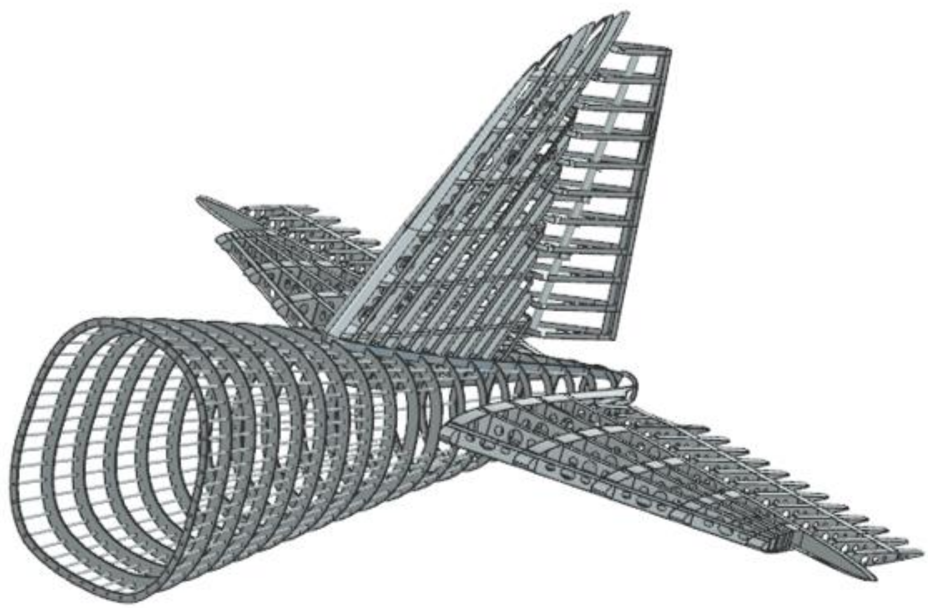
# MTA-10: DC-3 Empennage Redesign



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# Abstract

The report presents the redesign and analysis of the empennage of the Douglas DC-3 for modern day use, tailoring it specifically for military and arctic research applications. While the DC-3 remains iconic for its performance and reliability, modern applications necessitate improvements in its structural integrity and adaptability to a wide range of use cases. The redesign focuses on optimizing the durability of the empennage to enhance its maneuverability, stability and survivability under diverse operating conditions. Key changes in the design include optimized rib spacing, strategically positioned spars, and robust cross-sectional features tailored for increased durability and reliability under military conditions. The substructure was carefully modified to accommodate surface control linkages, allowing for little change in repairability and extending the operational capability of the DC-3 fleet in military scenarios. With manufacturability being a high priority, the empennage is designed to be compatible with existing control systems and sensors. This report outlines comprehensive engineering justifications, highlights competitive advantages, and provides clear recommendations to proceed effectively into Phase III, ensuring the continued use of the DC-3 in a wide range of scenarios.

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## 1. Introduction

The D3-C is one of the most well-known aircraft in history. However, being manufactured in the late 1930s is outdated for modern day use. The airframe is still usable, however innovations in aviation technology have necessitated the design of new substructure components. This report documents the redesign for the Douglas C-47's empennage and rear fuselage as part of its refit into the Basler BT-67 for Basler Turbo Conversions. The proposed redesign includes significantly increased engine output. Additionally, the proposed applications are military and artic research. Both factors necessitate significantly increasing the strength of the substructure. The redesign this report covers is limited to the substructure and linkages for the parts. Justifications for the redesign are provided based on the reference material listed in the appropriate section of this report. The outer mold line (OML) was provided and used as a reference when creating the ribs, spars, bulkheads, longerons and stringers. All parts in this report were created using the computer aided design (CAD) software NX.

## 2. Method

The design of the substructure is primarily based off of provided military and structural handbooks, [1], [2], [3]. Additional sources were used throughout the design process and are noted as such in the report.

In designing the DC-47's empennage the structure was divided into several main components which were then designed by the team members. These parts include the rear fuselage, the horizontal tail, the elevators, the vertical tail, and the rudder. These parts and their subcomponents were modeled parametrically in reference to existing documentation of the DC-3. Following construction of the individual components and their substructure the parts were assembled in a single file, evaluated, and modified to better interconnect with one another.

The team who engineered these parts is led by Tiger Sievers, who also designed the linkages. Owen Whillock served as the presentation lead and designed the V-tail substructure. Joshua Bryant designed the H-tail and substructure. Austin Seher oversaw the rudder substructure, elevator and aircraft assembly. And Nicholas Yeary served as report lead and designed the rear fuselage substructure.

Due to an increase in proposed top speed, military and arctic research applications for Basler BT-67, reinforcing the structural integrity of the empennage was a primary focus. For a general increase in durability, modern aluminum alloys were selected for use in the substructure.

### 2.1 Rear Fuselage

The rear fuselage substructure was created by Nicholas Yeary. The design is heavily based on the original DC-3 substrucutre, which can be seen in Figure 2.1.1.

