POTENTIAL STRUCTURAL MATERIALS AND DESIGN CONCEPTS FOR LIGHT AIRPLANES

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INTRODUCTION

This four-part paper is based on a study conducted by San Diego Aircraft Engineering Company for NASA, Mission Analysis Division, Ames Research Center. The complete report of the study was published as NASA CR-1285, March 1969; a summary report was published as NASA CR-73257.

The series of papers presented here contains material of possible interest to sailplane designers and builders. The NASA report CR-1285 is available for sale @ $3.00 through CFSTI, Springfield, Virginia 22151.

The remaining three parts of the paper will appear serially in Technical Soaring.

PART I

POTENTIAL STRUCTURAL MATERIALS

This article concerns the investigation of a wide variety of structural materials applicable in the design of light aircraft (including helicopters) during the next five to 15 years. Materials available in five years are classified near-term. Those available 15 years from now are considered far-term. High-priced near-term materials are also considered as far-term, anticipating cost reductions during the next 15 years.

The objective of this investigation was to determine, from the initial compilation, a list of promising candidate materials based on parameters involving strength, stiffness, weight, and raw material cost.

Candidate materials will be further evaluated in subsequent chapters against such parameters as design-concept compatibility, method of joining, fatigue, formability, and costs relating to fabrication.

Materials were first selected from the broad spectrum of the various types available. In the beginning, an effort was made to pick representative examples from each type, basing the selection on one or more of the following characteristics:

(1) Accepted use in present-day aircraft construction.
(2) Low density.
(3) Low material cost:

Not always an important factor because fabrication costs can be far more significant.

(4) High stiffness:

Many areas of light aircraft and helicopter structures are designed for stiffness. This takes precedence on static strength requirements.

(5) High strength.

(6) Weldability, brazability, bondability:

Inasmuch as present-day fabrication methods such as riveting contribute considerably to the overall cost of the finished product, a number of potential materials lending themselves to welding, brazing, and/or bonding were included.

(7) Minimum maintenance.

(8) Materials exhibiting good corrosion resistance to atmospheric environments were considered.

Tables I and II tabulate the initial selection of materials, together with their pertinent properties.

In evaluating the initial selection of materials, structural efficiencies were determined for comparison purposes. These structural efficiencies are:

$$\text{Tension} = \frac{F_{tu}}{w}$$

$$\text{Column} = \frac{\sqrt{E_c}}{w}$$

$$\text{Shear Buckling} = \frac{\sqrt[3]{E_c}}{w}$$

Each structural efficiency was also divided by the material cost to obtain additional comparisons. In the case of far-term materials (to be used 15 years from now), the projected cost 15 years from now will be used. Comparative structural efficiencies are also presented in Tables I and II.

Material Costs

Material costs, in dollars per pound, were determined by using price information obtained from the following companies:

Steel	- Ryerson & Sons, Los Angeles, California Republic Steel, Los Angeles, California
Aluminum	- Aluminum Company of America, San Diego, California
Magnesium	- The Dow Chemical Company, Los Angeles, California
Titanium	- Reactive Metals, Inc., Los Angeles, California
Beryllium	- Beryllium Metals & Chemicals Corp., New York, New York
Plastics (Reinforced)	- Whittaker Corp. (Narmco Division), San Diego, California Owens-Corning Fiberglas Corp., New York, New York General Dynamics/Convair, San Diego, California Goodyear Aerospace Corporation, Akron, Ohio
Plastics (Unreinforced)	- Whittaker Corp. (Narmco Division), San Diego, California General Electric (Chemical Material Dept), Pittsfield, Massachusetts U.S. Rubber Company, Chicago, Illinois DuPont (Textile Fibers Dept), Wilmington, Delaware Borg-Warner (Marbon Chemical Division), Washington, West Virginia Fibertite Corporation, Orange, California
Woods	- Niedermeyer-Martin Company, Portland, Oregon Gordon Plywood Company, Alhambra, California
Core Materials	- Hexcel Products, Inc., Los Angeles, California

