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AIRCRAFT WING STRUCTURE DETAIL DESIGN

**421S93ADP02-2
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Submitted to:
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**(NASA-CR-195485) AIRCRAFT WING
STRUCTURE DETAIL DESIGN
(Embry-Riddle Aeronautical Univ.)
36 p**

N94-24498

Unclass

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1. Project Summary

The provisions of this project call for the design of the structure of the wing and carry-through **structure** for the **Viper** primary trainer, which is to be certified as a utility **category** trainer under FAR part 23.

The specific items to be designed in this statement of work were 1) **Front Spar**, 2) **Rear Spar**, 3) **Aileron Structure**, 4) **Wing Skin**, and 5) **Fuselage Carry-through Structure**.

In the design of these parts, provisions for the fuel system, electrical system, and control routing were required. Also, the total weight of the entire wing planform could not exceed 216 lbs.

Since this aircraft is to be used as a primary trainer, and the SOW requires a useful life of 10^7 cycles, it was decided that all of the principle stresses in the structural members would be kept below 10 ksi. The only drawback to this approach is a weight penalty.

Summary of Critical Detail Parts

Part Name	Material Used	Stress (max psi)	M.S.	Page	Fasteners
Front Spar cap	NAS341-8	9076	0.102		A D 6 - 1 0
Front Spar web	Al 2024-T4 0.040"	9310	0.074		AD6-10
Rear Spar cap	NAS341-14	42176	0.043		
Rear Spar web	Al 2024-T4 0.040"				
Aileron Spar Cap	Al 2024-T4	1167	0.29		
Aileron Spar web	Al 2024-T4	665	3.0		
Front carrythrough cap	NAS344-69	10000	0.14		AD6-12
Front carrythrough web	2024-T4	7076.5	0.0.196		
Front carrythrough stiffeners	NAS341-6	9900	0.12		AD5-7
Rear carrythrough cap	NAS344-51	10000	0.16		AD6-9
Rear carrythrough web	2024-T4	3042.4	0.016		
Rear carrythrough stiffeners	NAS341-3	10880	0.178		AD4-8
Skin					
Carrythrough attachments	2024-T4	11770	0.25		D6-16

2. Description of Design

2.1 Front Spar

The front spar was designed to make use of the maximum height

available in the wing. It was placed at 25% of the chord line, which allowed it to be 9.5 inches high at the root and 4.5 inches high at the tip.

The front spar was designed to be able to handle all of the lift loads present on the aircraft. The initial sizing was done using the dimensions at the root and the maximum theoretical loadings at the center line of the aircraft. This gave an overly conservative design.

A solid web with no lightening holes was used outboard until the 30% span mark. This allows for an integral fuel tank and provides extra strength for handling the landing gear loads which occur at 30% span.

From the 30% span mark outboard, lightening holes were sized using the maximum loadings at 30%, 60%, and 90%. These calculations yielded 3 inch diameter lightening holes until 75% span, where the holes were reduced to 2 inches. This is based on a stiffener spacing of 7 inches, which was chosen arbitrarily as suggested rib locations and is the same as the stiffener spacing on the rear spar for uniformity.

Due to the height of the spar and the loadings present, the NAS341-8 extrusion was found to be more than adequate as a spar cap.

The spar caps are attached to the web using AD6-10 rivets in a double row with 0.75 inch horizontal spacing between the rivets. The vertical stiffeners are attached to the spar cap using AD6-12 rivets, and are attached to the web using AD5-7 rivets.

2.2 Rear Spar

The rear spar was designed similarly to the front spar. It was placed at the 75% chord point to allow the flap and aileron loads to be transferred directly to it and to provide the largest moment arm possible between it and the front spar.

The first bay, outboard to 30% span, was kept solid for the same reasons as the front spar, except for access holes for the flap linkage.

This rear spar had to be designed to carry part of the lift loads, as well as the shear, bending, and torsional loads induced by aileron and flap deflection.

Since the height of the rear spar is smaller than that of the front spar, larger spar caps were needed to provide the required moment of inertia. In this case, NAS341-14 extrusions were chosen as the spar caps, attached to the web using MS20430D5 rivets spaced 0.8 inches apart, with a total of 400 rivets.

As with the front spar, stiffeners were placed every 7 inches, and the lightening holes were sized to be 1.5 inches in diameter based on this and the 0.040 inch web thickness.

2.3 Carrythrough Structure

The carrythrough structure was designed as a continuation of the front and rear spars. The carrythrough structure had to be designed to carry twice as much loading as the front and rear spar. The carrythrough structure was designed similarly to both the front and rear spars. The structures maintained the same height as each of the spars but were of different web thickness and stiffener

spacing. Also, the structure had to account for the mounting of the engine and the attachment to the fuselage. Finally, the structure had to provide a 1.6° dihedral the wing.

Large width spar caps were chosen to facilitate the mounting of the engine bracket. To attach the structure to the fuselage, a series of AN3 bolts were used in the front and rear spar. These bolts were attached through the four longerons on the bottom of the aircraft and to the bottom spar caps of the front and rear spars.

In attaching the carrythrough structures to the wing spars, an attachment bracket had to be designed. In providing for the dihedral, the lower attachment bracket was designed to be (.25 in for the front and .11 in. for the rear spar) longer than the top attachment bracket. These brackets were machined out of 2024-T4 aluminum. The brackets were then attached to the spars and carrythrough structures using D6 rivets.

2.4 Aileron Structure

The aileron design consists of a built up C channel for the spar of the aileron made of 2024-T3 Aluminum. The aileron is supported by two hinges which connect to the rear spar of the wing and the spar of the aileron at the upper surface. Two end ribs are used as well as three interior ribs to **support** the hinges and give the aileron skin its aerodynamic shape. The web is 0.02 in thick 2024-T3 aluminum which geometrically fits the shape of the aileron. Extruded caps are used as the caps to the spar and are connected to the web by rivets. The aileron actuator was placed on the aileron spar according to a lightening hole in the rear spar.

2.5 Wing Skin

3. Loads and Loadings

The external loadings on the wing structure were determined using the stripwise estimation method outlined in Chapter 3 of the Niu text.

This method yielded a non-dimensional lift distribution over half of the planform, which was multiplied by $n*(W/2)$ to determine the actual loads present.

