Walt Lounsbery

CHAPTER V

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5.1. STRUCTURES

5.1.1 Structural Requirements

The RPV structure had to be configured around many requirements including take-off and landing and manuevering flight loads, propulsive system demands and stability and control while providing an excellent platform for the mission equipment. At the same time, it was necessary to keep the production costs to a minimum, build in a high degree of maintainability and keep the structural weight down to a point that allowed the mission objectives to be met. Obviously, trade-offs were necessary and these are presented here to indicate the philosophy used in this design phase.

From the beginning, a rocket-assisted take-off was used for take-off load estimation. A 3-5g acceleration gave the necessary take-off performance but produced large structural loads in the longitudinal direction. This indicated a need for internal bracing to support internal components (fuel tanks, electronics, power plant, etc.). Furthermore, the take-off load was applied by the rocket-powered sled (or hydraulic catapult) to a hook toward the front of the underside of the vehicle resulting in a very concentrated load on the structure (≈ 1000 lbs.). Similarly, on landing a rear hook would snare a horizontal net to bring the craft to a stop (and also the forward hook was to prevent the RPV from being ejected backwards off the net in a sling-shot manner). In order to come to a stop in a reasonable distance, decelerations on the order of 5 g's were necessary resulting in a similar load being placed on the rear hook as the front hook encountered on take-off.

In flight, the loads act primarily along the RPV's vertical axis in both the positive and negative directions. To be manueverable, the aircraft must be able to execute sharp manuevers such as pull-ups, push-overs, and tight horizontal turns. This would allow "close in" flying (road or river following, tree-top flying, etc.) that would make the aircraft harder to detect and track and thus, to bring down. For this reason, the goal of +8 g's to -5 g's was set. This also carried over to the ability to take the large gust loads which could well be encountered in a battlefield zone.

To provide for maximum longitudinal stability throughout the flight envelope called for a well-placed c.g. as well as small c.g. travel for all mission profiles. Flexibility in locating mission equipment in the nose due to the availability of a large volume with which to work with inside the revolved NACA 0018 airfoil helped in this matter. Judicious choices in propulsion system locations, fuel tank locations, and horizontal tail location and size produced the longitudinal stability desired.

5.1.2 Candidate Construction Methods

The size of this RPV (15 ft. wing span) is about half the size of a general aviation airplane and about twice the size of a radio-controlled model airplane. This would seem to indicate that construction techniques from either might be employed. For this reason, metal skin over metal ribs and spars was compared with fiber-reinforced epoxy over a foam core for the RPV construction.

The conventional construction technique (metal skin over metal ribs and spars) has been used for over four decades and has provided aircraft with a rugged though fairly expensive structure. Unfortunately,

it provides a large radar return, usually requires a protective coating (paint), has a large weight penalty and does not conform well to aerodynamic shaping. The latter problem has led to many aircraft having less efficient wing sections in order to reduce manufacturing problems and consequently, costs.

The use of fiber-reinforced epoxy (typically fiberglass) skins over foam cores was a recent addition to the construction scene for R-C modelers. This technique has drastically reduced construction time, tools and complexity while keeping the costs down and the durability and maintainability high. These advantages plus the fact that the result is a light, easily manufactured article that has no radar return makes this method quite attractive. However, this type construction will not carry the concentrated loads created by the rigors of take-off and landing the RPV nearly as well as the conventional construction. For this reason, a compromise was searched for to minimize this problem while maintaining the advantage of the epoxy-foam combination.

5.1.3 Wing

5.1.3.1 Wing Configuration

The wing chosen was the NACA 4412 airfoil with an elliptical planform for low induced drag. This was economically feasible from a manufacturing point of view only if a fiber-reinforced epoxy skin was utilized. Many candidate fibers were reviewed (Table 5.1-1)[1] and the strength-to-weight ratios of the better ones compared with other materials[2] in Table 5.1-2. These, along with the vibrational damping characteristics[3] (Table 5.1-3) and excellent resistance to chemicals[3] (Table 5.1-4), pointed to Du Pont's Kevlar 49 aramid

Type →	Acrylics							Polyolefins		
	Polyacrylonitrile (Orlon)	Acylonitrile Vinyl Chloride Derivatives	Acrylonitrile Vinyl Chloride (Dyne)	Modified Acrylic (Verel)	Acrylonitrile Base (Creslan)	Dinitrile[a] (Darvan)	Nitrile[b] Alloy (Zefran)	Polyethylene Type I	Polyethylene Type II	Polypropylene
NATURE OF FIBER										
Form	Staple	Staple	Staple	Staple	—	—	—	Monofilament		Monofil.
Length, in.	—	—	—	—	—	—	—	—		—
Width,	14-27	15-30	—	—	—	—	—	250-1300		—
Cross Section	Dogbone	—	—	—	—	—	—	Circular		Circular
PROPERTIES[c]										
Spec. grav.	1.14	1.17	1.3	1.37	1.17	1.18	1.19	0.92	0.95-0.96	0.90-0.91
Breaking Tenacity, gm/den	2.2-2.6	2.5	2.5-3.3	2.5-2.8	3.3	1.75	3.5	1.0-3.0	5.0-7.3	5.5-7.0
Wet	1.8-2.1	2.0	2.5-3.3	2.4-2.7	3.3	1.5	3.1	1.0-3.0	5.0-7.3	5.5-7.0
Ten Str, 1000 psi	32-39	37-40	40-57	42-47	41	26	53	11-35	50-90	—
Breaking Elong, %	20-28	36	30-42	33-35	32	30	33	20-80	10-40	12-25
Wet	26-34	44	30-42	32-34	32	30	33	20-80	10-40	—
Stiffness (avg), gm/den[d]	10	7	8.2	8.0	10.3	6	11	2-12	20-50	—
Strain Recovery[e]	—	99, 89 (5%)	94	88 (4%)	90 (1%)	100 (3%)	99, 72 (10%)	90-95 (5%)	Slow	—
(at 2%), %				55 (10%)	48 (5%)	75 (5%)				
Toughness (avg), gm-cm/den-cm	0.40	0.46	0.53	0.46	0.53	0.3	0.58	0.3	—	—
Moisture Regain, %	1.5	1.2	0.3-0.4	3.5-4	1.3	2-3	2.5	None	None	—
CORROSION RESISTANCE										
Strong Acids	Good-exc.	Good-exc.	Good	Exc.	Good-exc.	Good-exc.	Exc.	Exc. to all but oxidizing acids		Sim. to polyethylene
Weak Acids	Exc.	Exc.	Exc.	Exc.	Exc.	Exc.	Exc.			
Strong Alkalies	Poor	Poor	Good	Discolors	Poor	Poor	Fair	Exc.	Exc.	Exc.
Weak Alkalies	Fair-good	Fair-good	Exc.		Fair-good	Fair-good	Good	Exc.	Exc.	Exc.
Heat	Soft at 455 F	5% shrinkage at 487 F	Unless HT,[f] shrinks 250 F	Stiffens above 300 F	Sticks at 450 F[g]	Sticks at 450 F[g]	Sticks at 490 F[g]	Melts 225 F	Melts 265-280 F	Melts 325-335 F

[a] Though not an acrylic (actually a polymer of vinylidene cyanide) it is listed here because of similar properties. [b] Nitrile alloy based on acrylonitrile. [c] 70 F, 65% RH, unless otherwise noted. [d] Ratio of breaking stress to breaking strain (i.e., gm/den to rupture divided by strain in cm/gage cm at breaking stress). [e] Recovery after 2% strain, except where specific percentage is given in parentheses. [f] Heat treated. [g] Copper block method.

Type →	Nylon							Cellulose Esters	
	6/6			6			Qiana	Cellulose Acetate	Cellulose Triacetate (Arnel)
	Regular	High Tenacity	Staple	Regular	High Tenacity	Staple			
NATURE OF FIBER									
Form	Filament Cont.	Filament Cont.	Staple —	Filament Cont.	Filament Cont.	Staple —	Filament Cont.	Fil, Staple —	Fil, Staple —
Length, in.									
Width, μ	11-43	16-43	14-43	—	—	—	19-35	11-46	—
Cross section	Round	Round	Round	Round	Round	Round	Trilobal	Clover Leaf	Clover Leaf
PROPERTIES[a]									
Spec Gravity	1.14	1.14	1.14	1.14	1.14	1.14	1.03	1.32	1.3
Breaking Tenacity, gm/den	4.6-5.9	5.9-8.8	4.0-4.7	4.5-5.8	6.8-8.6	3.8-5.5	2.7-3.8	1.3-1.5	1.2-1.4
Wet	4.0-5.2	5.1-7.6	3.5-4.2	4.3-5.3	5.4-7.5	—	—	0.8-1.2	0.8-1.0
Ten Str, 1000 psi	67-86	86-128	58-69	73-84	109-125	70-80	35.5-50.0	22-28	20-26
Breaking elong, %	26-32	18-28	38-42	24-34	16-17.5	37-40	26-36	23-34	22-28[b]
Wet	30-37	21-32	42-46	28-38	19-24	42-46	—	30-45	30-40
Stiffness (avg), gm/den[c]	—	—	—	—	—	—	7.5-15.0	5.5	5.2
Strain recovery[d] (at 2%), %	100, 100	100 (4%)	—	—	100, 100	100 (4%)	100	48-65 (4%)	88 (3%) 43 (10%)
Toughness (avg), gm-cm/den-cm	0.76	0.85	0.87	0.67	0.75	0.64-0.78	0.85-1.0	0.17	0.16
Moisture Regain, %	4.5	4.5	4.5	4.0	4.0	4.0	2.5	6	3.2
CORROSION RESISTANCE									
Strong Acids	Dissolves in cold HCl, H_2SO_4 and HNO_3			Degraded by oxidizing agents & mineral acids			Depends on conc.	Decompose	Decompose
Weak Acids	Ult disintegration in 5% boiling HCl			Weakens on prolong. exp. to benzoic and oxalic acids			Excel.	Decompose	Decompose
Strong Alkalis	Substantially inert			Substantially inert			Excel.	Saponifies, Res (cold) similar to viscose.	
Weak Alkalis	Substantially inert			Substantially inert			Excel.	Same as strong alk.	
Heat	Yellows slightly after 5 hr at 300 F; melts at 482 F			Yellows slightly after 5 hr at 300 F; melts at 420 F			Good	Soft 350-375 F; Melts 500 F	Melts at 575 F

[a] 70 F; 65% RH, unless otherwise noted. [b] For filament; 35-400% for staple. [c] Ratio of breaking stress to breaking strain (i.e., gm/den to rupture divided by strain in cm/gage cm at breaking stress). [d] Recovery after 2% strain except where specific percentage strain is given in parentheses. [e] Basic flammability of untreated fiber.

Table 5.1-1

Type →	Regenerated Cellulose (rayons)				Aramids			Polyesters		
	Viscose		Saponified Acetate					Polyethylene Terephthalate (Dacron)		
	Reg to Med Tenacity	High Tenacity	(Fortisan)	(Fortisan 36)	Nomex[a]	Kevlar 29	Kevlar 49	Regular	High Tenacity	Staple
NATURE OF FIBER										
Form	Fil, staple	Filament	Filament	Filament	Fil, staple	Filament	Filament	Fil, staple	Fil, staple	Fil, staple
Length, in.	—	—	—	—	1-2.5	Cont.	Cont.	1.5-4.0	1.5-4.0	1.5-4.0
Width, μ	4.3-8.4	10-15	3-9	3.9	—	11.9	11.9	11-28	11-28	18-25
Cross section	Irreg	Irreg	Irreg	Irreg	Round	Round	Round	Circular	Circular	—
PROPERTIES[b]										
Spec grav	1.46-1.52	—	1.5	1.5	1.38	1.44	1.45	1.38	1.38	1.38
Breaking Tenacity, gm/den	1.5-3.2	3.0-5.0	6-7	8	5.3	21.5	21.5	4.4-5.0	6-7	3.8-4.3
Wet	0.7-1.9	1.9-3.6	5.1-6.9	6.0-6.4	4.1	21.5	21.5	4.4-5.0	6-7	3.8-4.3
Ten Str, 1000 psi	29-65	65-105	136	155	95.5	400	400	77-88	106-123	67-76
Breaking Elong, %	15-30	9-22	6	6.2	12.2	3.4	2.25	19-25	9-11	30-36
Wet	17-40	14-30	6	6	16	4	2.25	19-25	9-11	30-36
Stiffness (avg), gm/den[c]	11.1-16.6	25.5-29	117	135	—	460	1000	—	—	—
Strain Recovery[d] (at 2%), %	30-97	70-100	100 (20%) 60 (40%)	85.7 (5%)	—	—	—	97, 80 (8%)	100, 90 (8%)	—
Toughness (avg), gm-cm/den-cm	0.19-0.21	0.22-0.30	0.21	0.26	—	—	—	0.78	0.50	1.03
Moisture Regain, %	13	13	10.7	9.6	5.0	5.0	3.5	0.4	0.4	0.4
CORROSION RESISTANCE										
Strong Acids	Disintegrates in hot dilute or cold concentrated acids		Similar to cotton		Str loss	Good	Good	Dissolves in H_2SO_4		
Weak Acids			Similar to cotton		Mod str loss	Good	Good	Good		
Strong Alkalies	Swell, str reduced		Similar to cotton		Str loss	Good	Good	Disintegrates when boiled		
Weak Alkalies	Good		Similar to cotton		Better than Nylon 6/6	Good	Good	Good		
Heat	—		Similar to cotton		[f]	320 F long term	390 F long term	Melts at 480 F		

[a] 70 F, 65% RH, unless otherwise noted. [b] Ratio of breaking stress to breaking strain (i.e., gm/den to rupture divided by strain in cm/gage cm at breaking stress). [d] Recovery after 2% strain except where specific percentage strain is given in parentheses. [c] 20 denier yarn with 3 yarns/in. of twist. [f] After 1000 hr at 500 F has 65% RT breaking strength; degrades above 700 F.

Type →	Organic, man-made							Organic, natural		
	Vinyl Derivatives					Novoloid	Fluorocarbon			
	Vinyl Chloride Acetate	Vinylidene Chloride, saran			Polyvinyl Alcohol	Kynol	TFE	Cotton	Hemp	Silk
		Mono Filament	Filament	Staple						
NATURE OF FIBER										
Form	Staple	—	—	—	Staple	Fil, staple	Filament	Staple	Staple	Fil, staple
Length, in.	—	—	—	—	—	—	—	1-1.5	—	—
Width	16-18	1300	50	—	—	14	—	16-21	18-23	10-13
Cross section	Barbell	Circular	Circular	Circular	Peanut	—	Circular	Ribbonlike	Triangular	Triangular
PROPERTIES[a]										
Spec grav	1.33-1.35	1.7	1.7	1.7	1.26-1.30	1.25	2.3	1.55[d]	1.48	1.25[f]
Breaking Tenacity, gm/den	0.7-1.0	1.2-2.3	Up to 2	Up to 1.5	4.4-6.0	1.7	1.6	1.5-6.0[e]	5-7	3.5-4.5
Wet	0.7-1.0	1.2-2.3	Up to 2	Up to 1.5	3.7-5.0	1.56	1.6	1.5-6.0	5-7	3-4
Ten Str, 1000 psi	12-17	15-45	44	33	—	27	47	—	—	—
Breaking Elong, %	100-120	20-30	15-25	15-25	15-17	35	13	6-9	1-3	20-25
Wet	100-120	20-30	15-25	15-25	—	37	13	7-10	1-3	25-30
Stiffness (avg), gm/den[b]	1.5	7-10	8-12	8-12	24-40	45	12	60-70	200	100
Strain Recovery[c] (at 2%), %	—	95 (10%)	95 (10%)	95 (10%)	—	95	88 (3%)	95	90 (<1%)	90 (<2%)
Toughness (avg), gm-cm/den-cm	1.3	0.17-0.27	0.125	0.125	0.79-0.92	0.5	0.12	0.15	0.04	0.44
Moisture Regain, %	up to 1.5	None	None	None	4.5-5.0	6	None	6[f], 8[g]	8[h]	10
CORROSION RESISTANCE										
Strong Acids	Excellent	Exc; fair to conc H_2SO_4			—	Res hot and conc non-oxidizing mineral acids	Inert	Dissolves	Dissolves	Dissolves
Weak Acids	Excellent	Excellent			—		Inert	Stable	Stable	Fair
Strong Alkalies	Excellent	Excellent except to NH_4OH			—	Some instability	Inert	Swell	Swells	Dissolves
Weak Alkalies	Excellent	Excellent			—	—	Inert	Good	Stable	Fair
Heat	Melts 260F	Softens at 240-280 F			Melts 420 F	Good to 570F	Good to 400 F	Good	Stable	Good

[a] 70 F, 65% RH, unless otherwise noted. [b] Ratio of breaking stress to breaking strain (i.e., gm/den to rupture divided by strain in cm/gage cm at breaking stress). [c] Recovery after 2% strain except where specific percentage strain is given in parenthesis. [d] Dry cotton @ 68 F. [e] Depends on type and growth conditions. [f] Scoured. [g] Mercerized. [h] Bleached. [i] Reasoned dry @ 77 F.

Table 5.1-1 cont.

Type →	Inorganic, man-made					Inorganic, natural				
	Glass[a]		Graphite		Boron[f]	Asbestos		Alumina Silica	Carbon	Zirconia
	Type E	Type S	High Mod.	High Str.		Chrysotile	Crocidolite	—	—	—
NATURE OF FIBER										
Form	Cont, Staple	Cont.	Cont, Chopped	Cont, Chopped	Cont	Crude	—	Staple	Cont, Fil	Can be cont
Length, in.	—	—	—	—	—	3/8-2	1/8-3	1/4-10	—	—
Width, μ	—	—	7.1-7.6	7.49-7.99	—	0.02	0.02	3-20	8-10	—
Cross section	Cyl, tub	Cyl	Circular	Circular	Circular	Tub	Cyl	—	Irreg.	—
Min/Max dia, mil	0.03 0.04	0.03 0.04	0.072-0.075	0.078 0.08	2-8	—	—	—	0.03 0.04	0.039[e]
PROPERTIES										
Spec grav	2.54	2.49	1.85-1.9	1.79 1.83	2.3-3.18	2.4 2.6	3.2-3.3	2.73	1.4-1.85	5.6-5.9
Break Tenacity gm/den										
70F, 65% RH	3.9-4.7	—	—	—	—	2.5-3.1	—	1.4-6.5	7.5	—
Wet	4.0-4.6	—	—	—	—	—	—	—	—	—
Tenstr (70F 65%RH 1000psi	300-500	500-650	340 min	410 min	400 avg	350 750	100-300	50 230	30-180	150-200
Breaking Elong, %, 70F 65% RH	3-4	—	0.62-0.68	1.2 1.4	—	—	None	1.4 2.7	2.5	—
Wet	2.5-3.5	—	—	—	—	—	None	—	—	—
Strain Recovery (at 2%), %	100	—	—	—		—	100	—	100	—
Toughness (avg), gm-cm/den cm	0.07	—	—	—		—	—	—	—	—
Moisture Regain (70 F, 65 RH), %	0	—	—	—		—	0	—	2-14	—
Ther Cond Btu-ft/hr-sq ft-F	7.2	—	—	—		—	—	—	11	—
CORROSION RESISTANCE										
Strong Acids	Attack only by HF and hot H_3PO_4		Excellent		—	Poor	Good, exc. HF	Sim to boro sil glass	Excel.	Fair, exc. HF, hot H_2SO_4
Weak Acids	Stable		Excellent		—	Poor-good	Excel.	—	Excel	Good
Strong Alkalies	Resist most		Excellent		—	Excel.	Excel.	—	Excel	Excel.
Weak Alkalies	Resist most		Excellent		—	Excel.	Excel.	—	Excel	Excel.
Heat	600 F		4500 F[h] 750 F[i]	1700 F[h] 600 F[i]	—[g]	1400 1900 F	1400 F	2300 F max 320 F melts	4500 F max, 6040 F[h]	—
Sunlight	Inert		Inert		Inert	Inert	Inert[j]	Inert	Inert	Inert

[a] Properties may vary widely depending on glass comp, values shown are for borosilicate [b] Sublimes [c] In inert atmosphere [d] In air [e] Metal [f] On tungsten substrate [g] Function of the matrix when used in composites

Table 5.1-1 cont.

Strength-To-Weight Ratios of Various Types of Materials

Material	Strength-to-Weight Ratio* x 10^{-3}
Polycarbonate	210
Polystyrene	230
Nylon	260
Styrene-Acrylonitrile Copolymers	310
Brass (Yellow Cast)	320
Zinc Alloys (Cast)	350
Glass/Polystyrene	360
Glass/Polycarbonate	370
Glass/Styrene-Acrylonitrile Copolymers	410
Magnesium	460
Aluminum	530
Glass/Nylon	550
Orlon	850
Nylon 6/6	1322
Boron	3833
Type E Glass	4861
High Strength Graphite	6170
Type S Glass	6395
Kevlar 49	7639

* Tensile strength in psi divided by weight in pounds per cubic inch.

Table 5.1-2

DECAY OF FREE VIBRATIONS

	Loss Factor x 10^{-4}
1020 Steel	<20
Ductile Cast Iron	30
Graphite/Epoxy	30
Fiberglass/Epoxy	47
Kevlar 49/Epoxy	160
Cured Polyester Resin	400

$$\text{Loss Factor} \approx \frac{An}{An + 1}$$

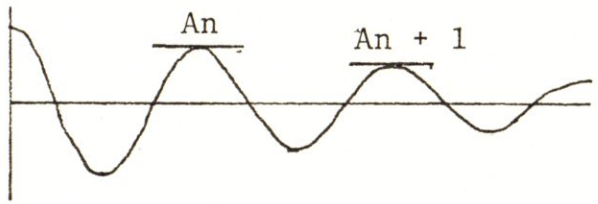


Table 5.1-3

ENVIRONMENTAL STABILITY OF "KEVLAR" 49
UNIDIRECTIONAL TAPE REINFORCED 3M SP-306
EPOXY RESIN COMPOSITES

Environment	Interlaminar Shear Strength, psi*
Control	10,520
Water Boil (2 hours)	9,290
Salt Water Room Temp. 100 hours	9,770
Texaco "Abjet K-40" Jet Fuel Room Temp. 100 hours	10,480
"Skydrol" Lubricating Oil Room Temp. 100 hours	10,460

* Short Beam Shear, 4/1 span/depth ratio

Table 5.1-4

fiber. The Kevlar was found to be available as woven fabric in several styles[4] (Table 5.1-5) and style 285 was chosen for its conformability and lower costs[5]. Typical properties of the various fabric styles in an epoxy composite[4] (usually 50-50 by volume) are given in Table 5.1-6. As a point of comparison, the yarn and composite properties[6] are shown in Table 5.1-7.

Research showed Kevlar to be in use in several applications including the skin of the Lockheed Quila RPV[7]. Use as hulls for boats[8] has demonstrated its resistance to sharp inward blows in that the composite does not crack but can be "popped" back out without structural failure. Repair has proven comparatively easy requiring only a simple fabric and epoxy patch as with fiberglass followed by sanding to smooth contours. Painting is unnecessary for the Kevlar but camouflage might still be required. For best results, the fabric is pre-impregnated with XCE epoxy resin ("pre-peg"), cut, vacuum molded, cured and joined section-to-section with epoxy. Unfortunately, the Kevlar fabric costs about $14.00 per square yard at present and this is much higher than that for a similar weave of fiberglass (about $1.00 per square yard). This, plus the increased tooling costs of Kevlar (cutters, drills, sanders, etc.) drive up the manufacturing costs on a per unit area basis over fiberglass. Fortunately, the total area involved (less than 40 square yards per RPV) is not large so the increased costs incurred are not overly burdensome.

In order to provide structural mounting and stress distribution, aluminum main and rear spars were placed at basically the 30% and 75% chord locations, respectively, and run parallel to each other

FABRICS OF KEVLAR® 49 ARAMID

Style	Basis Weight ($oz./yd.^2$)	Fabric Construction (Ends/Inch)	Yarn Denier*	Weave	Fabric Thickness (mils)
120	1.8	34 x 34	195	Plain	4.5
143	5.6	100 x 20	380/195	Crowfoot	10
181	5.0	50 x 50	380	8-harness satin	9
243	6.7	38 x 18	1140/380	Crowfoot	13
281	5.0	17 x 17	1140	Plain	10
285	5.0	17 x 17	1140	Crowfoot	10
328	6.8	17 x 17	1420	Plain	13

*Denier: Weight in grams of 9000 meters of yarn.

Table 5.1-5

TYPICAL COMPOSITE PROPERTIES

(Vacuum Bag, Autoclave Molded Epoxy)*

Style	Fabric v/o	Tensile Strength (10^3 lb/in^2)	Tensile Modulus (10^6 lb/in^2)	Flex Strength (10^3 lb/in^2)	Flex Modulus (10^6 lb/in^2)	Shear Strength (lb/in^2)
120	45	65/65	4.3/4.3	50/50	4.0/4.0	7000
181	40	60/60	4.0/3.2	50/50	3.8/3.2	6300
281	40	55/55	3.8/3.8	50/50	3.3/3.3	6000
285	40	55/55	4.0/3.8	50/50	3.6/3.1	6000
328	45	55/55	3.8/3.8	45/45	3.3/3.3	6000
143	40	110/13	6.3/1.1	65/18	5.8/1.0	7500/2500
243	40	115/20	6.8/1.7	65/25	6.1/1.2	7000/4500

*350°F (177°C) service temperature

Table 5.1-6

"KEVLAR" 49: YARN PROPERTIES

DENSITY	1.44 g/cc (0.052 lb/in.³)	• 40% lower than glass.
FILAMENT DIAMETER	0.00047 in.	• About the same as glass.
FIBER ELONGATION*	2.8%	• Significantly lower than other organic fibers.
TENSILE STRENGTH*	525,000 psi	• Substantially above conventional organic fibers, equivalent to S-glass, and higher than graphite.
SPECIFIC TENSILE*	10×10^6 in.	• Highest of any commercially available fiber.
MODULUS	19×10^6 psi	• Twice that of E-glass.
SPECIFIC MODULUS	3.5×10^8 in.	• Between that of glass fibers and the high modulus graphites.
CHEMICAL RESISTANCE	Good	• Highly resistant to organic solvents, fuels and lubricants.
TEXTILE PROCESSIBILITY	Excellent	• Can be readily woven on conventional fabric looms. • Yarns retain 90% of their tensile strength after weaving. • Knot strength is 35% of straight tensile strength. • Can be easily handled on filament winding and pultrusion equipment.
FLAMMABILITY CHARACTERISTICS	Excellent	• Inherently flame resistant. Self-extinguishing when flame is removed. Does not melt.
TEMPERATURE RESISTANCE	Excellent	• No degradation of yarn properties in short term exposures up to temperatures of 500°F.