TABLE 1. INITIAL SELECTION OF METALLIC MATERIALS AND COMPARATIVE STRUCTURAL EFFICIENCIES

Material	Availability	F_{tu}	F_{ty}	F_{cy}	E_c	w	Material Cost	Characteristics	$\frac{F_{tu}}{w}$	$\frac{F_{tu}}{w\ \$/lb}$	$\frac{\sqrt{E_c}}{w}$	$\frac{\sqrt{E_c}}{w\ \$/lb}$	$\frac{\sqrt[3]{E_c}}{w}$	$\frac{\sqrt[3]{E_c}}{w\ \$/lb}$	Ref.
	(5)	KSI	KSI	KSI	$\frac{PSI}{10^6}$	$\frac{LB}{in^3}$	$\frac{\$}{LB}$ (6)		$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-2}$	$\times 10^{-2}$	
									Tension		Column		Shear Buckling		
Alloy Steels															
1025 Tube	N	55	36	36	29	.284	0.50 (3)	Low Cost, Weldable	194	388	19	38	-	-	4
4130 Norm. Tube	N	95	75	75	29	.283	0.92 (3)	High Strength, Weldable	336	365	19	21	-	-	4
4130 (180HT) Bar	N	180	163	179	29	.283	0.13 (1)	High Strength, Weldable	635	4900	19	146	-	-	4
4340 (260HT) Bar	N	260	217	242	29	.283	0.16 (1)	Ultra High Strength, Weldable	919	5750	19	119	-	-	4
25Ni Maraging	N	319	284	-	24	.296	2.25 (1)	Ultra High Strength, Weldable	1078	480	17	8	-	-	5
Stainless Steel															
301 (Full Hard)	N	185	140	179	28	.286	0.75	Corrosion Resistant, Weldable	645	860	18	24	11	15	4
PH15-7Mo (RH950)	N	225	200	210	30	.277	1.28	Ultra High Strength, Corrosion Resistant	813	635	20	16	11	9	4
Aluminum Alloys															
Sheet															
2024-T3	N	64	42	45	10.7	.100	0.65	Common use, Good Strength/wgt.	640	985	33	50	22	34	4
2024-T3 (CLAD)	N	60	45	37	10.2	.100	0.66	Low Cost, High Energy Absorb.	600	910	32	48	22	34	4
2219-T87	N	62	50	50	10.8	.102	0.86	Weldable	610	710	32	37	22	25	4
5086-H32	N	40	28	26	10.4	.096	0.53	Weldable, Low Cost	417	787	34	64	23	43	4
5456-H343 (4)	N	53	41	39	10.4	.096	0.60	High Welding Efficiency	552	920	34	57	23	38	4
6061-T6	N	42	36	35	10.1	.098	0.54	Low Cost, Corr. Resist, Weldable Formable, High Energy Absorb.	428	794	32	60	22	41	4
7005-T6	N	47	38	39	10.5	.101	0.65	Weldable, Low Distortion	465	716	32	49	22	33	6
7075-T6	N	76	66	67	10.5	.101	0.71	High Strength/weight	752	1060	32	45	22	31	4
7178-T6	N	83	73	73	10.5	.102	0.71	High Strength/Weight	814	1145	32	45	21	30	4
Extrusions															
2014-T6	N	60	53	55	10.7	.101	0.97	Low Cost, Heavy Extrusions	590	608	32	33	-	-	4
2024-T4	N	60	44	39	10.7	.100	1.12	Common use, Good Str./Weight Low Cost, High Energy Absorb.	600	535	33	29	-	-	4
6061-T6	N	38	35	34	10.1	.098	0.44	Low Cost, Corr. Resist., Weldable Formable, High Energy Absorb.	388	1710	32	73	-	-	4
7075-T6	N	81	73	74	10.5	.101	1.39	High Strength/Weight	802	577	32	23	-	-	4
7075-T73	N	66	58	58	10.5	.101	1.42	Stress Corrosion Resistant	655	462	32	23	-	-	7
7178-T6	N	88	79	79	10.5	.102	1.49	High Strength/Weight	863	579	32	21	-	-	4
6061-T6 (Tube)	N	42	35	34	10.1	.098	0.70	Low Cost, Corr. Resist. Weldable Formable, High Energy Absorb.	428	612	32	46	-	-	4
Forgings															
2014-T6	N	65	55	55	10.7	.101	-	Common use	643	-	32	-	-	-	4
5151-T6	N	44	37	39	10.3	.098	-	High Forgeability, Low Cost	450	-	33	-	-	-	4
Castings															
356-T6	N	25	16.5	16.5	10.3	.097	-	Low Cost, Common use	258	-	33	-	-	-	4
A356-T61	N	38	28	28	10.5	.097	-	Premium Type	392	-	33	-	-	-	4
359-T61	N	45	34	34	10.7	.097	-	High strength	463	-	34	-	-	-	4
Magnesium Alloys															
Sheet															
AZ31B-H24	N	39	29	24	6.5	.064	1.10	High Stiff/wt. weld. Low Dens.	610	555	40	36	29	27	4
LA 141-T7	P	19	14	15	6.1	.048	25 (5) (2)	Low Density	396	80	57	10	38	8	4, 8
Mg Yttrium-T5	P	55	50	50	6.5	.067	(6) (2)	Good Strength/weight, Weldable	820	137	38	6	28	5	9
Extrusions															
AZ31B-F	N	35	22	12	6.5	.064	1.20	High Stiff/wt. weld. Low Dens.	547	455	40	33	-	-	4
ZK60A-T5	N	45	36	30	6.5	.066	3.06	Good Strength/weight & Stiffness/weight	682	223	39	13	-	-	4
Castings															
ZK51A-T6	N	34	23	-	6.5	.065	-	Good Strength/Weight	523	-	39	-	-	-	10
ZL63A-T6	N	38	24	-	6.5	.065	-	Good Strength/weight, weldable	585	-	39	-	-	-	10
AZ91C-T6	N	27	14	14	6.5	.065	-	Ductile, Sound Castings	416	-	39	-	-	-	4
Titanium Alloys															
Bars															
Ti-6Al-4V (8)	N	160	150	-	16.4	.160	4.33	High Strength, Weldable Corrosion Resistant	1000	231	25	6	-	-	4
Ti-13V-11Cr-3Al	N	170	160	162	15.5	.174	5.73		977	170	23	4	-	-	
Ti-6Al-4V Sheet (8)	N	157	143	152	16.4	.160	13.65		980	72	25	2	16	1	4
Beryllium Alloys															
Sheet															
Unalloyed (Hot Pressed)	P	40	27	27	42.5	.067	-	High Stiffness/Weight Excellent for Compression	597	-	97	-	-	-	4
Powder Sheet	P	70	50	50 (2)	42.5	.067	275 (70) (2)		1045	15	97	1	52	1	11
Lockalloy (7)	P	44	31	28	28	.076	290 (70) (2)		580	8	70	1	40	1	11
Extrusions															
Unalloyed	P	93	45	45 (2)	42.5	.067	-		1390	-	97	-	-	-	11
Lockalloy (7)	P	56.5	44.5	40 (2)	28	.076	-		743	-	70	-	-	-	11

