COMSOL CONFERENCE BOSTON 2012

A Computational Approach for Optimizing the First Flyer Using COMSOL Multiphysics

Research Computing and Cyberinfrastructure
The Pennsylvania State University
University Park

A.H. Aziz
H.B. Pourzand
A.K. Singh

October 3, 2012

PENNSTATE 1855

Objective

Data from Wright brothers' flight tests at Kitty Hawk on December 17, 1903

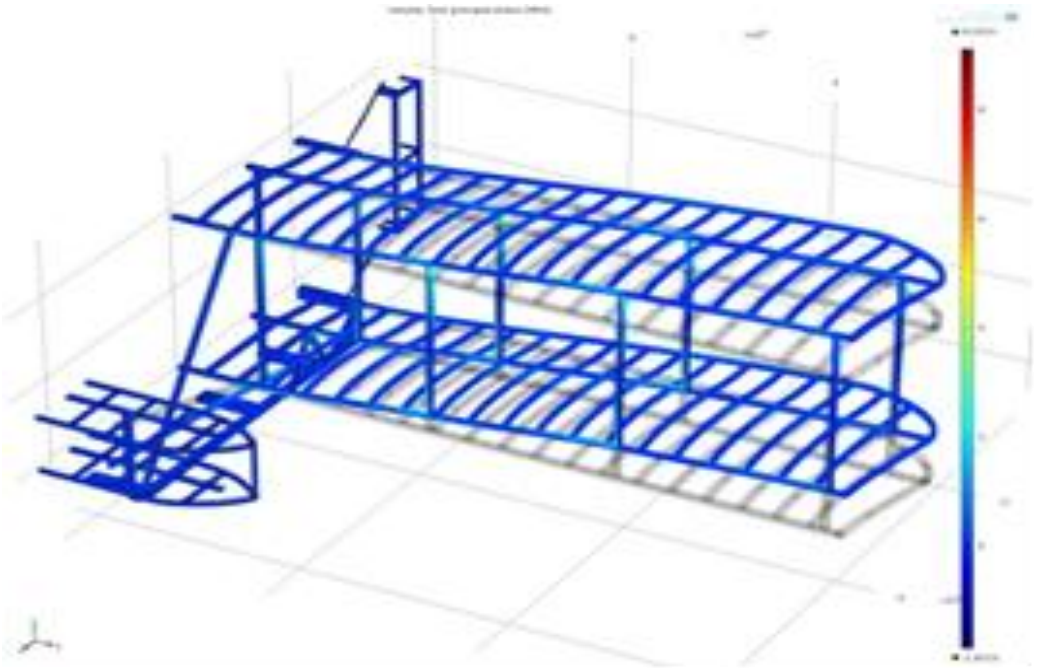
Flight Number	Time (sec)	Distance (feet)	Speed (mph)	Headwind (mph)
1	12	120	6.8	24
2	13	175	9.2	21
3	15	200	7.9	21
4	**59**	**852**	**8.5**	**21**

- To cover 852 feet in a shorter time by reducing the airplane weight
- To model the whole airplane, a large and complicated geometry
- To solve a large system: ≈10 million DOFs
- To comprehend how the solution of such large problems scales in a high performance computing environment

Testing Structural Integrity

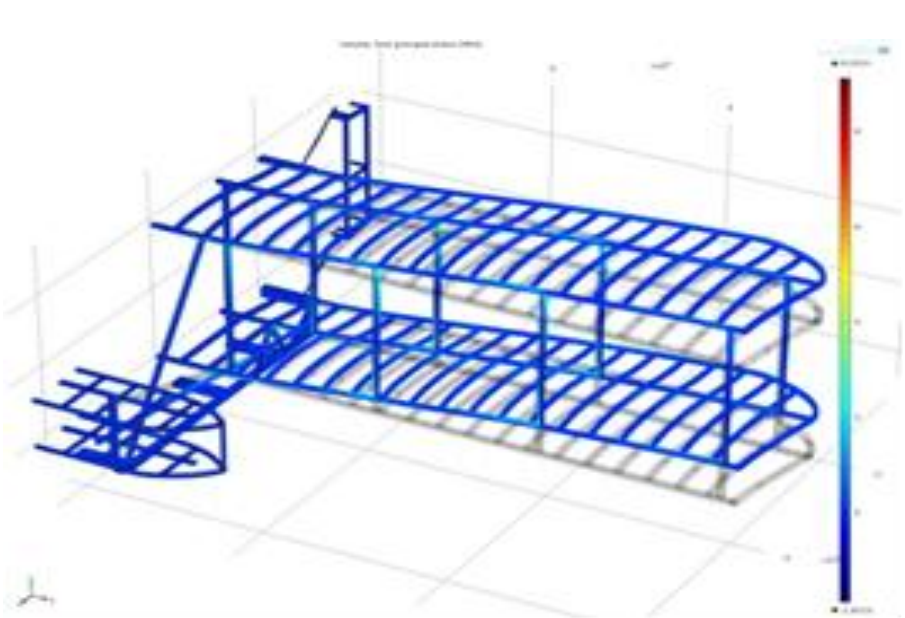
Load on the structure:

