A Computational Approach for Optimizing the First Flyer Using COMSOL

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Abstract: In this present study, COMSOL Multiphysics software is used to structurally optimize the Wright brothers' flyer shown in the historical photo below. As can be seen from figure 1, there are sixteen vertical bars that connect the upper and lower wings. The main objective of this project is to reduce the weight of the airplane by removing four vertical bars. The structure mechanics module in COMSOL was used to maintain structural integrity after the removal of the bars. The CFD module in COMSOL was used to compute the aerodynamics forces (lift and drag). These aerodynamics forces were used to calculate the flight duration and the horizontal distance travelled by the airplane. It was found that approximately three percent weight reduction resulted in a sixteen percent decrease in flight time.

Figure 1: THE FIRST TWELVE SECONDS OF THE AGE OF POWERED FLIGHT, KITTY HAWK, N.C., DECEMBER 17, 1903

Orville and Wilbur Wright did four successful flights on Thursday 17 December, 1903 and the longest flight duration was fifty nine seconds and it was achieved by Wilbur in flight number 4. Table 1 shows operational data for the four successful flights. COMSOL Multiphysics software was used for structural and aerodynamics analyses on this large model and due to the large size of the model, only half of the main wings were analyzed.

Table 1: The four flights of Orville and Wilbur Wright on 17 December, 1903 (reproduced from reference 5)

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

The main objective of this project is to decrease the duration of this historic flight by twenty percent using COMSOL Multiphysics.

Keywords: Structural Analysis, Computational Fluid Dynamics, Flight Dynamics

1. Introduction

The subject of airplane flight dynamics is divided into three areas (performance, stability and control, aeroelasticity). The present analyses are focused on the performance of the first airplane to fly. The mathematical model of a rigid airplane is derived from Newton's laws of motion and is treated in details in reference 1. These six degrees of freedom equations (three in the longitudinal and three in the lateral-directional directions) were programmed in FORTRAN and presented in reference 2. These equations are generally second-order differential, nonlinear and highly coupled. In the present analyses, A simplified set of the equations of motion of the airplane in the longitudinal direction were integrated in MATLAB to obtain the duration of flight and the distance travelled by the airplane. The main objective of these analyses is to increase the flight time of the Wright brothers' original flight machine by reducing the weight without altering the original design as depicted in figure 2:

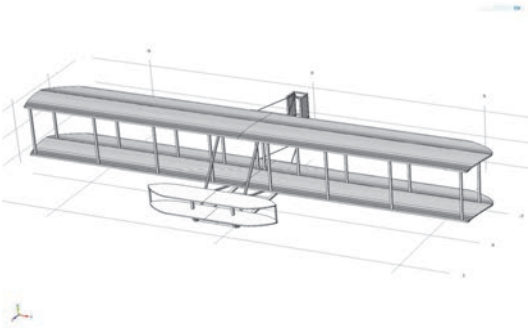

Figure 2: The Wright brothers' original flyer as modeled using SolidWorks

The Wright brothers' original flyer was modeled in SolidWorks, exported to COMSOL using the LiveLink for SolidWorks and is shown in Figure 3. The number of elements is 172K and the type of the elements is tetrahedral. The number of Degrees Of Freedom (DOF) is 1,027,470.

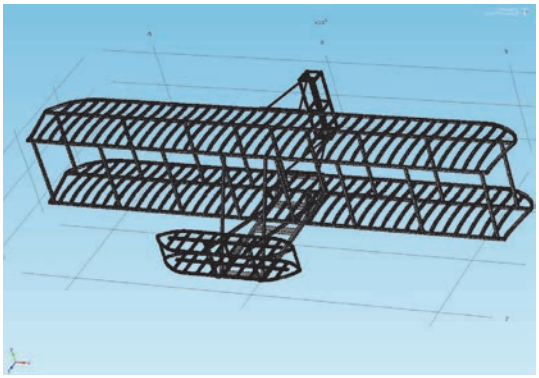

Figure 3: The original Wright brother's was meshed using COMSOL. Over a million DOF.