*ASTM D2343-67

"KEVLAR" 49: GENERAL COMPOSITE* PROPERTIES

DENSITY	• 25-30% lower than that of glass composites.
SPECIFIC TENSILE	• Superior to all other composites reinforced with commercially available fibers.
SPECIFIC MODULUS	• About two times that of S-glass composites.
PROCESSIBILITY	• Can be readily handled using conventional reinforced plastics fabrication techniques. • Machining techniques for drilling, routing, cutting and milling have been developed.
ELECTRICAL PROPERTIES	• Superior to glass composites and equivalent to quartz fiber composites in dielectric constant and loss tangent.
ENVIRONMENTAL STABILITY	• Useful long term temperature range: −320° to +320°F. • No degradation in jet fuel, lubricating oils, water, salt water, or high humidity. • Good UV stability.
FLAMMABILITY	• Meets all FAA flammability and smoke requirements in flame resistant, low smoke resins.
IMPACT STRENGTH	• Far exceeds impact strengths of graphite and boron and better than glass in some tests.
SPECIFIC COMPRESSIVE STRENGTH	• About half that of glass composites.
INTERLAMINAR SHEAR	• Equivalent to glass and graphite in some resins.
TENSION—TENSION FATIGUE	• Far superior to glass.
CREEP RUPTURE	• Superior to glass.
VIBRATION DAMPING	

*Composite made with 8-harness satin weave fabric (~5 oz/yd²), epoxy resin, v/o = ~ 55 (autoclave cured)

TEST DATA FOR "KEVLAR" 49 PLASTIC COMPOSITES

MECHANICAL PROPERTIES

	UNIDIRECTIONAL*	FABRIC**
DENSITY	.050 lbs/cu. in.	0.048 lbs/cu. in.
TENSILE STRENGTH	200,000 psi	75,000 psi
TENSILE MODULUS	11.0×10^6 psi	4.5×10^6 psi
COMPRESSIVE STRENGTH	40,000 psi	25,000 psi
COMPRESSIVE MODULUS	11.0×10^6 psi	4.5×10^6 psi
INTERLAMINAR SHEAR STRENGTH	9,000 psi	7,500 psi
IMPACT STRENGTH (Charpy Unnotched)	150 ft. lbs/in²	75 ft. lbs/in²

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT (10^6Hz)	3.3	4.1
LOSS TANGENT (10^6Hz)	0.023	0.024
VOLUME RESISTIVITY		5×10^{15} ohms-cm.
DIELECTRIC STRENGTH (125 mil)		960 V/mil

*Filament wound, continuous aligned fiber reinforced epoxy resin, v/o = 65. (Autoclave cured)

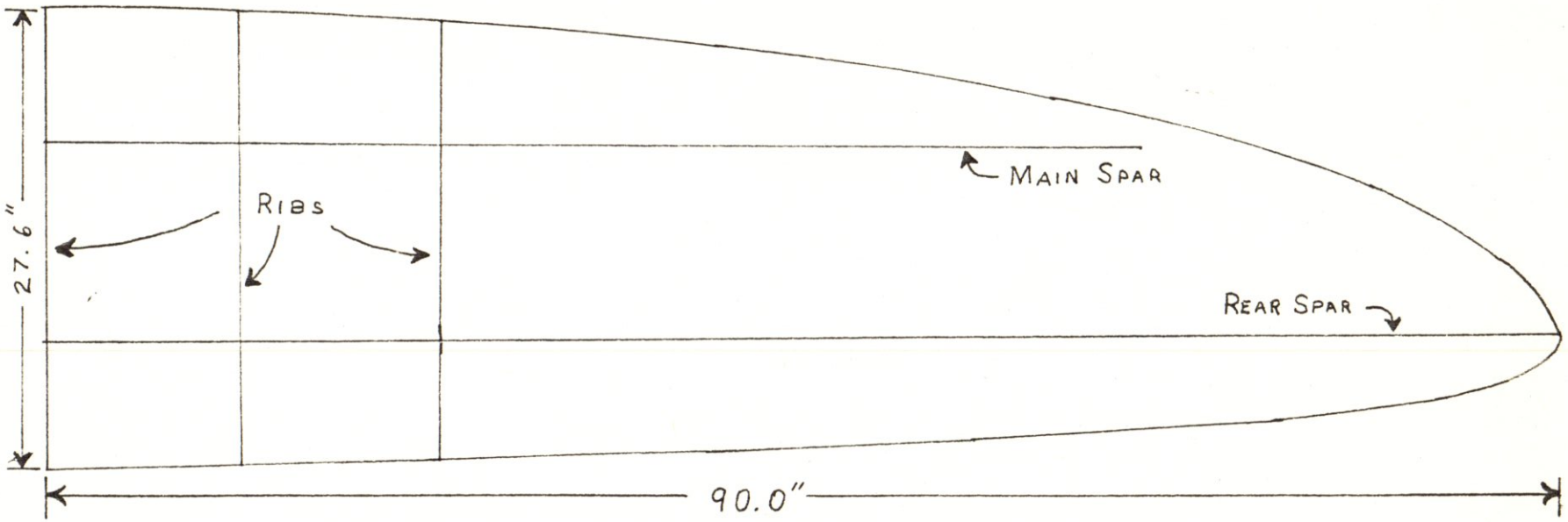
**8-Harness satin weave fabric (~5 oz/yd²), epoxy resin, v/o = ~ 55. (Autoclave cured)

Table 5.1-7

(Figure 5.1-1). Due to the elliptic nature of the planform, it was possible to locate only the rear spar on a constant chord line and maintain a meaningful structure. Therefore, the main spar was positioned parallel to the rear spar but its length was limited by the planform to approximately 73% of the full span. Its chordwise location was expected to be roughly that of the wing elastic axis thus minimizing the torsional loads encountered by the I-beam cross-section of the main spar. The rear spar (a hollow tube) was located to act as a hinge point for the full span flaps as well as to provide additional torsional rigidity in the wing. The cross-sectional properties of the spars are shown in Figure 5.1-2. Both the main and rear spars were of extruded 2024-T6 aluminum for strength and low manufacturing costs. The two different sized sections of the rear spar were welded together via a machined joint.

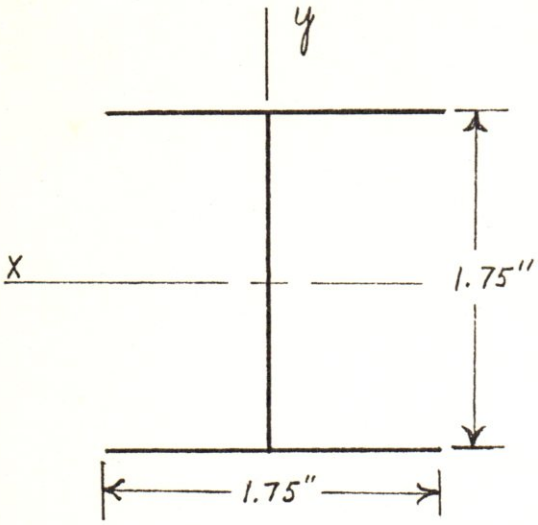
Five aluminum ribs, spaced 12" apart, were used to provide additional support of the wing structure in and around the area of the wing-fuselage mounting and wing fuel tanks (four plastic tanks sandwiched between the five ribs and positioned fore and aft by the main and rear spars). The ribs were stamped .050" 2024-T6 aluminum. The servo motors (2) for the flaps were each mounted to the outboard ribs and the flaps were driven simultaneously through a universal joint at the wing root. This provided redundancy in the flap deflection system while insuring equal flap deflections for both wings. Also, the spoiler servos (one each) were braced to the main spar and skin.

Foam was used to fill spaces remaining such as those forward of the main spar, outboard of the ribbed section and the interior of the flaps. The foam contributed little strength and an insig-



WING SEMI-SPAN PLANFORM

FIGURE 5.1-1



MAIN SPAR

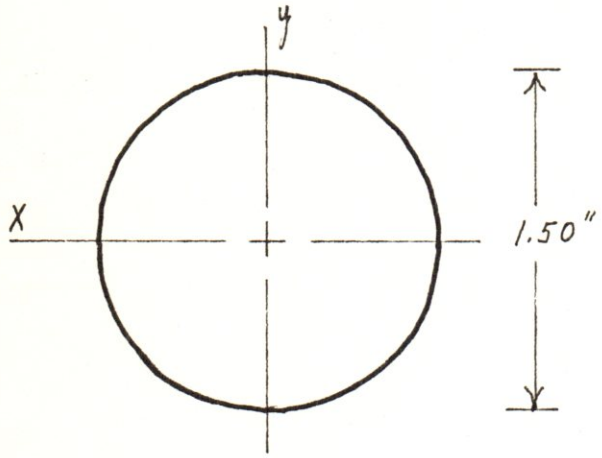
Thickness = 0.04"

Area = 0.20680 sq. in.

I_x = 0.11789 in.^{4}

I_y = 0.08571 in.^{4}

J = 0.20360 in.^{4}



INBOARD REAR SPAR

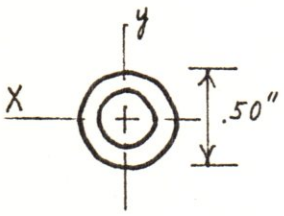
Thickness = 0.01 "

Area = 0.04681 sq. in.

I_x = 0.01299 in.^{4}

I_y = 0.01299 in.^{4}

J = 0.02598 in.^{4}



OUTBOARD REAR SPAR

Thickness = 0.10"

Area = 0.12566 sq. in.

$I_x = I_y$ = 0.00267 in.^{4}

J = 0.00534 in.^{4}

Wing Spars' Cross-Sectional Properties

Figure 5.1-2

nificant weight but eliminated volumes for water condensation and created a rigid containment for wires and tubing. Additional wing stiffness was obtained (but not used in the calculations) by assuming a slight "overfill" of the foam thereby pre-stressing the skin a small amount. Finally, in order to have the fuel tanks tightly located but cushioned slightly, foam was used to fill all the spaces around them.

5.1.3.2 Wing Construction

A construction technique similar to the Aquila was envisioned for the wing. The wing upper and lower surface shells and flaps would be formed of a single layer of prepeg Kevlar and the rib and spar structure would be assembled. The rear spars would be joined at the root by a universal joint, as mentioned above, and the main spar would have to be cut and welded to account for the 7.50^{o} anhedral. The metal and skin structures would be joined with epoxy with the upper wing surface shell used first to allow checking the operation of the control surfaces. All tanks, wiring, and tubing would be positioned, as would the flaps, prior to mating the lower wing surface shell. Again all surfaces would be joined with epoxy. Finally, all cavities would be filled by injecting structural foam.

5.1.4 Fuselage

5.1.4.1 Fuselage Configuration

There were many factors affecting the fuselage configuration, the major ones of which are:

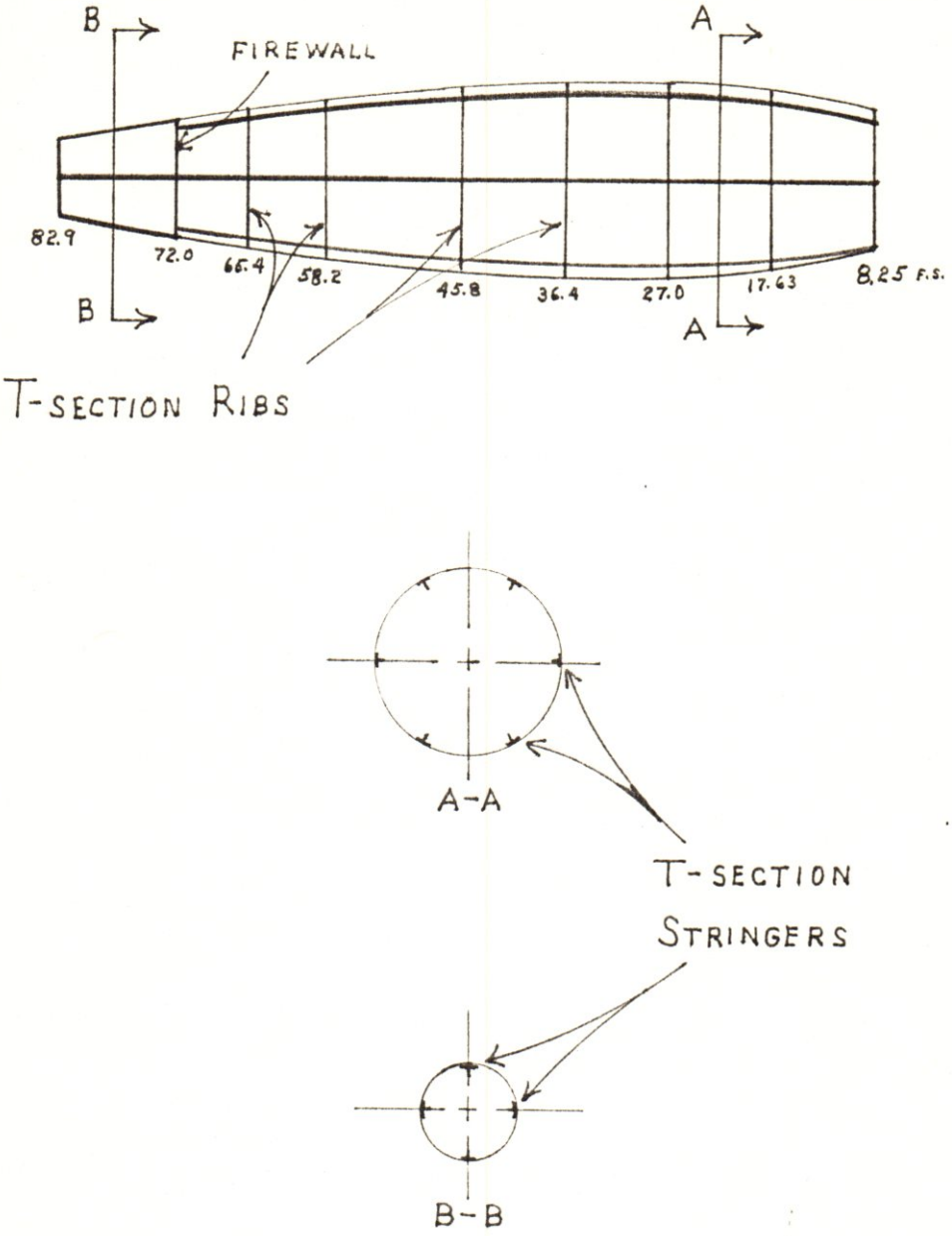
1.) low drag,
2.) large forward volume for missions equipment,
3.) adequate structure for rear-mount propulsion system and tail boom,

4.) adequate volume for fuel, propulsion and electronics,
5.) large, localized take-off and landing loads,
6.) light weight,
7.) minimize radar cross-section, and
8.) ease in manufacture and maintenance.

All these were well satisfied by the configuration arrived at. The revolved NACA 0018 airfoil provided the necessary volume for the missions equipment, fuel, propulsion and control electronics while keeping the drag respectably low. The Kevlar skin over aluminum bulkheads and stringers was chosen for the high strength-to-weight ratio possible (and necessary), low radar return and comparative ease in manufacture and maintenance.

The internal structure (Figure 5.1-3) consisted basically of nine (9) bulkheads spaced out along the approximately 90 inch length of the fuselage braced by six (6) stringers running longitudinally from the first bulkhead at the 8.25 F.S. (fuselage station in inches) to the eighth bulkhead (also the engine firewall) at the 72.0 F.S. Two stringers were located on either side of the fuselage centerline (in the horizontal plane) with the others spaced out in 60^{o} increments. This arrangement allowed maximum visibility downward for cameras, laser target designators, etc. The two horizontal stringers were run all the way to the ninth bulkhead with only two additional stringers, spaced at 90^{o} intervals, between them to brace the last two bulkheads. This was considered more than adequate for this section since very little weight and thus small loads were involved.

Due to the fact that the wing rode imbedded in the fuselage, small changes had to be made in the locations of the bulkheads and



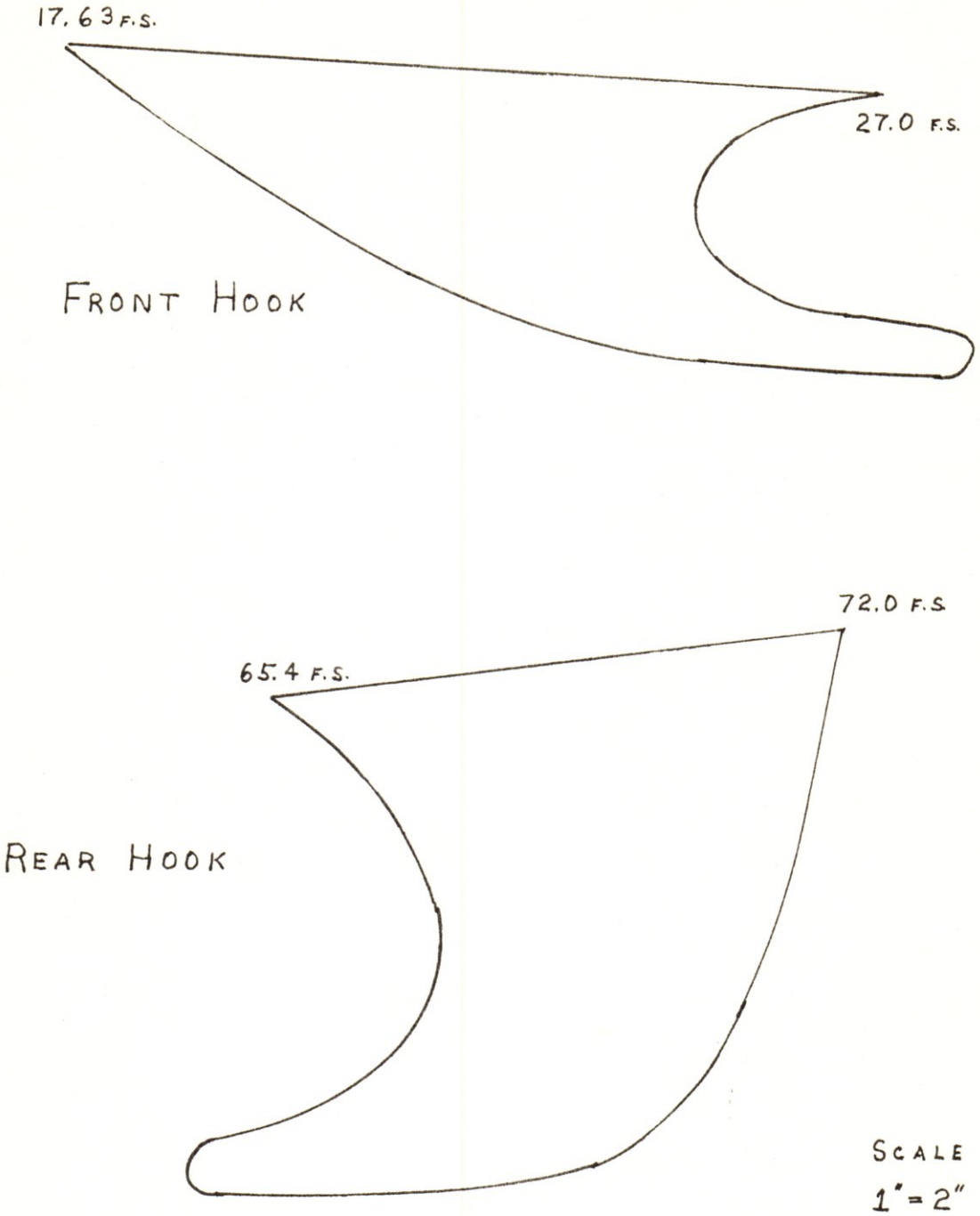
Fuselage Basic Internal Structure

Figure 5.1-3

stringers in the affected area. Two bulkheads were located at the positions of the wing main and rear spars to facilitate load carry-through. Stringers maintained their angular locations with respect to the fuselage centerline, however, and these provided extra support of the wing. Because of the imbedded nature of the wing and to keep the flow as undisturbed as possible, a wing-cap was added to smooth the change of contours between the fuselage and the top of the wing. This, too, was of Kevlar.

To absorb take-off and landing loads, two hooks (Figure 5.1-4) were attached to the underside of the fuselage. The one in front (27.0 F.S.) took the take-off loads from the rocket sled or hydraulic catapult of 1000 lbs. or so. The rear hook (65.4 F.S.) was designed to snag a horizontal net and decelerate the aircraft with an initial force of about 1000 lbs. Additionally, when landing, the front hook was to snag the net after the RPV was slowed before it could be shot backwards after stretching the net but, this load was considered small compared to that encountered at take-off. These hooks were designed as Kevlar structures supported internally by two 1.2" O.D. aluminum rods 0.10" thick.

The nose was configured as a plexiglass or acrylic hemisphere that would be replaceable and mount to the first bulkhead. Portions of the underside were available, if needed, to be replaced by optical glass for cameras in the areas forward and aft of the front hook. For accessibility to the missions equipment, the top third of the fuselage between the first and fourth bulkheads was hinged. This allowed quick replacement of equipment and easy refueling access without necessitating wing removal. For the most part, the missions



Profile of Recovery Hooks

Figure 5.1-4

equipment was mounted on racks which attached to the stringers. Access to the engine compartment was provided by several removable skin panels. The tail boom was located immediately behind the wing and bolted to two bulkheads thus allowing for removal-replacement.

5.1.4.2 Fuselage Construction

The fuselage construction was envisioned to be similar to that of the wing. The aluminum frame would be assembled with the fuel tank, muffler, intake cooling air ducting, tubing and wiring in place. The Kevlar skin (5 layers thick) would be epoxied to the metal frame and all joints sealed. Note that the loop-type dipole communications antenna would be laid-up in the fuselage skin and thus be protected. The engine and shroud assembly would be added separately.

5.1.5 Tail

5.1.5.1 Tail Configuration

A conventional tail was decided upon -- it would be supported by a single boom affixed to the fuselage immediately behind the wing. The boom had a 31.2^{o} incline from the top of the fuselage in order to clear the propeller shroud. Once the shroud was cleared (7.5 inches above the fuselage centerline) the boom extended horizontally for a distance of 68 inches at which point the tail was attached.

The boom was configured as a tube of Kevlar wrapped spirally with a thickness of 0.20 inches (20 ply) and an outside diameter of 3.00 inches. This insured the tail would not deflect vertically more than 4.0 inches under the maximum download of 250 lbs. The

circular cross-section yields the best torsional stiffness and thus minimize twisting of the tail about the boom. The hollow interior of the boom afforded space for wires and cables running between the fuselage and the servos in the tail as well as possible additional antennas in the tail.

The horizontal tail consisted of a symmetrical (NACA 0009) airfoil with 25% of the area of the wing. An elliptical planform was also used here with an axis of symmetry about the 50% chord line. A single spar was placed here and provided the pivot point for movement of this all-moving horizontal tail. The spars from both halves of the horizontal tail were extended into the boom where they were geared to the servo.

The vertical tail was designed to be identical to one-half of the horizontal tail so as to cut manufacturing costs and reduce the numbers of different spare parts required on hand. Each airfoil section had four ribs spaced every ten inches and braced by the main spar. Foam filled all remaining spaces and pre-stressed the skin.

5.1.5.2 Tail Construction

Tail construction would consist of three basic steps: 1) boom construction, 2) airfoil construction (3 per vehicle), and 3) integration of the parts.

The boom would be laid up with various orientations of the multiple plys to insure no directional properties. The airfoil sections would be constructed identically to the wing (minus fuel tanks and control surfaces). Finally, servos, gears, and control linkage would be mounted in the boom as a single assembly and the

tail surfaces added. Completion of the basic RPV would only require bolting the tail boom and wing to the fuselage and mating electrical and fuel line connectors.

5.2. WEIGHT AND BALANCE

5.2.1 Basic RPV

The RPV in its basic form, i.e. no payload and no fuel, was determined to have, at 93 lbs., a weight of less than half its design maximum take-off gross weight of 210 lbs. This weight and its moment arm(s) was obtained from a NASTRAN model of the RPV (section 5.3). The weights and moments of the various components were approximated and compared with the total obtained from NASTRAN (Table 5.2-1). The light weight of the structure allowed great flexibility in the carrying of fuel and equipment with the c.g. location and length of travel becoming the limiting factors. Thus, the missions equipment was positioned so as to produce favorable center of gravity locations throughout the mission and the fuel tanks were positioned to reduce c.g. travel during the mission. The fuselage fuel tank was positioned so that its center of gravity coincides with that of the wing tanks. This caused the c.g. shift to be a straight line with no "jumps" as the wing tanks empty.

5.2.2 Mission A

The surveillance-reconnaissance mission (Chapter 2) was equipped with a television camera in the nose for flight control and real-time surveillance and three TA-8M2 motorized photo-reconnaissance cameras mounted in tandem. Together with full fuel (5 gallons in wing tanks + 8 gallons in fuselage), the take-off gross weight (T.O.G.W.) comes to 221 lbs. which amounts to only 5% over the design T.O.G.W. This small increase in weight came while increasing the fuel capacity by 30% (to 13 gallons) and adding the third still camera to the structure that was originally estimated. Even so,

Component	Weight	Arm	Moment
Fuselage	18.0 lbs	45.8"	824.4 in-lbs
Wing	10.0	47.5	475.0
Tail	2.50	147.3	368.75
Boom	7.5	110.0	830.8
Engine	10.0	74.75	747.5
Alternator	7.0	70.00	490.0
Drive Shaft	0.5	82.90	41.5
Fan and Shroud	1.5	88.00	132.0
Batteries	10.0	65.4	654.0
Muffler	6.0	65.4	212.4
Flap Servos	4.0	58.2	232.9
Tail Servos	2.0	147.3	294.6
Autopilot, Radios, Etc.	10.0	43.0	430.0
Fuselage Fuel Tank	1.0	52.0	52.0
Wiring, Tubing, Etc.	3.0	52.0	156.0
Fuel	78.0	52.0	4056.0

Totals

Basic RPV/DRY	93.0 lbs	63.9"	5941.85 in-lbs
NASTRAN	93.04	63.75"	5931.0
Basic RPV/WET	171.0 lbs	58.5"	9997.9 in-lbs
NASTRAN	171.04 lbs	58.4"	9987.0

Basic RPV Component Weights and Moments

Table 5.2-1

a sizeable fraction of the available payload volume remained unused.

The weights and moments used for this mission appear in Table 5.2-2. The relative change in c.g. is shown in Figures 5.2-1 and 2. Note the extremely small change in c.g. throughout this mission (0.45") which would indicate that the manueverability (static margin) does not change appreciably.

5.2.3 Mission B

The laser target designator-damage reporting mission as described in Chapter 2 consists of the basic RPV equipped with the Honeywell laser target designator with infrared sensor in the nose and one TA-8M2 mounted behind the front hook. Its T.O.G.W. came to 229 lbs which was about 9% over the design T.O.G.W.. But here, too, endurance was increased by over 35% over the original design estimation.

Table 5.2-3 lists the weights and moments of the components of this mission and the relative locations and changes are illustrated in Figures 5.2-3 and 4. Due to the heavy laser target designator being located at the very nose, the c.g. was shifted forward several inches from Mission A. Even with the c.g. travel five times that of Mission A (2.21"), the location and travel were well within the limits allowed due to the large tail moments available.

Component	Weight	Arm	Moment
Basic RPV/Dry	93.0 lbs	63.8 "	5931.0 in-lbs
TV Camera	10.0	10.0	100.0
2 Photo Cameras	27.0	27.0	729.0
1 Photo Camera	13.2	38.0	501.6
Fuel	78.0	52.0	4056.0
Totals			
Mission A/DRY	143.2 lbs	50.71"	7261.6 in-lbs
Mission A/WET	221.2	51.16	11317.6

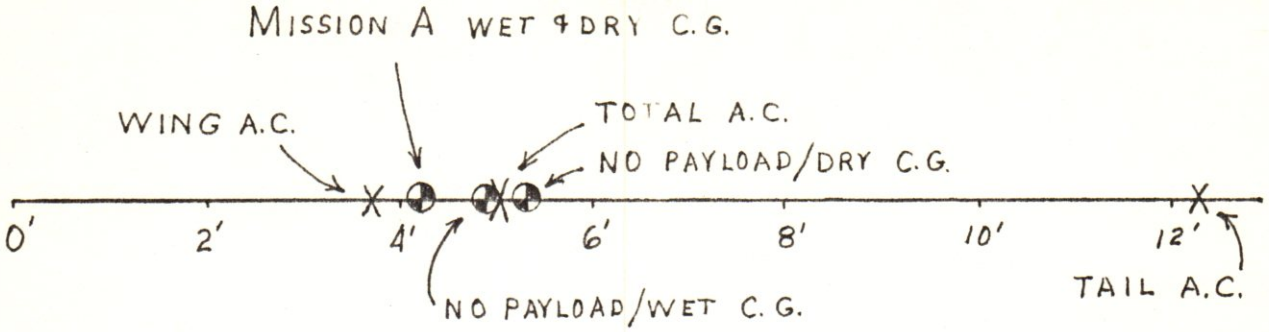
Mission A Weights and Moments

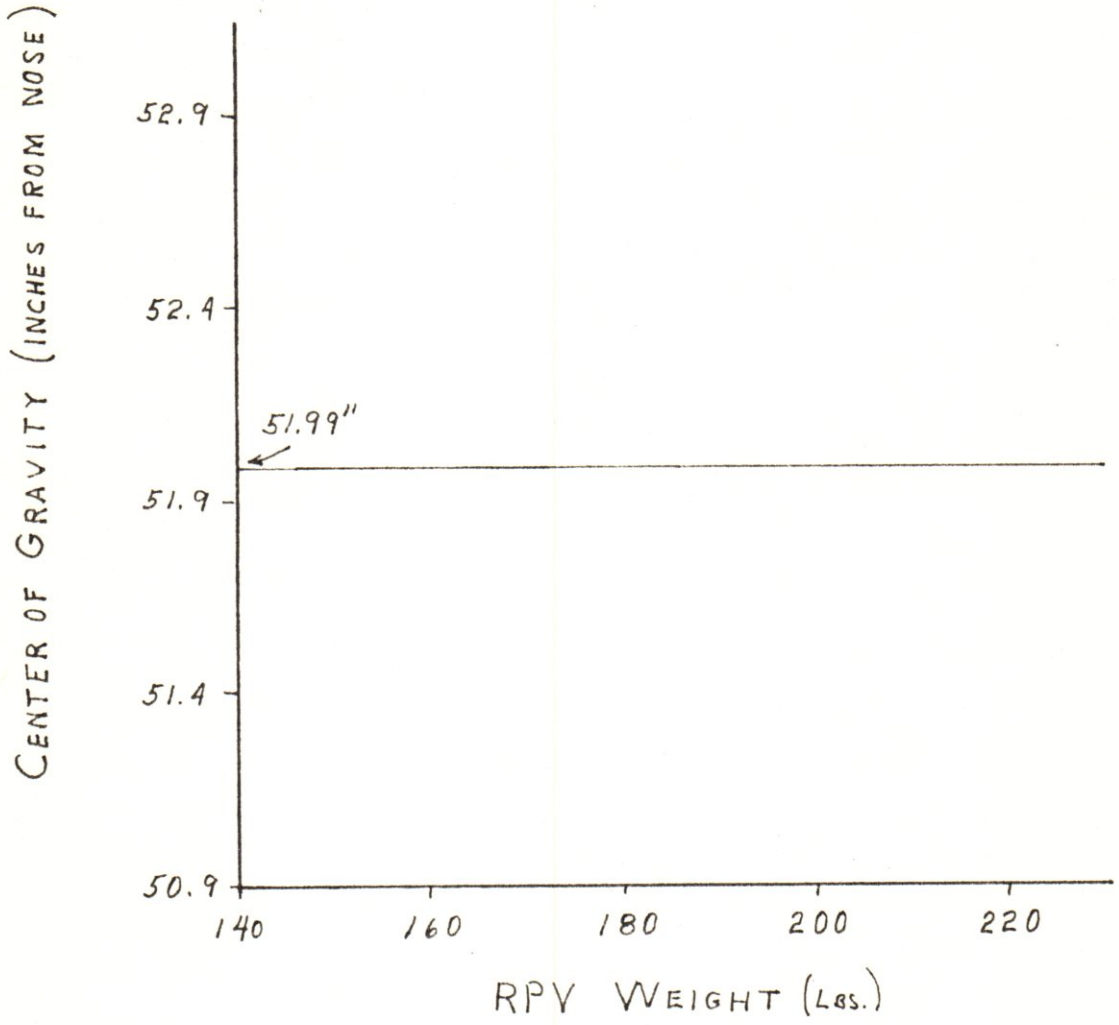
Table 5.2-2

Component	Weight	Arm	Moment
Basic RPV/Dry	93.0 lbs	63.8 "	5931.0 in-lbs
Laser Target Designator	45.0	10.0	450.0
1 Photo Camera	13.2	38.0	501.6
Fuel	78.0	52.0	4056.0
Totals			
Mission B/DRY	151.2 lbs	45.52"	6882.6 in-lbs
Mission B/WET	229.2	47.73"	10938.6

