NASA-CR-195528

NASW-4435

IN-05-CR

204267

P. 121

UNIVERSITY of NOTRE DAME

NASA/USRA UNIVERSITY ADVANCED DESIGN PROGRAM 1992-1993

PROJECT CENTER MENTOR:
NASA-AMES DRYDEN FLIGHT RESEARCH FACILITY

FINAL DESIGN PROPOSAL

The Gold Rush

A Simulated Commercial Air Transportation Study

April 1993

Department of Aerospace and Mechanical Engineering
University of Notre Dame
Notre Dame, IN 46556

N94-25002

Unclas

G3/05 0204267

(NASA-CR-195528) THE GOLD RUSH: A SIMULATED COMMERCIAL AIR TRANSPORTATION STUDY (Notre Dame Univ.) 121 p

April 8,1993
University of Notre Dame
AE441: Aerospace Design

GoldTeam presents its Final Proposal for

GoldRush

A design concept targeting a high traffic market in Aeroworld

GoldTeam is...

Amanda Clarke
Chris Degiorgio
Edmund Galka
Albert Stumm
Lisa Valenta
Tom Winter

Table of Contents

EXECUTIVE SUMMARY

The Gold Design Group designed the Remotely Piloted Vehicle (RPV) GoldRush to complete the mission of transporting passengers in Aeroworld at a lower cost per seat per thousand feet (CPSPK) than the competition, the HB-40. To this end, the Gold Design Group selected a high traffic market to serve more effectively than the HB-40. This market consisted of travel routes in the range of 10,000 feet. It was determined that this market would best be served by an aircraft capable of carrying 80 or 84 passengers; thus the GoldRush concept was born.

The first constraint encountered in the design was the takeoff distance of 24 feet needed to take off from city C. This constraint led to the choice of a wing area of 10.9 square feet, as well as the decision to use the Astro 25 motor, which will run off of a battery pack with a 900 mah capacity. Due to its high lift curve, and excellent low Reynolds number performance, the airfoil chosen was the Wortmann FX 63-137. Also, in order to increase the Reynolds number to a higher, more desirable value, a chord of 15 inches was chosen. This led to a R_e of approximately 200,000.

One way in which the design could be improved is in the area of aerodynamic drag. A less conservative drag estimation technique may have yielded the shorter takeoff distance without the need for the larger motor. Another possible area of improvement might be the ability to move the battery pack or some other method of adjusting the location of the center of gravity. The majority of the weight of the plane is in the nose which created a c.g. which was so far forward it created problems with stability.

GoldRush's wing has a span of 8.75 feet and an aspect ratio of 7. It is mounted on top of a box-like truss structure fuselage. The horizontal tail is a flat plate with an area of 1.6 square feet, while the vertical tail has an area of 1 square foot. Structural design was considered a critical technical area due to its immense effect on weight. Another critical issue was longitudinal static stability. The forward location of the center of gravity and a large nose down pitching moment necessitated the use of a considerably large tail downlift for trim. This downlift contributed to the detriment of the aircraft lift-to-drag ratio.

In the final performance analysis, the takeoff distance was determined to be 16.3 feet. The stall speed is 16.1 feet per second, while the cruise speed is 30 feet per second. The maximum level flight speed is 49 feet per second. GoldRush fulfills its design requirements and objectives in full. It also provides a lower CPSPK than the HB-40. GoldRush's CPSPK is 0.3 cents lower than the HB-40's CPSPK of .9 cents. This represents a 33% reduction in CPSPK.

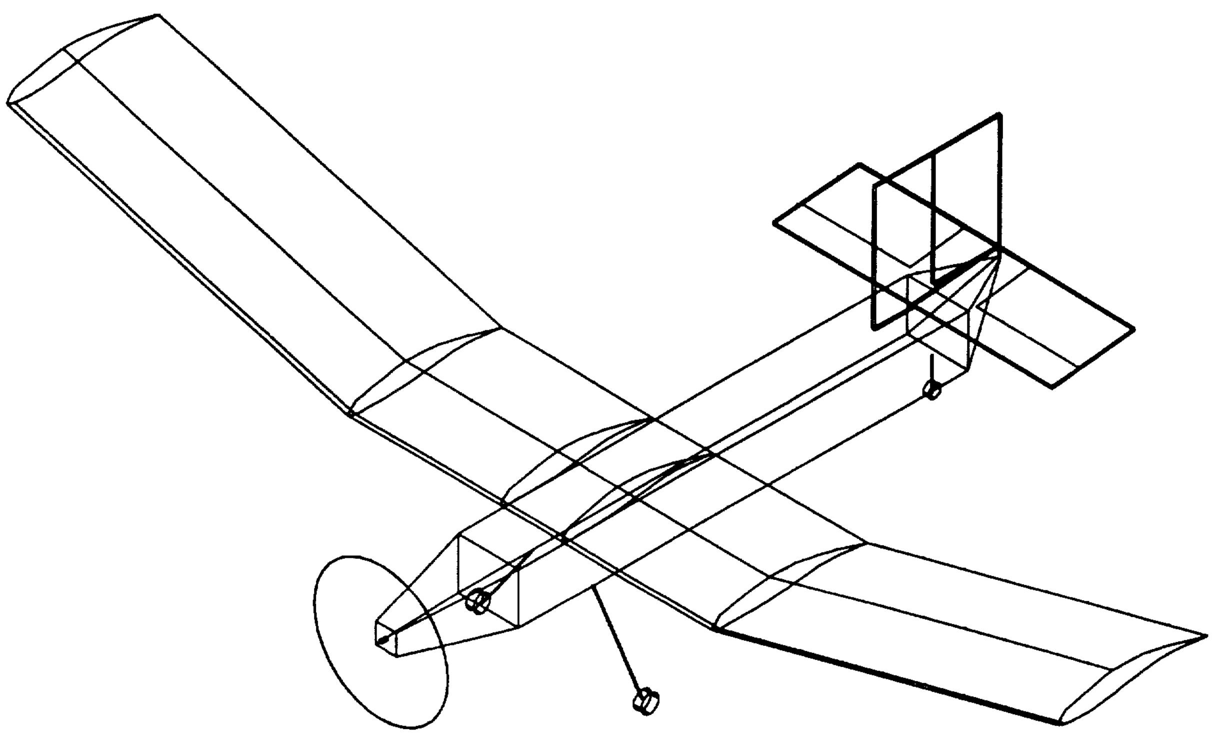
GoldTeam has developed a plane that can effectively compete in and win the target market. Additionally, GoldRush's ability to serve the three airports with shortened runways allows the airplane's market to expand beyond that serviced by the HB-40.

Major Influences

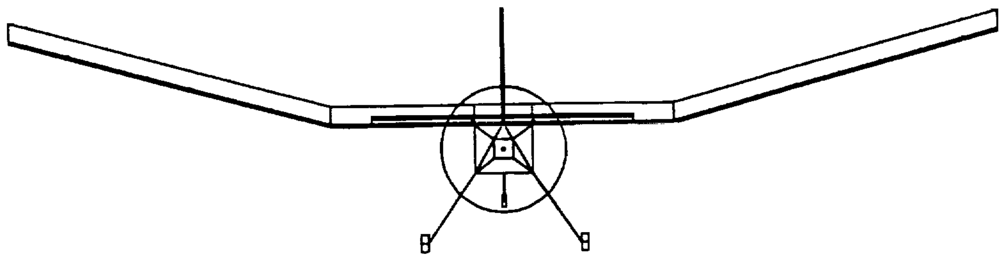
There were two major factors which were constant considerations in the design process. The cost of manufacturing was the most important. In light of this the designs were kept as simple as possible while considering trade-offs in performance. For example, the wing was not tapered so that several ribs could be cut at one time.

Also of major importance was the takeoff distance. In order to serve all the cities in Aero World it was necessary to maintain a takeoff distance requirement of 24 feet. The takeoff distance proved to be the number one force in driving the design process. The Astro 25 engine and 13 inch propellor, a large wing area, and the high lift Wortmann airfoil were all chosen in order to satisfy this objective.

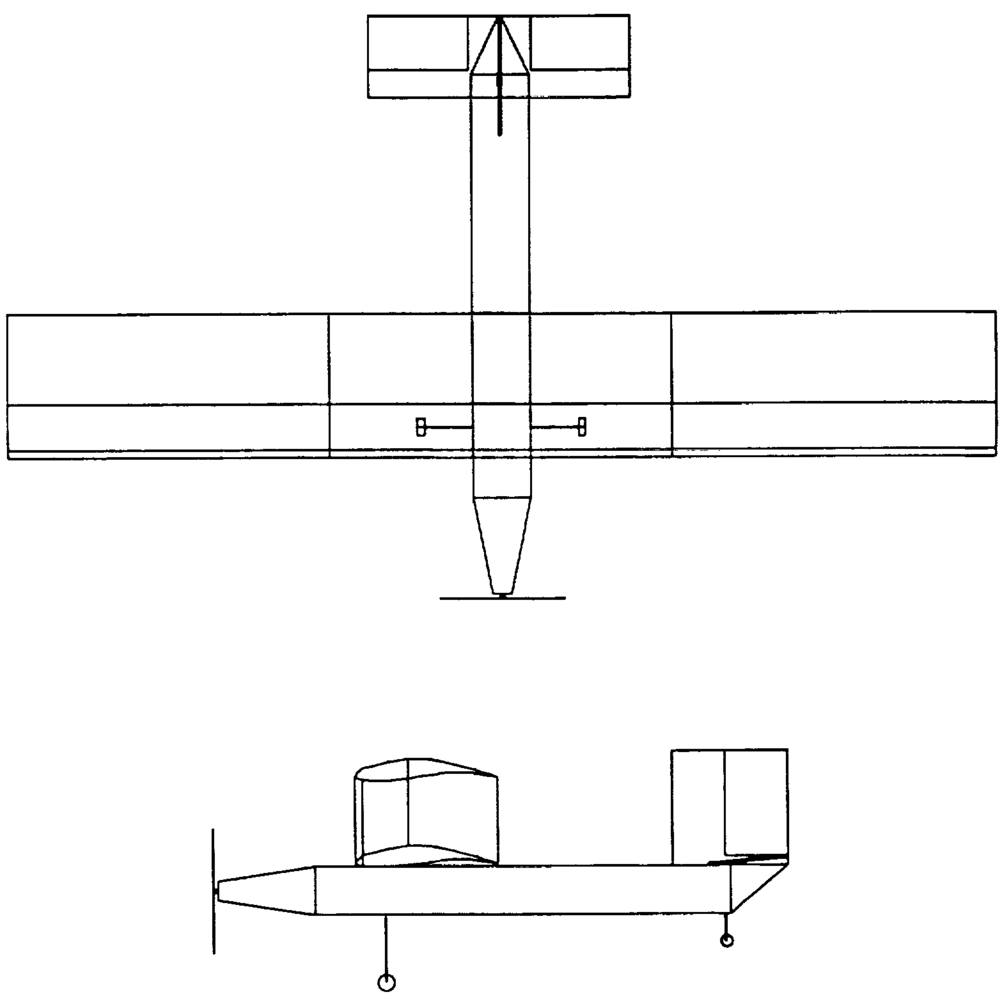
GOLDRUSH



THREE VIEW DRAWING OF GOLDRUSH



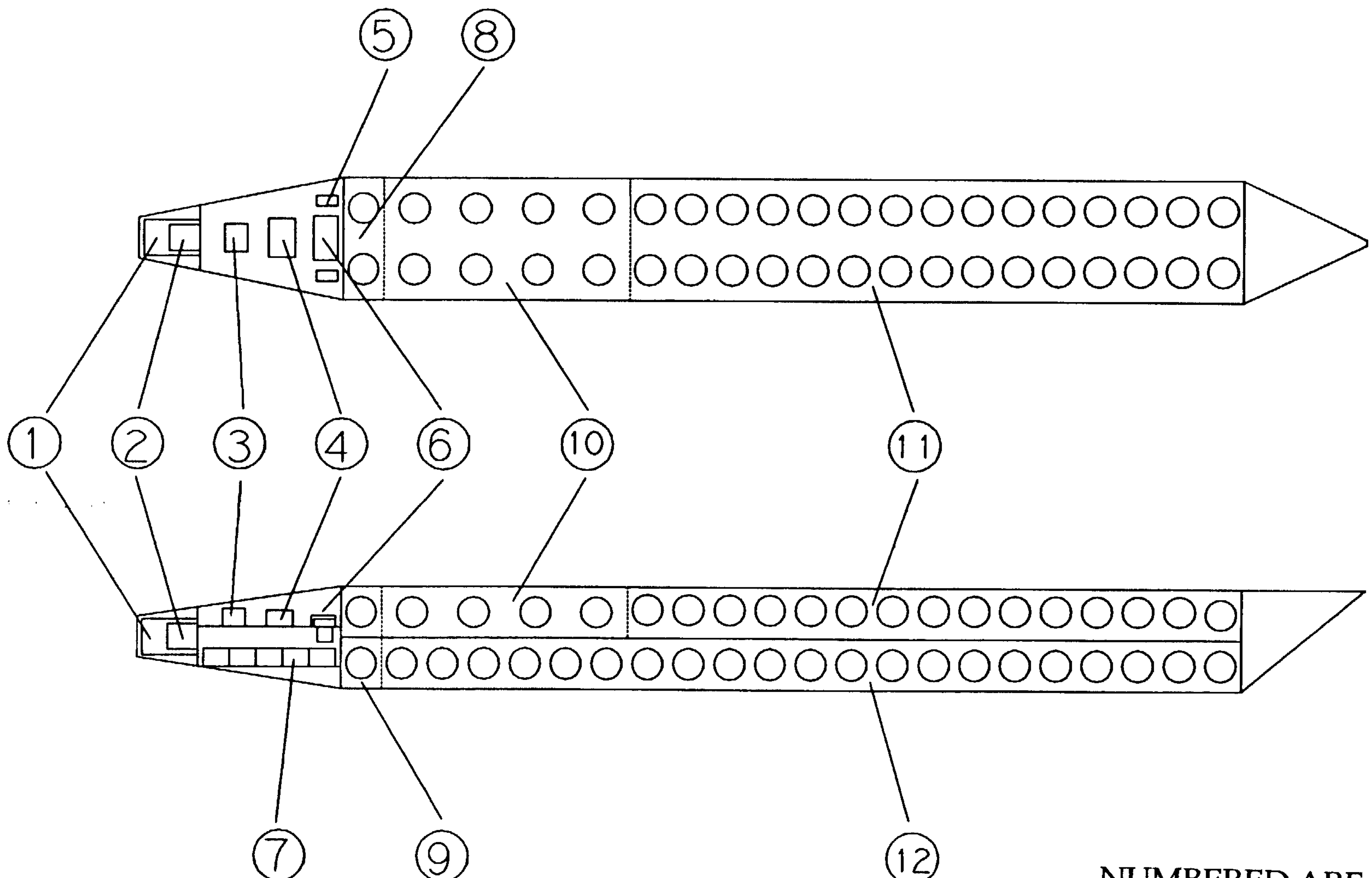
DIMENSIONS ARE GIVEN ON THE NEXT PAGE



Geometric Parameters (in inches):

FUSELAGE	
Length	60
Width	6
Height	5
WING (FX63-137 Airfoil)	
Span	105
Chord	15
Dihedral	15 Degrees
From fuselage centerline	18
VERTICAL TAIL (Flat Plate Airfoil)	
Span	12
Chord	12
Thickness	.25
RUDDER SIZE	72 sq. in.
HORIZONTAL TAIL (Flat Plate Airfoil)	
Span	27.4
Chord	8.4
Thickness	.25
Mounted Angle of Attack	-5 Degrees
ELEVATOR SIZE	115 sq. in.
LANDING GEAR	
Forward gear assembly height	8
Forward gear ground width	16
Forward gear aft position	17.4
Taildragger assembly height	3.5
Taildragger aft position	54.5
PROPELLER (ZingerJ 13x6)	
Diameter	13

INTERIOR LAYOUT FOR GOLDRUSH



NUMBERED AREAS ARE EXPLAINED ON THE NEXT PAGE

Interior Components/Sections:

1) Motor

2) Engine Mount

3) Speed Controller

4) Receiver

5) Servos (2)

6) System Battery

7) Fuel (13 Batteries)

8) Crew Area

9) Flight Attendant Area
   The exterior door shall be positioned in this area.

