

Dynamic and Static Loading Effects on Aircraft Avionics Support Structures

ES-202 Final Report

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Introduction:

Aircraft are subject to a wide range of mechanical loads throughout their operational cycle, including while parked, taxiing, accelerating, cruising, encountering turbulence, and landing. Each of these phases introduces unique stresses to the aircraft's structure, from static gravitational loads to dynamic inertial and vibrational forces. These stresses are not only critical to the structural integrity of the aircraft as a whole but are especially significant for internal support systems, such as those securing avionics boxes and other sensitive components. Understanding how these loads interact with mounting structures is essential to ensuring long-term safety, performance, and durability.

In real-world engineering, the principles of solid mechanics are applied to quantify these forces and design structures capable of withstanding them. This project applies those theoretical concepts—such as shear and bending moment analysis, stress transformation, and inertial force modeling—to a practical case study involving an avionics box mounted within an F-22 jet, allowing us to evaluate its behavior under typical and extreme loading scenarios.

Throughout the aircraft's operation, each phase introduces unique mechanical stresses that must be considered in the design of internal support structures. As the aircraft accelerates for takeoff, dynamic forces such as drag, vibration, and inertial loading increase, placing additional stress on components like avionics mounts. During flight, turbulence can momentarily alter the effective weight on structures due to rapid vertical and lateral accelerations, leading to fluctuating stress cycles. Landing produces the highest loads, with both vertical g-forces from touchdown and horizontal forces from braking combining to test the strength and stability of all support systems. Understanding and accounting for these loads is essential to ensure that mounting systems maintain integrity and safety under all expected operating conditions.

Objective:

The primary objective of this project is to analyze and quantify the forces acting on a mounting structure within an aircraft—specifically an avionics box—across various flight conditions including parked (static), taxiing, takeoff, level flight, turbulence, and landing. The project focuses on identifying and categorizing all relevant structural loads, and calculating the effects of acceleration, vibration, and aerodynamic forces on the mounting system. To support this analysis, shear and bending moment diagrams were developed for each phase of flight. Additionally, stress concentrations and transformations were evaluated using both analytical methods and computational tools. The final goal was to determine whether the

material properties and structural design of the support system are sufficient to withstand the maximum expected loading conditions throughout the aircraft's operation.

Approach:

To meet the objectives of the project, a structured approach was followed, beginning with a comprehensive research phase. This phase involved reviewing relevant aerospace engineering literature, FAA guidelines, and structural dynamics principles to understand the different types of loads an aircraft experiences, their magnitudes, and how these loads impact mounting structures.

Following the research, the modeling and design phase began, where a CAD model of the mounting structure was created using SolidWorks. This model allowed for the analysis of the geometry, material properties, and mass distribution of the mounting system. Subsequently, various load cases were defined, including static loads, dynamic loads, and environmental factors such as turbulence and wind. These load cases were crucial for simulating realistic operational conditions.

The next phase focused on force and stress analysis, which involved both manual calculations and SolidWorks simulations to determine internal forces, moments, and stress distributions within the mounting system. Shear and moment diagrams were then developed to visualize the structural response across different flight phases, helping to further understand the behavior of the mounting structure under various loading conditions.

Stress transformation techniques were applied using Mohr's Circle to assess the principal and shear stresses under combined loading conditions. These transformations were essential to evaluating how the material would behave under complex forces. Finally, the computed stresses were compared to the material's limits to assess safety margins and failure risks in worst-case scenarios. The results were then interpreted in the context of solid mechanics theory, and real-world applications of academic concepts were discussed in the conclusion of the project.

Load Effects:

The flight stages considered in this project include takeoff, level flight, and landing. Each of these phases subjects the aircraft and its internal structures to distinct loading conditions, which vary in intensity and direction. By evaluating each stage, the design of the mounting structure for the avionics box can be assessed under a comprehensive range of operational scenarios, from minimal loads during static parking to extreme forces encountered during turbulent flight or hard landings.

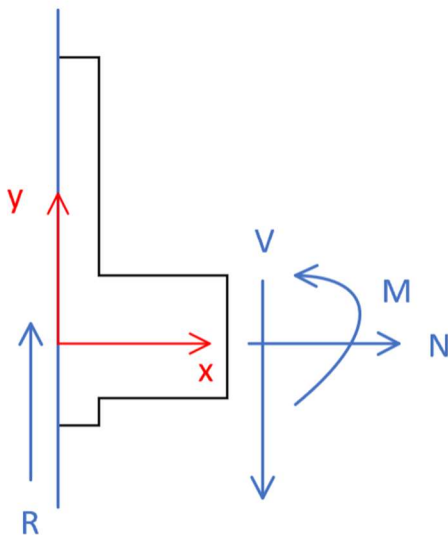
During takeoff, the aircraft begins to experience dynamic loads, including drag, rolling resistance, and acceleration-induced inertial forces. In-flight turbulence introduces rapid, unpredictable changes in vertical and lateral acceleration, producing cyclical stress and potential vibration throughout the mounting system. Landing introduces the most significant vertical and horizontal loads due to the sudden impact with the runway and braking forces, often resulting in elevated g-forces.

Critical load effects were identified primarily during the landing and takeoff phases. These stages involve both the highest magnitudes of force and the most abrupt changes in direction. The most vulnerable locations in the mounting structure are at points of stress concentration—particularly near fasteners, joints, and support interfaces where bending moments and shear forces are highest. These areas must be carefully reinforced or redesigned to handle worst-case loading scenarios, ensuring the mounting system remains structurally sound across the aircraft's entire operational envelope.

Moment and Shear Diagrams for Level Flight:

The structure is assessed via its front and side views, as the box may be under any orientation during flight. These extremes should account for the whole flight envelope. During level flight the box does not experience significant loading in terms of the vertical. Therefore, the structure is only responsible for its own weight.

Side View:



$$\begin{aligned}\text{Weight} &= (5.103 \text{ kg})(-9.81 \text{ m/s}^2) \\ &= -50.06 \text{ N} \\ &= \text{Max Shear Load}\end{aligned}$$

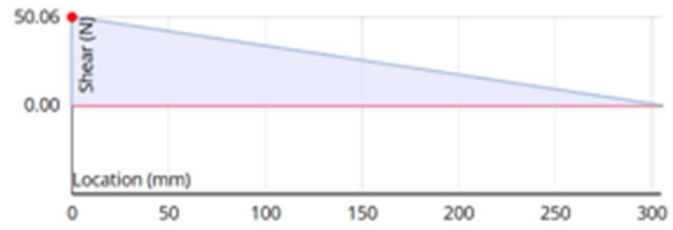
$$\begin{aligned}\sum F_y &= R + V \\ R &= -V = 50.06 \text{ N/m}\end{aligned}$$

$$\begin{aligned}\text{Moment} &= (-50.06 \text{ N})(.5)(134.7) \\ &= -7629.14 \text{ N/mm}\end{aligned}$$

Shear Diagram

(Max +ve)Shear Load (N): 50.060,

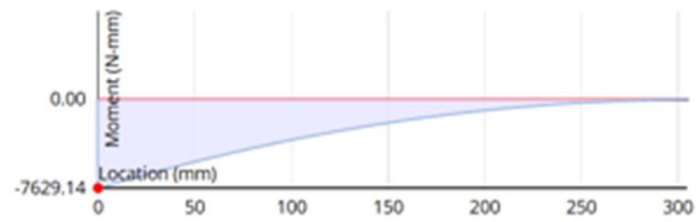
Location (mm): 0.000



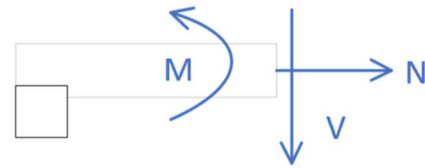
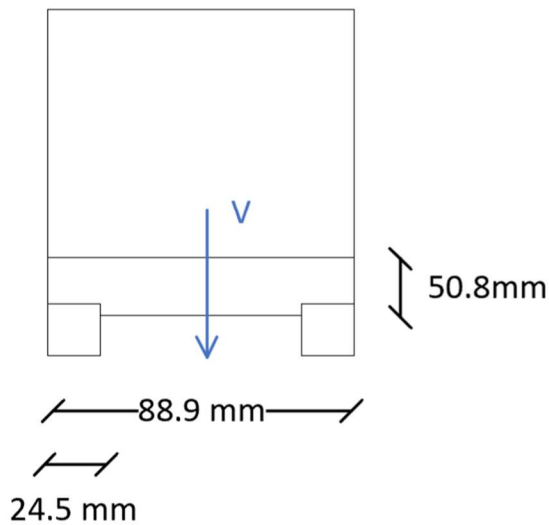
Moment Diagram