- Weight due to gravity
- Lift
- Drag

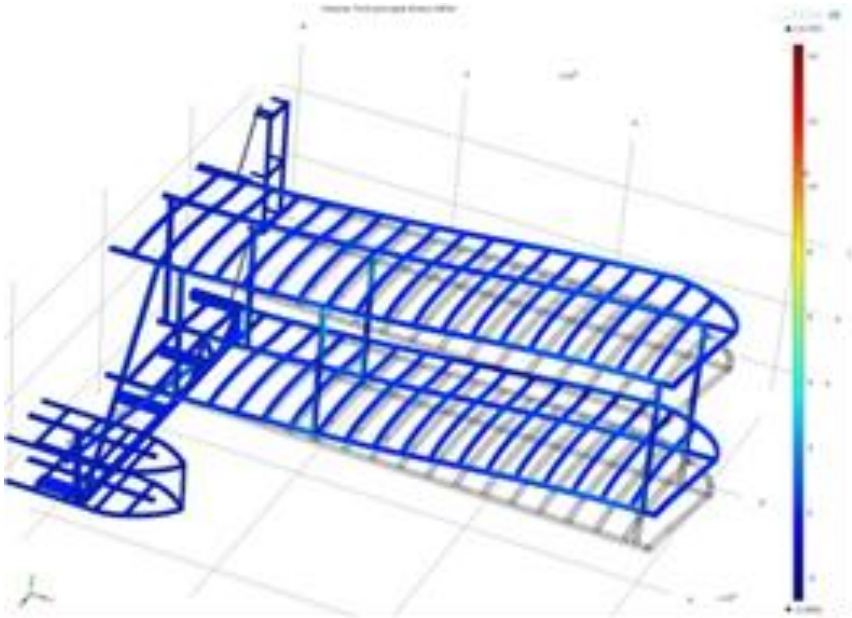


Maintaining Structural Integrity

Two struts were removed

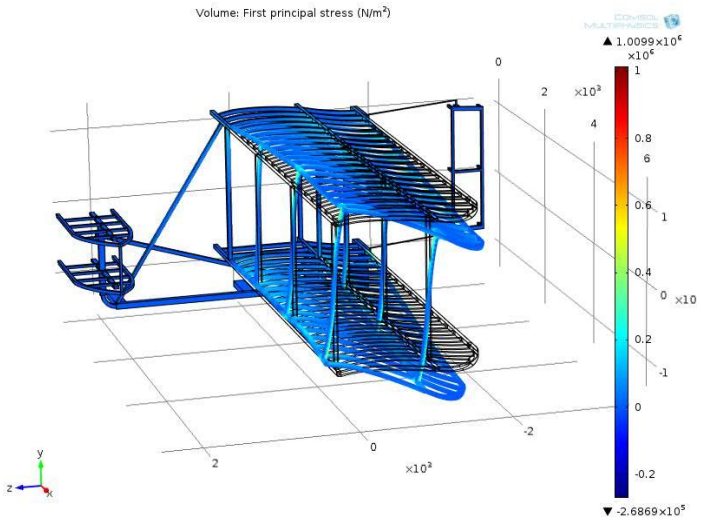


Maximum stress: 9.1 MPa

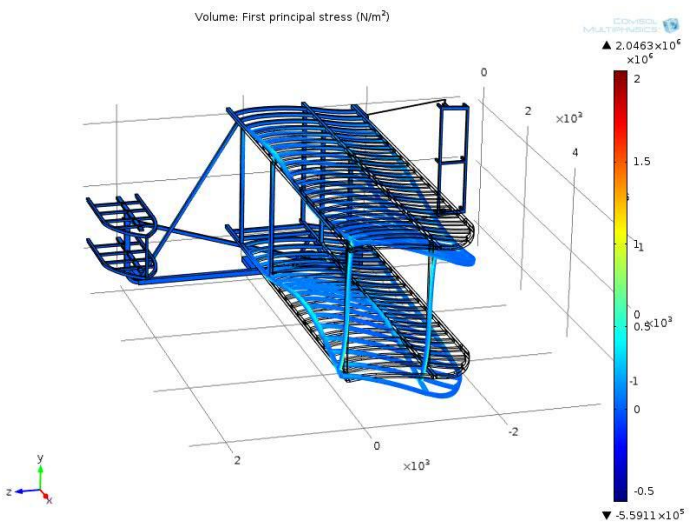


Maximum stress: 10.66 MPa

Effect of Torsion



Maximum stress: 1.01 MPa



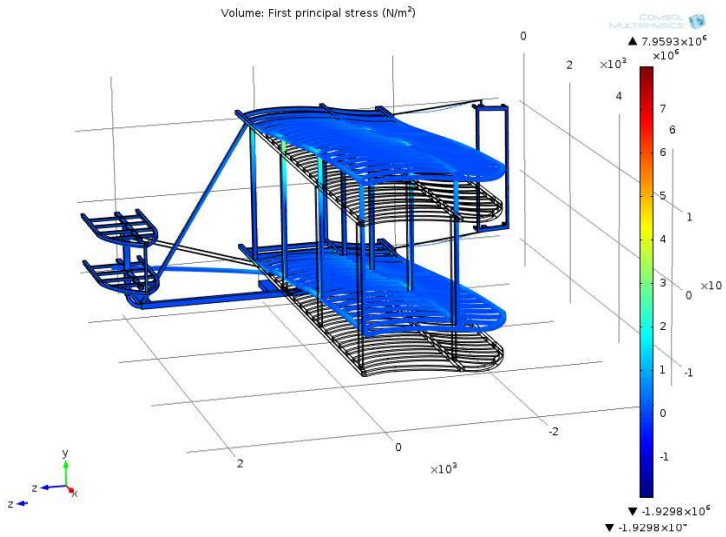
Maximum stress: 2.05 MPa

PENNSTATE

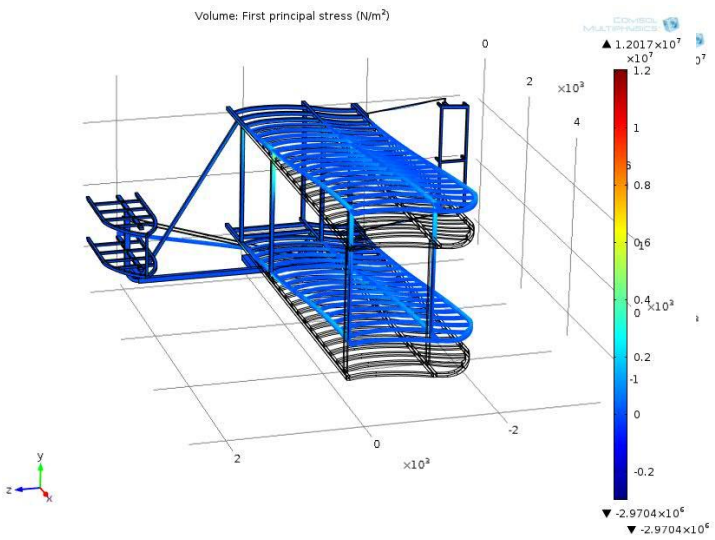