A curve was faired through the points determined by this estimation, and the lift force at 10% span increments was found from this graph.

This lift distribution is shown in the accompanying graph.

From this, the maximum lift force at the centerline of the aircraft, due to the lift on each half-span, was found to be 3538 lbs., and the maximum bending moment was determined to be 1485 ft.-lbs.

At high angles of attack, these loads were assumed to act at 25% of the wing chord, and at low angles of attack these forces were assumed to move to the 33% chord point.

The front spar was assumed to carry this entire load at high alphas, and 2/3 of this load at low alphas.

At high angles of attack, the rear spar carries none of the primary lift loads, and carries 1/3 of these loads at low angles of attack.

The rear spar also carries the lift loads from the flaps and ailerons, which are transmitted to it at their respective hinge

points.

The ailerons exert a maximum force of 181 lbs. on the rear spar, and the flaps exert a maximum force of 261 lbs. This results in a total force at the rear spar attachment of 1521 lbs. This doesn't account for landing gear loads.

4. Structural Substantiation

4.1 Front Spar

The front spar was designed to handle all of the aerodynamic loads exerted upon the wing. It was initially designed using the dimensions and loadings of the root, and stiffeners and lightening holes were sized from there.

at the root:

$$\text{stress} = My/I$$

$$I(\text{req}) = M*y/(\text{allowable stress})$$

$$= (1485)(12)(4.75)/10000$$

$$I(\text{req}) = 8.46 \text{ in}^4$$

using NAS341-8 extrusions as the spar caps, the **I(actual)** becomes

$$I(\text{actual}) = 9.33 \text{ in}^4$$

$$\text{M.S.} = 0.1$$

with these extrusions, the shear flow is found by

$$q = VQ/I$$

$$= (3538)(4.75 - 0.356)(0.4808)/(9.33)$$

$$= 801 \text{ lb/in}$$

by choosing **AD6** rivets, the required rivet spacing is

$$\text{spacing} = (862)/(801) = 1.08 \text{ in.}$$

using a rivet spacing of 0.75 in yields

$$M.S. = (1.08)/(0.75) - 1 = 0.44$$

The shear flow in the web is given by

$$q = V/h = (3538)/(9.5) = 372 \text{ lb/in}$$

$$t = (372)/(10000) = 0.0372$$

$$t = 0.040$$

Similar calculations were performed at 30% span and at 60% span to ensure the feasibility of these initial choices.

At 30%:

$$V = 2177 \text{ lb.}$$

$$M = 630.5 \text{ ft.-lb.}$$

$$I(\text{req}) = 3.026 \text{ in}^4$$

$$I(\text{actual}) = 7.74 \text{ in}^4$$

$$q(\text{cap}) = 492.7 \text{ lb/in}$$

$$q(\text{web}) = 272 \text{ lb/in}$$

At 60%:

$$V = 984 \text{ lb}$$

$$M = 161.6 \text{ ft.-lb}$$

$$I(\text{req}) = 0.636 \text{ in}^4$$

$$I(\text{actual}) = 4.07 \text{ in}^4$$

$$q(\text{cap}) = 336.5 \text{ lb/in}$$

$$q(\text{web}) = 151 \text{ lb/in}$$

Lightening holes and stiffeners were used from 30% span outboard. Stiffeners were placed arbitrarily at 7 in. intervals. The allowable hole size using 0.040 in. thick sheet for the web worked out to be 4 in. However, due to geometric constraints, this

was reduced to 3 in., with a further reduction to 2 in. at spar station 122.

Composite analysis on web

$$N_{xy} = 3538 \text{ lb}$$

$$GT = 600000 \text{ lb/in}$$

$$ET = 1.5 \times 10^6 \text{ lb/in}$$

Using data from p. 519 of the Niu text, the size of the web is dependant upon the stiffness requirements, which yields 24 plies, 0.005 in thick each, 0.12 in. total thickness

4.2 Rear Spar

$$f = My/I = (12834.2)(2)/(0.1443) = 42176 \text{ psi}$$

$$M.S. = (44000)/(42176) - 1 = 0.043$$

This moment of inertia was obtained using NAS341-14 extrusions.

At 40% outboard, the loads were rechecked and the spar cap changed to a NAS341-13.

$$M = 5208 \text{ in.-lb.} \quad I = 0.1248 \text{ in.}^4$$

$$M.S. = 0.27$$

At 60% outboard, the spar caps were changed again, this time to NAS341-7.

$$M = 1939.2 \text{ in.-lb} \quad I = 0.0348 \text{ in.}^4$$

$$M.S. = 0.2$$

Using D5 rivets, the rivet spacing is

$$(755)/(943) = 0.8$$

$$M.S. = (943)/(681) = 0.39$$

This requires **400 rivets**.

Web thickness

$$t = 0.040$$

$$M.S._{allow} = 8284/8224 - 1 = 0.007$$

$$M.S._{ult} = 60000/(8225*1.5) - 1 = 3.86$$

$$M.S._{yield} = 45000/8225 = 5.47$$

Fatigue analysis

$\%n_{limit}$	# cycles	$f = f_{limit} * n_{limit}$	N	n/N
45	10000	13500		$9 * 10^5$ 0.011
55	3000	16500		$18 * 10^5$ 0.0167
65	1000	19500		$3.5 * 10^4$ 0.0286
75	300	22500		$1.8 * 10^4$ 0.0167
85	200	25500		$1 * 10^4$ 0.02
95	30	28500		$5 * 10^3$ 0.006
105	10	31500		$4 * 10^3$ 0.0025
115	3	34500		$3 * 10^3$ 0.001
125	2	37500		$2.5 * 10^3$ 0.0008

$$D = 0.10037$$

$$\begin{aligned} \text{safe life} &= (1/D) * (1000) / (\text{scattor}) \\ &= (1/0.10037) * (1000) / (3) \\ &= 3321 \text{ flight hours.} \end{aligned}$$