NOTES: (1) Bar (2) Estimated (3) 3/4" Diameter x .065" Wall (4) t = .050" Minimum Thickness (5) N = Near Term, P = Potential (6) Costs: t = .032" for Sheet, t = .125" for Extrusion, ( ) = 1982 Estimate (7) 62% Be - 38% Al (8) Solution Heat Treated and Aged

TABLE 2. INITIAL SELECTION OF NON-METALLIC MATERIALS AND COMPARATIVE STRUCTURAL EFFICIENCIES

MATERIAL	AVAIL-ABILITY	F_{tu}	F_{ty}	F_{cu}	E_c	w	MATERIAL COST	CHARACTERISTICS	$\frac{F_{tu}}{w}$	$\frac{F_{tu}}{w\ \$/LB}$	$\frac{\sqrt{E_c}}{w}$	$\frac{\sqrt{E_c}}{w\ \$/LB}$	$\frac{\sqrt[3]{E_c}}{w}$	$\frac{\sqrt[3]{E_c}}{w\ \$/LB}$	REF.
		KSI	KSI	KSI	$\frac{PSI}{10^6}$	$\frac{LB}{in^3}$	$ / LB		$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-2}$	$\times 10^{-2}$	
	(2)						(3)			(5)		(3)		(3)	
GLASS REINFORCED PLASTICS															
Chopped Fiber															
E-Glass/Polyester	N	20	-	26	1.99	.070	0.63	Corrosion Resistant, Formable	286	454	20	32	18	29	12
E-Glass/Nylon 6/10	N	20	-	18	1.0	.048	1.64(0.65)	Low Density, Formable	418	261 (643)	21	13 (22)	21	13 (32)	13
1" S-Glass/Epoxy	N	45	-	62	7.8	.060 (1)	4.00(2.00)	High Strength & Stiff/Weight	750	190 (380)	46	12 (24)	33	8 (16)	14
Continuous Fiber															
181 Cloth E-Glass/Epoxy	N	45	-	45	3.3	.070	2.00(1.00)	Corrosion Resistant	643	321 (643)	26	13 (26)	21	11 (21)	15
143 Cloth E-Glass/Epoxy	N	85	-	60	5.1	.070	2.00(1.00)	Formable	1210	605(1210)	32	16 (32)	25	12 (25)	15
181 Cloth S-Glass/Epoxy	N	94	-	65	4.2	.070	4.00(2.00)	High Strength/Weight	1340	335 (770)	29	7 (14)	23	6 (12)	16
143 Cloth S-Glass/Epoxy	N	139	-	76	5.9	.070	4.00(2.00)		1980	495 (990)	35	9 (18)	26	6 (13)	16
Diallyl Phthalate (Prepreg)	N	49 (1)	-	-	2.6	.070 (1)	3.15	Low Curing Temp., Formable	700	223	23	7	20	6	17,18
FILAMENT REINFORCED PLASTICS/EPOXY MATRIX															
Unidirectional															
Boron	P	140	-	175	33	.071	700(10.00)	High Strength/Weight	1970	(197)	81	(8)	45	(5)	19,30
Graphite	P	95.9	-	56.5	15.4	.051	600 (1.00)	Low Density	1870	(1870)	77	(77)	49	(49)	19,30
E-Glass	P	150	-	85	6.9	.076	2.00(1.00)	Corrosion Resistant	1970	(1970)	35	(35)	25	(25)	19
S-Glass	P	210	-	120	7.6	.073	4.00(2.00)		2880	(1440)	58	(19)	27	(14)	19
Hollow Glass	P	80	-	80	4.5	.065	-		1230	-	33	-	25	-	19
Hi-Modulus Glass	P	210	-	120	9.2	.073	-		2880	-	42	-	29	-	19
Laminate (t=.016 in) ±45° Layers															
Boron	P	19.8	-	37.7	4.18	.071	700(10.00)	High Strength/Weight	279	-	-	-	-	-	19,30
Graphite	P	5.6	-	31.6	2.10	.051	600 (1.00)	Low Density	114	-	-	-	-	-	19,30
E-Glass	P	17.5	-	29.8	2.19	.076	2.00(1.00)	Corrosion Resistant	230	-	-	-	-	-	19
S-Glass	P	17.7	-	37.3	2.49	.073	4.00(2.00)		243	-	-	-	-	-	19
Hollow Glass	P	17.6	-	28.8	1.53	.065	-		271	-	-	-	-	-	19
Hi-Modulus Glass	P	17.7	-	37.3	2.98	.073	-		243	-	-	-	-	-	19
Laminate (t=.040 in) ±45°, 0°, 0°, 0° Layers															
Boron	P	91.9	-	120.1	21.9	.071	700(10.00)	High Strength/Weight	1295	-	-	-	-	-	19,30
Graphite	P	59.5	-	46.5	10.2	.051	600 (1.00)	Low Density	1175	-	-	-	-	-	19,30
E-Glass	P	97.0	-	62.9	5.0	.076	2.00(1.00)	Corrosion Resistant	1275	-	-	-	-	-	19
S-Glass	P	133.1	-	86.9	5.6	.073	4.00(2.00)		1825	-	-	-	-	-	19
Hollow Glass	P	55	-	59.5	3.3	.065	-		847	-	-	-	-	-	19
Hi-Modulus Glass	P	133.1	-	86.9	6.8	.073	-		1825	-	-	-	-	-	19
UNREINFORCED THERMOPLASTICS															
ABS (Sheet)	N	3.8	-	5.0	.190	.040	0.90	Low Density	95	105	11	12	14	16	20
ABS (High Strength)	N	7.3	-	10.4	.180	.039	0.46 (6)	Formable	187	407	11	24	14	31	21
Polycarbonate	N	9.5	8.5	-	.345	.043	1.90		221	116	14	7	16	9	22
Nylon Yarn	N	22	-	-	.640	.049	5.10		450	88	16	5	18	3	23
Whittaker PBI-8	N	20	-	30	.700	.043	5.00		465	93	20	4	21	4	-
WOOD															
Hardwoods (4)				F_{cy}											
White Ash	N	13.2	7.2	4.3	1.4	.022	5.80	Low Density	600	104	54	9	-	-	24
Yellow Birch	N	15.1	7.6	4.6	1.85	.025	6.60	Presently used in	603	92	54	8	-	-	24
Softwoods (4)								some light aircraft							
White Cedar	N	10.2	6.7	4.1	1.4	.016	2.10		638	303	74	35	-	-	24
Douglas Fir	N	10.9	5.9	4.2	1.5	.018	0.52		606	1170	68	131	-	-	24
Sitka Spruce	N	9.4	5.3	3.5	1.4	.015	0.67		626	935	79	118	-	-	24
Plywoods, 3-ply (.070 in thick) parallel to face grain															
Birch-Birch	N	8.6	-	2.7	1.2	.028	2.06		307	149	39	19	38	18	24
Poplar-Poplar	N	4.6	-	1.6	.8	.020	2.12		230	109	45	21	46	22	24
Mahogany-Poplar	N	6.7	-	2.6	.9	.020	2.05		340	166	48	23	48	23	24
Modified Woods, Staypak (parallel laminated)															
Birch, t=0.46	P	44.1	18.9	8.0	4.4	.049	-	Good Strength/Weight	900	-	43	-	-	-	24
Spruce, t=0.32	P	35.8	25.9	4.3	4.7	.047	-	Stabilized Wood	760	-	46	-	-	-	24

