Design of a Next Generation Military Heavy

I. Introduction

HIS paper is an overview of the work and results of the preliminary design for a next generation military heavy-lift air transport. The work during spring 2016 encompassed the class I design of the aircraft up through the preliminary drag polars and proves that the design point chosen is a viable one for the level of technology chosen for this aircraft.

The work during spring 2017 reevaluates some of the aspects of the preliminary design to address important remaining issues, verifies the class I deisgn, and moves into the class II design of the aircraft. The work to date in class II design covers class II design of landing gear and tires, a preliminary structural arrangement, a V-n diagram and the beginning of class II weight and balance estimations.

II. Project Schedule

This project is a year-long project to execute the class II design of a next generation military air transport in partial satisfaction of the requirments for a Masters of Science in Aerospace Engineering

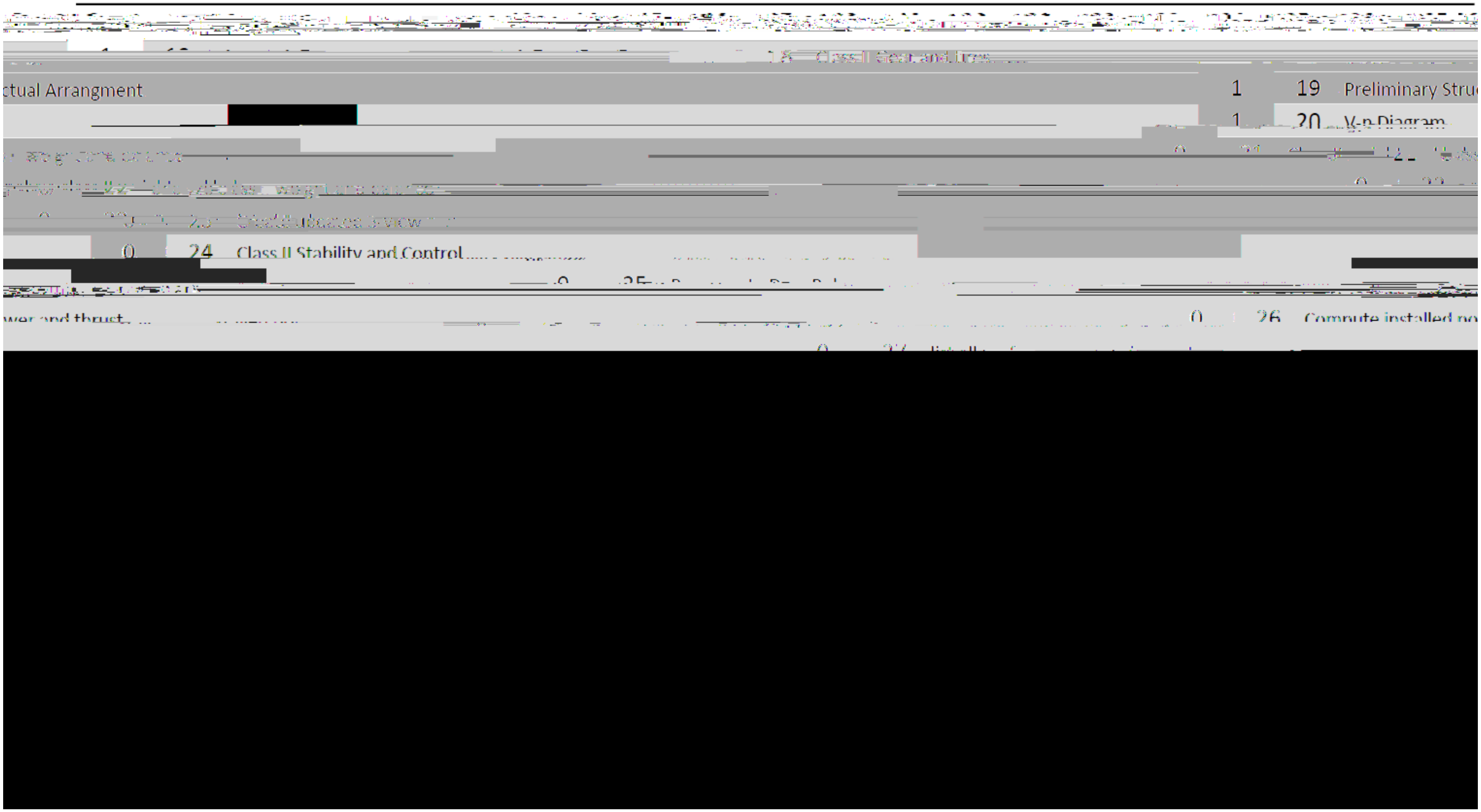

Figure 1. Projected Project Schedule. *A predicted schedule of the project outlining the duration and sequence of steps in class II aircraft design as outlined by Roskam*[1].