4.3 Carrythrough Structure

4.3.1 Front Spar

Shear Calculation

$$V = 3538.2 \text{ lb (from wing loading)}$$

$$h = 9.5 \text{ in.}$$

$$V_{tot} = 7076.4 \text{ lb.}$$

$$q = V_{tot}/h = 7076.4/9.5 = 744.9 \text{ lb/in} = q$$

*** use 2024-T4 Al**

$$\text{*assumed} \quad h = 9.5 \text{ in.} \quad D = 4.0 \text{ in.} \quad b_s = 10 \text{ in.}$$

Table 4.1.1

t	b_s/t	F_c	K_2	F_s	f_s
.05	200	6800	1.38	9384	14898
.063	159	8100	1.19	9639	11824
.071	141	9000	1.08	9720	10492
.08	125	9500	0.98	9310	9311
.09	111	11000	0.9	9900	8278

(From Niu text pg. 169)

Fig. 4.1.1

t = 0.09 in.

$$\text{M.S.} = 9900/8278 - 1 = \mathbf{0.196 = M.S.}$$

Stiffener Area

These equations are taken from the Niu text ex.#2
pg. 169 & 170.

$$A_c = b_s(t) \{ .385 - 0.08(b_s/h)^3 \}$$

$$A_c = \sim$$

* This equation provided a negative area.

$$A_{req} \quad \text{let } t_o = t = .09$$

$$b_{o1}/t_o = 9 \quad b_{o2}/t_o = 12$$

$$b_{o1} = 9(.09) = 0.81$$

$$b_{o2} = 12(.09) = 1.08$$

$$A_{c:req} = (.81+1.08)(.09) = \mathbf{0.1701 = A_{o:req}}$$

Inertia of Stiffeners

$$I_o = F_s t b_s h^2 / 10^6 (h-D)$$

$$= 9900 (.09) (10) (9.5)^2 / 10^6 (9.5 - 4.0)$$

$$I_o = 0.00139 \text{ in.}^4$$

This is the minimum moment of inertia required for the stiffeners.

Actual I_o

$$= t_o b_o^3 (4b_{o1} + b_{o2}) / 12 (b_{o2} + b_{o1})$$

$$I_{creq} = \mathbf{0.0216 \text{ in.}^4} > \text{minimum inertia.}$$

* Use stiffener to fit required moment of inertia

NAS341-6

Web-to-Flange Riveting Strength

$$q_r = 1.25 F_s t (h/h-d)$$

$$= 1.25 (9900) (.09) (9.5/9.5-4.0)$$

$$= \mathbf{1923.8 \text{ lb/in} = q_r}$$

* use **AD6** rivets, double row, spaced 0.8 in.

$$q_{r(all)} = 862(2)/0.8 = 2155 \text{ lb/in}$$

$$\text{M.S.} = 2155/1923.8 - 1 = \mathbf{0.1201 = M.S.}$$

Web-to-Stiffener Rivet Strength

$$P_{st} = .0024 A_o F_o b_s/t (h/h-D)$$

$$P_{st} = .0024 (.2003) (9900) (10) (9.5/5.5) / .09$$

$$\mathbf{P_{st} = 940.7 \text{ lb}}$$

* use **AD5** rivets .75in. spacing

$$P_{st} = 596(2) = 1192 \text{ lb}$$

$$\text{M.S.} = 1192/940.7 - 1 = \mathbf{0.267 = M.S.}$$

Equivalent-Weight Thickness (web)

$$t_{eq} = t(1 - 0.785 D^2/b_s h + A_o/b_s t)$$

$$t_{c,q} = 0.0987 \text{ in.}^2$$

Spar Caps

$$\text{Stress} = M y / I = 1485.6(12)(2)(4.75) / I_y = 10^3$$

$$I = 16.94 \text{ in.}^4$$

* using parallel axis theorem and assume a cap area and thickness.

use NAS 344-69 extrusion

Note: this is very overdesigned, but the width of the extrusion provides attachment space for the fuselage and engine mountings.

4.3.2 Rear Spar

Use the same analysis as the front spar...

$$V = 1521.2 \text{ lb}$$

$$t = 0.071$$

$$D = 1.0 \text{ in.} \quad h = 4.0 \text{ in.} \quad b_s = 5 \text{ in.}$$

$$\text{M.S. (web)} = 0.016$$

$$\text{Stiffener area required} = 0.1344 \text{ in.}^2$$

$$\text{Actual inertia of stiffener} = 0.0135 \text{ in.}^2$$

use NAS341-3 spar caps

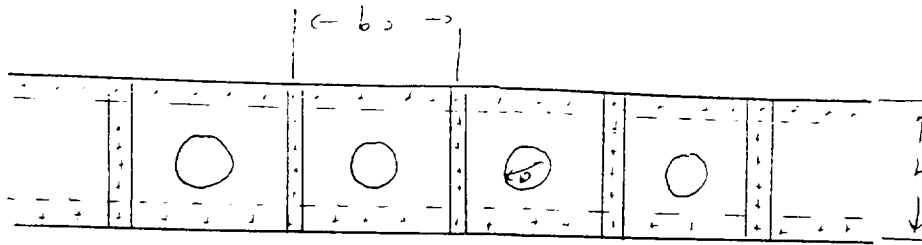


FIG. 4.1.2

Web-to-Flange Rivet Strength

Use **AD6** double row spaced 1.25 in.

M.S. = 0.071

Web-to-Stiffener Rivet Strength

use **AD4** rivets 5/8 in. spacing

M.S. = 0.178

Equivalent web thickness

$t_{eq} = 0.095 \text{ in.}^2$

Spar Caps

use **NAS344-51** for caps

4.3.3 Attachment to Wing Spars

use 2024-T4 Al

$V = 3538.2 \text{ lb}$

use **AN8** bolts in double shear

$f_s = 11770.5 \text{ lb/in}^2$

$f_{s(ult)} = 14700 \text{ lb/in}^2$

M.S. = 0.25

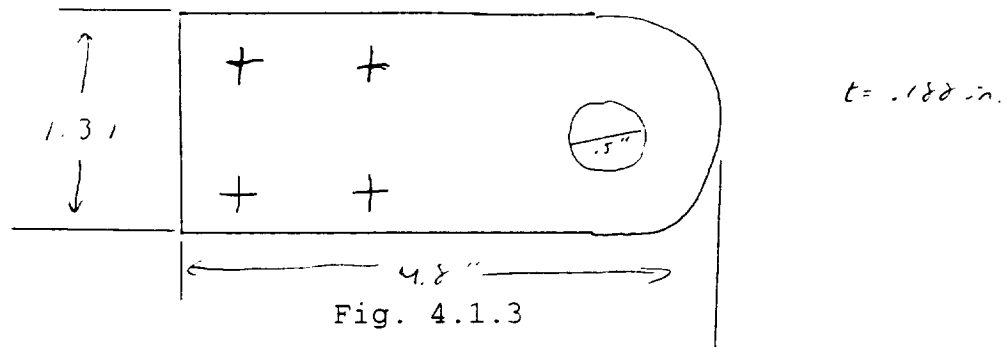
M.S. (tension) = 4.73

M.S. (bearing) = 3.29

M.S. (tear-out) = 4.27

M.S. (rivet) = 0.0355

* Note: bottom attachment must be .25 longer on the front spar and .11 longer on the rear spar.



