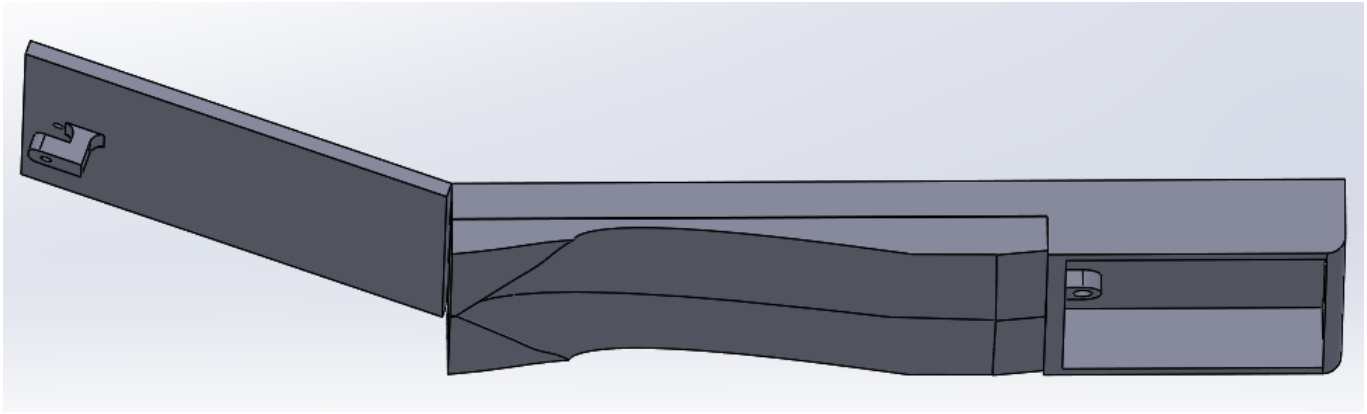
Photo Credit: Lauren Hughes



Photo Credit: Nathan Sam

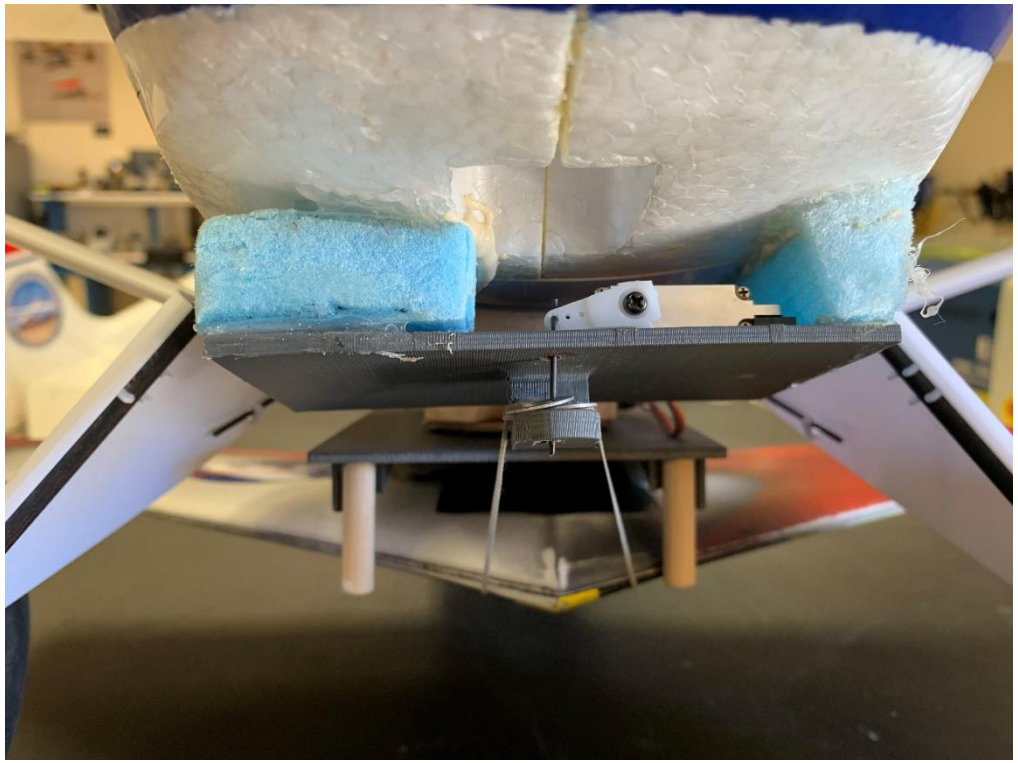
Mechanical Release Design

- Tasked with developing a new modular mechanical release mechanism for PRANDTL-M glider flight tests
- Worked with Paul Bean and Brandon Alba on implementing magnetic separation technology for use in the PRANDTL release mechanism