III. Motivation and Literature Review

The C-

C-5 fleet has undergone a refit program to extend the service life to 2040.[2] However, with the historically long design and manufacturing phases for United States military aircraft, it is necessary to begin the design phase in order to have a viable replacement aircraft at the C- rvice. For comparison, the F-35 began its process in 1997 when Lockheed Martin was selected for the Joint Strike Fighter concept demonstration phase; the F-35 entered active service in July of 2015.[3]

The timeline is not the only motivating factor for a next generation military heavy lift transport. When it was introduced, the C-5 was capable of carrying two M1 Abrams main battle tanks (MBT). With the most recent version of the M1 platform, the M1A2 SEP, weighing almost 24000 lb more than the original M1, the C-5 is no longer capable of carrying a pair of modern MBTs; this results in approximately a 25% decrease in the military airlift capacity for [4]

Additionally, with the change in the worldwide military situation, a set piece battle of conventional forces between NATO and former Warsaw Pact nation forces is all but unthinkable. Instead, military operations are conducted in more remote territories where infrastructure is far less considerable than that found in the staging areas of the European theatre. As such, a successor to the C-5 which improved its landing and takeoff field length and range would be invaluable in reorienting the military airlift capacity of the United States towards modern challenges while retaining traditional capabilities.

Finally, when the C-5 was designed and introduced, the power, efficiency and physical envelope of turbofan jet engines were all much lower and smaller than they are today. These limitations required the use of four of the biggest engines then available for the initial design. With advances in engine design an aircraft of similar scale would have vastly improved performance and efficiency. Some effort has been made to employ these benefits in the form of the C-5M refit program, however, fundamental design choices remain in the form of wing structure and load distribution. To fully utilize both modern

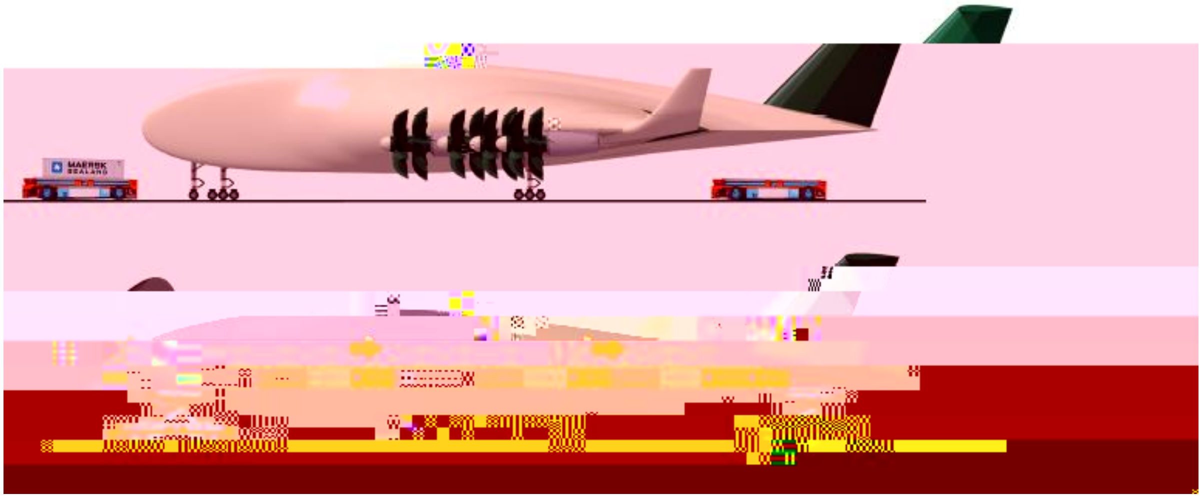

Figure 3. Recent Proposed LH_2 Powerd Aircraft. *A liquid hydrogren powered design concept side view presented in 2012 by Delft University.*

Table 1. HUULC Aircraft Data. *General sizeing and performance data presented for the Delft's HUULC aircraft design.*[6]

Parameter	Value
W_e	[illegible]
W_f	[illegible]
W_{tfo}	2,[illegible]
W_{pay}	1,248,[illegible]
W_{to}	2,[illegible]92,[illegible]
W/S $[N/m^2]$	2867
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible] m
$C_{L_{max}}$ clean	1.6
$C_{L_{max}}$ take	1.7
[illegible]	[illegible]
A	5.59
e	0.7

In the case of the hydrogen powered aircraft it would be necessary to not only implement complex cryogenic fluid handling systems in the aircraft (assuming vapor cooling permitted, without this a complex refrigeration system would also be required) but also require that facilities at all potential destinations maintain supplies of cryogenic liquid hydrogen and all the attendant refrigeration and handling equipment. A potential design was presented in the mid

volume. However, without compelling performance increases over traditional designs and the additional complexity, nothing was ever done with the design.

More recently, a potential hydrogen powered aircraft design was presented by Delft University in 2012[6]. This design utilizes several non-conventional features including a hybrid flying wing lifting body design, liquid hydrogen powered propulsion, extreme wingspan and dedicated airports. For reasons of logistical integration with the current military airlift network such compromises are unacceptable for a C-5 Galaxy replacement.

