Cabin- Fuselage-Wing Structural Design Concept with Engine Installation

SOW #421F93ADP01-7
6 December 1993

AE 421/02/A
Lead Engineer: Scott Ariotti
Team Members:
M. Garner, A. Cepeda
J. Vieira, D. Bolton

Submitted to:
Dr. J. G. Ladesic
# Table of Contents

1.0 Project Summary ........................................................ Page 1
2.0 Description of the Design ................................................. Page 1
3.0 Loads and Loadings .......................................................... Page 4
4.0 Structural Substantiation ................................................ Page 11
5.0 Manufacturing and Maintenance Provisions .......................... Page 15
6.0 Weight Estimation .......................................................... Page 17
7.0 Conclusions ............................................................... Page 19
## List of Figures and Tables

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Wing Lift Distribution</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Wing Shear Diagram</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Wing Moment Diagram</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Front Spar Shear Diagram</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Front Spar Moment Diagram</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Rear Spar Shear Diagram</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Rear Spar Moment Diagram</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Wing Torsion Diagram</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Front Spar Section Modulus</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Rear Spar Section Modulus</td>
</tr>
<tr>
<td>F93-2A-102-7</td>
<td>Fuselage Structural Layout and Details</td>
</tr>
<tr>
<td>F93-2A-103-7</td>
<td>Fuselage Skin Panel Layout</td>
</tr>
<tr>
<td>F93-2A-104-7</td>
<td>Wing Structural Layout and Details</td>
</tr>
<tr>
<td>F93-2A-105-7</td>
<td>Control Systems Layout</td>
</tr>
<tr>
<td>F93-2A-106-7</td>
<td>Wing Skin Panel Layout</td>
</tr>
<tr>
<td>F93-2A-107-7</td>
<td>Wing Access Panel Layout</td>
</tr>
</tbody>
</table>
1. **Project Summary**

The purpose of this project is to provide a fuselage structural assembly and wing structural design that will be able to withstand the given operational parameters and loads provided by Federal Aviation Regulation Part 23 (FAR 23) and the Statement of Work (SOW). The goal is to provide a durable lightweight structure that will transfer the applied loads through the most efficient load path. Areas of producability and maintainability of the structure will also be addressed. All of the structural members will also meet or exceed the desired loading criteria, along with providing adequate stiffness, reliability, and fatigue life as stated in the SOW. Considerations need to be made for control system routing and cabin heating/ventilation. The goal of the wing structure and carry through structure is also to provide a simple, lightweight structure that will transfer the aerodynamic forces produced by the wing, tailboom, and landing gear. These forces will be channeled through various internal structures sized for the pre-determined loading criteria. Other considerations were to include space for flaps, ailerons, fuel tanks, and electrical and control system routing. The difficulties encountered in the fuselage design include expanding the fuselage cabin to accept a third occupant in a staggered configuration and providing ample volume for their safety. By adding a third person the CG of aircraft will move forward so the engine needs to be move aft to compensate for the difference in the moment. This required the provisions of a ring frame structure for the new position of the engine mount. The difficulties encountered in the wing structural design include resizing the wing for the increased capacity and weight, compensating for a large torsion produced by the tail boom by placing a great number of stiffeners inside the boom, this problem will result in relocating the fuel tank. Finally, an adequate carrythrough structure for the wing and fuselage interface will be designed to effectively transmit loads through the fuselage.

2. **Description**

2.1 **Fuselage Structure**

The cabin fuselage structure provides a stiff structure that will maintain the proper shape under the applied limit loads as indicated in the FAR 23. The applied loads are distributed through the use of various members such as longerons, ring
frames, bulkheads, and skin. These provide paths for bending moments, torsion, and shear flow. The longerons of the fuselage assembly are extruded 7075-T6 Z-channels under the floor and 2024-T3 brake formed C-channels along the sides. Lightening holes are cut in the extruded longerons to reduce weight. In addition, stiffeners have been used along the bottom, in between the Z-channels, to account for torsion produced by the occupants during emergency landing conditions.

2.2 **Nose Cone/Engine Mount Assembly**

The nose cone assembly is fabricated out of a fiberglass/epoxy composite and is installed using flathead screws. The structure can be easily removed to allow for easy access to the nose gear assembly. The powerplant is installed directly to the aft ring frame. A series of longerons leading from this ring frame to the aft bulkhead provide adequate stiffness for the engine during all loading conditions.

2.3 **Spatial Requirements**

The minimum volumetric requirements need to assure adequate occupant safety, seating, and cabin ingress and egress. These areas are provided for by using the Jungle Aviation and Radio Services (JAARS) seat, that is certified under current FAR 23 dynamic crashworthiness conditions, and four point seat belt connections to the fuselage structure. The seat adjustments are relative to pilot physique, and the geometric extent of travel provide acceptable limits for human comfort while maintaining aircraft control.

2.4 **Wing Structure**

2.4.1 **Front Spar and Lug**

The process of designing the front spar began by determining the position within the given airfoil that would allow the height to be a maximum. For the NLF 0414 airfoil the maximum thickness occurs over a range of 25% to approximately 70% of the total chord length, thereby placing the spar at 25% of the chord.

After determining the position, several ideas were considered for construction from a series of extruded I-beams to brake-formed C-channels. Finally, it was decided to use an aluminum shear web of increasing thickness capped on top and bottom by NAS 344 series extruded aluminum T-sections. This built-up member would then be attached to the carrythrough using machined, quadruple shear, 4340 steel lugs and shear bolts.
Using the total lift distribution, shear and bending moment diagrams were generated for the entire wing. From the maneuvering point (A) on the V-n diagram, 88% of these loads were applied to the front spar as a result of a chordwise equilibrium analysis. From these loading diagrams, a required section modulus was determined at intervals along the span and plotted. The sizes of the spar cap T-section were then chosen, based on the required section modulus and available sizes of stock NAS 344. In order to accommodate the increased loads imposed by the tail boom and landing gear, a large ΔS was retained until station 80.

2.4.2 Rear Spar and Lug

The design of the rear spar was performed similarly to the front spar. For strength/weight efficiency, the spar was designed as a built-up shear web type, incorporating T-sections spar caps attached to an aluminum shear web. The rear spar was located approximately at the 67% chord on the airfoil and was designed to take up 12% of the total lifting load of the entire wing at the maneuvering point (A) on the V-n diagram.

Since the wing was chosen to a NLF 0414 airfoil, the height of the front spar and rear spar were almost identical, thereby allowing the design of the spar caps to depend on the respective shear and bending moment diagrams for each section. The spar caps needed to provide the required moment of inertia and subsequently the available section modulus (S) is plotted versus the required section modulus. In the case of the available section modulus, a NAS 344-32 extruded T-section was chosen as the spar cap at the root of the wing and varied to a NAS 344-2 at the tip. This built-up member would then be attached to the carrythrough using machined, quadruple shear, 4340 steel lugs and shear bolts.

2.4.3 Carrythrough Structure

The carrythrough structure was initially designed as a continuation of the front and rear spars, but due to the configuration of the tail boom, and the location of the engine, the carrythrough was modified significantly to accommodate the loading conditions. The front spar carrythrough incorporated two C-sections riveted together and attached to the firewall of the aircraft. The rear spar carrythrough was designed with a half-hoop C-section connected to another C-section on top of the hoop, this change was necessary due to the
3. **Loads and Loading**

3.1 **Fuselage Bending**

The highest bending loads are imposed on the structure during the landing condition. In order to comply with FAR Part 23, the structure must be able to withstand a 3g impact under normal landing conditions. Both the bending moment of the passengers, the JAARS system, and the nose gear landing loads are reacted through the floor structure and the longerons to the wing main spar. This moment calculation is shown below.

\[ F_c = \left[ 3 \cdot W_g + 3 \cdot W_{ng} \right] \cdot 3g \]
\[ = \left[ 3 \cdot (200) + 3 \cdot (30) \right] \cdot 3 \]
\[ = 2070 \text{ lbs} \]
\[ M_c = F_c \cdot d_c = 2070 \cdot (40) \]
\[ = 82800 \text{ in} \cdot \text{lbs} \]

The bending moments from the nose gear load are \( M_{ng} = 727.2 \times 10^3 \) lb-in and the resulting stress is \( f_{\text{bend}} = 29.3 \) ksi.

\[ F_{NG} = W_{NG} \cdot 3g = 1987 \times 3 \]
\[ = 5961 \text{ lbs} \]
\[ M_{NG} = F_{NG} \cdot d_{NG} = 5961 \cdot (122) \]
\[ = 727200 \text{ in} \cdot \text{lbs} \]

This bending stress is less than the given ultimate stress of 48 ksi, and this results in a margin of safety of 0.363.