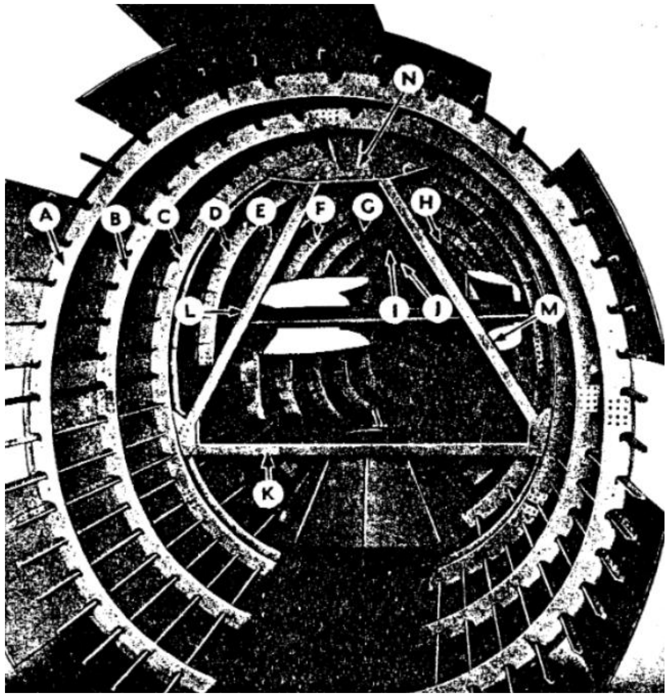


**FIGURE 2.1.1: DC-3 REAR FUSELAGE SUBSTRUCTURE [3]**

The rear fuselage substructure was created in reference to a datum plane 510 inches from the global origin along the x-axis. A sketch was created on the datum plane where a rectangle covering the cross section of the fuselage was placed. This rectangle was then extruded by 0.75 inches, the width of a DC-3 bulkhead according to Reference [1]. It should be noted that all dimensions of the bulkheads and longerons were defined by expressions however for the purposes of this paper these expressions are not named. As can be seen on Figure 2.1.2: Dimensioned view of fuselage substructure the extrude was patterned by a pitch of 13.5 inches and a span of 265 inches, the span being the length of the rear fuselage. The pitch notably differs from the original design the distances varied from 3 to 25 inches, decreasing the total number of bulkheads in the redesign. The bulkheads in front of the empennage were then shelled on both faces to 4.75 inches while those in the empennage were shelled to 2.75 inches.

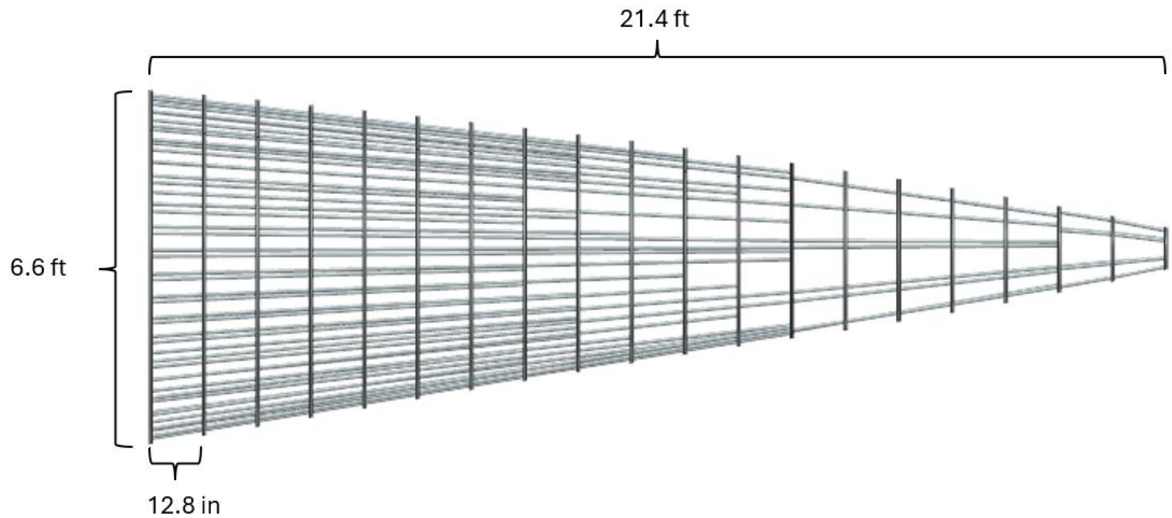


FIGURE 2.1.2: DIMENSIONED VIEW OF FUSELAGE SUBSTRUCTURE

Sketches were then placed on the first, thirteenth, and eighteenth bulkhead faces, facing the tail. In these sketches a radial configuration was created to form the longerons as can be seen in Figure 2.1.3 Cross-Sectional View of Rear Fuselage With Sketch Lines. To account for the lower number of bulkheads the total number of longerons was increased from 44 to 48, each 7.5 degrees apart. Construction lines were used to define longeron positions, one end of the lines coincident with the center of the fuselage cross section, and the other end coincident to the other wall of the bulkheads, while circles representing longeron cross-sections were had their centers coincident to the lines. Because of the limitations of the pattern tool these features were copy and pasted in sets of four and their relations manually adjusted. It should also be noted that the longeron cross sections are modeled as circles rather than L-beams due to the processing limitations of NX. Accurate modeling of the longerons causes NX to lag to the point of being unusable, causing the geometry to be simplified.