CAD Credit: Eathan Devine

Mechanical Release Design

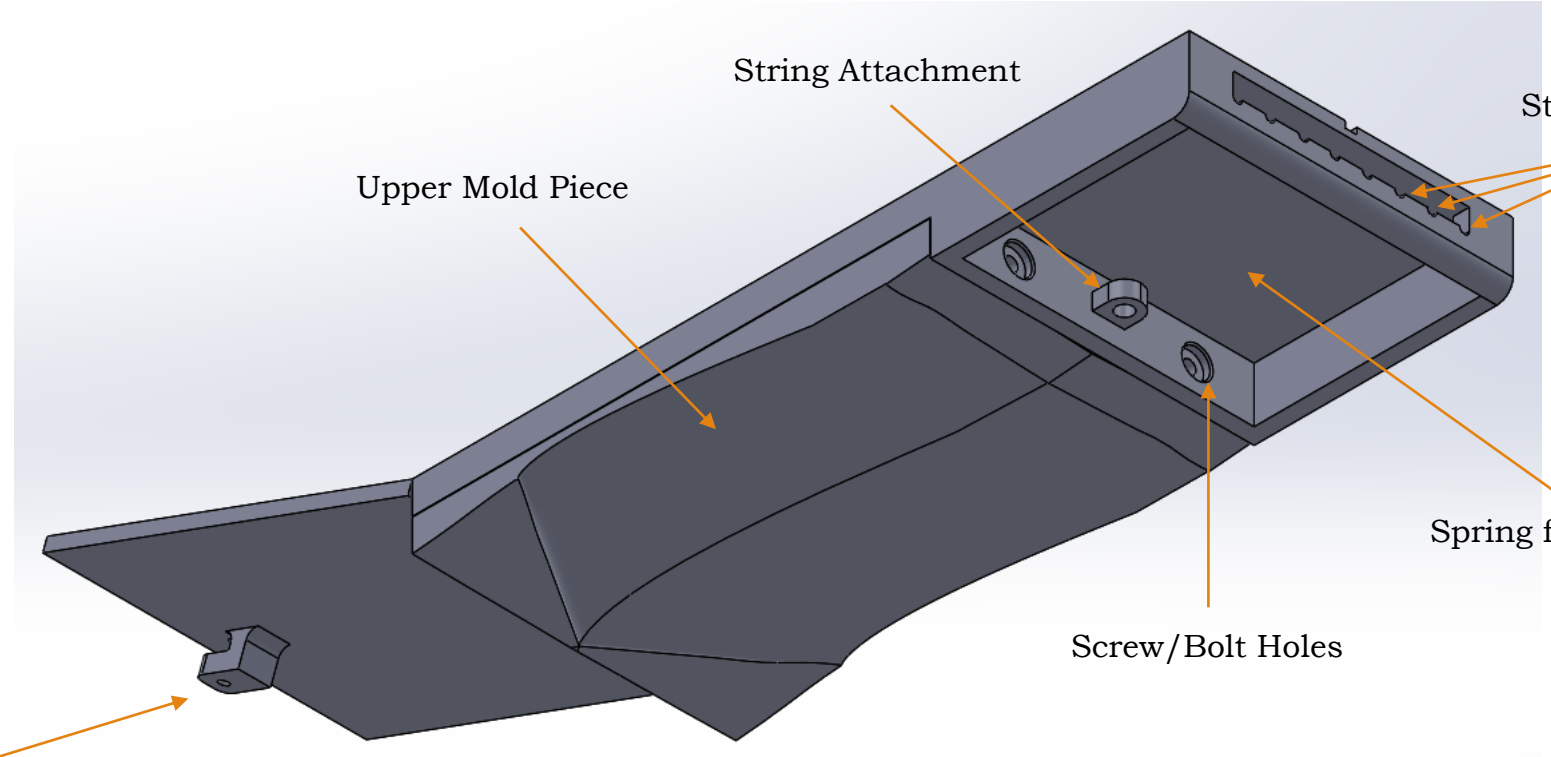


Servo pin mechanism will still be used with new design. New features include:

- Modular upper mold pieces for custom fit to each PM series wing
- Clips to adjust the length of the strings
- Multiple channels for adjusting the position of the strings

