

A Computational Approach for Optimizing the First Flyer Using STAR-CCM+

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Abstract: In this present study, STAR-CCM+ software was used to optimize the Wright brothers' flyer shown in the historical photo in Figure 1. As can be seen from Figure1, there are sixteen vertical bars (struts) that connect the upper and lower wings. The main objective of this project is to reduce the weight of the airplane by removing four struts. STAR-CCM+ 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 concluded that a three percent weight reduction resulted in a sixteen percent decrease in flight time for the same range of 892 feet.

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. STAR-CCM+ software was used for aerodynamics analyses on this large model and due to the large size of the model, only half of the main wings were analyzed.

1. Introduction

The subject of airplane flight dynamics is divided into three areas (performance, stability and control, aero-elasticity). 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.

The Wright brothers' original flyer was modeled in SolidWorks, exported to STAR-CCM+ 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. The reduction in weight is achieved by removing four struts 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.

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 STAR-CCM+. 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 Figure 4, while the velocity profile over the chord is shown in Figure 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.

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 STAR-CCM+.

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.

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

$$\dot{w} = \frac{F_x}{m} - Qw + g \sin(\theta) \quad (2)$$

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

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. These analyses are done using STAR-CCM+ STAR-CCM+ 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 STAR-CCM+. Further expansion of this model is needed to include the lateral-directional mode of motion.

6. References

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flight, *MS Thesis in Aerospace Engineering*, The University of Kansas

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3. Amteh, Ghassan M. et al, Design and Stress Analysis of a General Aviation Aircraft Wing, *Excerpt from the Proceedings of the STAR-CCM+ Conference 2010 Boston* (2010)
4. <http://wright.nasa.gov/first.htm>
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6. Kelly, Fred C., *How We Invented the Airplane* (1953)