4.3.4 Composite Analysis

This is a copy of example of #2 pg. 519 in the Niu text.

$$N_x = 0$$

$$N_y = 0$$

$$N_{xy} = 744.9$$

$$G_T = 600000 \text{ lb/in}$$

$$E_T = 1.5 \times 10^6 \text{ lb/in}$$

Shear Requirement

of +/- 45° plies

$$N_{xy} / (t F_{12}) = 744.9 \text{ lb/in} / (.005 \times 38000)$$

4.3.5 Aileron Structure

Web

$$\text{shear} \quad f_s = V / ht$$

$$V = 90.5 \text{ lb}$$

$$h = 3.5 \text{ in}$$

$$f = 34000 \text{ psi}$$

$$t = 0.00076 \text{ inch}$$

Use thickness skin = 0.02 in

buckling $f_{crit} = (3.1415)^2 k_c E / 12(1 - \nu_p^2) (t/b)_2$

$k_c = 4.0$ from Bruhn

$\nu_p = 0.3$

$E = 10.6E6$

$f_{crit} = 665.3 \text{ lb}$

Caps

compression $f_c = My/I$

$M = 778 \text{ inlb} \times 1.5$

$y = 2.4 \text{ in}$

$f_c = 38000 \text{ lb}$

$I = 0.0737$ use Cap with $I = 0.0776$

Skin

torque $f_s = T/2At$

$T = 4675.0 \text{ inlb}$

$A = 21 \text{ in}^2$

$f_s = 39000 \text{ lb}$

$t = 0.00286$ use 0.02 in thick skin

4.3.6 Composite Investigation

Composite investigation for the aileron skin

$F_y = 13110 \text{ lb}$

$F_x = 0.0 \text{ lb}$

$F_{xy} = 5565 \text{ lb}$

for 45° plies $N_{xy} = n^{45} \times t \times F_{12}$

$$5565 \text{ lb/} (0.005)(38000) = 29.8 \text{ plies}$$

$$\text{for } 90^\circ \text{ plies } N_y = F_{2245} \times t_{45} / t \times F_{11} = n^{90}$$

$$13110 = (15000)(0.005)(30) / (0.005)(98000) = 22.16 \text{ plies}$$

for 0° plies $F_x = 0$ therefore use 10% of total number for stability

$$45^\circ \text{ plies} = 30 \text{ plies}$$

$$90^\circ \text{ plies} = 23 \text{ plies}$$

$$0^\circ \text{ plies} = 5 \text{ plies}$$

5. Manufacturing and Maintenance

When assembling this wing, the wing structure alone should be assembled first, including the skin and ailerons, and then it should be attached to the carrythrough structure within the fuselage.

The front and rear spars are constructed of thin aluminum sheet with extrusions riveted to them. It is recommended that the web be cut to dimension first, including cutting lightening holes, and then the spar caps and stiffeners riveted to the web.

The spar assemblies can be covered with skin and the ailerons then attached to the rear spar.

Manufacturing of the ailerons begins with the making of the spar which is a built up C channel. A 0.02 inch thick sheet of 2024-T3 aluminum is cut to the proper dimensions to serve as the web of the spar. The extruded L sections used for the caps are then riveted to the sheet according to the design

drawings. Five ribs, which can be hydropressed, are connected perpendicular to the spar to give the skin of the aileron its airfoil shape. For the skin two sheets of 2024-T3 aluminum is again used at 0.02 inches thick for both the upper and lower half of the skin. Two hinges are used at 25 and 75% span of the aileron to connect the aileron itself to the rear spar of the wing. No access panels are incorporated into the aileron design because interior parts do not need to be inspected on a regular basis.

This manufacturing process seems to be the most reasonable. A built up C channel is cheaper to make than an extruded C section because of the changing height of the web. From the composites calculation a composite structure could work for the skin but it was felt that this would add to much cost to the aircraft and also a primary trainer would be subjective to frequent inspections and unusual loading. With these considerations aluminum pieced together would be more logical.

From this, all that remains is bolting the wing structure to the carrythrough.

6. Cost Analysis

7. Weight summary

Front spar- 22lbs.

Rear Spar-

Carrythrough- 16.37 lbs

Aileron-

caps 2 at 2.8 lbs each	5.60 lbs
web 1 at .1505 lbs	0.31 lbs
ribs 5 at 0.0541	0.27 lbs
skin 2 at 1.86	3.72 lbs
rivets 1 lb	1.00 lbs
total aileron weight half span	10.90 lbs