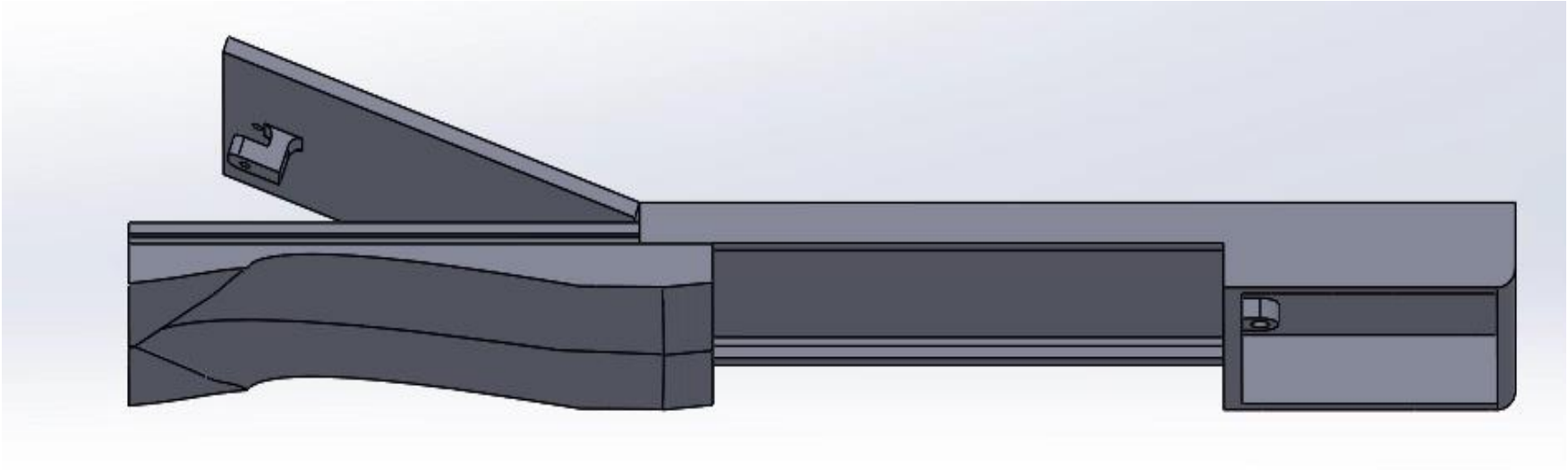
Photo Credit: Nathan Sam

Mechanical Release Design



CAD Credit: Eathan Devine

Mechanical Release Design



CAD Credit: Eathan Devine

COVID-19 Impacts

Cons:

- I was not able to come on site to participate in fabrication or flight tests or meet all the awesome people in person
- It was sometimes difficult to visualize how the fabrication process worked in order to properly design the mold and release mechanism since I was not on site.
- I had to learn to navigate the new online experience and troubleshoot technology issues

Pros:

- I gained invaluable real-world experience in the aerospace field
- I learned how to better adapt and grow in the midst of this challenge

Lessons Learned

- Asking questions and communicating are critical skills especially in a COVID world
- Potential solutions that end up being “wrong” are invaluable to finding an effective solution
- NASA is an awesome place to work and everyone is welcoming and willing to help
- I learned so much about aerodynamics and airplane design
- I gained practical experience with design tools
- I discovered that I really like working in the aeronautics field

Future Work

Project:

- Fully design and implement PM 7.2 cosine sweep
- Fabricate PM 7.1 and 7.2
- Perform flight tests and collect data
- Implement and adjust new release mechanism potentially with magnetic separation technology

My Plans:

- Finish my final year pursuing B.S. in Mechanical Engineering
- I would love to continue interning at AFRC in the future!
- I would like to pursue a career in aerospace



Acknowledgements

- Dave Berger
- Oscar Murillo
- Michael Butros
- Lisa Illowsky
- Robert (Red) Jensen
- Derek Abramson
- Justin Hall
- Logan Shaw
- John Bodylski
- Nathan Sam
- Bradley Arias
- Mani Bhuma
- Jared Quillen
- PRANDTL-M Team
- AFRC Interns
- John Lee



Open Flight Simulation (OFS) for PRANDTL-M

MANI BHUMA

SUMMER 2020 INTERN

MENTOR: DAVE BERGER

Objective

Challenge: In our current virtual setting any sort of flight tests are extremely difficult if not impossible. This forces the team to use predicted or past data and impedes progress.

Task:

- Create a simulation with the current model of the glider
- Perform flight tests and various maneuvers in a realistic environment
- Modify the simulator to be user-friendly and adjustable in order to change different aspects of the glider

Open Flight Simulation (OFS)

- Simulates physical model of glider
- Uses OpenVSP/AVL as sources of aerodynamic data
- Data is augmented and parsed into intermediate form known as Open Flight Dynamics Model

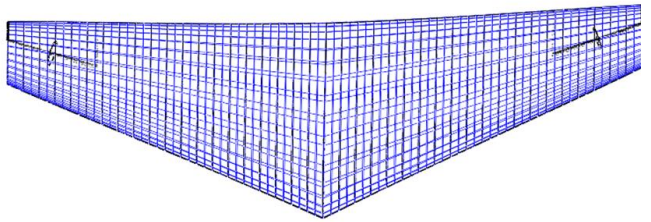


Image Credit: Mani Bhuma



Open Flight Analysis

- Creates graphical time-domain and frequency domain analysis
- Relays aerodynamic information such as various moment coefficients and more
- Flight data from OFS is automatically loaded and segmented