(Max -ve)Moment Load (N-mm): -7629.142,

Location (mm): 0.000



Front View:



Method of Sections:

$$\begin{aligned}\sum F_y &= R_a + R_b - V \\ R_a + R_b &= V \\ R_a = R_b &\rightarrow 2R = V\end{aligned}$$

$$\begin{aligned}2R &= 50.06 \\ R &= 25.03 \text{ N}\end{aligned}$$

$$\begin{aligned}M &= (25.03 \text{ N})(152.4 \text{ mm}/2) \\ &= 1907.28 \text{ N} \cdot \text{mm}^2\end{aligned}$$

Reaction forces are equal. Supports are same distance and magnitude from center.

Moment and Shear for takeoff:

During the first stage of takeoff, the supports experience lateral acceleration and the corresponding reactions fall to the normal direction. The forces coupled with this acceleration are derived from preexisting information considering the circumstances and conditions we are assuming. This diagram is the same as level flight.

During the second stage of takeoff, the aircraft inclines at varying angles. During this period the supports experience a great increase in the gravitational force acting on the system as well as the angular relation that the vertical forces have to the supports. Reaction forces become split into vertical and horizontal components in the effort to counterbalance the weight distribution.

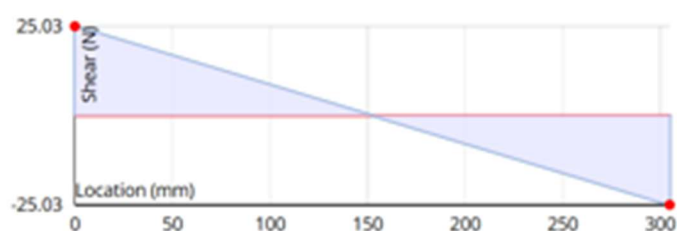
Shear Diagram

(Max +ve)Shear Load (N): 25.030,

Location (mm): 0.000

(Max -ve)Shear Load (N): -25.030,

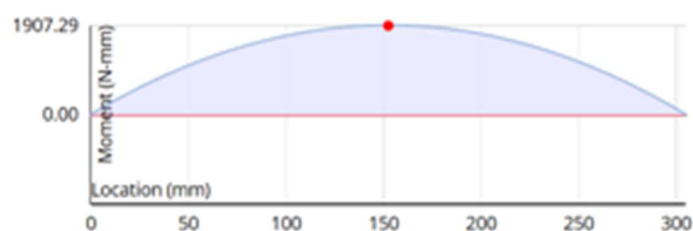
Location (mm): 304.800



Moment Diagram

(Max +ve)Moment Load (N-mm): 1907.285,

Location (mm): 152.400



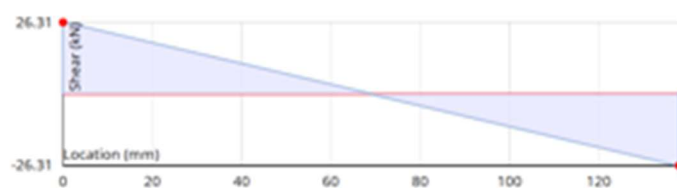
Shear Diagram

(Max +ve)Shear Load (kN): 26.314,

Location (mm): 0.000

(Max -ve)Shear Load (kN): -26.314,

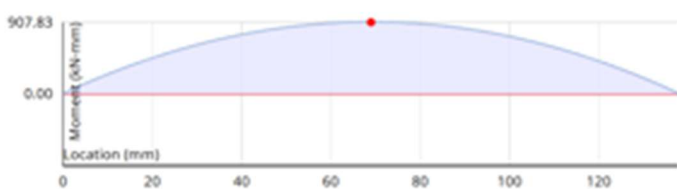
Location (mm): 138.000



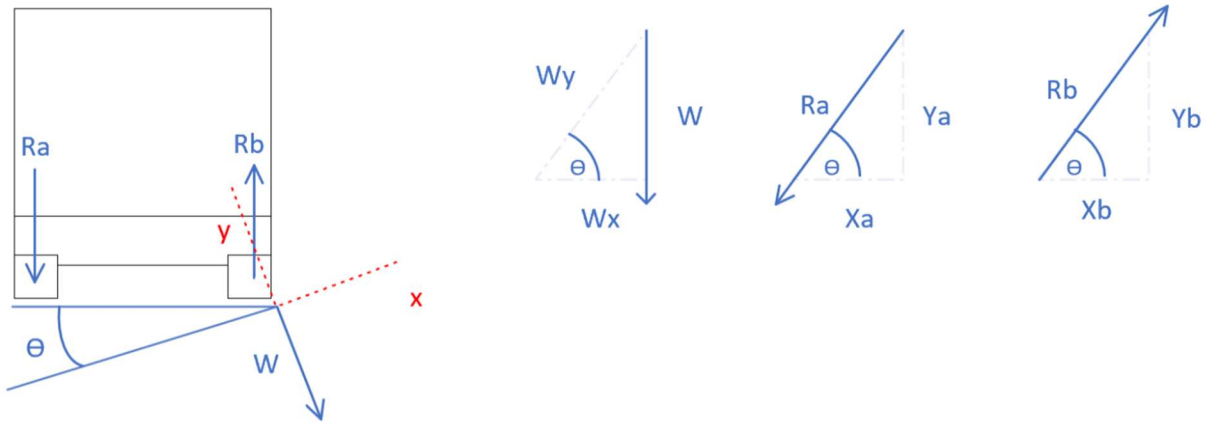
Moment Diagram

(Max +ve)Moment Load (kN-mm): 907.827,

Location (mm): 69.000



Front View:



Moment and Shear Diagram Landing:

Landing procedures endure the same angular disparity as takeoff does, however the vital tradeoff is the downward acceleration that in fact reduces the downward force applied to the box. During this time the supports will not be under forces larger than the weight of the box while experiencing level glide or downward acceleration.

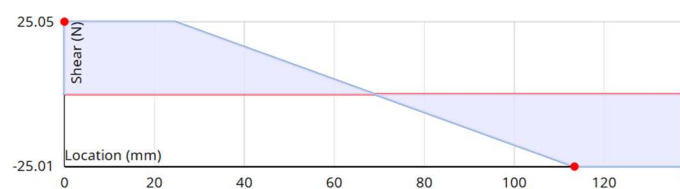
Shear Diagram

(Max +ve)Shear Load (N): 25.048,

Location (mm): 0.000

(Max -ve)Shear Load (N): -25.012,

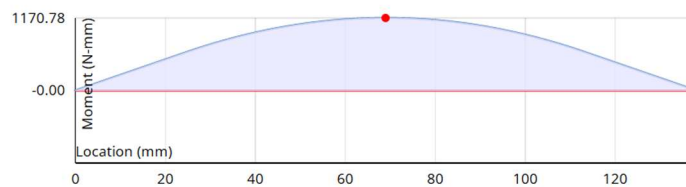
Location (mm): 113.400, 138.000



Moment Diagram

(Max +ve)Moment Load (N-mm): 1170.777,

Location (mm): 68.950

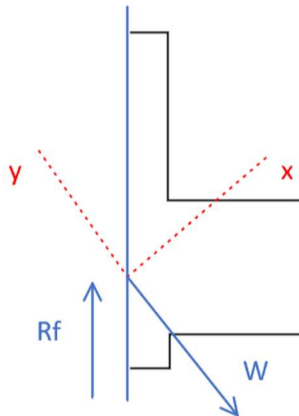


$$\begin{aligned}\sum F_y &= R_a + R_b - V \\ R_a + R_b &= V \\ R_a &= R_b \rightarrow 2R = V\end{aligned}$$

$$\begin{aligned}2R &= 50.06 \\ R &= 25.03 \text{ N}\end{aligned}$$

$$\begin{aligned}M &= (25.03 \text{ N})(.67 \text{ mm})(68.95 \text{ mm}) \\ &= 1170.78 \text{ N} - \text{mm}^2\end{aligned}$$

Side View:



$$W = 50.06 \text{ N}$$

$$\sin\theta = W/W_y$$

$$W_y = W/\sin\theta$$

$$\tan\theta = W/W_x$$

$$W_x = W/\tan\theta$$

$$0 \leq W_y(\theta) \leq 25.03 \text{ N}$$

$$0 \leq W_x(\theta) \leq 25.03 \text{ N}$$

The forces act in the same direction as takeoff and weight is still a function of theta.