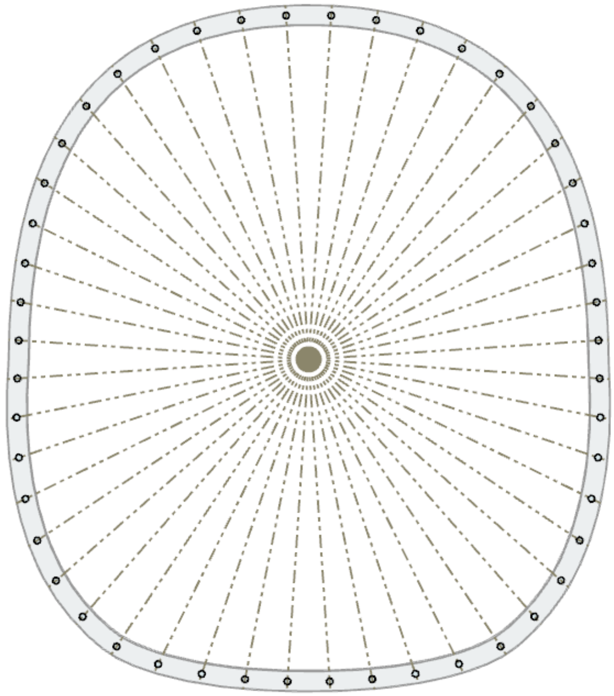

FIGURE 2.1.3 CROSS-SECTIONAL VIEW OF REAR FUSELAGE WITH SKETCH LINES

Once this process was finished on one sketch it was copied and pasted to other sketches and adjusted to meet the new dimensions. Then the bulkheads were hidden and the through curve tool, with single curve selection, was used to model the longerons, every cross section individually connected to its counterpart. Then, following the Reference [1] and the trim body tool, select longerons were trimmed against the bulkhead faces, decreasing the number of longerons towards the tail as needed structural support decreased as seen in Figure 2.1.2: Dimensioned view of fuselage substructure.

In the tail section, composed of the last three bulkheads, a sketch was placed on each bulkhead face with a radial longeron pattern composed of six longerons rather than the previous forty-eight. These were then modeled with the through curve like previous longerons. Some longerons were stubborn about being through curved so the swept tool was used alongside equidistant guide curves to model these features.

## 2.2 H-tail

The H-tail was designed by Josh Bryant. The design varies from the original H-tail of the DC-3, which can be seen in Figure 2.2.1. The original design has modified by reducing the number of spars and ribs, while increasing their thickness.