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

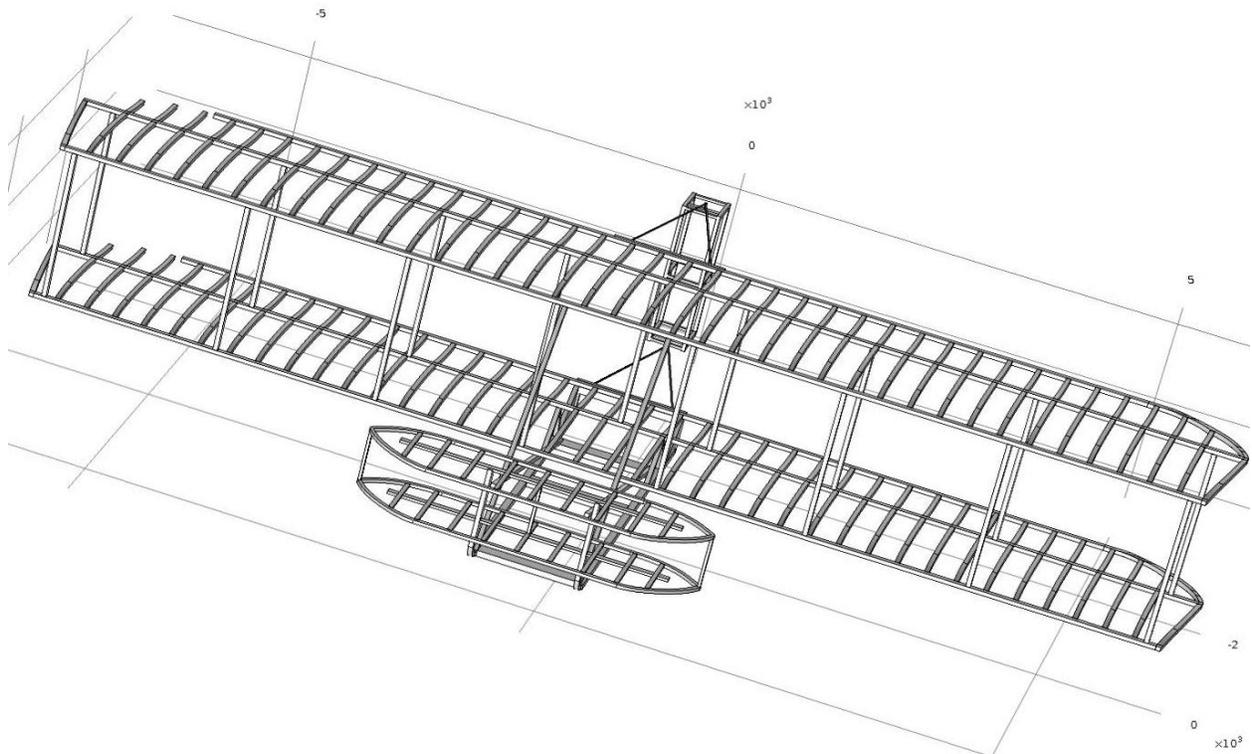


Figure 2: The Wright brothers' original flyer as modeled using SolidWorks

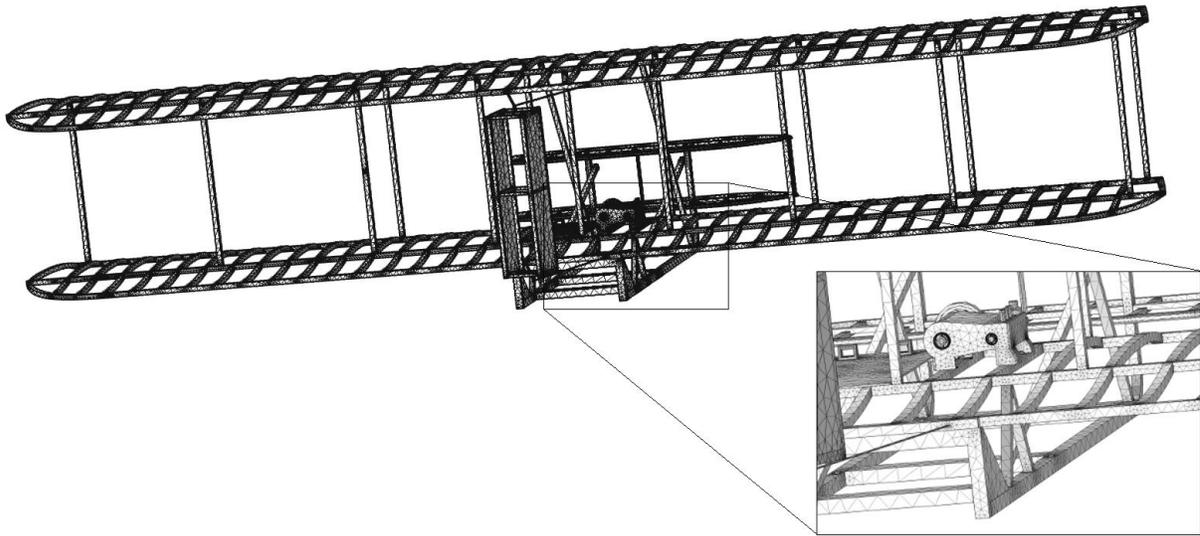


Figure 3: The original Wright brother's was meshed using STAR-CCM+. Over a million DOF.

