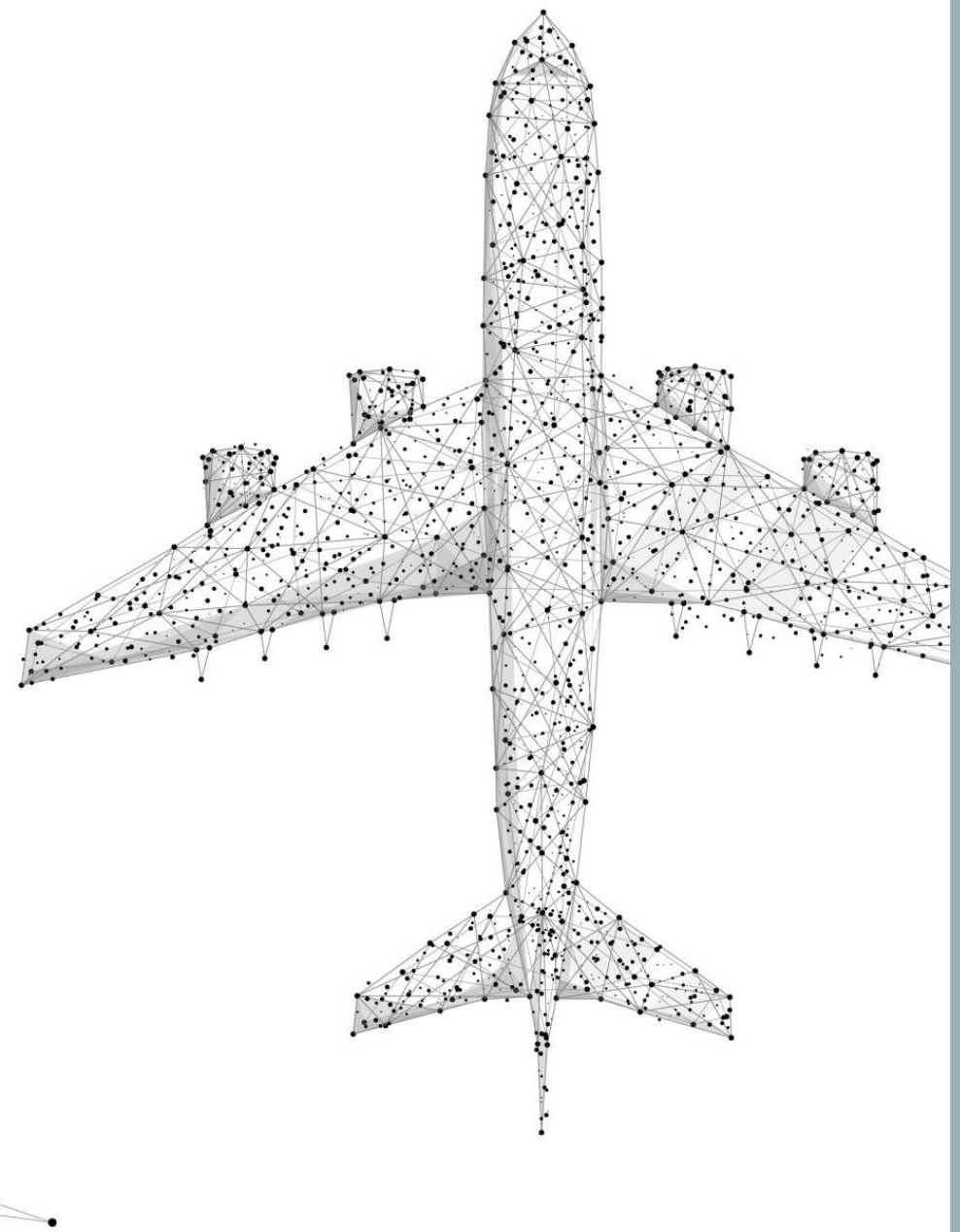

# ME 497R PROJECT #3 AIRFRAME DESIGN

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# PROJECT INTRODUCTION

*Overview and purpose of project*

# OPTIMIZATION OF AIRFRAME AERODYNAMIC DESIGN

- Previous two projects analyzed effects of various geometric and mechanical characteristics of airfoils and wings
- Now these characteristics will be optimized under a certain set of conditions to create an optimal wing configuration
- This will be accomplished through use of Julia packages VortexLattice and SNOW
- Results from three optimization problems will be presented

# DESIGN SET-UP

*Creating the right questions for the optimization problems*

# DESIGN SET-UP: FORMULATING THE RIGHT QUESTION

- In Dr. Ning's textbook *Engineering Design Optimization*, there are 5 guiding steps to construct an optimization problem:
  1. Describe the problem
  2. Gather information
  3. Define the design variables
  4. Define the objective
  5. Define the constraints

# DESIGN SET-UP: PROBLEM 1

1. Describe the problem
   - Simple RC plane ~300 grams in weight, ~0.75 meters in length
2. Gather information
   - Aspect ratio, 6-8, wingspan 0.5-1.0 m, pitch angle of 5◦ , and 3 N of weight (306 grams) at a speed of 15 m/s
3. Define the design variables
   - Aspect ratio, specifically, the wingspan and chord distribution of the wing
4. Define the objective
   - Minimize induced drag. Need higher lift to drag ratio to fly more effectively and conserve energy consumption.
5. Define the constraints
   - Lift generated by the wing; the aircraft needs sufficient lift force

| | |
|---|---|
| minimize | induced drag |
| subject to | $6 \leq \text{span/chord} \leq 8$ |
| | $0 \leq \text{Lift} - 3.0 \leq 0$ |