CORE MATERIALS	AVAIL-ABILITY	F_{su} (min)	F_{cu} (min)	w	MATERIAL COST	CHARACTERISTICS	REF.
	(2)	PSI	PSI	LB/FT³	$/LB		
Resin Coated Nylon 3/8 cell	N	45	140	7.0	22.90	Light Weight, Fireproof	25
3003 Aluminum 1/4 cell	N	44	92	2.3	4.17	Inexpensive, presently	25
5052 Aluminum 1/4 cell	N	52	112	2.3	4.84	used in aircraft	25
2024 Aluminum 1/4 cell	N	138	300	2.8	11.62	High Strength/Weight	25
Nylon Phenolic 3/8 cell	N	56	160	2.5	14.10	Good Strength/Weight	25

NOTES: (1) ESTIMATED (2) N = NEAR TERM, P = POTENTIAL (3) ( ) = 1982 ESTIMATE (4) PARALLEL TO GRAIN (6) RESIN

(5) MIL HDBK 17 material properties were used in this table if available. Otherwise, manufacturers published data were used.

Promising Candidate Materials

The selection of promising candidate materials was based primarily on an evaluation of the comparative structural efficiencies listed in Tables I and II for all initially selected materials. Additional considerations, such as ability to absorb energy, formability, fatigue, stress corrosion and atmospheric corrosion, low-quench sensitivity, loading intensity, and accepted usage in present-day aircraft, also influenced the choosing of candidates. Metallic material candidates are listed in Table III, together with their structural efficiencies. Nonmetallic material candidates are presented in Table IV in a similar manner. Figures 1, 2, and 3 list the comparative structural efficiency of materials by decreasing order of magnitude.

Metallic Materials (Ref. Table III)

TUBING - Two steels and one aluminum alloy were selected as tubing candidates. While the 6061-T6 aluminum alloy is superior from the standpoint of structural efficiencies, 1025 steel is still being used today in areas where low cost and ease of welding so dictate. The 4130 normalized steel tubing is used where column loading intensities are moderate-to-high and size limitations are present. The most likely areas of application for tubing are fuselage weldments and engine mounts.