Skin-

Total half span weight =

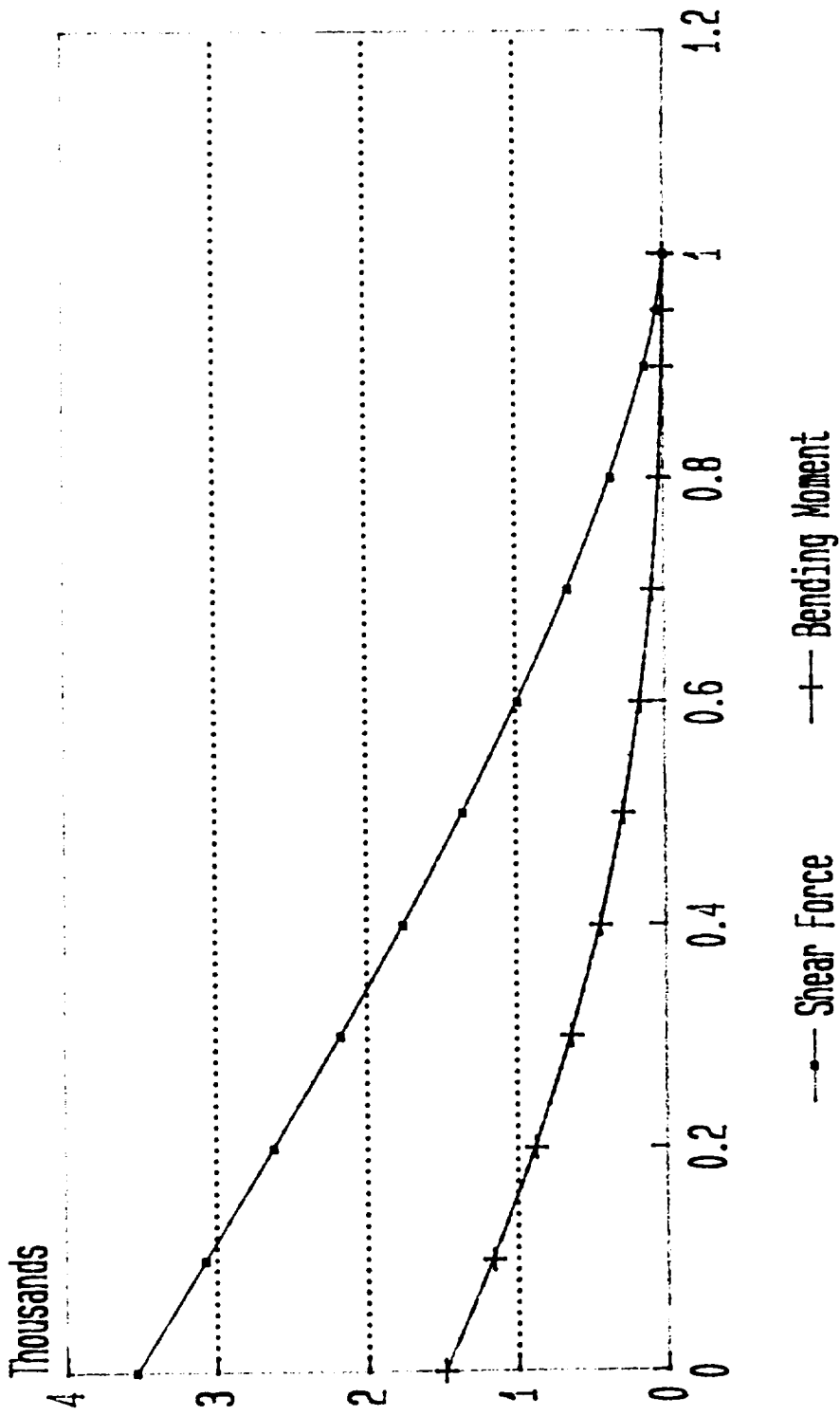
Total planform weight=

8. Conclusions

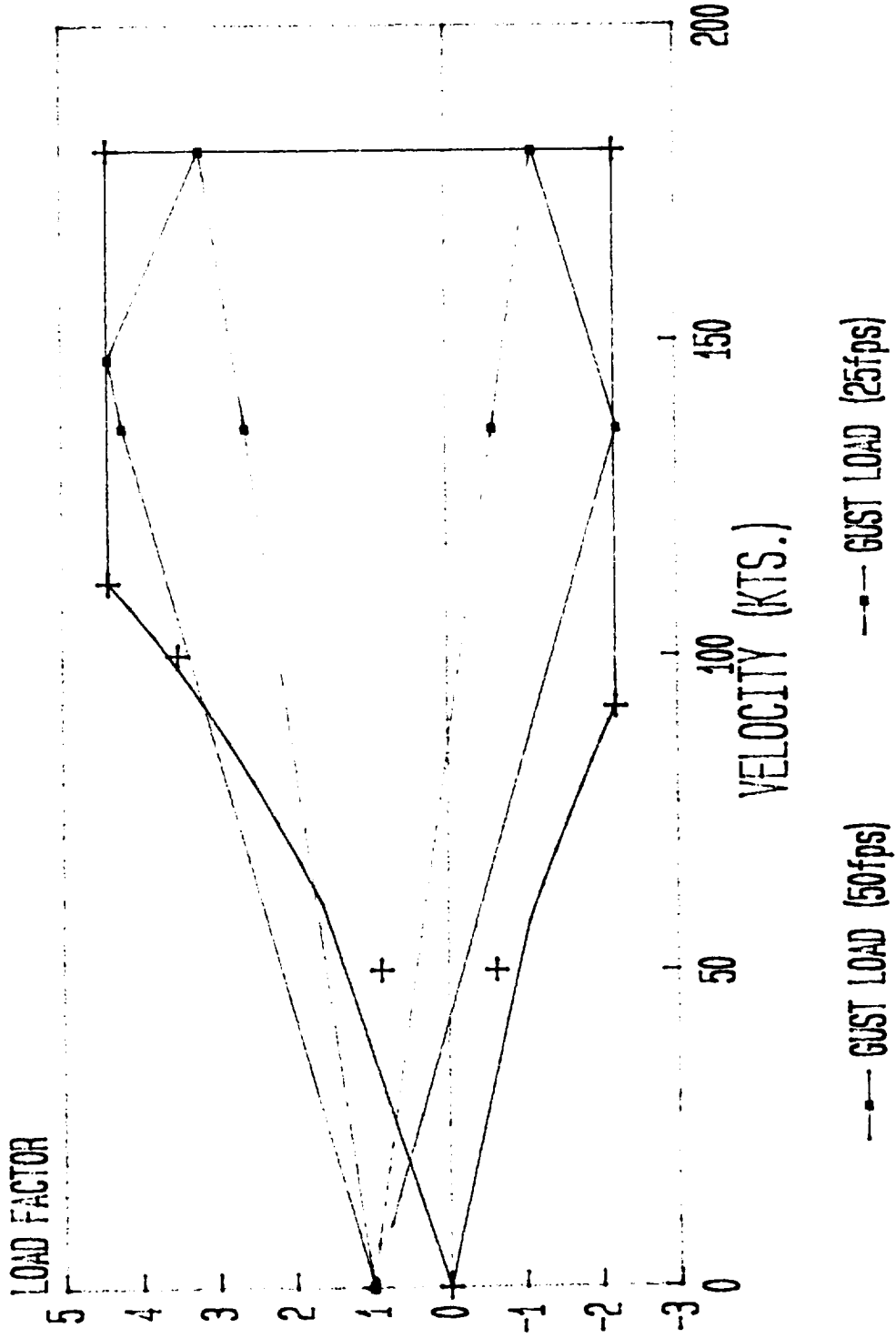
Due to the time constraints, complete optimization analysis was not possible. This resulted in a structure that would be slightly over the minimum possible weight to carry the loadings present.