# DESIGN SET-UP: PROBLEM 1

# DESIGN SET-UP: PROBLEM 2

1. Describe the problem
   - Elliptical wing, similar to the famous World War II aircraft, the Supermarine Spitfire
2. Gather information
   - Wing of span 8.0 m, pitch angle of 5◦, capable of carrying 1.7 N of weight at speed of 1 m/s, and zero sweep
3. Define the design variables
   - Chord lengths along the wingspan.
4. Define the objective
   - Minimize induced drag.
5. Define the constraints
   - Lift generated by the wing; the aircraft needs to produce sufficient lift force
   - Chord lengths must decrease from root to chord

| | |
|---|---|
| minimize | induced drag |
| subject to | $0 \leq \text{Lift} - 1.7 \leq 0$ |
| | $-\text{Inf} \leq \text{difference(chords)} \leq 0$ |
| | $0 \leq \text{chords} \leq 10$ |

# DESIGN SET-UP: PROBLEM 2

# DESIGN SET-UP: PROBLEM 3

1. Describe the problem
   - Rectangular wing with elliptical lift distribution
2. Gather information
   - Wing of span 8.0 m, pitch angle of 5◦, capable of carrying 1.7 N of weight at speed of 1 m/s, and zero sweep
3. Define the design variables
   - Twist values along the wingspan.
4. Define the objective
   - Minimize induced drag.
5. Define the constraints
   - Lift generated by the wing; the aircraft needs to produce sufficient lift force

| | |
|---|---|
| minimize | induced drag |
| subject to | $0 \leq \text{Lift} - 1.7 \leq 0$ |
| | $-\text{Inf} \leq \text{difference(chords)} \leq 0$ |
| | $0 \leq \text{twists} \leq 10*\text{pi}/180$ |

# DESIGN SET-UP: PROBLEM 3

# METHODS & RESULTS

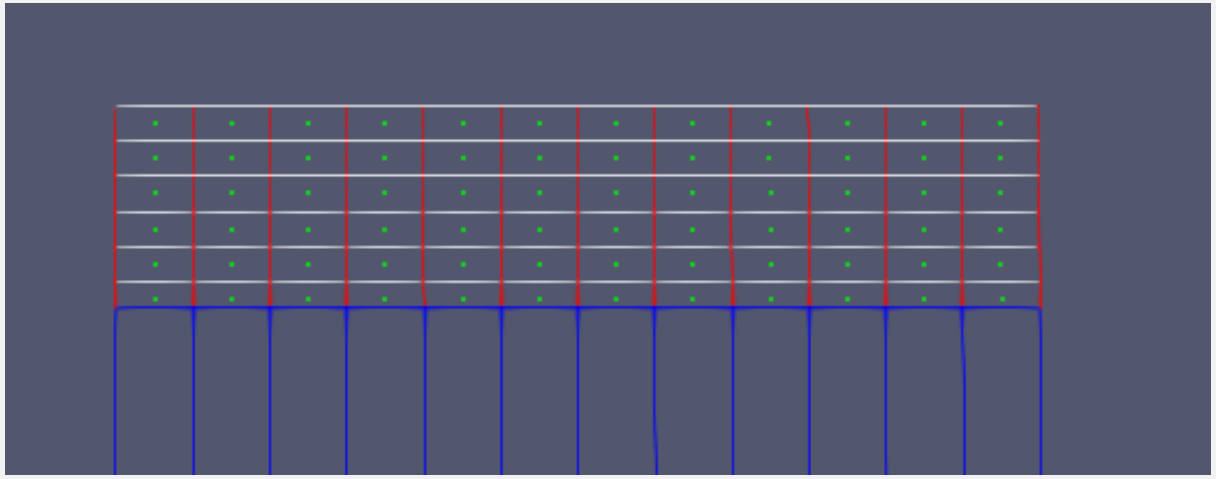
*Processes followed to obtain desired solutions*

# METHODS & RESULTS: PROBLEM 1

- Design variables are span and chord
- The lift constraint is 3 N (about 306g) flying at 15m/s with an angle of attack of 5 degrees. The result took 6 iterations.
- Relatively straight forward, laid foundation for further problems

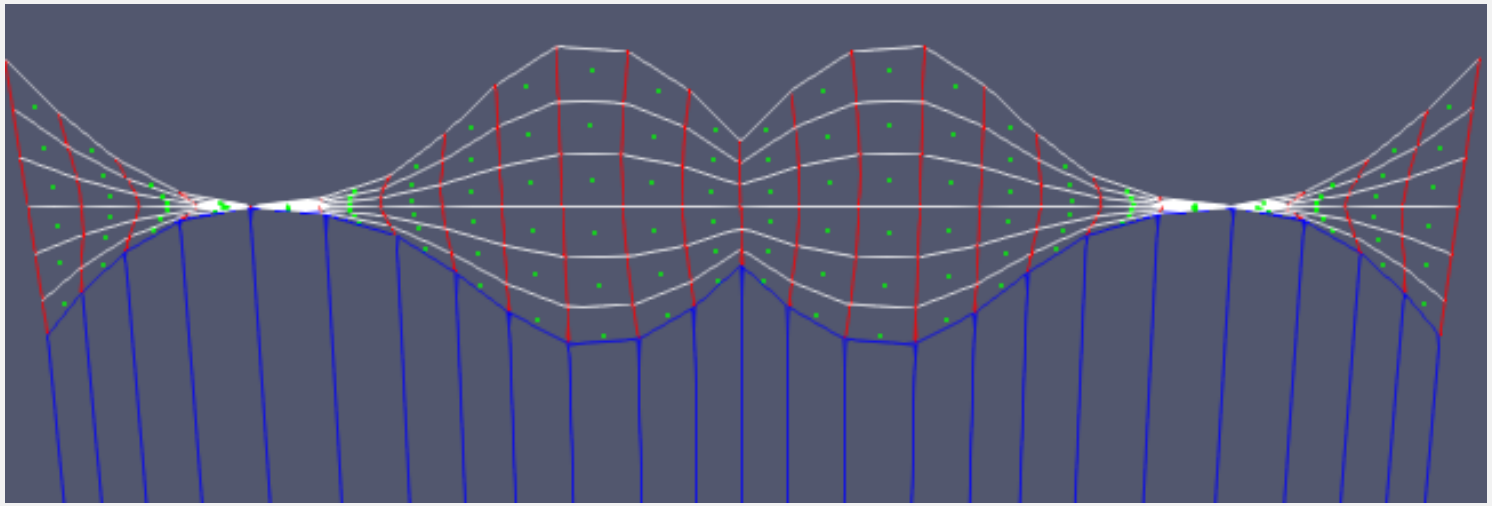
```
EXIT: Optimal Solution Found.
xstar = [0.6582074577685973, 0.08227593142699367]
fstar = 0.04817499633118145 5
info = Solve_Succeeded
```

| | |
|---|---|
| minimize | induced drag |
| subject to | $6 \leq \text{span/chord} \leq 8$ |
| | $0 \leq \text{Lift} - 3.0 \leq 0$ |



