

X-51 Composite Airframe

Brendon J Townshend¹

California Polytechnic State University, San Luis Obispo, CA, 93401

This paper gives an overview of the progress that has been made in the design build of the X-51. The X-51 is a composite scale replica of a P-51D fuselage integrated with a P-51H wing. Issues with the airframe as well as current action items are discussed, as well as findings so far in preliminary design.

I. Introduction

THIS paper reflects the progress made in building an entirely composite scale replica of a North American aircraft to be raced. Named the X-51, the aircraft will utilize different components of all the generations of P-51. There are several benefits of using this airframe to contend for the record and for racing. Light weight composites combined with elimination of rivets give the airframe low drag characteristics. The integration of a high performance racing engine provides the necessary power required to push through the abrupt drag rise near the transonic regime. Also, the combination of a P-51D fuselage with a P-51H wing gives the carbon X-51 the fastest components of all twelve P-51 Mustang generations.

The project so far has consisted of research into tooling for construction, basic configuration studies, a visit to the facility, generating a computer model, and basic analytical aerodynamic calculations. The tooling has already been developed but without any engineering drawings, leaving many questions open as to the manufacturing process and systems integration into the airframe. The issues associated with this project are discussed in depth giving insight in to the status of the project and the action items that still have to be accomplished. There are several benefits of using this airframe for a race aircraft that will be examined as well.

II. Background

The P-51 project is driven by the tooling that has already been created for construction. In the early 80's, Cameron Aircraft and Sons developed tooling for the composite Cameron P-51 project. The approach was unique in the sense that Cameron Aircraft created polyurethane foam molds from an original metal P-51D Mustang to serve as master tools. These foam molds served as the shell in order to fabricate the graphite fuselage tool. Since the tools were constructed, three aircraft have been built, all of which utilized a 1450 horsepower Lycoming T-53 turbine engine. Although the airframe is intended for an inline cylinder engine propulsion system, Cameron Aircraft opted for the turbine in light of money savings on both fuel and time between rebuild. The TBO, (Time Between Overhaul) for the T-53 is 2500 hours making the approximate direct operating cost between \$100-\$150. Originally, the carbon P-51 was intended to be sold as a kit build aircraft to the general public. Due to the high acquisition cost only three were ever built and sold.

The combination of a light weight airframe, smooth surface finish and high power engine make the X-51 an attractive option. The downside is that the original P-51 was designed with 1940 aerodynamic knowledge, thus not giving it the edge as compared with new age technology. Race aircraft such as the Nemesis NXT shown in Fig 1 utilize state of the art materials and aerodynamics giving it the edge. The decision to build the X-51 is driven by advertising and crowd appeal. The aircraft must be large enough to see on the backside of the race course and draw a crowd at the races it goes to. Due to its size, the nemesis NXT would not serve this purpose because it can barely be seen on the backside of the course at Reno. The P-51 is not only a recognizable airframe that draws on tradition and history, but a large platform for advertisements. These two reasons combined with existing tooling made the X-51 the choice for the project.

¹ Student Engineer, Aerospace Engineering, California Polytechnic State University.

The unique method of developing the tooling for the project leaves a need for plans to be developed. There is currently no documentation of the parts specifications or a plan for assembling them. Therefore an important part of the project is developing a builders plan for the aircraft. This is critical if more than one X-51 is to be made in the future. Also, a builders plan is necessary for gathering funding from outside sponsors as it adds credibility to the project.



Figure 1. Nemesis NXT. *The Nemesis NXT demonstrates state of the aerodynamic technology coupled with a light weight composite airframe yet it is too small to see on the backside of the course at Reno.*

A. Configuration

The design philosophy of the carbon P-51 is to integrate the fastest components of the twelve generations of P-51 Mustangs. The X-51 has the general appearance of a P-51D but utilizes the faster P-51H wing. The P-51H wing utilizes a thinner airfoil than its P-51D counterpart. Also, a clipped wingspan will be used for the racing model. The wingspan has been reduced from 37' 4" to 32' 2" for increased performance at high airspeed. Figure 2 shows the planform of the P-51D compared to the P-51H model. The P-51D wing incorporates leading edge wing root extensions that will be included in the X-51 wing. Figure 3 shows the model developed for the X-51 wing. Notice the wing planform follows that of the P-51H wing and incorporates the leading edge root extensions of the P-51D