In landing, the supports will not experience forces larger than the weight of the structure.

Overlooked factors:

During landing, these combined loads can significantly increase the force on mounting systems. For example, if an aircraft experiences 2.5g during touchdown, a component that weighs 100 N at rest could momentarily exert 250 N of force on its mounting structure. This increase must be accounted for in structural design and fatigue analysis to ensure safety and reliability. In reality the loading during landing, would be more significant due to G-Force factors.

Combined Loading:

To transition into the calculations of combined loading we took the internal force calculations and applied them to the cross section of the mount. This cross-section was derived from our cad design of the structure in solid works. Solid Works calculates the moment of inertia as part of the overall mass properties. It considers the objects shape, mass and axis of orientation.

The total normal stress at each stage of flight can be calculated using a combination of the axial stress and the bending moment. There is no axial stress present at any stage of flight, therefore this term is equal to zero. The total stress will simply be the sum of the bending moments. The shear stress at a specific point on the cross section of the beam. These values determine the intensity of internal forces.

These calculations were done at the points where the structure experiences the maximum moments. This should account for any stresses lesser than the max.

Overall, landing proves to be the most stressful state the structure will endure.

Takeoff:

$$\sigma = N/A + Mc/I$$

$$= (1.8367)(.26162\text{m}) / (2926.8 \times 4.16 \times 10^{-7})$$

$$\sigma = 394.7 \text{ kPa}$$

The N/A term is =0 because
there is no axial load in
takeoff.

$$A' = 26.88 \text{ in}^2 = .0173 \text{ m}^2$$

$$\bar{y} = 4.62 \text{ in}$$

$$\bar{y}' = .117 \text{ in}$$

$$\text{Center of mount} = .26162 \text{ m}$$

$$I = \text{Moment of Inertia}$$

$$= (2926.8)(4.16 \times 10^{-7}) \text{ in}^4$$

*solid works given value

$$Q = \bar{y}' \times A'$$

$$= (.117 \text{ m})(.0173 \text{ m}^2)$$

$$=.00306 \text{ m}^3$$

$$\tau = VQ / It$$

$$= (26.31 \text{ kN})(.00306 \text{ m}^3) / (2926.8 \times 4.16 \times 10^{-7} \text{ m}^4) (.26162 \text{ m})$$

$$= 252.7 \text{ MPa}$$

Level Flight:

$$\begin{aligned}\sigma &= N/A + Mc/I \\ &= (.007629)(.26162) / (2926 \times 4.16 \times 10^{-7}) \\ &= 1.63 \text{ MPa}\end{aligned}$$

$$\begin{aligned}\tau &= (.051)(.00306) / ((2926 \times 4.16 \times 10^{-7})(.26162)) \\ &= .4899 \text{ MPa}\end{aligned}$$

Landing:

$$\begin{aligned}\sigma &= N/A + Mc/I \\ &= (.8742)(.26162) / (2926 \times 4.16 \times 10^{-7}) \\ &= 187.8 \text{ MPa}\end{aligned}$$

$$\begin{aligned}\tau &= (25.05)(.00306) / (2926 \times 4.16 \times 10^{-7})(.26162) \\ &= 240.7 \text{ MPa}\end{aligned}$$

Stress Transformation:

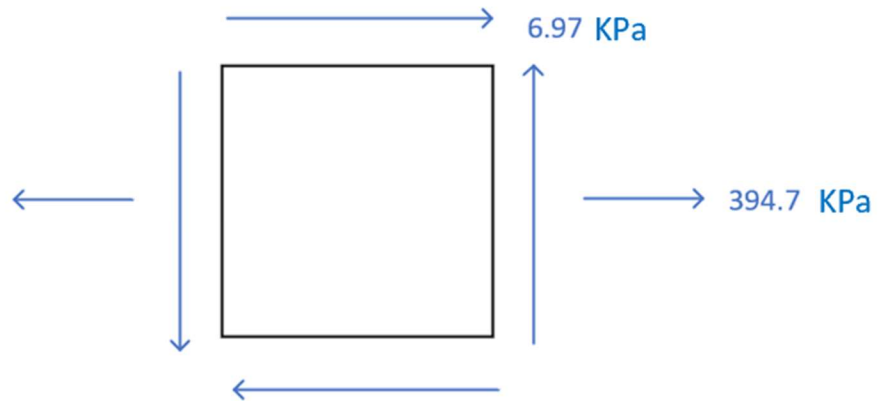
Stress transformation refers to the method of determining normal and shear stresses acting on different planes at a point within a material. This is critical in understanding how materials behave under various loading conditions, particularly when subjected to complex forces. Using the applied loads that act on the Avionics box and by extension the supporting structure, we can analyze the stress transformation that we can expect to see when extreme circumstances are experienced.

We sought to consider the principal stresses derived from the maximum and minimum normal stress, and the shear stress to ensure that our supporting structure is sufficient to withstand the expected conditions. Without this consideration, there is a risk that the material or the structure could be insufficient to support the box.

Using Mohr's circle, we calculated the maximum normal and shear stress experienced by the cross section of the supporting structure so that we can definitively tell if the chosen material is capable of meeting those stress thresholds the system requires.

Takeoff:

$$\begin{aligned}\sigma_x &= 394.7 \text{ KPa} \\ \sigma_y &= 0 \\ \tau_{xy} &= 252.7 \text{ KPa}\end{aligned}$$