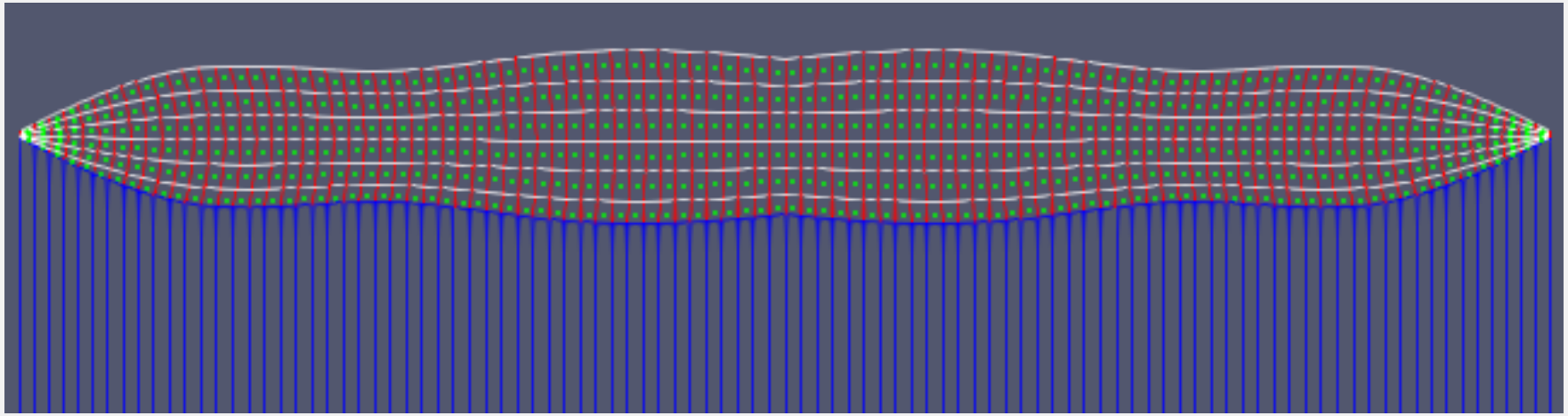
# METHODS & RESULTS: PROBLEM 2

- First successful run of optimizer
- Chord distribution fluctuates wildly
- Error: failed to update the number of spanwise sections being analyzed in VortexLattice
- Solution: increase number of spanwise sections to correspond with spline function



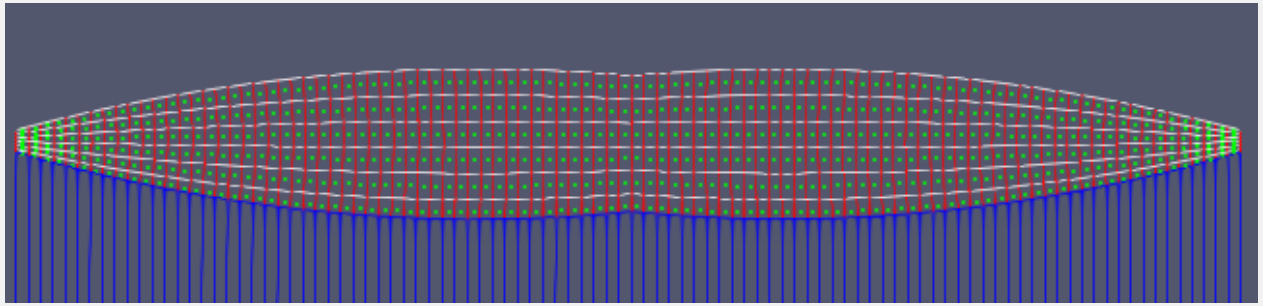
# METHODS & RESULTS: PROBLEM 2

- Optimizer began to return more elliptical shaped wings
- Was always uneven and somewhat curvy
- Error: optimal solution from the optimizer set some chord values to be greater than root chord
- Solution: include a constraint to insure decreasing chord lengths from root to tip