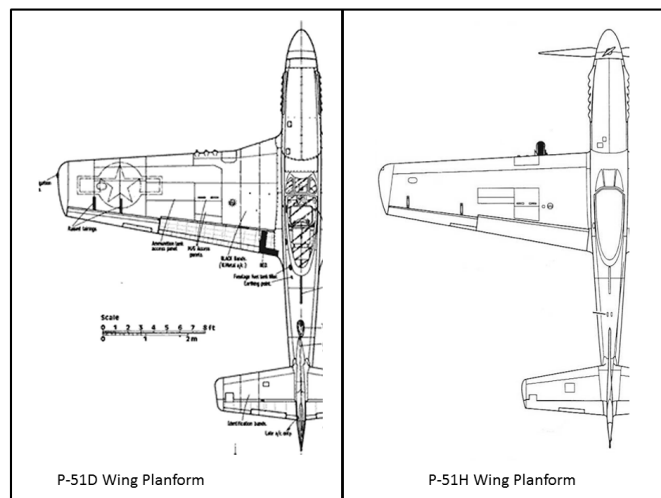


Figure 2. Wing Planform comparison. *The P-51 D wing planform has leading edge root extension that will be included on the X-51 wing planform.*

model. This was done by Cameron Aircraft during the initial build; and analysis will have to be done to figure out if this is the best option for the racing version.

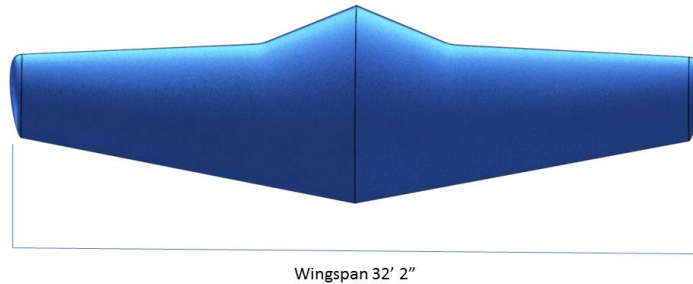


Figure 3. Wing Planform for X-51. *The X-51 wing uses the leading edge root extensions of the P-51D wing. Also the wingspan is reduced by 5' 2" to reduce aspect ratio.*

The fuselage is a scale replica of the P-51D. Modifications to the canopy have been made to offer a two seat bubble canopy, single seat bubble canopy, and a racing version. Once again, no analysis has been done yet to determine if the racing canopy is of greater aerodynamic benefit when compared to the reduced visibility from the cockpit. Figure 4 below shows the three canopy options.

B. Manufacturing

The information available on the carbon P-51 is limited to artist renderings and photographs of the original construction. Several questions were raised in the development stages of this project directed primarily at manufacturing of the aircraft. Four major questions were raised in relation to the manufacturing process. Although there have been three Cameron P-51s built previously, they have all been powered by the Lycoming T-53 turbine engines. The lack of drawings made it imperative that a visit to the facility in Coeur d'Alene, ID be made in order to answer these questions.



Two Person Bubble Canopy



Single Person Bubble Canopy



Racing Canopy

Figure 4. Three Canopy Configurations. *The racing canopy shown on the bottom will likely be the choice for the X-51, yet no analysis has been done to show an aerodynamic benefit.*

The first major issue deals with the addition of over 300 pounds to the nose of the aircraft by the replacement of the Lycoming T-53 turbine with a piston engine. A shift in center of gravity on the light carbon airframe was of primary concern. It was discovered that the Cameron P-51 was designed to accommodate the piston engine and in order to use the Lycoming turbine, lead weights had to be added in the nose to make up for the difference in weight. This also confirmed that the wing was positioned in accordance with the center of gravity location determined by the piston engine. Figure 5 shows the integration of the Lycoming Turbine in the Cameron P-51. Notice the large cavity below the turbine that will be entirely filled when the piston engine is installed. The Lycoming turbine was entirely air cooled. Therefore, the original air scoop beneath the fuselage that was used for the liquid cooling system