$$\sigma_{avg} = (\sigma_x + \sigma_y) / 2$$

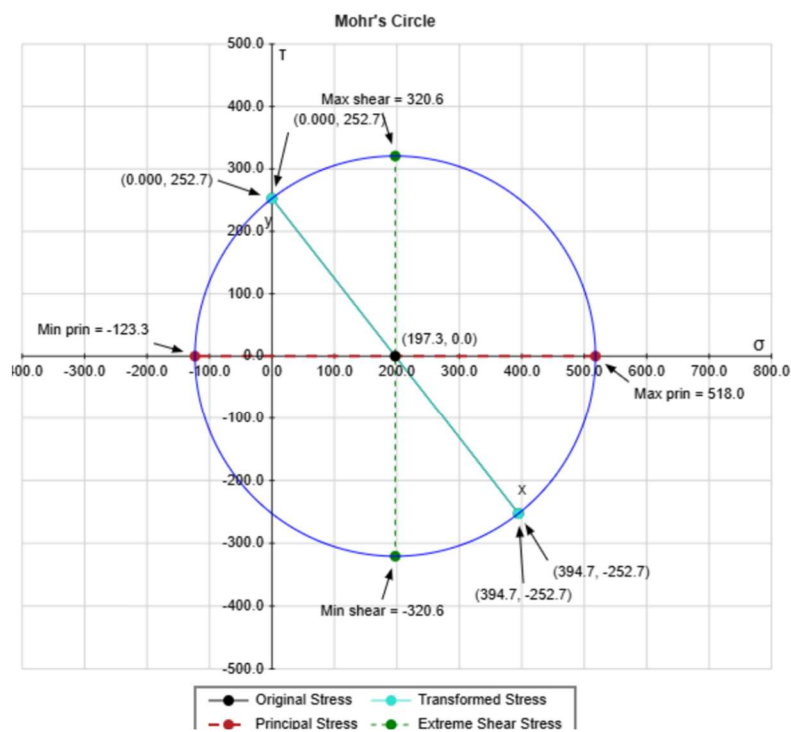
$$= (394.7 + 0) / 2$$

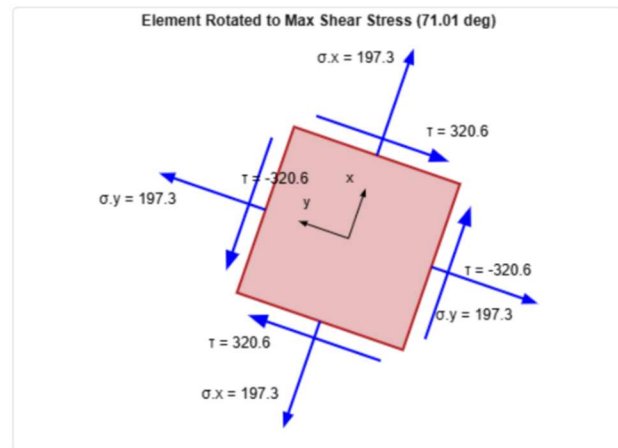
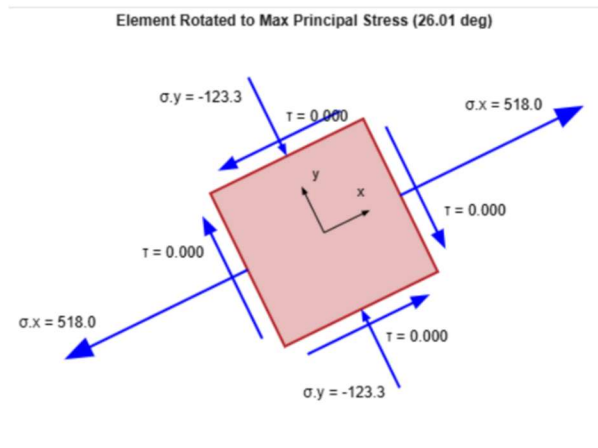
$$= 197.4 \text{ KPa}$$

$$R = \sqrt{[(\sigma_x - \sigma_y) / 2]^2 + \tau_{xy}^2}$$

$$= \sqrt{[(197.4)^2 + (252.7)^2]}$$

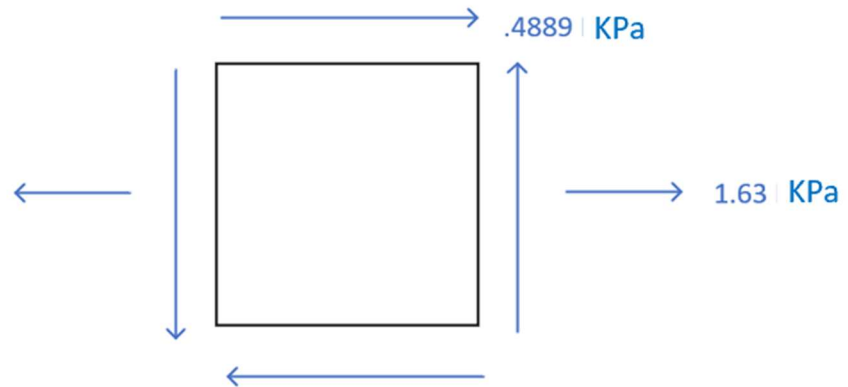
$$= 370.7$$





Level Flight:

$$\begin{aligned}\sigma_x &= 1.63 \text{ KPa} \\ \sigma_y &= 0 \\ \tau_{xy} &= .4899 \text{ KPa}\end{aligned}$$

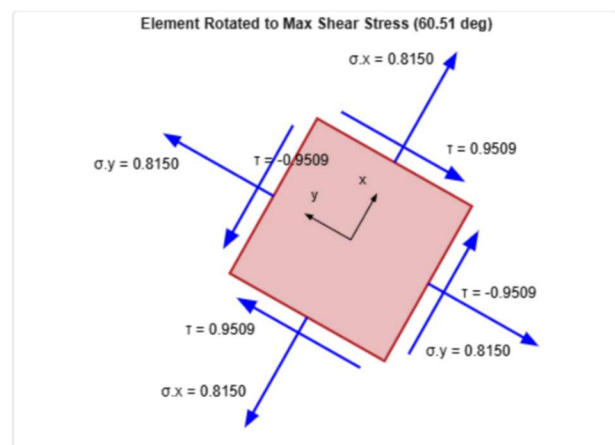
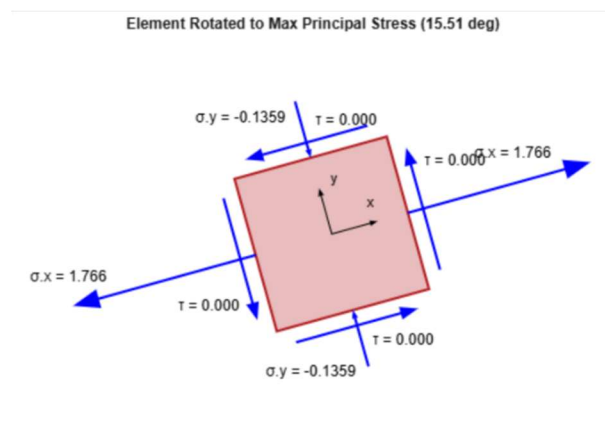
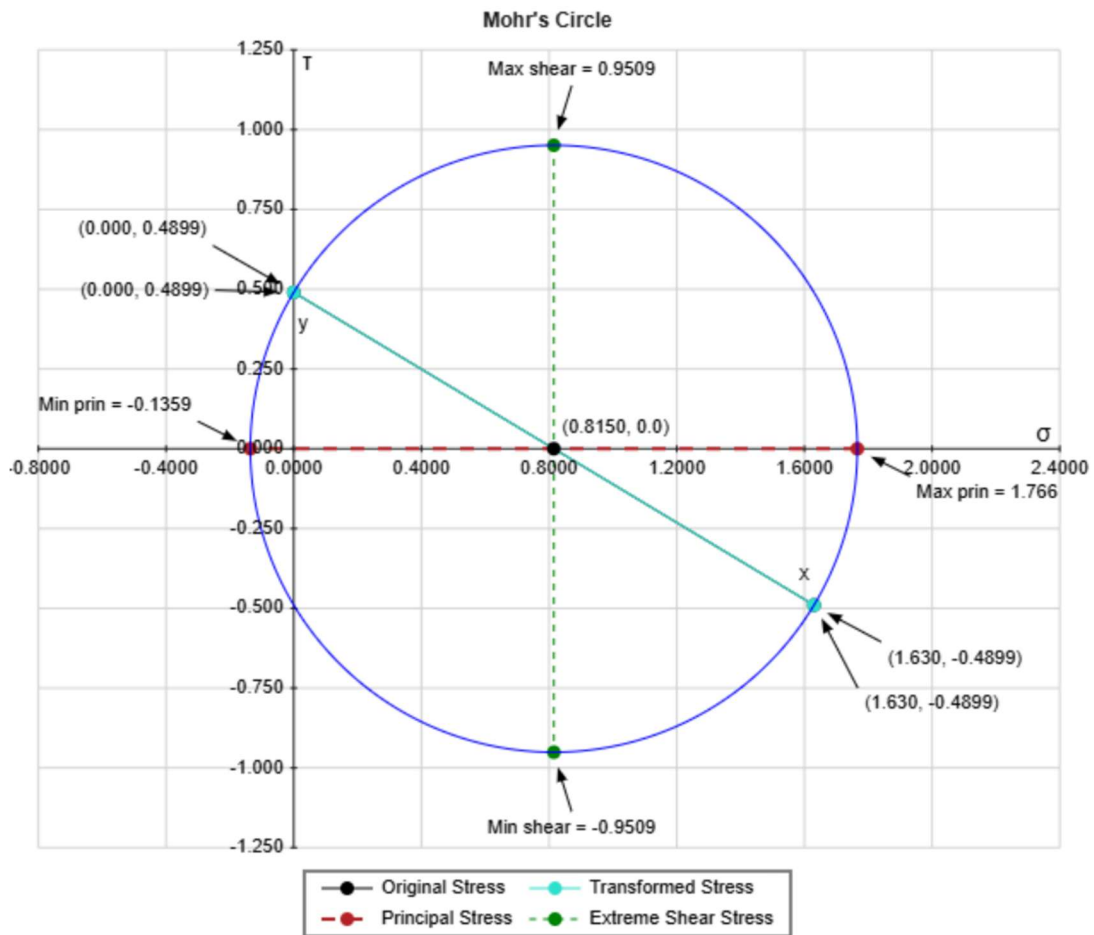


$$\sigma_{avg} = (\sigma_x + \sigma_y) / 2$$

$$= .815 \text{ KPa}$$

$$R = \sqrt{[(\sigma_x - \sigma_y) / 2]^2 + \tau_{xy}^2}$$

$$= .951$$



Conclusion and Suggestions:

Based on the initial design and the calculated forces and stresses during different flight conditions (such as taxiing, takeoff, turbulence, and landing), the mounting structure will need to be thoroughly evaluated against the material's strength limits for both normal and shear stresses. The initial design would fulfill the strength requirements.