JSBSim

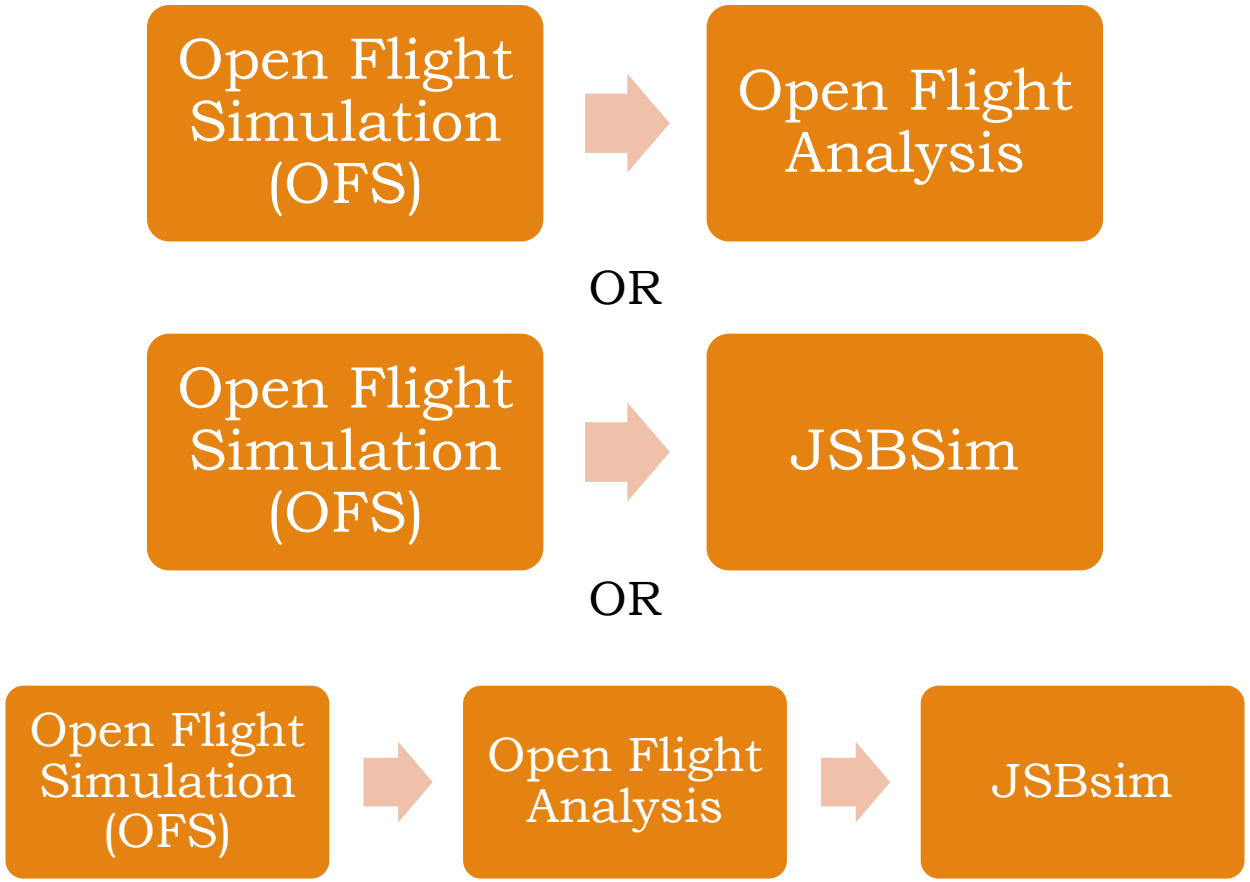
- Generates complete simulation in a realistic environment
- Tests various maneuvers of aircraft model
- Tune gain controller or simulate doublet

Con:

- Real life is not predictable, and simulation uses ideal scenarios

Image Credit: Mani Bhuma

Putting it all together



Corona Virus Impact

Cons:

- Difficulty defining appropriate intern task
- Time delay on receiving specific test materials

Pros:

- Improved communication skills in a group setting
- Narrowed interest in aerospace department

Lessons Learned

Technical Lessons:

- Parameter Estimation
  - pEst
- Python
- General aerodynamics properties (proverse yaw)

Practical Lessons:

- Adaptability
- Communication in a virtual setting
- Importance of listening to other's experiences
- Working in an engineering profession

Future Work

Project Goals:

- Record accurate documentation
- Bridge the team's individual efforts
- PRANDTL-D model -> PRANDTL-M model

My Goals:

- Pilot's License
- Graduate school for Master's in aerospace engineering
- Work on heavy lift systems for NASA
- Eventually apply to become an astronaut

Acknowledgements

- Dave Berger
- Oscar Murillo
- Michael Butros
- Lisa Illowsky
- Nathan Sam
- Eathan Devine
- Jared Quillen
- Bradley Arias
- Rich Maine
- Mark Smith
- Loren Newton
- Carmen J. Fuchs
- David Voracek
- ARFC Interns

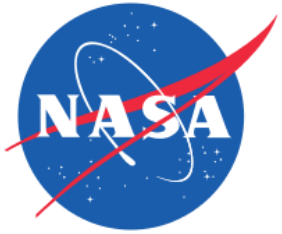


Do you have any Questions?