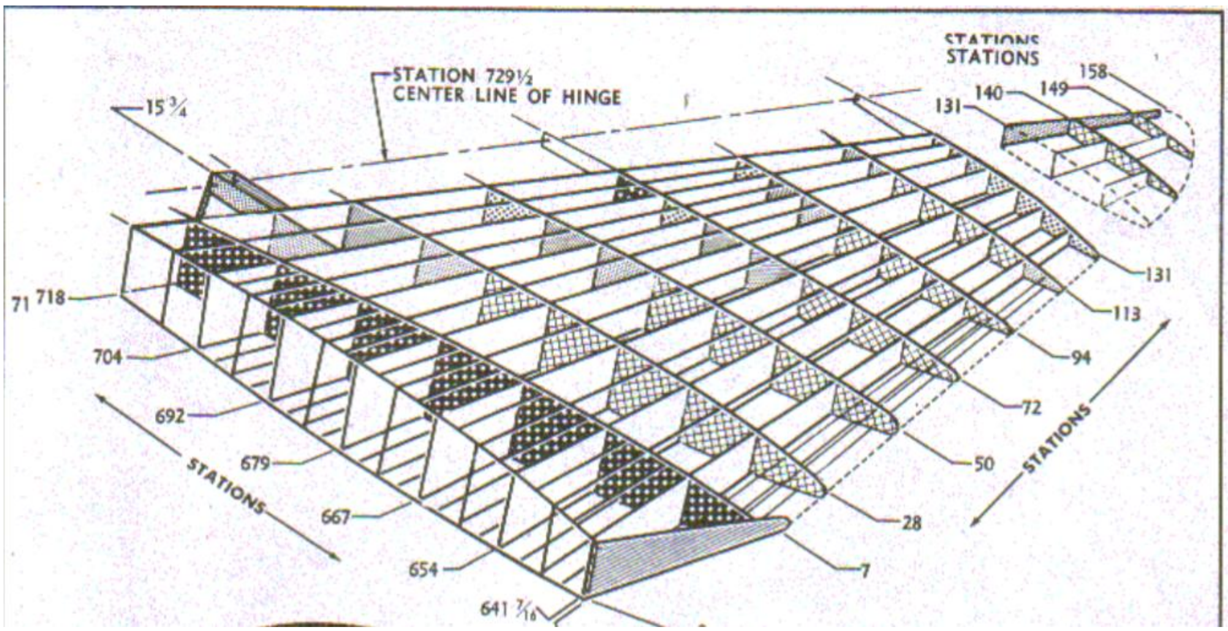


**FIGURE 2.2.1: DC-3 H-TAIL SCHEMATIC [2]**

The substructure of the H-tail was constructed utilizing the provided outer mold line (OML) geometry. Initially, five ribs were created using extruded profiles (Extrude tool) oriented perpendicularly to the primary spanwise axis, each rib having a uniform thickness of 5 inches. These extrusions were accurately trimmed to the OML using NX's trim body tool. The ribs were spaced using the pattern feature tool, with the spacing scaled using the swept command from root to tip, covering a horizontal tail span of 11.9 ft and a root chord length of 10 ft.

Five spars were placed equidistantly along the spanwise axis, created through rectangular extrusions and trimmed precisely to match the OML geometry using the trim body tool. Circular lightening holes with diameters of 3 inches and 5 inches, shown in **Error! Reference**

**source not found.**2 were added to the ribs and spars using the hole command, strategically positioned for optimal weight reduction. Specifically, 3-inch and 5-inch holes were carefully placed to maximize weight efficiency.

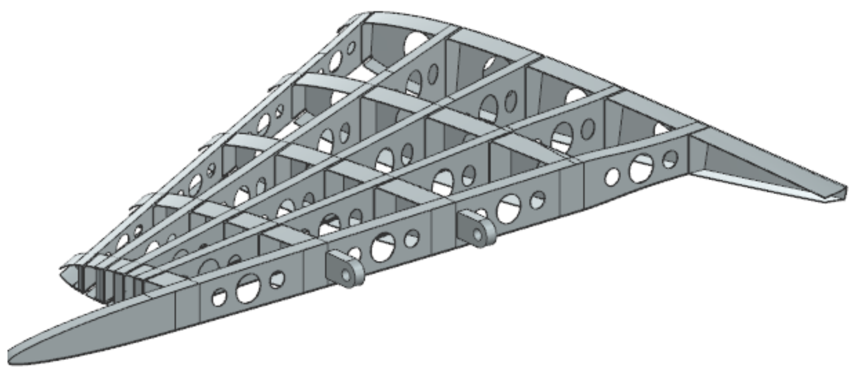

FIGURE 2.2.2: ISOMETRIC VIEW OF H-TAIL SUBSTRUCTURE

A shell operation was employed with a uniform thickness of 0.1625 inches to thin structural elements, further reducing overall weight without compromising strength. Additional structural integrity was achieved through precise edge blending and subtraction operations, refining the geometry further. The overall dimensions of the H-tail can be seen in Figure 2.2.33

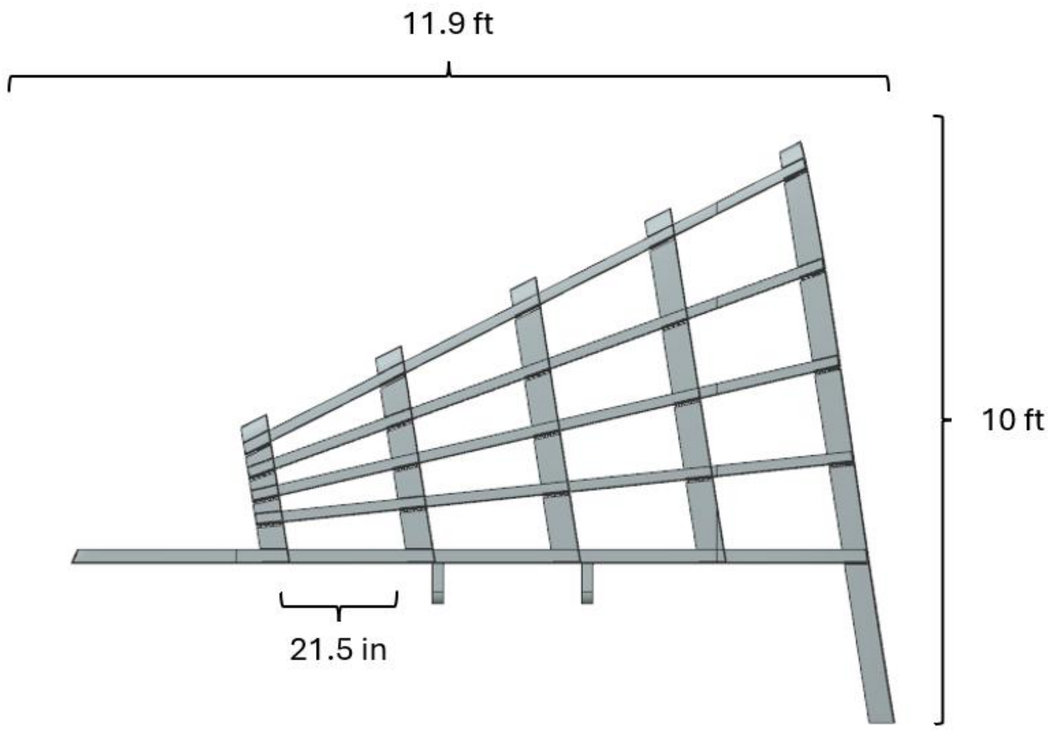


**FIGURE 2.2.3: DIMENSIONED VIEW OF H-TAIL**

## 2.3 Elevator

The elevator substructure was designed by team member Austin Seher. The substructure once again takes influence from the elevator substructure of the DC-3, shown in Figure 2.3.1.