However, if stress levels approach or exceeds the yield or ultimate strength of the material, modifications will be necessary to ensure structural integrity. Potential improvements include selecting a higher-strength material, adjusting the geometry of the mounting structure to better distribute loads, adding reinforcements, redesigning fasteners or joints for greater load-bearing capacity, and incorporating stress-relief features such as fillets at high-stress points. These modifications would help reduce the risk of failure and ensure the mounting system remains safe and effective under all operational loading conditions.

This report has comprehensively analyzed the various structural loads encountered by an aircraft throughout its operational phases—parking, taxiing, takeoff, turbulence, and landing—with special emphasis on their impact on support and mounting systems, particularly for components like avionics boxes. By treating static load as a foundational baseline, we were able to assess how additional dynamic forces such as acceleration, vibration, wind, and shear affect structural integrity at different moments in flight. Among these, landing emerged as the most critical phase, where combined vertical and horizontal forces can significantly amplify the loading on the aircraft's structure and must be thoroughly considered in design.

This project significantly enhanced our understanding of solid mechanics, especially in applying core principles like shear and bending moment analysis, stress transformation, and inertial loading to a complex, real-world system. Through moment and shear diagrams, we directly connected classroom concepts with practical structural design considerations. Utilizing tools like SolidWorks and Mohr's Circle allowed us to simulate and validate structural responses, reinforcing the importance of theoretical knowledge in engineering practice. Overall, this work bridged the gap between abstract concepts and their tangible applications in aerospace design, deepening both technical competence and appreciation for the complexity of real-world engineering systems.

Sources:

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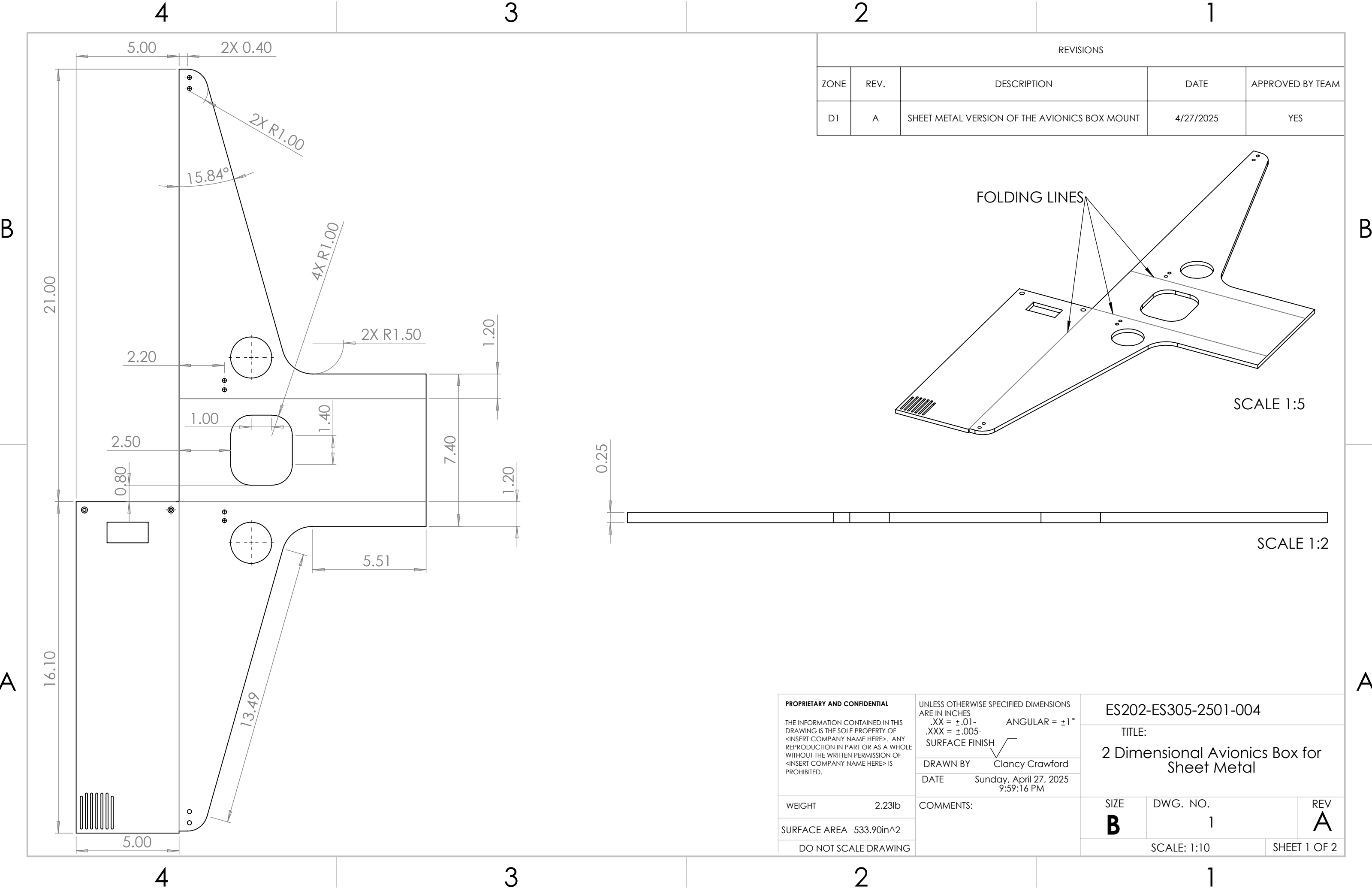
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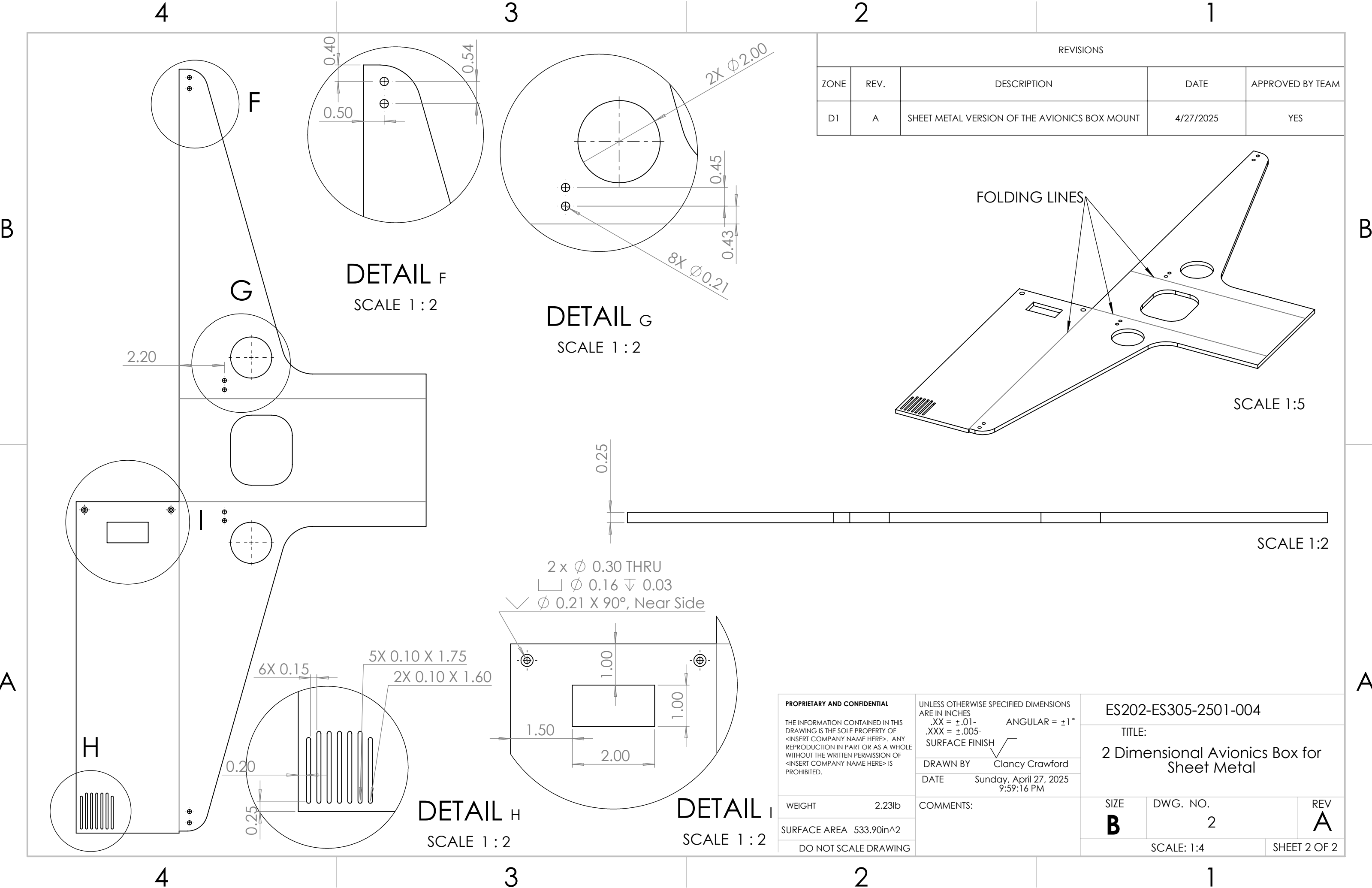
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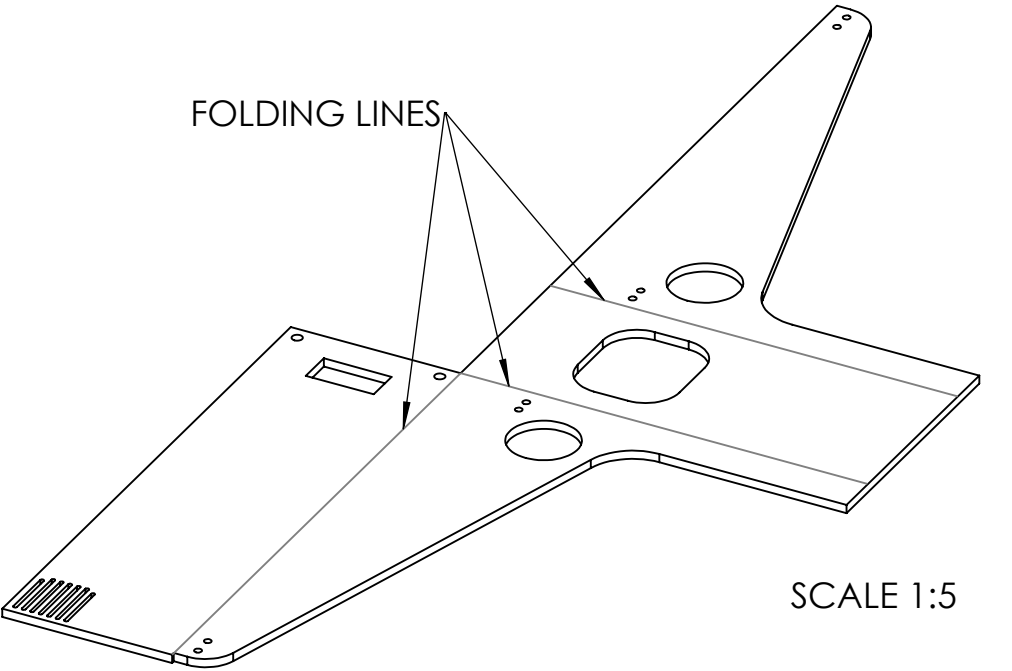
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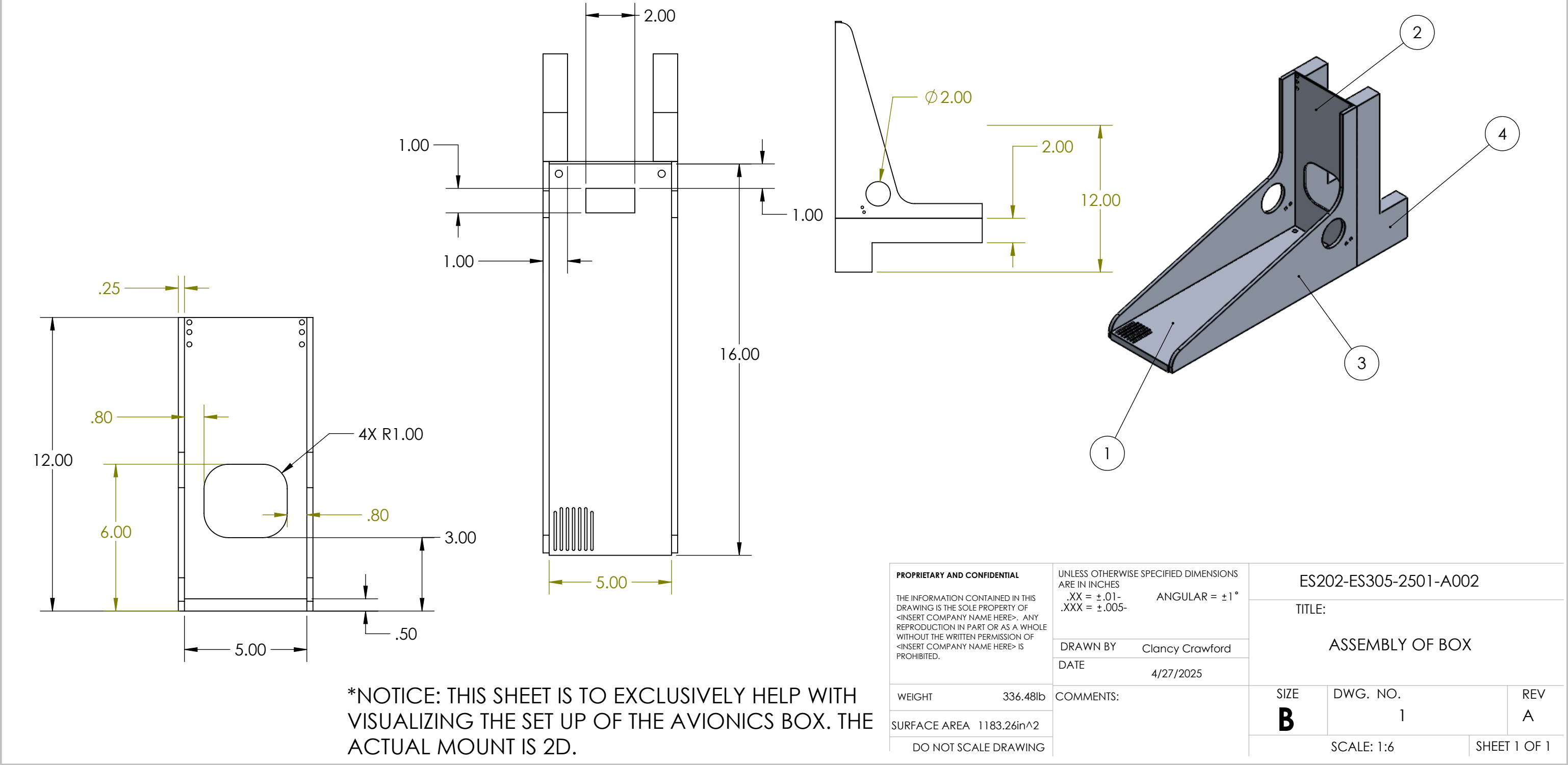


REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED BY TEAM
D1	A	SHEET METAL VERSION OF THE AVIONICS BOX MOUNT	4/27/2025	YES



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<div>DRAWN BY</div> <div>DATE</div>		<div>TITLE:</div> <div>2 Dimensional Avionics Box for Sheet Metal</div>				
		<div>Clancy Crawford</div> <div>Sunday, April 27, 2025 9:59:16 PM</div>				
		<div>COMMENTS:</div>				
<div>WEIGHT</div>	<div>2.23lb</div>	<div>SCALE: 1:4</div>		<div>SIZE</div>	<div>DWG. NO.</div>	<div>REV</div>
<div>SURFACE AREA</div>	<div>533.90in^2</div>			<div>B</div>	<div>2</div>	<div>A</div>
<div>DO NOT SCALE DRAWING</div>				<div>SHEET 2 OF 2</div>		

4				3				2				1			
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.					REVISIONS							
1	Connector Plate with flush back		1					ZONE	REV.	DESCRIPTION	DATE	APPROVED BY TEAM			
2	Flat Bottom w flush back		1												
3	Side with flush back		2												
4	Supports w flush back		2												



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		DRAWN BY		Clancy Crawford		TITLE: ASSEMBLY OF BOX		
		DATE		4/27/2025				
		COMMENTS:				SIZE	DWG. NO.	REV
WEIGHT		336.48lb		B		1		A
SURFACE AREA		1183.26in^2						
DO NOT SCALE DRAWING						SCALE: 1:6		SHEET 1 OF 1

4

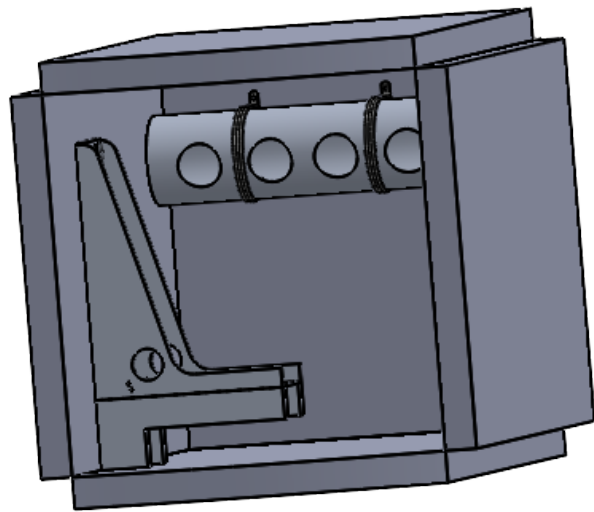
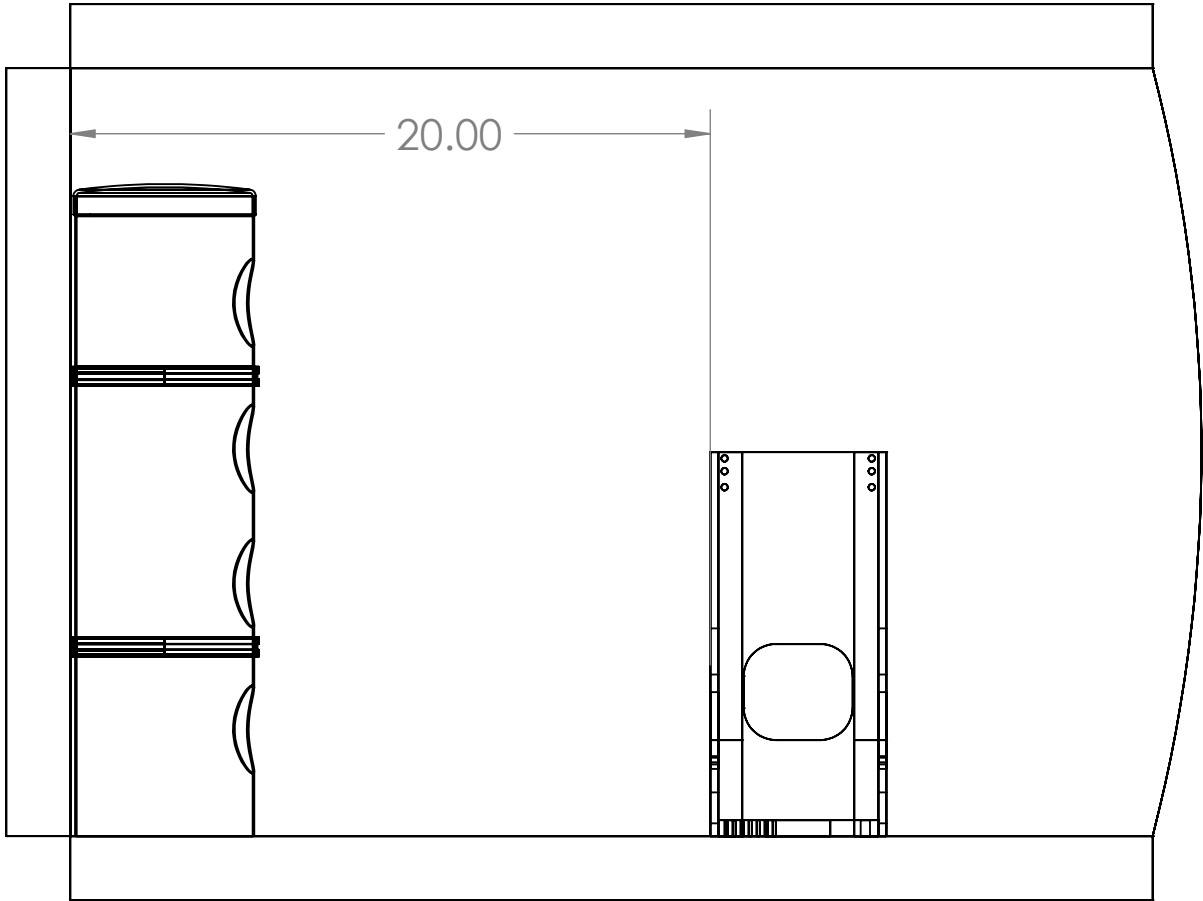
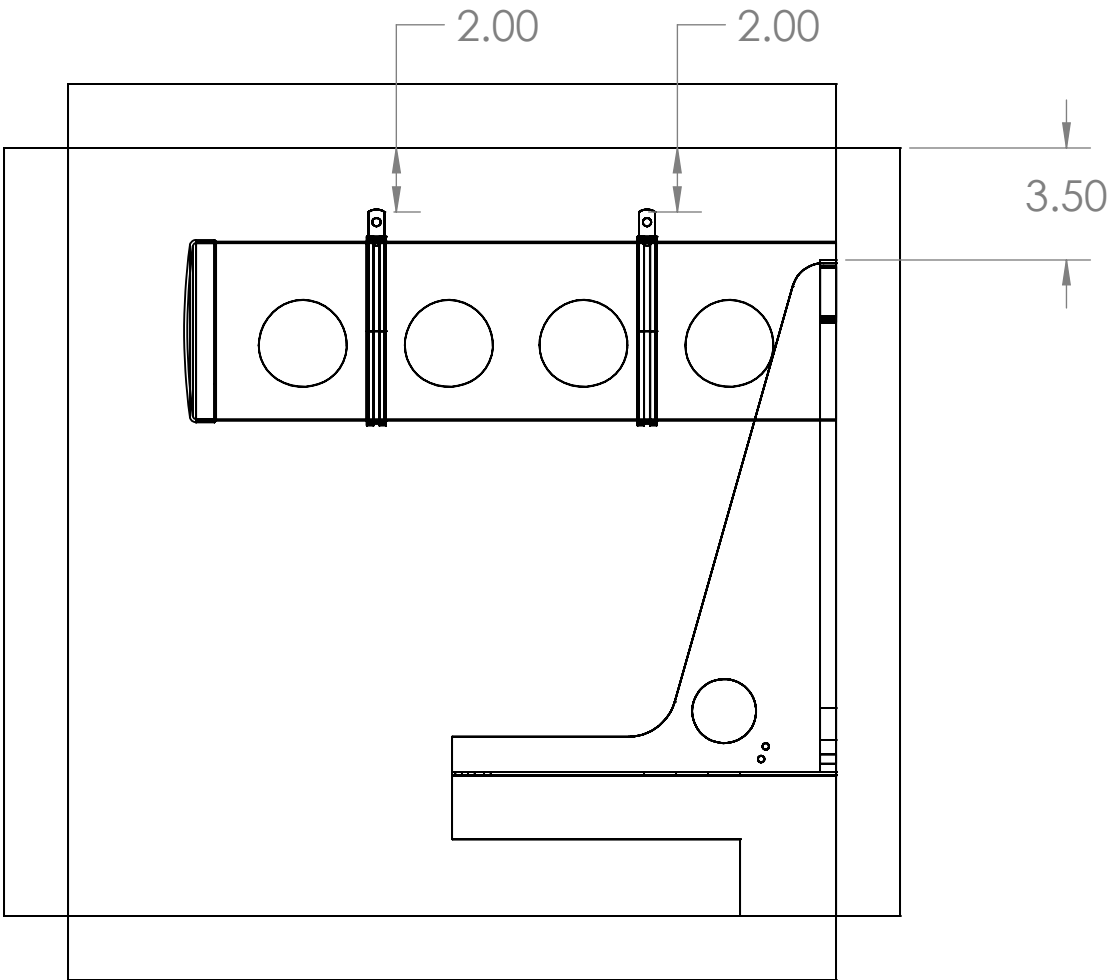
3