NASA email: Nathan.sam@nasa.gov
Personal: Nathan.sam40@gmail.com

NASA email: Eathan.t.devine@nasa.gov
Personal: eathand9@gmail.com

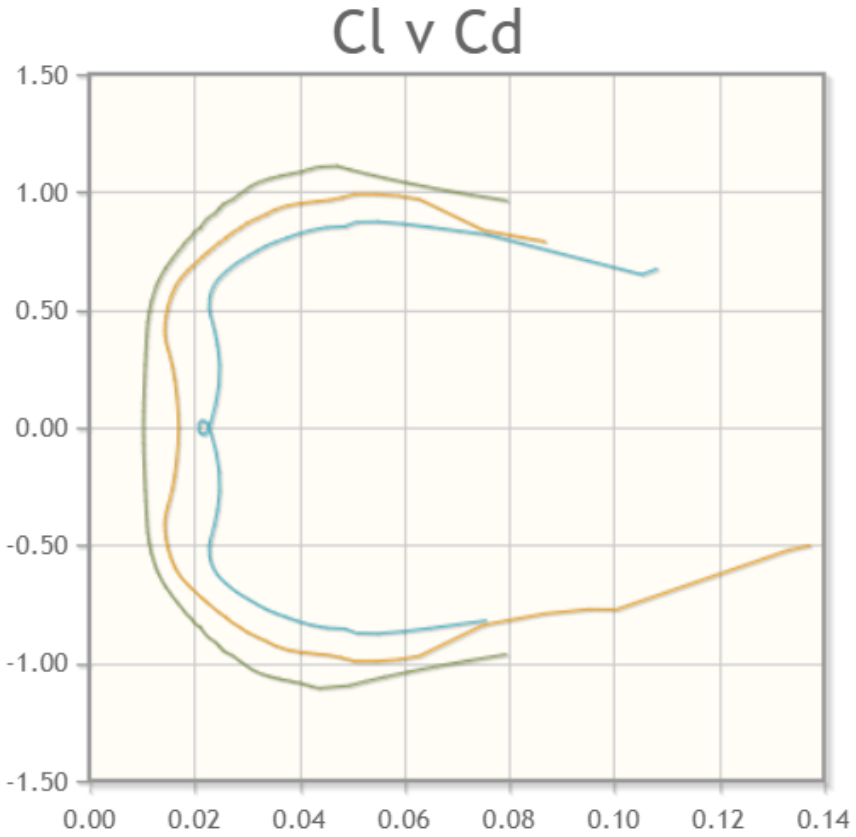
NASA email: m.bhuma@nasa.gov
Personal: manibhuma@gmail.com