In the case of nuclear powered propulsion there are several obvious concerns making such a system prohibitively complex. The foremost concern from a purely aircraft design perspective is that a nuclear reactor, even one designed for aircraft, would be extremely heavy and additional shielding would be required to make sure that any crew, passengers, and sensitive cargo would also be safe from radiation exposure. Operational concerns involve the fallout in the case of a crash, security of nuclear materials and technology in the case of aircraft loss and provisions for refueling and maintaining a nuclear-powered aircraft.[5] The weight concern can be seen in the following figure from reference 5 showing the extreme size and extremely poor

IV. Misson Specifications

The mission specification for the proposed aircraft design, the Goliath, represents a significant improvment in payload mass, range, cruise speed, and operational costs over the C5-B and C-5M aircraft currently in operation.

While many of the specifications of the two aircraft are similar, there are several important distinctions in the specifications. The modest increase in maximum payload capacity ensures that there is sufficient margin to safely accommodate two battle-ready MBTs with the potential for secondary equipment and supplies to be included. The cruise velocity increase of 8% corresponds to a cruise mach increase of 0.08 from mach 0.77 to 0.85 at the design cruise altitude. This allows the Goliath to arrive 45 minutes sooner than the C5-M over its full payload operational range. Finally, the operational range figure is misleading for the C-5, the operational range of the C-5M is rated at 120000 lb of cargo not its full rated payload capacity. At maximum payload capacity, the estimated range for the C-5M is approximately 3500 km while the

This estimation was performed using the Brequet range equation, utilizing the ratio of C-
weight and the sum of payload and empty operating weight as the mass fraction with all other values assumed to be similar.

The primary mission profile of the Goliath is the same as the C-5M in the form of a point to point cargo mission with contingincies for missed approach and diversion to alternate landing sites. A diagram of this flight profile is shown in figure 5. The affect of this flight profile on aircraft design will be discussed further in section 4.

V. Class I Design Overview

A. Configuration

The configuration for the Goliath was chosen based primarily upon the desire to reduce cost in development, aquisiton and operation. Due to the necessities of the cargo transport mission as well as to enable the use of

Combining these changes of aspect ratio and C_f the new L/D ratio for the aircraft was determined by revaluating the drag polars. These revaluated drag polars as well as the cruise condi