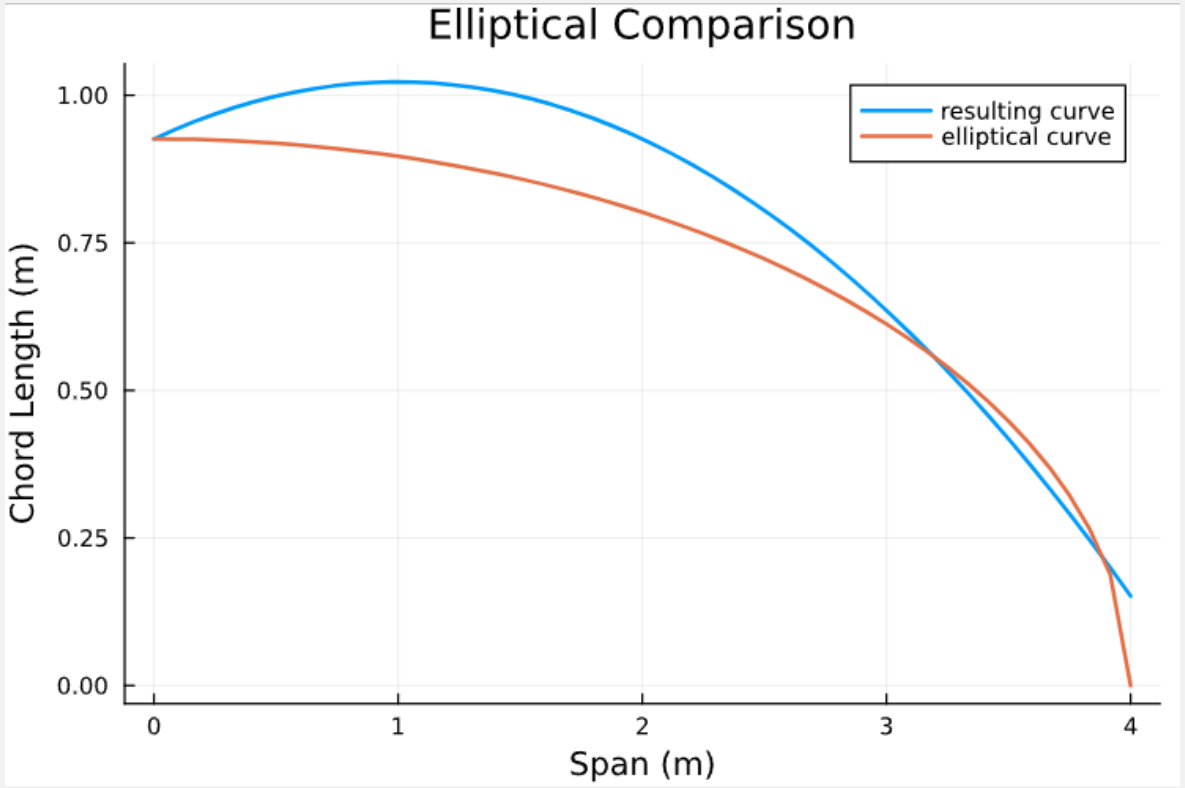


# METHODS & RESULTS: PROBLEM 2

- Optimal solution found for 3 chord length values
- Elliptical distribution is not perfect due to few values



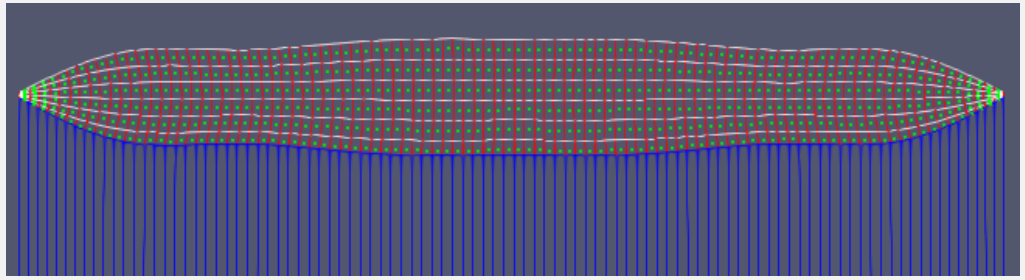
```
EXIT: Optimal Solution Found.
xstar = [0.9259052543175672, 0.9259052471943864, 0.15179738749121324]
fstar = 0.023168251586042465
info = Solve_Succeeded
```



# METHODS & RESULTS: PROBLEM 2

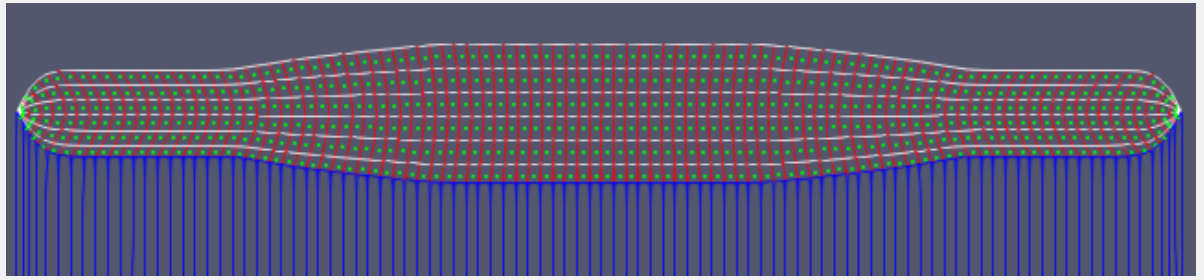
- Increasing number of chord values results in error

5 Chord Values



```
EXIT: Maximum Number of Iterations Exceeded.
xstar = [0.9676597760662764, 0.9676597489769582, 0.8041631498578127, 0.80076008057
43338, 0.04567840545252929]
fstar = 0.022637780522614476
info = Maximum_Iterations_Exceeded
```