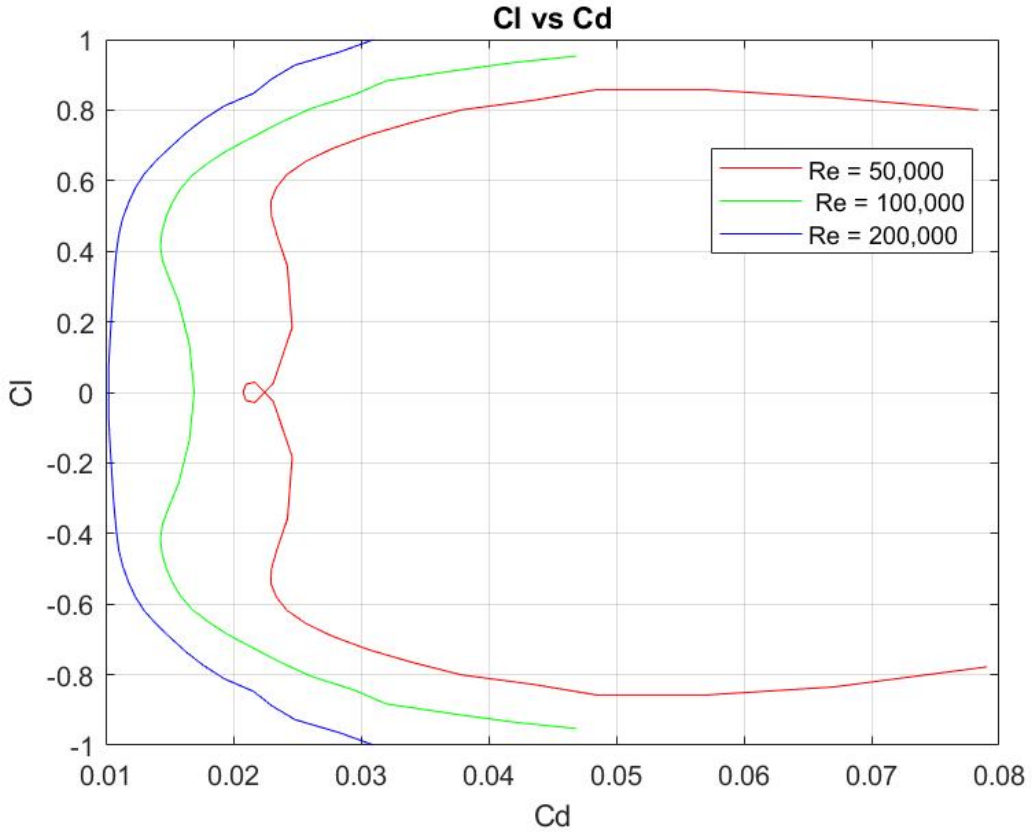
Backup Slides

NACA 0012 Airfoil

Airfoiltools.com



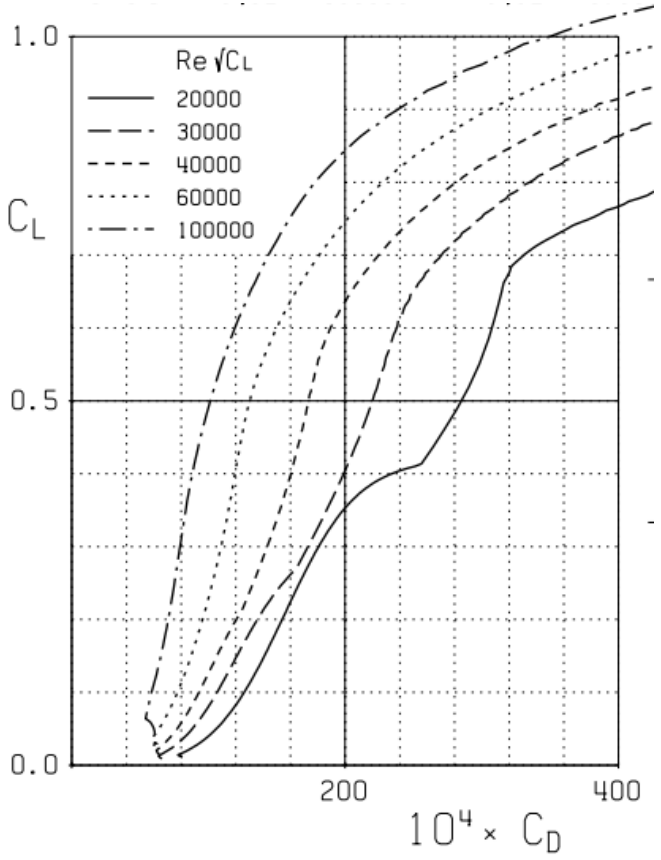
XFLR5 Results in MATLAB



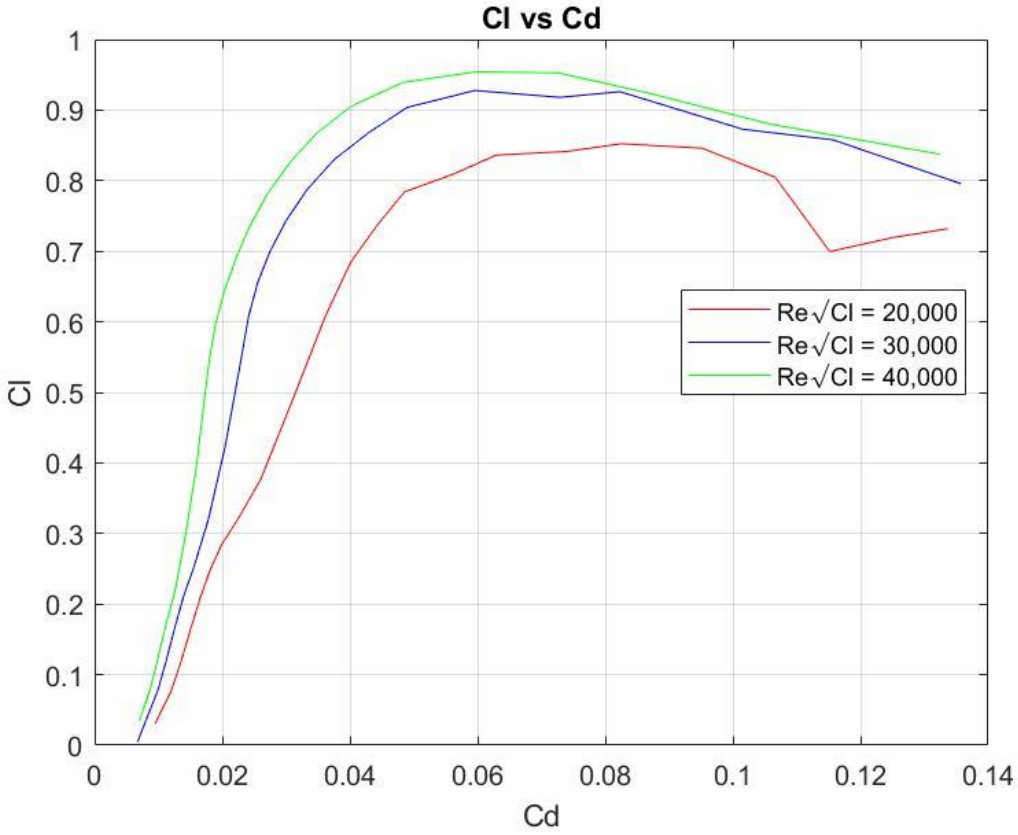
http://airfoiltools.com/airfoil/details?airfoil=n0012-il