Mission B Weights and Moments

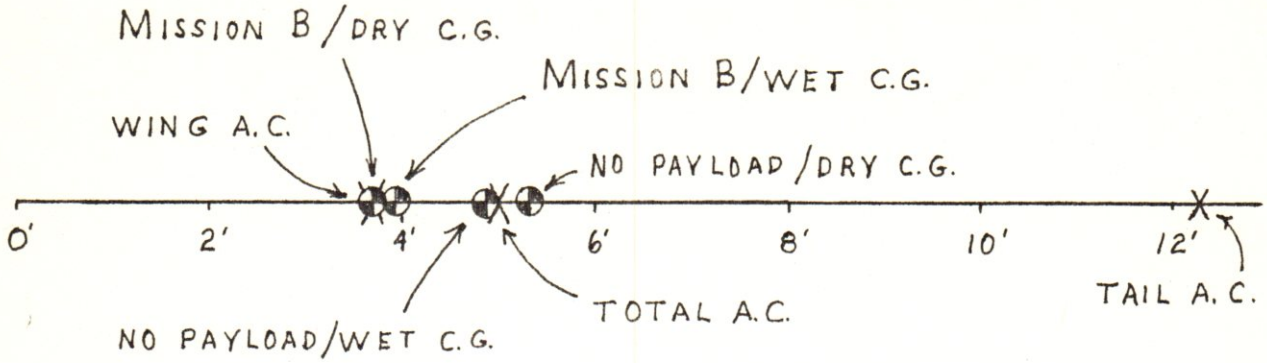
Table 5.2-3

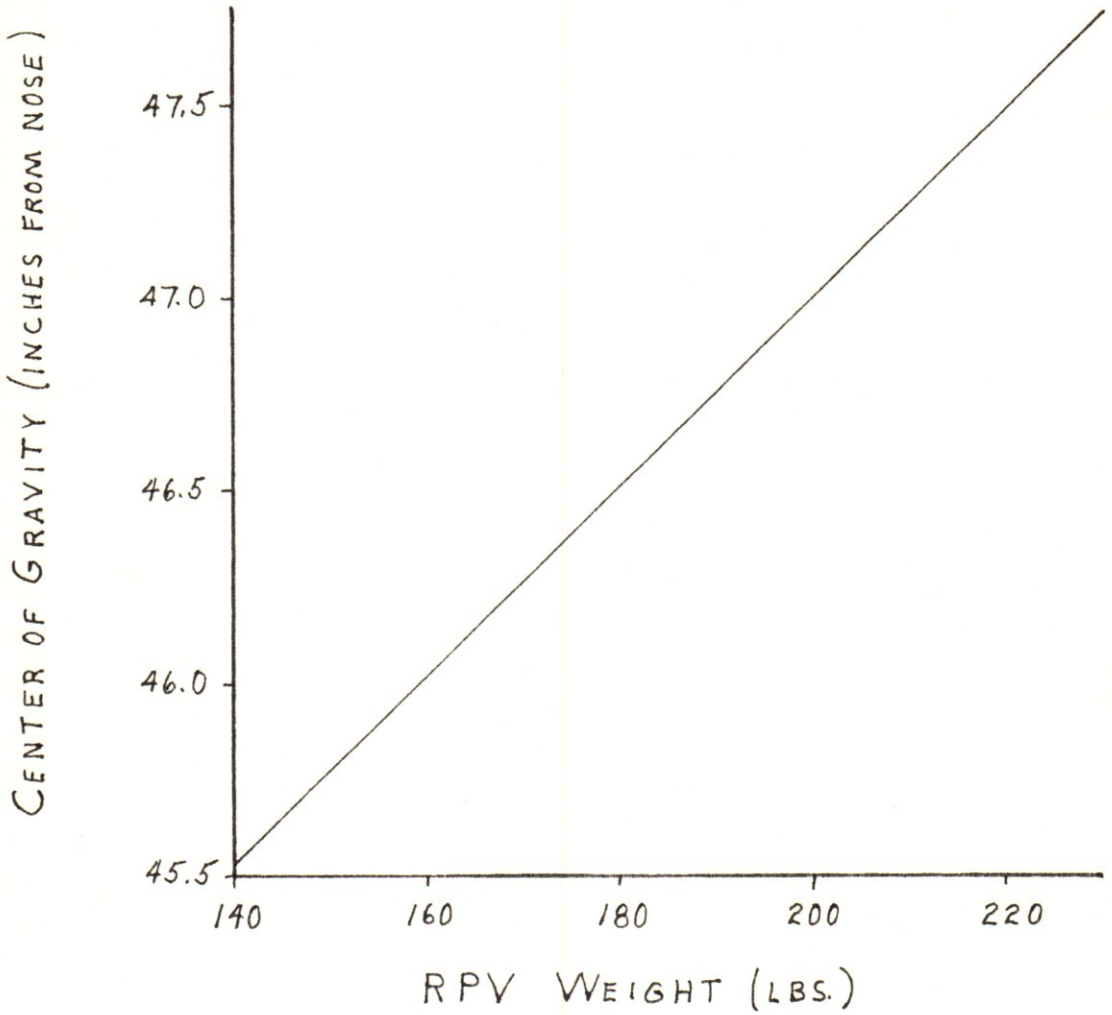




Mission A C.G. Location and Travel

Figures 5.2-1 and 2





Mission B C.G. Location and Travel

Figures 5.2-3 and 4

5.3. NASTRAN MODEL

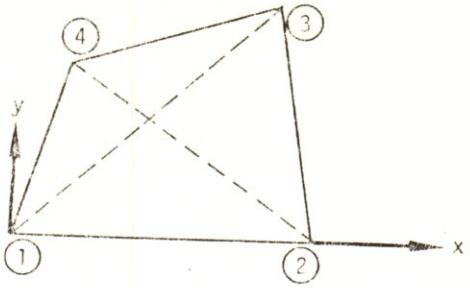
5.3.1 NASTRAN Modeling

NASTRAN (NAsa STRuctural ANalysis Program) is a general purpose digital computer program designed to solve (among other things) static and dynamic loading problems, buckling analysis and normal modes analysis using a finite element approach. It assumes "the distributed physical properties of a structure are represented by a model consisting of a finite number of idealized elements that are interconnected at a finite number of grid points, to which loads are applied"[9]. Everything is then referenced to these grid points throughout the problem. The structural elements provide the means of specifying the properties of the structure including material properties and mass distribution. Finally, constraints are applied to specify boundary conditions.

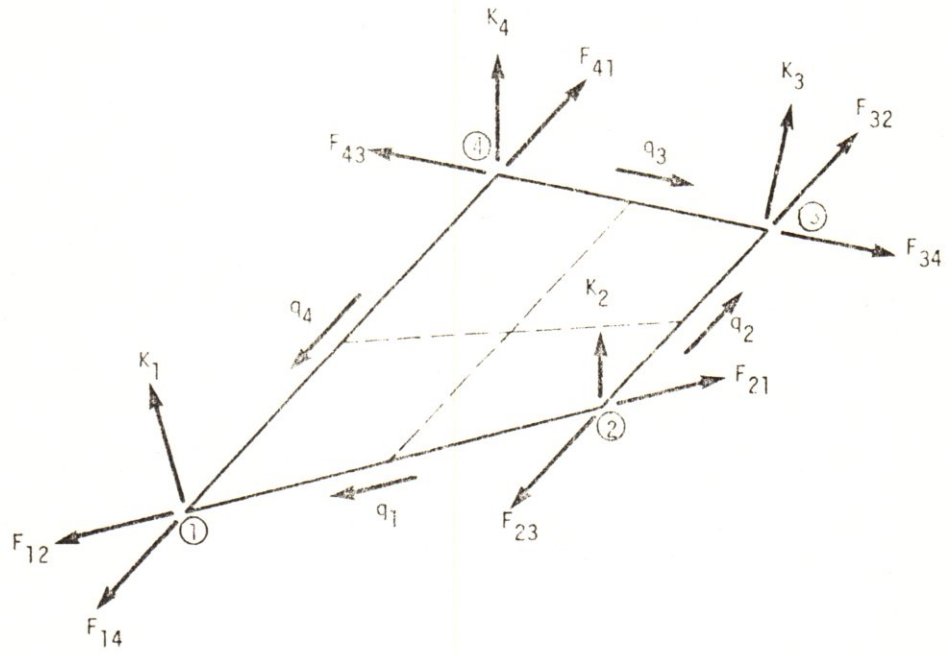
5.3.1.1 Grid Points

The structure was modeled using 263 grid points located in three-dimensional space with the origin being the tip of the fuselage airfoil (the point defined by the nose of the NACA 0018 airfoil coordinates before being modified by the hemispherical glass nose). The coordinate axes used coincide with the stability axes system (Figure 5.1-3). Furthermore, symmetry about the XZ-plane was assumed so only one-half (right side) was modeled.

A FORTRAN program was written to generate the locations of the grid points defining the fuselage (Appendix A.5.2) as well as the structural elements involved and punch cards for input to NASTRAN. Each grid point was initially given all six degrees-of freedom (DOF) available -- 3 translational and 3 rotational.



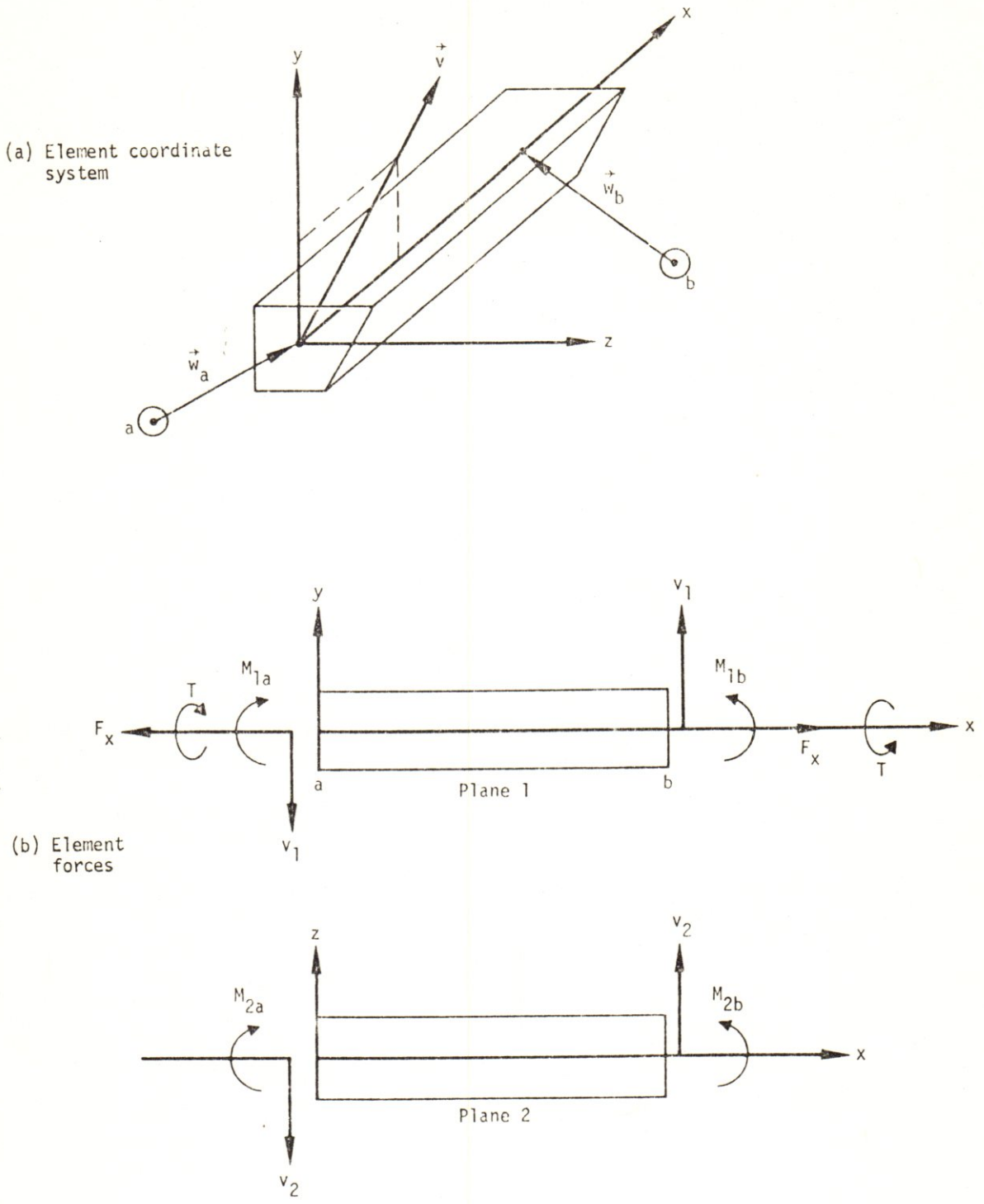
(a) Coordinate System.



(b) Corner forces and shear flows.

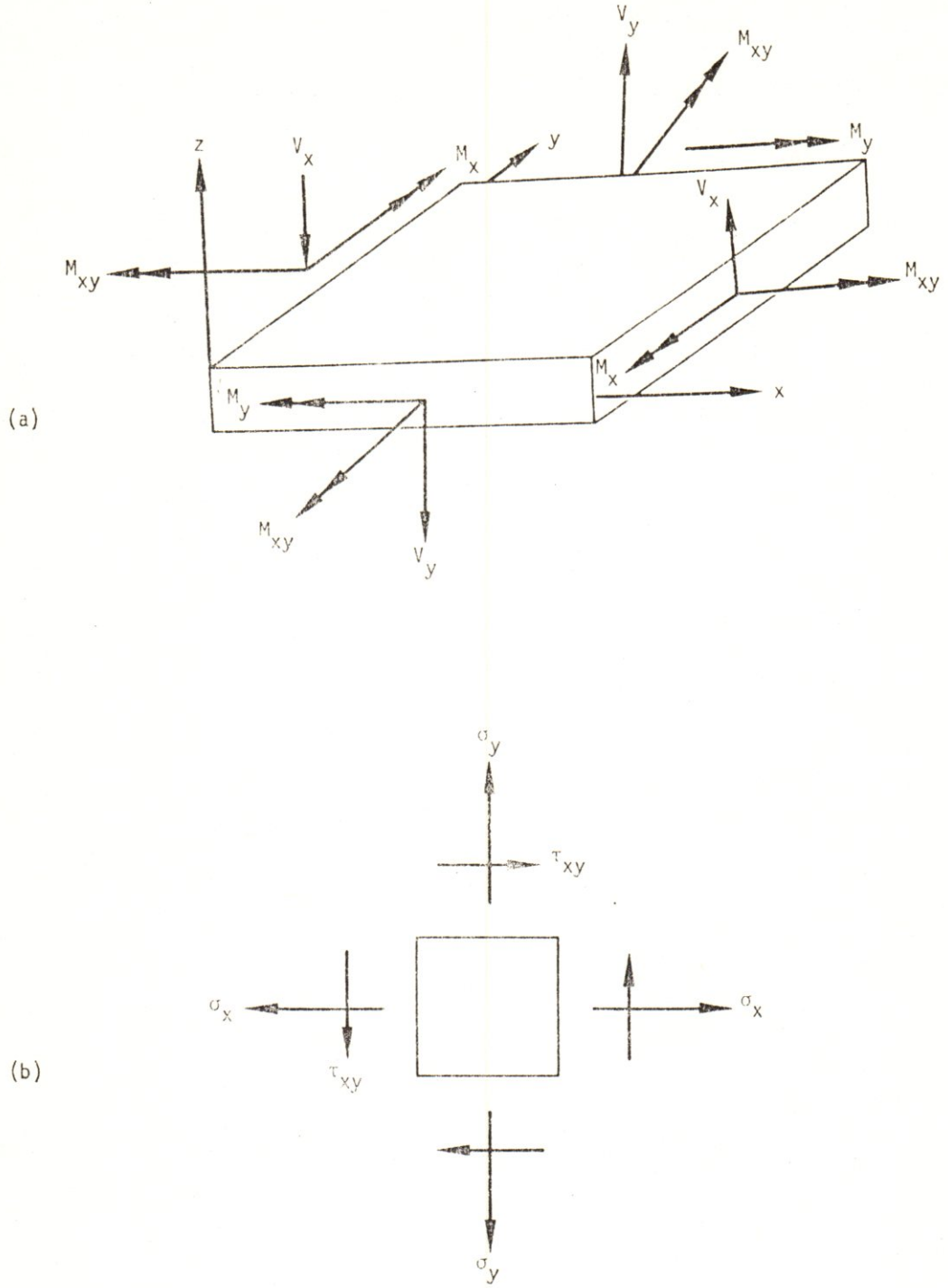
Coordinate System and Element Forces for CQDMEM2 Elements

Figure 5.3-1



Bar Element Coordinate System and Element Forces

Figure 5.3-2



Forces and Stresses in CQUAD2 Elements

Figure 5.3-3

Similarly, the wing was modeled using its own program (Appendix A.5.3) but its coordinate axes were located at the leading edge of the wing root. A coordinate transformation card was then used to properly position the wing on the fuselage.

The same wing modeling program was used to model the tail surfaces and coordinate transformations were applied to these structures to locate them properly with respect to the fuselage. Finally, the grid point locations of the hooks, tail boom, propulsion system and missions equipment were entered by hand.

5.3.1.2 Elements

There were three basic elements used in the NASTRAN model of the RPV structure: 1) membrane element, 2) bar element and 3) plate element. A quadrilateral membrane element (Figure 5.3-1) was used to model the Kevlar skin. This element (CQDMEM2) assumes finite inplane stiffness and zero bending stiffness[10]. This says that the Kevlar skin absorbs its share of the load through tension and compression only which is standard procedure for modeling aircraft skins. The bar element (CBAR) was used to model all the aluminum spars, and ribs and stringers. It can include all six DOF at each end (Figure 5.3-2) which are extension, torsion, bending in two perpendicular planes and the associated shears. All the aluminum wing ribs were modeled with a plate element (CQUAD2) which included both inplane and bending stiffness for a solid homogeneous cross section (Figure 5.3-3).

All the elements were positioned by using them to connect the appropriate grid points. Properties (mass and inertia) were assigned through "property" cards. For the skin and plate (CQDMEM2 &

CQUAD2) elements this consisted of only material properties (Young's modulus, shear modulus, Poisson's ratio, and mass density) and element thicknesses (Table 5.3-1). Bar elements required, in addition, moments of inertia in bending and the torsional moment of inertia and the cross-sectional area. The values of these used and the cross-section involved are listed in Figure 5.3-4 as calculated in Appendix A.5.4.

In addition to the basic RPV structure, the masses of various system components had to be included in the final model. The use of CONM2 cards enabled the components to be modeled as concentrated masses located at specified grid points within the interior of the structure. The components involved include the engine, fan and shroud assembly, muffler, batteries, autopilot and radios, servos, alternator, fuel tanks, fuel, and missions equipment.

5.3.1.3 Constraints

Two types of constraint are available to the user of NASTRAN -- singe-point constraints (SPC's) and multipoint constraints (MPC's). The SPC's constrain designated degrees-of-freedom to zero thus enforcing zero motion of the specified grid point(s) in the direction of the degrees(s)-of-freedom indicated. Throughout, SPC's were used to eliminate degrees-of-freedom either where the elements used provided no stiffness for that motion or where the effects of those degrees-of-freedom were considered negligible. For example, they were used to eliminate the inplane bending D.O.F. in the membrane elements since they provided no stiffness for that motion.

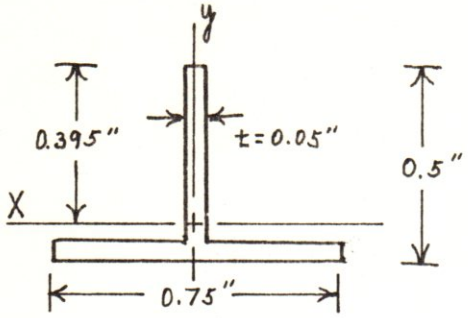
Multipoint constraints are used to specify a linear relationship among selected degrees of freedom. This allows one to define, in effect, infinitely rigid, zero mass elements. One way they were

	Young's Modulus	Shear Modulus	Poisson's Ratio*	Density (lbm/in^3)
Aluminum	10.6×10^6 PSI	4.0×10^6 PSI	0.33	0.100
Kevlar	4.5×10^6 PSI	2.0×10^6 PSI	0.13	0.48

* $\mu = \frac{E}{2G} - 1$

Materials Properties

Table 5.3-1



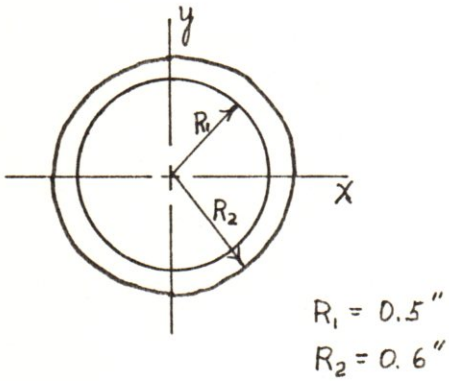
Fuselage Ribs & Stringers

Area = .0625 inches^2

I_x = 0.00128 inches^4

I_y = 0.00176 inches^4

J = 0.00304 inches^4



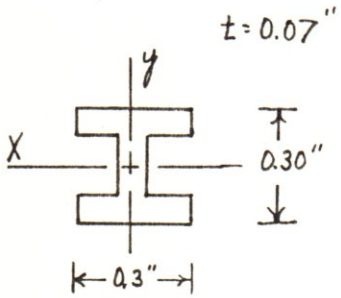
Hook Reinforcement Tube

Area = 0.350 inches^2

I_x = 0.0527 inches^4

I_y = 0.0527 inches^4

J = 0.1054 inches^4



Tail Spars

Area = 0.05356 inches^2

$I_x = 5.5 \times 10^{-4}$ inches^4

$I_y = 3.0 \times 10^{-4}$ inches^4

$J = 8.5 \times 10^{-4}$ inches^4

Component Cross-Sectional Properties

Figure 5.3-4

used was in constraining points along the centerline of the fuselage to always remain "centered" within the fuselage structure during deformation of the structure due to the applied loads.

5.3.2 NASTRAN Results

5.3.2.1 Weights and Moments Inertia

NASTRAN computed total weights, moments of inertia and center of gravities using the mass densities and element volumes input. This feature was of great convenience in that weights and balances did not have to be recalculated by hand each time the structure was modified or for different missions.

A portion of one such output is shown in Figure 5.3-5. Due to the locations of the fuel tanks and missions equipment, the moments of inertia stayed within the same order of magnitude during changes in missions and fuel quantities. The values obtained are small enough to provide the RPV with excellent manueverability dynamics but also indicates the RPV would be susceptible to gusts.

5.3.2.2 Displacements

Loadings were applied to the structure and the deformation noted. Since the RPV was designed to have an operational load range of +8 g's to -5 g's, the analysis was run to 150% of these values. To simulate these loading conditions, a gravitational load was applied in the appropriate direction and pressure loads applied to the lifting surfaces to simulate the lift produced. For take-off and landing, concentrated loads were applied at the hooks in the appropriate directions.

The displacements obtained due to these loadings were compared with those expected or allowed. Especially important were

```
              C U T P U T   F R O M   G R I D   P C I N T   W E I G H T   G E N E R A T C R
                                      REFERENCE PCINT =          1

                                             M C
***                                                                                          ***
*   1.1303C2E C2   0.C              0.0             0.0            -2.133727E 02 -4.770828E 02 *
*   0.0            1.130302E C2 -1.795339E-C7   2.133727E 02 -1.299748E-C5 -5.785832E 03 *
*   0.0           -1.795339E-C7  1.1303C2E C2   4.770828E 02  5.785832E 03  3.039556E-07 *
*   0.0            2.133727E C2  4.770828E 02   1.613702E 04  2.600242E 04 -1.557912E 04 *
* -2.133727E 02 -1.299748E-C5  5.785832E C3   2.600242E 04  3.665844E 05  2.973034E 03 *
* -4.770828E 02 -5.785832E 03  3.039556E-C7 -1.557912E 04  2.973034E 03  3.784057E 05 *
***                                                                                          ***
                                             S
                   ***                                           ***
                   *  1.CCCCOCE CO  0.0             0.0             *
                   *  0.0           1.CCOCCCE CO   0.0             *
                   *  C.C           0.0            1.000000E 00    *
                   ***                                           ***
          CIRECTICN
 MASS AXIS SYSTEM (S)       MASS            X-C.G.          Y-C.G.          Z-C.G.
          X             1.130302E 02     0.0            4.220843E CC -1.88775CE CO
          Y             1.130302E 02    -5.118837E 01 -1.149912E-07 -1.88775CE CO
          Z             1.1303C2E C2    -5.118837E 01  4.220843E CC  2.689154E-C9
                                             I(S)
                   ***                                           ***
                   *  1.372053E C4 -1.581352E C3  4.656926E 03 *
                   * -1.581352E 03  7.0C1450E C4 -2.072422E 03 *
                   *  4.656926E 03 -2.072422E C3  8.022494E 04 *
                   ***                                           ***
```

(1) Rigid body mass matrix [MO] relative to the reference point in the basic coordinate system.

(2) Transformation matrix [S] from basic coordinate system to principal mass axes.

(3) Principal masses and associated centers of gravity.

(4) Inertia matrix I(S) about the center of gravity relative to the principal mass axes.

Figure 5.3-5

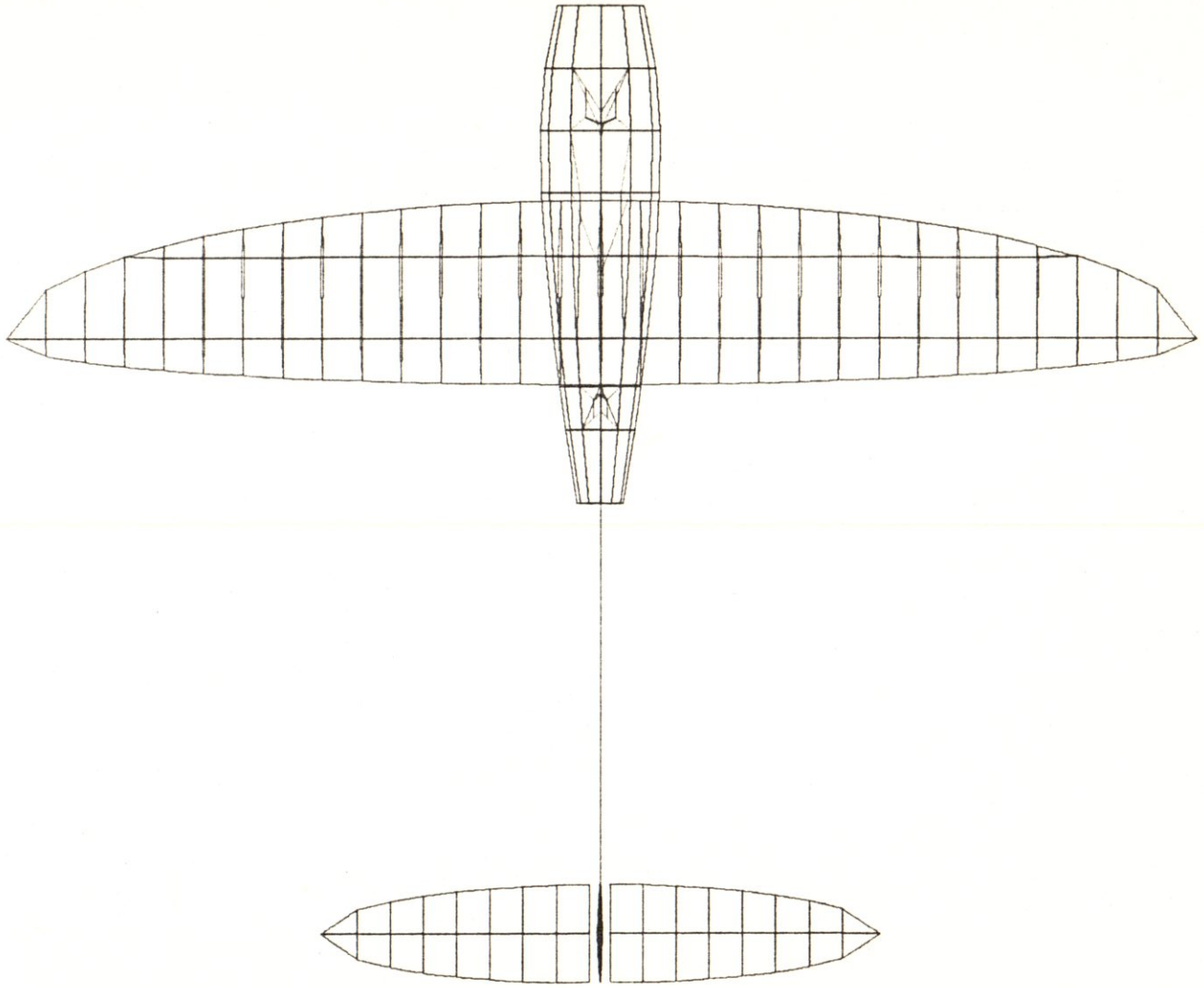
those of the wing-tips and the tail. These results were then used to improve the model through structural modifications.