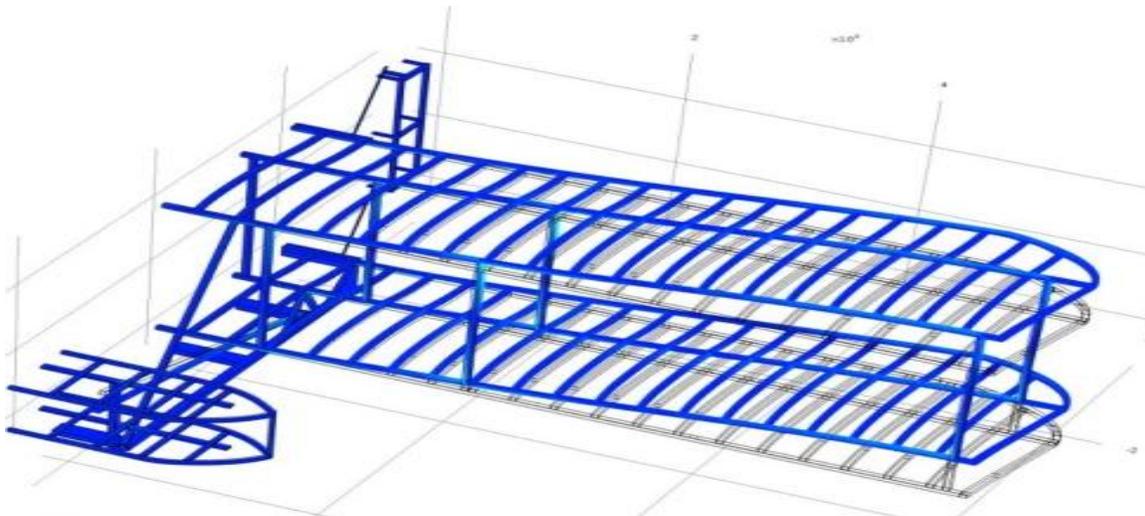


Figure 4: Modified flyer model with four struts removed.

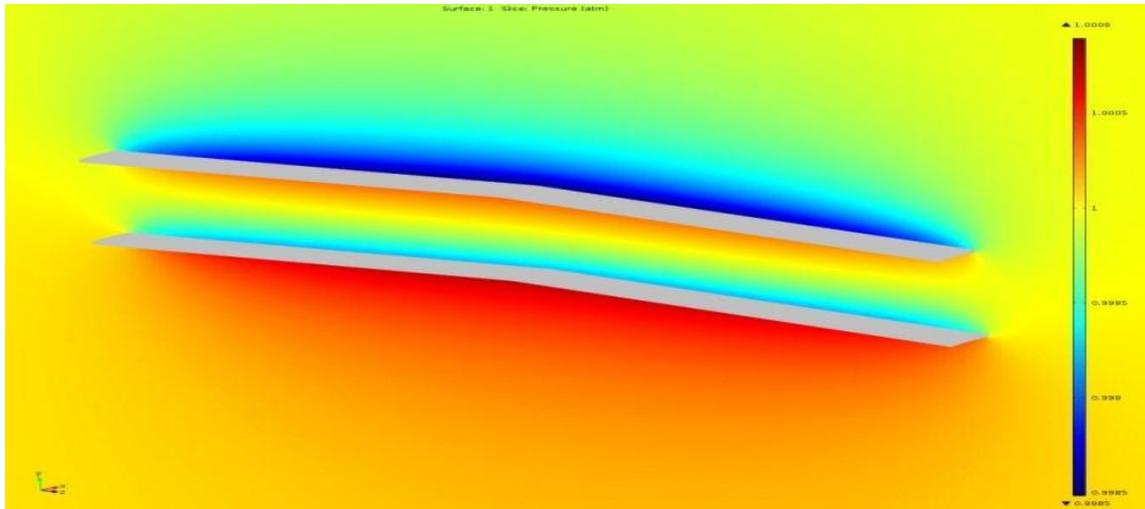


Figure 5: The pressure distribution on the two wings obtained from STAR-CCM+.

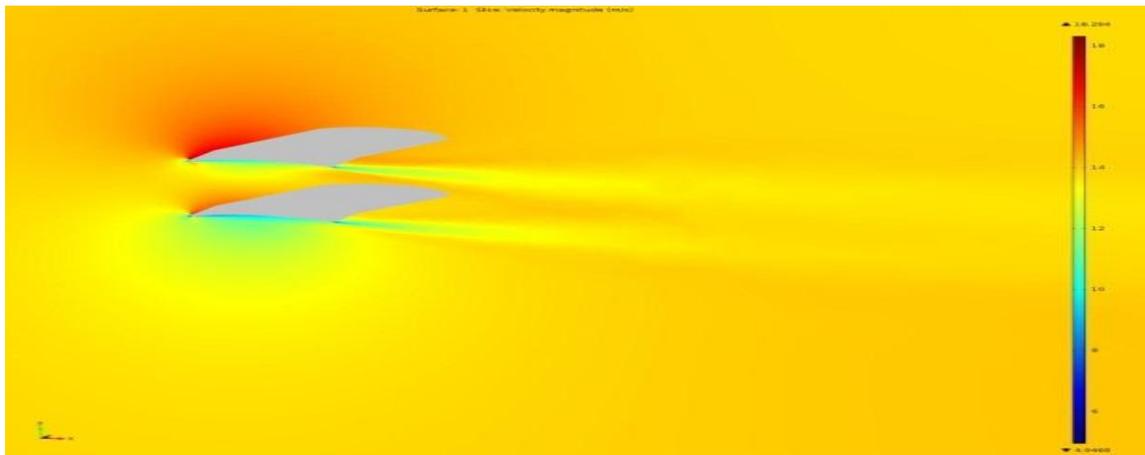


Figure 6: The velocity profile on the two wings obtained from STAR-CCM+.