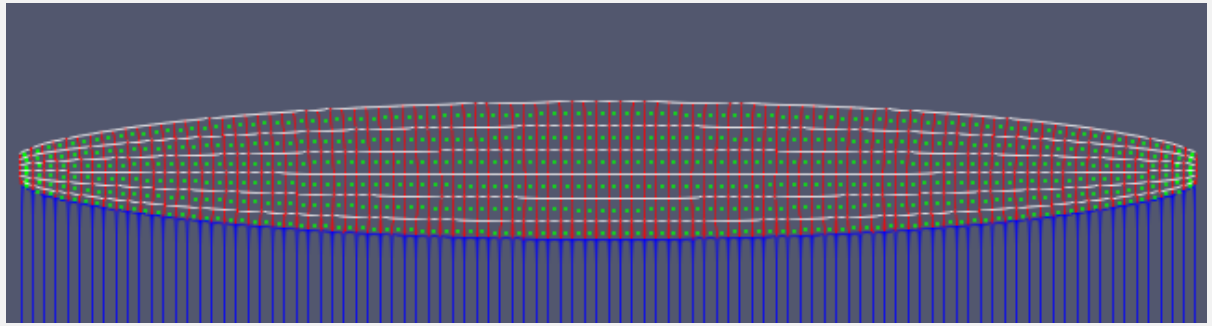
25 Chord Values



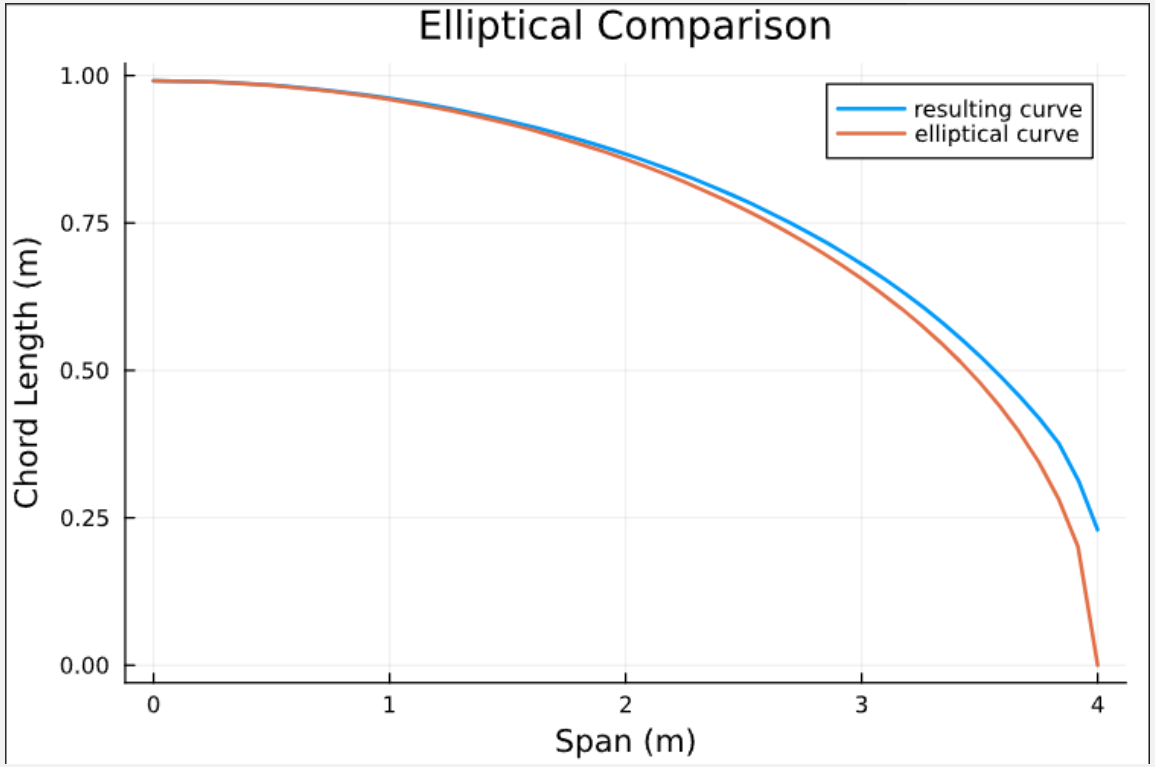
```
EXIT: Maximum Number of Iterations Exceeded.
xstar = [1.00039492021738, 1.00039428211377, 1.0003936826854725, 1.000393067375234
1, 1.000392175919842, 1.000390748648174, 1.0000859053830036, 1.0000809354932634, 0
.9660427772340056, 0.932005321298212, 0.8932479299876651, 0.8531635722932792, 0.80
86038840580031, 0.7609531548658109, 0.7017324401211877, 0.6424190110798923, 0.6343
354378782706, 0.6339434084453713, 0.6305979442442758, 0.6303891976522474, 0.630386
9623088677, 0.6303860576509073, 0.6303840693192846, 0.537851597025525, 1.949409028
14509e-7]
fstar = 0.021633291627803995
info = Maximum_Iterations_Exceeded
```

# METHODS & RESULTS: PROBLEM 2

- Successful elliptical wing with proper elliptical distribution
- Solution: use "grid_to_surface_panels" in VortexLattice to create the wing geometry instead of the previous "wing_to_surface_panels" method