1855

RESEARCH COMPUTING
AND CYBERINFRASTRUCTURE

Torsion Added to Flight Loads



Maximum stress: 7.96 MPa



Maximum stress: 12.02 MPa

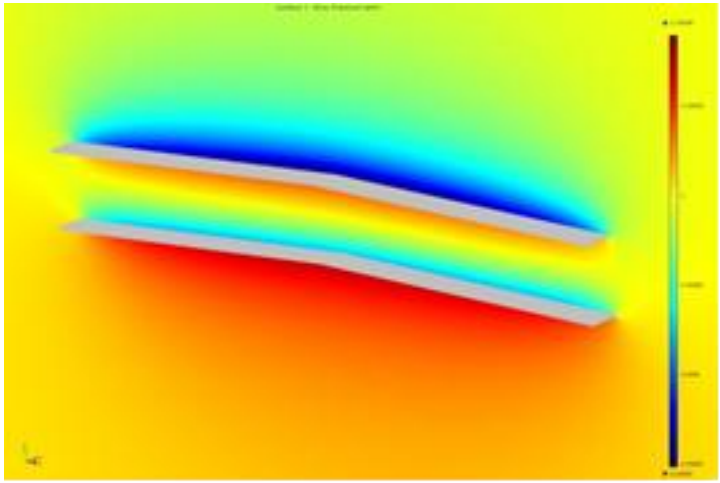
PENNSTATE

1855

RESEARCH COMPUTING
AND CYBERINFRASTRUCTURE

Aerodynamic Model of the Original Flyer

- Air flow is laminar and compressible
- Wind speed is 30 mph
- Multigrid solver used
- On the right: Pressure distribution over the biplane at wind speed of 30 mph