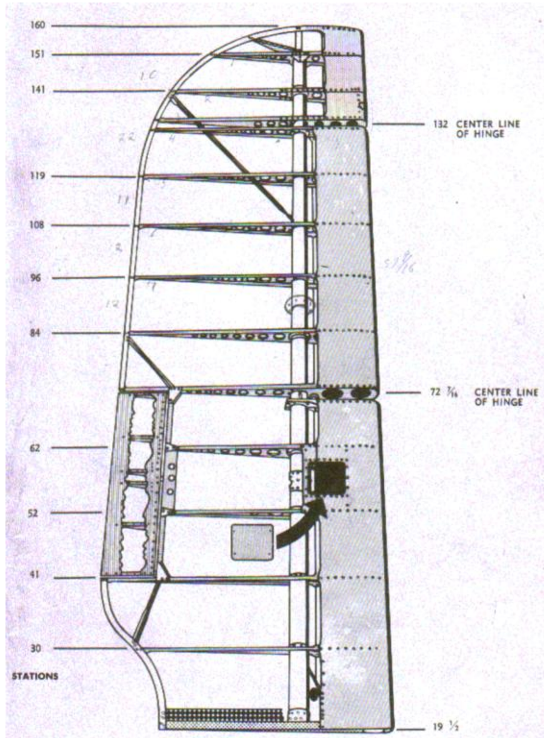


FIGURE 2.3.1: DC-3 ELEVATOR SUBSTRUCTURE [2]

The substructure of the elevator was created utilizing the provided OML as a reference base. Fourteen ribs, each 2.5 inches wide, as shown in Figure 2.3.2. The ribs were initially formed by extruding rectangular profiles directly through the OML geometry. These ribs were replicated along the elevator span using NX's pattern feature tool.

The primary circular spar was developed using the extrude tool, passing through all ribs to provide structural continuity and attachment points for connection to the horizontal tail. Additionally, two supplementary spars were incorporated aft of the primary spar, created through extrusion techniques and subsequent trimming processes.

Circular lightening holes were strategically placed within the ribs and spars to further reduce weight while preserving structural integrity. Finally, a shell operation was performed, uniformly thinning the structural components to a thickness of 0.1625 inches, optimizing weight and aerodynamic efficiency. A rear spar cap was integrated at the trailing edge of the elevator, serving as the connection point for elevator linkages, thus ensuring structural integrity and effective control surface operation.

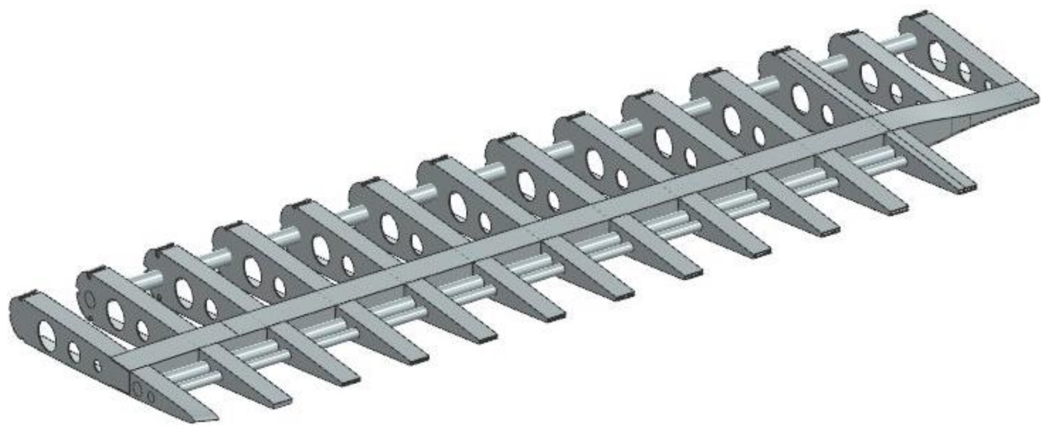

FIGURE 2.3.2: ISOMETRIC VIEW OF ELEVATOR SUBSTRUCTURE

## 2.4 V-tail

The V-tail was designed by Owen Whillock. The inspiration behind the design of the V-tail was heavily influenced by the legacy design in the DC-3 repair manual, Reference [1], seen in Figure 2.4.1. Many of the same geometries seen in the design of the vertical stabilizer was adopted into the updated model such as the spacing of the spars and ribs. However, changes were also made to the substructure that included the number of spars and stringers applied as well as the thickness of the spars themselves.