Also, many of the detail parts were chosen based on conservative assumptions, since this aircraft will be used as a trainer and is destined for abuse unknown to other types of aircraft. Again, this results in a conservative design which satisfies the FAR "fail-safe" requirement.

Shear and Bending Distribution Half-Spanwise



V-N DIAGRAM



AIRCRAFT WING STRUCTURE DETAIL DESIGN

Report Additions: Wing Skin

421S93ADP02-2

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04/16/93

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2.5 Wing Skin

The wing skin carries the torque load created by the 1) lift distribution 2) moment about the mean aerodynamic chord and 3) flap and aileron hinge forces. The center of torque was assumed to be at 40% of the chord by Niu (pg.85) suggestion. The torque loading varies parabollically from 0.0 at the wing tip to a maximum value at the root, the hinge reactions from the flaps and ailerons were modeled as point loads (see Appendix: graph 3).

The shear flow calculations indicated that a very thin aluminum skin would provide the needed shear flow path. However a 0.02in. skin was selected to avoid wrinkling, meet environmental condition requirements, and aid in easy manufacturing and assembly.

4.5 Wing Skin

The wing skin provides the reaction for the wing torque created by the aerodynamic loads which acts about the 40% chord. The shear flow at 1) the root 2) the midspan and 3) slightly in-board of the tip are the critical positions for determining skin thickness and rivet spacing.

In-board of Tip:

$$q = T/2A (568 \text{ lbs.})/2*(41.6) = 6.83 \text{ lbs./in.}$$

$$\text{Rivets} = \text{MS20470AD-3} \quad \text{From Mil-HB5 } f_s = 217 \text{ lbs.}$$

$$\text{Recommended Spacing: } 217 \text{ lb}/6.83 \text{ lbs/in} = 31 \text{ in.}$$

This large calculated rivet spacing is due to the reduction of torsion to zero at the tip.

$$\text{Selected Spacing: } 4.0 \text{ in.}$$

At midspan (Skin over-lap):

$$T = 10,260 \text{ in-lbs.} \quad \text{Area} = 108 \text{ in}^2$$

Same rivet and math as above,

$$q = 47.5 \text{ lbs/in.} \quad \text{Calculated spacing} = 4.6 \text{ in.}$$

$$\text{Selected spacing} = 2.5 \text{ in.}$$

$$\text{Spacing M.S.} = 2.5/4.6 - 1 = 0.45$$

At Wing Root:

$$T = 28,061 \text{ in-lbs.} \quad \text{Area} = 208 \text{ in}^2$$

Same rivet and math as above,

$$q = 67.5 \text{ lbs/in.} \quad \text{Calculated spacing} = 3.2 \text{ in.}$$

$$\text{Selected spacing} = 2.0 \text{ in.}$$

$$\text{Spacing M.S.} = 2.0/3.2 - 1 = 0.38$$

Skin Thickness Selection:

Due to the low torsional load on the wing a very thin skin could be used however it would be extremely fragile. Therefore a thickness of 0.020in was selected. This thickness provides 34×10^3 psi. which greatly exceeds the maximum shear at the root of 2,700psi.

Weight Estimation:

Skin weight is determined from the volume of Al sheet plus the estimated weight of the rivets.

$$\text{Volume of Al skin matterial} = 476 \text{ in}^3$$

$$\text{Weight} = (\text{volume}) * (\text{density}) = (473) * (0.0984)$$

$$\text{Weight of skin} = 46.8 \text{ lbs.}$$

$$\text{Weight of rivits} = 8.0 \text{ lbs.}$$

$$\text{Total Weight} = \underline{\underline{54.8 \text{ lbs.}}}$$

Composite Analysis

4.5 Wing Skin Composite Analysis

This method of determining the type and number of plies of composite was determined by the method presented in Nui pg.519. To handle the shear load +/- 45⁰ plies were used.

$$N_x = 0 \qquad N_y = 0 \qquad N_{xy} = 67.5 \text{ lbs./in.}$$

$$\begin{aligned}\text{Number of } +/- 45^{\circ} \text{ plies} &= N_{xy} / t * F_{12} \\ &= 67.5 / (.005)(3.8\text{ksi}) \\ &= 9 \text{ plies of } +/- 45^{\circ}\end{aligned}$$

The use of graphite composites for the wing skin would provide a weight reduction of 15%, however the cost of manufacturing would increase to an unacceptable level for the mission requirements of the PFT Viper.

5.5 Manufacturing and Maintenance of Wing Skin

The wing skin consist of five separate panels that will be riveted to the spars, ribs and each other. The four panels the cover the upper and lower planform will be cut from 4'x8' Al sheets, the outboard panel will be installed first so that the inboard panel over-laps the out-board panel by about 3.0inches. The final panel will be a 3'x16' sheet that will be hand formed around the leading edge. To avoid flow spoilage no rivets will be used on the nose of the airfoil and as few as possible in the region near the leading edge, approximately 2in. away.

The four wing skin panel will be riveted to the front and rear spar, the ribs spaced 7.0in. apart and at the over lap point. The rivet spacing determined near the root (high stress area) should be 2.0 in., near the midspan (panel over-lap) 2.5 in., and near the wing tip 4.0 inches. The skin will be fastened to the ribs by 425 MS2047AD-3 rivets and to the front and rear spar by 218 rivets; the rivet edge distance will be 0.25 in. Note the number of parts listed above is for a semi-span, multiply by 2 for the total number of parts for the entire wing.