5.3.2.3 Stresses

For the most part, the limiting factor for the structural loads was the stresses encountered. For each loading condition, the stresses in all the members was compared with the materials' limitations to determine margin of safety. If the structural limits were exceeded, that portion of the structure was strengthened. The final structure was able to carry all the design loads without failure in any part of the structure and stayed within the weight limitations.

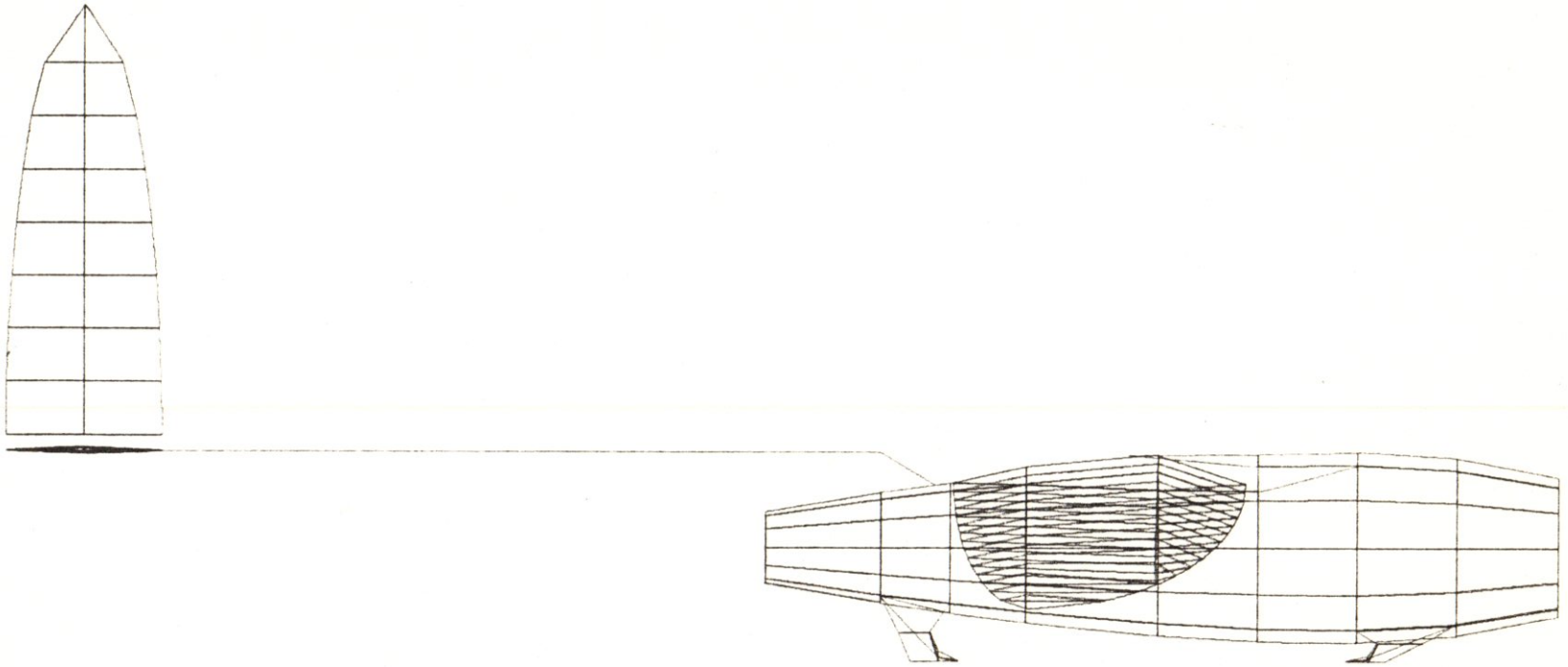
5.3.2.4 Final Structure

NASTRAN provides structured plots as a standard feature. This feature was used to insure all the grid points were located properly. Another convenience feature is the ability to have the plotter show the structure as reflected about a plane of symmetry. This enabled the final plots to show the entire structure as reflected about the XZ-plane. The final 3-view plots are shown in Figures 5.3-6, 7, and 8.



RPV FUSELAGE-WING STRUCTURE ANALYSIS
AIRFOIL- -NACA 4412 FUSELAGE- -REVOLVED NACA 0019
KEVLAR SKIN WITH ALUMINUM BRACING
UNDEFORMED SHAPE

Figure 5.3-6



FRV FUSELAGE-WING STRUCTURE ANALYSIS
AIRFOIL- -NACA 4412 FUSELAGE- -REVOLVED NACA 0012
KEVLAR SKIN WITH ALUMINUM BRACING
UNDEFORMED SHAPE

Figure 5.3-7

RPV FUSELAGE-WING STRUCTURE ANALYSIS
AIRFOIL- -NACA 4412 FUSELAGE- -REVOLVED NACA 0019
KEVLAR SKIN WITH ALUMINUM BRACING
UNDEFORMED SHAPE

Figure 5.3-8

5.5 REFERENCES

1. "1978 Materials Selector", Materials Engineering, Mid-November, 1977, pp. 224-226.

2. "Reinforced Thermoplastic", Encyclopedia of Polymer Science and Technology, Vol. 12, John Wiley & Sons, New York, 1970, pp. 31-41.

3. "Characteristics and Uses of Kevlar 49 Aramid High Modulus Organic Fiber", E.I. DuPont De Nemours & Co., Inc., 1975.

4. "Properties of Kevlar 49 Aramid Fabrics and Fabric Reinforced Epoxy and Polyester Composites", E.I. DuPont De Nemours & Co., Inc., Dec. 1975.

5. Personal Correspondence, Textile Fibers Dept. -- Kevlar Special Products, E.I. DuPont De Nemours, & Co. Inc., March 13, 1978.

6. "Properties and Characteristics of Kevlar 49 Yarn and Composites", E.I. DuPont De Nemours & Co., Inc., 1975.

7. "Remotely Pilot Vehicles and Target Drones", Aviation Week and Space Technology, March 13, 1978, pp. 122-123.

8. Hand, A.J., "Kevlar Boats -- Say Goodbye to Fiberglass?" Popular Science, Feb. 1977, pp. 99-101.

9. NASTRAN User's Manual -- Level 15.5

10. NASTRAN Theoretical Manual -- Level 15.5

APPENDICES

A 2.2-1

The thrust and final velocity for take-off and kinetic energy for landing were found from the following basic equations:

$$\text{Force } (F) = M \; a$$

$$\text{Kinetic } (K) = 1/2 \; M \; V^2$$

and

$$\text{distance } (s) = V_o t + \frac{1}{2} a t^2$$

where M = mass of RPV
a = acceleration
V = velocity

Knowing the weight of the RPVs and acceleration of the Aquila system, the thrust was found to be

$$F = (146 \text{ lbm}) \; (6 \text{ gs}) = 876 \text{ lbs.}$$

With this information and knowing the Aquila landing speed the following table was made.

	Aquila	RPV
Weight	146 lb	230 lb
Take-Off Velocity	83 ft/sec	70 ft/sec
Take-Off Distance	20 ft	20 ft
Acceleration	6 gs	3.8 gs
Landing Velocity	98 ft/sec	70 ft/sec
Kinetic Energy Landing	21773 ft-lbs	17500 ft-lbs

A.3.1

Let $S \equiv$ Wing Area

$b \equiv$ Wing Span

$c_r \equiv$ Wing Root Chord.

For elliptic wing

$$c = c_r \sqrt{1 - \frac{4x^2}{b^2}}$$

where the x axis lies along the span.

Let $a_1 + a_2 = 1$

then $c_r = c_r (a_1 + a_2)$

or, $$c_1 = c_r a_1 \sqrt{1 - \frac{4x^2}{b^2}}$$

$$c_2 = c_r a_2 \sqrt{1 - \frac{4x^2}{b^2}}$$

and $c = c_1 + c_2$

A.3.2.

The following program assumes an elliptic untwisted planform. The input consists of the dimensions of the wing root chord and span along with Oswald efficiency factor, e, and the airfoil section data. Lift coefficient is assumed to be that of the section. Drag coefficient is calculated on the basis of the following equation,

$$C_D = C_{D_o} + \frac{C_L^2}{\pi A R e}$$

where e was assumed safely to be 0.95. The induced angle of attack is also given from;

$$\alpha_i = - \frac{C_L}{\pi A R} .$$

```
      $JCB                ,NOEXT,T=99,P=5000
    1       DIMENSION CLS(35),CDS(35),CMS(35),ALPHA(80),X(100),CL(80),CD(80)
    2       DIMENSION CM(80),CLALF(80),CDALF(80),CMALF(80),RANGE(80),ENDUR(80)
    3       DIMENSION ALPHI(80)
    4       COMMON CLS,CDS,CMS
    5       COMMON K
    6    1000 FORMAT(1X,10(2X,F8.3))
    7    1100 FORMAT(1X,'     ALPHA          CL         CLALPHA          CD
        *CM         CMALPHA      RANGE       ENDUR        IALPHA')
    8    1200 FORMAT('1')
    9       WRITE(6,1200)
   10       READ,NCL,NSEC,K,E
   11       DO 100 I=1,NCL
   12     100 READ,CLS(I),CDS(I),CMS(I)
   13       READ,CR,B
   14       S=.785398*CR*B
   15       CBAR=S/B
   16       XBAR=(B/2.)*(1.-(CBAR/CR)**2)**.5
   17       AR=B*B/S
   18       WRITE(6,1000)S,CBAR,AR,XBAR
   19       PRINT,'      '
   20       PRINT,'      '
   21       PRINT,'      '
   22       DX=B/(2.*NSEC);X(1)=0.0;NNNN=NSEC+1
   25       DO 110 I=2,NNNN
   26     110 X(I)=X(I-1)+DX
   27       NCLCL=NCL*2.
   28       DO 120 J=1,NCLCL
   29       S=0.0
   30       ALPHA(J)=J/2.-K
   31       CLF=0.0;CDF=0.0;CMF=0.0
   34       CALL SECLDM(ALPHA(J),CLALPH,CDALPH,CMALPH,CLOCAL,CDOCAL,CMOCAL)
   35       DO 125 I=1,NNNN
   36       C=1.-X(I)**2*4./(B*B)
   37       IF(C.LT.0.)C=0.
   38       C=CR*(SQRT(C))
   39       S=S+C*DX
   40       CLF=CLF+CLOCAL*C*DX
   41       CDF=CDF+CDOCAL*C*DX
   42       CMF=CMF+CMOCAL*C*C*DX
   43     125 CONTINUE
   44       S=S*2.
   45       CL(J)=2.*CLF/S
   46       CD(J)=2.*CDF/S+(CL(J)**2)/(3.1417*AR*E)
   47       CM(J)=2.*CMF/S/CBAR
   48       RANGE(J)=CL(J)/CD(J)
   49       IF(CL(J).GE.0.)GO TO 10
   50       ENDUR(J)=0.
   51       GO TO 120
   52      10 ENDUR(J)=(CL(J)**1.5)/CD(J)
   53     120 CONTINUE
   54       CLALF(1)=0.;CDALF(1)=0.;CMALF(1)=0.;ALPHI(1)=0.
   58       DO 130 J=2,NCLCL
   59       CLALF(J)=(CL(J)-CL(J-1))/(ALPHA(J)-ALPHA(J-1))
   60       CDALF(J)=(CD(J)-CD(J-1))/(ALPHA(J)-ALPHA(J-1))
   61       CMALF(J)=(CM(J)-CM(J-1))/(ALPHA(J)-ALPHA(J-1))
   62       GAMA=.5*CL(J)*CR
   63       W=-GAMA/2./B
   64       ALPHI(J)=ATAN(W)*57.2958
   65     130 CONTINUE
```

```
      WRITE(6,1100)
      DO 140 J=1,NCLCL
      WRITE(6,1000)ALPHA(J),CL(J),CLALF(J),CD(J),CDALF(J),CM(J),CMALF(J)
     *,RANGE(J),ENDUR(J),ALPHI(J)
  140 CONTINUE
      WRITE(6,1200)
  150 CONTINUE
      STOP;END


      SUBROUTINE SECLDM(XXX,XX,XY,YX,YY,ZZ,ZY)
      DIMENSION CLS(35),CDS(35),CMS(35)
      COMMON CLS,CDS,CMS
      COMMON K
      II=XXX
      I=II+K
      IF(I.GT.1)GO TO 5
      XX=CLS(I+1)-CLS(I)
      XY=CDS(I+1)-CDS(I)
      YX=CMS(I+1)-CMS(I)
      GO TO 10
    5 CONTINUE
      XX=CLS(I)-CLS(I-1)
      XY=CDS(I)-CDS(I-1)
      YX=CMS(I)-CMS(I-1)
   10 CONTINUE
      YY=XX*(XXX+K-I)+CLS(I)
      ZZ=XY*(XXX+K-I)+CDS(I)
      ZY=YX*(XXX+K-I)+CMS(I)
      RETURN;END

$ENTRY
```

A.3.3.

The changes in the airfoil section characteristics as the result of flap deflection were calculated using the methods suggested by Mc Cormick. The governing equations were the following;

$$\Delta C_l = 2\pi \eta \tau \delta_f$$

$$\Delta C_d = \delta_1 \delta_2 \delta_f$$

$$\Delta C_m = -\mu_1 \Delta C_L$$

where

$$\eta = f_1(\delta_f)$$

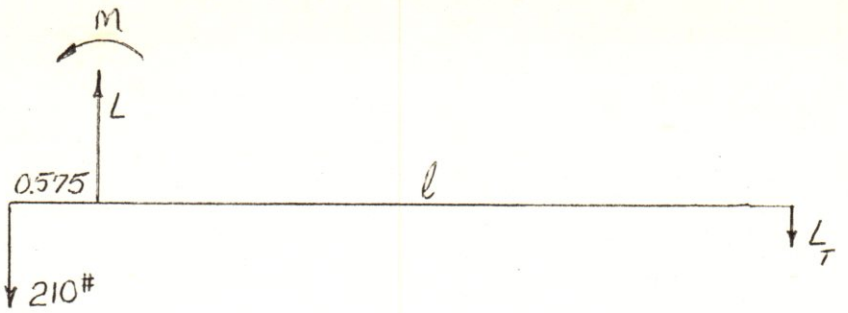
$$\tau = f_2\left(\frac{c_f}{c}\right)$$

$$\delta_1 = f_3\left(\frac{c_f}{c}\right)$$

$$\delta_2 = f_4\left(\frac{b_f}{b}\right)$$

$$\mu_1 = f_5\left(\frac{c_f}{c}\right) .$$

A.3.4.



$$L = L_T + 210 = \frac{1}{2}\rho V^2 C_L S_w$$

$$M = \frac{1}{2} V^2 \bar{c}\, S_w C_m$$

$S_w = 25.92\ ft^2$

$\rho = 0.002378\ slugs/ft^3$

$\bar{c} = 1.788\ ft$

V = from 56.6 fps to 54.4 fps.

ℓ	L_T	$S_{H.T.}$
5.2	36.72	11.27
6.2	30.51	9.61
7.2	26.10	8.37
8.2	22.8	7.40
9.2	20.24	6.66
10.2	18.20	6.04

After the tail airfoil was chosen, $S_{H.T.}$ was reduced to 6.5 ft with $\ell = 8.4$ ft. without degrading the performance.

A. 3.5

This program is capable of calculating the force and moment coefficients of the RPV in six degrees of freedom. The input consists of the following;

1 T, δ_s

2 - 53 α_{i_w}, α_w, C_{L_w}, $C_{L_{\alpha_w}}$, C_{D_w}, $C_{D_{\alpha_w}}$, C_{m_w}, $C_{m_{\alpha_w}}$

54 - 113 δ_F, $\Delta C_{L_{\delta_F}}$, $\Delta C_{d_{\delta_F}}$, $\Delta C_{m_{\delta_F}}$

114 - 142 $\alpha_{H.T.}$, C_{L_T}, $C_{L_{\alpha_T}}$, C_{D_T}, $C_{D_{\alpha_T}}$

143 b_w, C_{r_w}, $\eta_{H.T.}$, tail boom angle with respect to fuselage chord line, shroud area.

144 $b_{H.T.}$, $C_{r_{H.T.}}$, H.T. to W. distance, tail boom diameter.

145 - 170 fuselage normalized C_D

171 altitude, density, weight, $\delta_F)_{max.}$, $X_{c.g.}$ from nose.

Also are calculated the horizontal velocity for level flight, power required, $\bar{X}_{a.c.}$, $\bar{X}_{a.c.}$, $\alpha_{H.T.}$, C_L/C_D, and $C_L^{3/2}/C_D$. For glide condition line number 69 must be deleted. The following appendices show the methods by which different parameters of this program were calculated.

```
$JOB                ,T=99,P=15000
C       C(I,1)=ABSOLUTE ANGLE OF ATTACK
C       C(I,2)=WING CL
C       C(I,3)=WING CL-ALPHA
C       C(I,4)=WING CD
C       C(I,5)=WING CD-ALPHA
C       C(I,6)=WING CM
C       C(I,7)=WING CM-ALPHA
C       C(I,8)=WING DOWNWASH ANGLE AT H.TAIL
C       C(I,9)=D(DOWNWASH ANGLE)/D(ALPHA)
C       C(I,10)=GEOMETRIC ANGLE OF ATTACK OF H.TAIL
C       C(I,11)=H.TAIL CL
C       C(I,12)=H.TAIL CL-ALPHA
C       C(I,13)=H.TAIL CD
C       C(I,14)=H.TAIL CD-ALPHA
C       C(I,15)=FUSELAGE NORMALIZED CD
C       C(I,16)=FLAP DEFLECTION ANGLE
C       C(I,17)=CHANGE OF CL DUE TO THE FLAPS
C       C(I,18)=CHANGE OF CD DUE TO THE FLAPS
C       C(I,19)=CHANGE OF CM DUE TO THE FLAPS
C       C(I,20)=GEOMETRIC ANGLE OF ATTACK
C       C(I,21)=ROLLING MOMENT COEFFICIENT DUE TO SIDE-SLIP
C       C(I,22)=ROLLING MOMENT COEFFICIENT DUE TO RUDDER DEFLECTION
C       C(I,23)=ROLLING MOMENT COEFFICIENT DUE TO SPOILER DEFLECTION
C       C(I,24)=SIDE FORCE COEFFICIENT DUE TO SIDE-SLIP
C       C(I,25)=SIDE FORCE COEFFICIENT DUE TO RUDDER DEFLECTION
C       C(I,26)=YAWING MOMENT COEFFICIENT DUE TO SIDE-SLIP
C       C(I,27)=YAWING MOMENT COEFFICIENT DUE TO RUDDER DEFLECTION
C       C(I,28)=SIDE FORCE COEFFICIENT DUE TO YAW RATE
C       C(I,29)=ROLLING MOMENT COEFFICIENT DUE TO YAW RATE
C       C(I,30)=YAWING MOMENT COEFFICIENT DUE TO YAW RATE
```

```
      DIMENSION C(61,50)
  100 FORMAT('1')
  105 FORMAT('0',1X,I2,18(1X,F6.2))
      NNNN=1
      MMMM=2
      READ(5,*)SIDE,DELS
      DO 1 I=1,25
      READ(5,*)C(I,20)
    1 READ(5,*)(C(I,J),J=1,7)
      DO 5 I=1,61
    5 READ(5,*)(C(I,J),J=16,19)
      DO 3 I=1,29
    3 READ(5,*)(C(I,J),J=10,14)
      CLAVEW=0.0
      CLAVEH=0.0
      DO 13 I=1,12
      CLAVEW=CLAVEW+C(I,3)/12.
      J=I+8
      CLAVEH=CLAVEH+C(J,12)/12.
   13 CONTINUE
      READ(5,*)BW,CRW,GAMA,SHROWD
      READ(5,*)BHT,CRHT,ETHAHT,XL,DB
      DO 4 I=1,25
    4 READ(5,*)C(I,15)
      DO 11 IW=1,16
      READ(5,*)ALTITU,RHO,WI,DELFI,XCGI
      WRITE(6,100)
      PRINT,' ALTITUDE=',ALTITU,' DENSITY=',RHO
      PRINT,'          '
      W=WI
      XCG=XCGI
      DO 11 IDELF=1,13,2
      DELF=DELFI-(IDELF-1)*5
      PRINT,'          '
      PRINT,' WEIGHT=',W,' XCG=',XCG,' DELF=',DELF
      PRINT,'          '
      K=DELF+1
      E=6.78195/(XL)**0.25
      DO 2 I=1,25
      C(I,8)=(C(I,2)+C(K,17))*E
    2 C(I,9)=C(I,3)*E
      XD=3.568-XCG
      SW=.785398*BW*CRW
      CBARW=SW/BW
      ARW=BW/CBARW
      SHT=.785398*BHT*CRHT
      CBARHT=SHT/BHT
      ARHT=BHT/CBARHT
      DO 11 I=1,25
      STALL=C(25,1)-4.*C(K,16)/60.
      IF(C(I,1).GT.STALL)GO TO 8
      CLW=C(I,2)+C(K,17)
      CMW=-C(I,6)-C(K,19)+.0689*C(I,2)
      CLH=-SW*(XD*CLW+CBARW*CMW)/(XD*ETHAHT*SHT*(1.+XL/XD))
      Q=W*XD/(-XL*SHT*ETHAHT*CLH-CBARW*SW*CMW)
      IF(Q.LE.0.0)GO TO 12
      V=(Q*2./RHO)**0.5
      J=0
    6 J=J+1
      IF(J.GT.29)GO TO 9
```

```
      7 DIFFER=CLH-C(J,11)
        IF(ABS(DIFFER).GT.0.15)GO TO 6
        DELTAH=DIFFER/C(J,12)+C(J,10)+C(I,8)
        CDHT=(DIFFER/C(J,12))*C(J,14)+C(J,13)
        A=(GAMA-C(I,1))/57.2958
        CDBN=0.05*DB*(XL-1.725)*(TAN(A))/(12.*SW)
        CDHTN=CDHT*SHT/SW
        CDSHRD=0.2*SHRCWD/SW
        CDSHRD=0.
        CDFN=C(I,15)
        CDVN=C(15,13)*SHT*0.5/SW
        CDTOT=C(I,4)+CDFN+CDBN+CDHTN+CDVN+CDSHRD+C(K,18)+(C(K,17)*C(K,17)+
       *2.*C(K,17)*C(I,2))/(2.9845*ARW)
        ENDURE=0.0
        IF(CLW.LE.0.0)GO TO 10
        ENDURE=CLW**1.5/CDTOT
     10 RANGE=CLW/CDTOT
        XCGP=(XCG-3.125)/1.788
        STATIC=CLAVEH*ETHAHT*SHT*(1.-C(I,9))/(SW*CLAVEW)
        XACP=(0.24800+STATIC*4.71300)/(1.+STATIC)
        CLP=CLW+CLH*ETHAHT*SHT/SW
        CLAP=C(I,3)+C(J,12)*ETHAHT*SHT*(1.-C(I,9))/SW
        CMAP=CLAP*(XCGP-XACP)
        CMP=C(11,6)+CMAP*C(I,1)
        PI=CLP*COS(C(I,20)/57.296)+CDTOT*SIN(C(I,20)/57.296)
        POWER=W*V*CDTOT/PI/550.
        C(I,21)=-.2215*CLAVEW*SIDE-.0089*CLW-.00265*CLH-.0089*CLAVEH*(2.31
       **CCS(C(I,20)/57.296)-(8.84-XCGP*CBARW)*SIN(C(I,20)/57.296))
        C(I,22)=-.0089*CLAVEH*(2.31*COS(C(I,20)/57.296)-(8.84-XCGP*CBARW)*
       *SIN(C(I,20)/57.296))
        C(I,23)=.898*CLAVEW*SIN(DELS/57.296)
        C(I,24)=-.134*CLAVEH
        C(I,24)=C(I,24)*57.296
        C(I,25)=-C(I,24)
        C(I,26)=.0089*CLAVEH*((8.84-XCGP*CBARW)*COS(C(I,20)/57.296))
        C(I,26)=C(I,26)*57.296-.0279*XCG+.0973
        C(I,27)=-C(I,26)
        C(I,28)=CLAVEH*.01588*(8.84-XCGP*CBARW)*COS(C(I,20)/57.296)
        C(I,29)=C(I,28)*(-SIN(C(I,20)/57.296)*(8.84-XCGP*CBARW)+1.43)/15.
        C(I,30)=-C(I,28)*(8.84-XCGP*CBARW)*COS(C(I,20)/57.296)/15.
        C(I,21)=C(I,21)*57.296
        C(I,22)=C(I,22)*57.296
        C(I,28)=C(I,28)*57.296
        C(I,29)=C(I,29)*57.296+1.96*CLW/V
        C(I,30)=C(I,30)*57.296
        WRITE(6,105)NNNN,C(I,1),C(I,20),CLW,ENDURE,RANGE,V,DELTAH,C(I,8),P
       *OWER,XACP,XCGP,CMAP
        WRITE(6,105)MMMM,CLP,CDTOT,CMP,(C(I,J),J=21,30)
        GO TO 11
     12 PRINT,Q,'     ...TOO LOW AN ANGLE OF ATTACK..DOWNWARD LIFT....  '
        GO TO 11
      8 PRINT,'    ...TOO HIGH AN ANGLE OF ATTACK...WING STALL...     '
        GO TO 11
      9 PRINT,'    ...IMPOSSIBLE CONFIGURATION...H.TAIL STALL...     '
     11 CONTINUE
        WRITE(6,100)
        STOP;END

$ENTRY
```

A.3.6

$$\left.\frac{dM}{d\alpha}\right)_B = \frac{q}{36.5}\int_0^{\ell} w_f^2(x)\left.\frac{d\bar{\varepsilon}}{d\alpha}\right|_x dx$$

$$\left.\frac{dM}{d\alpha}\right)_B = \frac{q}{36.5}\sum_{i=1}^{i=n} w_f^2(x_i)\left.\frac{d\bar{\varepsilon}}{d\alpha}\right|_i \Delta x_i$$

Ahead of the wing

$$\left.\frac{d\bar{\varepsilon}}{d\alpha}\right|_{C_{L_\alpha}} = \frac{C_{L_\alpha}}{0.08} \cdot \left.\frac{d\bar{\varepsilon}}{d\alpha}\right|_{0.08}$$

where $\left.\frac{d\bar{\varepsilon}}{d\alpha}\right|_{0.08}$ is given by the author.

Behind the wing

$$\frac{d\varepsilon}{d\alpha} = 18\, C_{L_\alpha} \cdot \frac{\lambda^{0.3}}{AR^{0.725}}\left(\frac{3\bar{c}}{\ell_H}\right)^{0.25}$$

where then $$\left.\frac{d\bar{\varepsilon}}{d\alpha}\right|_{x_i} = \frac{x_i}{\ell_H}\left(1 - \frac{d\varepsilon}{d\alpha}\right).$$

Thus $$\Delta \bar{X}_{a.c._B} = -\frac{dM/d\alpha}{\bar{q} S \bar{c}\, C_{L_{\alpha_w}}}$$

$$\frac{dM}{d\alpha} = \frac{q}{36.5} \cdot \frac{1}{1728} \cdot \frac{C_{L_\alpha}}{0.08}\,(16106.647)$$

$$\Delta \bar{X}_{a.c._B} = -0.0689$$

and $$C_{m_f} = C_{L_w} (0.0689)$$

Wing a.c. is given by;

$$X_{a.c.} = \frac{\int_0^1 C_{l_\alpha} c \times d\left(y/b/2\right)}{\int_0^1 C_{l_\alpha} c \, d\left(\frac{y}{b/2}\right)}$$

$$c = 2.3\sqrt{1-\left(y/\frac{b}{2}\right)^2}$$

$$X_{a.c.} = 1.725 \frac{\int_0^{\frac{\pi}{2}} \cos^2\theta \left(1-\cos\theta\right) d\theta}{\int_0^{\frac{\pi}{2}} \cos^2\theta \, d\theta}$$

$$X_{a.c.} = 0.2608$$

A.3.7.

$$C_L = C_{L_0} + C_{L_\alpha}\alpha + C_{L_{i_H}} i_H + C_{L_{\delta_E}} \delta_E$$

For all moving symmetrical tail and wing flaps

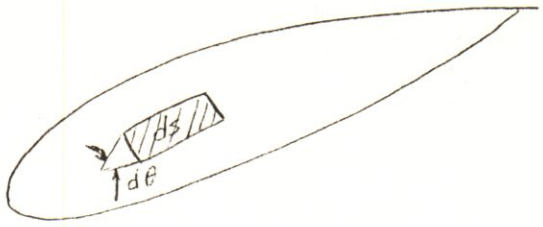
$$C_L = C_{L_w} + C_{L_{\delta_F}} \delta_F + \frac{S_H}{S_w} \eta_H C_{\alpha_H} \alpha_H$$

where $\alpha_H = \alpha - \varepsilon$

and $\varepsilon = 18 C_{L_w} \frac{\lambda^{0.3}}{AR^{0.725}} \left(\frac{3\bar{c}}{l_H}\right)^{0.25}$

Throughout the stability calculations η_H was safely assumed to be 0.95.