10) First Class Passenger Section
    Provides first class accommodations for 8 passengers (80 total passengers) if this seating option is chosen.

11) Upstairs Passenger Section
    Provides coach accommodations for 30 passengers if the first class option is chosen. If the non first class option is chosen (84 total passengers) this section expands across the entire top section and accommodates 42 passengers.

12) Downstairs Passenger Section
    Provides accommodations for 42 passengers for both seating scenarios. A staircase will be placed at the front of this section in order to provide access to the upper floor.

Performance Parameters:

TAKEOFF	
Distance at WMTO	16.3 feet
Distance at OEW	15.6 feet
VELOCITY	
V_{min} at WMTO	17.2 fps
V_{max} at WMTO	49.0 fps
V_{stall} at WMTO	17.2 fps
RANGE	
Maximum at WMTO	16,600 feet
Maximum at E_{max}	19,900 feet
Maximum at W_{min}	20,250 feet
ENDURANCE	
At Maximum Range	618 seconds
At WMTO	618 seconds
GLIDE	
Minimum Glide Angle	5.5 degrees
ROC	
Maximum at WMTO	12 fps

POST FLIGHT MANAGEMENT REVIEW: **Goldrush**

April 30, 1993

The following observations were made during the flight test validation for this aircraft design. This assessment is obviously quite qualitative and is based primarily upon the pilot's comments and instructor's observations.

1. Cruised best at almost engine idle condition.

2. Didn't appear to have enough elevator power to stall.

3. Slowed to very low speed for first landing and kept trying to increase angle of attack until the aircraft just dropped.

4. ** Ground crew failed to turn off the motor after the first flight and when they shut off the transmitter, the motor came on and broke a prop - could have been a more serious accident.

5. "Very slow flyer"

6. For the second flight it took off at half throttle and was still climbing at 1/3 throttle setting.

7. Turned with very little rudder deflection and was "smooth" in the turns.

8. Flew very well but appeared to be very overpowered for the design requirements.

9. No direct attempt to measure the take-off distance.

10. Successful validation of basic flight concept. Flew under control through entire closed course at approximately the required loiter speed. Landing and take-off performance was acceptable based upon the requirements.

	A	B	C	D	E	F
1	Parameter	Initials of RI:	Date: March 2	Date:	Date:	Date:
2	*[all distances relative					
3	to aircraft nose					
4	and in common units]*					
5						
6	DESIGN GOALS:					
7	V cruise					31 fps
8	Max # of passengers					80
9	# passenger-coach					72
10	# passengers - 1st class					8
11	# crew					4
12	Max Range at Wmax					16600 ft
13	Altitude cruise					25 ft
14	Minimum turn radius					
15	Max Range at Wmin					17450 ft
16	Maximum TO Weight-WMTO					5.4 lb
17	Minimum TO Weight - Wmin					4.82 lb
18	Total Cost per Aircraft					
19	DOC					
20	CPSPK (max design conditions)					
21						
22	BASIC CONFIG.					
23	Wing Area					10.94 sq ft
24	Maximum TO Weight - WMTO					5.4 lb
25	Empty Flight Weight					4.82 lb
26	Wing loading(WMTO)					.49 lb/sq ft
27	max length					5.0 ft
28	max span					8.75 ft
29	max height					1.75 ft
30	Total Wetted Area					35.1 sq ft
31						
32	WING					
33	Aspect Ratio					7
34	Span					8.75 ft
35	Area					10.94 sq ft
36	Root Chord					1.25 ft
37	Tip Chord					1.25 ft
38	taper Ratio					1
39	C mac - MAC					-0.24
40	leading edge Sweep					0 degrees
41	1/4 chord Sweep *					0 degrees
42	Dihedral					15 degrees
43	Twist (washout)					0
44	Airfoil section					FX63-137
45	Design Reynolds number					200000
46	t/c					0.137
47	Incidence angle (root)					0 degrees
48	Hor. pos of 1/4 MAC					
49	Ver. pos of 1/4 MAC					
50	e- Oswald efficiency					0.88
51	CDo -wing					0.03
52	CLo - wing					0.46
53	CLalpha -wing					.0854/ degree
54						
55	FUSELAGE					
56	Length					5.0 ft
57	Cross section shape					.42 ft x .5 ft
58	Nominal Cross Section Area					.021 sq ft
59	Finess ratio					12
60	Payload volume					4.67 sq ft
61	Planform area					2.24 sq ft
62	Frontal area					.03 sq ft
63	CDo - fuselage					0.002
64	CLalpha - fuselage					0.000238
65						

	A	B	C	D	E	F
66	EMPENNAGE					
67	Horizontal tail					
68	Area					1.6 sq ft
69	span					2.3 ft
70	aspect ratio					3.3
71	root chord					.7 ft
72	tip chord					.7 ft
73	average chord					.7 ft
74	taper ratio					0
75	l.e. sweep					0 degrees
76	1/4 chord sweep					0 degrees
77	incidence angle					-5.0 degrees
78	hor. pos. of 1/4 MAC					4.475 ft
79	ver. pos. of 1/4 MAC					.4167 ft
80	Airfoil section					Flat Plate
81	e - Oswald efficiency					0.8
82	CDo -horizontal					0.0007
83	CLo-horizontal					0
84	CLalpha - horizontal					.068/ degree
85	CLde - horizontal					.0544/degree
86	CM mac - horizontal					0
87						
88	Vertical Tail					
89	Area					1.0 sq ft
90	Aspect Ratio					1
91	root chord					1
92	tip chord					1
93	average chord					1
94	taper ratio					0
95	l.e. sweep					0 degrees
96	1/4 chord sweep					0 degrees
97	hor. pos. of 1/4 MAC					4.25 ft
98	vert. pos. of 1/4 MAC					.708 ft
99	Airfoil section					Flat Plate
100						
101	SUMMARY AERODYNAMICS					
102	Cl max (airfoil)					1.58
103	CL max (aircraft)					1.6
104	lift curve slope (aircraft)					.095/degree
105	CDo (aircraft)					0.0415
106	efficiency - e (aircraft)					0.83
107	Alpha stall (aircraft)					12 degrees
108	Alpha zero lift (aircraft)					-4.5 degrees
109	L/D max (aircraft)					10.5
110	Alpha L/D max (aircraft)					4.5 degrees
111						
112	WEIGHTS					
113	Weight total (empty)					4.82 lbs
114	C.G. most forward-x&y					1.455 ft
115	C.G. most aft- x&y					1.533 ft
116	Avionics					.375 lb
117	Payload-Crew and Pass-max					.496 lb
118	Engine & Engine Controls					.886 lb
119	Propeller					.061 lb
120	Fuel (battery)					1.056 lb
121	Structure					2.075 lb
122	Wing					.840 lb
123	Fuselage/emp.					.860 lb
124	Landing gear					.375 lb
125	Icg - max weight					
126	Icg - empty					
127						
128	PROPULSION					
129	Type of engines					Astro 25
130	number					1

Critical Data Summary - AE441 Spring 1993

	A	B	C	D	E	F
131	placement					0 ft
132	Pavil max at cruise					64 watts
133	Preq cruise					25 watts
134	max. current draw at TO					11.3 Amps
135	cruise current draw					5.2 Amps
136	Propeller type					Zinger J
137	Propeller diameter					1.08 ft
138	Propeller pitch					6 degrees
139	Number of blades					2
140	max. prop. rpm					6270 rpm
141	cruise prop. rpm					4188 rpm
142	max. thrust					2.68 lb
143	cruise thrust					.7 lb
144	battery type					P90 SCR
145	number					13
146	individual capacity					900 mah
147	individual voltage					1.2 Volts
148	pack capacity					900 mah
149	pack voltage					15.6 Volts
150						
151	STAB AND CONTROL					
152	Neutral point					1.828 ft
153	Static margin %MAC					13.60%
154	Hor. tail volume ratio					0.344
155	Vert. tail volume ratio					0.215
156	Elevator area					.8 sq ft
157	Elevator max deflection					20 degrees
158	Rudder Area					.55 sq ft
159	Rudder max deflection					45 degrees
160	Aileron Area					0
161	Aileron max deflection					0
162	Cm alpha					0.0169/deg
163	Cn beta					.0316/degree
164	Cl alpha tail					.068/degree
165	Cl delta e tail					.0544/degree
166						
167	PERFORMANCE					
168	Vmin at WMTO					20.6 fps
169	Vmax at WMTO					49.0 fps
170	Vstall at WMTO					17.2 fps
171	Range max at WMTO					16600 ft
172	Endurance @ Rmax					618 seconds
173	Endurance Max at WMTO					618 seconds
174	Range at @Emax					19900 ft
175	Range max at Wmin					20250 ft
176	ROC max at WMTO					12 fps
177	Min Glide angle					5.5 degrees
178	T/O distance at WMTO					16.3 ft
179						
180	SYSTEMS					
181	Landing gear type					
182	Main gear position					1.45 ft
183	Main gear length					.67 ft
184	Main gear tire size					.17 ft
185	nose/tail gear position					4.3 ft
186	n/t gear length					.292 ft
187	n/t gear tire size					.083 ft
188	engine speed control					FutabaMC114H
189	Control surfaces					
190						
191	TECH DEMO					
192	Max Take-Off Weight					
193	Empty Operating Weight					
194	Wing Area					
195	Hor. Tail Area					

	A	B	C	D	E	F
196	Vert Tail Area					
197	C.G. position at WMTO					
198	1/4 MAC position					
199	Static margin %MAC					
200	V takeoff					
201	Range max					
202	Airframe struct. weight					
203	Propulsion sys. weight					
204	Avionics weight					
205	Landing gear weight					
206						
207	ECONOMICS:					
208	raw materials cost					$90
209	propulsion system cost					$244.00
210	avionics system cost					$170.00
211	production manhours					$110.00
212	personnel costs					$1,100
213	tooling costs					$500
214	total cost per aircraft					$2,104
215	Flight crew costs					
216	maintenance costs					
217	operation costs per flight					$0.26
218	current draw at cruise WMTO					5.2A
219	flight time - design Range max					618 sec
220	DOC					$4.88 - $5.60
221	CPSPK					$0.006 - $0.00

Section 2: Detailed Mission Definition Study and Quantitative Design Requirements and Objectives

2.1 Market Analysis- The information was provided on the AeroWorld market for the number of passengers desiring transportation for one city to another each day. It was noted that an equal number of passengers wanted to go from city A to City B as wanted to go from city B to city A. Also, an equation for determining the number of flights needed per day as a function of the distance between cities was given. This was based on the concept that the longer the distance between the cities, the longer a customer would be willing to wait for a flight.

The number of flights needed per day was computed for each route. Also computed was the number of flights that could be filled per day for each route. These numbers were then compared. Based on this comparison it was determined which routes would be profitable and which would not. Many of the shorter routes were eliminated. This was due to the fact that passengers travelling shorter distances were not willing to wait long periods of time for flights. Consequently, a large number of flights were needed per day to keep the customers satisfied. If the number of flights required per day for a route was greater than the number of full flights per day for that route, then the average passenger capacity was determined by dividing the number of passengers per day travelling that route by the number of flights required per day for the route.

If the average passenger load was less than 50 passengers per flight, the route was not served. Finally, all routes not within the 10000 feet target operating range were eliminated.

The results can be seen in Table 2.1. This shows the number of passengers served per day and the number of flights for each route. The number of passengers is the top number while the number of flights is the bottom number. Keep in mind that the number of passengers served from city A to city B is the same as the number of passengers served from city B to city A (hence the symmetric matrix). The total number of passengers served per day is 35,566 and there are 474 flights per day. This yields an average passenger load of 75 passengers per flight.

It should also be noted that this data is based on the design objective of 10000 feet range. The actual range of the aircraft in the final proposal has been estimated at approximately 17000 feet. This would provide an operating range of 14000 feet instead of the 10000 feet cut-off used in the market analysis. The reasons for choosing the 10000 foot range target are illustrated in Graph 2.2. This range represents the largest market segement, and was therefore the obvious choice from an economic standpoint.