3.2 **Safety Harness**

The JAARS shoulder harness must withstand an impact of 18g's according to FAR Part 23. The attachment bolts have a bearing stress of 99 ksi. In order to accommodate this stress an extruded aluminum T-section was sized under the following conditions:

\[ f_{\text{bolt}} = 99 \text{ ksi} \]
\[ V = 10.91 \times 10^3 \text{ lbs} \]
\[ D_{\text{bolt}} = 0.5 \text{ in.} \]

The resulting thickness of the T-section is 0.220 inches. A similar evaluation of the rear occupant's harness attachment yields similar results with a margin of safety of 1.17.

3.3 **Engine Torque**

The torque produced by the engine was assumed to be 12,000 in lbs, and is reacted through the engine mounts to the ring frame. This, in turn, translates the torque into shear flow in the surrounding skin panels. The skin thickness and rivet spacing must be determined to withstand the buckling loads imposed by the torque. For a ring frame area of 1,773 in\(^2\), the resulting stress of 136 psi is well under the \( F_{\text{crit}} \) of 1778 psi prescribed using the method outlined in Niu (Fig 5.4.6 pg 139).
3.4 **Landing Load Torque**

A torque of 81,300 in-lbs is imposed on the fuselage during emergency landing.

\[
T_c = F_c \cdot d_c + F_{cw} \cdot d_{cw}
\]

\[
F_c = (100) (1.5) = 1500 \text{ lbs}
\]

\[
T_c = 2700 (21.5) + 1500 (15.5)
\]

\[
T_c = 81,300 \text{ in-lbs}
\]

As with the engine torque considerations, the skin thickness and rivet spacing must be determined to withstand the buckling loads caused by the torsional moment. The stress due to shear flow is 8,470 psi. Using Niu’s method, the critical stress for buckling of the skin is 13,900 psi. The resulting margin of safety is 0.09.

3.5 **Fuselage Bending due to Engine Weight**

The weight of the engine applied a bending stress on the fuselage structure which is reacted through a series of 15 inch C-section longerons to the spars. The eleven longerons each carry a stress of 15.6 ksi, thus allowing for a margin of safety of 1.56.

3.6 **Buckling Considerations of Engine Longerons**

Upon impact during an emergency landing, the engine longerons must withstand an 18g forward buckling load. The C-sections have an ultimate margin of safety of 2.14. The thickness of the members can be changed to allow buckling at different loading conditions. This technique can be used to design a “mechanical fuse” that can steer the engine in a desired direction at impact.

3.7 **Rivet Spacing**

3.7.1 **Lower Skin**

Using a 3/16” diameter rivet and assuming a maximum rivet spacing of 1.5 inches, the maximum bearing stress on each rivet is 510 lbs. The bearing and ultimate stresses on each rivet is 675 lbs and 966 lbs, respectively, and the ultimate margin of safety was 0.324 and the bearing margin of safety was 0.263.

3.7.2 **Upper Skin**

Using a 1/8” diameter rivet and assuming a maximum rivet spacing of 1.0 inch, the maximum bearing stress on each rivet is 3.4 lbs. The bearing and ultimate stresses on each rivet is 281 lbs and 429 lbs, respectively. The ultimate and bearing margins of safety is over 80.

3.8 **Engine Mount Bolts**

The design of the engine mount requires mounting bolts to withstand the shear load of an
18g impact. With four 1/2" bolts the required shear load each must withstand is 10.8 ksi. A sheet thickness of 0.16 inches is necessary to avoid tear out around the bolts.

3.9 Nose Gear Landing Load

The shear stress on the nose gear mounting plate and bolts was calculated using four 1/2" bolts. The supporting C-section is designed to help carry the loads through the fuselage. The thickness of the plate required to avoid a tear out was 0.0951 inches.

3.10 Wing Structure

3.10.1 Lift Reactions

The first task undertaken in the design of the wing structure was determining the loads induced on the wing at the maneuvering and dive condition.

\[ L_A = C_{la} \cdot q_A \cdot S_w \]
\[ = 1.4 \times 43 \times 152 \]
\[ = 9150 \text{ lbs} \]

\[ D_A = (C_{D_a} + kC^2) \cdot q_A \cdot S_w \]
\[ = (0.00785 + 0.056 \times 1.4^2) \times 43 \times 152 \]
\[ = 769 \text{ lbs} \]

\[ N_A = \sqrt{(9150.4^2 + 769^2)} \]
\[ = 9182 \text{ lbs} \]

From this data the percentage of these loads were decomposed onto the front and rear spar.

\[ x_A = \frac{C_M \cdot C}{C_{la}} = -0.07 \times 58.6 = -2.93 \]
\[ x_D = \frac{C_M \cdot C}{C_{D_a}} = -0.07 \times 0.45 = -9.12 \]

Using a static equilibrium analysis about the front spar position, the force on the rear spar required to balance with the normal force at the center of pressure was calculated to be 1093 pounds.

From these calculations, it was shown that the front spar carries 88% of the total wing loading at maneuvering speed while the rear spar carries 12%.

\[ M_{Ps} = N_A \cdot x_A - (F_{Ps} \times 24.6) = 0 \]
\[ = (9182 \times 2.93) - (F_{Ps} \times 24.6) = 0 \]
\[ F_{Ps} = 1093 \text{ lbs} \]
\[ F_{Ps} = N_A - F_{Rs} \]
\[ = 9182 - 1093 \]
\[ F_{Ps} = 8089 \text{ lbs} \]

At dive speed, the rear spar bears a greater load due to the rearward movement of the center of pressure at low angles of attack. Summing moments about the front spar again yielded the following:
\[ M_{FS} = (N_A \times X_A) - (F_{ES} \times (24.6)) = 0 \]

\[ F_{ES} = 3404 \text{ lbs} \]
\[ F_{ES} = N_A - F_{RS} \]
\[ F_{RS} = 5778 \text{ lbs} \]

The load distribution between the spars at the dive condition was determined to be 63% for the front spar and 37% for the rear. So, the maneuvering condition sized the front spar and the dive condition sized the rear spar.

3.10.2 *Total Wing Lift Distribution*

The external lift distribution on the wing structure was determined using an elliptical and trapezoidal lift distribution. Taking the average of the two gave a close approximation to the actual lift distribution of the wing. This lift distribution is shown in figure 1.

3.10.3 *Spar Shear and Moment Diagrams*

Once the total lift distribution was determined for the half-span of the wing, the shear and moment diagrams were plotted versus wing station.

Using the percentages calculated in section 3.10.1, shear and moment diagrams for the respective spars were produced.
maneuver, and flapped conditions. The aerodynamic change in torque was calculated using the following relation,

$$\Delta T = q \cdot C_n \cdot S_{loc} \cdot C_{loc}$$

$$\Delta T = (119.5)(-0.07)(3.07)(2.91)$$

$$\Delta T = -74.73 \text{ inlbs}$$

ever the various flight condition. The boom torque, produced by the tail force, was determined as follows,

$$\frac{W_{ac}}{S_w} = 4.4 \frac{2091}{152} = 60.5 \text{ lb/ft}$$

From Fig A5-FAR 23 Appendix A,

$$w = 38 \text{ lb/ft}^2$$

$$L_r = w \cdot S_{cr} = (38)(55.3)$$

$$L_r = 2100 \text{ lbs}$$

$$M_z = L_r \cdot d_z = (2100)(165)$$

$$M_z = 346500 \text{ inlbs}$$

The landing loads are also present at the boom and are determined to be,

$$F_z = \mu \cdot W_{ac} \cdot 3g = (0.8)(2091)(3)$$

$$F_z = 5018 \text{ lbs}$$

$$T_o = F_z \cdot d_v \cdot W_{ac} \cdot (3g) \cdot d_b$$

$$T_o = (5018)(38) + (2091)(3)(21.5)$$

$$T_o = 325600 \text{ lbs}$$

These torques are plotted versus wing station to produce the torque curve shown below.
From the torque curve, the rib and stringer spacings were determined using buckling characteristics of the skin panels.

3.11 Environmental Considerations

3.11.1 Temperature

Cabin ventilation has been incorporated to allow occupant comfort in high temperature conditions. A supplemental heating system will provide warm air to the cabin for operation in cold weather conditions. All structural members and joints are designed taking into account tolerances for thermal expansion for the given thermal operating range (-40degree F to +122degree F) of the aircraft.

3.11.2 Atmospheric Pressure

FAR Part 91.211(a) defines the requirements for supplemental oxygen in non-pressurized civil aircraft registered in the United States. The cabin of the aircraft shall be equipped with supplemental oxygen for necessary crew members and passengers for the given conditions,
up to 16,000 feet, defined by the FAR's.

3.11.3 **Sand and Dust**

All external surfaces will be coated with chip resistant aircraft paint to withstand dust and sand damage specified in the SOW. Door hinges will be outfitted with plastic washers between moving parts to reduce friction damage caused by particle matter. All windows will be sealed with rubber weatherstrip to keep out excessive sand and dust. Air filters are to be installed in the intake ducts to prevent engine and environmental control system damage by sand and dust.