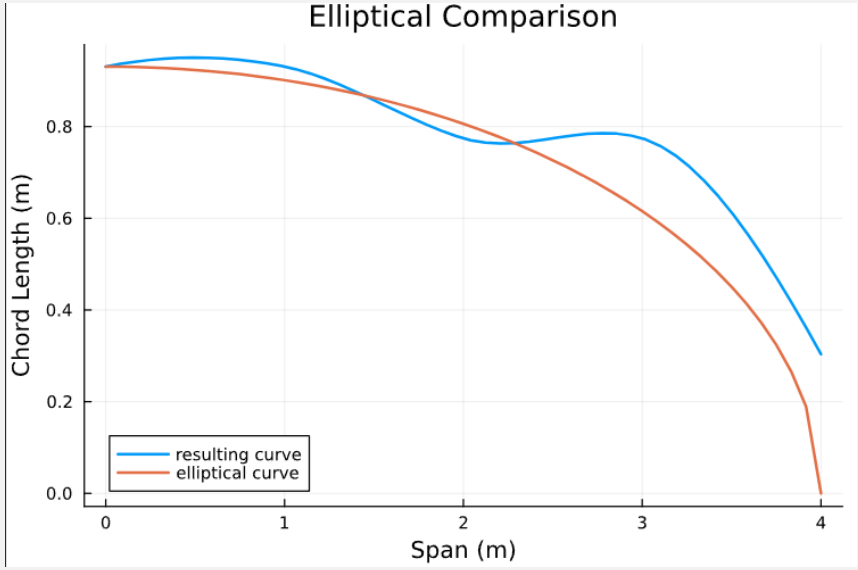


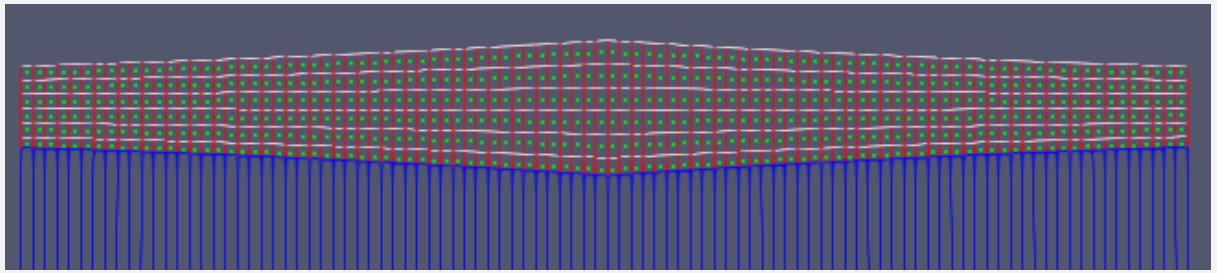
```
EXIT: Optimal Solution Found.
xstar = [0.990932018620797, 0.9901227276962783, 0.9876950391365055, 0.9836395846845459
, 0.9779377415600808, 0.9705537573419005, 0.9614514416082949, 0.9505850247326799, 0.93
78873506742835, 0.9232818775588912, 0.9066758650159614, 0.8879547755259892, 0.86698696
31395322, 0.8435921206514606, 0.8175710615376739, 0.788653699646549, 0.756495428115846
4, 0.720650363448121, 0.6805130642433932, 0.6352470697987135, 0.5837433109668767, 0.52
47002199709955, 0.45702640872075895, 0.3773794195347345, 0.22969457677817823]
fstar = 0.023330481752910446
info = Solve_Succeeded
```



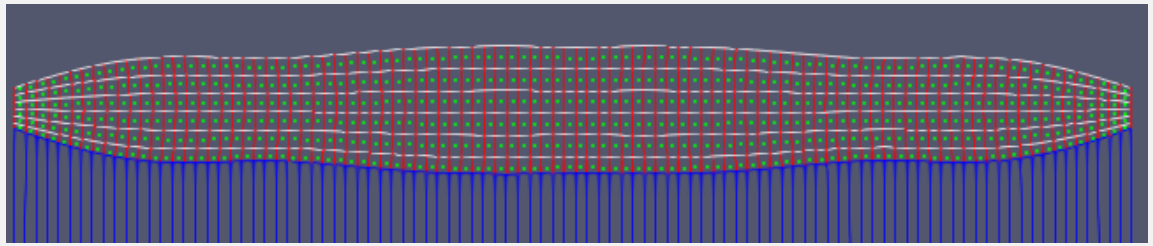
# METHODS & RESULTS: PROBLEM 2

- Dropping the number of chord values to 3 (below) and 5 (right)
- 5 values is not enough for elliptical distribution
- With only 3 values it doesn't converge



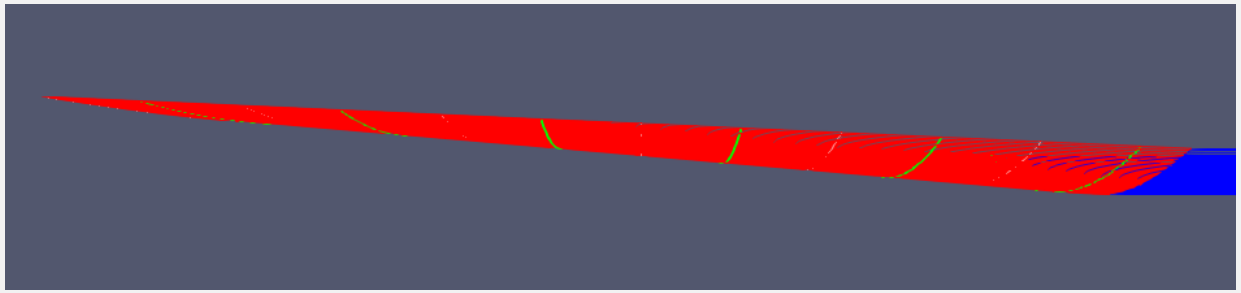
```
EXIT: Maximum Number of Iterations Exceeded.
xstar = [0.9646078073223542, 0.7349725243547954, 0.5807530250365702]
fstar = 0.0190515627169542 33
info = Maximum_Iterations_Exceeded
```



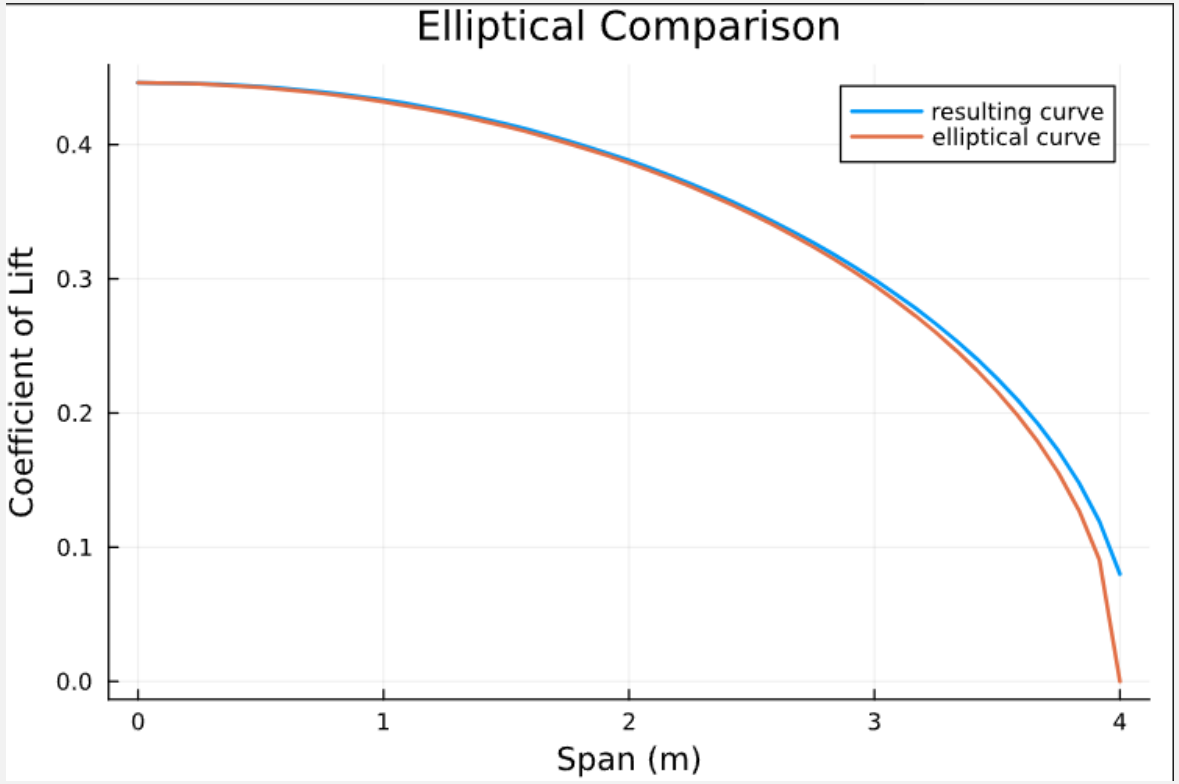
```
EXIT: Optimal Solution Found.
xstar = [0.9307524436528909, 0.9307523295670074, 0.7743711598753611, 0.77437101923
06222, 0.3037182771899257]
fstar = 0.021147587860360043
info = Solve_Succeeded
```