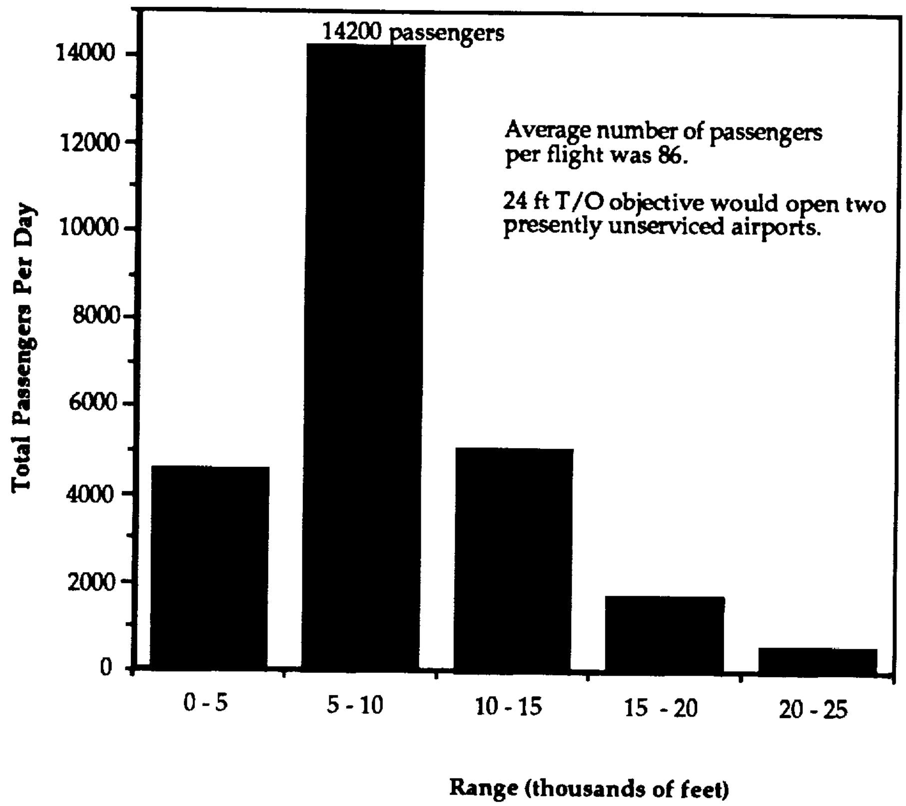
Table 2.1

Passengers and Flights Per Day

city	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
A	0	480 6	400 5	0	0	480 6	320 4	0	0	0	0	0	0	0	0
B	480 6	0	600 8	0	0	450 6	300 5	450 6	0	400 5	0	0	0	0	0
C	400 5	600 8	0	480 6	300 4	380 5	0	0	0	0	0	0	0	0	0
D	0	0	480 6	0	0	0	0	0	0	0	0	0	0	0	0
E	0	0	300 4	0	0	474 6	0	0	350 7	400 5	553 7	480 6	400 5	400 5	0
F	480 6	450 6	380 5	0	474 6	0	800 10	0	300 5	450 6	480 6	0	0	0	0
G	320 4	300 5	0	0	0	800 10	0	702 9	600 8	0	248 4	0	0	0	0
H	0	450 6	0	0	0	0	702 9	0	546 7	800 10	0	0	0	0	0
I	0	0	0	0	350 7	300 5	600 8	546 7	0	600 8	0	0	300 5	0	0
J	0	400 5	0	0	400 5	450 6	0	800 10	600 8	0	0	480 6	450 6	400 5	0
K	0	0	0	0	553 7	480 6	248 4	0	0	0	0	480 6	450 6	600 8	0
L	0	0	0	0	480 6	0	0	0	0	480 6	480 6	0	348 6	0	0
M	0	0	0	0	400 5	0	0	0	300 5	450 6	450 6	348 6	0	0	252 4
N	0	0	0	0	400 5	0	0	0	0	400 5	600 8	0	0	0	400 5
O	0	0	0	0	0	0	0	0	0	0	0	0	252 4	400 5	0

Graph 2.1

Market Analysis



2.2 Design Requirements and Objectives

Requirements

Takeoff Distance: The design must be able to takeoff in under 40 feet.

Passenger Volume: Coach passengers must be provided with at least 8 in^3 of space while first class passengers must have 12 in^3 of space.

Flight Crew: There must be a flight crew of 2 in addition to 1 flight attendant per 40 passengers.

Performance: The design must be able to perform a level 60′ radius turn at 25 ft/sec.

Ceiling: The design must not exceed an altitude of 25 feet during the entire flight test.

Control System: Control for the design will be provided by a Futaba 6FG radio control system with a maximum of 4 S28 servos. In addition, the entire control and propulsion system must be removable and able to be installed in 20 minutes.

Design Life: The design must have a design life of at least 50 hours.

Self imposed requirements on the transport design include the following:

Flexible Passenger Load: The design should be capable of flying either with a full capacity of passengers or with no passengers on board. This will require proper planning of passenger placement around the center of gravity for all loading scenarios.

Takeoff Speed less than 25 ft/sec: To sustain a level 60′ radius turn at a speed of 25 ft/sec as required by Aeroworld regulations, the design may approach its stall velocity. To avoid stall under these conditions, it would be desired that the stall velocity be at a lower speed than 25 ft/sec. Since stall velocity dictates takeoff speed, it follows that the takeoff speed would need to be less that 25 ft/sec.

An Environmentally Clean Propulsion System: In the interest of preserving Aeroworld's pristine environment, the design should consider the noise levels and pollutants produced by its propulsion system. A system with low noise levels and few pollutants will be required.

Transportability: The technology demonstrator will be required to be transported through 7′ high and 2′9″ wide doors from its fabrication lab

(Hessert) to the demonstration arena (Loftus). This will make necessary proper sizing and possible removability of components.

Provide Control with a Simple Rudder and Elevator Assembly: In order to decrease weight, only two aerodynamic control surfaces will be employed. Rudder and elevator control are sufficient means of control provided the rudder area in combination with an appropriate wing polyhedral are large enough to produce the roll needed for the maneuvering requirement. In addition the elevator must be large enough to allow the aircraft to trim for all flight conditions.

Objectives

Lower Cost per Seat per Thousand Feet (CPSPK): The chief objective of this aircraft is to compete with the HB-40 by achieveing a lower Cost per Seat per Thousand Feet. Efficient aircraft design and manufacturing and an increased seating capacity will lead toward meeting this objective.

24 ft takeoff objective: This will open two presently untapped airports which represent 15% of the current market.

80 Passenger Capacity: The aircraft will accomodate 80 passengers and must include a 1.5 inch aisle along the length of the cabin. This capacity is based on a market analysis which points to a large market sector requiring 80 passengers per flight and a 10,000 foot range. Along with the passenger capacity this range will allow Goldrush to serve 35640 passengers with 464 flights per day.

10,000 foot Range: A 10,000 ft range was determined in the market study as the largest segment since it contained 14,200 passengers per day.

Controllable tail wheel: The rudder servo will rotate both wheel and rudder, thereby eliminating the need for separate servo motors. This controllable wheel will allow for ground maneuverability at the airports. Because of this the airplane will be able to reduce taxi time thus helping it to service Aeroworld more efficiently.

Manufacturing costs: will be reduced through a number of techniques. Prior manufacturing experience within the group as well as a considerable effort in planning of the manufacturing process will help reduce the manufacturing cost to below that of the HB-40. A projected 15% reduction in personnel hours, a 5% reduction in tooling costs, and a 20% reduction in disposable materials and hazardous waste costs will help lower manufacturing costs to approximately $2100, a 10% savings over the HB-40.

2.3 Changes from Original DR&O

There is one change in a design requirement and one change in a design objective from the original DR&O. Based on the analysis of the available market a passenger load of 80 or 84 was set for Gold Rush. With first class seating the passenger capacity is 80 passengers. However, with the option given to the airline of altering first class seating to provide for more coach seating, the passenger capacity becomes 84. It is believed that this added flexibility will be a very attractive sales point.

Originally the range objective was 15000 feet. This was based on an operating range of 10000 feet (also provided by the market study) and allowed for the two minute loiter time and flight to the next nearest airport. When the requirement was relaxed to only the two minute loiter time, the objective became the 10000 feet operating range with the two minute loiter.

SECTION 3: Concept Selection

3.1 Concept Requirements and Objectives

Each of the concepts was considered as a design which would try to meet Gold Team's goals which were as follows:

- Serve the largest number of Aeroworld passengers per day as possible
- Carry approx. 80 passengers and have a range of about 13,000 ft
- Employ simple, methodical, repeatable manufacturing characteristics
- Reduce costs

3.2 Concept Selection

After the initial market study a few initial concepts were determined. First, for the design goal of ease in manufacturing to lower manufacturing time and, thereby, lower cost of manufacturing, fuselage and wing shapes have been kept as simple as possible. The wing and tail sections will be rectangular in shape and the fuselage is box shaped. The elimination of curved surfaces will greatly reduce cutting time. Also, the rectangular wing will allow many wing spars to be cut at once. For stability purposes the wing will be mounted above the fuselage. For ground handling and stability in landing and takeoff a tail dragger landing gear configuration will be utilized.

In approaching the project of targeting a specific Aeroworld market and serving it effectively, several design concepts were considered for the wing, fuselage, propulsion system and landing gear. Each concept had its own strengths and weaknesses and Gold Team was faced with weighing the pros and cons and deciding which concept would be the best balance of customer service, cost, ease of manufacturing, and performance. Several of the major concepts are shown in Table 3.1. The concepts presented in bold were used in the final design.

Table 3.1

Concept Selection

	Concept #1	**Concept #2**	**Concept #3**
Wing	Ailerons	Dihedral	**Polyhedral**
Fuselage	Single Deck	**Double Deck**	
Propulsion System	**Nose Mounted**	Wing Mounted	
Landing Gear	Fixed Rear Wheel	**Maneuverable Rear Wheel**	

The first design area considered was the wing structure. It was a great concern whether or not comparable roll control be achieved with dihedral or polyhedral as with ailerons. After determining the control power achieved with ailerons of 15 percent total wing area it was found that dihedral could in fact effectively provide roll control based on the coupled motion of the rudder deflection with the roll due to the dihedral. Therefore, due to the added assembly time and extra servo associated with ailerons, this concept was eliminated.

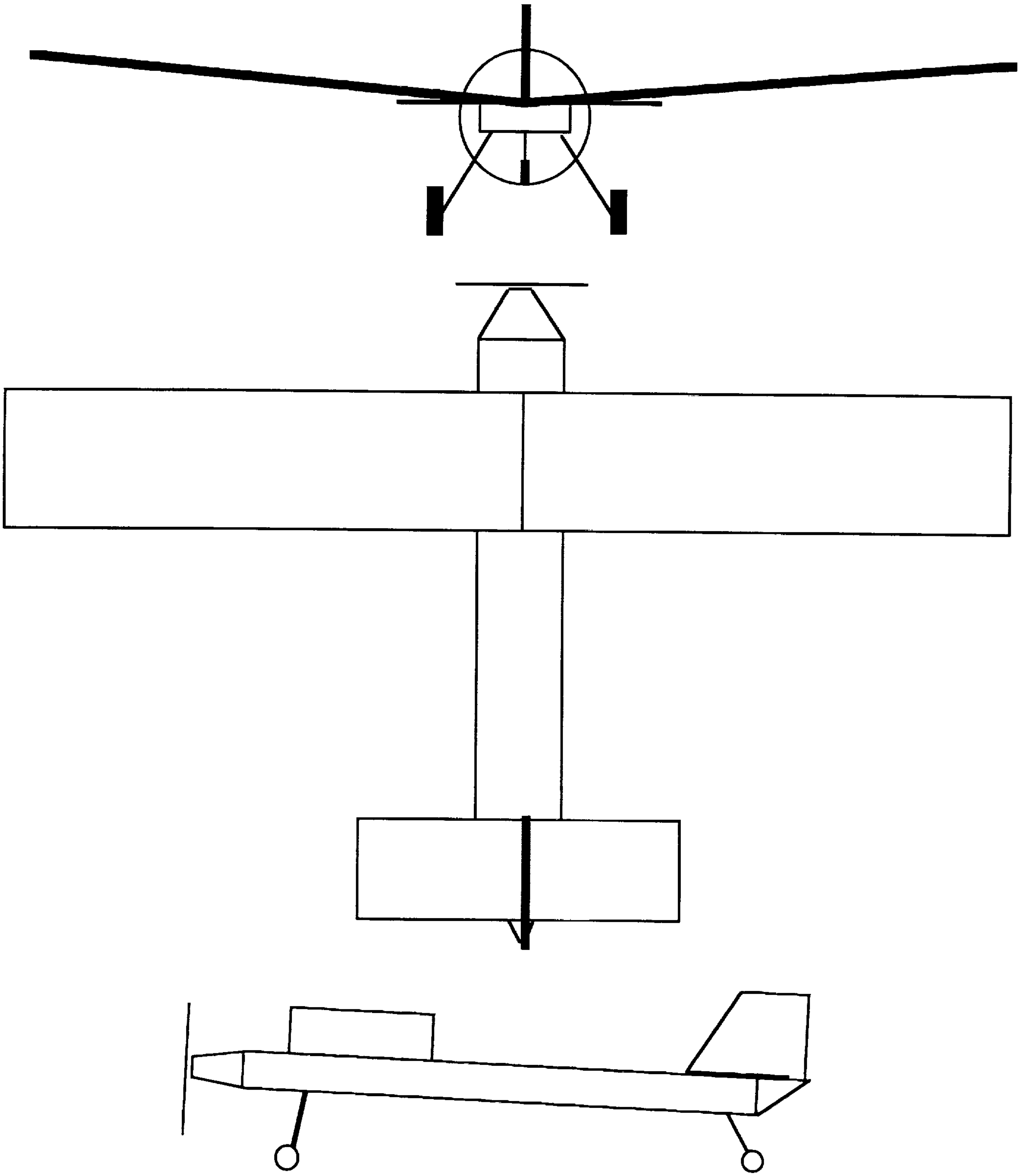
There were several advantages of using a three panel polyhedral wing configuration over the simple dihedral. Structurally, the polyhedral, having a flat panel in the middle section, would not require a joint at the point of attachment of the wing to the fuselage where the bending moment and shear stresses are the greatest. The polyhedral wing concentrates the dihedral at the tips of the wing where it is most effective. The dihedral close to the fuselage has a very small moment arm which renders it useless. It first inspection it might seem that there is a disadvantage in the polyhedral since it requires two joints instead of one. However, since the largest piece of balsa wood available is three feet in length, these joints would be necessary even with a straight wing. Also, for a given planform area, the more dihedral the larger the wetted area of the wing. The closer in to the fuselage the dihedral begins the more wetted area which translates not only to more drag but also more weight. The only limit to the polyhedral is the concern of tip stall in turning maneuvers. Larger dihedral angles are needed for the polyhedral which makes the local angle of attack for the outboard panels higher than that of the simple dihedral. This means it is operating closer to the stall angle. However, this proved to be of little significance since the airfoil chosen for takeoff reasons had a very high angle of attack. Also, the polyhedral wing is more likely to flutter than the dihedral, however, this is unlikely in this flight regime.

The fuselage configuration decision was driven by the cross-sectional shape of the double deck and single deck fuselages. Since the perimeter of a square is less than the perimeter of a rectangle, the total wetted area of the double deck fuselage with 2 passengers across was less than that of the single deck fuselage with 4 passengers across. With this in mind it is apparent that a circular cross section would have even less drag but in the interest of keeping manufacturing simple this concept was not considered. The only drawback of the double deck is the added weight of the floor section between decks.