3.11.4 **Rain**

All windows and doors will be outfitted with weatherstripping and/or sealant to prevent water intrusion and subsequent damage. Filters are to be installed in the engine air intake ducts to prevent excessive water accumulation. Drainage holes are to be made in the air ducts at locations susceptible to water accumulation and icing.

3.11.5 **Humidity**

All external skin panels are manufactured from 2024 aircraft aluminum and resist corrosion under the conditions specified in the SOW. At certain cabin temperatures and pressures, excess humidity is expected to condense on the front windshield and side windows. A heated defrost system has been integrated into the aircraft to eliminate windshield condensation.

3.11.6 **Ice**

All doors are to be equipped with seals designed to prevent water intrusion and subsequent freezing of the latch mechanism. Teflon or plastic washers between metal hinge parts will help prevent icing of the door hinges.

3.11.7 **Snow**

All skin panels and internal supporting members have been designed to support loads in excess of those encountered by the weight of 20 inches of wet snow.

3.11.8 **Salt/Fog Atmosphere**

All external skin panels are manufactured from 2024 aircraft aluminum to resist corrosion from salt and fog. Rivets and interface materials have been chosen that will resist corrosion also. Plastic washers between moving door hinge parts will help to prevent corrosion as well.

3.11.9 **Wind and Gust**

The fuselage structure has been designed to withstand gust loadings as defined by FAR Part
23. All tie-down fittings will be attached to the wings and tail structure.

4. Structural Substantiation

4.1 Floor Structure Bending Due to Occupants

Under aerodynamic loads, the occupants exert a bending moment on the floor members that needs to be counteracted. This is accomplished with the use of 4 NAS346-45 7075-T6 channels (see dwg. F93-2A-102-7). Values for the beams are $I_{xx} = 0.7258 \text{ in}^4$ (4 beams) = 2.9032 in$^4$.

\[
\frac{f}{I} = \frac{M_{eq} Y}{I} = \frac{(82800)(1.5)}{2.9032} = 42.8 \text{ksi}
\]

$F_{ty} = 76 \text{ ksi}$ \hspace{1cm} (MS)$_{ty} = 0.78$

$F_{tu} = 83 \text{ ksi}$ \hspace{1cm} (MS)$_{tu} = 0.29$

4.2 Fuselage Bending Due to Nose Gear Load

This is a worst case of the aircraft landing with the entire weight on the nose wheel. This bending moment is transferred through fuselage longerons and underfloor members. The simplified model yields $I_{total} = 198.22 \text{ in}^4$ and $y = 8.0 \text{ in}$ (see dwg F93-2A-102-7; Parts 1,2,3).

\[
\frac{f}{I} = \frac{M_{eq} Y}{I} = \frac{(727200)(8.0)}{198.22} = 29.3 \text{ksi}
\]

$F_{ty} = 47 \text{ ksi}$ \hspace{1cm} (MS)$_{ty} = 0.60$

$F_{tu} = 62 \text{ ksi}$ \hspace{1cm} (MS)$_{tu} = 0.41$

4.3 Skin Buckling Due to Landing Load

The torque that the occupants produce during the landing criteria stated in FAR 23 is absorbed by the torque box formed by the under floor carry through (see dwg F93-2A-102-7, Section A-A). The torque produced is 81,300 inlbs through an area of 120 in$^2$ and skin thickness of 0.040 in.

$F_{tu} = 62 \text{ ksi}$ \hspace{1cm} (MS)$_{tu} = 0.41$

4.4 Skin Buckling Due to Engine Torque

The torque that is produced by the engine is reacted through the engine ring frame, and into the fuselage skin. The calculation is the same as that in 4.3 with the following changes.

\[
q = \frac{T_c}{2A} = \frac{12000}{(2)(1773)} = 3.401 \text{ lb/in} \text{ch}
\]

\[
f = q t = 3.40 \times 0.025 = 136 \text{ p.s.i.}
\]

\[
F_{exit} = K E \left( \frac{E}{D} \right)^2 = 8(10^7) \left( \frac{0.025}{15} \right)^2 = 222 \text{ p.s.i.}
\]

$F_{exit} = 222 \text{ p.s.i.}$
4.5 **Fuselage Bending Due to Engine Load**

The moment produced by an acceleration on the engine is reacted through 11 longerons spaced around the periphery of the fuselage (see dwg F93-2A-102-7; Part 15). The stress in each member is,

\[
f = \frac{M_{max} \gamma_f}{I_{max}} = \frac{(83072)(1.5)}{7.99} = 15.5 \text{ksi}
\]

\(F_{ty} = 47 \text{ ksi}\)  \((\text{MS})_{ty} = 2.0\)

\(F_{tu} = 62 \text{ ksi}\)  \((\text{MS})_{tu} = 1.6\)

4.6 **Seat Track Fasteners**

The seat tracks are fixed through the floor panel into the NAS346-45 channel with four 5/16 in screws per track.

\[
f_s = \frac{V}{A} = \frac{(6210)(1.5)(1.2)}{\left(\frac{\pi}{4}\right)(\frac{5}{16})^2} = 36.4 \text{ksi}
\]

\[
f_b = \frac{V}{D_{bc}} = \frac{(6210)(1.5)(1.2)}{\left(\frac{5}{16}\right)\left(\frac{189}{16}\right)} = 47.6 \text{ksi}
\]

\(F_{su} = 75 \text{ ksi}\)  \((\text{MS})_{su} = 0.05\)

\(F_{bu} = 251 \text{ ksi (for steel)}\)  \((\text{MS})_{bu} = 5.27\)

4.7 **Nose Gear Bolt Sizing**

The nose gear is held onto the forward bulkhead with 4 ASN8C-11 bolts (see dwg F93-2A-102-7).

\[
f_s = \frac{V}{A} = \frac{(5961)(1.5)(1.2)}{\left(\frac{\pi}{4}\right)(\frac{1}{2})^2} = 13.7 \text{ksi}
\]

\[
f_b = \frac{V}{D_{bc}} = \frac{(5961)(1.5)(1.2)}{\left(\frac{1}{2}\right)(0.1)} = 53.6 \text{ksi}
\]

\(F_{su} = 75 \text{ ksi}\)  \((\text{MS})_{su} = 2.64\)

\(F_{bu} = 118 \text{ ksi}\)  \((\text{MS})_{bu} = 0.46\)

4.8 **Engine Mount Bolt Sizing**

The engine is connected to the ring frame with four gusset plates. These plates allow the use of AN8C-7 bolts, one per plate, to transfer the engine loads into the ring frame and longerons (see dwg F93-2A-102-7).

\[
f_s = \frac{V}{A} = \frac{(8496)(1.5)(1.2)}{\left(\frac{\pi}{4}\right)(\frac{1}{2})^2} = 19.5 \text{ksi}
\]

\[
f_b = \frac{V}{D_{bc}} = \frac{(8496)(1.5)(1.2)}{\left(\frac{1}{2}\right)(0.1)} = 47.9 \text{ksi}
\]

\(F_{su} = 75 \text{ ksi}\)  \((\text{MS})_{su} = 1.56\)

\(F_{bu} = 118 \text{ ksi}\)  \((\text{MS})_{bu} = 0.64\)

4.9 **Spar Cap Sizing**

The principle of the section modulus was used to generate the spar cap sizing. The caps start off as an NAS344-69 for the front spar and -33 for the rear spar (see dwg F93-2A-104-7). The justification for the sizes is detailed below.
The section modulus plotted over the span of the wing for both spars yields the following curves.

**Figure 9**

4.10 **Spar Cap Fatigue**

Fatigue estimations were performed on the spar caps using half of the weight of the aircraft distributed over the spars as designated in 3.10.1. Pfs=920 lbs and Prs=324 lbs at a distance of 44 inches. Using the S-N curve from Fig 3.7.4.1.8(g) from MIL-HDBK-5E and the following,

\[
\frac{f_{\text{mean}}}{f_{\text{max}}} = \frac{P_l}{S} = \frac{(940)(44)}{(5.63)} = 7190 \text{ p.s.i.}
\]

\[
f_{\text{mean}} = 2.2 f_{\text{mean}} = 2.2(7190) = 1518 \text{ p.s.i.}
\]

\[N = 2 \times 10^5 \text{ cycles}\]

Similarly, the rear spar yields a count of \(5 \times 10^5\) cycles.