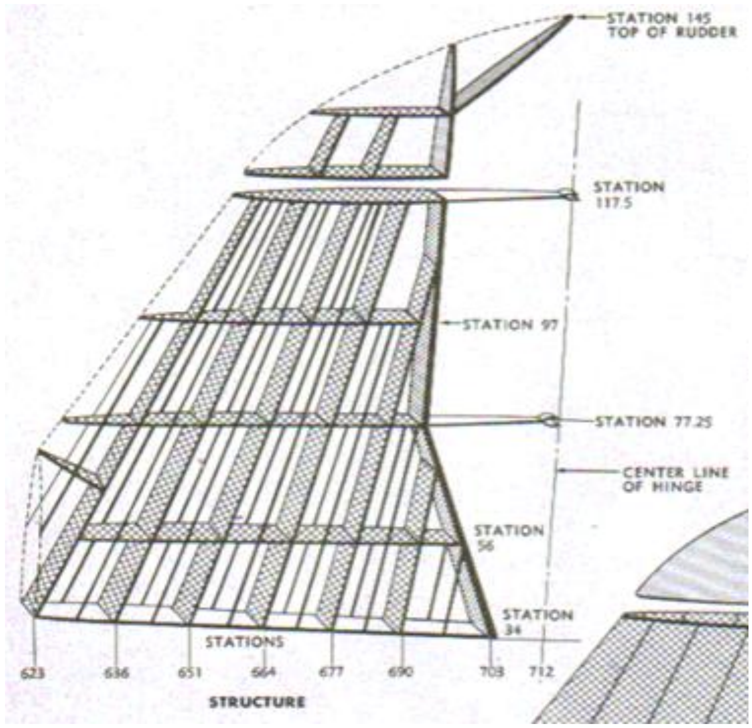


FIGURE 2.4.1: DIMENSIONED VIEW OF DC-3 REPAIR MANUAL V-TAIL

The overall goal of the V-tail substructure redesign was to increase the amount of tensile strength whilst also attempting to mitigate the amount of overall weight being distributed on the interior. The intent behind trying to increase the tensile strength experienced by each spar was to maximize the overall structural integrity that the V-tail could endure for the more demanding aerodynamic loads that the aircraft would encounter in its military applications. To begin accomplishing this task, a sketch was created with respect to the OML that was provided as the foundation of the vertical stabilizer. With this new sketch, a horizontal line was placed across the body to begin creating an initial idea as to where the ribs might best be located. Once the location of all the ribs fit within the parameters of the OML, the ribs were then patterned vertically and evenly spaced approximately 15 to 18 inches apart from one another, each possessing a thickness of 2 inches. Once the ribs were properly dimensioned, constrained, and extruded within the body, the beginning phases for constructing the spars were underway. The design for the spars began by creating a sketch that was parallel with the leading edge of the vertical stabilizer and emulated a slanted, rectangular shape similar to that of the design instituted in the DC-3 repair manual, Reference [4]. Once the first spar was properly created and constrained, it was patterned 5 times, one less than that of the repair manual design, horizontally with approximately 9-10 inches of space in between each one. To increase the structural integrity and tensile strength within the spars as well as compensate for the reduced quantity of overall spars, the thickness was increased to 3-3.5 inches each to withstand more load when faced with challenging, more demanding military applications. The placement of the spars and ribs can be seen in Figure 2.2.3: Dimensioned View of H-tailFigure 2.2.3Figure 2.4.2.