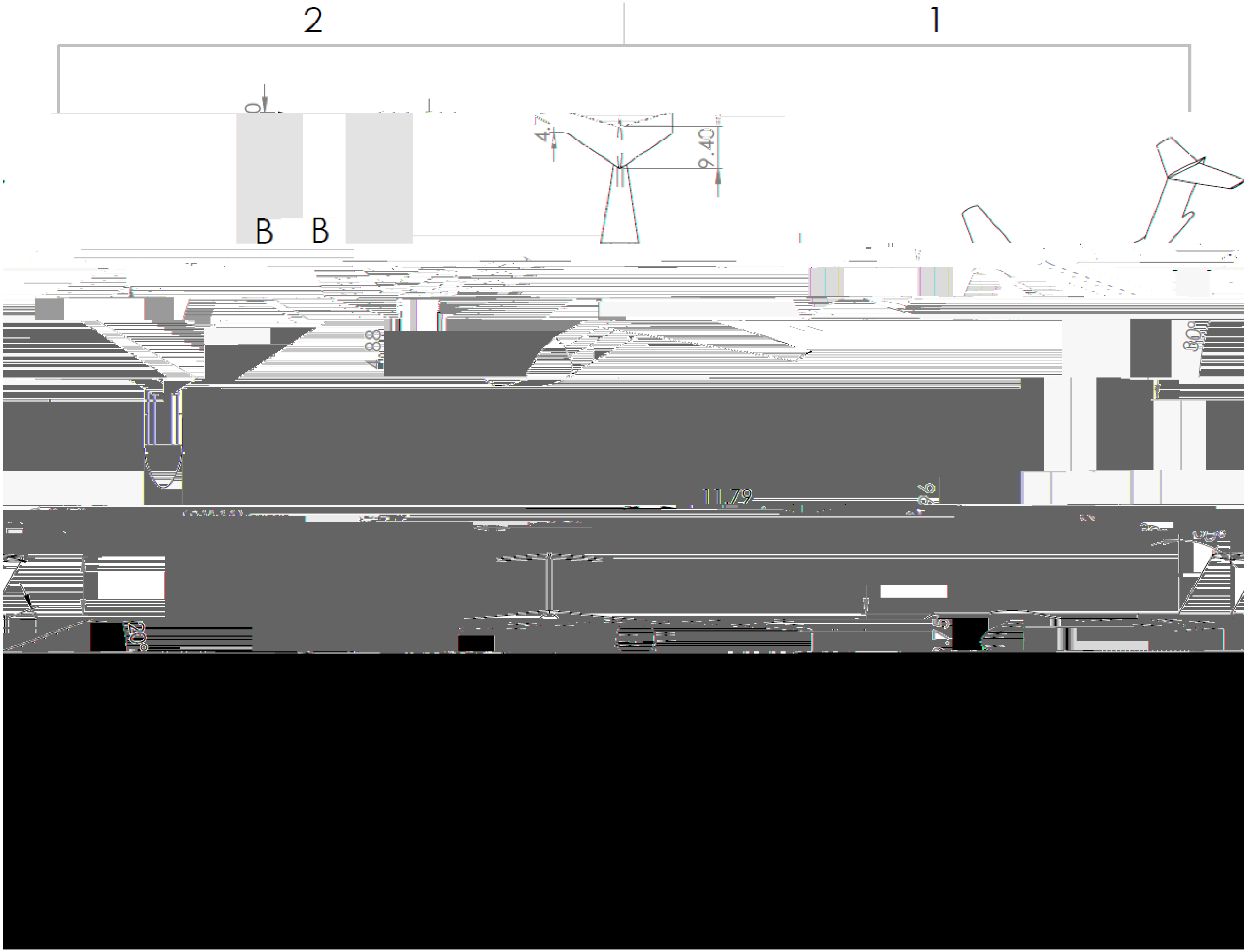

Figure 12. Revised Aircraft Geometry. *Revised aircraft geometry to reflect class I reevaluation.*

VII. Class II Landing Gear and Tire Design

With the revision of the aircraft to resolve the major outstanding issues, class II design can commence. The first step in the class II design conducted was the class II landing gear configuration. The preliminary gear configuration has been selected in class I design and these class II steps will serve to determine the true strut and tire size. The first step in this procedure is to calculate the equivalent single wheel load (ESWL). This can be calculated for the given strut configuration as ESWL=P/2 where P is the per strut load on the gear (applicable to both main and nose gear). From geometric layout of the aircraft the load distribution between the main and nose gear can be calculated based on a simple ratio of the respective distance from the center of mass (calculated with rearmost CG for main gear and most forward for nose gear). This ratio can be found to be 24:5 (meters) for the (respectively) nose and main gear spacing

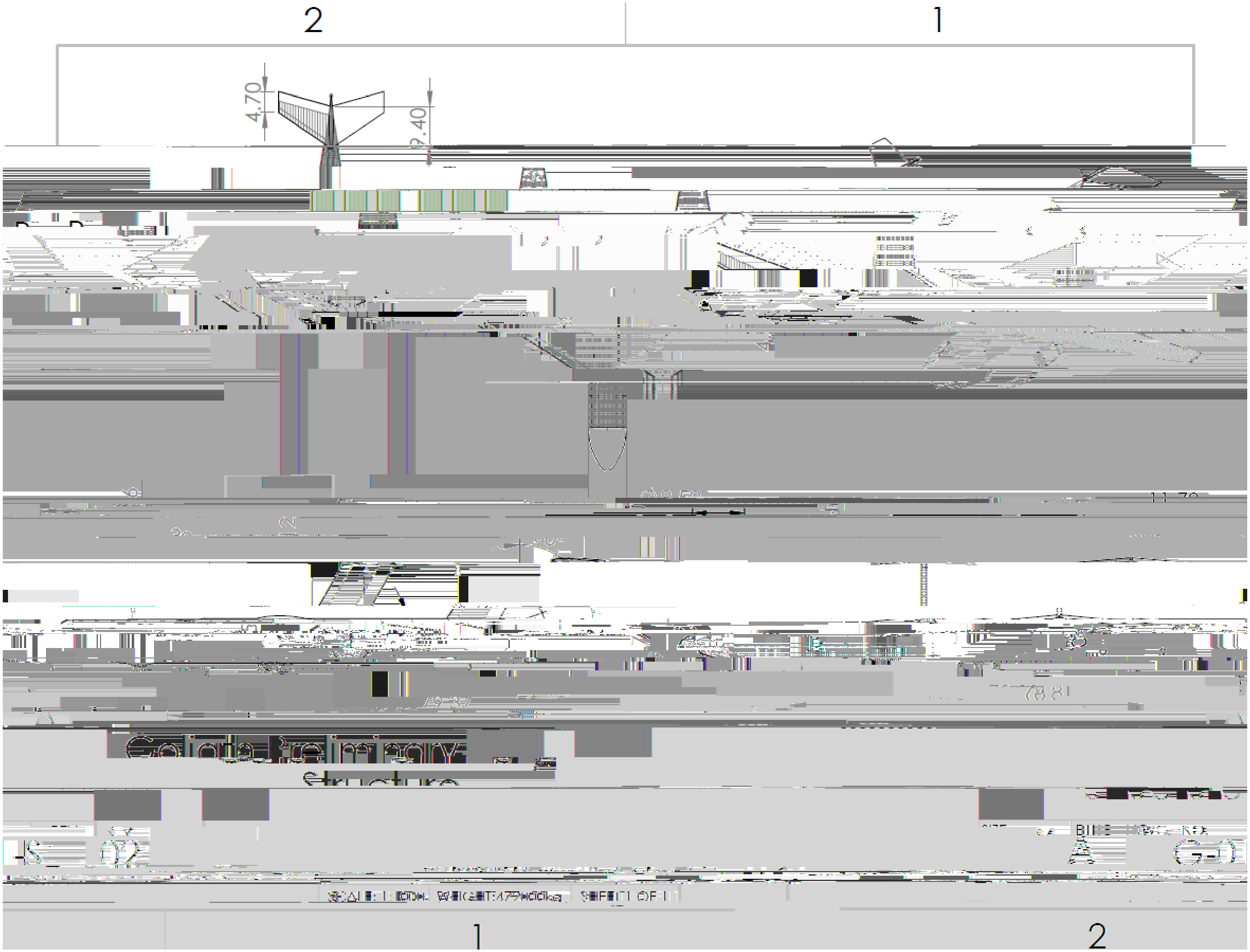

Figure 14. Partial Outline of Preliminary Structural Elements

IX. V-N Diagram

The V-n diagram is based on several critical speed values which are calculated as shown here per Roskam[1].