4.11 **Shear Web Sizing**

Shear flow is determined from the torque diagram and the web thicknesses are justified by meeting the buckling criteria. A sample calculation is shown below.

\[q = 709 \text{ lb/inch}\]

\[f_{l.l.} = \frac{q}{c} = \frac{709}{0.125} = 5672 \text{ p.s.i.} \]

\[f_{u.} = f_{l.l.} (1.5) = 5672 (1.5) = 8508 \text{ p.s.i.} \]

\[F_{\text{crit}} = KE \left( \frac{c}{D} \right)^2 = 5 \times 10^7 \times \left( \frac{0.125}{8.8} \right)^2\]

\[F_{\text{crit}} = 10,088 \text{ p.s.i.} \]

\[(\text{MS}) b = 0.19\]

(see dwg F93-2A-104-7 for remaining thicknesses).
4.12 **Rib Sizing**

From the torque diagram the value for torque at WS172 can be determined. The rib is then sized using the buckling criteria used previously. See drawing F93-2A-104-7 for a complete list of thicknesses.

\[
q = 1.76 \text{ lb/inch}
\]

\[
f_{L.L.} = \frac{q}{t} = \frac{1.76}{0.032} = 55.1 \text{ p.s.i.}
\]

\[
f_{ult} = f_{L.L.} = (1.5) = 82.7 \text{ p.s.i.}
\]

\[
F_{cr} = \frac{K_{t}}{D}(\frac{t}{D})^{2} = 7 \times 10^{7} \times \left(\frac{0.032}{20}\right)^{2} = 179 \text{ p.s.i.}
\]

4.12 **Lightening Hole Justification**

Lightening holes were considered for the ribs inboard of the boom due to their thickness and weight. Using the calculations in Niu and figure 6.2.3, the following dimensions were obtained; D=5.25 inches, b=7.7 inches. Values previously determined; q=709 lb/in, rivet diameter=.375 in., and rivet spacing=5.5 in.

\[
f_{s,web} = \frac{q}{t} \left(\frac{b}{b-D}\right)
\]

\[
f_{s,web} = \frac{709}{0.125} \left(\frac{7.7}{7.7-5.25}\right)
\]

\[
f_{s,web} = 17.8 \text{ ksi}
\]

\[
z_{s-d} = \frac{5.5 - 0.375}{5.5} = 0.932
\]

\[
f_{s,slit} = \frac{q}{K_{t} t} = \frac{709}{(0.932)(0.125)} = 6.1 \text{ ksi}
\]

\[
f_{s,hoole} = \frac{q}{709} \left(\frac{b}{h-D}\right)
\]

\[
f_{s,hoole} = \frac{0.125}{709} \left(\frac{8.8}{8.8-5.25}\right)
\]

\[
f_{s,hoole} = 14.1 \text{ ksi}
\]

4.13 **Lug Justification**

The lug's purpose is to transfer shear and bending moments to the fuselage carry-through. They are subject to the highest shear and bending moment since they are at the root of the wing.

4.13.1 **Forward Lug**

According to the shear and moment diagram for the front spar the values are 919.6 lbs and 88282 inlbs at the root, respectively. The lugs are 5.8 inches apart which yields a loading, P, of 15,200 lbs. The bolt is in quad shear so the stress is,

\[
f_{s} = \frac{P}{(4)(A)}
\]

\[
f_{s} = \frac{15,200(1.5)(1.2)(4.4)}{(\pi)(0.75)^{2}(4)}
\]

\[
f_{s} = 68 \text{ ksi}
\]

(Fsu)bolt = 75 ksi

\[
(Fsu)bolt = 75 \text{ ksi}
\]

The material for the lug was chosen to be 4340 steel because of its high strength properties. After
calculating flange thicknesses required over stresses for bearing, tensile, tear out, and fatigue, the thickest requirement came from tensile stress. The flange thickness needs to be .125 inches to satisfy the tensile stress requirement. Fatigue assessments were made at an infinite life of 10^7 cycles.

4.13.2 Rear Lug

Using the same procedure as the front lug the bolt diameter was found to be 7/16 inches and the flange thickness in quad shear was .114 inches. As before the lug thickness was checked for each type of stress and tensile stress was the sizing factor.

4.14 Carry Through Structure

The carry through structure for the wing is designed to carry a pure bending moment. The shear reactions are taken up by the fuselage structural members. The pure moment, determined from the moment diagram, is taken up in the moment of inertia (I_{front}=31 \text{ in}^4 \text{ I}_{rear}=10.8 \text{ in}^4) for the carry through.

5.0 Manufacturing and Maintenance Provisions

5.1 Fuselage Assembly

The fuselage structure assembly is comprised of four main components: longerons, ring frames, bulkheads, and skin. The floor longerons of the Quest PFT are manufactured from 7075-T6 Aluminum extrusions, while the remaining components are manufactured from 2024-T3 Aluminum sheet brake formed and fitted to shape. The entire fuselage skin is riveted together using AN456DD-4 rivets, while the internal components use AN430DD-8 rivets. Aircraft quality AN designation type bolts are used to mount the engine and nose landing gear. The skin thickness was changed under the belly of the aircraft in order to account for the torsional loading produced by the occupants.

5.2 Engine Mounts

The engine mounts to a ring frame attached to the rearward bulkhead by the use of brake formed aluminum sheet c channels. The engine truss is mounted to the ring frame with reinforcing brackets attached to the longerons. Engine maintenance is accomplished through the use of engine cowlings located on the left and right side of the engine.

5.3 Control System and Ventilation Routing

The control system installation simply requires allowing space for the routing of this
system. This is provided via a channel running between of the four floor longerons. This system will incorporate push-pull rods for control. Access to the control systems are provided by inspection plates located under the fuselage. The venting system runs along the side of the aircraft in between the two side longerons. The blower is located under the engine and fresh air is provided via the air cooling vents on the engine. This system is easily maintained from the same location of the engine cowling doors.

5.4 Front and Rear Spar

The front and rear spar is comprised of two main components: the spar caps and shear web. The spar caps are manufactured from 7075-T6 Aluminum extrusions T-sections with varying section properties. The shear web is manufactured from 2024-T3 Aluminum sheet formed and fitted to shape with varying thickness to account for the shear flow. These parts are connected using high quality NAS 1304-4P steel bolts and rivets.

5.5 Front and Rear Lugs

The lug assembly is comprised of one piece shaped to the designed configuration. It is composed of a high strength steel (4340 steel), which may have to be cadmium plated to resist corrosion. The lug is connected to the spar cap on the respective spars with the use of 0.25" diameter NAS bolts.

5.6 Wing Carrythrough Structure

The wing carrythrough structure was one of the difficulties encountered in the design of the wing. The front spar carrythrough was assembled using two 2024 aluminum sheet brake formed c-sections attached to the firewall by 24 bolts sized according to the moment produced at the root of the wing. The rear spar was modified slightly, wherein a half-hoop aluminum sheet c-section brake formed was attached to a straight c-section on top of the hoop. This was done in order to compensate for the engine location, while at the same time providing support for the engine.

5.7 Internal Wing Structure and Skin

The sizing of the ribs, along with the spacing were designed from the torsion induced from the aerodynamic loads of the aircraft. The ribs are manufactured from 2024 aircraft aluminum brake formed and fitted to shape. Various stiffeners were also placed in the wing to help meet the required buckling criteria. The entire wing skin
is riveted together using quality AN rivets, the skin is manufactured from 2024 aluminum sheet of 0.032\" thickness outboard of the tail booms, and 0.05\" thickness inboard of the tail booms. This was designed due to the large torsion produced by the booms. Finally various access panels or holes were placed at strategic locations in order to provide for maintenance of the wing and control systems.