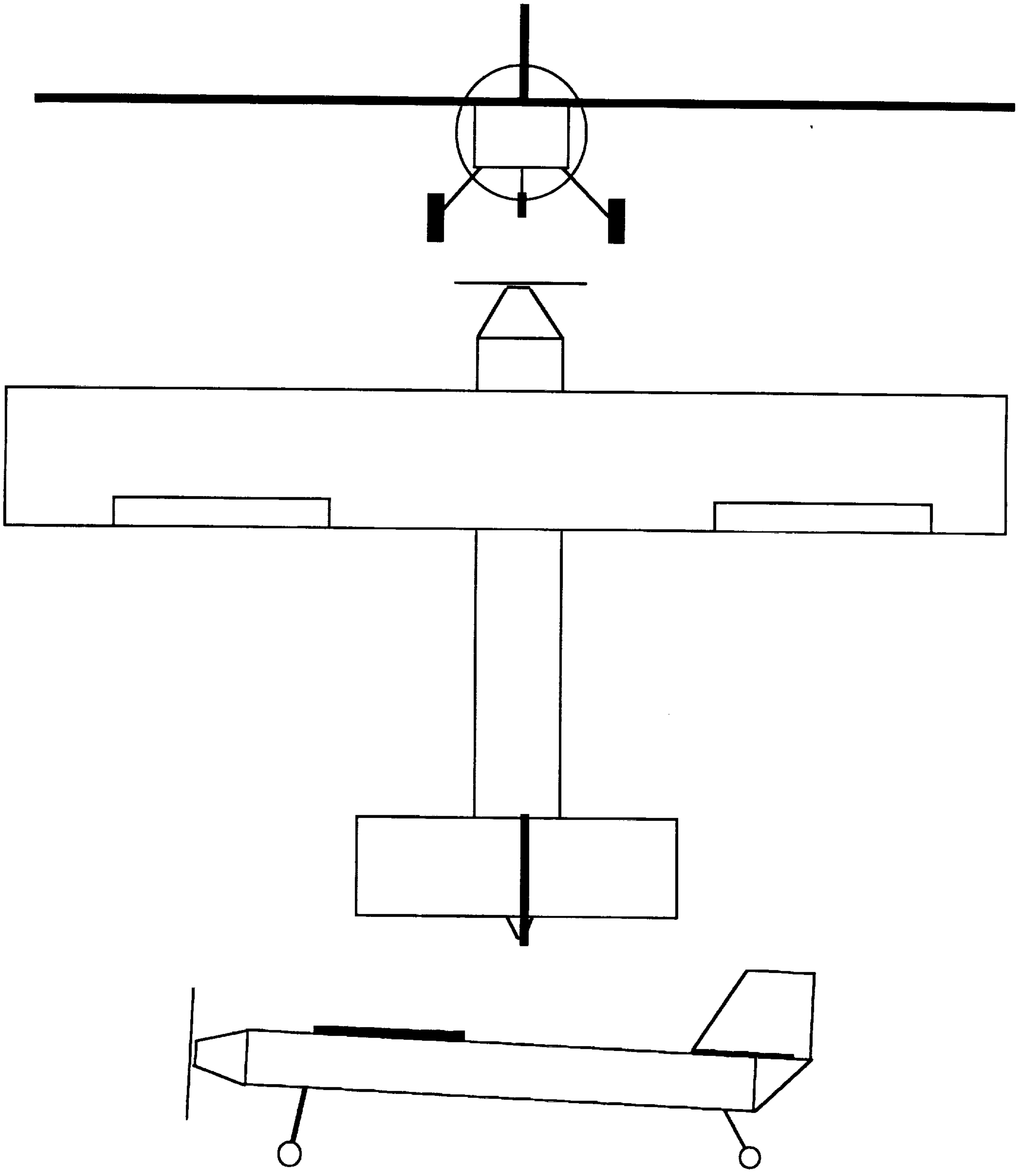
The alternate propulsion system with the propeller mounted above the wing was the most revolutionary concept considered. This idea had many advantages. In the traditional configuration with the propeller mounted in the nose, the fuselage interference causes about a 20 percent reduction in thrust. This could be avoided by having nothing in the direct wake of the propeller. Also, because of the requirement of a 20 minute assembly time for the propulsion system, the wing mounted propeller would allow for easy access and assembly. There were also many drawbacks to this system. Since it was so revolutionary there was no database from which to draw information. The effects of the propellers interference with the air flow over the wing and tail sections was unknown. Also of concern was the relocation of the thrust vector approximately 9 inches from the centerline of the fuselage and, thereby creating a large nose down moment. Knowing that a high lift airfoil would have to be chosen for the purposes of takeoff performance and would already have a large nose down moment this was of great concern. Finally, the added weight and drag of the truss structure needed to support the propeller and motor was a large contributor to the decision to use the traditional nose mounted configuration.

It had previously been decided that the landing gear would be a tail dragger system. The only consideration was if a maneuverable rear wheel would be possible without an additional servo. It was decided that the rear wheel could be connected to the same servo as the rudder. This system would provide ground handling capabilities while eliminating the additional time and price of the extra servo.

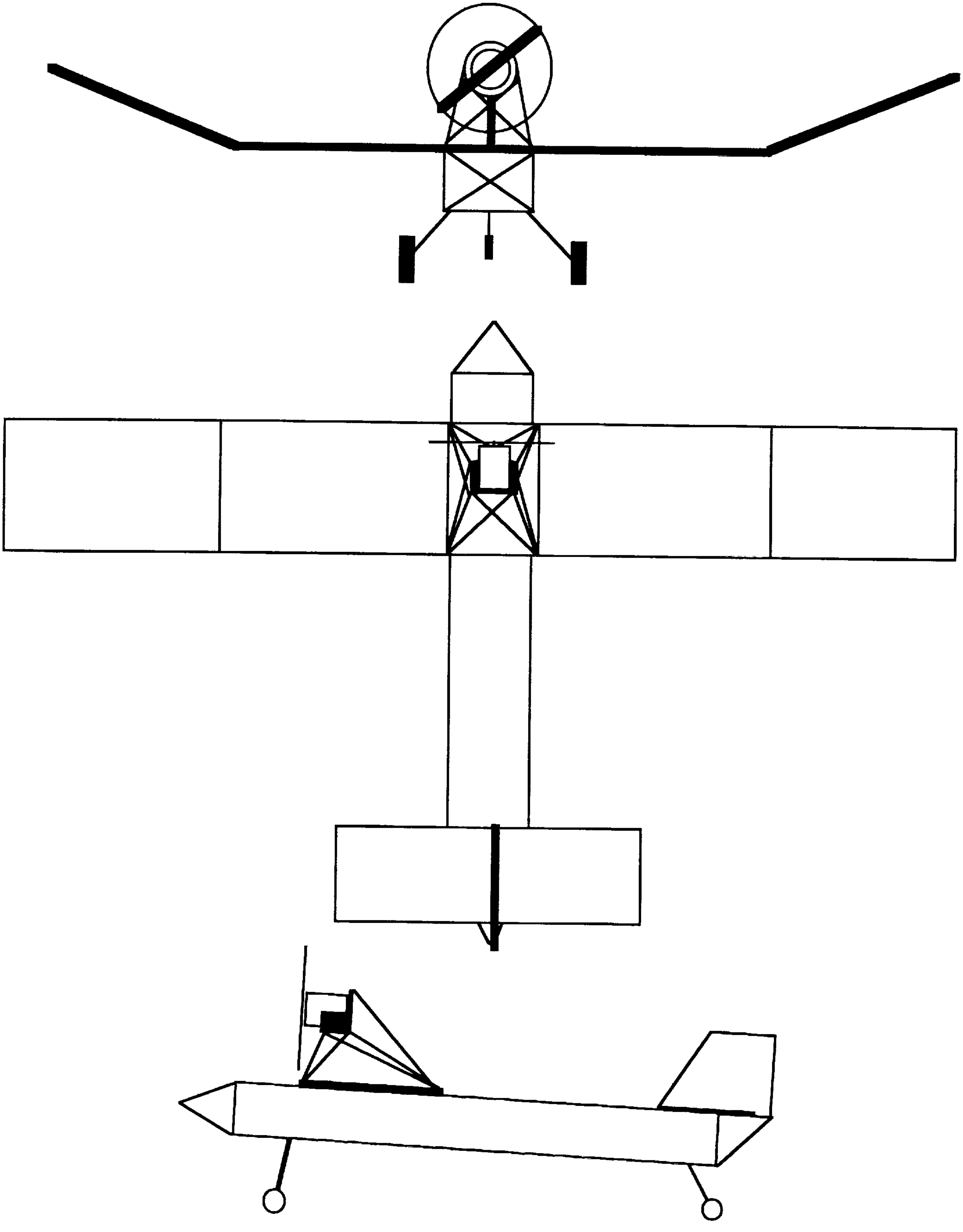
Concept #1



Concept#2



Concept#3



3.3 Final Concept: GoldRush

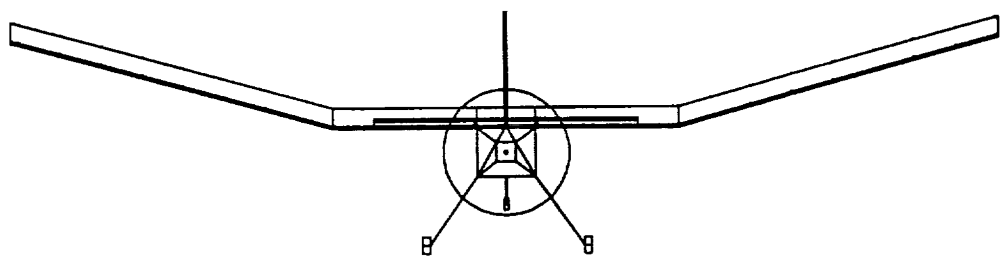
The selected concept was a high-mounted polyhedral wing with a nose-mounted motor, tail empenage and tail-dragging landing gear with a steerable rear wheel. It would employ an 80 or 84 passenger double-deck cabin with two rows of 20 passenger on each deck. The advantages and disadvantages of each system chosen is summarized in Table 3.2.

Table 3.2

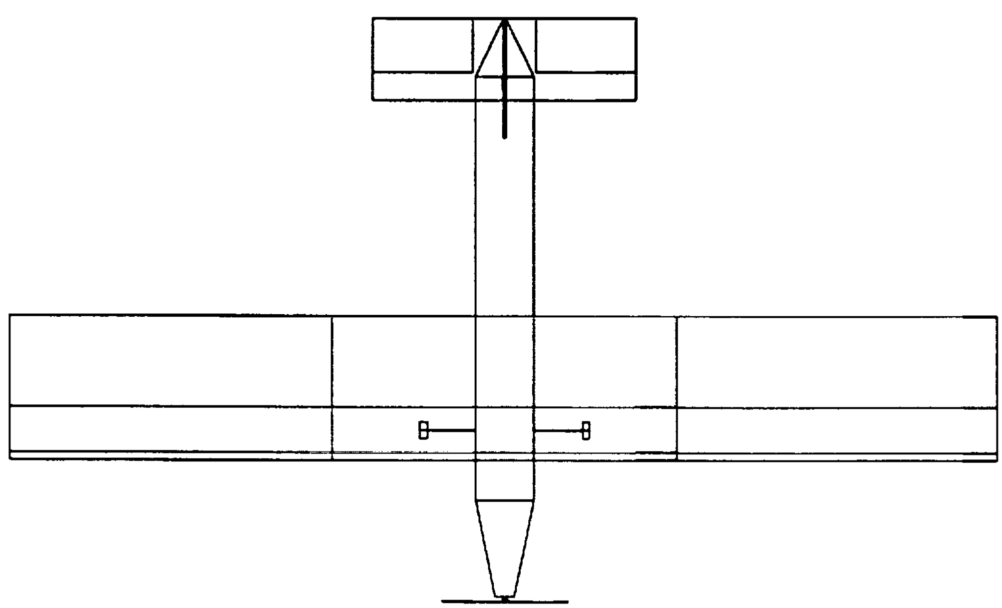
Advantages and Disadvantages

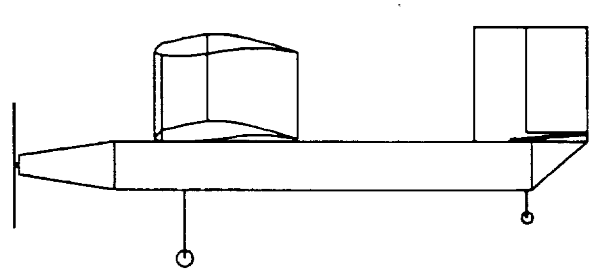
KEY FEATURES	ADVANTAGES	DISADVANTAGES
Double Deck Fuselage	Lower Induced Drag More Resistant To Torsion	Additional Floor Section
Nose Mounted Propeller	Large Data Base No Nose Down Moment No Wing Flow Interference No Truss Structure Needed	Loss of Thrust By Fuselage Interference More Difficult Assembly
Polyhedral Wing	No Joint At Center Of Wing Concentration At Tips Of Wing No Additional Servo Needed	Possible Tip Stall
Maneuverable Rear Wheel	Ground Maneuverability	Servo Attachment