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8ˆ L & A O E J Q R A N 5 E L J A C A R @8ˆ Û J^{4àº}_{ß Ù à} L y u àä x Ût^{4àº} L s r u àä v • • / Š „ :s v;

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X. Class II Weight Estimation

Table 9. Class II Fixed Equip. Component Weights *Breakdown of class II weight estimates for all major fixed system components.*

D. Center of Gravity

In what is practically an accounting exercise, the weights and locations of all of these items have been tabulated and used to calculate the CG of both the empty and loaded aircraft. The table and these results can be found in table 10.

Table 10. Class II Center of Gravity Table *Breakdown of class II weight estimates for all major components and their locations..*

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2ØßØÖ L 2ØßØÖäè / ßØßØÖ L s rG 9 / räí L s sää G 9 :t u;

2

Figure 18. Approximate Thrust-Speed Characteristics at SL. Approximate engine thrust

XIII. Performance Evaluation

With the bulk of the design complete it is necessary to assess the ability of the Goliath to meet its designed mission goals. These goals are broken down into sections for discussion their respective values. These calculations were completed within the AAA software suite and utilize the equations presented in Roskam[1] for their completion. The original mission specifications for this aircraft are shown below in table 10 (identical to table 3). Performance for this aircraft is evaluated at 1500 and 0 meters for landing and takeoff operations and 11000 meters for enroute operations (maneuver, cruise speed, etc)

A. Takeoff

Takeoff performance makes use of several different equations. These equations are shown below and their results are tabulated at the end of the section with all other performance parameters. These equations are those presented in Roskam[1] and utilized by the AAA[10] software used to compute these calculations.

[redacted]

T

$$S_{TOG} = \frac{\frac{V_{LOF}^2}{2g}}{\text{[illegible]}}$$

[redacted]

These equations use the normal geometry terms for a takeoff roll and this aircraft uses a 50 ft obstacle for these calculations. This geometry is shown ing

The results of solving these equations and graphing the thrust available and thrust required versus flight speed are plotted below in figure 20.

In addition to cruising speed, at the specified cruise speed range is also a factor. Using the thrust required at speed and the specific fuel consumption of the engine it is possible to approximate the range of the aircraft at speady crusing speed. The results of this calculation are presented in the summary at the end of this section

Endurance is much the same way except the speed and flight attitude used are different from those for maximum range since a different quanitiy is being maximized.