6.0 **Weight Summary**

The weight of the aircraft is an essential design aspect that must be addressed to allow for maximum stiffness of members for given applied loading conditions, while at the same time providing a light, yet durable structure. Weight savings are accomplished by using aluminum sheet for the majority of the structural members since it provides a relatively high stiffness-to-weight ratio at a low cost. Additional weight savings include punching lightening holes in the extruded aluminum floor longerons. Extruded parts are usually thicker than brake formed members so they tend to be heavier. Rivet weight is compensated for by allowing them to add 1\% to overall structural weight. The total weight for the aircraft structure is 144 lbs. The weight for the structure in the two seater version was 131 lbs. An increase in 13 lbs for the structural weight to support the loadings imposed by a third passenger seems to be valid. The total weight of the aircraft wing is 269 lbs. The weight for the two seater version was 253 lbs. Thereby, an increase of 13 lbs, also, for the third passenger seems to be valid.
<table>
<thead>
<tr>
<th>PART</th>
<th>QTY</th>
<th>GAGE (IN)</th>
<th>WEIGHT (LB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RIB WS 192</td>
<td>2</td>
<td>0.016</td>
<td>0.701344</td>
</tr>
<tr>
<td>RIB WS 172</td>
<td>2</td>
<td>0.016</td>
<td>0.788608</td>
</tr>
<tr>
<td>RIB WS 148</td>
<td>2</td>
<td>0.032</td>
<td>1.881024</td>
</tr>
<tr>
<td>RIB WS 99</td>
<td>2</td>
<td>0.032</td>
<td>2.495104</td>
</tr>
<tr>
<td>RIB WS 87</td>
<td>2</td>
<td>0.032</td>
<td>2.676096</td>
</tr>
<tr>
<td>RIB WS 75</td>
<td>2</td>
<td>0.032</td>
<td>2.805376</td>
</tr>
<tr>
<td>RIB WS 49</td>
<td>2</td>
<td>0.05</td>
<td>4.9288</td>
</tr>
<tr>
<td>RIB WS 42</td>
<td>2</td>
<td>0.125</td>
<td>10.12525</td>
</tr>
<tr>
<td>RIB WS 35</td>
<td>2</td>
<td>0.125</td>
<td>10.12525</td>
</tr>
<tr>
<td>RIB WS 28</td>
<td>2</td>
<td>0.125</td>
<td>10.12525</td>
</tr>
<tr>
<td>RIB WS 21</td>
<td>2</td>
<td>0.125</td>
<td>10.12525</td>
</tr>
<tr>
<td>F-SPAR CAP 0-80</td>
<td>2</td>
<td>0.125</td>
<td>12.84256</td>
</tr>
<tr>
<td>F-SPAR CAP 80-120</td>
<td>2</td>
<td>0.125</td>
<td>1.635696</td>
</tr>
<tr>
<td>F-SPAR CAP 120-192</td>
<td>2</td>
<td>0.125</td>
<td>1.6704</td>
</tr>
<tr>
<td>R-SPAR CAP 0-20</td>
<td>2</td>
<td>0.125</td>
<td>1.102868</td>
</tr>
<tr>
<td>R-SPAR CAP 20-100</td>
<td>2</td>
<td>0.125</td>
<td>3.464398</td>
</tr>
<tr>
<td>R-SPAR CAP 100-140</td>
<td>2</td>
<td>0.125</td>
<td>0.531468</td>
</tr>
<tr>
<td>BUCKLE STIFFENER (#9)</td>
<td>44</td>
<td>0.02</td>
<td>3.26634</td>
</tr>
<tr>
<td>BUCKLE STIFFENER (#10)</td>
<td>28</td>
<td>0.02</td>
<td>4.010104</td>
</tr>
<tr>
<td>BUCKLE STIFFENER (#11)</td>
<td>12</td>
<td>0.02</td>
<td>2.63004</td>
</tr>
<tr>
<td>BUCKLE STIFFENER (#12)</td>
<td>4</td>
<td>0.02</td>
<td>1.25846</td>
</tr>
<tr>
<td>SPAR SHR WEB (20-49)</td>
<td>4</td>
<td>0.125</td>
<td>12.4432</td>
</tr>
<tr>
<td>SPAR SHR WEB (49-76)</td>
<td>4</td>
<td>0.05</td>
<td>4.52682</td>
</tr>
<tr>
<td>SPAR SHR WEB (76-172)</td>
<td>4</td>
<td>0.032</td>
<td>7.632691</td>
</tr>
<tr>
<td>SPAR SHR WEB (172-192)</td>
<td>4</td>
<td>0.016</td>
<td>0.58176</td>
</tr>
</tbody>
</table>
The goal of this design project is to provide a cabin fuselage structure detail design along with an adequate wing structure that meets the loading criterion defined by FAR Part 23. Control systems and ventilation routing have been designed for ease of maintenance and removal. Volumetric cabin requirements were also met that assured adequate spacing and safety of the occupants. Calculations of the torsion, or shear flow, induced by the occupants required a change to the original floor design in which stiffeners were added to counteract these loads. Calculations of the aerodynamic forces induced by various aircraft components such as the twin tail booms, the landing gear, and the wing were performed and decomposed into the sizing of the total wing structure. This included sizing the front and rear spar and lug, the wing skin, ribs, along with other parts. The location of the wing on the mid-fuselage required a different approach to designing the wing carrythrough structure. Also the large torsion produced inboard of the tail booms required a change to the skin thickness to counteract this torque. The cabin was expanded to accommodate a three-seat passenger configuration. The new engine
location required providing a ring-frame structure to account for a longer moment arm. Weight estimates and sizes provided by the preliminary design report were for a two-seat configuration aircraft. Certain assumptions needed to be made about the weight of this larger aircraft that will need to be validated. Finally, environmental conditions were addressed for all relevant parts. This design meets all of the requirements, but further optimization may be performed through later iterations.
Appendices
Fig. 5.4.5 Compression buckling coefficients $K_c$ (circular cylinders).

$$F_c = k_c \frac{\pi^2 E}{12(1-\mu^2)} \left( \frac{t}{L} \right)^2$$

Theoretical
Recommended for design
- Simply supported edges
- Fixed edges

Fig. 5.4.6 Shear buckling coefficients $K_s$ (circular cylinders).

$$F_s = K_s \frac{t}{E} \left( \frac{1}{a} \right)^2$$

Simply supported edge
Fixed edges

Airframe Structural Design 139
6.2 Lightly Loaded Beams

The ideal construction for most shear-carrying beams is a tension field (or diagonal tension beam per Ref. 6.8). However, in some cases it is advantageous, and in other cases necessary, to incorporate circular, flanged holes in the beam webs. These cases come under two main categories:

- Lightly loaded or very shallow beams. In such cases it may not be practical to construct an efficiently designed tension field beam because of minimum gage considerations and other restrictions due to the small size of the parts involved. It may then be advantageous from a weight standpoint to omit web stiffeners and, instead, introduce a series of standard flanged lightening holes, as shown in Fig. 6.2.1.
- Moderately loaded beams with access holes. Where it is necessary to introduce access holes into the web of a shear-carrying beam, a light, low cost construction is obtained by using a flanged hole with web stiffeners between the holes.

**Lightly Loaded or Very Shallow Beams**

The following two types of beam construction are considered. The standard flanged lightening holes as shown in Fig. 6.2.2 are centered and equally spaced.

- The limiting conditions for the design curves is given in Fig. 6.2.3.

### Table 6.2.1

<table>
<thead>
<tr>
<th>( D ) (in)</th>
<th>( f ) (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>0.25</td>
</tr>
<tr>
<td>2.5</td>
<td>0.3</td>
</tr>
<tr>
<td>3.0</td>
<td>0.4</td>
</tr>
<tr>
<td>3.5</td>
<td>0.45</td>
</tr>
<tr>
<td>4.0</td>
<td>0.5</td>
</tr>
<tr>
<td>4.5</td>
<td>0.55</td>
</tr>
<tr>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>6.0</td>
<td></td>
</tr>
</tbody>
</table>

(a) Lightening holes of typical flanged holes (45° flanged)

\( D_0 = \text{Outside diameter} \)

\( D = \text{Inside diameter} \)

\( R = 0.155 \text{ inch} \)

### Table 6.2.2

<table>
<thead>
<tr>
<th>( D_0 ) (in)</th>
<th>( D ) (in)</th>
<th>( \alpha ) (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.7</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>1.95</td>
<td>1.05</td>
<td>0.25</td>
</tr>
<tr>
<td>2.65</td>
<td>1.7</td>
<td>0.25</td>
</tr>
<tr>
<td>3.0</td>
<td>2.05</td>
<td>0.25</td>
</tr>
<tr>
<td>3.65</td>
<td>2.7</td>
<td>0.25</td>
</tr>
<tr>
<td>3.9</td>
<td>2.95</td>
<td>0.25</td>
</tr>
<tr>
<td>4.95</td>
<td>3.8</td>
<td>0.4</td>
</tr>
<tr>
<td>5.95</td>
<td>4.8</td>
<td>0.4</td>
</tr>
<tr>
<td>6.95</td>
<td>5.8</td>
<td>0.4</td>
</tr>
<tr>
<td>7.44</td>
<td>6.3</td>
<td>0.4</td>
</tr>
<tr>
<td>7.95</td>
<td>6.8</td>
<td>0.4</td>
</tr>
<tr>
<td>8.95</td>
<td>7.8</td>
<td>0.4</td>
</tr>
<tr>
<td>9.45</td>
<td>8.3</td>
<td>0.4</td>
</tr>
</tbody>
</table>

(b) Lightening holes with beaded flanged

\( t = 0.032 \text{ in} - 0.125 \text{ in} \)

![Fig. 6.2.1 Common flanged lightening holes.](Image)

![Fig. 6.2.2 Lightly loaded or very shallow beams.](Image)

![Fig. 6.2.3 Ultimate allowable gross shear stress for aluminum alloy webs with flanged holes as shown in Fig. 6.2.1(a).](Image)
FIGURE 3.7.4.1.8(g). Best-fit S/N curves for notched, \( K_i = 4.0 \), 7075-T6 aluminum alloy sheet, longitudinal direction.