2

1


REVISIONS

ZONE	REV.	DESCRIPTION	DATE	APPROVED BY TEAM
1G	A	ASSEMBLY OF BOX	4/27/2025	YES



*NOTICE: THIS SHEET IS TO EXCLUSIVELY HELP WITH VISUALIZING THE SET UP OF THE AVIONICS BOX.

- NOTE:
- THE BOTTOM OF THE FLUSH BACK ASSEMBLY IS COINCIDENT WITH THE BOX.
 - THE PIPE AND FLUSH BACK ASSEMBLY ARE COINCIDENT WITH THE SIDE OF THE BOX.
 - THE PIPE IS RESTING IN THE CLAMPS.
 - THE CLAMPS ARE COINCIDENT WITH THE BOX.

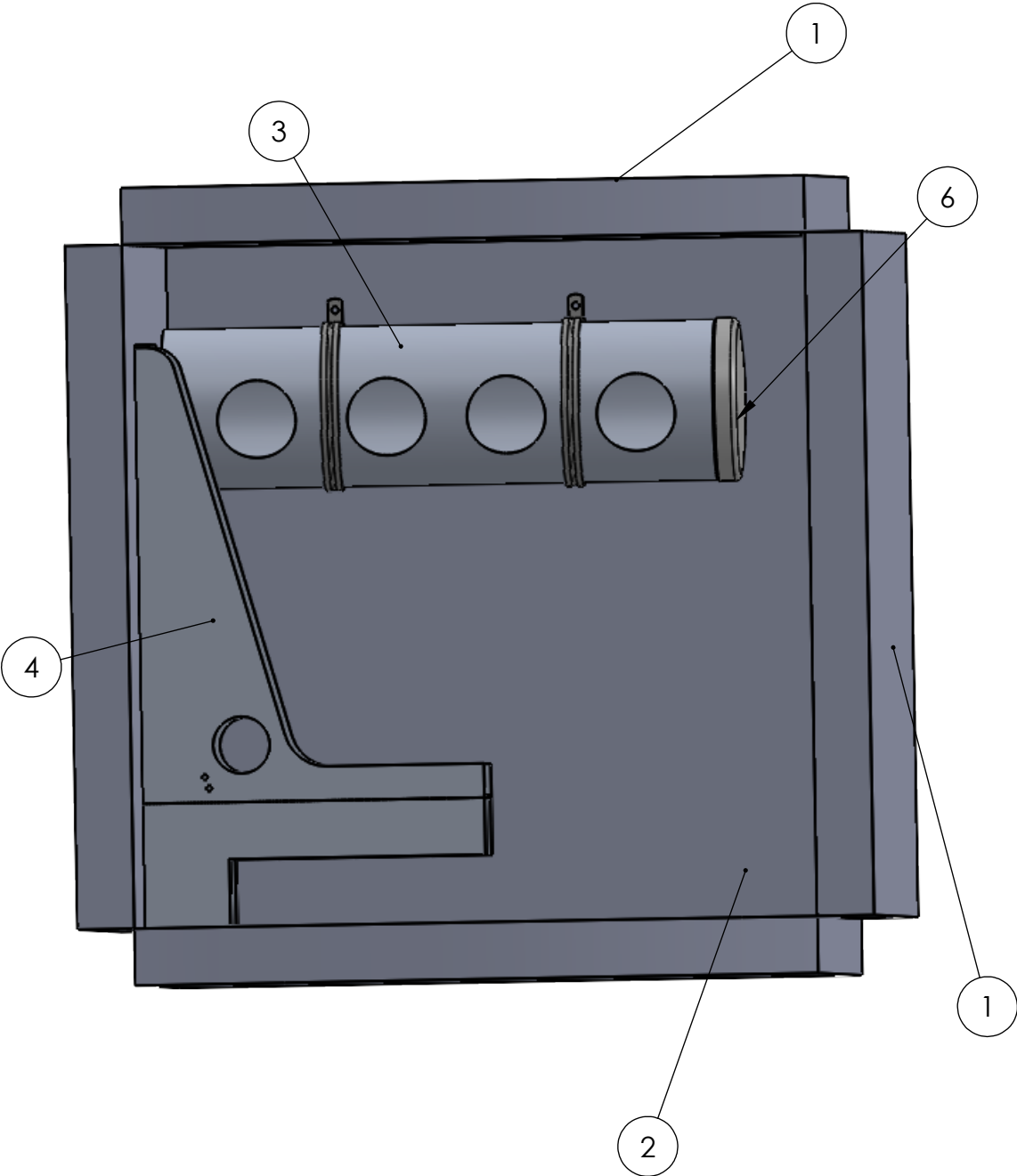
<div>PROPRIETARY AND CONFIDENTIAL</div> <div>THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.</div>		<div>UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES .XX = ±.01- .XXX = ±.005- SURFACE FINISH </div> <div>ANGULAR = ±1°</div>		ES202-ES305-2501-A002	
		DRAWN BY Clancy Crawford		TITLE: ASSEMBLY OF BOX	
		DATE 4/27/2025			
WEIGHT 336.48lb	COMMENTS:	SIZE B	DWG. NO. 1	REV A	
SURFACE AREA 1183.26in^2		SCALE: 1:8		SHEET 1 OF 2	
DO NOT SCALE DRAWING					

3

2

1

4		3	
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	BOX	A-ES202305-006	1
2	BOX LID	A-ES202305-007	1
3	PIPE 9056K727	THIN-WALL BUTT-WELD UNTHREADED PIPE FITTING	1
4	AVIONICS MOUNT	3D ASSEMBLY WITH FLUSH BACK	1
5	3225T11	VIBRATION-DAMPING LOOP CLAMP	2
6	PIPE CAP 45735K282	THIN-WALL BUTT-WELD UNTHREADED PIPE FITTING	1



*NOTICE: THIS SHEET IS TO EXCLUSIVELY HELP WITH
VISUALIZING THE SET UP OF THE AVIONICS BOX.

<div>PROPRIETARY AND CONFIDENTIAL</div> <div>THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.</div>		UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES .XX = ±.01- .XXX = ±.005-		ANGULAR = ±1°	
		DRAWN BY		Clancy Crawford	
		DATE		4/27/2025	
		COMMENTS:			
WEIGHT		336.48lb		ES202-ES305-2501-A002	
SURFACE AREA		1183.26in^2		TITLE:	
DO NOT SCALE DRAWING				ASSEMBLY OF BOX	
				SIZE	DWG. NO.
				B	2
				REV	
				A	
				SCALE: 1:6	
				SHEET 2 OF 2	