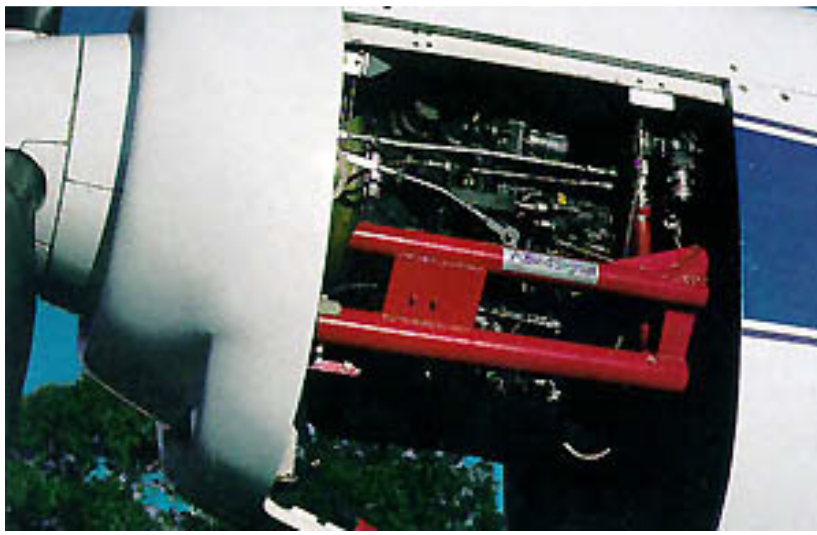


Figure 5. T-53 Lycoming Turbine. *The turbine engine takes up less space in the engine compartment than the piston engine will. Over 300 pounds of lead was required in the nose to balance the airframe.*

needed for the piston was made into a cargo bay on the Cameron P-51 model. It was confirmed that this was a later addition to the turbine model and can easily be reversed to accommodate the piston engine cooling system.

Due to the limited information on manufacturing, it was critical to visit the facility to get an idea of how the parts of the aircraft fit together. The twelve major components of the aircraft can be seen in Fig 6 below. Utilizing top and bottom construction the number of parts on the aircraft are drastically reduced. The internal structure of the aircraft is made up of ribs and spars in the lifting surfaces. The fuselage is made up of a series of longerons that run the length support the skin. Construction of these parts was done by fitting the tools to the inside of each of the skins. No drawings were made in the development of these tools. Each of the skins is vacuum bagged and autoclaved at 250 °F. The longerons spars and ribs are constructed from IM7 graphite material and autoclaved at 350 °F. Documentation of the curing process of the longerons, spars and ribs can be seen in Fig 7. Each part is glued in place with high strength epoxy resin.

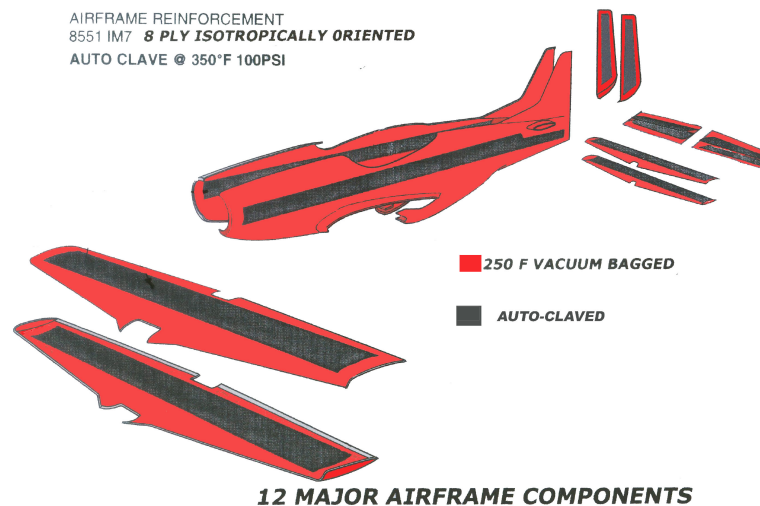


Figure 6. 12 Major Airframe Components. *The tooling developed for the project makes up the 12 components shown above. The reduced part count makes this aircraft light, strong and simple.*



Figure 7. Fabrication of Longerons and Spars. *The fabrication of the longerons and spar is done in and autoclave on site at 350°F.*

Since the last build of the Cameron P-51 in 1998, the tools have been sitting covered in the facility. It was critical to the project that the tools be inspected for aging due to temperature fluctuations and humidity from the previous ten years. The tools were found to be in perfect condition. Some areas have been patched due to blowouts from the original construction. Blow out is a normal occurrence in new tooling and is due to air bubbles and defects in the composite material. The affected areas can be patched without any detriment to the tool or the subsequent parts. Images of the tooling are shown in Fig 8. Notice all tooling is built on steel support frames to prevent warping during storage. The tool surface is smooth without any fractures or delamination. Due to the age of the tooling Cameron Aircraft, determined the maximum temperature that the tooling can be subjected to is 250 °F. The tooling is constructed from 350 °F material, but due to the age and the potential to make more than one subsequent aircraft, the additional stress from 350 °F has been decided to be too detrimental. Therefore all carbon material used on the aircraft is limited to a 250 °F curing temperature.