TABLE 3. PROMISING CANDIDATE MATERIALS
METALLIC

MATERIAL	AVAILABILITY	F_{tu}	F_{ty}	F_{cy}	F_{su}	E_c	e	w	CORROSION RESISTANT	MATERIAL COST	WELDABILITY	THERMAL CO-EFF. $\alpha/10^5$	$\frac{F_{tu}}{w}$	$\frac{F_{tu}}{w\ \$/LB}$	$\frac{\sqrt{E_c}}{w}$	$\frac{\sqrt{E_c}}{w\ \$/LB}$	$\frac{\sqrt[3]{E_c}}{w}$	$\frac{\sqrt[3]{E_c}}{w\ \$/LB}$	REF.
	(6)	KSI	KSI	KSI	KSI	$\frac{PSI}{10^6}$	%	$\frac{LB}{in^3}$		$ / LB		in/in/°F							
TUBING																			
1025 Steel	N	55	36	36	35	29	8-13	.284	POOR	0.50 (1)	EXCEL	.70	194	388	19	38	-	-	4
4130(Normalized)	N	95	75	75	55	29	12	.283	FAIR	0.92 (1)	GOOD	.63	336	365	19	21	-	-	4
6061-T6	N	42	35	34	27	10.1	12	.098	EXCEL	0.70 (1)	GOOD	1.30	428	612	32	46	-	-	4
BAR (t=1.00 in)																			
4130 (180HT)	N	180	163	179	109	29	12	.283	FAIR	0.13	GOOD	.63	635	4900	19	146	-	-	4
4340 (260HT)	N	260	217	242	149	29	10	.283	FAIR	0.16	FAIR	.63	919	5750	19	119	-	-	4
25 Ni (Maraging)	N	319	284	-	-	24	8	.296	GOOD	2.25	FAIR	.59 (5)	1078	480	17	8	-	-	5
FORGING																			
6181-T6	N	44	37	39	28	10.3	10	.098	EXCEL	-	-	1.28	450	-	33	-	-	-	4
2014-T6	N	65	55	55	39	10.7	7	.101	POOR	-	-	1.25	643	-	32	-	-	-	4
SHEET (t=.032 in)																			
2024-T3	N	64	42	45	40	10.7	15	.100	POOR	0.65	GOOD	1.29	640	985	33	50	22	34	4
2024-T3 CLAD	N	60	45	37	38	10.2	15	.100	GOOD	0.65	GOOD	1.29	600	910	32	48	22	33	4
5086-H32	N	40	28	26	24	10.4	6	.096	GOOD	0.55	EXCEL	1.32	417	787	34	64	23	43	4
5456-H343 (4)	N	53	41	39	31	10.4	6	.096	GOOD	0.60	EXCEL	1.33	552	920	34	57	23	38	4
6061-T6	N	42	36	35	27	10.1	10	.098	EXCEL	0.54	GOOD (2)	1.30	428	794	32	60	22	41	4
X7005-T6	N	47	38	39	-	10.5	-	.101	GOOD	0.65	GOOD	1.32	465	716	32	49	22	33	6
7075-T6	N	76	66	67	46	10.5	7	.101	POOR	0.71	GOOD	1.29	752	1060	32	45	22	31	4
7178-T6	N	83	73	73	50	10.5	7	.102	POOR	0.71	GOOD	1.30	814	1145	32	45	21	30	4
AZ 31B-H24	N	39	29	24	18	6.5	6	.064	POOR	1.10	GOOD	1.40	610	555	40	36	29	27	4
EXTRUSION(t≤.250)																			
2014-T6	N	60	53	55	35	10.7	7	.101	POOR	0.97	GOOD	1.25	590	608	32	33	-	-	4
2024-T4	N	60	44	39	32	10.7	12	.100	POOR	1.12	GOOD	1.29	600	535	33	29	-	-	4
6061-T6	N	38	35	34	24	10.1	10	.098	EXCEL	0.44	GOOD	1.30	388	1210	32	73	-	-	4
7075-T6	N	81	73	74	45	10.5	7	.101	POOR	1.39	GOOD (2)	1.29	802	577	32	23	-	-	4
7075-T73	N	66	58	58	-	10.6	-	.101	GOOD	1.42	GOOD	1.29	655	462	32	23	-	-	7
7178-T6	N	88	79	79	47	10.5	5	.102	POOR	1.49	GOOD	1.30	863	579	32	21	-	-	4
Mg Yttrium-T5	P	55	50	50	30	6.5	4	.067	POOR	(6.00) (3)	GOOD	1.40 (5)	820	(137)	38	(6)	-	-	9
CASTING																			
A356-T61	N	38	28	28	27	10.5	5	.097	GOOD	-	-	1.19	392	-	33	-	-	-	4
356-T6	N	25	16.5	16.5	25	10.3	3	.097	GOOD	-	-	1.19	258	-	33	-	-	-	4
359-T61	N	45	34	34	31	10.7	4	.097	GOOD	-	-	1.16	463	-	34	-	-	-	4
ZK 61A-T6	N	34	23	-	-	6.5	2	.065	FAIR	-	-	1.40 (5)	523	-	39	-	-	-	10
ZE 63A-T6	N	38	24	-	-	6.5	4	.065	FAIR	-	-	1.40 (5)	585	-	39	-	-	-	10
AZ 91C-T6	N	27	14	14	-	6.5	2	.065	FAIR	-	-	1.40	416	-	39	-	-	-	4

(1) 3/4 x .065 WALL (2) RESISTANCE WELDABILITY (3) ( ) = 1982 ESTIMATE (4) t = .051 (5) ESTIMATED
(6) N = NEAR TERM, P = POTENTIAL