THREE VIEW DRAWING OF GOLDRUSH

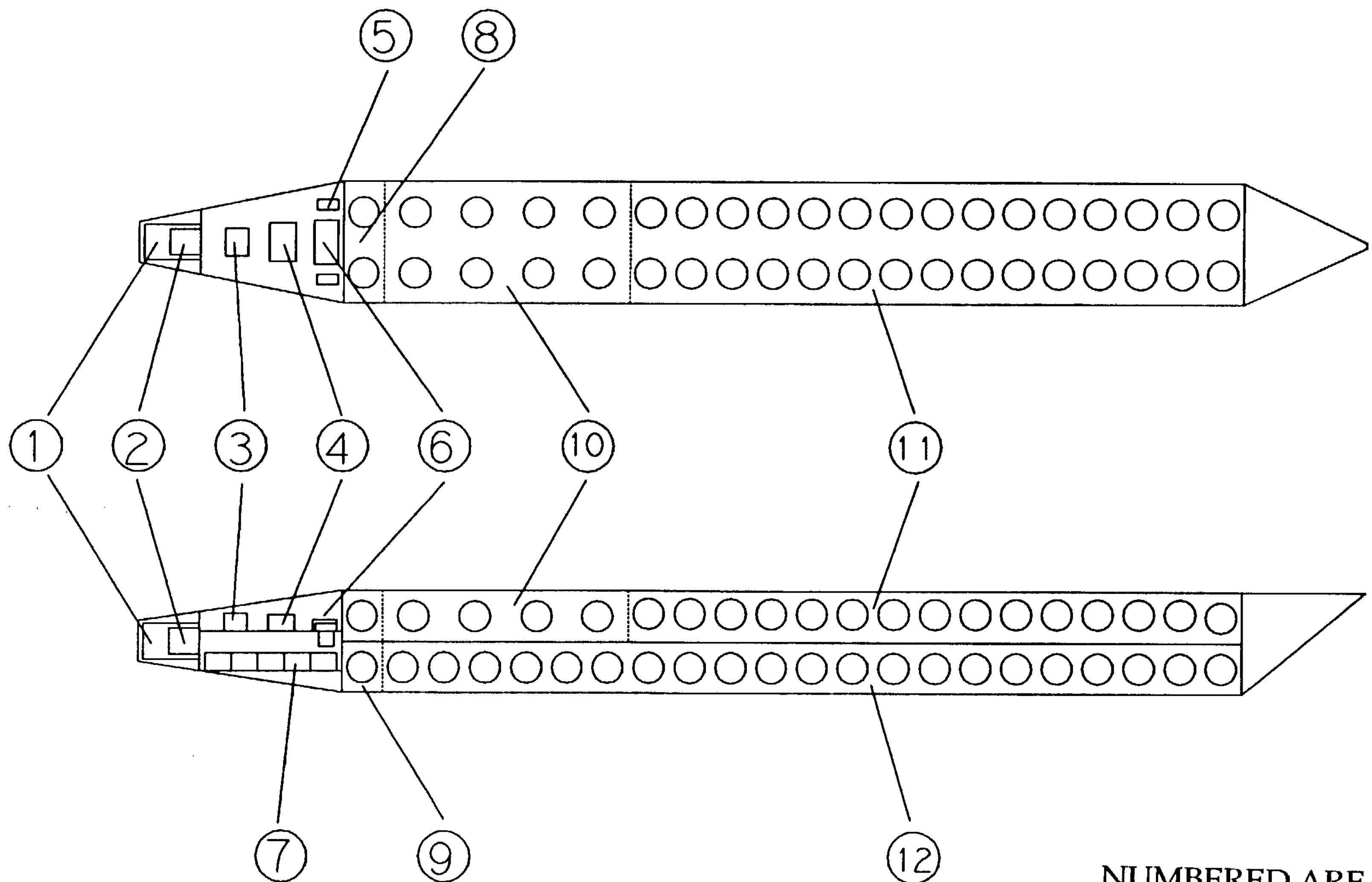


DIMENSIONS ARE GIVEN
ON THE NEXT PAGE





INTERIOR LAYOUT FOR GOLDRUSH



NUMBERED AREAS ARE EXPLAINED ON THE NEXT PAGE

Section 4: Aerodynamic Design Detail

4.1 Airfoil Selection and Characteristics-

Data concerning many airfoils was available to GoldTeam during the design process, but many of these airfoils were eliminated from consideration for two main reasons. The first reason was that many airfoils lacked adequate test data at low Reynolds numbers (R_{emean} = 200,000), the regime in which GoldRush will operate. Other airfoils' lift performance and lift to drag ratio dropped off drastically within the GoldRush Reynolds number regime. Thus, the field of consideration was reduced to the three airfoils whose data was readily available to GoldTeam and whose C_{lmax} exceeded ~1.1 at R_e = 200,000. These three airfoils were the FX63-137, the Clark Y, and the GO 624. Table 4.1 shows the relative ranking of the three airfoils with respect to the three main design goals - achieving the takeoff distance of 24 feet; maintaining ease of manufacturing in order to reduce risk and cost in production; and reducing operating costs by reducing drag.

After a certain amount of deliberation considering the rankings represented in Table 4.1 (where the number 1 indicates the best ranking and the number 3 indicates the worst) the Wortmann FX63-137 was chosen as the cross-section of the wing of GoldRush. Because the Wortmann airfoil ranked best in the two most important categories: lifting capabilities (for achieving the desired takeoff distance) and lift to drag ratio (for optimum efficiency and operating costs), the additional difficulty in manufacturing a more complex airfoil shape was deemed a negligible sacrifice compared to the advantages gained in performance. This was due to the planning in manufacturing which would efficiently produce the ribs and avoid a large cost increase.

The advantageous characteristics of the chosen airfoil included its high lift capabilities at low Reynolds numbers (C_{lmax} = 1.6), its high stall angle of 12°, its high lift coefficient at zero angle of attack of 0.6, and its high lift to drag ratio (L/D = 75). These characteristics are quite suitable to the environment in which GoldRush will be operating. This C_{lmax} helps GoldRush to achieve its desired takeoff distance without difficulty. GoldRush, because of its high stall angle, also will be able to climb at high angles of attack. This quality allows GoldRush to reach its cruise altitude quickly after takeoff, which is desirable at some airports which have noise restrictions. Furthermore, the airfoil's high lift at zero angle of attack allows the wing and fuselage's angle of incidence to be 0° while still creating enough lift for the desired straight and level cruise speed of 31 ft/s. Finally, the high lift to drag ratio gives an aircraft with the FX63-137 airfoil the potential to be a highly efficient aircraft.

In addition to the aforementioned qualities of the FX63-137, the airfoil also has a thickness ratio of t/c = 0.137 and a high camber of 5.94% which create a large 'nose down' C_{mo} of - 0.24. This characteristic of the airfoil is a disadvantage because, although the horizontal tail moment arm is large (l_t = 2.942 ft), a large down lift on the tail is required to trim the airfoil. Even though this is to the detriment of the lift-curve slope and lift-to-drag ratio of the entire aircraft, the advantages of choosing the FX63-137 outweigh its disadvantages, especially because GoldRush's takeoff regime is of utmost importance. In addition this problem could not have been avoided by using one of the other two airfoils because they both have C_{mo}'s approximately equal to that of the Wortmann. Structurally, the Wortmann is a better choice than the other two airfoils, because its higher thickness ratio makes it more resistant to lateral twist. Also, because the wing will be thicker throughout due to this high ratio, it will have better resistance to longitudinal twist than the others. Although the trailing edge of the airfoil is "sharper" than that of the other airfoils, it was not necessary to add weight to the wing structure in order to structurally compensate for this, therefore presenting no adverse effects to the design.

Figure 4.1 illustrates the airfoil's shape. Its lift curve, which illustrates some of the above characteristics as well as the airfoils lift-curve slope of 0.08/degree and its C_{lmax} of 1.6, is shown in Graph 4.1.

Table 4.1

Comparison of Airfoils

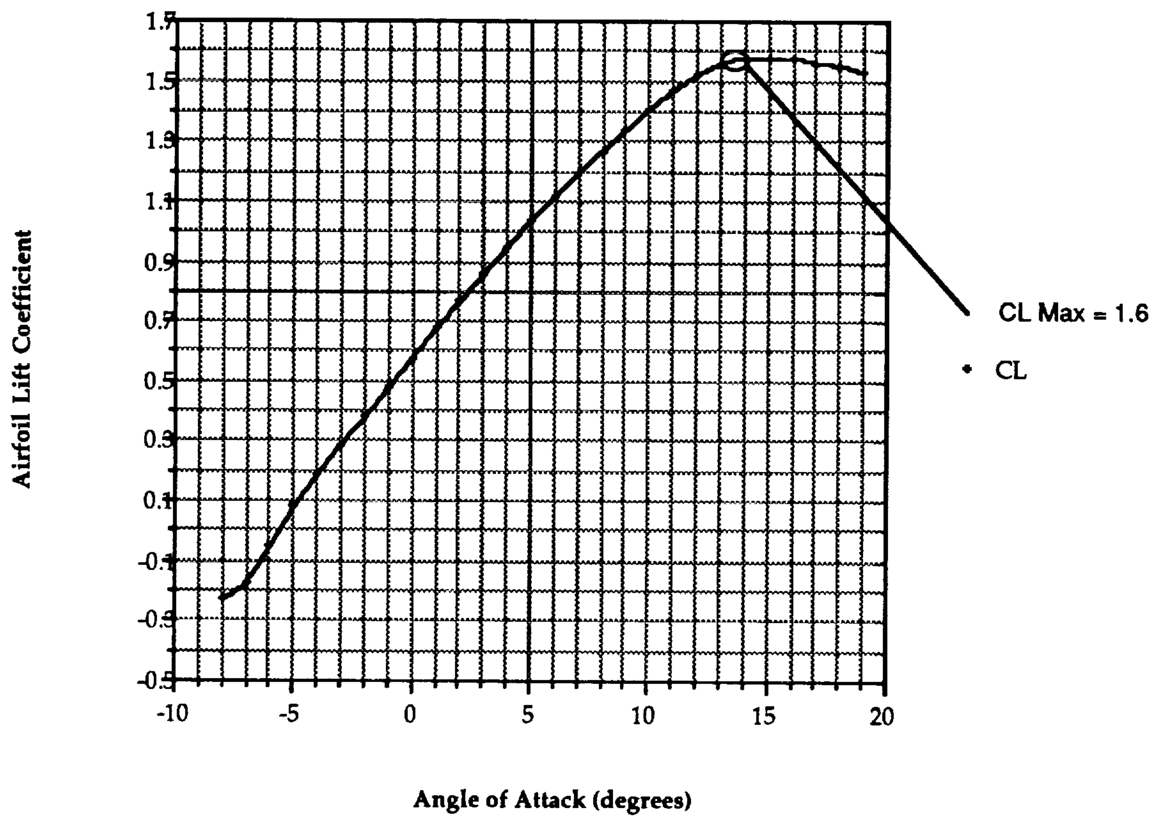
	TAKEOFF	EASE OF MANUFACTURING	REDUCTION OF OPERATING COST
FX63-137	1	3	1
CLARK Y	3	2	2
GO 624	2	1	3

Figure 4.1

The Wortmann FX 63-137

Graph 4.1

FX 63-137 Airfoil Lift Curve at Re=200,000



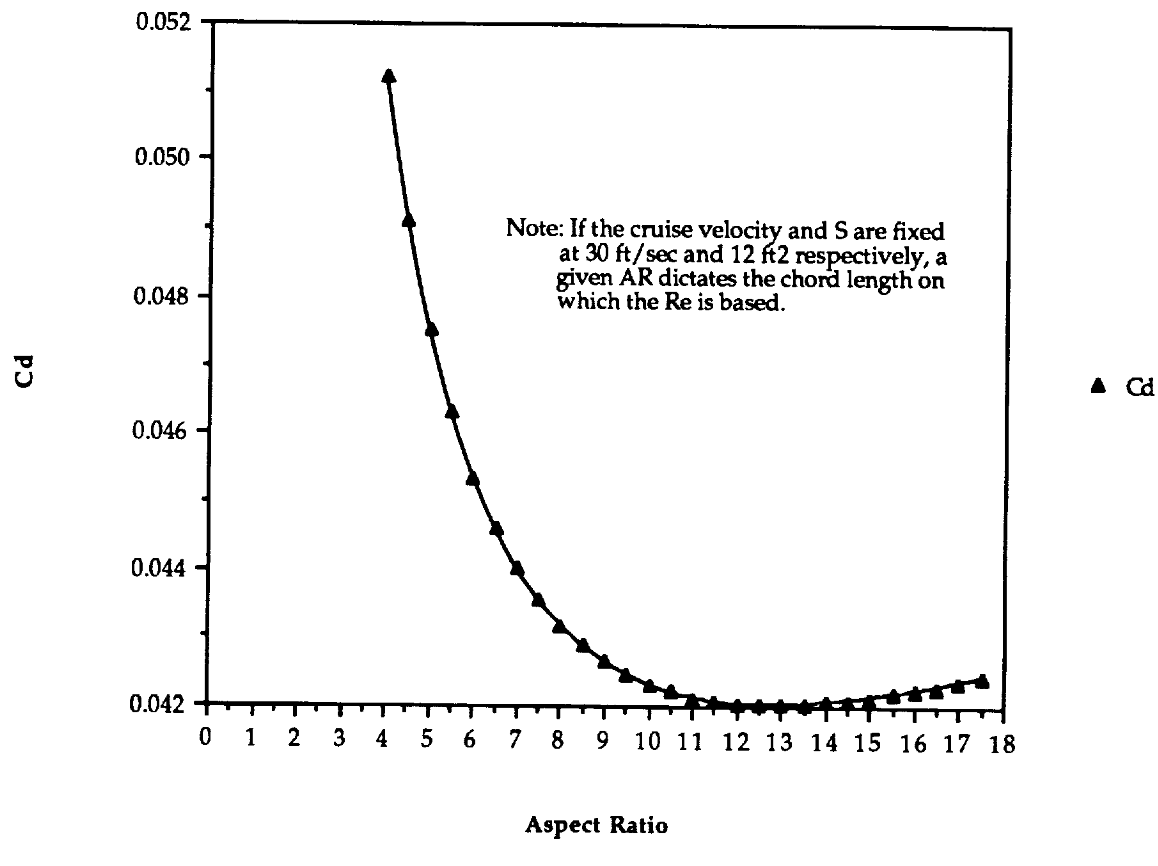
Manufacturing the ribs for the wing such that the airfoil, or more importantly the three dimensional wing, maintains its expected performance should not be difficult considering the machinery available to cut these crucial pieces. It is expected that any variance in the effective wing cross-sectional shape will be caused by difficulty in getting the Monokote covering of the wing to conform properly to the supports at the lower-aft-concave section of the wing. Being fully aware of this potential problem is very important to the effective production of the GoldRush wing. Every attempt will be made during the manufacturing process to avoid this problem.

4.2 Wing Design and Detailed Characteristics

The wing area was driven primarily by the take-off distance requirement. The wing aspect ratio was a topic of debate for structural and aerodynamic reasons. Small aspect ratios were sought to improve wing stiffness and wing weight, however this would lead to an induced drag penalty. A trade study was therefore commissioned to evaluate the effect of aspect ratio on wing drag coefficient. Graph 4.2 graphically summarizes the results of the trade study.

Graph 4.2

Effect of Reynolds Number and Aspect Ratio on Wing Drag Coefficient



The interesting thing about Graph 4.2 was that increasing the aspect ratio past 13 actually increased the wing drag coefficient. This was a result of the adverse effects of low Reynolds numbers on airfoil performance. This was important because it showed that small, low speed RPV design required consideration of subtle aerodynamic differences between RPV's and full scale aircraft. The aforementioned criterion were compromised by choosing a design aspect ratio equal to 7. Notice that decreasing the aspect ratio from the optimum 13 to 7 produced slightly more drag but allowed for a much lighter structure.