a) Fuselage Master Tool



b) Inner Surface of Fuselage Tool



c) Mirror Finish on all Surfaces



d) Steel Frames Support all Tools

Figure 8. Documentation of Tooling During Facility Visit. *The tooling for the project is shown in the four pictures above. All inner surfaces are smooth with no irregularities. Tooling is supported by steel frames to prevent warping during curing.*

The lynch pin of the manufacturing plan has been the landing gear. The original P-51 gear was designed for off field landings in fully loaded configurations. The X-51 will not land off field and therefore does not need the robustness of the original gear. The gear used on the turbine power Cameron P-51 used Cleveland wheels and brakes from the Beech King Air twin and Bridgestone 24x7.7 tires. The tail wheel assembly is from a North American T-6 trainer. There is no information available on the olio strut or the wing landing gear integration. Figure 9 shows the gear on the Cameron P-51, but little is known on the type and how it is integrated.



Figure 9. Landing Gear From Cameron P-51. *The landing gear on the Cameron P-51 integrates components from several aircraft. The gear had problems with the electrical actuation system on deployment.*

III. Preliminary Design

Design of the racing X-51 has been limited primarily due to lack of engineering knowledge on the aircraft tooling. The visit to the facility shed light on some of the issues of concern, yet left many questions open. Thus, focus was turned to developing a model to illustrate the items of concern, primarily the landing gear interface with the carbon wing structure and documentation of the manufacturing process.

A. Computer Model

In order to create a model of the X-51, it was critical to look at how the original tooling was constructed. The fuselage and tail group are an exact replica of the P-51D. From 3-view drawings of a P-51D the fuselage was built in Solidworks using curves projected from opposing planes. Figure 10 shows how the construction of the fuselage was accomplished. The process requires that a master sketch that reflects the true dimensions of the aircraft be

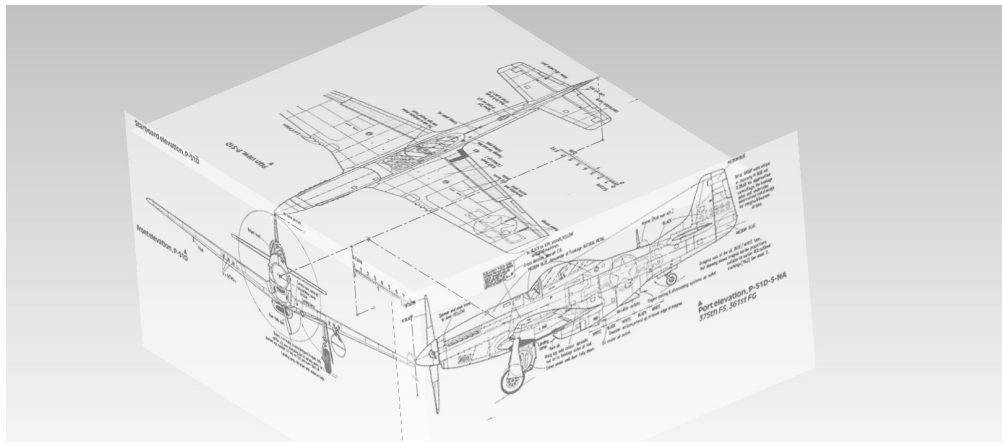


Figure 10. 3-view Drawings used to create Solidworks Drawing. *The use of 3-view sketches in Solidworks made it possible to develop a 3-D model of the X-51.*

created in each place for reference when inserting the three view drawings. Curves were generated by sketching the lines of the aircraft in opposing planes then projecting them onto one another. Loft sections were used in creating the solid. The wing section uses a P-51H 3-view model set for the correct dimensions of the original aircraft. Deviation from the drawing came with the reduction in wingspan for the racing version of the aircraft. The wing was placed aft of the datum based on the location of the wing on the P-51D model. It was decided that the model would use the single place bubble canopy based on the current use of the canopy on the existing turbine model.

The model has served as a marketing tool for the project as well. In order to provide potential sponsors with concrete information as to the scope of the project, a series of graphics wraps were designed and placed on the model for marketing purposes. All financial support for the project has come from sponsors, which made the model an important marketing device and design tool. Examples of the marketing model are shown in Fig11.