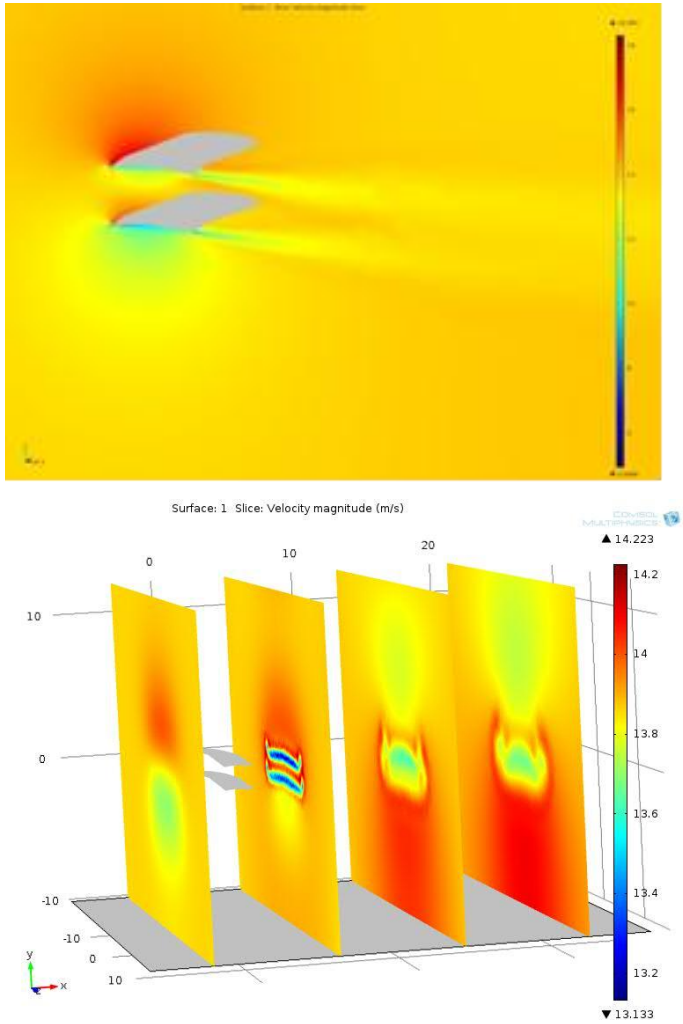


PENNSTATE
1855

RESEARCH COMPUTING
AND CYBERINFRASTRUCTURE

Aerodynamic Analysis Continued

- Air flow is laminar and compressible
- Wind speed is 30 mph
- Multigrid solver used
- On the right: Velocity profile over the biplane at wind speed of 30 mph



A Simplified Dynamic Model

Equations of motions:

$$\dot{u} = \frac{F_x}{m} - Qw - g\sin\theta$$

$$\dot{w} = \frac{F_z}{m} + Qu + g\cos\theta$$

$$\dot{Q} = \frac{M}{I_{xx}}$$

Integrate to obtain the total flight time

Hardware Used

Component	Server	Quantity	Processor	Number of Processor Cores	Memory (GB)
Login Node	Dell PowerEdge R810	1	Intel Xeon E7-8837 Eight-Core 2.66 GHz	16	256
Compute Node	Dell PowerEdge R910	1	Intel Xeon E7-8837 Eight-Core 2.66 GHz	32	512
Compute Node	Dell PowerEdge R910	1	Intel Xeon E7-8837 Eight-Core 2.66 GHz	32	1024

Software/Packages Used

- COMSOL Multiphysics® 4.3
- COMSOL Livelink™ for SolidWorks®
- MATLAB®

Concluding Remarks

- A 3% reduction in weight of the flyer led to a 16% reduction in flight time
- Established a workflow for simulating large problems, to be used in teaching and research
- Meshing a whole airplane is a challenging task using COMSOL