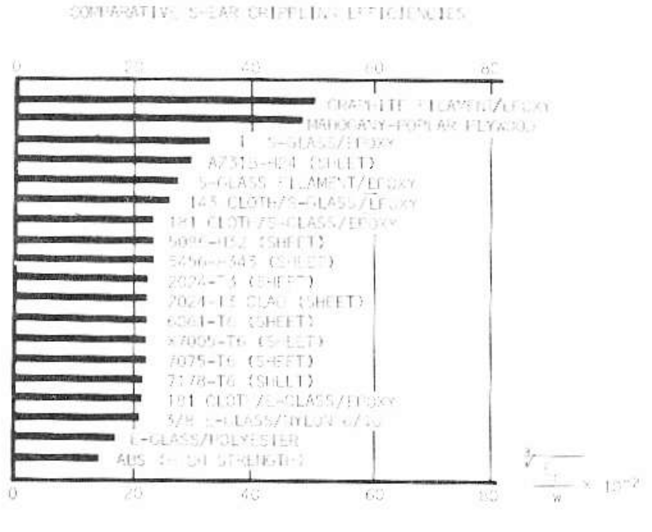

FIGURE 1

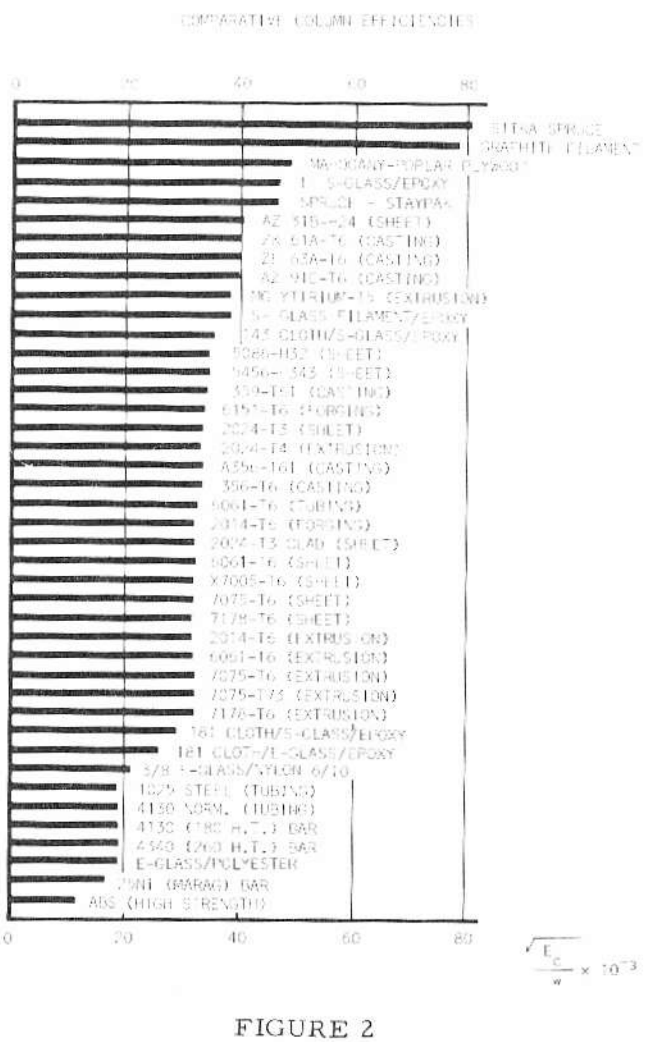

FIGURE 2

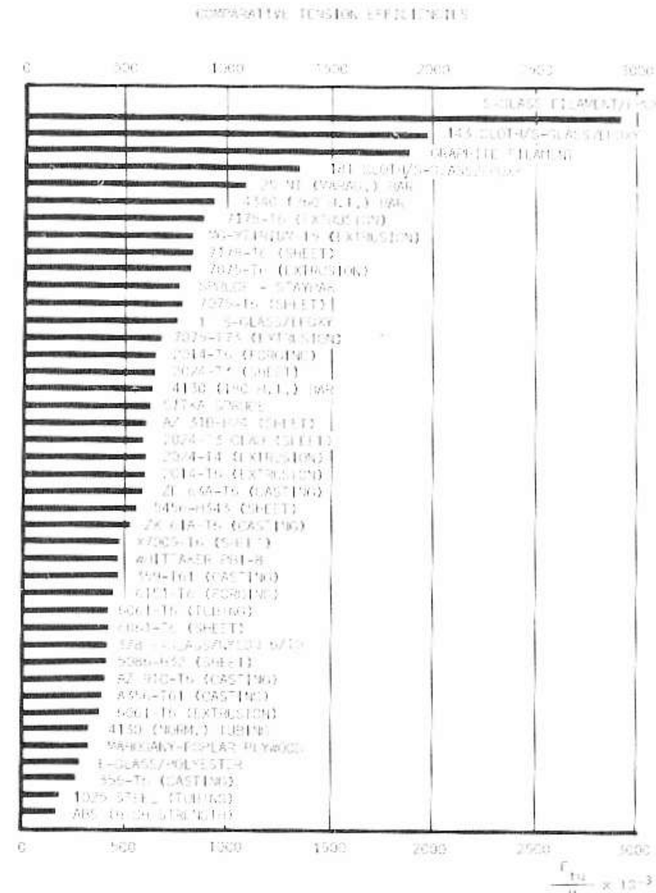

FIGURE 3

BAR MATERIAL - Candidates are listed with the intent of showing materials of high strength for use in areas of landing-gear assemblies, rotor mechanisms, and primary structural fittings having space limitations. Although there are many types of high-strength materials available, the selection represents the lower and upper end of the chrome-alloy series (4130 and 4340), and also includes one of the newer types of maraging steels, 25 Ni. This steel, although 1.8 times as strong as 4130 (180 H.T.), is also 17 times as costly (\$2.25/lb vs. \$0.13/lb). It is a high-quality steel with superior corrosion resistance and toughness over the commonly-used chrome-alloy series.

FORGINGS are occasionally used in helicopters and light aircraft. When used, 2014-T6 is the primary forging alloy, especially for miscellaneous low-stressed fittings where economy and increased corrosion performance predominate.

SHEET - A number of sheet materials are available for use in the construction of light aircraft and helicopters. Sheet stock is used mainly as a covering for the airframe. It is also bent and formed into frames, ribs, stringers, stiffeners, and various types of brackets.

The 2024-T3 alloy, especially the clad version, is by far the most commonly-used skin covering on present-day light aircraft. In addition to having high structural efficiencies, it is a good corrosion-resistant candidate, exhibiting superior qualities of fatigue, energy absorption, and formability when compared to most of the other sheet materials.

The 5XXX series aluminum sheet material is included because of its low-cost structural efficiencies. It also has good formability.

Type 6061-T6 is next in importance to 2024-T3 clad as a material candidate. Its low cost, coupled with its high corrosion resistance and high stress corrosion resistance, formability, and energy absorption characteristics, makes it extremely attractive.

Type X7005 aluminum alloy is one of the more recently developed materials. It can be easily brazed, soldered, or welded, and still maintain its high properties without requiring solution heat treating afterwards. Its low-quench sensitivity, eliminating severe distortion during cooling after heat treatment, makes this alloy a material candidate.