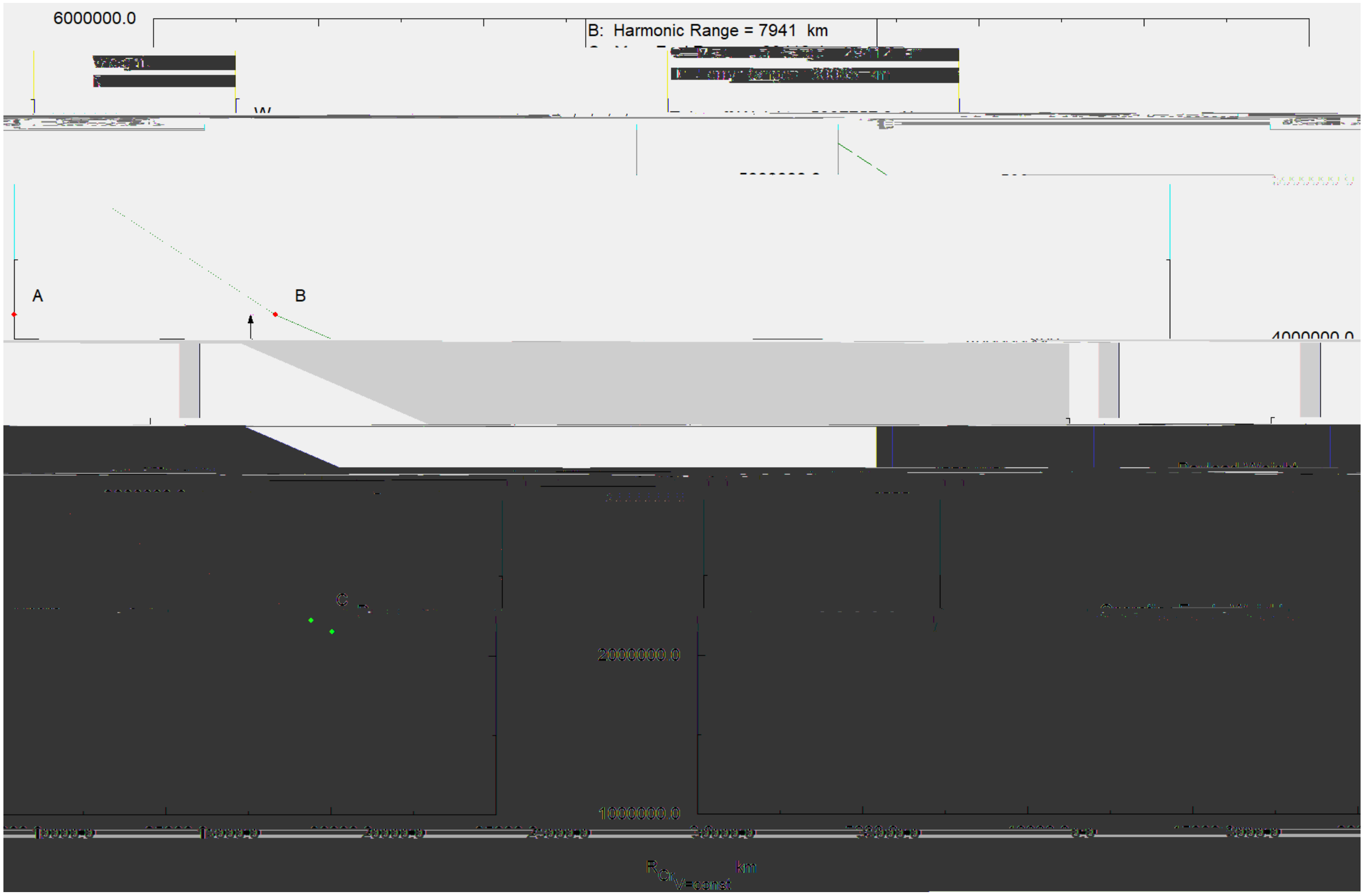

Figure 21. Payload vs. Range. Payload vs fuel tradeoffs and their effect on maximum range.

C. Landing

Landing performance is critical for virtually any aircraft since runways have limited lengths, for the mission of the Goliath it is even more critical since military transports must at times get into facilities and locations without typical infrastructure in place. For this reasone landing performance had been a driving concern over and above the takeoff performance for this deisgn. To assess the landing distance of the design. To assess the design the process from Roskam[1] is again used. The equations uses in this process are shown below, their implementation fairly obvious.

[redacted] (39)

[redacted] (40)

$$C_{D_A} = C_{D_{o_{L\_down}}} + B_{DP_{L\_down}} C_{L_A}^2 \tag{41}$$

[redacted] (42)

$$V_{TD} = V_A \left[1 - \left(\frac{\overline{\gamma}^{\,2}}{\Delta n}\right)\right]^{1/2} \tag{43}$$

$$S_{LG} = \frac{V_{TD}^2}{2\overline{a}} \tag{44}$$

$$S_L = S_{air} + S_{LG} \tag{45}$$

Table 9. Class II Fixed Equip. Component Weights *Breakdown of class II weight estimates for all major fixed system components.*

XV. Final Geometry

A. Wing

Figure 22. Basic Wing Planform.