A.3.8.



$$dS = r\,d\theta\,dx$$

$$S = \int_0^c \int_0^{\pi} r\,d\theta\,dx$$

$$C_{D_F} = \frac{1}{S_w} \int_0^c \int_0^{\pi} C_D\, R(x)\, dx\, d\theta + C_{D_i}$$

$$C_D = C_{D_o} + C_{D_\alpha}\,\alpha$$

$$\alpha = \alpha_i \sin\theta$$

$$C_{D_F} = \frac{1}{S_w} \int_0^c \int_0^{\pi} \left[C_{D_o} + C_{D_\alpha} (\alpha \sin\theta) \right] R(x)\, dx\, d\theta + C_{D_i}$$

The same method results in

$$C_{L_F} \cong \frac{1}{S_w} \int_0^{\pi} \int_0^c C_{L_\alpha}\, \alpha \sin^2\theta\, R(x)\, dx\, d\theta$$

$$C_{L_F} \cong \frac{\pi}{2S_w} \int_0^c C_{L_\alpha}\, \alpha\, R(x)\, dx$$

then

$$C_{D_F} = \frac{1}{S_w} \left\{ \left[(\pi - 2.)\, C_{D_o} + 2 C_D \right] \int_0^c R(x)\, dx + \frac{C_{L_F}^2}{\pi AR e} \right\}$$

A.3.9.

$$C_D = C_{D_o} + C_{D_\alpha}\,\alpha + C_{D_{i_H}}\,i_H + C_{D_{\delta_E}}\,\delta_E$$

$$C_D = C_{D_w} + C_{D_{fuselage}} + C_{D_{Flaps}} + \frac{\left(\Delta C_{l_{Flaps}}^2 + C_{L_w}\cdot\Delta C_{l_{Flap}}\right)}{\pi AR\,e}$$

$$+ \frac{S_{boom}}{S_w}\,C_{D_{boom}} + \frac{S_H}{S_w}\,\eta_H\,C_{D_H} + C_{D_{shroud}}$$

For the case of power-on $C_{D_{shroud}} = 0.$

A.3.10

$$C_m = C_{m_o} + C_{m_\alpha}\alpha + C_{m_{i_H}} i_H + C_{m_{\delta_E}} \delta_E$$

Considering the special structure on hand;

$$C_m = \left(C_{L_{0_{WB}}} + C_{L_{\alpha_{WB}}} \alpha \right)\left(\bar{X}_{c.g.} - \bar{X}_{a.c.} \right) + C_{m_{a.c._{WB}}}$$

$$+ C_{L_{\alpha_H}} \eta_H \frac{S_H}{S_w} \left(\bar{X}_{a.c._H} - \bar{X}_{c.g.} \right)(\alpha - \varepsilon)$$

It was assumed in this part that

$$C_{L_{WB}} = C_{L_w}$$

A.3.11.

To find $\bar{X}_{a.c.}$ $\quad C_{m_\alpha} = 0$

then

$$\bar{X}_{a.c._{plane}} = \frac{\bar{X}_{a.c._{WB}} + \frac{C_{L_{\alpha_H}}}{C_{L_{\alpha_{WB}}}} \eta_H \frac{S_H}{S_w} \bar{X}_{a.c._H} \left(1 - \frac{d\varepsilon}{d\alpha}\right)}{1 + \frac{C_{L_{\alpha_H}}}{C_{L_{\alpha_{WB}}}} \eta_H \frac{S_H}{S_w} \left(1 - \frac{d\varepsilon}{d\alpha}\right)}$$

For the specific structure on hand $\bar{X}_{a.c._{plane}}$ stays constant wether the power is on or off due to passing of the thrust line through c.g.

A.3.12.

$$\tan \Lambda_n = \tan \Lambda_m - \frac{4}{AR_w}\left[(n-m)\frac{(1-\lambda)}{(1+\lambda)}\right]$$

where $n, m \equiv$ fractions of chord

$\lambda \equiv$ taper ratio $= \frac{2}{3}$

For this structure $m = \frac{3}{4} \Rightarrow \tan \Lambda_{c\,3/4} = 0$

then $\tan \Lambda_n = \frac{4}{AR\,w}\left[\left(\frac{3}{4} - n\right)\frac{\left(1-\frac{2}{3}\right)}{\left(1+\frac{2}{3}\right)}\right]$

therefore

at leading edge $\Lambda_o \cong 4.23^\circ$

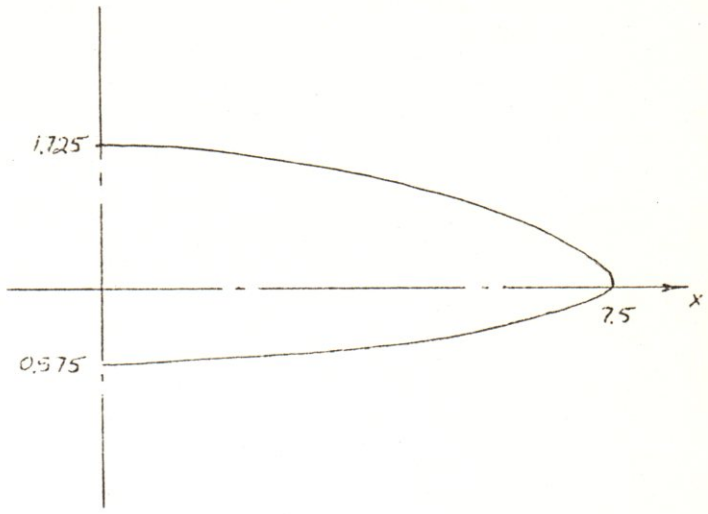
at $c/4$ $\Lambda_{c/4} \cong 2.82^\circ$

at trailing edge $\Lambda_c \cong -1.41^\circ$

For horizontal tail $m = 0.5 \Rightarrow \tan \Lambda_{c/2} = 0$

therefore $\Lambda_{L.E.} \cong 3.23^\circ$

A. 3. 13



$$C_l = C_{l_o} + C_{l_\beta}\beta + C_{l_{\delta_s}}\delta_s + C_{l_{\delta_R}}\delta_R$$

C_{l_o} : $\quad C_{l_o} = 0.0$

C_{l_β} : $\quad C_{l_\beta} = C_{l_{\beta_{WB}}} + C_{l_{\beta_H}} + C_{l_{\beta_V}}$

$$C_{l_{\beta_{WB}}} = C_{l_{\beta_\Gamma}} + C_{l_{\beta_\Lambda}} + C_{l_{\beta_{\text{wing location}}}}$$

Dihedral Effect.

$$c = 2.3\sqrt{1 - \frac{x^2}{(7.5)^2}}$$

$$dL_\beta = -2\int x\, c\, dx\, C_{l_\alpha}\, d\alpha$$

$$dL_\beta = -\int_{x=0.25}^{7.5} 4.6\, x\sqrt{1 - \frac{x^2}{(7.5)^2}}\; C_{l_\alpha}\, d\alpha\, dx$$

$$d\alpha = \beta\Gamma$$

and $\quad C_{l_\beta} = \dfrac{L_\beta}{Sb}$

$$C_{l_{\beta_{dihedral}}} = -0.2215\, C_{L_\alpha}\, \Gamma$$

Sweep Effect (Wing)

$$dL_{\beta_\Lambda} \cong -\chi\, C_{L_\alpha}\, \alpha\, c\, dx\, (2\beta \sin 2\Lambda)$$

$$C_{l_{\beta_{sweep}}} = -.00887\, C_L$$

Sweep Effect (H. Tail)

$$dL_{\beta_{\Lambda_H}} = -\chi\, C_{L_{\alpha_H}}\, \eta_H \left[\beta \sin 2\Lambda\right](2.452)(3.375)/3.$$

$$C_{l_{\beta_{\Lambda_H}}} = -0.00265\, C_{L_H}$$

Vertical Tail and Body

$$\bar{z} = \frac{\int_0^{3.375} x\sqrt{1-\frac{x^2}{(3.375)^2}}\, dx}{\int_0^{3.375} \sqrt{1-\frac{x^2}{(3.375)^2}}\, dx} = \frac{4b_v}{3\pi}$$

then $$\bar{z}_v = \frac{4b_v}{3\pi} + 0.75$$

$$AR_{eff_v} = \frac{A_v(B)}{A_v}\, A_v \left\{1 + K_H \left[\frac{A_{v_{HB}}}{A_{v_B}} - 1\right]\right\}$$

$S_v = 3.25\ ft^2$

$b_v = 3.375\ ft \quad \Rightarrow \quad A_v = 3.5$

$\lambda = 2/3 \quad \Rightarrow \quad \frac{A_{VB}}{A_v} = 1.0\ , \quad \frac{A_{VHB}}{A_{VB}} = 0.9\ ; \quad K_H = 0.97$

then $\quad AR_{eff._v} = 3.16$

For side wash effect;

$$\left(1 + \frac{\partial \sigma}{\partial \beta}\right) \eta_v = 0.724 + 3.06 \frac{S_v/S_w}{1 + \cos \Lambda_{c/4_w}} + 0.4 \frac{z_w}{d} + 0.009 AR_w$$

therefore $\quad \left(1 + \frac{\partial \sigma}{\partial \beta}\right) \eta_v = 1.069$

$$C_{Y_{\beta_{VBW}}} = -k C_{L_{\alpha_v}} \left(1 + \frac{\partial \sigma}{\partial \beta}\right) \eta_v \frac{S_v}{S_w}$$

where $\quad k = 1.0$

then $\quad C_{Y_{\beta_{VBW}}} = -0.134\ C_{L_{\alpha_v}}$

therefore since $\quad C_{l_{\beta_{VBW}}} = C_{Y_{\beta_{VBW}}} \frac{\bar{z}_v \cos\alpha - \ell_v \sin\alpha}{b_w}$

Thus $\quad C_{l_\beta} = -0.02215\ C_{L_{\alpha_w}} \bar{\Gamma} - 0.0337\ C_{L_w} - 0.00265\ C_{L_H}$

$$- 0.0089\ C_{L_{\alpha_v}} \left[2.31 \cos\alpha - (8.84 - \bar{x}_{c.g.} \cdot \bar{c}) \sin\alpha\right]$$

$C_{l_{\delta_s}}$:

$$C_{l_{\delta_s}} = \frac{C_{l_\alpha}}{2} \Delta\alpha_s'$$

$$\Delta\alpha_s' = 1.167 \frac{h_s}{c} - 0.05835$$

$$h_s = (\text{spoiler width}) \sin\delta_s + 0.05$$

$$\beta = \sqrt{1-M^2} \cong 1$$

$$\beta AR \cong 8 > 2$$

$$\Lambda_\beta = \tan^{-1}(\tan 2.86/\beta) = 2.876 < 60$$

therefore the above method is applicable and,

$$b = 0.25'$$

$$\left.\begin{aligned} y_i = 5.0 &\Rightarrow \eta_i = 0.667 \\ y_o = 6.0 &\Rightarrow \eta_o = 0.8 \end{aligned}\right\} \Rightarrow \eta_{ave.} = 0.7335$$

$$C_{l_{\delta_s}}' \beta/\kappa = 0.675$$

$$\kappa = C_{l_\alpha}/2\pi$$

then

$$C_{l_{\delta_s}}' \cong \frac{0.675}{2\pi} C_{l_\alpha}$$

therefore

$$C_{l_{\delta_s}} = \frac{0.675}{4\pi} C_{l_\alpha} \left[1.167 (0.25 \sin\delta_s + 0.05) - 0.5835\right]$$

thus

$$C_{l_{\delta_s}} = 0.898\, C_{l_\alpha} \sin\delta_s$$

$C_{l_{\delta_R}}$:

For all moving vertical tail

$$C_{l_{\delta_R}} = C_{l_{\beta_V}}$$

therefore;

$$C_{l_{\delta_R}} = -0.0089\, C_{l_{\alpha_V}} \left[2.31 \cos\alpha - (8.84 - \bar{X}_{c.g.}\bar{c}) \sin\alpha\right]$$

Magnitudes and Comments

derivative	accepted	available	comments
C_{l_β}	+0.1 – -0.4	0. – -0.63	Resistance to side-slip is desirable during landing
$C_{l_{\delta_A}}$	0.0 – 0.4	0.08	Spoiler has twice as much range of deflection
$C_{l_{\delta_R}}$	-0.04 – +0.04	-0.13 – -0.05	Vertical tail has one forth the freedom of motion of rudder.

A.3.14.

$$C_Y = C_{Y_0} + C_{Y_\beta}\beta + C_{Y_{\delta_R}}\delta_R + C_{Y_{\delta_S}}\delta_S$$

$$C_{Y_0} = 0$$

$$C_{Y_{\delta_S}} \cong 0$$

C_{Y_β} was calculated in the previous part. For all moving V. tail

$$C_{Y_\beta} = -C_{Y_{\delta_R}}$$

Therefore $$C_{Y_\beta} = -0.134\, C_{l_{\alpha_V}}\, \beta$$

and $$C_{Y_{\delta_R}} = 0.134\, C_{l_{\alpha_V}}\, \delta_R .$$

Magnitudes and Comments.

derivative	accepted	available	Comments
C_{Y_β}	-0.1 - -2.0	-0.78	acceptable
$C_{Y_{\delta_R}}$	0. - 0.5	0.78	V. tail has one forth the freedom of motion of rudder.

A.3.15.

$$C_n = C_{n_o} + C_{n_\beta}\beta + C_{n_{\delta_S}}\delta_S + C_{n_{\delta_R}}\delta_R$$

$$C_{n_o} = 0. \quad \text{and} \quad C_{n_{\delta_S}} \cong 0.$$

For all moving vertical tail;

$$C_{n_\beta} = -C_{n_{\delta_R}}$$

$$C_{n_\beta} = -C_{n_{\delta_R}} = -C_{Y_V} \cdot \ell_V + f(c.g.)$$

or, $$C_{n_\beta} = 0.0089\, C_{L_{\alpha_V}} \left(8.84 - \bar{x}_{c.g.}\bar{c}\right)\cos\alpha - 0.0279\, x_{c.g.} + 0.0973$$

Magnitudes and Comments.

derivative	accepted	available	Comments
C_{n_β}	0. – 0.4	0.38	acceptable
$C_{n_{\delta_R}}$	0. – -0.15	-0.38	V. tail has one forth the freedom of motion of rudder

A.3.16

$$C_{Y_r} = C_{Y_{r_{WBH}}} + C_{Y_{r_V}}$$

Due to the small size of the body and length,

$$C_{Y_{r_{WBH}}} \cong 0$$

$$C_{Y_{r_V}} = C_{L_{\alpha_V}} \frac{2 \cdot l_V}{b} \eta_V \frac{S_V}{S}$$

Assuming $\eta_V = 0.95$

then $$C_{Y_r} = C_{Y_{r_V}} = C_{L_{\alpha_V}} (0.01588)(8.84 - \bar{x}_{cg} \cdot \bar{c}) \cos\alpha$$

Magnitudes and Comments.

derivative	accepted	available	Comments
C_{Y_r}	0 – 1.2	0.65 – 0.74	acceptable.

A. 3. 17.

$$C_{l_r} = C_{l_{r_W}} + C_{l_{r_B}} + C_{l_{r_H}} + C_{l_{r_V}}$$

$$C_{l_{r_B}} \cong 0. \quad \text{and} \quad C_{l_{r_H}} \cong 0.$$

$$C_{l_{r_W}} = \frac{1}{q.Sb} \int_{-7.5}^{7.5} y\, c\, C_{L_w} \left(0.5\rho \Delta\bar{w}^2 + \rho V \Delta\bar{w}\right) dy$$

$$c = 2.3\sqrt{1 - \frac{y^2}{(7.5)^2}}$$

$$\Delta\bar{w} = ry$$

therefore

$$C_{l_{r_W}} = 1.96 \frac{C_{L_W}}{V}$$

$$C_{l_{r_V}} = C_{L_{\alpha_V}} \frac{2.\, l_v \cdot z_v}{b^2} \eta_v \frac{S_v}{S}$$

Magnitudes and Comments.

derivative	accepted	available	Comments
C_{l_r}	0. – 0.6	0.05 – 0.09	acceptable

A.3.18

$$C_{n_r} = C_{n_{r_{WB}}} + C_{n_{r_V}}$$

Due to the small sizes of the body;

$$C_{n_{r_{WB}}} \cong 0$$

therefore

$$C_{n_r} = C_{n_{r_V}}$$

$$C_{n_{r_V}} = -C_{L_{\alpha_V}} \frac{2 \cdot l_v^2}{b^2} \eta_V \frac{S_V}{S}$$

or

$$C_{n_r} = -C_{Y_{r_V}} \cdot \frac{l_v}{b}$$

Magnitudes and Comments.

derivative	accepted	available	Comments
C_{n_r}	0. – -1.0	-0.36 – -0.39	acceptable.

A.3.19

Landing can be performed in any direction. The following are suggested for load and weather conditions.

Weather	Load	Flaps (DEG.)	Stall Speed (Nauts)	Air Speed (Nauts)	Approach Angle (deg.)	max. R.C. Available (fpm)	Descend Rate (fpm)
Turbulent	empty 143.2 #	20	27	33	less than 4	310	Any
	full 229.24 #	20	35	42	less than 0.5	50	Any
Calm	empty 143.2 #	60	24	29	1.2	—	80
	full 229.24 #	40	32	39	2.4	—	165

For other flap settings refer to Figures A.3.19.a and A.3.19.b.

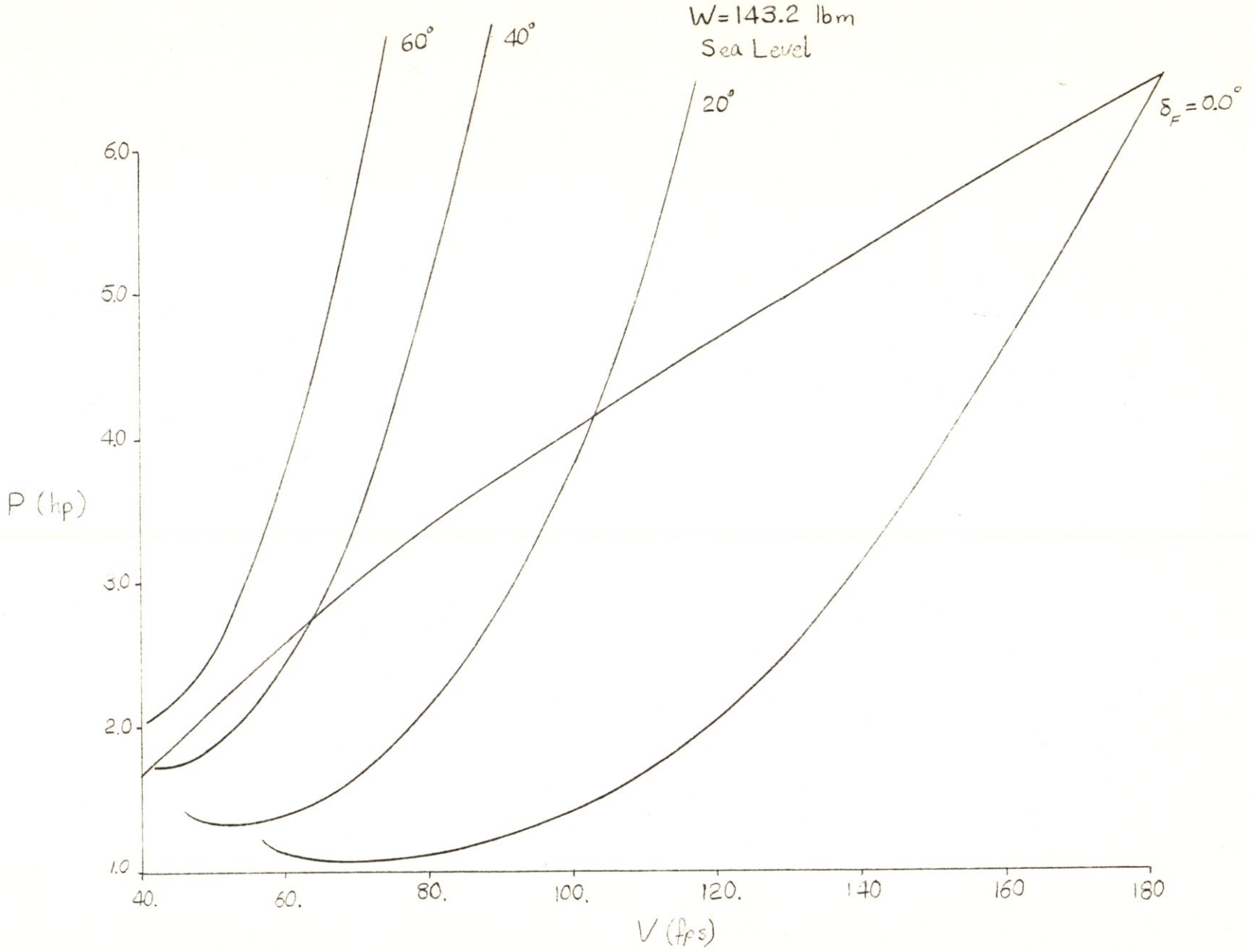

W=143.2 lbm
Sea Level
60°
40°
20°
$\delta_F = 0.0°$
6.0
5.0
4.0
3.0
2.0
1.0
P (hp)
40.
60.
80.
100.
120.
140
160
180
V (fps)

Fig A.3.19.a

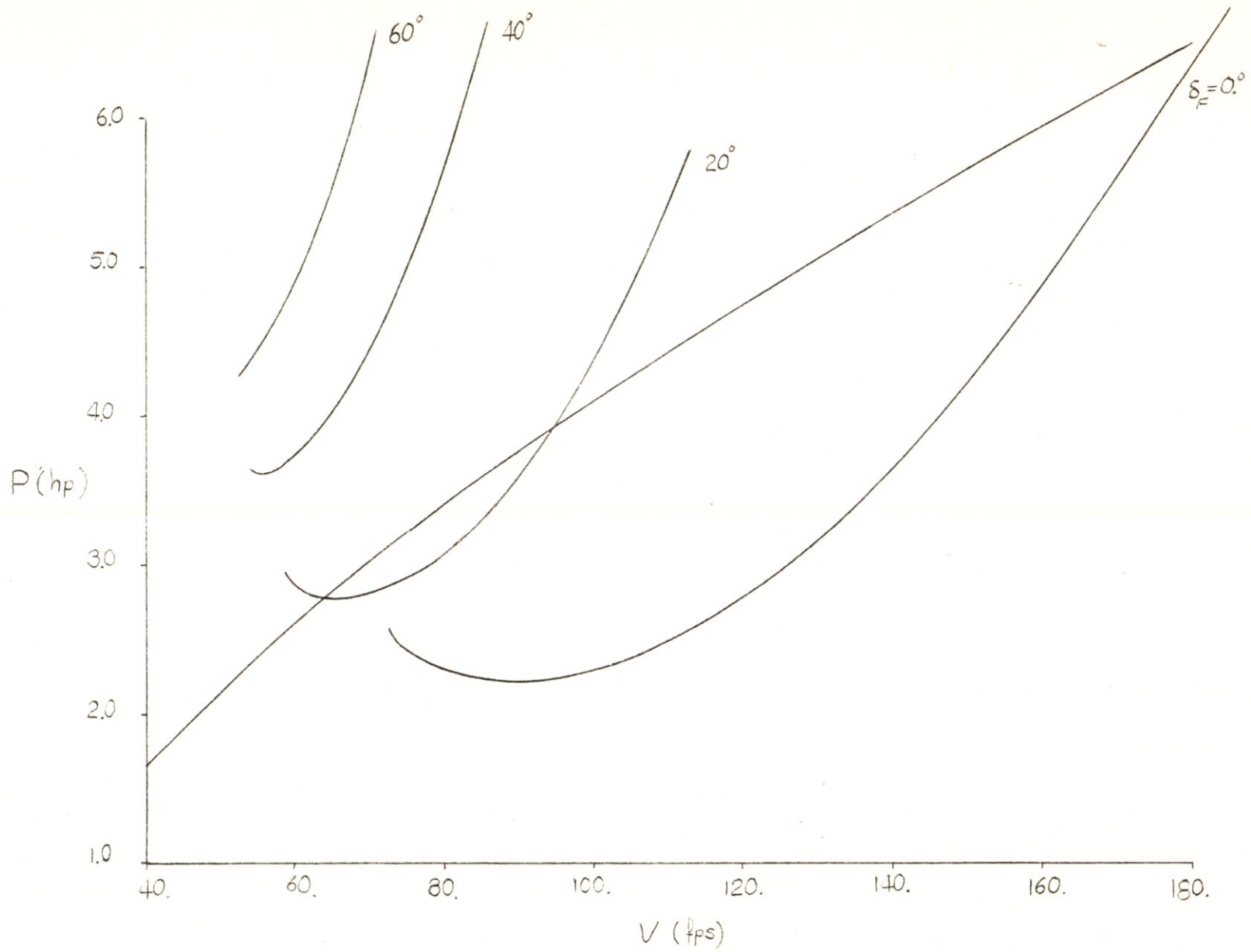

60°
40°
20°
$\delta_E = 0.°$
6.0
5.0
4.0
3.0
2.0
1.0
P (hp)
40.
60.
80.
100.
120.
140.
160.
180.
V (fps)

Fig A.3.19.b

Appendix 4

A.2.2.2

A. $\Delta H_p = 6130 \frac{BTU}{lbm_{fuel}}$ $2g_c \Delta H_p = 3.065 \times 10^8 \frac{ft}{s^2}$

ideal $V_j = \sqrt{2g_c \Delta H_p} = 17{,}500$ fps

Propulsive efficiency, η_p

$\eta_p = \frac{2r}{1+r^2}$, $r = \frac{U}{V_j}$

U – forward vel. V_j – jet velocity

For H_2 & O_2

$r = \frac{110}{17500} = 0.006286$ $\eta_p = \frac{2(0.006286)}{1+(0.006286)^2}$

$\eta_p = 0.0126$

Power required is $1650 \frac{ft-lbf}{s}$

$1\ BTU = 777\ ft\text{-}lbf$

at $\eta_p = 0.022 = \frac{\text{Power out}}{\text{Power in}} = \frac{1243 \frac{ft-lbf}{s}}{P_{in}}$

$P_{in} = 75000 \frac{ft-lbf}{s}$ $\Delta H_p = 6130 \frac{BTU}{lbm_f}$

$\Delta H_p = (6130 \frac{BTU}{lbm_f})(777 \frac{ft-lbf}{BTU})$

$\Delta H_p = 4763010 \frac{ft-lbf}{lbm_f}$

$\dot{m}_f = \frac{P}{\Delta H_p} = \frac{75000 \frac{ft-lbf}{s}}{4763010 \frac{ft-lbf}{lbm_f}} = 0.01575 \frac{lbm_{fuel}}{s}$

$\dot{m}_f = (0.01575 \frac{lbm_f}{s})(3600 \frac{s}{hr}) = 56.687 \frac{lbm_f}{hr}$

over 20 hours for $V_j = 10000 \frac{ft}{s}$

$m_f = 1133.74\ lb_{mf}$

B. $m_f = (15 lb_f)(0.6 \frac{lb_{mf}}{lb_f\text{-}hr})(20\ hr) = 180\ lb_{mf}$

C. $m_f = \frac{180\ lb_{mf}}{2} = 90\ lb_{mf}$

D. $m_f = (3\ hp)(0.48 \frac{lb_{mf}}{hp\text{-}hr})(20\ hr) = 28.8\ lb_{mf}$

E. $shp = \frac{hp_{req}}{\eta} = \frac{3\ hp}{0.85} = 3.53\ hp$

$m_f = (3.53\ hp)(0.6 \frac{lb_{mf}}{hp\text{-}hr})(20\ hr) = 42.36\ lb_{mf}$

F. $shp = \frac{hp_{req}}{\eta} = \frac{3\ hp}{0.5} = 6\ hp$

$m_f = (6\ hp)(0.6 \frac{lb_{mf}}{hp\text{-}hr})(20\ hr) = 72\ lb_{mf}$

G. $m_f = (15 lb_f)(2 \frac{lb_{mf}}{lb_f\text{-}hr})(20\ hr) = 600\ lb_{mf}$

4.2.2.3 Preliminary estimates of Preq

Dash $C_D \doteq 0.015$ $37.5\ ft^2$ wing

10.75 hp req. at 220 fps
or 150 mph

@ ~~SS~~ $\eta_{Prop} = 0.65$ $shp_{req} = \frac{10.75\ hp}{0.65} = 16.54\ hp$

4.2.2.4

fuel heating value $\simeq 18000\ \frac{BTU}{lbm}$

$c_{p\,air} = 0.24\ \frac{BTU}{lbm-°R}$ $1\ hp = 0.70733\ \frac{BTU}{s}$

for 10 hp and $SFC = 0.9\ \frac{lbm}{hp-hr}$

fuel flow of $9\ \frac{lbm}{hr}$ is required

$\dot{m}_f = \frac{9\ \frac{lbm_f}{hr}}{3600\ \frac{s}{hr}} = 0.0025\ \frac{lbm_f}{s}$

Heat flow $= (18000\ \frac{BTU}{lbm})(0.0025\ \frac{lbm}{s})$

$\dot{Q}_{Gen} = 45\ \frac{BTU}{s}$

9 hp gets outside the fuselage to the fan

$\dot{Q}_{fan} = (9\ hp)(0.70733\ \frac{BTU}{hp-s}) = 6.366\ \frac{BTU}{s}$

Assume 50% of $\dot{Q}_{Gen}$ goes out the tailpipe (Accounts for unburnt fuel, too)

$\dot{Q}_{excess} = 0.5(45\ \frac{BTU}{s}) - 6.366\ BTU$

$= 16.134\ \frac{BTU}{s}$

at ~~80 ft/s~~ sea level $\rho = 0.076572\ \frac{lbm}{ft^3}$

if surroundings 90°F allow air temp. out of cooling system to be 150°F. $\Delta T = 60\,^\circ R$

$$\text{air flow} = \frac{16{,}134\ \frac{BTU}{s}}{(0{,}24\ \frac{BTU}{lb_m\text{-}^\circ R})(60\,^\circ R)} = \dot{m}_a = 1{,}1204\ \frac{lb_m}{s}$$

at $V = 80\ \frac{ft}{s}$ $\quad A = \frac{1{,}1204\ \frac{lb_m}{s}}{(0{,}076572\ \frac{lb_m}{ft^3})(80\ \frac{ft}{s})} = 0{,}1829\ ft^2$

$A = 26{,}34\ in^2$

Allowing for a 1" diam. hub and 6" id. for duct end.