Figure 11. Computer Model as a Marketing Tool. *The figure shows the computer model wrapped in a Red Bull graphic. Red Bull is one of the potential financial backers of the project.*

B. Drag Build-up

From the model it was possible to do a basic drag build-up based on wetted areas of the airframe. The method from Roskam's, "Airplane Aerodynamics and Performance" was used to write a MATLAB script that takes the basic geometric values of the airframe as inputs and outputs a drag coefficient based on altitude and velocity values. The profile drag of the aircraft has been determined to be 180 counts of drag, which is very similar to a Bombardier Learjet. The P-51H root airfoil is slightly thinner than the P-51D. Figure 12 shows a comparison of the two wings airfoils.

C. Future Design Action Items

There are two action items currently in progress for the project. The first is determining the landing gear to be used on the aircraft. The first option is to utilize the original landing gear of the P-51. This has been thrown out because the gear is overbuilt for the racing models concept of operation. The second option is using the gear on the Cameron P-51. This option has been decided against based on the fact that the gear had issues with the electrical actuation system. Research is being done on the Tsunami aircraft that had attempted the piston driven speed record before crashing in 1995. There is not much information on the type of gear, but it is the most promising at this moment.

Another important item to accomplish before the project moves into the construction phase is a feasibility study determining whether this X-51 can break 530 mph speed record. The issues associated with approaching the

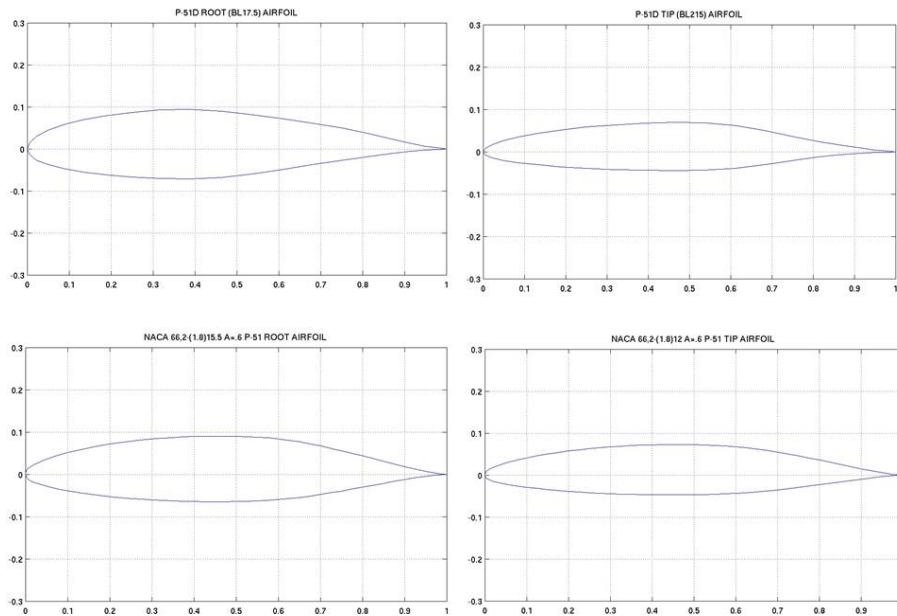


Figure 15. Root and Tip Airfoil from the P-51D and P-51H Wing. *The four airfoils are shown above. The top two represent the root and tip airfoils used on the P-51D wing. Notice a slightly thinner airfoil used for the root on the H wing (bottom left).*

transonic regime are important to analyze before continuing. Flutter has always been an issue with the P-51 airframe, so the effects of composite materials dampening those aero elastic modes must be analyzed as well.

IV. Conclusion

The overview of the X-51 project reveals that there is significant work that must be done before any building starts. There are many factors working against the airframe including the need to make modification to the existing landing gear configuration. Before any work can be done on the airframe, engineering drawings will have to be produced. This will allow for a thorough understanding of the changes and modifications. Also without any financial backing the project will go nowhere. Overall, the project offers a broad range of topics to be involved in and represents a possibility to produce a truly state of the art aircraft.

References

- Roskam, Jan. H., Lan, Edward, "Airplane Aerodynamics and Performance" 2003, pp. 135, 155.
- "Flight tests on the North American P-51H Airplane," AAF No-44-64161, 1945
- MATLAB, Educational, Software Package, Ver. 2010, MathWorks.
- Solidworks, 3-D design Student Software Package, Ver. 2010, E. S. Dassault Systems
- UIUC Applied Aerodynamics Group, "Airfoil Coordinates Database"
http://www.ae.illinois.edu/m-selig/ads/coord_database.html