# METHODS & RESULTS: PROBLEM 3

- 3 twist values
- Same parameters as previous problem:
  - spline fit of 50 points, wingspan of 8, and lift constraint of 1.7 N
- Constant chord value of 1

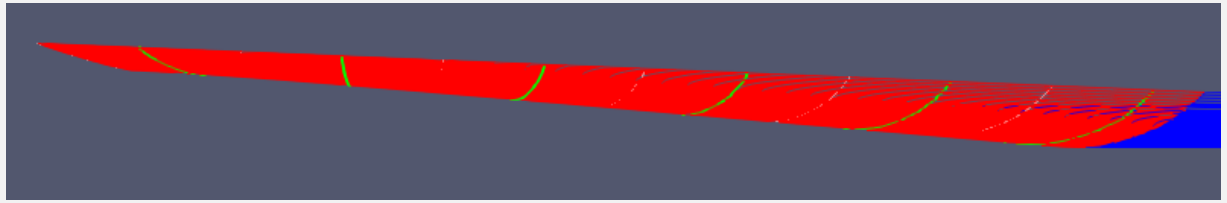


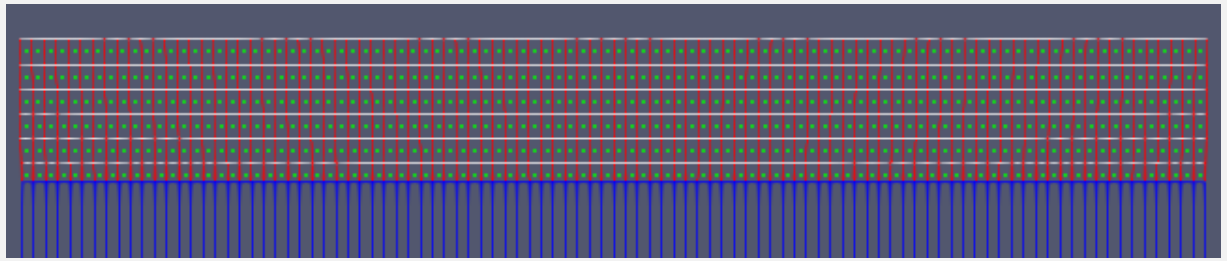
```
EXIT: Optimal Solution Found.
xstar in radians = [0.08613842882004043, 0.07843036402538514, 0.04525050917931647]
xstar in degrees = [4.935368425276372, 4.493728844329251, 2.592663196792824]
fstar = 0.023636515980784534
info = Solve_Succeeded
```