An important design requirement was to provide ample control power with only the rudder and elevator assembly. Roll control was provided by the coupling effects of rudder deflection and wing dihedral. It was, therefore, necessary to consider both the wing design and the design of the vertical tail simultaneously.

The magnitude and location of the dihedral had to be determined. The position of the dihedral was simplified by considering that the longest piece of balsa available is 3 feet. Since a joint in the center panel was not wanted, the center panel length should not exceed 3 feet. Thus the dihedral will begin at 1.5 feet from the fuselage centerline. It was also undesirable to have joints on the outboard panels. With a projected span of 8.75 feet and the dihedral joint at 1.5 ft this will be avoided.

The determination of adequate dihedral required consideration of the vertical tail. The DR&O stated as a design requirement to provide ample control with the tail assembly. Therefore, the next step was to determine what would be considered ample control power. For this process the same airplane was considered with ailerons of area 10% of the wing planform area and chord 20% of the wing chord located at the tips of the wings. This size of ailerons is consistent with previously designed planes of similar type. The equation used to calculate the roll control coefficient due to aileron deflection was: $c_{l_{\delta a}} = \frac{2c_{L_{\alpha w}}\tau}{Sb}\int_{y1}^{y2} cy\,dy$

where τ is the flap effectiveness parameter, a function of the ratio of the control surface to the lifting surface, y is the distance from the fuselage centerline to the point on the wing and $C_{l\alpha w}$ is the lift curve slope of the wing. This term was then multiplied by the maximum aileron deflection, 20° to give a value of C_l = 0.0809. The object was to create the same roll moment coefficient with rudder deflection and dihedral.

The upper limit of the dihedral was governed by tip stall. It was calculated that the necessary bank angle, ϕ, for a turn of radius 60 feet at 25 feet/s is 18°. From the simple relation that in the turn the lift equals the weight divided by the $\cos\phi$, the coefficient of lift needed to maintain a level turn was found. This gave the necessary angle of attack in the turn which was 1°. Knowing that the stall angle of attack is 15°, the local change in angle of attack of the outboard panels due to dihedral and sideslip angle could not exceed 14°.

Given that the definition of C_l is the moment divided by the product of the dynamic pressure, wing planform, and wing span, the total roll moment that needed to be generated was found. Considering that the roll moment was equal to twice the product of the local change in lift and the distance between the fuselage centerline to the middle of the dihedral section, the local change in lift was found. This, consequently, showed the local change in angle of attack required to produce equivalent roll control is equal to 4.42°.

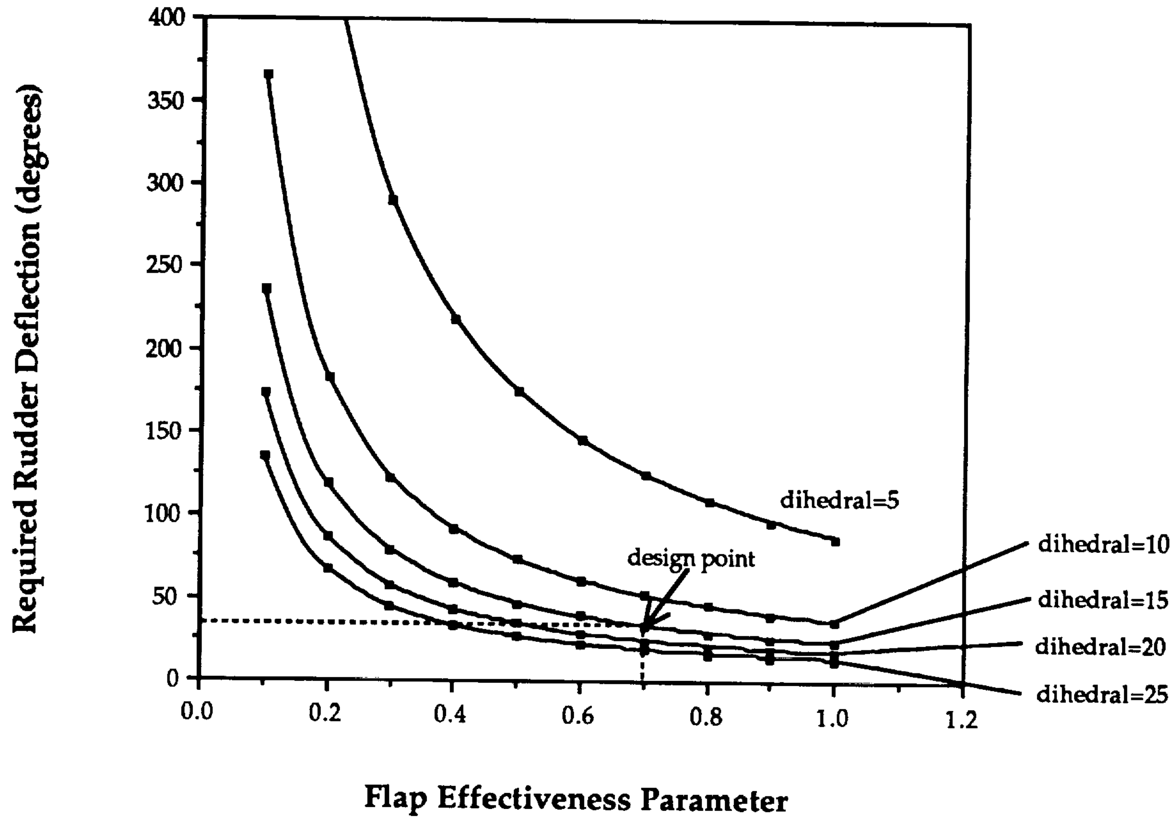
The relation between the local change in angle of attack and the dihedral and sideslip is: $\Delta\alpha = \text{Arctan}(\sin B \tan\Gamma)$ where B is the sideslip angle and Γ is the dihedral angle. For a given dihedral the necessary side slip angle could be calculated.

Next, it was necessary to determine a method of approximating the sideslip angle due to rudder deflection. It was assumed that in a steady state turn the total yaw moment is zero. This provided the relationship, $C_{n\delta_r}\delta_r + C_{n\beta}\beta = 0$, which gave the relation between the rudder deflection and sideslip angle. The yaw coefficients were calculated from the following relations: $C_{n_{\delta r}} = -V_v \tau C_{L_{\alpha v}}$ and $C_{n_\beta} = \eta_v V_v C_{L_{\alpha v}}\left(1+\frac{d\sigma}{d\beta}\right)$ where η_v is the vertical tail efficiency factor, V_V is the vertical tail volume ratio and σ is the sidewash angle due to wing vortices.

The end result was the rudder deflection as a function of the wing dihedral angle and the flap effectiveness parameter of the vertical tail. These results can be seen in Graph 4.3. It is evident from this graph that the increase in dihedral angle becomes less effective past 15° dihedral. Also, the value of required rudder deflection levels off after approximately τ=0.6 It is estimated that a reasonable rudder deflection is around 30°; therefore, the wing dihedral is set at 15° and the flap effectiveness parameter is 0.7. This means that the rudder will be 55% of the vertical tail area.

Graph 4.3

Required Rudder Deflection Based on Wing and Tail Configurations



4.3 Drag Prediction and Component Breakdown

The drag prediction method used for GoldRush is the method described in detail in Barnes W. McCormick's Aerodynamics, Aeronautics, and Flight Mechanics. In this method the drag polar for the entire aircraft is represented by the following equation:

$$C_D = C_{Do} + C_L^2/\pi ARe$$

where C_{Do} is the parasite drag of the aircraft composed of the parasite 'drags' of each separate component, AR is the aspect ratio of the wing, and e is the Oswald efficiency factor of the aircraft.

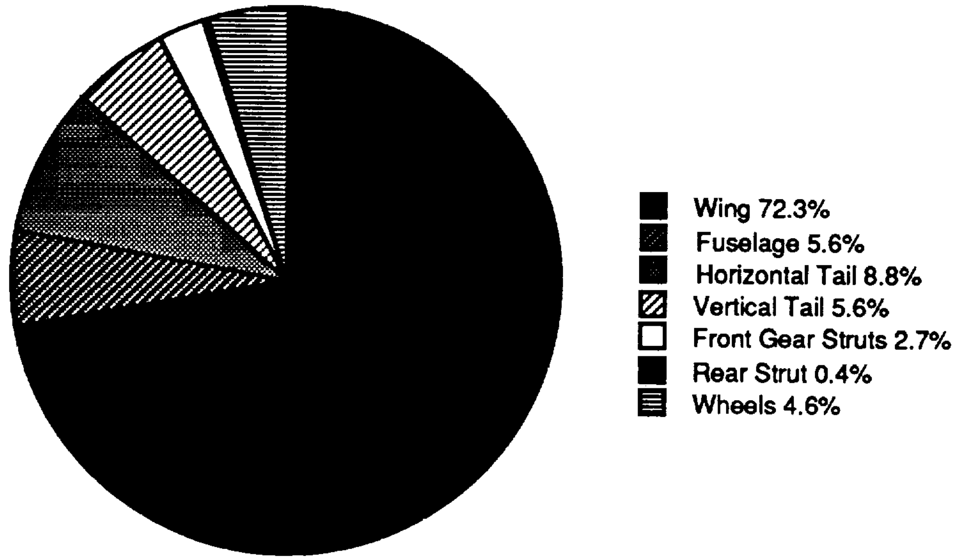
The parasite drag of the aircraft is equal to the sum of the parasite drag of each component part multiplied by the reference area of that particular component and divided by the normalizing reference area, which in the case of GoldRush is the wing planform area of 10.94 ft^2. The parasite drag of each component was determined using various empirical graphs(McCormick). A tabular listing of this break down appears in Table 4.2 and the values are presented in Graph 4.4.

Table 4.2

Component	C_{do}	Area(ft^2)	Reference Graph	%Contribution
Wing	0.03	10.94 (plan)	FX63-137 Drag	72.3
Fuselage	0.12	0.208 (frontal)	Figure 4.13 (McCormick)	5.6
Horizontal Tail	0.025	1.6 (plan)	Figure 3.68 (McCormick)	8.8
Vertical Tail	0.025	1.0 (plan)	Figure 3.68 (McCormick)	5.6
Front Gear Struts	1.0	2 x 0.0061 (frontal)	Figure 4.6 (McCormick)	2.7
Rear Strut	1.0	0.00191 (frontal)	Figure 4.6 (McCormick)	0.4
Wheels	1.0	3 x .0069 (frontal)	Figure 4.6 (McCormick)	4.6

Graph 4.4

Component Contributions to Parasite Drag



The result of the summation of the above component contributions to the aircraft profile drag is $C_{Do} = 0.0415$. The only remaining quantities necessary to determine the drag polar are the aspect ratio of the wing and the Oswald efficiency factor of the craft. The aspect ratio was set at 7.0, the reasons for which are discussed in the section concerning wing planform design.

The efficiency factor of the aircraft is defined as follows:

$$1/e_{a/c} = 1/e_{wing} + 1/e_{fuselage} + 1/e_{other}$$

where e_{other}, according to Daniel T. Jensen's A Drag Prediction Methodology for Low Reynolds Number Flight Vehicles, can be effectively estimated to be 20.0 for all aircraft operating in the low Reynolds number regime. Use of this value for e_{other} makes its contribution greater than the contribution of the entire fuselage which may be an overly conservative estimate, but is suitable for this use because of its small effect upon the drag polar.

The value for the efficiency factor of the fuselage may be determined from the following relation:

$$e_{fuselage} = (E_{fuselage} \times S_{reference}) / S_{fuselage}$$

where the reference area is the wing planform area of 10.94 ft^2, $S_{fuselage}$ is the frontal area of the fuselage and is equal to 0.16 ft^2, and $E_{fuselage}$ is the fuselage efficiency parameter determined(Jensen Figure 3.4) as a function of aspect ratio of the fuselage and is equal to 0.6 for the GoldRush body. This calculation yields an $e_{fuselage}$ equal to 41.0.

The value for e_{wing} is determined from the equation:

$$e_{wing} = 1/(1 + \delta + k\pi AR)$$

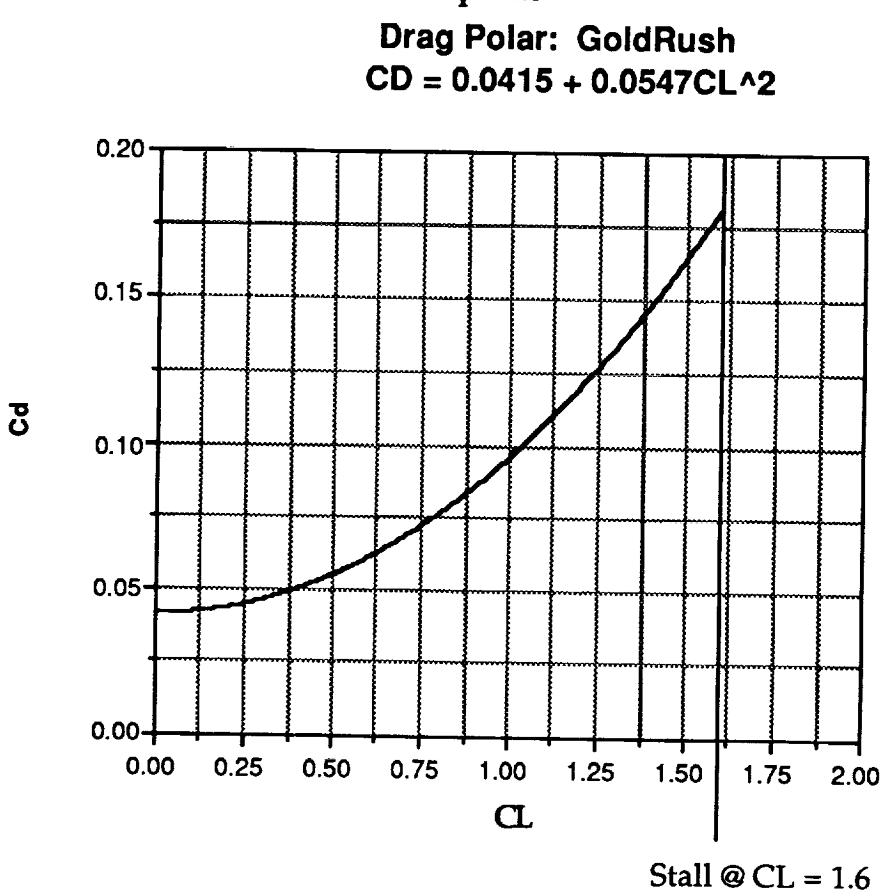
where δ is a function of taper ratio($\lambda = 1.0$) and wing aspect ratio($AR = 7.0$), as shown in McCormick(Figure 4.22), and is equal to 0.075. The value of k is equal to $0.126Re^{(-0.322)}$ which for the GoldRush case is 0.00247 for a mean Reynolds number of 200,000. Therefore, the result of the above equation is $e_{wing} = 0.88$. Combining the three components of the Oswald efficiency factor yields the value $e_{aircraft} = 0.83$. Table 4.3 shows the relative contributions that each of the components makes to the efficiency factor of the aircraft.