**Correlative Information for Figure 3.7.4.1.8(g)**

**Product Form:** Bare sheet, 0.090 inch

**Properties:**

<table>
<thead>
<tr>
<th>TUS, ksi</th>
<th>TYS, ksi</th>
<th>Temp., F</th>
</tr>
</thead>
<tbody>
<tr>
<td>82</td>
<td>76</td>
<td>RT</td>
</tr>
<tr>
<td>82</td>
<td></td>
<td>RT (unnotched)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RT (notched)</td>
</tr>
</tbody>
</table>

**Specimen Details:**

<table>
<thead>
<tr>
<th>Notch Type</th>
<th>Gross Width</th>
<th>Net Width</th>
<th>Notch Radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge</td>
<td>2.25</td>
<td>1.500</td>
<td>0.057</td>
</tr>
<tr>
<td>Edge</td>
<td>4.10</td>
<td>1.500</td>
<td>0.070</td>
</tr>
<tr>
<td>Fillet</td>
<td>2.25</td>
<td>1.500</td>
<td>0.0195</td>
</tr>
</tbody>
</table>

**Surface Condition:** Electropolished

**Reference:** 3.2.3.1.8(b), (f), (g), and (h)

**Test Parameters:**

- **Loading:** Axial
- **Frequency:** 1100 to 1800 cpm
- **Temperature:** RT
- **Environment:** Air
- **No. of Heats/Lots:** Not specified

**Equivalent Stress Equation:**

\[
\log N_f = 10.2 - 4.63 \log (S_{eq} - 5.3)
\]

- \( S_{eq} = S_{max} (1-R)^{0.51} \)
- **Standard Error of Estimate:** 0.51
- **Standard Deviation in Life:** 1.08
- **\( R^2 \):** 78%

**Sample Size:** 126

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above]
FIGURE 3.2.3.1.8(h). Best-fit S/N curves for notched, \( K_t = 4.0 \) of 2024-T3 aluminum alloy sheet, longitudinal direction.

Correlative Information for Figure 3.2.3.1.8(h)

**Product Form:** Bare sheet, 0.090 inch

**Properties:**

<table>
<thead>
<tr>
<th>TUS, ksi</th>
<th>TYS, ksi</th>
<th>Temp., F</th>
</tr>
</thead>
<tbody>
<tr>
<td>73</td>
<td>54</td>
<td>RT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(unnotched)</td>
</tr>
<tr>
<td>67</td>
<td></td>
<td>RT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(notched, ( K_t = 4.0 ))</td>
</tr>
</tbody>
</table>

**Specimen Details:** Notched, \( K_t = 2.0 \)

<table>
<thead>
<tr>
<th>Notch Type</th>
<th>Gross Width</th>
<th>Net Width</th>
<th>Notch Radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge</td>
<td>2.25</td>
<td>1.50</td>
<td>0.057</td>
</tr>
<tr>
<td>Edge</td>
<td>4.10</td>
<td>1.50</td>
<td>0.070</td>
</tr>
<tr>
<td>Fillet</td>
<td>2.25</td>
<td>1.50</td>
<td>0.0195</td>
</tr>
</tbody>
</table>

**Surface Condition:** Electropolished, machined, and burrs removed with fine crocus cloth

**Test Parameters:**

- Loading: Axial
- Frequency: 1100 to 1800 cpm
- Temperature: RT
- Environment: Air

**Equivalent Stress Equation:**

\[
\log N_t = 8.3 - 3.30 \log (S_{eq} - 8.5)
\]

\( S_{eq} = S_{\text{max}} (1-R)^{0.66} \)

Standard Error of Estimate = 0.39

Standard Deviation in Life = 1.24

\( R^2 = 90\% \)

Sample Size = 126

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above]

**Reference:** 3.2.3.1.8(b), (e), (f), (g), and (h)
FIGURE 2.3.1.3.8(n). Best-fit S/N curves for notched, $K_t = 2.0$, AISI 4340 alloy steel bar, $F_w = 260$ ksi, longitudinal direction.

Correlative Information for Figure 2.3.1.3.8(n)

<table>
<thead>
<tr>
<th>Product Form:</th>
<th>Rolled bar, 1-1/8 inches diameter, air melted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Properties:</td>
<td>TUS, ksi TYS, ksi Temp., F</td>
</tr>
<tr>
<td></td>
<td>266 232 RT (unnotched)</td>
</tr>
<tr>
<td></td>
<td>390 — RT (notched)</td>
</tr>
<tr>
<td>Specimen Details:</td>
<td>Notched, V-Groove, $K_t = 2.0$</td>
</tr>
<tr>
<td></td>
<td>0.300-inch gross diameter</td>
</tr>
<tr>
<td></td>
<td>0.220-inch net diameter</td>
</tr>
<tr>
<td></td>
<td>0.030-inch root radius, $r$</td>
</tr>
<tr>
<td></td>
<td>$60^\circ$ flank angle, $\omega$</td>
</tr>
<tr>
<td>Surface Condition:</td>
<td>Lathe turned to RMS 10</td>
</tr>
<tr>
<td>Reference:</td>
<td>2.3.1.3.8(a)</td>
</tr>
</tbody>
</table>

Test Parameters:

- Loading - Axial
- Frequency - 2000 to 2500 cpm
- Temperature - RT
- Atmosphere - Air

No. of Heats/Lots: 1

Equivalent Stress Equation:

$$\log N_f = 9.46 - 2.65 \log (S_{eq} - 50.0)$$

$$S_{eq} = S_{max} (1-R)^0.64$$

Standard Error of Estimate = 0.22

Standard Deviation in Life = 0.34

$R^2 = 58\%$

Sample Size = 30

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above]
**Empty Weight Estimation**

\[ \text{Gross weight} = 1560 \text{ lbs} \]

\[ \frac{W_e}{W_0} = A W_0^c \quad \text{where} \quad A = 2.36 \quad \text{and} \quad c = -0.18 \]

\[ W_e = \left( \frac{W_e}{W_0} \right) W_0 = 2.36 (1560)^{-0.18} (1560) \]

\[ W_e = 980 \text{ lbs} \]

**Fuel Weight Estimation**

\[ W_0 = W_{\text{crew}} + W_{\text{payload}} + W_{\text{fuel}} + W_{\text{empty}} \]

\[ 1560 = 350 + 50 + W_{\text{fuel}} + 980 \]

\[ W_{\text{fuel}} = 180 \text{ lbs} \]

---

**Payload Trade-off**

\[ W_0 = \frac{200}{0.883 - 2.36 W_0^{-0.18}} \quad 200 \text{ lbs Payload} \]

\[ 1300 = 855 \]
\[ 1100 = 935 \]
\[ 1000 = 988 \]

\[ W_0 = \frac{600}{0.883 - 2.36 W_0^{-0.18}} \quad 600 \text{ lbs Payload} \]

\[ 1800 = 2216 \]
\[ 1900 = 2369 \]
\[ 2000 = 2118 \]
\[ 2100 = 2087 \]

\[ W_0 = \frac{800}{0.883 - 2.36 W_0^{-0.18}} \quad 800 \text{ lbs Payload} \]

\[ 2400 = 2652 \]
\[ 2500 = 2616 \]
\[ 2675 = 2590 \]

---

**Graph**

The graph shows the relationship between TOSW (lbs) and Payload (lbs) with data points marked. The line of best fit through these points indicates a direct proportionality.
Figure A5—Average limit control surface loading.

Figure A6—Average limit control surface loading.
Leading edge Access Panels
Fwd of front spar

Wing Access Panels
Fwd of control surface linkage

Routing

DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED DECIMAL

\[ XX \pm 0.01 \]
\[ XXX \pm 0.001 \]

ANGULAR
\[ \pm 1/2^\circ \]

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY
DAYTONA BEACH FLORIDA

SIZE DATE SCALE DRAWN BY
B 12-06 1/20 A. CEPEDA

TITLE
WING ACCESS PANEL LAYOUT

DRAWING NO.
F93-2A-107-07

SHEET 1/1
1 Panel Lower Surface from front spar to rear spar

MS20430DD-8 Rivet Spacing 2.0" inboard of tail boom

1 Panel Flat Wrapped from top of rear spar to bottom of front spar

1 Panel Upper Surface

1 Panel Lower Surface from rear spar to
NOTE: All wing panels fabricated of 2024-T3 Aluminum.
0.032" skin thickness outboard of tail boom.
0.05" skin thickness inboard of tail boom.
No control surfaces show.