AG04 Airfoil

Online Reference



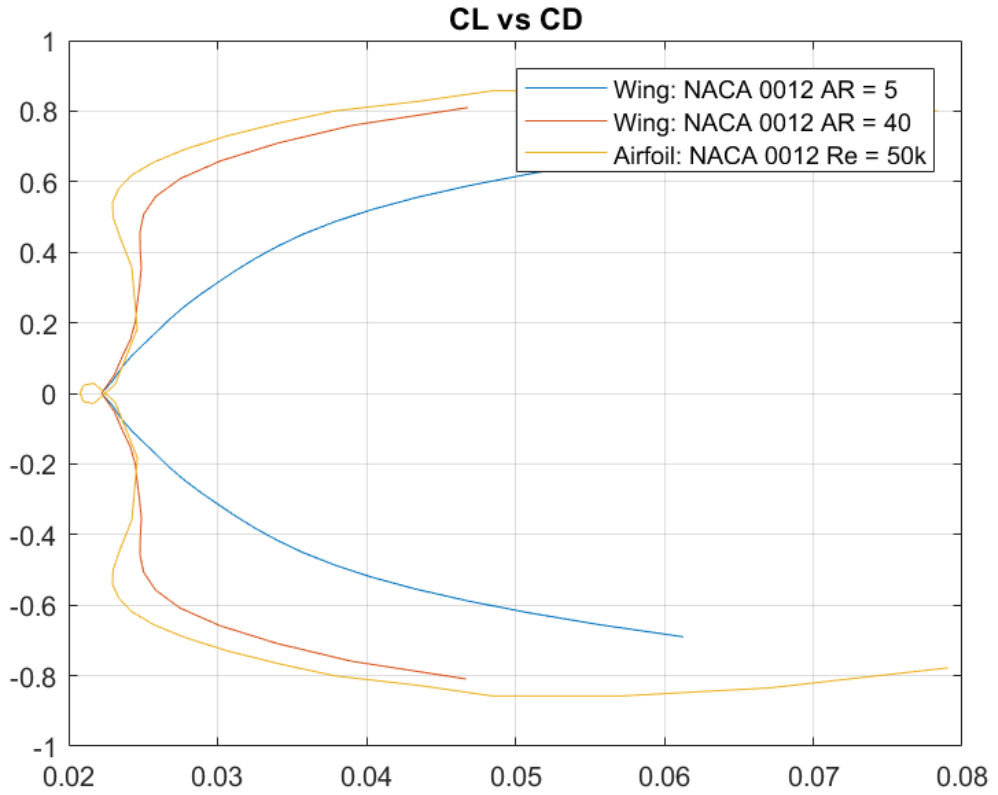
XFLR5 Results in MATLAB



http://www.charlesriverrc.org/articles/drela-airfoilshop/ag04_polars.pdf

Aspect Ratio Check for NACA 0012

XFLR5 Results in MATLAB

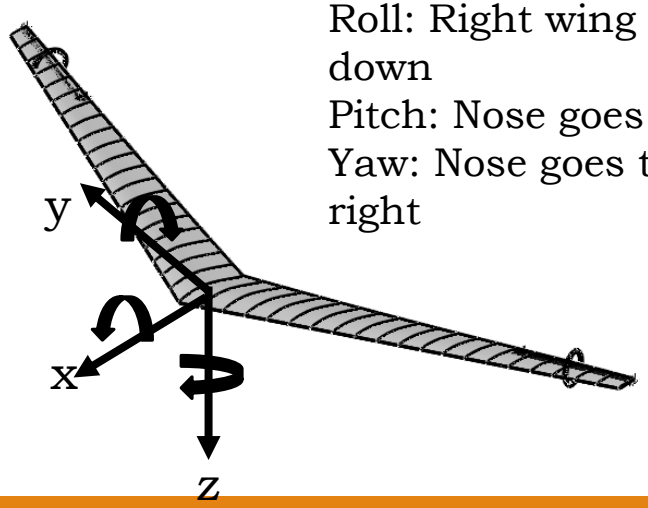


VSP Sign Conventions

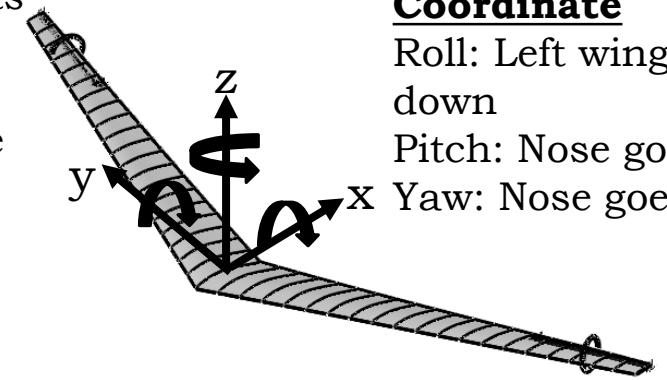
Setup: Right aileron is deflecting up and the left is deflected down. For proverse yaw, right wing should be pointing down and nose should go to the right.