Table 4.3

Component	Efficiency Factor	%Contribution
Wing	0.88	94%
Fuselage	41.0	2%
Other	20	4%

Following the determination of all of the factors necessary for the computation of the drag polar, the following was produced:

Graph 4.5



Section 5 : Propulsion System

5.1: Propulsion System Requirements and Objectives

The request for proposals outlined some specific requirements for the propulsion system of GoldRush. In addition, Gold Team set specific objectives for its prototype which had a large impact on the propulsion system design. Those requirements and objectives were:

- Complete radio and propulsion system installation must take no more than 20 min
- The propulsion must be environmentally clean
- Takeoff distance <24 ft.

The primary task of the propulsion team was to satisfy these requirements and objectives in an economically efficient way by choosing a specific motor, propeller, and battery pack.

5.2: Motor and Propeller Choice

The self-imposed objective which had the largest effect on the design of GoldRush was been the takeoff distance of 24 ft. As well as requiring large wing areas, lift coefficients, and low rolling coefficients of friction, the thrust and power capabilities of the propulsion system were of great concern to ensure the fulfillment of this takeoff objective.

The type of propulsion system was of concern to GoldTeam since it wanted to operate in populated environments with a minimum of annoyance to Aeroworld citizens. Also of importance was the preservation of the Aeroworld environment. A gas powered aircraft was judged to be too loud and polluting for the Aeroworld environment, so electric power was chosen for its environmentally clean operation.

The first step in tackling the propulsion problem was to investigate what magnitudes of thrust would be required to produce a takeoff distance of 24 ft. Graph 5.1 shows the thrust vs. power required for several propellers. The horizontal line represents an initial estimate of the amount of thrust GoldRush would need to fulfill its takeoff objective of 24 ft. This value of 2 lb was purely an estimate, and it was conservatively assumed that more thrust would probably be required in the final design. This initial estimate simply offered a parameter to begin the propulsion analysis. Propeller data came from the "PROPELLER" database of candidate propellers, and the propellers of diameter greater than 10 inches are the ones shown in Graph 5.1. As can be seen, the propellers of diameter equal to 10 inches cannot reach the estimate of required thrust with an input power of under 300 W. For this reason, propellers of diameter greater than 10 inches were the only ones considered. This narrowed the field of candidate propellers to the ZingerJ 13-6, the Top Flight 12-6, and the Top Flight M 12-6.

When the data in Graph 5.1 was considered in combination with the power output capabilities of several motors, GoldTeam was strongly limited to motors with at least 200W of power output. Graph 5.1 showed that a motor with a maximum power output of 200 W would offer very little flexibility in design, thus risking successful completion of our takeoff objective. Thus other motors were considered as the powerplant for GoldRush.

Graph 5.1

Thrust vs. Power for Various Propellers

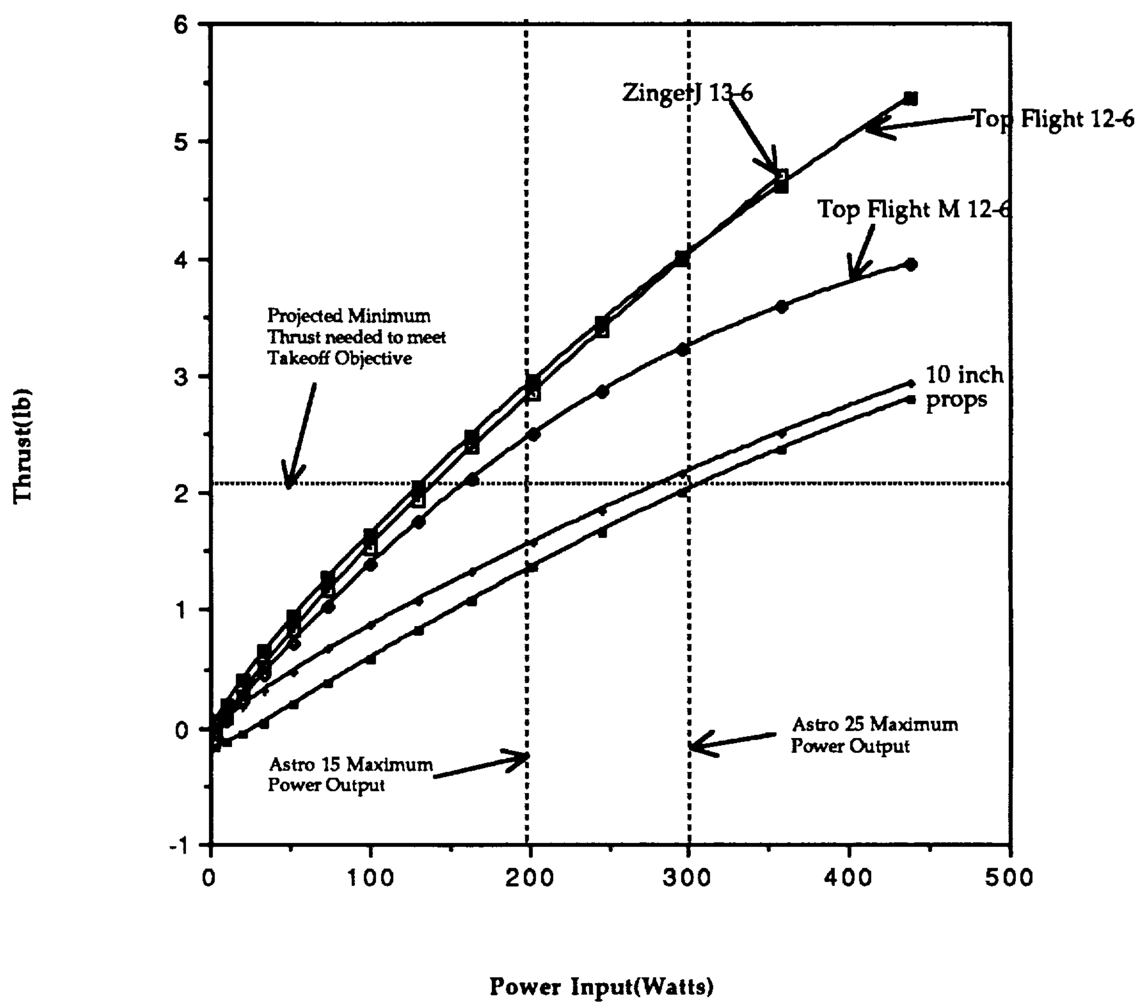


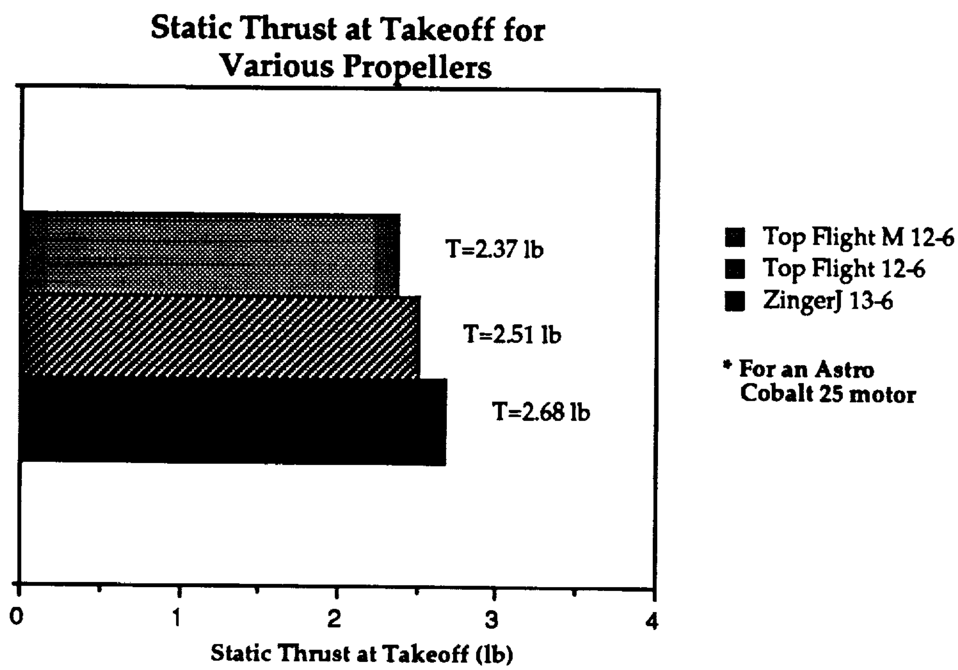
Table 5.1 Motor Comparison

Motor	Advantages	Disadvantages	Cost	% total cost incr.
Cobalt 15 Pmax=200W	•low weight(7oz) • inexpensive • smaller diameter (1.31in)	• little flexibility in design to produce takeoff objective	$124.95	0% increase in projected materials costs compared to using Cobalt 15
Cobalt 25 Pmax=300W	•Power capacity can turn a large prop to fulfill takeoff requirement •current savings (25% at takeoff, 30% at cruise)	•higher weight (6% over weight with Astro 15) •larger diameter (1.62 in) •larger battery requirement • higher cost	$149.95	5% increase in projected materials costs compared to using Cobalt 15
Cobalt 40 Pmax=450W	•Huge power capacity •Current savings greater than Cobalt 25	•higher weight (7% over weight usign Astro 15) •larger battery requirement • higher cost	$159.95	8% increase in projected materials costs compared to using Cobalt 15

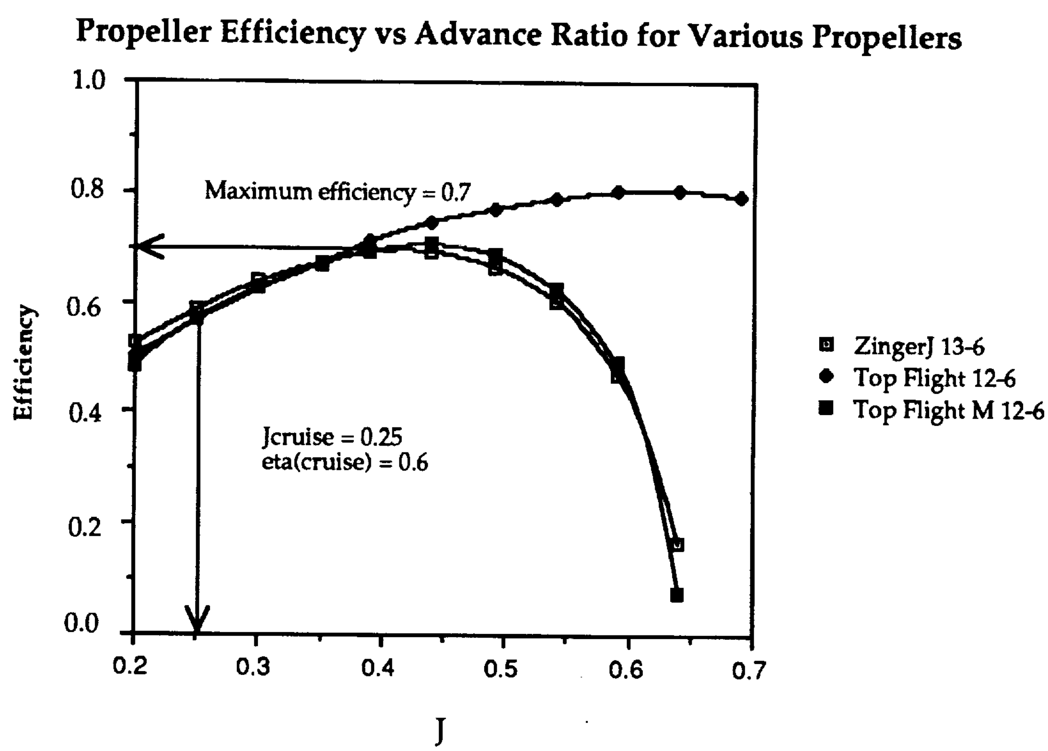
Plot 5.1 showed that the Cobalt 25 provided ample power above the minimum required for takeoff objective fulfillment. Selection of the Cobalt 15 would lower costs and weight of GoldRush, but 15% of the Aeroworld market which was originally targeted would be lost due to their use of an airport with a short runway. This penalty was deemed unaccceptable. GoldTeam opted to incur the 5% increase in projected materials costs, the 3-7 oz. weight increase, and the increased design challenge in order to satisfy its original takeoff objective. The Cobalt 25 was thus selected as the motor for GoldRush. The Cobalt 40 could have been selected, but its capabilities, weight, and cost seemed to exceed the needs of GoldRush's mission.

Propeller selection was also intertwined with the motor choice.

Graph 5.2



Graph 5.3

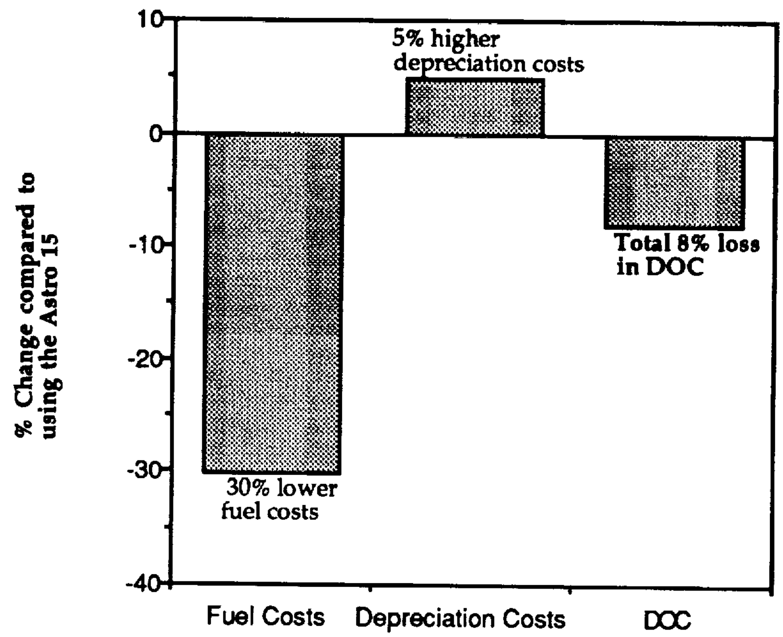


Graphs 5.2 and 5.3 offered evidence that the ZingerJ 13-6 might be the best choice as a propeller for GoldRush. It was known that GoldRush needed the largest thrust possible at takeoff to become airborne in 24 ft. Graph 5.2 shows that the ZingerJ 13-6 has about a 10% greater static thrust than the other two propellers. Graph 5.3 shows that the cruise efficiencies of the three props are about the same. All three props cruise at about $\eta=0.59$. Since there was no efficiency advantage to using a 12 inch prop, the ZingerJ 13-6 was chosen as the propeller for GoldRush.