Future Direction

Statistics

Complete mesh

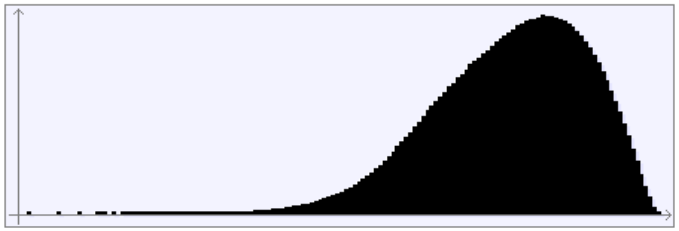
Element type: All elements

Tetrahedral elements:	10917592
Triangular elements:	174894
Edge elements:	19249
Vertex elements:	646

Domain element statistics

Number of elements:	10917592
Minimum element quality:	0.01417
Average element	0.7693
Element volume ratio:	1.341E-10
Mesh volume:	478.5 m^3
Maximum growth rate:	4.759
Average growth rate:	1.616

Element Quality Histogram

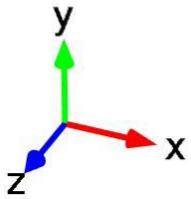


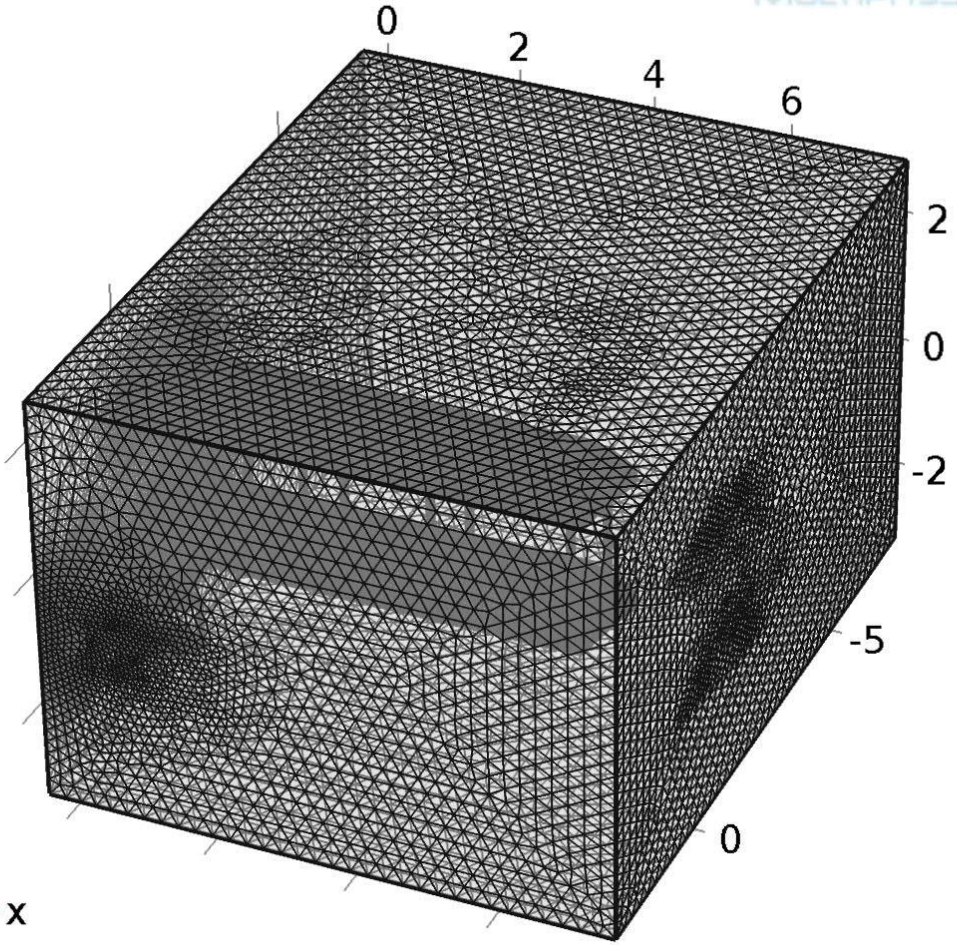
Number of Degrees of Freedom

mod1.u2: 5608119

mod1.p: 1869373

Total: 7477492





PENNSTATE

1855

RESEARCH COMPUTING AND CYBERINFRASTRUCTURE

Future Work

- Include lateral-direction motion
- Use FSI with the surface (fabric) included
- Include the propellers, engine, chains, and wires in the analyses
- Further optimization (parametric sweep)
- A real time controller by linking MATLAB® with COMSOL Multiphysics®
- Post-Processing using EnSight (immersive environment)

Acknowledgements

- COMSOL Program Committee
- Vijay Agarwala, Senior Director, RCC
- Domain Software Expert group