$A = \pi(3''^2 - 0.5''^2) \doteq 27.5''^2$

~~4,2,2,2~~

4,2,2,3

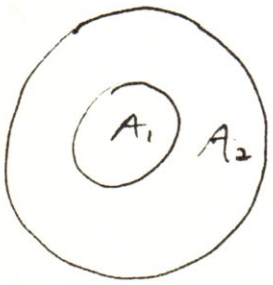
Fan sizing estimation

Assume 1,02 pressure ratio at 5006 ft. Assume Pressure = P = 14,5 psia

Thrust Loading $= \cancel{(14,5)(0,}$

$\hookrightarrow = (14{,}5\ \frac{lb_f}{in^2})(0{,}2) = 0{,}29\ \frac{lb_f}{in^2}$

$$A_{req} = \frac{12{,}1\ lb_f}{0{,}29\ \frac{lb_f}{in^2}} = 41.72\ in^2$$

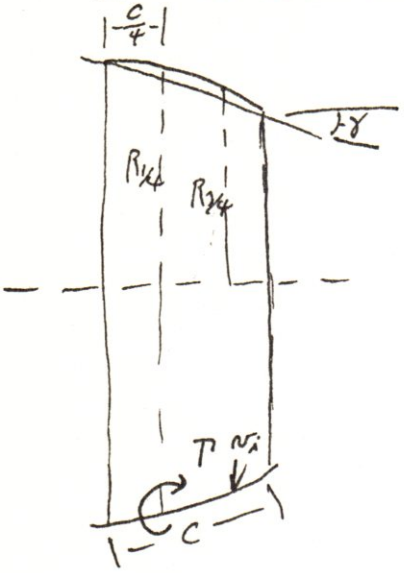


$A_2 = \pi r_2^2 - \pi r_1^2 \quad r_2 = \sqrt{\frac{A_2 + \pi r_1^2}{\pi}}$

$r_2 = \sqrt{\frac{41.72 + \pi(3)^2}{\pi}} = 4.72''$

$r_1 = r_{hub} = 3''$

Shroud Design



approximation to a ring airfoil by McCormick

$$v_i = \frac{T}{\pi D_{1/4}} f\left(\frac{c}{D_{1/4}}, \frac{D_{3/4}}{D_{3/4}}\right)$$

v_i is radial (outward) velocity induced by the ring lift at $c_{3/4}$.

From the boundary condition at $c_{3/4}$ in that radial velocity in total is zero, finding the radial v_i induced by the rotor must be equal and opposite. The free-stream condition of the rotor under the same shroud internal axial velocity solves for T.

$$v_{iR} = -\frac{1}{2} \frac{R R_R^2 w_o}{(z^2 + R_R^2)^{3/2}}$$

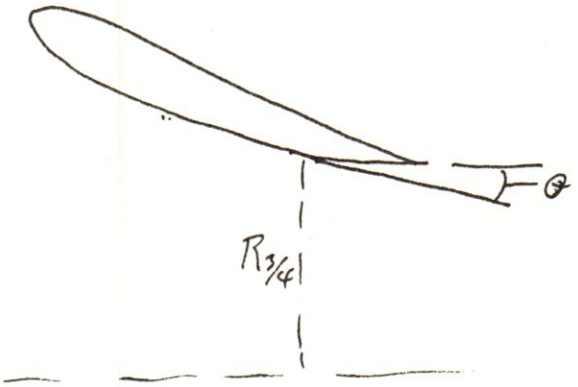
$$w_o = \frac{1}{2}\left\{-V + \left[V^2 + \frac{T_R}{(\rho/2)\pi R R^2}\right]^{1/2}\right\}$$

Continuity $(V + w_a)\pi R^2 = (V + w_o)\pi R^2$

$$w_a = \frac{R_R^2}{R^2}(V + w_o) - V$$

The resultant flow should be tangent to the shroud.

Therefore for a shroud inner surface angle of θ at $c_{3/4}$



$$\theta = \frac{-V_{iR_{3/4}} - V_i}{V + W_{a_{3/4}}}$$

or $$V_i = -V_{iR_{3/4}} - \theta(V + W_{a_{3/4}})$$

giving $$T = \frac{\pi D_{1/4}}{f\left(\frac{c}{D_{1/4}}, \frac{D_{3/4}}{D_{1/4}}\right)} \left[-V_{iR_{3/4}} - \theta(V + W_{a_{3/4}})\right]$$

From the Kutta - Joukowski law the force on the shroud is

$$T_S = -\rho V_{iR_{3/4}} \Gamma \pi D_{1/4}$$

$$T_S = \frac{-\rho (\pi D_{1/4})^2 \left[-V_{iR_{3/4}} - \theta(V + W_{a_{3/4}})\right] V_{iR_{3/4}}}{f\left(\frac{c}{D_{1/4}}, \frac{D_{3/4}}{D_{1/4}}\right)}$$

Defining a thrust coefficient

$$C_T = \frac{T}{\frac{1}{2}\rho A V^2}$$

Solve for C_T in terms of f, w_o, $v_{iR1/4}$, $v_{iR3/4}$; C_{TR} (rotor)

$$T_s = \rho v_{iR3/4} \Gamma \pi D_{1/4}$$

$$T = v_{iR3/4} \pi D_{1/4} \frac{1}{f\left(\frac{c}{D_{1/4}}, \frac{D_{3/4}}{D_{1/4}}\right)}$$

$$v_{\lambda 3/4} = -v_{iR3/4} - \theta (V + w_{a3/4})$$

$$w_{a3/4} = \frac{R_R^2}{R_{3/4}^2}(V + w_o) - V$$

$$v_{i3/4} = -v_{\lambda R3/4} - \theta \left(V + \frac{R_R^2}{R_{3/4}^2}(V + w_o) - V\right)$$

$$w_o = \frac{V}{2}\left\{-1 + [1 + C_{TR}]^{1/2}\right\}$$

$$v_{i3/4} = -v_{iR3/4} - \theta \frac{R_R^2}{R_{3/4}^2} \frac{V}{2}\left\{-1 + [1 + C_{TR}]^{\frac{1}{2}}\right\}$$

~~$T = \frac{\rho}{f}$~~ $\quad T = \frac{v_{i3/4}}{f} \pi D_{1/4}$

$$T_s = \frac{\rho \pi^2 D_{1/4}^2}{f} v_{iR1/4}\left(v_{iR3/4} + \theta \frac{R_R^2}{R_{3/4}^2} \frac{V}{2} \left\{-1 + [1 + C_{TR}]^{\frac{1}{2}}\right\}\right)$$

$$C_{T_s} = \frac{2\pi D_{1/4}^2}{f R_R^2 V^2}\left[v_{iR3/4} v_{iR1/4} + v_{iR1/4}\theta \frac{R_R^2}{R_{3/4}^2} \frac{V}{2}\left\{-1 + [1 + C_{TR}]^{\frac{1}{2}}\right\}\right]$$

$$v_{iR1/4} = \frac{1}{2} \frac{R_{1/4} R_R^2 w_o}{(z^2 + R_R^2)^{3/2}} \quad \text{define } L = \frac{c}{R}$$

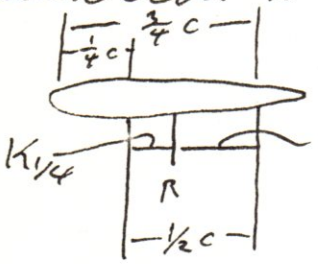
$z = K \frac{c}{R_R} R_R$ where K is a function of c

$\Rightarrow z^2 = K^2 \xi^2 L^2 R_R^2$

so $v_{iR_{1/4}} = \frac{1}{2} \frac{R_{1/4}}{R_R} \frac{W_o}{(K_{1/4}^2 L^2 + 1)^{3/2}}$

similarly $v_{iR_{3/4}} = \frac{1}{2} \frac{R_{3/4}}{R_R} \frac{W_o}{[K_{3/4}^2 L^2 + 1]^{3/2}}$

relation between $K_{1/4}$ & $K_{3/4}$



$K_{1/4} + K_{3/4} = \frac{1}{2}$

$K_{1/4} = \frac{1}{2} - K_{3/4}$

$K_{1/4}^2 = \frac{1}{4} - 2K_{3/4} + K_{3/4}$

$K_{3/4}^2 = \frac{1}{4} - 2K_{1/4} + K_{1/4}^2$

giving, in the end

~~$C_{T_S} = \frac{R_{1/4} 2\pi D_{1/4}^2}{\frac{1}{2}}$~~

$$C_{T_S} = \frac{\pi R_{1/4}^3 \{-1 + [1 + C_{T_R}]^{\frac{1}{2}}\}}{\frac{1}{2} R_R^2} \left\{ \frac{R_{3/4}}{R_R^2 \{(K_{1/4}^2 L^2 + 1)[(\frac{1}{2} - K_{1/4})^2 L^2 + 1]\}^{3/2}} + \theta \frac{R_R}{R_{3/4}^2} \frac{1}{(K_{1/4}^2 L^2 + 1)^{3/2}} \right\}$$

Drag of the shroud

$$C_{D_S} = C_f \frac{S}{A} \doteq 8 \frac{c}{D} C_f$$

where S is the surface area of the shroud, A is the rotor area reference. C_f is the skin friction coefficient.

$$C_T = C_{T_R} + C_{T_S} - C_{D_S}$$

But $C_{T_S} = f(C_{T_R})$ so we wish to optimize C_{T_S} for the design point.

Model shroud with a conical inner surface. Vary the major parameters $D_{3/4}/D_{1/4}$, radius, chord, and rotor location for the loiter condition. ~~Hanson~~ Solve for the shroud coefficient of Thrust factor F and solve for required C_{T_R}.

Program follows:

```
C       PROGRAM SHROUD OPTIMIZE,
C       OPTIMIZATION OF A SHROUDED PROPELLER SHROUD
        DIMENSION F(11,4)
        REAL L
        INTEGER H
        COMMON F
        WRITE(6,70)
        DO 10 I=1,11
   10   READ(5,11)F(I,1),F(I,2),F(I,3),F(I,4)
        DO 50 H=1,21,2
        R=(0.4+0.01*FLOAT(H-1))*12.0
        D=0.6
        DO 50 J=2,3
        D=D+0.2
        DO 50 J1=11,28
        C=FLOAT(J1)/2.0
        L=C/R
        CD=0.0096*C/R
        DO 50 J2=5,55,5
        CK1=(FLOAT(J2)-5.0)/100.0
        ST=(R*(1.0-D))/(C*(CK1*(D-1.0)+0.5))
        IF(ST.GT.1.0) GO TO 50
        T=ARSIN(ST)
        R1=R+CK1*C*ST
        R3=R-(0.5-CK1)*C*ST
        CD1=C/(2.0*R1)
        IF(CD1.LT.0.4) GO TO 50
        CALL TABLE(J,CD1,FF)
        Z=R3/(2.0*(R**2.0)*(((CK1*L)**2.0+1.0)*(((0.5-CK1)*L)*2.0+1.0))**1
       @.5)
        Q=T*R/((R3**2.0)*((CK1*L)**2.0+1.0)**1.5)
        FFF=(R1**3.0)*ATAN(1.0)*4.0*(Z+Q)/((R*R)*FF)
        S3=0.0
        S=10000.0
        DO 20 J3=75,250
        S2=FLOAT(J3)/100.0
        S1=ABS(2.0-2.0*SQRT(1.0+S2)+(1.0+(R*R)/(FFF*ATAN(1.0)*4.0))*S2-((R
       @*R)/(FFF*ATAN(1.0)*4.0))*(38.55057/((R*R)-9.0)+CD))
        IF (S1.GT.S) GO TO 20
        S=S1
        S3=S2
   20   CONTINUE
   50   WRITE(6,60)S3,FFF,CD,C,R1,R3,CK1,R
        STOP
   11   FORMAT(4(2X,F4.2))
   60   FORMAT(8(4X,F9.6))
   70   FORMAT(1X,'ROTOR THRUST',1X,'SHROUD THRUST',2X,'SHROUD DRAG',8X,'C
       @HORD',1X,'1/4 C RADIUS',1X,'3/4 C RADIUS',3X,'ROTOR LOC.')
        END
```

4.2.2.3 Fan Performance Relative to the Shroud

It is necessary to correct the fan performance ~~for~~ to conditions outside the duct (especially the free-stream velocity). Since the two parts of the propulsor, the duct and the fan, are highly dependent on each other, a program was written to take the geometric properties of shrouds and their performance properties (the thrust coefficient factor K) and arrive at the necessary correction factors. The program follows:

```
      $JOB
      C       SHROUD PERFORMANCE
 1        5   READ,R1,F,B,C1
 2            IF (R1.EQ.0) GO TO 20
 3            R0=3.0
 4            D=0.0096*C1/(R1-R0)
 5            Z=3.14159*F/B
 6            Y=3.14159*F/(R1*R1-R0*R0)
 7            PRINT 100, R1
 8            DO 10 I=1,1000
 9            C=FLOAT(I)/20.0
10            A=-1.0+SQRT(1.0+C)
11            Q=1.0+Z*A
12            S=Y*A
13            R=C/Q
14            V=SQRT(1.0+Z*A)
15            T=S+C-D
16            T1=C/T
17       10   PRINT 200,C,Q,S,R,V,T,T1
18            GO TO 5
19       20   STOP
20      100   FORMAT('1',4X,'PERFORMANCE FOR RADIUS OF ',F5.3,' INCHES'//5X,'CT
             @(R)',5X,'CQ RATIO',3X,'CT (S)',3X,'CT (R,P)',3X,'V RATIO',2X,'TOTA
             @L CT',3X,'ROTOR THRUST %')
21      200   FORMAT(2X,7(3X,F7.3))
22            END
```

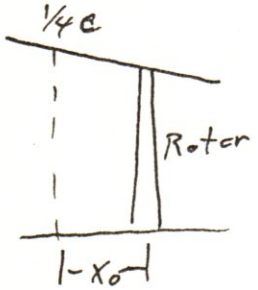
The main variables are:

$C_{T\acute{R}}$ – rotor thrust coefficient inside the duct

$\frac{V_R}{V_\infty}$ – shroud induced velocity at rotor over free-stream velocity

$\frac{C_Q^e}{C_Q}$ – rotor torque coefficient inside the duct under rotor torque coefficient outside the duct

C_{TS} – shroud thrust coefficient



$$A = \{-1 + [1 + C_{T\acute{R}}]^{1/2}\}$$

$$B = 2(R_R^2 - r_o^2)\left[1 + \left(\frac{X_o}{R_R}\right)^2\right]^{3/2}$$

$$C_{T\acute{R}} = \left\{1 + \frac{\pi (F)(A)}{B}\right\} C_{TR}$$

$$\frac{V_R}{V_\infty} = \left\{1 + \frac{\pi F(A)}{B}\right\}^{1/2}$$

$$p_V = \left(\frac{C_{\acute{Q}}}{C_Q}\right) p_R \qquad \frac{C_Q}{C_{\acute{Q}}} = \frac{1}{\left\{1 + \frac{\pi (F)(A)}{B}\right\}}$$

$$C_{TS} = \frac{\pi F}{R_R^2 - R_o^2}(A)$$

where R_o is the hub radius

also $$C_Q = \frac{Q}{\frac{1}{2}\rho V_\infty^2 R_R (R_R^2 - R_o^2)}$$

$$C_P = \frac{P}{\pi \rho V_\infty^3 R_R (R_R^2 - R_o^2)}$$

p_v is the virtual pitch of the fan referenced to the free-stream condition.

Effects of Reynolds Number

A good approximation for maximum performance of fans at the blade-element level is that, the higher the L/D, the better the efficiency. On this Reynolds number regime data for only four airfoils could be found:

Type	C_L	C_D	$(\frac{L}{D})_{max}$
N-60	1.0	0.025	40
NACA 4412	0.95	0.02	47.5
NACA 2412	0.8	0.014	57.14
NACA 0012	0.6	0.016	37.15

A very secondary parameter is the maximum lift coefficient

Type	$C_{L max}$
N-60	1.34
NACA 4412	1.21
NACA 2412	1.0
NACA 0012	0.82

The 2412, with the best $\frac{L}{D}$, appears to have an adequate stall margin for fan design.

Fan Design

A computer program was written for interactive design of fans using the NACA 2412. The program uses the vortex theory presented by Domasch and modified by Zoumbery. Linear variation of solidity in the fan, plus some control of fan loading, results in the most efficient fan possible ~~under~~ inside the shroud conditions. The program and the final fan design for the 7.2" radius duct ~~is~~ follow. The program contains data for the 2412 over a range of Reynolds numbers and finds the performance of each section according to a linear interpolation of characteristics.

Under no condition was the fan performance found to differ more than 3% from the design point (loiter), so that the loiter performance was used for all projections of ~~our~~ total propulsor performance.

```
10 DIM F(6,33),G(4,51)
20 FOR I=1 TO 33
30 READ F(1,I),F(2,I),F(3,I),F(4,I),F(5,I),F(6,I)
40 NEXT I
50 DATA -0.48,  0.0304,  -0.48,  0.0184,  -0.48,  0.016
60 DATA -0.42,  0.0284,  -0.42,  0.0172,  -0.42,  0.0152
70 DATA -0.032,  0.026,  -0.32,  0.016,  -0.32,  0.0142
80 DATA -0.24,  0.024,  -0.24,  0.0144,  -0.24,  0.0132
90 DATA -0.14,  0.0224,  -0.14,  0.014,  -0.14,  0.0126
100 DATA -0.04,  0.0212,  -0.04,  0.0136,  -0.04,  0.0124
110 DATA 0.06,  0.02,  0.06,  0.0126,  0.06,  0.012
120 DATA 0.14,  0.0196,  0.14,  0.0124,  0.14,  0.0118
130 DATA 0.22,  0.0192,  0.22,  0.0124,  0.22,  0.0116
140 DATA 0.312,  0.019,  0.312,  0.0124,  0.312,  0.0116
150 DATA 0.4,  0.0192,  0.4,  0.0124,  0.4,  0.012
160 DATA 0.48,  0.02,  0.48,  0.0128,  0.48,  0.0124
170 DATA 0.56,  0.0202,  0.56,  0.013,  0.56,  0.0132
180 DATA 0.64,  0.021,  0.64,  0.0132,  0.64,  0.0142
190 DATA 0.72,  0.022,  0.72,  0.0132,  0.72,  0.0154
200 DATA 0.784,  0.0248,  0.784,  0.014,  0.784,  0.0162
210 DATA 0.84,  0.028,  0.84,  0.017,  0.84,  0.0178
220 DATA 0.9,0.031,  0.9,  0.019,  0.92,  0.0194
230 DATA 0.952,  0.036,  0.952,  0.022,  0.968,  0.0214
240 DATA 0.98,  0.046,  0.98,  0.03,  1.02,  0.024
250 DATA 1.0,  0.06,  1.0,  0.05,  1.06,  0.028
260 DATA 1.0,  0.061,  1.0,  0.055,  1.092,  0.032
270 DATA 1.0,  0.062,  1.0,  0.06,  1.1,  0.036
280 DATA 0.996,  0.063,  0.996,  0.061,  1.092,  0.04
290 DATA 0.972,  0.064,  0.972,  0.062,  1.064,  0.044
300 DATA 0.952,  0.065,  0.952,  0.063,  1.04,  0.048
310 DATA 0.928,  0.066,  0.928,  0.064,  1.0,  0.052
320 DATA 0.92,  0.067,  0.92,  0.065,  0.98,  0.056
330 DATA 0.9,  0.068,  0.9,  0.066,  0.96,  0.06
340 DATA 0.88,  0.069,  0.88,  0.067,  0.944,  0.064
350 DATA 0.872,  0.07,  0.872,  0.068,  0.0928,  0.068
360 DATA 0.86,  0.071,  0.86,  0.069,  0.912,  0.07
365 DATA 0.84,  0.072,  0.84,  0.07,  0.9,  0.071
380 PRINT 'HUB SOLIDITY, 0.75 FOOT RADIUS SOLIDITY?'
390 INPUT S2,S3
394 PRINT 'BLADES?'
396 INPUT B
400 PRINT 'VELOCITY? (FT/SEC)'
410 INPUT V
420 PRINT 'RPM?'
430 INPUT W
440 W=W/60.0
450 PRINT 'AIR DENSITY? (SLUG/(FT CUBED))'
460 INPUT R5
462 PRINT 'MINIMUM ALPHA ZERO IS A MULTIPLE OF .2'
```

```
464 PRINT 'MINIMUM ALPHA ZERO?'
466 INPUT X9
470 P=V/W
472 T=0.0
474 Q=0.0
476 X=1
480 FOR R=0.25 TO 0.6 STEP 0.01
490 S0=ATN(P/(2*&PI*R))
500 S1=((S3-S2)/0.5)*(R-0.25)+S2
510 C=S1*2*&PI*R/B
520 R9=C*V/(SIN(S0)*1.5757E-4)
530 GOSUB 1520
540 J=(2*&PI*R)**2.0+P**2.0
550 K=R5*&PI*R*S1*(W*W)
560 D1=K*H*J
570 D2=K*R*I*J
580 G(1,X)=S1
590 G(2,X)=C
600 G(3,X)=B1
610 G(4,X)=B1*180.0/&PI
620 T=T+0.005*D1
630 Q=Q+0.005*D2
640 IF R<0.35 THEN 690
650 N=(T*P)/(2*&PI*Q)
660 C5=(2*T)/(R5*&PI*R*R*V*V)
670 CC=(2.0*Q)/(R5*&PI*(R**3.0)*V*V)
680 PRINT R,T,Q,N
690 T=T+0.005*D1
700 Q=Q+0.005*D2
705 X=X+1
710 NEXT R
720 PRINT
730 PRINT
740 PRINT 'BLADE GEOMETRY FOR ';B;' BLADES'
750 PRINT 'SOLIDITY OF ';S2;' AT ROOT, ';S3;' AT TIP'
760 PRINT 'VELOCITY= ';V;'  PITCH= ';P
770 PRINT
780 FOR X=1 TO 36
785 R=0.24+X*0.01
790 PRINT R,G(2,X),G(4,X)
800 NEXT X
810 PRINT
820 PRINT
822 PRINT 'CHANGE ALPHA ZERO MINIMUM? 1=Y'
824 INPUT X8
826 IF X8=1 THEN 462
830 PRINT 'TIP RADIUS?'
840 INPUT R1
850 IF R1=0 THEN 380
860 IF R1<0 THEN 1860
870 PRINT 'VELOCITY?'
```

```
880 INPUT V
890 FOR P=0.2 TO 4.0 STEP 0.04
900 X=1
902 T=0.0
904 Q=0.0
910 FOR R=0.25 TO R1 STEP 0.01
920 S0=ATN(P/(2.0*&PI*R))
930 C=S1*2.0*&PI*R/B
940 R9=C*V/(SIN(S0)*1.5757E-4)
950 B1=G(3,X)
960 GOSUB 1270
970 J=(2.0*&PI*R)**2.0+P**2.0
980 W=V/P
990 K=R5*&PI*R*S1*W*W
1000 D1=K*H*J
1010 D2=K*R*I*J
1020 T=T+0.01*D1
1030 Q=Q+0.01*D2
1040 IF R<>R1 THEN 1070
1050 T=T-0.005*D1
1060 Q=Q-0.005*D2
1070 NEXT R
1080 N=(T*P)/(2*&PI*Q)
1090 C5=(2.0*T)/(R5*&PI*R1*R1*V*V)
1100 C6=(2.0*Q)/(R5*&PI*(R1**3.0)*V*V)
1110 PRINT P,C5,C6,N
1120 NEXT P
1130 PRINT
1140 PRINT 'VELOCITY= ';V
1150 PRINT
1160 PRINT 'CHANGE V? 1=Y'
1170 INPUT Z
1180 IF Z=1 THEN 870
1190 PRINT 'CHANGE RADIUS?'
1200 INPUT Z
1210 IF Z=1 THEN 830
1220 PRINT 'CHANGE DESIGN?'
1230 INPUT Z
1240 IF Z=1 THEN 380
1250 STOP
1270 REM INDUCED FLOW SOLUTION
1280 A0=B1-S0
1290 C7=4.0*SIN(S0)/S1
1300 A0=180.0*A0/&PI
1302 IF A0>=-4.4 THEN 1304
1303 A0=-4.4
1304 IF A0<=19.2 THEN 1310
1305 A0=19.2
1310 Z1=INT(INT(10.0*A0+0.001)/8+9.001)
1320 IF R9>82800 THEN 1340
1330 R9=82800
```

S1 = G(1,X)

```
1340 IF R9<=333000 THEN 1360
1350 R9=332000
1360 IF R9<166000 THEN 1390
1370 Z2=1
1375 Z9=83200
1376 Z7=82800
1380 GO TO 1400
1390 Z2=3
1395 Z9=167000
1396 Z7=166000
1400 GOSUB 1730
1410 A0=A0*&PI/180.0
1420 T0=C0/(C0/A0+C7)
1430 A=A0-T0
1435 A1=A0
1436 A0=A*180.0/&PI
1438 Z1=INT(INT(10.0*A0+0.001)/8+9.001)
1440 GOSUB 1730
1450 Z2=Z2+1
1455 C1=C0
1460 GOSUB 1730
1465 A0=A1
1470 C2=C0
1480 S=S0+T0
1490 H=C1*COS(S)-C2*SIN(S)
1500 I=C1*SIN(S)+C2*COS(S)
1510 RETURN
1520 REM OPTIMIZED BLADE
1525 N1=0.0
1530 FOR X5=X9 TO 12.0 STEP 0.2
1540 A0=X5*&PI/180.0
1550 GOSUB 1290
1560 N=H/(I*R)
1570 IF N<=N1 THEN 1650
1580 N1=N
1590 A5=A0
1600 B1=S0+A0
1610 H1=H
1620 I1=I
1630 T1=T0
1640 A1=S0+T0
1650 NEXT X5
1660 N=N1
1670 A0=A5
1680 H=H1
1690 I=I1
1700 T0=T1
1710 A=A1
1720 RETURN
1730 REM TABLE INTERPOLATION
1740 IF Z1=33 THEN 1820
```

```
1750 Z8=((Z1-9)*8)/10.0
1755 Z8=A0-Z8
1760 Z3=(F(Z2,Z1+1)-F(Z2,Z1))/0.8
1770 Z4=Z3*Z8+F(Z2,Z1)
1780 Z3=(F(Z2+2,Z1+1)-F(Z2+2,Z1))/0.8
1790 Z5=Z3*Z8+F(Z2+2,Z1)
1800 C0=(R9-Z7)*(Z5-Z4)/Z9+Z4
1810 GO TO 1850
1820 Z4=F(Z2,Z1)
1830 Z5=F(Z2+2,Z1)
1840 C0=(R9-Z7)*(Z5-Z4)/Z9+Z4
1850 RETURN
1860 END
```

BLADE GEOMETRY FOR 4 BLADES
SOLIDITY OF .6 AT ROOT, .6 AT TIP
VELOCITY= 121.619 PITCH= 1.263136

~~Rdi~~ Radius (ft).	Blade chord (ft).	Blade Angle (Degrees)
.25	.2356194	42.20404
.26	.2450442	41.1115
.27	.2544689	40.07031
.28	.2638936	39.07756
.29	.2733183	38.13052
.3	.2827432	37.22659
.31	.2921679	36.3633
.32	.3015926	35.53836
.33	.3110175	34.74956
.34	.3204422	33.99486
.35	.3298669	33.27235
.36	.3392918	32.58023
.37	.3487165	31.91682
.38	.3581412	31.28052
.39	.3675661	30.66985
"	.3769908	30.08344

Propulsor Performance

Propulsive efficiency at 5000 ft cruise

$$hp_{out} = C_T\left(\tfrac{1}{2}\rho V_\infty^2 A_R\right)\frac{1}{550\ \frac{ft\text{-}lb}{hp\text{-}s}}$$

$$hp_o = C_T(282,811)\frac{1}{550}$$

$$C_T = \frac{2T}{\rho V^2 A} = \frac{2(151b_f)}{(0.002048\ \frac{lb_f\text{-}s^2}{ft^4})(110\frac{ft}{s})^2(0,2975ft^2)}$$

$C_T = 4,0693$

$hp_o = 2,092$

Looking up $C_T = 4,029$ in the propulsor performance table, we have

$C_a = 1,0883$ $\quad \rho_v = 0.8474$ $\quad C_p = 1,2843$
$C_{T\dot{R}} = 2.138$

at $110\frac{ft}{s}$ $\quad C_p = (0,2771)(hp)$

$hp = 4,635 \quad hp_o = 2,092$

$$\eta = \frac{hp_o}{hp} = 0,4513 \qquad SFC = 0,7$$

4.2.3.3 BLC Estimations

Take boundary layer at 80" from the nose (placement of BLC slots)

$80" = 6.67'$

Multiplying by 1.2 to correct for curvature, length is 8'

$\delta = \frac{0.37x}{Re_x^{0.2}}$ from Kuethe and Schetzer, Foundations of Aerodynamics, John Wiley & Sons, Inc., New York, 1959

at a flow velocity of $110 \frac{ft}{s}$

$Re_x = \frac{Vx}{\nu}$ $\quad \nu = 0.0001567 \frac{ft^2}{s}$ @ 5000 ft

$Re_x = \frac{(110 \frac{ft}{s})(8 ft)}{(0.0001567 \frac{ft^2}{s})} = 5.6158 \times 10^6$

boundary layer thickness - δ

$\delta = \frac{0.37(8 ft)}{(5.6158 \times 10^6)^{0.2}} = 0.1322 ft = 1.59 in.$

Displacement thickness

$\delta^* = 0.27\delta = 0.43 in.$

Area of air to be removed. Fuselage diameter at the slots is 5". Area of air to be removed would be:

$$A = \pi (2.93^2 - 2.5^2) = 7.33 \text{ in}^2$$

If this is removed at flight velocity, an overestimation results since the displacement thickness is equivalent to the thickness of stagnated air. Therefore, at 110 $\frac{ft}{s}$, the required area for cooling and BLC air is

$$A = \frac{(1.1204 \frac{lbm}{s})(1444 \frac{in^2}{ft^2})}{(0.076572 \frac{lbm}{ft^3})(110 \frac{ft}{s})} + 7.33 \text{ in}^2$$

$$A = 26.48 \text{ in}^2$$

To provide adequate suction of about 1 psia, the area would change by

$$\frac{A}{A_i} = \frac{P}{P_i} = \frac{13.7}{14.7} = 0.932$$

So that the actual area required through the fan is

$$A = 0.932 (26.48 \text{ in}^2) = 24.68 \text{ in}^2$$

McCormick states that the slots should be no wider than the

displacement thickness for stability of the remaining boundary layer. Two rows of 0.2" wide slots provide the correct intake area and slot width.