1 Panel Flat Wrapped from top of front spar to bottom of front spar

1 Panel Flat Wrapped from top of rear spar to bottom of rear spar

Press Formed Wing Tip

MS20426DD-5 Rivet Spacing 1.25” outboard of tail boom

1 Panel Upper Surface
1 Panel Lower Surface from front spar to rear spar

DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED DECIMAL

. XX ± .01
. XXX ± .001

ANGULAR ± 1/2°
Rudder/Steering
Elevator
Air Venting

Access panels
Engine cooling air flow
Fiberglass nose cone

Bottom panel skin thick (All others are 0.025 in...
Rivet spacing is 1 in

Gross is 0.040 in

DIMENSION TOLERANCES
UNLESS OTHERWISE SPECIFIED
DECIMAL

XX ± .01
XXX ± .001

ANGULAR
± 1/2°
<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Description</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>43</td>
<td>56</td>
<td>MS20430DD-12</td>
<td>2024-</td>
</tr>
<tr>
<td>42</td>
<td>488</td>
<td>MS20430DD-5</td>
<td>2024-</td>
</tr>
<tr>
<td>41</td>
<td>320</td>
<td>MS20430DD-2</td>
<td>2024-</td>
</tr>
<tr>
<td>40</td>
<td>680</td>
<td>MS20430DD-8</td>
<td>2024-</td>
</tr>
<tr>
<td>39</td>
<td>2090</td>
<td>MS20426DD-5</td>
<td>2024-</td>
</tr>
<tr>
<td>38</td>
<td></td>
<td>NAS 1307-15P</td>
<td>STANDA</td>
</tr>
<tr>
<td>37</td>
<td></td>
<td>NAS 1308-4P</td>
<td>STANDA</td>
</tr>
<tr>
<td>36</td>
<td></td>
<td>NAS 1305-1P</td>
<td>STANDA</td>
</tr>
<tr>
<td>35</td>
<td></td>
<td>AN 12-17-J</td>
<td>STANDA</td>
</tr>
<tr>
<td>34</td>
<td></td>
<td>NAS 1304-4P</td>
<td>STANDA</td>
</tr>
<tr>
<td>33</td>
<td></td>
<td>INBOARD BOTTOM WING PANEL</td>
<td>2024-</td>
</tr>
<tr>
<td>32</td>
<td></td>
<td>INBOARD TRAILING EDGE PANEL</td>
<td>2024-</td>
</tr>
<tr>
<td>31</td>
<td></td>
<td>INBOARD LEADING EDGE PANEL</td>
<td>2024-</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>CENTER WING SKIN PANEL</td>
<td>2024-</td>
</tr>
<tr>
<td>29</td>
<td></td>
<td>LEADING EDGE WING SKIN PANEL</td>
<td>2024-</td>
</tr>
<tr>
<td>28</td>
<td></td>
<td>OUTBOARD WING SKIN PANEL</td>
<td>2024-</td>
</tr>
<tr>
<td>27</td>
<td></td>
<td>PRESS FORM WING TIPS</td>
<td>2024-</td>
</tr>
<tr>
<td>26</td>
<td></td>
<td>REAR CARRY THROUGH</td>
<td>2024-</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>FRONT CARRY THROUGH</td>
<td>2024-</td>
</tr>
<tr>
<td>24</td>
<td></td>
<td>REAR LUG</td>
<td>2024-</td>
</tr>
<tr>
<td>23</td>
<td></td>
<td>FRONT LUG</td>
<td>2024-</td>
</tr>
<tr>
<td>22</td>
<td></td>
<td>SPAR SHR WEB 0.016” THICK</td>
<td>2024-</td>
</tr>
<tr>
<td>21</td>
<td></td>
<td>SPAR SHR WEB 0.032” THICK</td>
<td>2024-</td>
</tr>
<tr>
<td>ITEM</td>
<td>QTY</td>
<td>DESCRIPTION</td>
<td>MAT'L OR PART #</td>
</tr>
<tr>
<td>------</td>
<td>-----</td>
<td>-------------------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>SPAR SHR WEB 0.05&quot; THICK</td>
<td>2024-T3</td>
</tr>
<tr>
<td>19</td>
<td>4</td>
<td>SPAR SHR WEB 0.125&quot; THICK</td>
<td>2024-T3</td>
</tr>
<tr>
<td>18</td>
<td>4</td>
<td>BUCKLE STIFFNER (#12)</td>
<td>2024-T3</td>
</tr>
<tr>
<td>17</td>
<td>12</td>
<td>BUCKLE STIFFNER (#11)</td>
<td>2024-T3</td>
</tr>
<tr>
<td>16</td>
<td>28</td>
<td>BUCKLE STIFFNER (#10)</td>
<td>2024-T3</td>
</tr>
<tr>
<td>15</td>
<td>44</td>
<td>BUCKLE STIFFNER (#9)</td>
<td>2024-T3</td>
</tr>
<tr>
<td>14</td>
<td>2</td>
<td>REAR SPAR CAP NAS-344-02</td>
<td>2024-T3</td>
</tr>
<tr>
<td>13</td>
<td>2</td>
<td>REAR SPAR CAP NAS-344-32</td>
<td>2024-T3</td>
</tr>
<tr>
<td>12</td>
<td>2</td>
<td>REAR SPAR CAP NAS-344-33</td>
<td>2024-T3</td>
</tr>
<tr>
<td>11</td>
<td>2</td>
<td>FRONT SPAR CAP NAS-344-10</td>
<td>2024-T3</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>FRONT SPAR CAP NAS-344-30</td>
<td>2024-T3</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>FRONT SPAR CAP NAS-344-69</td>
<td>2024-T3</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>WING RIB 72.0&quot; CHORD</td>
<td>2024-T3</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>WING RIB 65.0&quot; CHORD</td>
<td>2024-T3</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>WING RIB 61.5&quot; CHORD</td>
<td>2024-T3</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>WING RIB 58.0&quot; CHORD</td>
<td>2024-T3</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>WING RIB 51.4&quot; CHORD</td>
<td>2024-T3</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>WING RIB 44.7&quot; CHORD</td>
<td>2024-T3</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>WING RIB 38.0&quot; CHORD</td>
<td>2024-T3</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>WING RIB 33.3&quot; CHORD</td>
<td>2024-T3</td>
</tr>
</tbody>
</table>

---

**EMBRY-RIDDLE AERONAUTICAL UNIVERSITY**
**DAYTONA BEACH FLORIDA**

**SIZE**
B 12-06

**DATE**
AS INDICATED

**SCALE**

**DRAWN BY**
ALPHA TEAM

**TITLE**
WING STRUCTURAL LAYOUT

**DRAWING NO.**
F93-2A-104-07

**SHEET**
1/13

DIMENSION TOLERANCES
UNLESS OTHERWISE SPECIFIED
DECIMAL

\[ \pm 0.01 \]

\[ \pm 0.001 \]

ANGULAR
\[ \pm 1/2^\circ \]
FUEL TANK

Detail 1

Detail 2

Tail Boom
DETAIL 3
SCALE: 1/2

W.S. 21

2.60 in.

Detail 3

W.S. 75

5.70 in.

Wing Skin

Stringer

Rib
<table>
<thead>
<tr>
<th>Rib Location and Dimensions for NLF(1)–0414</th>
</tr>
</thead>
<tbody>
<tr>
<td>W.S. (in.)</td>
</tr>
<tr>
<td>21.0</td>
</tr>
<tr>
<td>27.0</td>
</tr>
<tr>
<td>35.0</td>
</tr>
<tr>
<td>42.0</td>
</tr>
<tr>
<td>50.0</td>
</tr>
<tr>
<td>75.0</td>
</tr>
<tr>
<td>87.0</td>
</tr>
<tr>
<td>99.0</td>
</tr>
<tr>
<td>124.0</td>
</tr>
<tr>
<td>147.0</td>
</tr>
<tr>
<td>172.0</td>
</tr>
<tr>
<td>187.0</td>
</tr>
</tbody>
</table>
0.05 in. Thickness 2024-T3

MS20430DD-8
Stringers

0.125 in. Thickness 2024-T3

Center Rib Portion

Front Spar Cap

Front Spar Web

SCALE: 1/2

DATE 12-06  DWG BY ALPHA TEAM  DRAWING NO. F93-2A-104-07  SHEET 5/13
### FRONT SPAR CAP SIZE

<table>
<thead>
<tr>
<th>Wing Stations</th>
<th>Cap Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 - 101</td>
<td>NAS-344-69</td>
</tr>
<tr>
<td>101 - 141</td>
<td>NAS-344-30</td>
</tr>
<tr>
<td>141 - 192</td>
<td>NAS-344-10</td>
</tr>
</tbody>
</table>

### FRONT SPAR WEB THICKNESS

<table>
<thead>
<tr>
<th>Wing Stations</th>
<th>Web Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 - 41</td>
<td>0.125 in.</td>
</tr>
<tr>
<td>41 - 121</td>
<td>0.05 in.</td>
</tr>
<tr>
<td>121 - 161</td>
<td>0.032 in.</td>
</tr>
<tr>
<td>161 - 192</td>
<td>0.016 in.</td>
</tr>
</tbody>
</table>
Rear Spar Cap Size

<table>
<thead>
<tr>
<th>Wing Stations</th>
<th>Cap Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 - 41</td>
<td>NAS-344-33</td>
</tr>
<tr>
<td>41 - 121</td>
<td>NAS-344-32</td>
</tr>
<tr>
<td>121 - 192</td>
<td>NAS-344-02</td>
</tr>
</tbody>
</table>

Rear Spar Web Thickness

<table>
<thead>
<tr>
<th>Wing Stations</th>
<th>Web Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 - 41</td>
<td>0.125 in.</td>
</tr>
<tr>
<td>41 - 121</td>
<td>0.05 in.</td>
</tr>
<tr>
<td>121 - 161</td>
<td>0.032 in.</td>
</tr>
<tr>
<td>161 - 192</td>
<td>0.016 in.</td>
</tr>
</tbody>
</table>
FRONT LUG CARRYTHROUGH ATTACHMENT
FRONT LUG
WING ATTACHMENT
REAR CARRY THROUGH LUG
FULL SCALE

REAR CARRY THROUGH

NAS 1304-4P x 14

0.68 in. 2.00 in.