The reduction in weight is achieved by removing four vertical bars from the original design as shown in figure 4. The gross weight of the original flyer was (340.2 Kg or 750 lbs). The weight of each bar is 2.08 kg. The reduction of the weight is 2.35%, and as can be seen from table 2, this resulted in 16% gain in flight time.

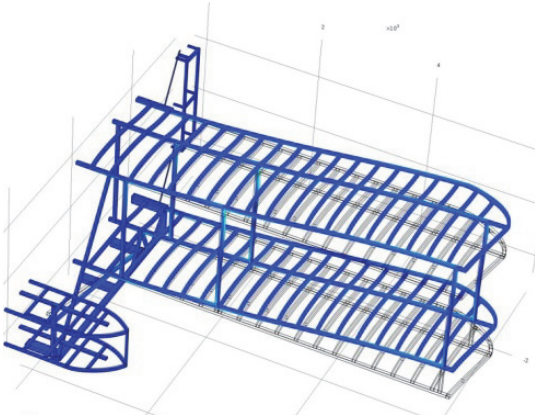

Figure 4: Modified flyer model with four struts removed

Table 2: comparison of flight duration and altitude for the flyer (actual vs. simulated)

	Flight Duration	Flight Distance
Actual data for flight 4	59 seconds	852 feet
Simulated data for flight 4	49.5 seconds	852 feet

2. Airplane Aerodynamics Model

Assuming most of the lift available to the vehicle is provided by the biplane, and without taking into account the compliant nature of the fabric over the wings, the flow over the wings of the Wright Flyer was simulated in COMSOL. Laminar, compressible flow of air was modeled at normal temperature and pressure. The velocity of the wind relative to the flyer (head wind) was taken as 30 mph. The domain was discretized with a mesh of 5.2 million tetrahedral elements, and 3.6 million degrees of freedom were solved for using the geometric multigrid solver. The pressure distribution over the span of the wings is shown in Fig. 4, while the velocity profile over the chord is shown in Fig. 5. The values for lift and drag are obtained from this model integrating components of pressure over the wing surface, and used both for the structural integrity analysis as well as the flight dynamics calculation.

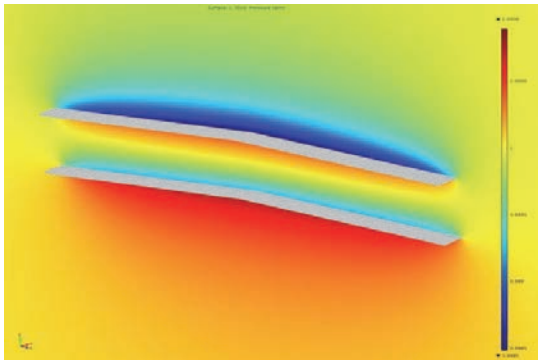

Figure 4: The pressure distribution on the two wings obtained from COMSOL.

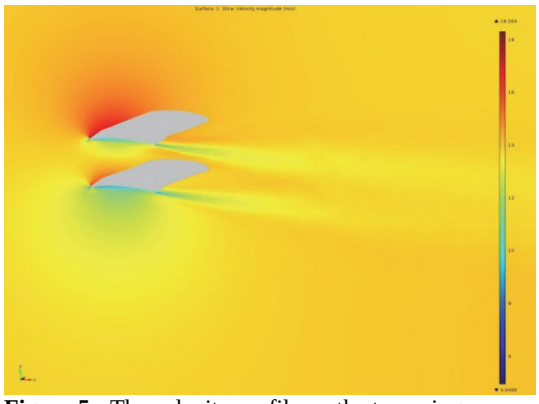

Figure 5: The velocity profile on the two wings obtained from COMSOL.