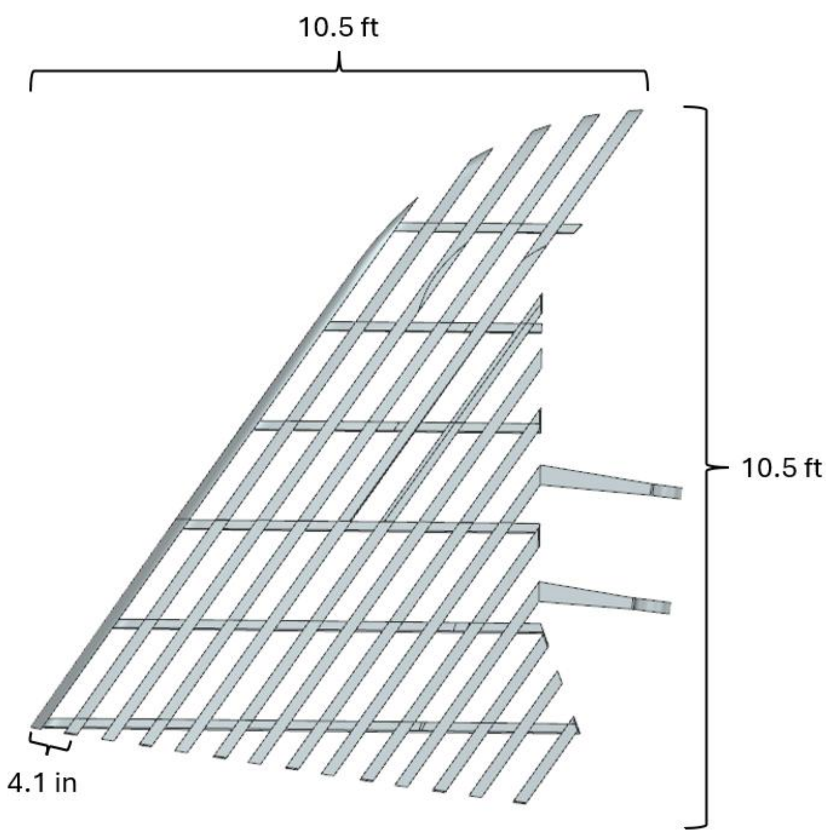


**FIGURE 2.4.2: DIMENSIONED VIEW OF V-TAIL**

The design and placement for the stringers was relatively simple as all that was needed was to take the initial sketch of the spars and pattern them as close to the middle of each spar as possible, which were then shelled from both sides to replicate a real-world stringer. Due to the number of spars being decreased by one, two more stringers were added across the substructure to ensure that the load that the V-tail would encounter would be more evenly distributed across the entirety of the assembly.

As it pertains to the goal of attempting to lower the amount of weight that the vertical stabilizer would experience, this was achieved by shelling each of the ribs by 0.25 inches to reduce the amount of material utilized as well as lowering the number of spars by one. Another method that was utilized to mitigate the amount of weight within the newly designed substructure was creating sketches on each of the spars and adding about three lightening holes to the blank space in-between each rib and spar. Once all the lightening holes were properly organized and constrained, the extrude tool was then incorporated to create that hollow, spherical shape with respect to each spar. With this reduction in weight now present, the BT-67 is better equipped to handle increased maneuverability and improved fuel efficiency in times of high intensity military operations that require these attributes. The modified features incorporated within the substructure of the V-tail will allow the transition of the DC-3 into its military counterpart, the BT-67, to be a seamless process, ensuring that all altered parts can be easily manufactured and are extremely beneficial to the performance of the vertical stabilizer as well as its other modified components.

## 2.5 Rudder

The substructure of the rudder was created by Austin Seher. It was made in a similar manner to the V-tail and H-tail. Its general dimensions are shown in Figure 2.5.1.

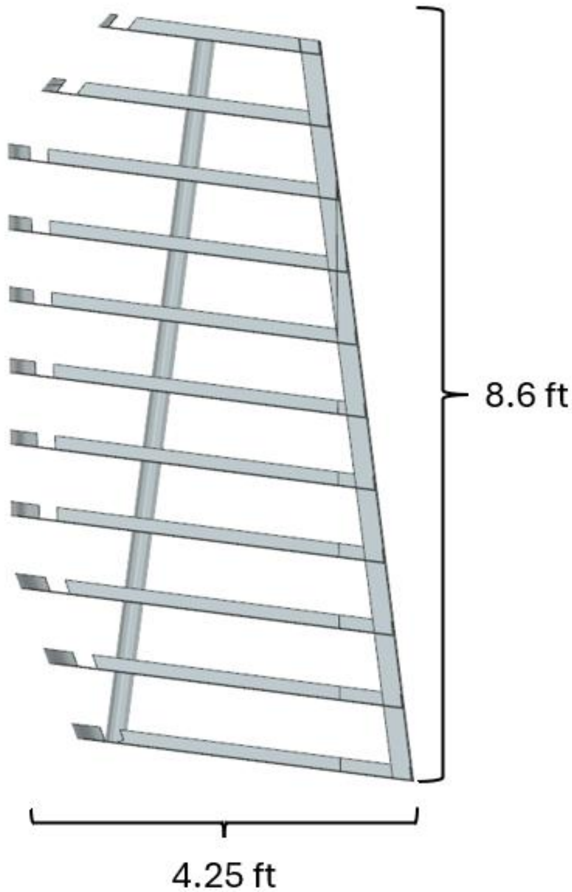


**FIGURE 2.5.1: DIMENSIONED VIEW OF RUDDER**

The OML was first healed using the built in NX heal geometry feature. The OML was then cut using a plane following two lines created on the midpoint of its root and tip. That plane was then used as a base for all geometry. First a rectangular extrude was created at the base of the rudder, then extruded through the height of the OML. It was patterned 10 times, to create a total of 11 ribs (original plus the 10 new). This increases the number of ribs by one from the original DC-3. [2]. This helps significantly with the increased structural requirements, increasing the max aerodynamic load. It also helps with rougher landings by having more ribs available to absorb the shock. The thickness of the ribs was also increased to two inches. The rudder rotates about a shaft mounted through the rear part of the first rib, as can be seen in Figure 2.5.2.