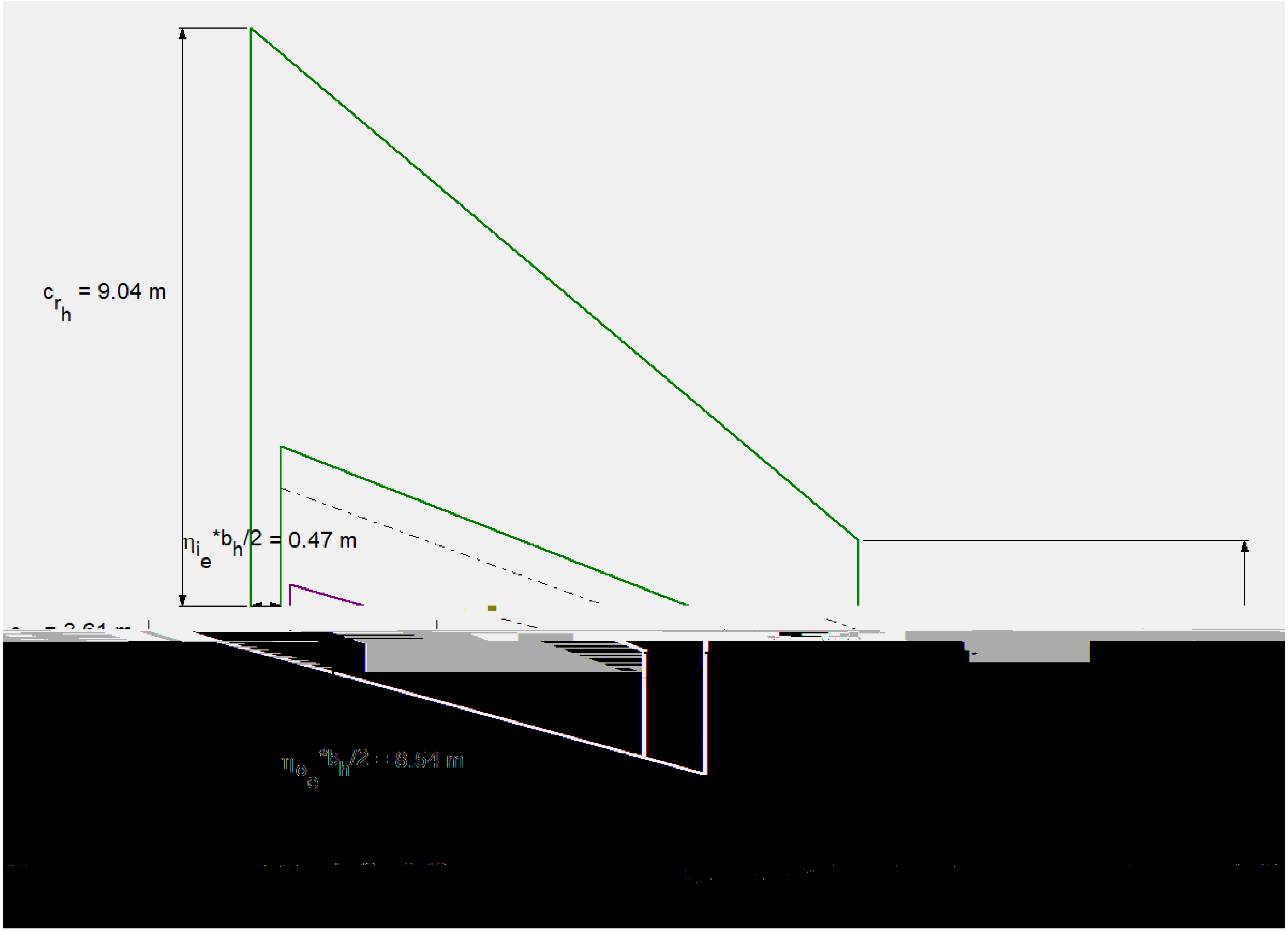

Figure 25. Horizontal Stabilizer Control Surface Layout.