3. The Structural Model

To ensure that the removal of struts from the flyer does not compromise the structural integrity of the aircraft, a static load test was performed on a symmetric half of the flyer model. Forces of lift, drag and weight due to gravity were applied for level flight conditions, i.e. the lift being equal to the weight of the aircraft. The removal of the two struts increases the first principal stress (maximum) from 9.1 MPa to 10.66 MPa as shown in figures 6 and 7 respectively. This value is well below the strength of spruce used in the construction of the Wright Flyer. Table 3 shows the most important data that was used as an input in COMSOL.

Table 3: Flight conditions for flight 4 on December 17, 1903

Item	Geometrical and Operational data
Forward speed (mph)	9.8
Gross weight (lbs)	750
Headwind (mph)	21
Wing Span (ft)	40.33
Wing Chord (ft)	6.5
Wing Incidence	3°25’

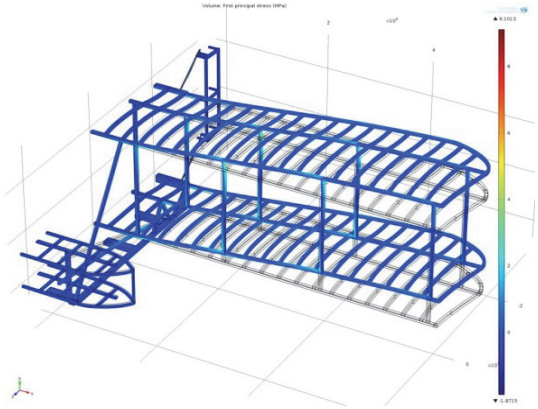

Figure 6. First principal stress for the flyer with the original 8 struts, as obtained from COMSOL.

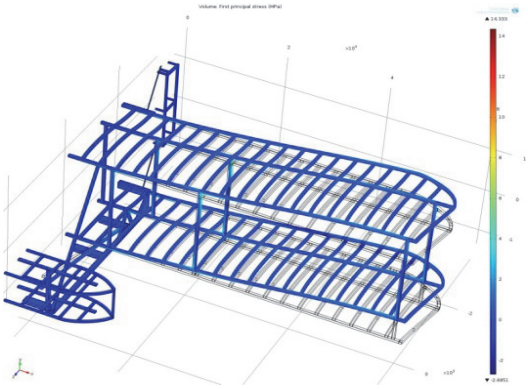

Figure 7. First principal stress for the flyer with two struts removed, as obtained from COMSOL.

4. The simplified dynamics model

The governing equations of motion for an airplane in a longitudinal mode may be reduced to the following set and reproduced from reference 3.

$$\dot{u} = \frac{F_x}{m} - Qw - g\sin(\theta) \quad (1)$$

$$\dot{w} = \frac{F_z}{m} + Qu + g\cos(\theta) \quad (2)$$

$$\dot{Q} = \frac{M}{I_{xx}} \quad (3)$$

A MATLAB script was developed to integrate the above equations to obtain the duration of flight for a travelled distance of 892 feet.

5. Conclusions

One of the most important events in aviation history is the Thursday, seventeenth of December, 1903. It is named the dawn of aviation and the place where four successful flights occurred was Kitty Hawk, North Carolina. As reported in reference 6, Wilbur and Orville Wright spent many years in the development of their flyer. Computer tools, hardware and software could have helped the Wright brothers in flying longer time. This present study is a first step in modeling the geometry of the flyer and the use of the present day technological advances in running various analyses. Theses analyses are done using COMSOL Multiphysics software package. Structural analyses were done on the original model and the modified model. Aerodynamic modeling was carried out to obtain the aerodynamic forces and moments were also carried out using COMSOL. Further expansion of this model is needed to include the lateral-directional mode of motion.

6. References

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7. Acknowledgements

The authors acknowledge the Research Computing and Cyberinfrastructure unit of Information Technology Services at The Pennsylvania State University for providing advanced computing resources and services that have contributed to the research results reported in this paper.