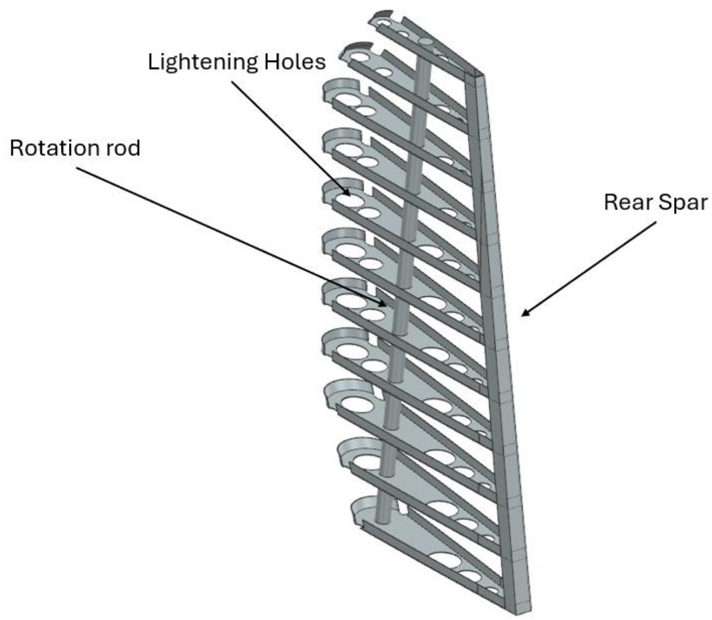


FIGURE 2.5.2: ISOMETRIC VIEW OF RUDDER SUBSTRUCTURE

Additionally, a rear spar was added at 75% chord of the rudder. This comes from typical spar locations in page 24 of reference [3]. This varies from the DC-3 which does not have a rear spar in its rudder. The purpose of this addition is to increase the maximum aerodynamic load the rudder is capable of handling. The spar was created similarly to the ribs, where a sketch was created on the central plane of the rudder OML. The sketch was extruded then trimmed to conform to the shape of the rudder. The resulting solid body was hollowed out using the shell command to create a c-channel. This was used as a tool to subtract the ribs and remove their shared intersection. The shell tool hollowed out one face of the ribs. The sketch and swept tools were used to create lightening holes along the path of the rudder's OML. The dimensions of the lightning holes are shown in

Table 2.5.1. It is worth noting that the holes diameter tapers relative to the thickness of the rudder. This is due to the use of the sweep function to guide the cutting bodies. The trim body

function was used to cut out the lightening holes in the ribs. The extra lightening holes were added to offset the increase in weight caused by adding a rear spar and more ribs.

TABLE 2.5.1: RUDDER LIGHTENING BASE HOLE SIZING

| | | | | | | |
|---|---|---|---|---|---|---|
| **Distance From Axis of Rotation (in)** | 13.3 in | 18.5 in | 18.7 in | 28.5 in | 34.2 in | 38.45 in |
| **Diameter (at sketch definition) (in)** | 3.5 in | 6.75 in | 3.75 in | 5 in | 3 in | 2 in |

To finish the creation of the rudder, bending slots were added which are necessary to manufacture the ribs using sheet metal bending. While the added mass of the spar does reduce the rudders responsiveness, the tradeoff is worth it to hold up under high stress maneuvers and in hostile environments such as the arctic.

# 3. Conclusions

This report details the Phase II preliminary redesign of the empennage for the Douglas DC-3 aircraft, specifically adapting the substructure for the use in the BT-67 military variant. Using the existing outer mold line to construct the modified structure including ribs, spars, bulkheads and stringers. The redesigned empennage aims to enhance the structural integrity without significantly increasing the weight of the aircraft and meeting military operational standards.

Innovative elements such as strategically positions spars; optimization of the rib placement and robust cross-sectional characteristics collectively contribute to the increase in resilience and reliability. Special attention was given to the efficient assembly and operational functionality of the control surface and attachments for both the elevator and rudder, ensuring precise and dependable maneuverability. The ease of manufacturing was also highly considered and integrated into the final design, allowing for increased feasibility and cost-effectiveness of this design.

Ultimately, the design achieves its goal of increasing the structural performance of the aircraft and extending the operational life and capabilities of the DC-3 in military and research roles. Further detailed analysis of the design, prototyping, and refinement of manufacturing methods will build upon this design, ensuring the continued use of this aircraft.

# 4. ML/AI statement

None of the text in this document was generated using natural language processing. All text was human constructed.

# References


[1] Douglas Aircraft Co, Strucural Repair Maunal For DC-3, Santimonica: Douglas Aircraft Co, 1946.

[2] douglasdc-3.com, "Technical Drawings for the DC-3/C-47," 1997. [Online]. Available: https://www.douglasdc3.com/tech/tech.htm.

[3] J. Roskam, Roskam Part III, DAR Corperation, 2011.

[4] United States Airforce, Douglas DC-47 Structural Repair Handbook, Los Angeles Lithograph Company, 1942.

[5] Aviation Library, "Douglas DC-3 Parts Catalog," 2025. [Online]. Available: https://www.avialogs.com/aircraft-d/douglas/item/56257-douglas-dc-3-parts-catalog. [Accessed March 2025].

[6] J. Roskam, Airplane Flight Dynamics And Automatic Flight Controls, Lawrence, Kansas: Design, Analysis, and Research Corporation, 2011.