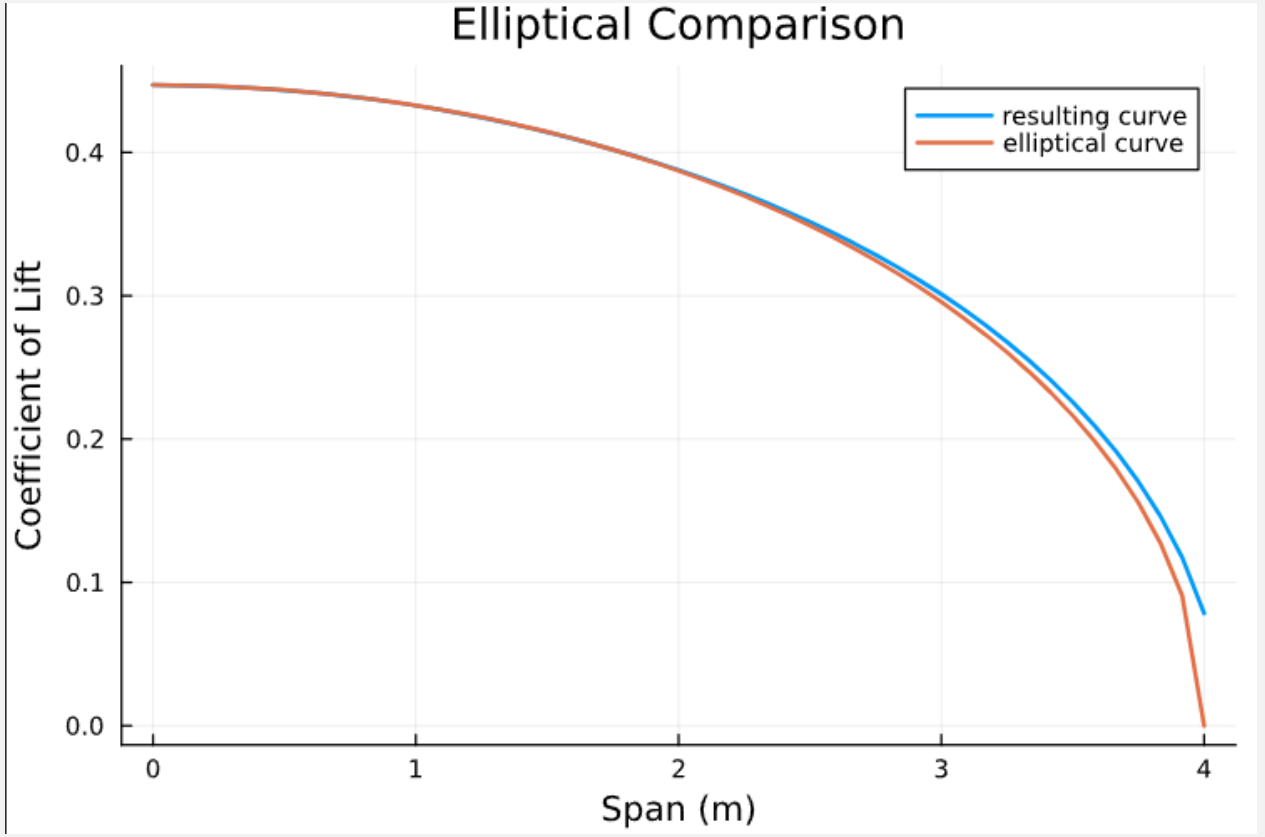
# METHODS & RESULTS: PROBLEM 3

- Note that using 5 twist values results in almost the same result as only using 3 values
- The induced drag generated by this twisted rectangular wing is 0.02363 which is only slightly higher compared to the elliptical wing drag of 0.02333



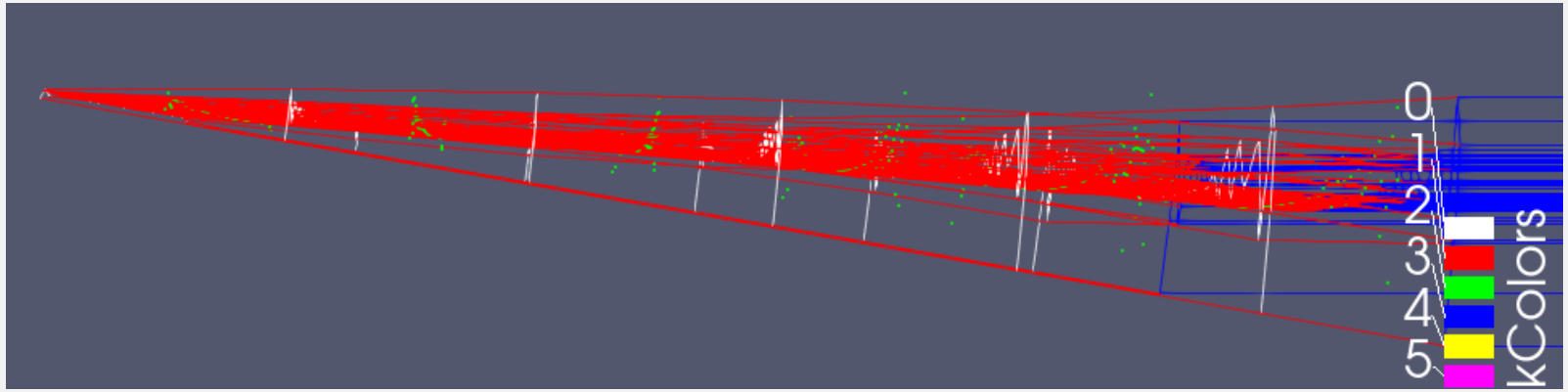


```
EXIT: Optimal Solution Found.
xstar in radians = [0.08689306092649526, 0.08517784073392665, 0.0780651844530549, 0.06617491944571376, 0.04172586118048137]
xstar in degrees = [4.978605660061302, 4.880330782091503, 4.4728055960703355, 3.7915435938575994, 2.390715742190341]
fstar = 0.023634978762491692
info = Solve_Succeeded
```



# METHODS & RESULTS: PROBLEM 3

- 25 twist values didn't converge
- Additionally, it failed to converge with a constraint of decreasing twist values




```
EXIT: Maximum Number of Iterations Exceeded.
xstar in radians = [0.08851720969415297, 0.08800507590508923, 0.08776831307966082, 0.08746433292699893, 0.08703209166166198, 0.086
36250210507646, 0.0854132933589281, 0.08477546164951986, 0.08374423949188695, 0.08268228503718097, 0.08137895500499175, 0.07992946
581169845, 0.07834370898816385, 0.07928825362985303, 0.06301233402045832, 0.09055154784397147, 0.04138402964470697, 0.090256529719
63222, 0.034547751053875864, 0.08130375840948882, 0.05811718470862865, 0.03534815428659849, 0.11785891194638065, -9.35947962335271
e-9, 0.17453293469554124]
xstar in degrees = [5.071662529749462, 5.042319425090066, 5.028753914447425, 5.011337134644156, 4.986571534408955, 4.9482068788105
68, 4.893821223779363, 4.857276158790657, 4.798191481417915, 4.737345973128146, 4.662670662971054, 4.579621049745526, 4.4887638764
22922, 4.542882297953408, 3.610340796640876, 5.188221519836515, 2.371130237885993, 5.1713182264320094, 1.979440327055729, 4.658362
215414984, 3.3298694009866665, 2.025300054199363, 6.7528182325316095, -5.362586808568037e-7, 10.000000544086927]
fstar = 0.021859204013043906
info = Maximum_Iterations_Exceeded
```

# TAKEAWAYS

*Impact and relevance of the project*

# TAKEAWAYS: ASK THE RIGHT QUESTION

- Biggest lesson learned was the importance of formulating the right question
- Optimization consists of creating a problem from real-world situation and formulating it in a way to be processed and iterated quickly by a computer
- After overcoming many different coding errors, I encountered wrong-right answers (results from a question I didn't know I had asked the optimizer)
- Had to learn how to be specific and thorough so that the optimizer solved the question that I wanted it to solve

# TAKEAWAYS: PERSONAL LEARNING

- First experience with optimization problems
- Improved ability to work with VortexLattice
- Strengthened capacity to debug codding errors
- Increased and reinforced understanding of wing geometry and aerodynamic principles from previous projects
- Exposure to the research process


Supermarine Spitfire