The wing skin will be painted to protect the material and meet the environmental requirements set in the Statement of Work #2. , See Appendix for Environmental Conditions.

8.1 Wing Skin Conclusion

The low wing torque created by the 1) lift distribution, 2) moment about the mean aerodynamic chord and 3) flap and aileron hinge forces permits a very thin skin which is extremely difficult to work with, so a durable and standard size Al sheets were used. The protective coating (paint) on the skin will meet the environmental requirements set in the Statement of Work #2.

Unfortunately the target wing weight of 216 lbs. was not achieved. Based on the findings in this report the wing designed by Team #2 is a suitably strong, rigid and light wing structure that is well suited for the Primary Flight Trainer Viper.

Appendix A

Environmental Conditions

1. Temperature

All modes of operation and storage shall not be degraded for temperatures from -40°F to $+122^{\circ}\text{F}$.

2. Atmospheric Pressure

Operation to 10,000 feet (ICAO Std.) shall be possible.

3. Sand and Dust

External surfaces, mechanisms and associated items shall endure up to 150 microns in size and combinations of sand and dust in concentrations up to 0.041 grams per cubic foot without degradation.

4. Rain

All external surfaces, mechanisms and associated items shall endure and seal against water intrusion from rainfall at a rate up to 4.0 inches/hour with wind velocities up to 50 mph. Any cavities that could hold water shall be provided with a drain.

5. Humidity

External surfaces, mechanisms and associated items shall endure up to 100 percent relative humidity at $+95^{\circ}\text{F}$ without degradation.

6. Ice

All external surface, mechanisms and associated items shall endure ice at temperatures to -40°F and remain operational.

7. Snow

All horizontal external surface, mechanisms and associated items shall endure accumulations for depths up to 8.0 inches of wet snow.

8. Salt/Fog Atmosphere

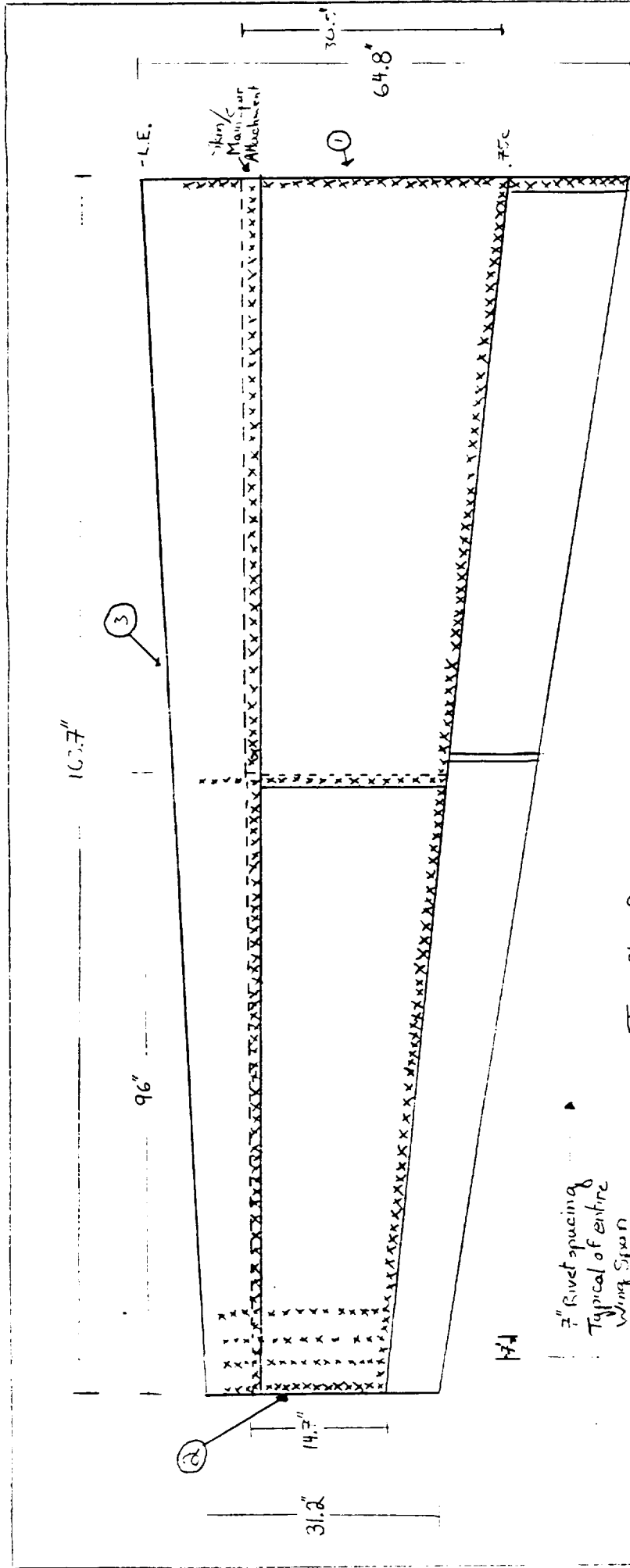
All external surface, mechanisms and associated items shall withstand prolonged exposure to salt/fog atmosphere as encountered in coastal areas without degradation in performance. there shall be no binding of moving parts nor corrosion that obstructs operation.

9. Wind and Gust

Wind of 50 mph with gust in accordance with FAR23 shall not degrade operation. Ground tie downs shall withstand loads associated with a wind of 120 mph from any lateral direction and from elevation/depression angles of up to 10 degrees.

10. Shock and Vibration

The airplane structure designed shall withstand shock vibration loads associated with normal operation and storage in accordance with FAR23 section 2.1 .