Types 7075-T6 and 7178-T6 are included as they represent the highest strength aluminum alloys available today. While their corrosion and stress-corrosion resistance, formability, energy absorption, and quench sensitivity characteristics are inferior to some of the other aluminum alloys, they exhibit superior tensile structural efficiencies and will outperform other aluminum alloys when used in areas of high-load intensity.

AZ 31B-H24 magnesium alloy has superior column and shear buckling structural efficiencies and is, therefore, listed with the aluminum sheet material. Its higher cost and lower corrosion resistance make it a less likely candidate.

EXTRUSIONS are used mainly as flange material in beams and major bulkheads, stringer material in wide columns (fuselage semi-monocoque, wing-plate stringer), and stiffeners in high-loading intensity areas.

Type 2014-T6 is generally used for sections greater than 0.125-inch thick where its low cost, together with its high-yield strength, makes it a desirable candidate.

Type 2024-T4 extrusions are commonly found in light aircraft for sections under 0.125-inch thick. This alloy, in addition to having good structural efficiencies, exhibits superior fatigue and energy-absorption qualities.

Type 6061-T6 shows considerable promise for extrusions requiring thin sections and high corrosion resistance. The low cost, high energy absorption, and stress-corrosion resistance of this alloy make it an excellent candidate.

The 7075 and 7178 extrusions have the highest mechanical properties of the aluminum alloys. While the T6 tempers are relatively low in stress-corrosion resistance and energy-absorption capabilities, the T73 temper of 7075 is excellent in both respects and warrants consideration in the final selection of candidate materials.

Mg Yttrium-T5 is a new high-strength magnesium alloy. Its high compression yield strength (improving the compressive tangent modulus), coupled with its low density, makes it the most efficient of all the metallic candidates when used in compression critical structures. However, the projected cost of $6.00 per pound 15 years from now reduces its chances of becoming a prime candidate.

CASTINGS are used mainly for rotor mechanisms, wheel hubs, pulleys, brackets, bellcranks, and various fittings.

A356-T61 and 359-T61 are premium-quality composite mold castings. Although they are in general use today, anticipated high production rates for light aircraft/helicopters make these alloys less likely candidates than a permanent mold or die-cast material.

Type 356-T6 is a permanent mold casting alloy in general use today, and it appears it will remain a likely candidate in the future.

AZ 91C-T6, available as a permanent mold casting, is one of the most common magnesium castings in use today.

CORE MATERIAL (Ref. Table II) is used in honeycomb-sandwich constructions. Type 3003 1/4-inch cell, 2.3 pounds per cubic foot aluminum honeycomb core, is considered to be the most promising candidate. It is of adequate strength for light aircraft construction and is only a fraction of the cost of the expensive reinforced plastic honeycomb.

Non-Metallic Materials (Ref. Table IV)

NON-REINFORCED THERMOPLASTICS are used for fairings and for low-stressed skin.

ABS (High Modulus) is low in cost and can be molded to shapes. This material, although not highly flammable, will support combustion.

CHOPPED FIBER-REINFORCED PLASTICS are best adapted for areas of low-loading intensity such as secondary fittings, fairings, and low-stressed skin.

3/8 E-Glass/Nylon 6/10 is a medium-cost injection moldable thermoplastic reinforced with 1/4-inch to 3/8-inch long glass fibers (30% by weight). It is finding use in the design of next-generation commercial transports in such areas as access covers for wing fuel tanks. Nylon 6/10 is a self-extinguishing material from the standpoint of flammability.

E-Glass/Polyester is a low-cost discontinuous glass fiber, reinforced polyester-type sheet molding compound. Fairings, low-stressed skins, and fittings are possible areas of application for this material. It is also a flame-retardant (non-burning) material.