C. Vertical Stabilize

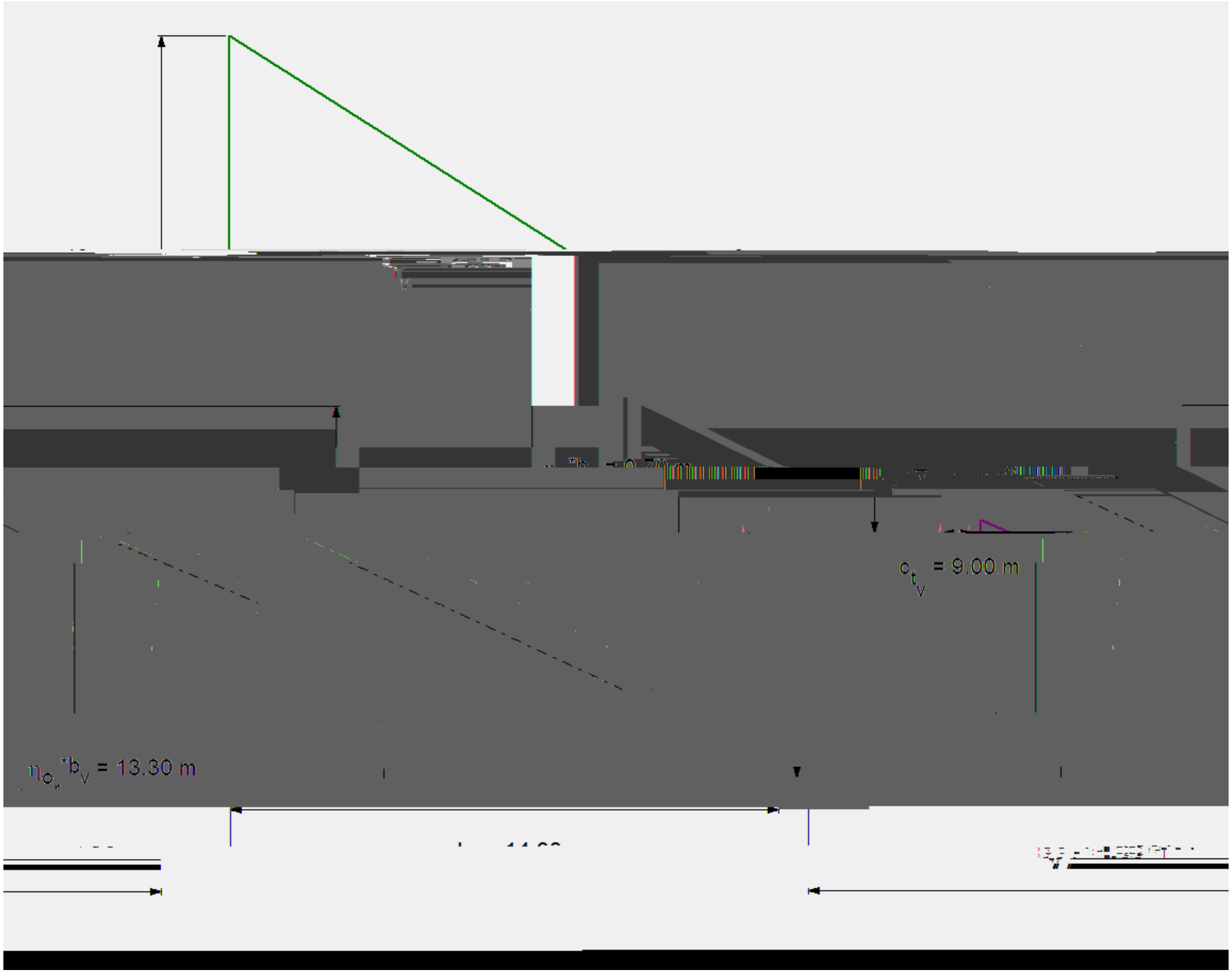

Figure 27. Vertical Stabilizer Control Surface Layout.

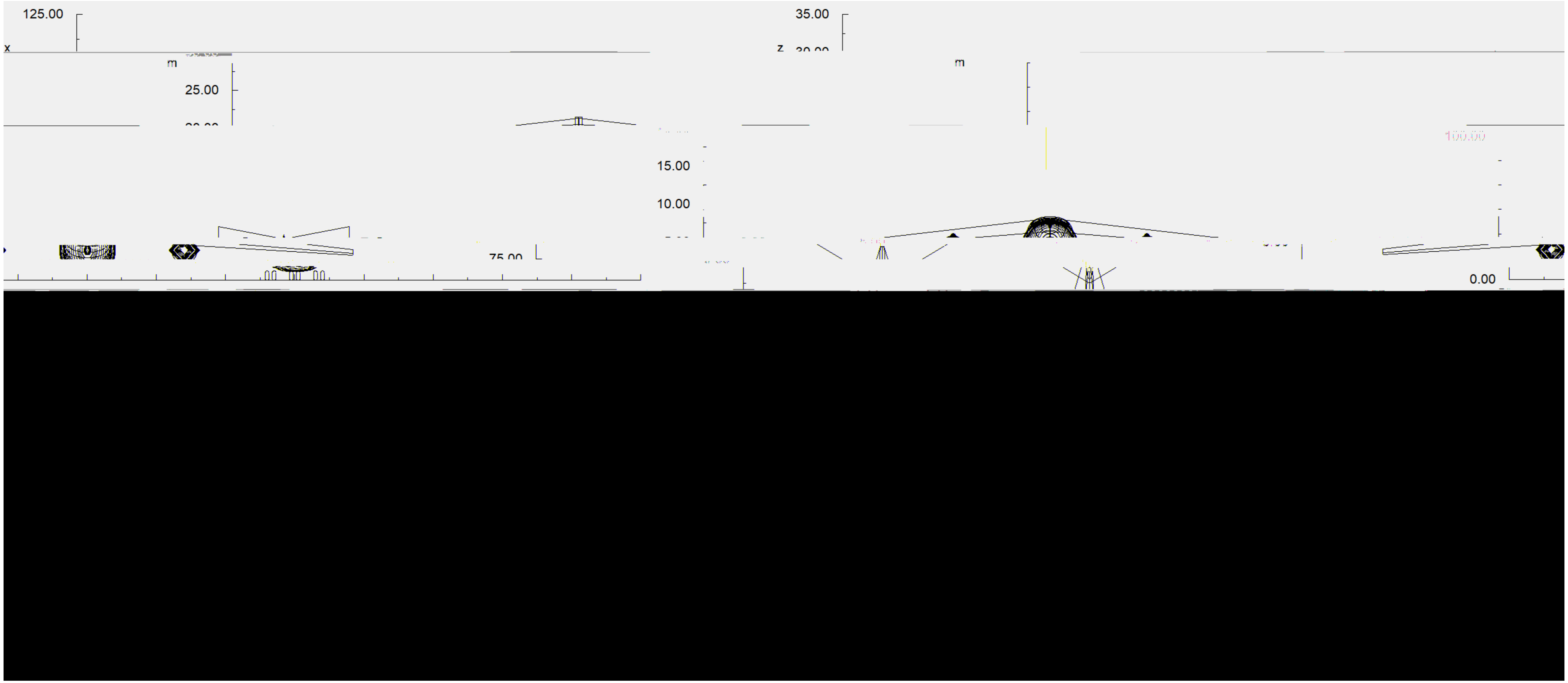

Figure 27. Vertical Stabilizer Control Surface Layout.

XVI. Discussion

While there are some aspects of the design that are less that perfrectly refined, the current state of the proposed Goliath design is certain to the point of indicating a feasible design point, it is impossible to state rather it is desireable or not without being the deciding body on such matters (in this case the US Air Force and government) and as such this discussion will proceed under the assumption that it is a desireable design point for their needs.