4.2.3.4

$$f_{max} = 1.3 \frac{V}{t} \qquad t = 0.11 \frac{S}{b}$$

$S = 25.95$ ft $= 2.411$ meters

$b = 15$ feet $= 4.572$ meters

$t = 0.058$

~~f_{max}~~ $V = 110 \frac{ft}{s} = 33.528 \frac{meter}{s}$

$$f_{max} = 1.3 \left(\frac{33.528}{0.058} \right) = 779.86 \text{ Hz}$$

$$OASPL = 10 \log \left[\left(\frac{\sin d}{r} \right)^2 \left(\frac{V^6 S}{AR^4} \right) \right] + 23.0$$

$AR = 8$ ~~$S = 25$~~ $S = 2.411$ meters

$V = 33.528 \frac{meter}{s}$ $r = 1000$ ft $= 304.8$ meters

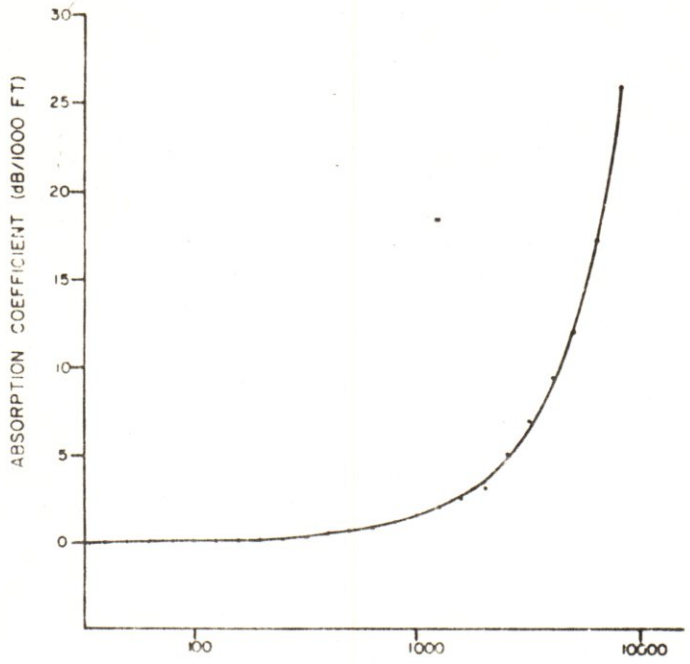
$OASPL = 9.38 + 23.0 = 32.38$ dB re $2 \times 10^{-5} \frac{N}{m^2}$

$L_p = L_w - 20 \log R - 0.5$

$L_w = 32.38 + 20 \log (1000 \text{ ft}) + 0.5$

$L_w = 92.88$ dB re $2 \times 10^{-5} \frac{W}{m^2}$

4.2.3.5 Detectability



ATMOSPHERIC ABSORPTION COEFFICIENT

$$\Delta L = 20 \log R + K(R/1000)$$

At 5000 ft

Hz	SPL (Watts x 10^{-5})	SPL Ground	dBA Corr	Corr. SPL
100	76	1,32	~~-24 -22,68~~	-22,68
125	80	5,22	~~-16 -10,78~~	-10,78
250	88	12,12	~~-9 3,12~~	3,12
500	93	15,52	-3	12,52
1000	94	13,02	0	13,02
2000	87	-1,98	+1	-0.98
4000	82	-33,08	+1	-32,08
8000	76	-92,9	-1	-93,9
16000	75	-93,9	-1	-94,9

Decibel Addition

ΔdB	Corr for higher level
0-1	3
2-3	2
4-8	1
9-∞	0

final total dBA is SPL = 16 dBA

For the detectability distance the distance R was varied until 50% detectability was reached for selected bands.

	Country		Arid		Near Urban	
Hz	AL	R	AL	R	AL	R
100	36	61 ft	29	29 ft	17	—
125	41	112	37	75	22	—
250	66	2000	52	400	42	130 ft
500	72	3100	64	1400	51	340
1000	76	3900	73	2900	57	650
2000	69	1750	70	1800	57	590
4000	68	—	70	—	60	690
8000	61	—	61	—	61	—
16000	57	—	57	—	57	—

4,7,3 Aux. Power Supply estimated

Total requirement of 350 WaHs for systems in emergency. At 28 V standard system 6.25 $\frac{Amp}{hr}$ required

$$I = \frac{P}{V} = (0.5)\frac{350\ W}{28\ V} = 6.25\ Amp$$

allowing a 50% demand average for the systems.

Energy required for APS

(350 WaH)(30)(60) = 6.3×10^5 joules

Systems

1: 23 batt. 14 + 46 batt. 12
28.75 V & 7.0 $\frac{A}{hr}$ at 14.4 lb

2: 35 batt. 1
30 V & 6.3 $\frac{A}{hr}$ at 21 lb

3: 5 batt. 8
30 V & 7.5 $\frac{A}{hr}$ at 16.5 lb

4: 10 batt. 2 + 3 batt 3
30 V & 7.5 $\frac{A}{hr}$ at 22.9 lb

5: 5 batt. 7
30 V & 6.0 $\frac{A}{hr}$ at 13 lb

~~6~~: At 3 x peak rating to account for control peaks

6: 15 batt. 1
30 V & 8.1 $\frac{A}{hr}$ at 9 lb

7: 4 batt. 2 + 1 batt 3
30 V & 9 $\frac{A}{hr}$ at 8.9 lb.

4.4.2 CER cost estimation

Engineering hours – E

$E = \exp(8.093 + 0.656 \ln S + 0.1 \ln CQ)$

CQ ≡ cumulative production
S ≡ top speed

$S = 125 \frac{mi}{hr}$ $CQ = 1040$

$E = \exp(8.093 + 0.656 \ln(125) + 0.1 \ln(1040))$

$E = 155,604.3$ hrs

Tooling hours – T

Wt = empty weight
Q = produced quantity

$Wt = 14216$ $Q = 1040$

$T = \exp(6.08 + 0.764 \ln Wt + 0.092 \ln Q)$

$T = \exp(6.08 + 0.764 \ln(142) + 0.092 \ln(1040))$

$T = 36511.2$ hrs.

Manufacturing labor – TL

$TL = 1000 \exp(0.565 \ln Wt + 0.306 TQ)$

$TL = 1000 \exp(0.565 \ln(142) + 0.306 \ln(1040)) = 552919$ hrs.

Material

MC ≡ materials cost in 1973 dollars

$$MC = 1000 \exp(0.622 \ln(W_t) + 0.803 \ln Q)$$

$$MC = 1000 \exp(0.622 \ln(142) + 0.803 \ln(1040))$$

MC = $5772994

Development support – DS ($)

$$DS = 1000 \exp(0.2255 \ln(1040) + 1.0987 \ln(142) + 1.0848 \ln(0.7))$$

(Q = 1040, W_t = 142, T_W = 0.7)

DS = $3004997.8

Flight test – FT ($)

$$FT = \exp(-2.577 + 0.781 \ln(FQ) + 0.867 \ln W_t + 1.5 \ln S)$$

FQ ≡ # of flight test vehicles

$$FT = \exp(-2.577 + 0.781 \ln(32) + 0.867 \ln(142) + 1.5 \ln(125))$$

FT = $116881

Labor rates (1973 dollars)

Engineering	$18.29 $\frac{1}{hr}$
Tooling	$14.23 $\frac{1}{hr}$
Man. Labor	$12.16 $\frac{1}{hr}$

A.5.1 NASTRAN Data Card Format

Input Data Card CBAR Simple Beam Element Connection

Description: Defines a simple beam element (BAR) of the structural model.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CBAR	EID	PID	GA	GB	X1,G0	X2	X3	F	abc
CBAR	2	39	7	3	13			2	123
+bc	PA	PB	Z1A	Z2A	Z3A	Z1B	Z2B	Z3B	
+23		513							

Field	Contents
EID	Unique element identification number (Integer > 0)
PID	Identification number of a PBAR property card (Default is EID unless BARØR card has nonzero entry in field 3) (Integer > 0 or blank*)
GA,GB	Grid point identification numbers of connection points (Integer > 0; GA ≠ GB)
X1,X2,X3	Components of vector $\vec{v}$, at end A, (figure 1(a) on page 1.3-15) measured at end A, parallel to the components of the displacement coordinate system for GA, to determine (with the vector from end A to end B) the orientation of the element coordinate system for the bar element (Real, $X1^2 + X2^2 + X3^2 > 0$ or blank*, see below).
G0	Grid point identification number to optionally supply X1, X2, X3 (integer > 0 or blank*) (see below)
F	Flag to specify the nature of fields 6-8 as follows:

	6	7	8
F = blank*			
F = 1	X1	X2	X3
F = 2	G0	blank/0	blank/0

PA,PB	Pin flags for bar ends A and B, respectively, that are used to insure that the bar cannot resist a force or moment corresponding to the pin flag at that respective end of the bar. (Up to 5 of the unique digits 1-6 anywhere in the field with no imbedded blanks; integer > 0) (These degree of freedom codes refer to the element forces and not global forces. The bar must have stiffness associated with the pin flag. For example, if pin flag 4 is specified, the bar must have a value for J, the torsional constant.)
Z1A,Z2A,Z3A Z1B,Z2B,Z3B	Components of offset vectors $\vec{w}_a$ and $\vec{w}_b$, respectively, (see figure 1(a), page 1.3-15) in displacement coordinate systems at points GA and GB, respectively. (Real or blank)

*See the BARØR card for default options for fields 3, 6, 7, 8 and 9.

Input Data Card CØNM2 Concentrated Mass Element Connection

Description: Defines a concentrated mass at a grid point of the structural model.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CØNM2	EID	G	CID	M	X1	X2	X3		abc
CØNM2	2	15	6	49.7					123
+bc	I11	I21	I22	I31	I32	I33			
+23	16.2		16.2			7.8			

Field	Contents
EID	Element identification number (Integer > 0)
G	Grid point identification number (Integer >0)
CID	Coordinate system identification number (Integer ≥ 0)
M	Mass Value (Real)
X1,X2,X3	Offset distances for the mass in the coordinate system defined in field 4 (Real)
Iij	Mass moments of inertia measured at the mass c.g. in coordinate system defined by field 4 (Real)

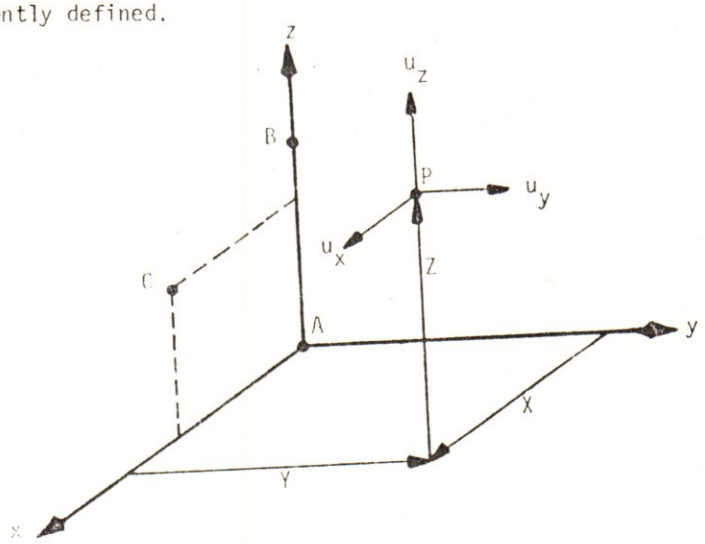
Remarks: 1. Element identification numbers must be unique with respect to all other element identification numbers.

2. For a more general means of defining concentrated mass at grid points, see CMM1.

3. The continuation card may be omitted.

Input Data Card CØRD2R Rectangular Coordinate System Definition

Description: Defines a rectangular coordinate system by reference to the coordinates of three points. The first point defines the origin. The second point defines the direction of the z-axis. The third point defines a vector which, with the z-axis, defines the x-z plane. The reference coordinate must be independently defined.



Format and Example:

1	2	3	4	5	6	7	8	9	10
CØRD2R	CID	RID	A1	A2	A3	B1	B2	B3	ABC
CØRD2R	3	17	-2.9	1.0	0.0	3.6	0.0	1.0	123
+BC	C1	C2	C3						
+23	5.2	1.0	-2.9						

Field	Contents
CID	Coordinate system identification number (Integer > 0)
RID	Reference to a coordinate system which is defined independently of new coordinate system (Integer ≥ 0 or blank)
A1,A2,A3 B1,B2,B3 C1,C2,C3	Coordinates of three points in coordinate system defined in field 3 (Real)

Remarks:

1. Continuation card must be present.
2. The three points (A1, A2, A3), (B1, B2, B3), (C1, C2, C3) must be unique and non-collinear. Noncollinearity is checked by the geometry processor.
3. Coordinate system identification numbers on all CØRD1R, CØRD1C, CØRD1S, CØRD2R, CØRD2C, and CØRD2S cards must all be unique.
4. An RID of zero references the basic coordinate system.
5. The location of a grid point (P in the sketch) in this coordinate system is given by (X, Y, Z).
6. The displacement coordinate directions at P are shown by (u_x, u_y, u_z).

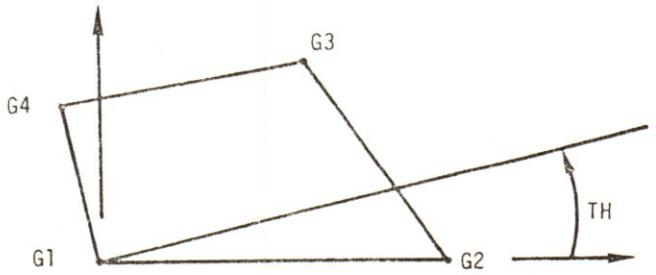
Input Data Card CQDMEM2 Quadrilateral Element Connection

Description: Defines a quadrilateral membrane element (QDMEM2) of the structural model consisting of four nonoverlapping TRMEM elements.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CQDMEM2	EID	PID	G1	G2	G3	G4	TH		
CQDMEM2	72	13	13	14	15	16	29.2		

Field	Contents
EID	Element identification number (Integer > 0)
PID	Identification number of a PQDMEM2 property card (Default is EID) (Integer > 0)
G1,G2,G3,G4	Grid point identification numbers of connection points (Integer > 0; G1 ≠ G2 ≠ G3 ≠ G4)
TH	Material property orientation angle in degrees (Real) The sketch below gives the sign convention for TH



Remarks:
1. Element identification numbers must be unique with respect to all other element identification numbers.
2. Grid points G1 through G4 must be ordered consecutively around the perimeter of the element.
3. All interior angles must be less than 180 degrees.

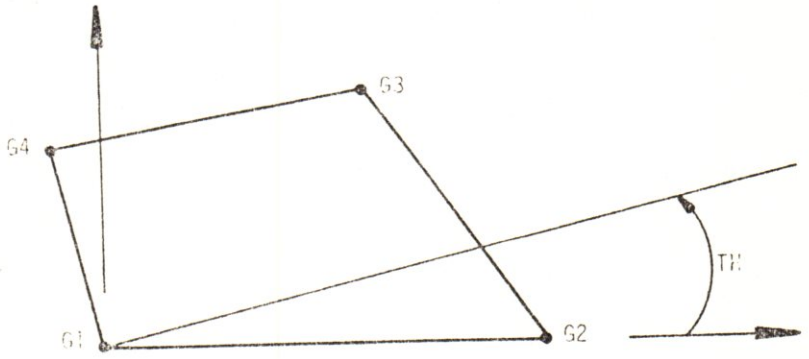
Input Data Card CQUAD2 Quadrilateral Element Connection

Description: Defines a homogeneous quadrilateral membrane and bending element (QUAD2) of the structural model.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CQUAD2	EID	PID	G1	G2	G3	G4	TH		
CQUAD2	72	13	13	14	15	16	29.2		

Field	Contents
EID	Element identification number (Integer > 0)
PID	Identification number of a PQUAD2 property card (Default is EID) (Integer > 0)
G1,G2,G3,G4	Grid point identification numbers of connection points (Integer > 0; G1 ≠ G2 ≠ G3 ≠ G4)
TH	Material property orientation angle in degrees (Real) The sketch below gives the sign convention for TH.



Remarks:
1. Element identification numbers must be unique with respect to all other element identification numbers.
2. Grid points G1 thru G4 must be ordered consecutively around the perimeter of the element.
3. All interior angles must be less than 180°.

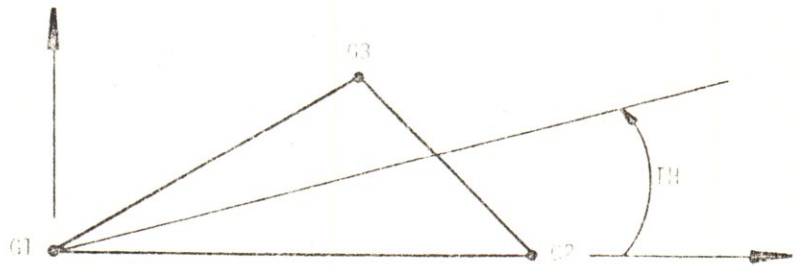
Input Data Card CTRIA2 Triangular Element Connection

Description: Defines a triangular membrane and bending element (TRIA2) of the structural model.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CTRIA2	EID	PID	G1	G2	G3	TH			
CTRIA2	16	2	12	1	3	16.2			

Field	Contents
EID	Element identification number (Integer > 0)
PID	Identification number of a PTRIA2 property card (Default is EID) (Integer > 0)
G1,G2,G3	Grid point identification numbers of connection points (Integer > 0; G1 ≠ G2 ≠ G3)
TH	Material property orientation angle in degrees (Real) - The sketch below gives the sign convention for TH.



Remarks: 1. Element identification numbers must be unique with respect to all other element identification numbers.

2. Interior angles must be less than 180°.

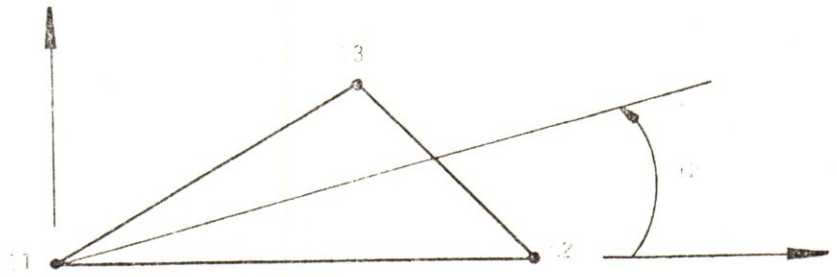
Input Data Card CTRMEM Triangular Element Connection

Description: Defines a triangular membrane element (TRMEM) of the structural model.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CTRMEM	EID	PID	G1	G2	G3	TH			
CTRMEM	16	2	12	1	3	16.3			

Field	Contents
EID	Element identification number (Integer > 0)
PID	Identification number of a PTRMEM property card (Default is EID) (Integer > 0)
G1,G2,G3	Grid point identification numbers of connection points (Integer > 0; G1 ≠ G2 ≠ G3)
TH	Material property orientation angle in degrees (Real) - The sketch below gives the sign convention for TH.



Remarks: 1. Element identification numbers must be unique with respect to all other element identification numbers.

2. Interior angles must be less than 180°.

Input Data Card FØRCE Static Load

Description: Defines a static load at a grid point by specifying a vector.

Format and Example:

1	2	3	4	5	6	7	8	9	10
FØRCE	SID	G	CID	F	N1	N2	N3		
FØRCE	2	5	6	2.9	0.0	1.0	0.0		

Field	Contents
SID	Load set identification number (Integer > 0)
G	Grid point identification number (Integer > 0)
CID	Coordinate system identification number (Integer ≥ 0)
F	Scale factor (Real)
N1,N2,N3	Components of Vector measured in coordinate system defined by CID (Real; $N1^2 + N2^2 + N3^2 > 0.0$)

Remarks: 1. The static load applied to grid point G is given by

$$\vec{f} = F\vec{N}$$

where $\vec{N}$ is the vector defined in fields 6, 7 and 8.

2. Load sets must be selected in the Case Control Deck (LOAD=SID) to be used by NASTRAN.

3. A CID of zero references the basic coordinate system.

Input Data Card GRID Grid Point

Description: Defines the location of a geometric grid point of the structural model, the directions of its displacement, and its permanent single-point constraints.

Format and Example:

1	2	3	4	5	6	7	8	9	10
GRID	ID	CP	X1	X2	X3	CD	PS		
GRID	2	3	1.0	2.0	3.0		316		

Field	Contents
ID	Grid point identification number (Integer > 0)
CP	Identification number of coordinate system in which the location of the grid point is defined (Integer ≥ 0 or blank*).
X1,X2,X3	Location of the grid point in coordinate system CP (Real)
CD	Identification number of coordinate system in which displacements, degrees of freedom, constraints, and solution vectors are defined at the grid point (Integer ≥ 0 or blank*)
PS	Permanent single-point constraints associated with grid point (any of the digits 1-6 with no imbedded blanks) (Integer ≥ 0 or blank*)

Remarks:

1. All grid point identification numbers must be unique with respect to all other structural, scalar, and fluid points.
2. The meaning of X1, X2 and X3 depend on the type of coordinate system, CP, as follows: (see CØRD__ card descriptions)

Type	X1	X2	X3
Rectangular	X	Y	Z
Cylindrical	R	Θ(degrees)	Z
Spherical	R	Θ(degrees)	Φ(degrees)

3. The collection of all CD coordinate systems defined on all GRID cards is called the Global Coordinate System. All degrees-of-freedom, constraints, and solution vectors are expressed in the Global Coordinate System.

* See the GRDSET card for default options for fields 3, 7 and 8.

Input Data Card LØAD Static Load Combination (Superposition)

Description: Defines a static load as a linear combination of load sets defined via FØRCE, MØMENT, FØRCE1, MØMENT1, FØRCE2, MØMENT2, PLØAD, PLØAD2, SLØAD, RFØRCE and GRAV cards.

Format and Example:

1	2	3	4	5	6	7	8	9	10
LØAD	SID	S	S1	L1	S2	L2	S3	L3	abc
LØAD	101	-0.5	1.0	3	6.2	4			
+bc	S4	L4		-etc.-					

(etc.)

Field	Contents
SID	Load set identification number (Integer > 0)
S	Scale factor (Real)
Si	Scale factors (Real)
Li	Load set identification numbers defined via card types enumerated above (Integer > 0)

Remarks:

1. The load vector defined is given by

$$\{P\} = S \sum_i S_i \{P_{Li}\}$$

2. The Li must be unique. The remainder of the physical card containing the last entry must be blank.
3. This card must be used if gravity loads (GRAV) are to be used with any of the other types.
4. Load sets must be selected in the Case Control Deck (LØAD=SID) to be used by NASTRAN.
5. A LØAD card may not reference a set identification number defined by another LØAD card.

Input Data Card MAT1 Material Property Definition

Description: Defines the material properties for linear, temperature-independent, isotropic materials.

Format and Example:

1	2	3	4	5	6	7	8	9	10
MAT1	MID	E	G	NU	RHØ	A	TREF	GE	+abc
MAT1	17	3.+7	1.9+7		4.28	0.19	5.37+2	0.23	ABC
+abc	ST	SC	SS						
+BC	20.+4	15.+4	12.+4						

Field	Contents
MID	Material identification number (Integer > 0)
E	Young's modulus (Real ≥ 0.0 or blank)
G	Shear modulus (Real ≥ 0.0 or blank)
NU	Poisson's ratio (-1.0 < Real ≤ 0.5 or blank)
RHØ	Mass density (Real)
A	Thermal expansion coefficient (Real)
TREF	Thermal expansion reference temperature (Real)
GE	Structural element damping coefficient (Real)
ST, SC, SS	Stress limits for tension, compression and shear (Real) (Used only to compute margins of safety in certain elements; they have no effect on the computational procedures)

Remarks:

1. One of E or G must be positive (i.e., either E > 0.0 or G > 0.0 or both E and G may be > 0.0).
2. If any one of E, G or NU is blank, it will be computed to satisfy the identity E = 2(1+NU)G; otherwise, values supplied by the user will be used.
3. The material identification number must be unique for all MAT1, MAT2 and MAT3 cards.
4. MAT1 materials may be made temperature dependent by use of the MATT1 card.
5. The mass density, RHØ, will be used to automatically compute mass for all structural elements except the two-dimensional bending only elements TRBSC, TRPLT and QDPLT.
6. If E and NU or G and NU are both blank they will be both given the value 0.0.
7. Weight density may be used in field 6 if the value $\frac{1}{g}$ is entered on the PARAM card WTMASS, where g is the acceleration of gravity (see Section 3.1.5).

Input Data Card MPC Multipoint Constraint

Description: Defines a multipoint constraint equation of the form

$$\sum_j A_j u_j = 0$$

Format and Example:

1	2	3	4	5	6	7	8	9	10
MPC	SID	G	C	A	G	C	A		abc
MPC	3	28	3	6.2	2		4.29		+B
+bc		G	C	A	-etc.-				
+B		1	4	-2.91					

Field	Contents
SID	Set identification number (Integer > 0)
G	Identification number of grid or scalar point (Integer > 0)
C	Component number - any one of the digits 1-6 in the case of geometric grid points; blank or zero in the case of scalar points (Integer)
A	Coefficient (Real; the first A must be nonzero)

Remarks:

1. The first coordinate in the sequence is assumed to be the dependent coordinate and must be unique for all equations of the set.
2. Forces of multipoint constraint are not recovered.
3. Multipoint constraint sets must be selected in the Case Control Deck (MPC=SID) to be used by NASTRAN.
4. Dependent coordinates on MPC cards may not appear on ØMIT, ØMIT1, SUPØRT, SPC or SPC1 cards.

Input Data Card PBAR Simple Beam Property

Description: Defines the properties of a simple beam (bar) which is used to create bar elements via the CBAR card.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PBAR	PID	MID	A	I1	I2	J	NSM		abc
PBAR	39	6	2.9		5.97				123
+bc	C1	C2	D1	D2	E1	E2	F1	F2	def
+23			2.0	4.0					
+ef	K1	K2	I12						

Field	Contents
PID	Property identification number (Integer > 0)
MID	Material identification number (Integer > 0)
A	Area of bar cross-section (Real)
I1, I2, I12	Area moments of inertia (Real)
J	Torsional constant (Real)
NSM	Nonstructural mass per unit length (Real)
K1, K2	Area factor for shear (Real)
Ci, Di, Ei, Fi	Stress recovery coefficients (Real)

Remarks:
1. For structural problems, PBAR cards may only reference MAT1 material cards.
2. See Section 1.3.2 for a discussion of bar element geometry.
3. For heat transfer problems, PBAR cards may only reference MAT4 or MAT5 material cards.

Input Data Card PLØAD2 Pressure Load

Description: Defines a uniform static pressure load applied to two-dimensional elements. Only QUAD1, QUAD2, QDMEM, QDMEM1, QDMEM2, QDPLT, SHEAR, TRBSC, TRIA1, TRIA2, TRMEM, TRPLT or TWIST elements may have a pressure load applied to them via this card.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PLØAD2	SID	P	EID	EID	EID	EID	EID	EID	
PLØAD2	21	-3.6		4	16		2		

Alternate Form

PLØAD2	SID	P	EID1	"THRU"	EID2				
PLØAD2	1	30.4	16	THRU	48				

Field	Contents
SID	Load set identification number (Integer > 0)
P	Pressure value (Real)
EID EID1 EID2	Element identification number (Integer > 0; EID1 < EID2)

Remarks:

1. EID must be 0 or blank for omitted entrys.
2. Load sets must be selected in the Case Control Deck (LØAD=SID) to be used by NASTRAN.
3. At least one positive EID must be present on each PLØAD2 card.
4. If the alternate form is used, all elements EID1 thru EID2 must be two-dimensional.
5. The pressure load is computed for each element as if the grid points to which the element is connected were specified on a PLØAD card. The grid point sequence specified on the element connection card is assumed for the purpose of computing pressure loads.
6. All elements referenced must exist.