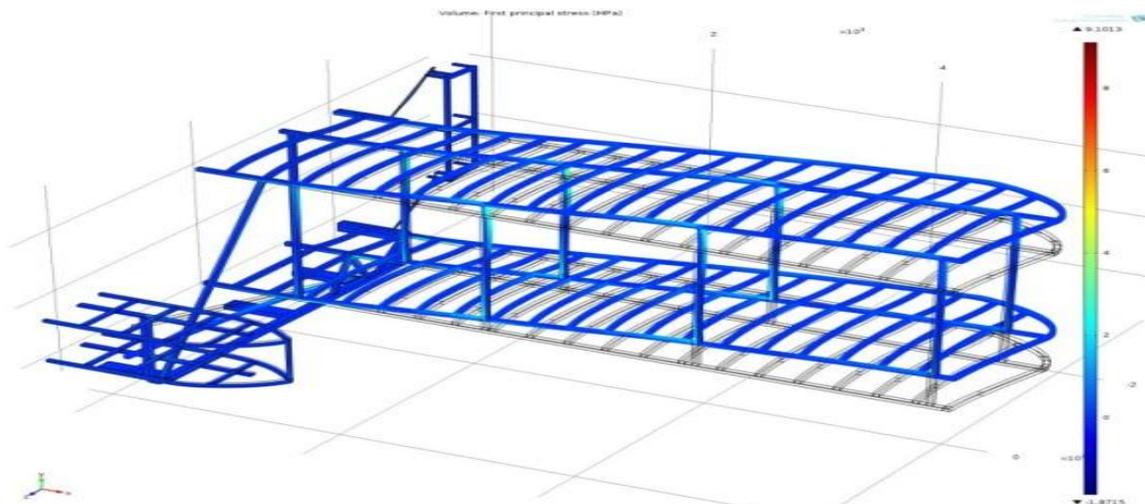


Figure 7: First principal stress for the flyer with the original 8 struts.

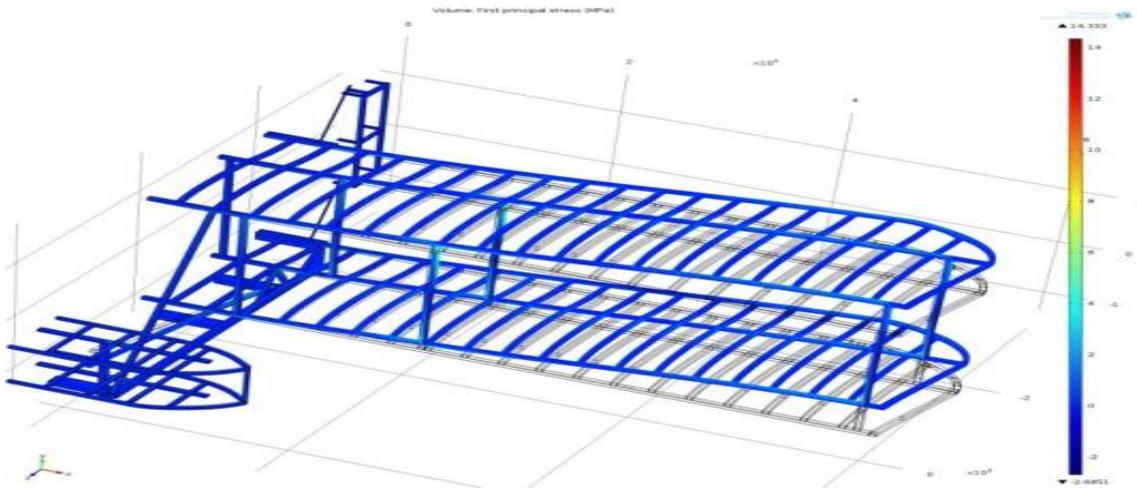


Figure 8. First principal stress for the flyer with two struts removed.

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

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

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

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'