Positive Moment Sign Conventions: Uses right hand rule

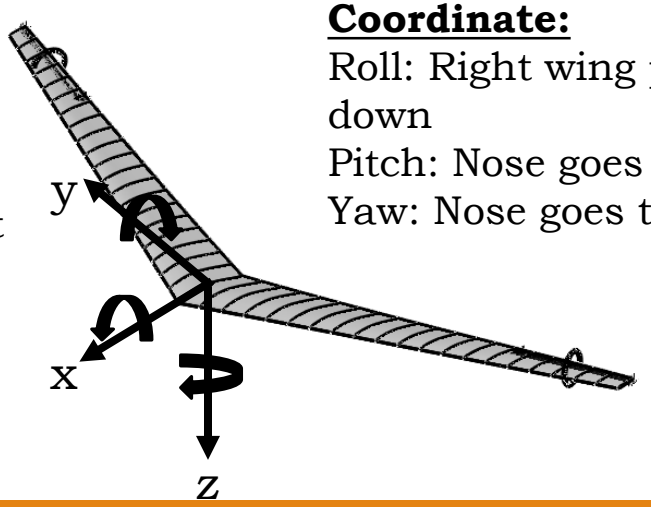
Al's Coordinate:
Roll: Right wing points down
Pitch: Nose goes up
Yaw: Nose goes to the right



VSPaero Geometry Coordinate
Roll: Left wing points down
Pitch: Nose goes up
Yaw: Nose goes to the left



VSPaero Aerodynamic Coordinate:
Roll: Right wing points down
Pitch: Nose goes up
Yaw: Nose goes to the right

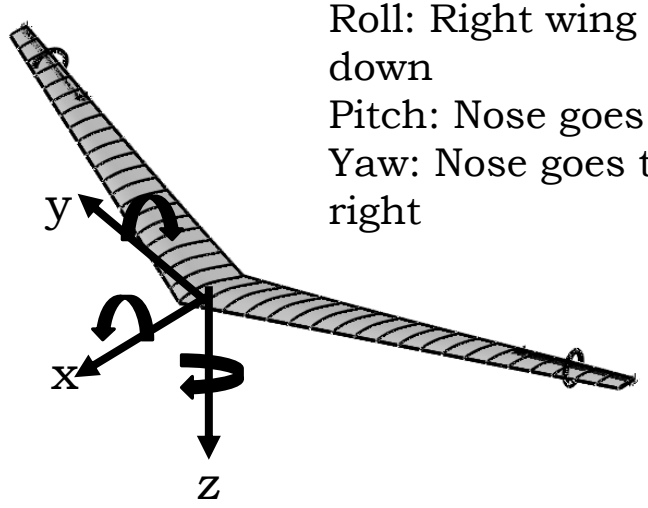


XFLR5 Sign Conventions

Setup: Right aileron is deflecting up and the left is deflected down. For proverse yaw, right wing should be pointing down and nose should go to the right.

Positive Moment Sign Conventions:

Al's Coordinate:
Roll: Right wing points down
Pitch: Nose goes up
Yaw: Nose goes to the right



XFLR5's Coordinate:
Roll: Right wing points down
Pitch: Nose goes up
Yaw: Nose goes to the right

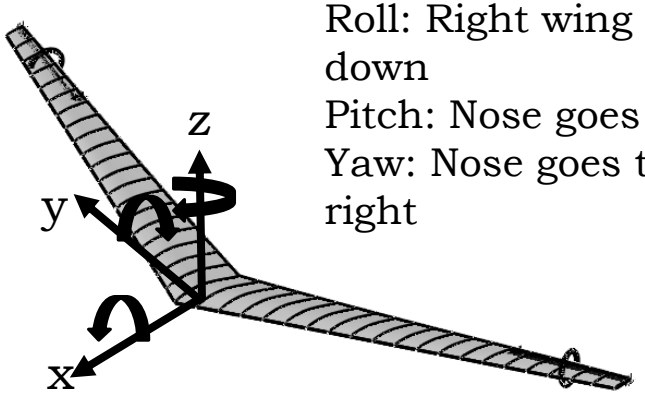


Table of Contents

- Our Backgrounds.....3-7
- Project History/Purpose.....8-10
- Approach.....11
- Aerodynamic Analysis for PRANDTL-M.....12-39
- XFLR5.....14-20
- OpenVSP and VSPaero.....21-39
- Nathan's Conclusion.....40-43
- Mechanical and Mold Design for PRANDTL-M....44-60
- Eathan's Conclusion.....61-64
- Open Flight Simulation for PRANDTL-M.....65-70
- Mani's Conclusion.....71-74
- Extra Slides.....76-82