Input Data Card PQDMEM2 Quadrilateral Membrane Property

Description: Used to define the properties of a quadrilateral membrane. Referenced by the CQDMEM2 card. No bending properties are included.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PQDMEM2	PID	MID	T	NSM	PID	MID	T	NSM	
PQDMEM2	235	2	0.5	0.0					

Field	Contents
PID	Property identification number (Integer > 0)
MID	Material identification number (Integer > 0)
T	Thickness of membrane (Real > 0.0)
NSM	Nonstructural mass per unit area (Real)

Remarks: 1. All PQDMEM2 cards must have unique property identification numbers.

2. One or two quadrilateral membrane properties may be defined on a single card.

Input Data Card PQUAD2 Homogeneous Quadrilateral Property

Decription : Defines the properties of a homogeneous quadrilateral element of the structural model, including bending, membrane and transverse shear effects. Referenced by the CQUAD2 card.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PQUAD2	PID	MID	T	NSM	PID	MID	T	NSM	
PQUAD2	32	16	2.98	9.0	45	16	5.29	6.32	

Field	Contents
PID	Property identification number (Integer > 0)
MID	Material identification number (Integer > 0)
T	Thickness (Real> 0.0)
NSM	Nonstructual mass per unit area (Real)

Remarks:
1. All PQUAD2 cards must have unique identification numbers.
2. The thickness used to compute membrane and transverse shear properties is T.
3. The area moment of inertia per unit width used to compute the bending stiffness is $T^3/12$.
4. Outer fiber distances of $\pm T/2$ are assumed.
5. One or two homogeneous quadrilateral properties may be defined on a single card.

Input Data Card PTRIA2 Homogeneous Triangular Element Property

Description: Defines the properties of a homogeneous triangular element of the structural model, including membrane, bending and transverse shear effects. Referenced by the CTRIA2 card.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PTRIA2	PID	MID	T	NSM	PID	MID	T	NSM	
PTRIA2	2	16	3.92	14.7	6	16	2.96		

Field	Contents
PID	Property identification number (Integer > 0)
MID	Material identification number (Integer > 0)
T	Thickness (Real> 0.0)
NSM	Nonstructural mass per unit area (Real)

Remarks:

1. All PTRIA2 cards must have unique identification numbers.
2. The thickness used to compute the membrane and transverse shear properties is T.
3. The area moment of inertia per unit width used to compute the bending stiffness is $T^3/12$.
4. Outer fiber distances of $\pm T/2$ are assumed.
5. One or two homogeneous triangular element properties may be defined on a single card.

Input Data Card PTRMEM Triangular Membrane Property

Description: Used to define the properties of a triangular membrane element. Referenced by the CTRMEM card. No bending properties are included.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PTRMEM	PID	MID	T	NSM	PID	MID	T	NSM	
PTRMEM	17	23	4.25	0.2					

Field	Contents
PID	Property identification number (Integer > 0)
MID	Material identification number (Integer > 0)
T	Membrane thickness (Real> 0.0)
NSM	Nonstructural mass per unit area (Real)

Remarks: 1. All PTRMEM cards must have unique property identification numbers.

2. One or two triangular membrane properties may be defined on a single card.

Input Data Card SPC1 Single-Point Constraint

Description: Defines sets of single-point constraints.

Format and Example:

1	2	3	4	5	6	7	8	9	10
SPC1	SID	C	G1	G2	G3	G4	G5	G6	abc
SPC1	3	2	1	3	10	9	6	5	ABC
+bc	G7	G8	G9	-etc.-					
+BC	2	8							

Alternate Form

SPC1	SID	C	GID1	"THRU"	GID2				
SPC1	313	12456	6	THRU	32				

Field	Contents
SID	Identification number of single-point constraint set (Integer > 0)
C	Component number (Any unique combination of the digits 1-6 (with no imbedded blanks) when point identification numbers are grid points; must be null if point identification numbers are scalar points)
Gi, GIDi	Grid or scalar point identification numbers (Integer > 0)

Remarks:

1. Note that enforced displacements are not available via this card. As many continuation cards as desired may appear when "THRU" is not used.
2. A coordinate referenced on this card may not appear as a dependent coordinate in a multipoint constraint relation, nor may it be referenced on a SPC, ØMIT, ØMIT1, SUPØRT card.
3. Single-point constraint sets must be selected in the Case Control Deck (SPC=SID) to be used by NASTRAN.
4. SPC degrees of freedom may be redundantly specified as permanent constraints on the GRID card.
5. All grid points referenced by GID1 thru GID2 must exist.

A.5.2 Fuselage Program Listing

```
      $JCB              ,NOEXT,T=28
 1          DIMENSION XRIBS(8)
 2          DATA XRIBS/8.25,17.63,27.00,36.40,45.80,58.20,65.40,72.00/
 3          DATA NRIBS/8/,NSTGR/6/,NGRID/2/,IDBAR/1200/,IDMEM/200/,MBAR1/110/,
           1MBAR2/10/,MMEM/320/,DTHETA/.52360/,C/100.0/
 4          WRITE(6,6600)
 5          CALL GRID(NGRID-1,0.,0.,0.)
 6          CALL GRID(NGRID,-1.75,0.,0.)
 7          NSTGR1=NSTGR+1
 8          DO 2000 I=1,NRIBS
 9          CALL COORDF(C,XRIBS(I),T)
10          CALL GRID(NGRID+2,XRIBS(I),0.,0.)
11          NGRID=NGRID+2
12          DO 1000 J=1,NSTGR1
13          NGRID=NGRID+2;N1=NGRID-2*NSTGR1-2
15          THETA=(J-1)*DTHETA
16          Z=-T*COS(THETA);Y=T*SIN(THETA)
18          Y1=-10.*COS(THETA);Z1=-10.*SIN(THETA)
20          IF(I.NE.4.OR.J.GT.2) GO TO 20
21          Z=-5.30;Y=-Z*TAN(THETA)
23          Y1=-10.0;Z1=0.0
25          GO TO 100
26       20 IF(I.NE.5.OR.J.GT.2) GO TO 40
27          Z=-5.40;Y=-Z*TAN(THETA)
29          Y1=-10.0;Z1=0.0
31          GO TO 100
32       40 IF(I.NE.6.OR.J.GT.2) GO TO 100
33          Z=-5.90;Y=-Z*TAN(THETA)
35          Y1=-10.0;Z1=0.0
37      100 CALL GRID(NGRID,XRIBS(I),Y,Z)
38          IF(J.EQ.1) GO TO 200
39          IF(I.EQ.2.OR.I.EQ.4) GO TO 200
40          IDBAR=IDBAR+1
41          CALL CBAR(IDBAR,MBAR1,NGRID,NGRID-2,10.,0.0,0.0)
42      200 IF(I.EQ.1) GO TO 400
43          IF(J.EQ.1.OR.J.EQ.3.OR.J.EQ.5.OR.J.EQ.7) GO TO 400
44          IDBAR=IDBAR+1
45          CALL CBAR(IDBAR,MBAR2,NGRID,N1,0.0,Y1,Z1)
46      400 IF(I.EQ.1.OR.J.EQ.1) GO TO 1000
47          IDMEM=IDMEM+1
48          CALL CQDMEM(IDMEM,MMEM,NGRID,NGRID-2,N1-2,N1)
49     1000 CONTINUE
50     2000 CONTINUE
51          WRITE(6,6600)
52     6600 FORMAT(1H1)
53          STOP;END

55          SUBROUTINE CBAR(ID,IPID,IGA,IGB,X,Y,Z)
56          WRITE(6,6601)ID,IPID,IGA,IGB,-X,Y,Z,1
57          WRITE(7,7701)ID,IPID,IGA,IGB,-X,Y,Z,1
58     6601 FORMAT(1X,'CBAR',4X,4I8,3F8.3,I8)
59     7701 FORMAT('CBAR',4X,4I8,3F8.3,I8)
60          RETURN
61          END

62          SUBROUTINE CQDMEM(ID,IPID,IG1,IG2,IG3,IG4)
63          WRITE(6,6601)ID,IPID,IG1,IG2,IG3,IG4,0.0
64          WRITE(7,7701)ID,IPID,IG1,IG2,IG3,IG4,0.0
```

```
65     6601 FORMAT(1X,'CQDMEM2 ',6I8,F8.3)
66     7701 FORMAT('CQDMEM2 ',6I8,F8.3)
67          RETURN
68          END

69          SUBROUTINE GRID(ID,X,Y,Z)
70          IF(X.EQ.0.0.AND.Y.EQ.0.0) GO TO 2
71          WRITE(6,6601)ID,-X,Y,Z
72          WRITE(7,7701)ID,-X,Y,Z
73          GO TO 9999
74        2 WRITE(6,6602)ID,-X,Y,Z,12456
75          WRITE(7,7702)ID,-X,Y,Z,12456
76     6601 FORMAT(1X,'GRID',4X,I8,8X,3F8.3)
77     6602 FORMAT(1X,'GRID',4X,I8,8X,3F8.3,8X,I8)
78     7701 FORMAT('GRID',4X,I8,8X,3F8.3)
79     7702 FORMAT('GRID',4X,I8,8X,3F8.3,8X,I8)
80     9999 RETURN
81          END

82          SUBROUTINE COORDF(C,X,T)
83          DIMENSION XC(18),YC(18)
84          DATA XC/0.,1.25,2.5,5.,7.5,10.,15.,20.,25.,30.,40.,50.,60.,70.,
           180.,90.,95.,100./
85          DATA YC/0.,2.841,3.922,5.332,6.3,7.024,8.018,8.606,8.912,9.003,
           18.705,7.941,6.845,5.496,3.935,2.172,1.210,0.189/
86          X1=X/C*100.
87          DO 1000 I=1,18
88          IF(XC(I).LT.X1) GO TO 1000
89          FRAC=(XC(I)-X1)/(XC(I)-XC(I-1))
90          T1=YC(I)-FRAC*(YC(I)-YC(I-1))
91          GO TO 9999
92     1000 CONTINUE
93     9999 T=T1*C/100.
94          RETURN
95          END

       $ENTRY
```

A.5.3 Wing Program Listing

```
      $JOB                ,NOEXT,T=28
    1       INTEGER*4 G1,G2,G3,G4,G5,G6,G7,G8
    2       DIMENSION GRID(3,1000)
    3       READ(5,*)B,C1,CSF,CSR,XNR,NR,NGRID1,ICP
    4       READ(5,*)NMEM,NBAR,NPLATE
    5       READ(5,*)NPMEM,NPBAR1,NPBAR2,NPPLT,NPPLT1,NPMEM1,NPMEM2
    6       WRITE(6,6600)
    7       NGRID=NGRID1;NSPARG=0;N11=NGRID-2;N21=NGRID-8
   11       CSF1=CSF;C=C1*2.;CSR1=CSR+CSF1
   14       C2=(CSF+CSR)*C;C3=1.-(CSF+CSR)
   16       IF(CSF.EQ.0.0) NSPARG=1000000
   17       DO 1000 I=1,NP
   18       Y=XNR*(I-1)
   19       C=2.*C1*(1-Y*Y/(B*B))**0.5
   20       N1=NGRID-1;N2=N1-1;N3=N2-1;N4=N3-1;N5=N4-1;N6=N5-1
   26       GRID(1,N1)=(CSF1+CSR)*C-C2
   27       IF(CSF.EQ.0.0) GO TO 200
   28       IF(I.LE.2) GO TO 500
   29       IF(NSPARG.NE.0) GO TO 200
   30       SLOPE=(GRID(1,N21)-GRID(1,N11))/XNR
   31       XINT=GRID(1,N11)
   32       CSF=(GRID(1,N1)-(Y*SLOPE+XINT))/C
   33       IF(CSF.GT.0.0) GO TO 500
   34       NSPARG=NGRID+4
   35   200 GRID(1,N2)=-C2
   36       GRID(1,N3)=GRID(1,N1)-C
   37       GRID(1,N4)=GRID(1,N2)
   38       DO 300 J=1,4
   39       GRID(2,NGRID-J)=Y
   40   300 CONTINUE
   41       CALL CORDW(C,CSF1,CSR1,Z2,Z3,Z4,Z5)
   42       GRID(3,N2)=Z4;GRID(3,N4)=Z5;GRID(3,N3)=GRID(3,N1)=0.0
   45       DO 400 J=1,4
   46       NJ=NGRID-J
   47       CALL SGRID(NJ,ICP,GRID(1,NJ),GRID(2,NJ),GRID(3,NJ),26)
   48   400 CONTINUE
   49       NGRID=NGRID-4
   50       GO TO 1000
   51   500 CONTINUE
   52       GRID(1,N4)=GRID(1,N1)-C
   53       GRID(1,N2)=GRID(1,N6)=GRID(1,N1)-CSF*C
   54       GRID(1,N3)=GRID(1,N5)=-C2
   55       GRID(3,N1)=GRID(3,N4)=0.0
   56       DO 700 J=1,6
   57       GRID(2,NGRID-J)=Y
   58   700 CONTINUE
   59       CALL CORDW(C,CSF,CSR1,Z2,Z3,Z5,Z6)
   60       GRID(3,N2)=Z2;GRID(3,N3)=Z5;GRID(3,N5)=Z6;GRID(3,N6)=Z3
   64       DO 900 J=1,6
   65       NJ=NGRID-J
   66       CALL SGRID(NJ,ICP,GRID(1,NJ),GRID(2,NJ),GRID(3,NJ),26)
   67   900 CONTINUE
   68       NGRID=NGRID-6
   69  1000 CONTINUE
   70       NTIP=NGRID-1
   71       GRID(1,NTIP)=-C2;GRID(2,NTIP)=B;GRID(3,NTIP)=0.0
   74       CALL SGRID(NTIP,ICP,GRID(1,NTIP),GRID(2,NTIP),GRID(3,NTIP),26)
   75       NGRID=NGRID1;NR1=NR-1
   77       IF(CSF.EQ.0.0) GO TO 2100
   78       DO 2000 I=1,NR1
```

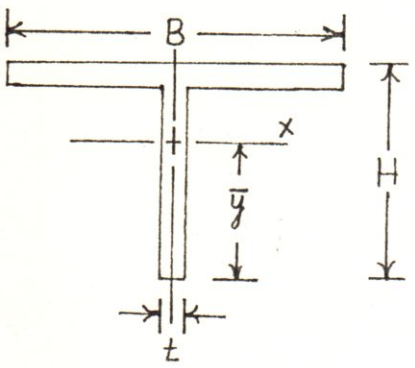
```
 79           G1=NGRID-1;G2=NGRID-2;G3=NGRID-8;G4=NGRID-7
 83           G5=NGRID-1;G6=NGRID-6;G7=NGRID-12;G8=NGRID-7
 87           CALL MEMBRN(NMEM,NPMEM,G1,G2,G3,G4)
 88           CALL MEMBRN(NMEM,NPMEM,G5,G6,G7,G8)
 89           Z1=(GRID(3,G2)-GRID(3,G6))/2.
 90           Z2=(GRID(3,G3)-GRID(3,G7))/2.
 91           CALL BAR(NBAR,NPBAR1,G2,G3,Z1,Z2)
 92           IF(G3.EQ.NSPARG) GO TO 2100
 93           NGRID=NGRID-6
 94      2000 CONTINUE
 95      2100 NGRID=NGRID1-1
 96           IF(CSF.EQ.0.0) NGRID=NGRID1
 97           DO 3000 I=1,NB1
 98           IF(NGRID-1.LE.NSPARG) GO TO 2500
 99           G1=NGRID-1;G2=NGRID-2;G3=NGRID-8;G4=NGRID-7
103           G5=NGRID-5;G6=NGRID-4;G7=NGRID-10;G8=NGRID-11
107           CALL MEMBRN(NMEM,NPMEM,G1,G2,G3,G4)
108           CALL MEMBRN(NMEM,NPMEM,G5,G6,G7,G8)
109           G1=NGRID-2;G2=NGRID-3;G3=NGRID-9;G4=NGRID-8
113           G5=NGRID-4;G6=NGRID-3;G7=NGRID-9;G8=NGRID-10
117           CALL MEMBRN(NMEM,NPMEM1,G1,G2,G3,G4)
118           CALL MEMBRN(NMEM,NPMEM1,G5,G6,G7,G8)
119           Z1=(GRID(3,G1)-GRID(3,G5))/2.
120           Z2=(GRID(3,G4)-GRID(3,G8))/2.
121           CALL BAR(NBAR,NPBAR2,G1,G4,Z1,Z2)
122           NGRID=NGRID-6
123           GO TO 3000
124      2500 G1=NGRID-1;G2=NGRID-2;G3=NGRID-6;G4=NGRID-5
128           G5=NGRID-1;G6=NGRID-4;G7=NGRID-8;G8=NGRID-5
132           IF(G1.NE.NSPARG) GO TO 2510
133           G3=G3-1;G4=G4-1;G5=G5-4;G7=G7-1;G8=G8-1
138      2510 CONTINUE
139           CALL MEMBRN(NMEM,NPMEM,G1,G2,G3,G4)
140           CALL MEMBRN(NMEM,NPMEM,G5,G6,G7,G8)
141           Z1=(GRID(3,G2)-GRID(3,G6))/2.
142           Z2=(GRID(3,G3)-GRID(3,G7))/2.
143           CALL BAR(NBAR,NPBAR2,G2,G3,Z1,Z2)
144           G1=G2;G2=G1-1;G3=G3-1;G4=G3+1;G5=G6;G6=G2;G7=G3;G8=G7-1
152           CALL MEMBRN(NMEM,NPMEM1,G1,G2,G3,G4)
153           CALL MEMBRN(NMEM,NPMEM1,G5,G6,G7,G8)
154           IF(NGRID-1.EQ.NSPARG) NGRID=NGRID-1
155           NGRID=NGRID-4
156      3000 CONTINUE
157           IF(CSF.EQ.0.0) GO TO 3100
158           G1=NSPARG+1;G2=NSPARG;G3=NSPARG-5;G4=NSPARG-4
162           CALL TRIMEM(NMEM,NPMEM2,G1,G2,G3)
163           CALL TRIMEM(NMEM,NPMEM2,G1,G4,G3)
164      3100 G1=NTIP+4;G2=NTIP+3;G3=NTIP;G4=NTIP+1;G5=NTIP+2
169           CALL TRIMEM(NMEM,NPMEM2,G1,G2,G3)
170           CALL TRIMEM(NMEM,NPMEM2,G1,G4,G3)
171           CALL TRIMEM(NMEM,NPMEM2,G2,G5,G3)
172           CALL TRIMEM(NMEM,NPMEM2,G4,G5,G3)
173           NGRID=NGRID1
174           DO 4000 I=1,NP
175           G1=NGRID-1;G2=G1-1;G3=G2-1;G4=G3-1;G5=G4-1;G6=G5-1
181           IF(G2.LT.NSPARG) GO TO 3500
182           CALL TRIPLT(NPLATE,NPPLT,G1,G2,G6)
183           CALL TRIPLT(NPLATE,NPPLT,G2,G3,G5,G6)
184           CALL TRIPLT(NPLATE,NPPLT,G3,G4,G5)
185           NGRID=NGRID-6
```

```
      GO TO 4000
 3500 CALL TRIPLT(NPLATE,NPPLT,G1,G2,G4)
      CALL TRIPLT(NPLATE,NPPLT,G2,G3,G4)
      NGRID=NGRID-4
 4000 CONTINUE
      WRITE(6,6600)
 6600 FORMAT(1H1)
      STOP
      END

      SUBROUTINE COORDW(CHORD,CSF,CSR,Z1,Z2,Z3,Z4)
      DIMENSION Z(3,18)
      DATA Z/0.0,0.0,0.0,1.25,.789,-.789,2.5,1.089,-1.089,
     15.0,1.481,-1.481,7.5,1.75,-1.75,10.,1.951,-1.951,15.,2.228,-2.228,
     220.,2.391,-2.391,25.,2.476,-2.476,30.,2.501,-2.501,40.,2.419,
     3-2.419,50.,2.206,-2.206,60.,1.902,-1.902,70.,1.527,-1.527,
     480.,1.094,-1.094,90.,.604,-.604,95.,.336,-.336,100.,.053,-.053/
      Z1=Z2=Z3=Z4=0.0;C=CHORD
      C1=CSF*100.;C2=CSR*100.
      DO 1000 I=1,18
      IF(Z1.NE.0.0) GO TO 500
      IF(C1.EQ.Z(1,I)) GO TO 200
      IF(C1.GT.Z(1,I).AND.C1.GT.Z(1,I+1)) GO TO 1000
      ZA=(C1-Z(1,I))/(Z(1,I+1)-Z(1,I))
      Z1=ZA*(Z(2,I+1)-Z(2,I))+Z(2,I)
      Z2=ZA*(Z(3,I+1)-Z(3,I))+Z(3,I)
      GO TO 1000
  200 Z1=Z(2,I);Z2=Z(3,I)
      GO TO 1000
  500 IF(C2.EQ.Z(1,I)) GO TO 700
      IF(C2.GT.Z(1,I).AND.C2.GT.Z(1,I+1)) GO TO 1000
      ZB=(C2-Z(1,I))/(Z(1,I+1)-Z(1,I))
      Z3=ZB*(Z(2,I+1)-Z(2,I))+Z(2,I)
      Z4=ZB*(Z(3,I+1)-Z(3,I))+Z(3,I)
      GO TO 1100
  700 Z3=Z(2,I);Z4=Z(3,I)
      GO TO 1100
 1000 CONTINUE
 1100 C=C/100.;Z1=Z1*C;Z2=Z2*C;Z3=Z3*C;Z4=Z4*C
      RETURN
      END

      SUBROUTINE SGRID(ID,ICP,X1,X2,X3,IPS)
      WRITE(6,6601)ID,ICP,X1,X2,-X3,IPS
      WRITE(7,7701)ID,ICP,X1,X2,-X3,IPS
 6601 FORMAT(1X,'GRID',4X,2I8,3F8.2,8X,I8)
 7701 FORMAT('GRID',4X,2I8,3F8.2,8X,I8)
      RETURN;END

      SUBROUTINE BAR(ID,IPID,IGA,IGB,Z1,Z2)
      ID=ID+1;IF=1;ID1=ID-1000;X1=-100.;X2=X3=0.0
      WRITE(6,6601)ID,IPID,IGA,IGB,X1,X2,X3,IF,ID1
      WRITE(7,7701)ID,IPID,IGA,IGB,X1,X2,X3,IF,ID1
      WRITE(6,6602)ID1,-Z1,-Z2
      WRITE(7,7702)ID1,-Z1,-Z2
 6601 FORMAT(1X,'CBAR',4X,4I8,3F8.2,I8,'+CBAR',I3)
 7701 FORMAT('CBAR',4X,4I8,3F8.2,I8,'+CBAR',I3)
```

```
249     6602 FORMAT(1X,'+CBAR',I3,32X,F8.2,16X,F8.2)
250     7702 FORMAT('+CBAR',I3,32X,F8.2,16X,F8.2)
251          RETURN;END

253          SUBROUTINE TRIMEM(ID,IPID,IG1,IG2,IG3)
254          ID=ID+1;TH=0.0
256          WRITE(6,6601)ID,IPID,IG1,IG2,IG3,TH
257          WRITE(7,7701)ID,IPID,IG1,IG2,IG3,TH
258     6601 FORMAT(1X,'CTRMEM  ',5I8,F8.2)
259     7701 FORMAT('CTRMEM  ',5I8,F8.2)
260          RETURN;END

262          SUBROUTINE TRIPLT(ID,IPID,IG1,IG2,IG3)
263          ID=ID+1;TH=0.0
265          WRITE(6,6601)ID,IPID,IG1,IG2,IG3,TH
266          WRITE(7,7701)ID,IPID,IG1,IG2,IG3,TH
267     6601 FORMAT(1X,'CTRIA2  ',5I8,F8.2)
268     7701 FORMAT('CTRIA2  ',5I8,F8.2)
269          RETURN;END

271          SUBROUTINE MEMBRN(ID,IPID,IG1,IG2,IG3,IG4)
272          ID=ID+1;TH=0.0
274          WRITE(6,6601)ID,IPID,IG1,IG2,IG3,IG4,TH
275          WRITE(7,7701)ID,IPID,IG1,IG2,IG3,IG4,TH
276     6601 FORMAT(1X,'CQDMEM2 ',6I8,F8.2)
277     7701 FORMAT('CQDMEM2 ',6I8,F8.2)
278          RETURN;END

280          SUBROUTINE QDPLT(ID,IPID,IG1,IG2,IG3,IG4)
281          ID=ID+1;TH=0.0
283          WRITE(6,6601)ID,IPID,IG1,IG2,IG3,IG4,TH
284          WRITE(7,7701)ID,IPID,IG1,IG2,IG3,IG4,TH
285     6601 FORMAT(1X,'CQUAD2  ',6I8,F8.2)
286     7701 FORMAT('CQUAD2  ',6I8,F8.2)
287          RETURN;END

     $ENTRY
```

A.5.4 CBAR Element Properties Calculations

Fuselage T-section Ribs & Stringers



$B = 0.75"$

$H = 0.55"$

$t = 0.05"$

$$\text{Area} = Bt + (H-t)t$$

$$= (.75)(.05) + (.55-.05)(.05)$$

$$= 0.0625 \text{ in.}^2$$

$$\bar{y} = H - \frac{H^2 t + t^2(B-t)}{2(\text{Area})}$$

$$= .55 - \frac{(.55)^2(.05) + (.05)^2(.75-.05)}{2(.0625)}$$

$$= 0.415 \text{ in.}$$

$$I_x = \frac{t\bar{y}^3 + B(H-\bar{y})^3 - (B-t)(H-\bar{y}-t)^3}{3}$$

$$= \frac{(.05)(.415)^3 + (.75)(.55-.415)^3 - (.75-.05)(.55-.415-.05)^3}{3}$$

$$= 0.00166 \text{ in.}^4$$

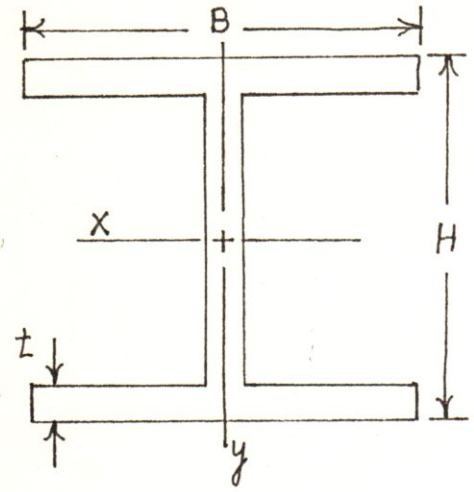
$$I_y = \frac{tB^3 + (H-t)t^3}{12}$$

$$= \frac{(.05)(.75)^3 + (.55-.05)(.05)^3}{12}$$

$$= 0.00176 \text{ in.}^4$$

$$J = I_x + I_y = 0.00342 \text{ in.}^4$$

Main Wing Spar



$B = H = 1.75"$

$t = 0.04"$

$$\text{Area} = 2Bt + (H-2t)t$$

$$= 2(1.75)(.04) + (1.75-.08)(.04)$$

$$= \underline{0.20680 \text{ in}^2}$$

$$I_x = \frac{BH^3 - (H-2t)^3(B-t)}{12}$$

$$= \frac{(1.75)^4 - (1.75-.08)^3(1.75-.04)}{12}$$

$$= \underline{0.11789 \text{ in.}^4}$$

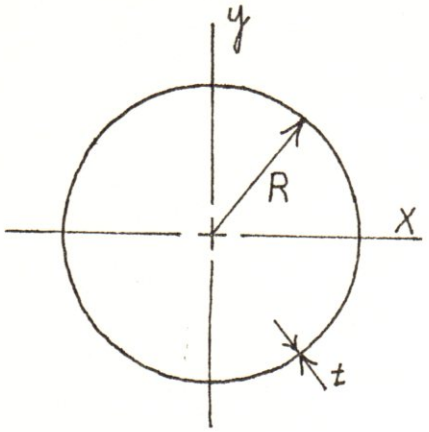
$$I_y = \frac{(H-2t)t^3 + 2tB^3}{12}$$

$$= \frac{(1.75-.08)(.04)^3 + 2(.04)(1.75)^3}{12}$$

$$= \underline{0.03574 \text{ in.}^4}$$

$$J = I_x + I_y = \underline{0.15363 \text{ in.}^4}$$

WING REAR SPAR (INBOARD)



$R = 0.75"$

$r = R - t$

$= 0.74"$

$t = 0.01"$

$$\text{AREA} = \pi (R^2 - r^2)$$

$$= \pi [(.75)^2 - (.74)^2]$$

$$= 0.04681 \text{ in}^2$$

$$I_x = I_y = \frac{\pi}{4}(R^4 - r^4)$$

$$= \frac{\pi}{4}[(.75)^4 - (.74)^4]$$

$$= 0.01299 \text{ in}^4$$

$$J = 2I_x = 0.02598 \text{ in.}^4$$

PROPOSAL COSTS

PROPOSAL COSTS

1. Personnel

A. 15 weeks for 4 engineering students at		
1) 4 hrs/week @ $10.00		$ 2400
2) 15 hrs/week @ $10.00		$ 9000
B. 1 week for 4 engineering students at		
50 hrs/week @ $10.00		$ 2000
Subtotal Personnel		$13,400

2. Use of Facilities, Equipment and Supplies

A. Computer	$ 2000
B. References	$ 50
Subtotal Facilities	$ 2050

3. Other Direct Costs

A. Xerograph	$ 75
B. Telephone	$ 40
C. Travel	
1) Two trips to Linda Hall Library	$ 60
2) One trip to AVRADCOM	$ 10
Subtotal Other Direct Costs	$ 190

Total Fixed Price $15,635