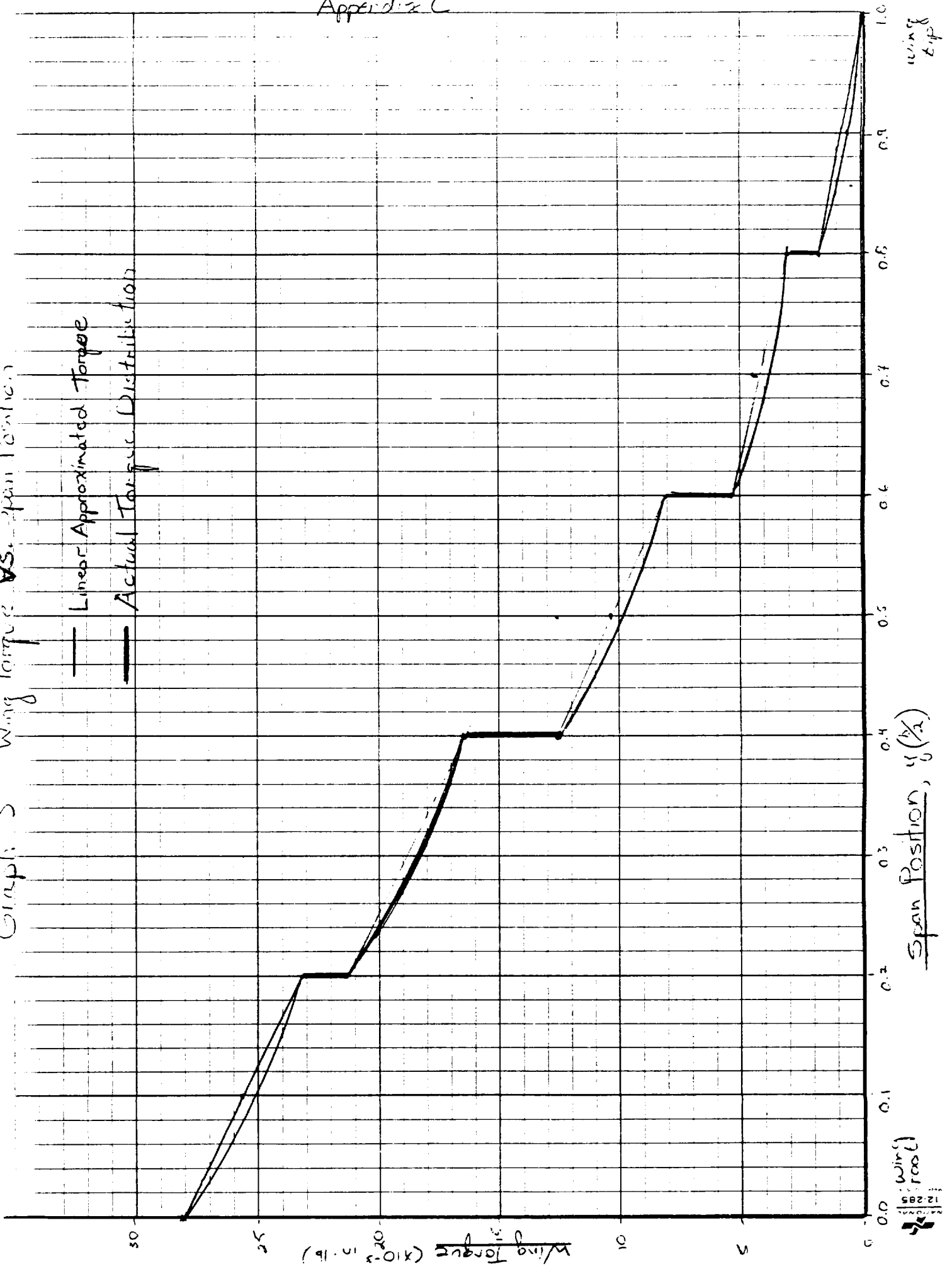
Part #	Description	Quantity
M-2012 40-3-4	Rivets for Wing skin Attachment	643
3	Leading Edge panel A-sheet 16 x 3' x 0.02'	2
2	Out board panel 4' x 8' x 0.02"	2
1	In board panel 4' x 8' x 0.02'	2
ERAU		
Size A	Part 4-16	Scale B Steinbach
Title Wing Skin Attachments		
Date 11-1-51		Sheet ①

Appendix C

Graph 3 Wing Torque vs. Span Position

— Linear Approximated Torque

— Actual Torque Distribution



```

program torque
dimension pos(12),sz(12),deltasz(11),dny(11),ny(11)
do 100 n=1,12
write(6,*),'enter span position, vertical shear force'
read (5,*) ,pos(n),sz(n)
100 continue
do 200 n=1,11
deltasz(n)=sz(n)-sz(n+1)
dny(n)=deltasz(n)*0.15*(69.36-38.3*pos(n))
200 continue
mom=0.0
do 400 k=1,11
do 300 l=k,11
mom=mom+dny(l)
300 continue
ny(k)=mom
mom=0.0
400 continue
write(6,*),'position      DeltaSz      dny      My'
do 500 j=1,11
write(6,450),pos(j),deltasz(j),dny(j),ny(j)
450 format (1x,f8.2,' ',f8.2,' ',f8.1,' ',f10.2)
500 continue
end

```

Chord length

This program calculates the moment created by the lift distribution.

Script started on Wed Apr 7 16:13:41 1993

a.outsun2%

enter span position, vertical shear force

0.3538.2

enter span position, vertical shear force

.1,3074

enter span position, vertical shear force

.2,2618.7

enter span position, vertical shear force

.3,2176.7

enter span position, vertical shear force

.4,1754.3

enter span position, vertical shear force

0.5,1354.8

enter span position, vertical shear force

.6,984.3

enter span position, vertical shear force

.7,650.2

enter span position, vertical shear force

.8,360.3

enter span position, vertical shear force

.9,125.9

enter span position, vertical shear force

.95,37.5

enter span position, vertical shear force

1.0

position	DeltaSz	dmy	My
0.00	464.20	4829.5	0.00 29275
0.10	455.30	4475.4	0.00 29445.5
0.20	442.00	4090.7	0.00 19970
0.30	422.40	3666.6	0.00 15879.4
0.40	399.50	3238.3	0.00 12712.8
0.50	370.50	2790.4	0.00 8974.5
0.60	334.10	2324.3	0.00 6154.1
0.70	289.90	1850.3	0.00 3065
0.80	234.40	1361.4	0.00 2009.5
0.90	88.40	462.6	0.00 648.1
0.95	37.50	185.5	0.00 185.5

sun2% exit

sun2%

script done on Wed Apr 7 16:16:37 1993