TABLE 4. PROMISING CANDIDATE MATERIALS
NON-METALLIC

												COMPARATIVE STRUCTURAL EFFICIENCIES						
MATERIAL	APPLICATION	F_{tu}	F_{ty}	F_{cu}	F_{su}	E_c	e	w	WEATHERABILITY	MATERIAL COST (2)	THERMAL CO-EFF. $\alpha/10^5$	$\frac{F_{tu}}{w}$	$\frac{F_{tu}}{w\ \$/LB}$	$\frac{\sqrt{E_c}}{w}$	$\frac{\sqrt{E_c}}{w\ \$/LB}$	$\frac{\sqrt[3]{E_c}}{w}$	$\frac{\sqrt[3]{E_c}}{w\ \$/LB}$	REF.
	(3)	KSI	KSI	KSI	KSI	$\frac{PSI}{10^6}$	%	LB/IN^3		$ / LB	in/in/°F							
NON-REINFORCED																		
ABS (High Strength)	NT-FT	7.3	-	10.4	-	.180	20	.039	EXCEL	0.46	6.00	187	407	11	24	14	31	5,21
NON-CONTINUOUS FIBER REINFORCED																		
3/8 E-Glass/Nylon 6/10	FT	20	-	18	11	1.0	5-6	.048	EXCEL	1.34 (0.65)	2.50	418	(645)	21	(32)	21	(32)	13
1" S-Glass/Epoxy	FT	45	-	62	8	7.8	-	.060	EXCEL	4.00 (2.00)	-	750	(375)	46	(23)	33	(16)	14
E-Glass/Polyester	NT	20	-	26	-	1.99	-	.070	EXCEL	0.63	1.20	286	454	20	32	15	29	12
CLOTH REINFORCED																		
DAP Prepreg	NT-FT	49 (1)	-	-	-	2.6 (1)	-	.070 (1)	EXCEL	3.15 (1.58)	-	700	(446)	23	(14)	20	(12)	17,18
181 Cloth/E-Glass	NT-FT	45	-	45	-	3.5	-	.070	EXCEL	(1.00)	-	643	(643)	26	(26)	21	(21)	15
181 Cloth/S-Glass	NT-FT	94	-	65	-	4.2	-	.070	EXCEL	(2.00)	-	1340	(670)	29	(14)	23	(12)	16
FILAMENT REINFORCED (EPOXY MATRIX)																		
Unidirectional																		
Graphite	FT	95.9	-	55.5	5.2	15.4	-	.051	EXCEL	(1.00)	-	1870	(1870)	77	(77)	49	(49)	19
S-Glass	FT	210	-	120	13.6	7.6	-	.073	EXCEL	(2.00)	-	2880	(1440)	38	(19)	27	(13)	19
±45° Layers (t=.016 in)																		
Graphite	FT	5.8	-	31.6	24.8	2.1	-	.051	EXCEL	(1.00)	-	114	(114)	28	(28)	25	(25)	19
S-Glass	FT	17.7	-	37.3	50.0	2.5	-	.073	EXCEL	(2.00)	-	349	(174)	22	(11)	19	(10)	19
±45°,0° Layers (t=.024 in)																		
Graphite	FT	35.8	-	59.9	20.4	6.6	-	.051	EXCEL	(1.00)	-	702	(702)	50	(50)	37	(37)	19
S-Glass	FT	81.8	-	64.9	39.5	4.2	-	.073	EXCEL	(2.00)	-	1120	(560)	28	(14)	22	(11)	19
±45°,0°,0° Layers (t=.032 in)																		
Graphite	FT	50.8	-	44.0	17.8	8.8	-	.051	EXCEL	(1.00)	-	1000	(1000)	58	(58)	41	(20)	19
S-Glass	FT	113.8	-	78.7	34.0	5.1	-	.073	EXCEL	(2.00)	-	1560	(780)	31	(15)	24	(12)	19
±45°,0°,0°,0° Layers (t=.040 in)																		
Graphite	FT	59.6	-	45.5	15.9	10.2	-	.051	EXCEL	(1.00)	-	1170	(1170)	63	(63)	43	(43)	19
S-Glass	FT	133.1	-	86.9	30.5	5.6	-	.073	EXCEL	(2.00)	-	1825	(912)	32	(76)	24	(12)	19
WOOD				F_{cy}														
Sitka Spruce	NT	9.4	5.3	3.5	1.0	1.4	-	.015	POOR	0.67	-	626	935	79	118	-	-	24
Mahogany/Poplar Plywd	NT	6.7	-	2.6	1.9	.9	-	.020	POOR	2.05	-	555	167	46	23	48	23	24
Spruce - Staypak	NT	35.8	25.9	4.3	1.3	4.7	.75	.047	FAIR	(4)	-	760	(4)	46	(4)	-	-	24

NOTES: (1) ESTIMATED (2) ( ) = 1982 ESTIMATE (3) NT - NEAR TERM, FT - FAR TERM (4) EXPERIMENTAL, NO PRICE AVAILABLE

1-inch S-Glass/Epoxy, a one-inch chopped fiber system with an epoxy matrix, is a high-strength, high-cost material used in helicopter wheels.

CLOTH REINFORCED THERMOSETS may be used for all types of structures by providing the optimum fiber orientation for each type of loading. They are best used in multi-layer combinations in laminates or in sandwich construction.

Type 143 Cloth/E-Glass in an epoxy matrix is used in laminate and sandwich form in light aircraft and helicopters. Its use is restricted, as a rule, to secondary structure. However, the advancing state of the art of fiberglass composites and resin systems indicates that this material is a candidate for primary structure.

Type 143 Cloth/S-Glass and epoxy matrix system is a higher-strength and higher-cost composite than the E-Glass system. It is a candidate material when structural efficiencies outweigh material cost, or can be shown cost effective.

UNIDIRECTIONAL FILAMENT-REINFORCED COMPOSITES are in their infancy at present. Most of the composites are extremely expensive and are being used only in isolated cases. However, their superior structural efficiencies indicate that, projected ahead 15 years from now, these composites, with reduced costs, will be potential candidates. They should be laminated in various fiber orientations, depending on the loading conditions.

Graphite filament/epoxy matrix composite exhibits exceptional structural efficiencies due to low density and high modulus.

S-Glass/epoxy matrix composites show superior tension efficiencies and modulus as compared with Graphite; however, they do not compare with the column and shear buckling efficiency of the Graphite system.

WOOD has been used as primary and secondary structure in light aircraft for many years. Although aluminum alloys have predominated the light aircraft field for the past decade, there are still a few airplanes being constructed of wood. Generally speaking, a wooden structure (such as a wing) is aerodynamically smoother and lighter than its metal counterpart. However, it is also more expensive to build. Another disadvantage to wood construction is its higher maintenance cost due to weathering and moisture absorption.

Sitka-Spruce is probably the most common wood used in light aircraft. It has a column efficiency more than twice that of the aluminum alloys.

Mahogany (poplar core) plywood is one of the more common woods used for skins. Its shear buckling efficiency is twice that of the aluminum alloys.

Spruce-Staypak is a compressed wood with greatly increased mechanical properties and higher density.

END OF PART I

LIST OF SYMBOLS

F_{tu} = Ultimate allowable tensile stress, psi

F_{ty} = Yield allowable tensile stress, psi

F_{cu} = Ultimate allowable compressive stress, psi

E_c = Modulus of elasticity in compression, psi

w = Density, lb/ft^3

F_{cy} = Yield allowable compressive stress, psi

F_{su} = Ultimate allowable shear stress, psi

e = Elongation in percent