1.35 in.

1.30 in. 1.75 in.

φ0.437 in.
DETAIL 2
SCALE 1/4

REAR CARRY THROUGH

F.S. 181

MS20430KE-7 x 6

W.L. 39

8.00 in.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Description</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
<td>3</td>
<td>TEE—FIREWALL BOLT</td>
<td>AN8-</td>
</tr>
<tr>
<td>45</td>
<td>1</td>
<td>DOUBLER</td>
<td>2024-</td>
</tr>
<tr>
<td>44</td>
<td>2</td>
<td>NAS341—26</td>
<td>2024-</td>
</tr>
<tr>
<td>43</td>
<td>6</td>
<td>BUCKLE STIFFENERS</td>
<td>2024-</td>
</tr>
<tr>
<td>42</td>
<td>6</td>
<td>BUCKLE STIFFENERS</td>
<td>2024-</td>
</tr>
<tr>
<td>41</td>
<td>1</td>
<td>FWD WINDSHIELD JOINT</td>
<td>2024-</td>
</tr>
<tr>
<td>40</td>
<td>20</td>
<td>FASTENING SCREWS</td>
<td>AN507DD</td>
</tr>
<tr>
<td>39</td>
<td>50</td>
<td>SPlicing RIVETS</td>
<td>AN430D</td>
</tr>
<tr>
<td>38</td>
<td>1</td>
<td>REAR DOOR LATCH C CHANNEL</td>
<td>2024-</td>
</tr>
<tr>
<td>37</td>
<td>924</td>
<td>LOWER SKIN RIVETS</td>
<td>AN456D</td>
</tr>
<tr>
<td>36</td>
<td>1200</td>
<td>UPPER SKIN RIVETS</td>
<td>AN456D</td>
</tr>
<tr>
<td>35</td>
<td>4</td>
<td>NOSE GEAR MOUNTING BOLTS</td>
<td>AN8C-</td>
</tr>
<tr>
<td>34</td>
<td>4</td>
<td>ENG MOUNTING BOLTS</td>
<td>AN8C-</td>
</tr>
<tr>
<td>33</td>
<td>4</td>
<td>ENG MOUNTING BRACKETS</td>
<td>2024-</td>
</tr>
<tr>
<td>32</td>
<td>1</td>
<td>NOSE CONE</td>
<td>GLASS/E</td>
</tr>
<tr>
<td>31</td>
<td>6</td>
<td>UNDER FLOOR CARRY THROUGHs</td>
<td>2024-</td>
</tr>
<tr>
<td>30</td>
<td>1</td>
<td>FIRE WALL</td>
<td>2024-</td>
</tr>
<tr>
<td>29</td>
<td>1</td>
<td>LOWER NOSE GEAR REINFORCER</td>
<td>2024-</td>
</tr>
<tr>
<td>28</td>
<td>1</td>
<td>UPPER NOSE GEAR REINFORCER</td>
<td>2024-</td>
</tr>
<tr>
<td>27</td>
<td>1</td>
<td>RT AFT FUSELAGE SKIN</td>
<td>2024-</td>
</tr>
<tr>
<td>26</td>
<td>1</td>
<td>LOWER AFT FUSELAGE SKIN</td>
<td>2024-</td>
</tr>
<tr>
<td>25</td>
<td>1</td>
<td>UPPER LT AFT FUSELAGE SKIN</td>
<td>2024-</td>
</tr>
<tr>
<td>24</td>
<td>1</td>
<td>UPPER RT MIDDLE FUSELAGE SKIN</td>
<td>2024-</td>
</tr>
<tr>
<td>23</td>
<td>1</td>
<td>LOWER MIDDLE FUSELAGE SKIN</td>
<td>2024-</td>
</tr>
<tr>
<td>22</td>
<td>1</td>
<td>UPPER LT MIDDLE FUSELAGE SKIN</td>
<td>2024-</td>
</tr>
<tr>
<td>21</td>
<td>1</td>
<td>UPPER RT FWD FUSELAGE SKIN</td>
<td>2024-</td>
</tr>
<tr>
<td>ITEM</td>
<td>QTY</td>
<td>DESCRIPTION</td>
<td>MAT'L OR PART #</td>
</tr>
<tr>
<td>------</td>
<td>-----</td>
<td>----------------------------------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
<td>LOWER FWD FUSELAGE SKIN</td>
<td>2024-T3</td>
</tr>
<tr>
<td>19</td>
<td>1</td>
<td>UPPER LEFT FWD FUSELAGE SKIN</td>
<td>2024-T3</td>
</tr>
<tr>
<td>18</td>
<td>1</td>
<td>FRONT BULKHEAD</td>
<td>2024-T3</td>
</tr>
<tr>
<td>17</td>
<td>1</td>
<td>ENG RING FRAME</td>
<td>2024-T3</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>ENG RING FRAME</td>
<td>2024-T3</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>AFT RING FRAME SECTION</td>
<td>2024-T3</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>AFT RING FRAME SECTION</td>
<td>2024-T3</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>MID RING FRAME SECTION</td>
<td>2024-T3</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>MID RING FRAME SECTION</td>
<td>2024-T3</td>
</tr>
<tr>
<td>11</td>
<td>8</td>
<td>RING FRAME BOTTOM CORNERS</td>
<td>2024-T3</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>FWD RING FRAME SECTIONS</td>
<td>2024-T3</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>FWD RING FRAME SECTIONS</td>
<td>2024-T3</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>FLOOR PANEL</td>
<td>2024-T3</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>LONGERON BRAKE FORM C</td>
<td>2024-T3</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>CEILING SUPPORT NAS 344-60</td>
<td>7075-T6</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>HINGE REINFORCER</td>
<td>2024-T3</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>ENG LONGERON BRAKE FORM C</td>
<td>2024-T3</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>LONGERON BRAKE FORM C</td>
<td>2024-T3</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>LONGERON BRAKE FORM C</td>
<td>2024-T3</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>FLOOR BRACE NAS 346-45</td>
<td>7075-T6</td>
</tr>
</tbody>
</table>

**DIMENSION TOLERANCES**

UNLESS OTHERWISE SPECIFIED

<table>
<thead>
<tr>
<th>DECIMAL</th>
<th>TOLERANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>.XX</td>
<td>± .01</td>
</tr>
<tr>
<td>XXX</td>
<td>± .001</td>
</tr>
</tbody>
</table>

**ANGULAR**

± 1/2°
TAIL 4

11

Ground Line

31

SOLLDOUT FRAME

DATE
10-13

DWG BY
ALPHA TEAM

DRAWING NO.
F93-2A-102-07

SHEET
4/10
Top View

Longeron

B.L. 21

B.L. 21

F.S. 180

Side View

1.50in.

1/2 Gus

Rear View

W.L. 69

DETAIL 2

SCALE: 1/2

Gus
NAS 344-60

AN8-10

Top View

1.50in.

AN456DD

F.S. 180

W.L 80

Side View

Fire Wall

DETAIL 3

SCALE: 1/2
DETAIL 5
SCALE: 1/2
AN430DD-8

Top View

AN456DD-4

Side View

AN515DD10

Rear View

Aluminum

DETAIL 4
SCALE: 1/2

DATE 10-13  DWG BY ALPHA TEAM  DRAWING NO. F93-2A-102-07  SHEET 8/10
AN8-10 for all seat belt attachments

---

Note: seat belt installation hardware supplied by manufacturer
Front View

Seat track

Top View

Floor thickness 0.025 in

C channel longeron

NAS 346-45

Stiffeners 0.040 in thick
DETAIL 9
SCALE: 1/4

Under floor carry through C channel

AN509-516
At 1.0 in intervals

AN456DD-6

Ring frame bottom corners

DATE 10-13  DWG BY J. VIEIRA  DRAWING NO. F93-2A-102-07  SHEET 10/10