It was a concern that GoldRush was cruising at 15% below the maximum prop efficiency. The large wing area and high cruise lift coefficient caused the cruise speed to be low, and this drove the cruise advance ratio down to 0.25. However, with another design iteration, the wing size, cruise C_l, and propeller choices may be changed to achieve a greater prop cruise efficiency. Implications of a greater efficiency at cruise for the propeller would be a lower fuel cost due to lower cruise current.

Once the motor and propeller choices were made, the actual effect of choosing the Astro 25 could be seen. As shown in Table 5.1, the Astro 25 gives a 30% current savings during cruise. Since cruise is the longest regime of any specific flight, this current savings translated to a 30% fuel cost savings. This more than offset the 5% increase in materials costs due to the increased price of the Astro 25 over the Astro 15, resulting in an overall 8% decrease in the DOC of GoldRush. Thus, the Astro 25 lowered the CPSPK 8%. This is illustrated in Graph 5.4.

Graph 5.4
Economic Effect of choosing the Astro 25 over the Astro 15



5.3: Battery Choice

The power pack for the propulsion system needed to supply the motor with enough power to produce thrust for takeoff and to sustain a cruising current long enough to meet the range objective of 10,000 ft with a two minute loiter. During the takeoff regime, a high motor torque and RPM generate a high current for a short duration in order to produce the takeoff thrust. Since the RPM of a prop is proportional to the voltage applied across the motor, the takeoff regime would determine what voltage was needed in GoldRush's battery. In the cruise regime the situation is different. A moderate voltage must be maintained at a moderate current for a long period of time to produce the cruise thrust. Since the battery drain is so much greater during cruise than during takeoff, the battery capacity is primarily dictated by the cruise current.

In order to determine what battery would fulfill these requirements, an Excel spreadsheet was employed which allowed GoldRush Propulsion to determine what the voltages, currents, and motor RPM's would occur at cruise. The voltage required at takeoff was obtained using reference 5.1.

	Voltage	Current	t	Battery Drain
Takeoff	15.6 V	11.2 A	10 s	7 mah
Cruise	9.7 V	5.2 A	419 s	608 mah

*For Vcr=30 ft/s

These values are based on what cruise time is required to achieve the design range of 13,000 ft. The previous table shows that the battery pack must consist of 13 X 1.2 V cells to supply the 15.6 necessary volts at takeoff. Each cell must also be of capacity greater than 615 mah. From the available list of battery types, the next lowest battery capacity was the P90SCR with 900 mah capacity. It was the most inexpensive cell available at $3.00/cell, putting the total cost of the battery pack at $39.00.

The excess capacity of the battery pack produced a range of about 20,000 ft which exceed our design range by about 7,000 ft. In order to serve the market which was targeted in the original market analysis, research would have to be done into the availability of different capacity battery packs or varying the design of GoldRush so that it met its target range.

5.4: Control System

Since the motor must operate at a variety of throttle settings during the takeoff, climb, cruise, and landing regimes, an electronic variable speed control will be employed to control the effective voltage which the motor can convert to power for the propeller. At takeoff, the speed control should be at full throttle. The pilot should begin throttling back during the climb phase of the mission, and then should lower the throttle to a constant level when cruise is obtained. Since it is impossible for the pilot to know the actual voltage he is flying at, he must use only his flying skill and judgement to find the combination of cruise throttle, incidence, and velocity. In approach to landing, the throttle will have to be lowered in order to decrease speed while simultaneously decreasing altitude.what combination of throttle and elevator setting produce trimmed flight. Finally, descent for landing should be induced through reduction of throttle.

5.5: Summary

Hardware

Motor: Astro Cobalt 25	$149.95
Propeller: ZingerJ 13-6	$5.00
Batteries: 13xP90SCR 900 mah	$39.00
Total Battery Voltage: 15.6 V	
Speed Controller: Futaba MC114CL	
TOTAL PROPULSION SYSTEM COST:	**$273.94**

Performance

	Voltage	Current	Max Power Av
TAKEOFF:	15.6 V	11.2 A	0 W
CRUISE:	9.7 V	5.2 A	63 W

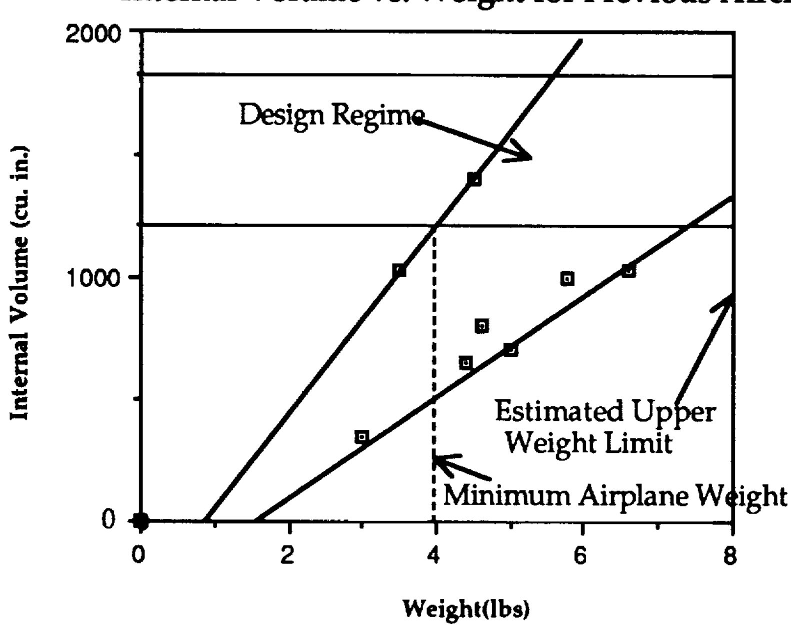
Max Rated Motor Power:	300 W
Max Power Available:	98 W
Max Prop Efficiency :	0.7
Max Static Thrust:	2.68 lb
Battery Capacity:	900 mah

Section 6: Preliminary Weight Estimation Detail

6.1 Preliminary Estimates

After defining the mission requirements and objectives, the number of passengers and their seating arrangements were known. This allowed for a calculation of the internal volume of the fuselage. Using the Internal Volume vs. Weight relationship (Graph 6.1) for previous RPV airplanes the initial GoldRush weight was between 4.5 and 8 pounds. This was based on an internal volume which initially ranged between 1237.5 and 1800 cubic inches.

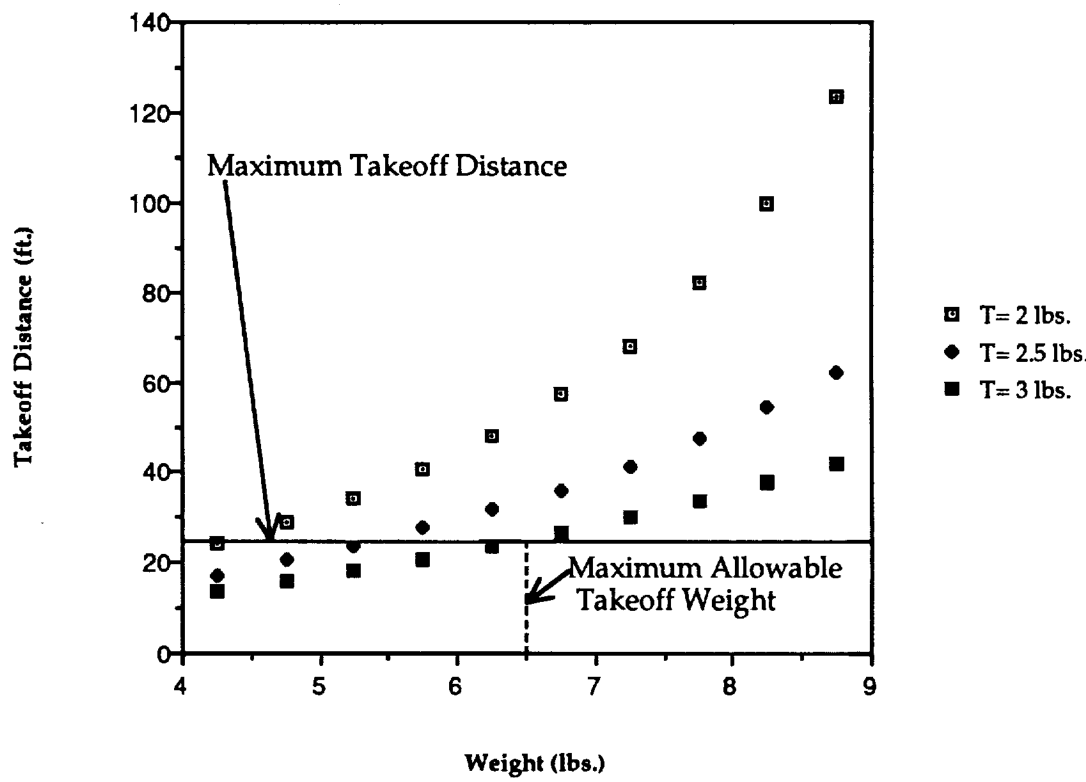
Graph 6.1
Internal Volume vs. Weight for Previous Aircraft



This weight range was reduced after considering the 24 foot takeoff distance requirement. A trade study was used to determine the takeoff distance versus weight while varying the maximum lift coefficient from 1.1 to 1.6, the rolling coefficient of friction between .12 and .22 and the thrust between 2 and 3 pounds. These values represented realistic ranges for these parameters. Graph 6.2 was developed from this trade study after assuming an average rolling coefficient of friction of .17 and a $C_{L_{max}}$ of 1.6 while varying the thrust over the aforementioned range of values. From this graph it was apparent that GoldRush could not exceed 6.5 pounds and still meet the takeoff distance requirement.

Graph 6.2

Takeoff Distance vs. Weight for Varying Thrusts (mu= .17, Cl= 1.6)



6.2 Secondary Estimates

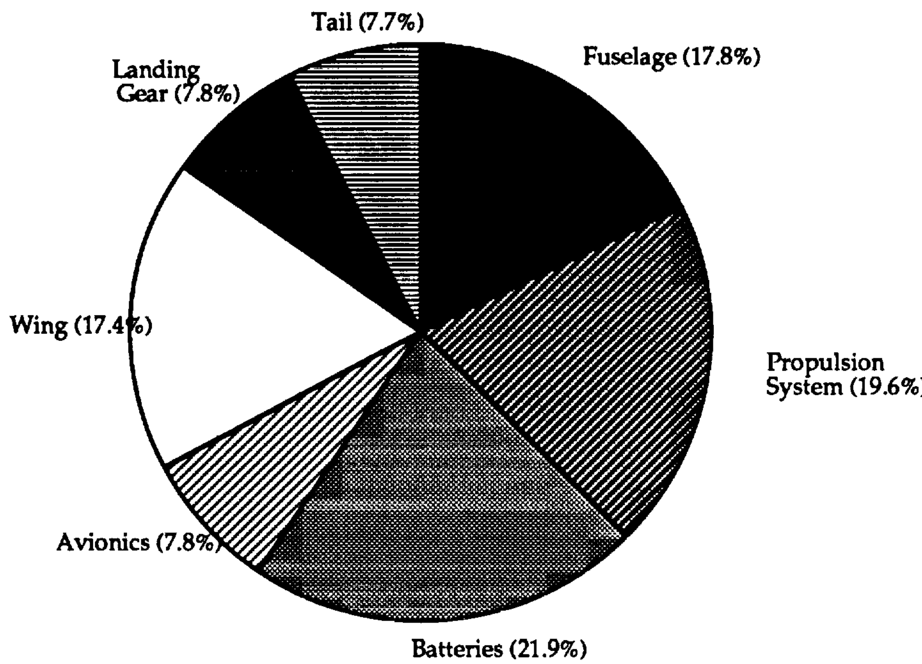
Although the 6.5 pound airplane theoretically could takeoff in 24 feet it was not practical to expect such performance. For this reason further weight savings were desired in order to achieve the takeoff requirement. In order to provide a more accurate weight estimate the structure of the fuselage was determined(see section 9). The structure of the Goldrush fuselage consisted of balsa and spruce beams and floors, and monokote covering. Knowing the densities and needed amounts of these materials the weight of the fuselage was determined to be 0.860 pounds. The weights of the propulsion components, including the Astro-25, engine mount and Zinger 13x6 propeller, were known, as were the weights of all the avionics equipment. The fuel weight depended upon the number of batteries. Thirteen batteries were used, each with a weight of 0.081 pounds, yielding a total fuel weight of 1.056 pounds. The wing, empennage and landing gear weights were all estimated using a percentage weight breakdown. The breakdown was performed using data from similar, passenger airplanes. Data from three such airplanes were utilized, and the percentage contributions of each airplanes components were averaged together. From this data it was determined that for Goldrush the wing constituted 17.4% of the total unloaded weight, the empennage 7.7% and the landing gear 7.8%. This corresponded to component weights of 0.840 pounds for the wing, 0.373 pounds for the empennage and 0.375 pounds for the landing gear. In addition the 80 passengers, along with the two crew members and two flight attendents weighed approximately 0.496 pounds. All of these weights and their percentage of the total aircraft weight appear in Table 6.1 and Graph 6.3.

Table 6.1 Weight Estimation

Airplane Component	Weight (pounds)	% of Aircraft Weight
Fuselage	.860	17.8
Propulsion System	.946	19.6
Motor	.813	16.8
Engine Mount	.073	1.5
Propeller	.061	1.3
Fuel (13 batteries)	1.056	21.9
Avionics	.375	7.8
System Battery	.125	2.6
Servos (2)	.075	1.6
Receiver	.060	1.2
Speed Controller	.113	2.3
Landing Gear	.375	7.8
Wing	.840	17.4
Tail	.373	7.7
Total Unloaded Airplane	4.825	-
Passengers/Crew (max)	.496	(9.3)
Total Loaded Airplane	5.321	-

Graph 6.3

Component Weight Contribution



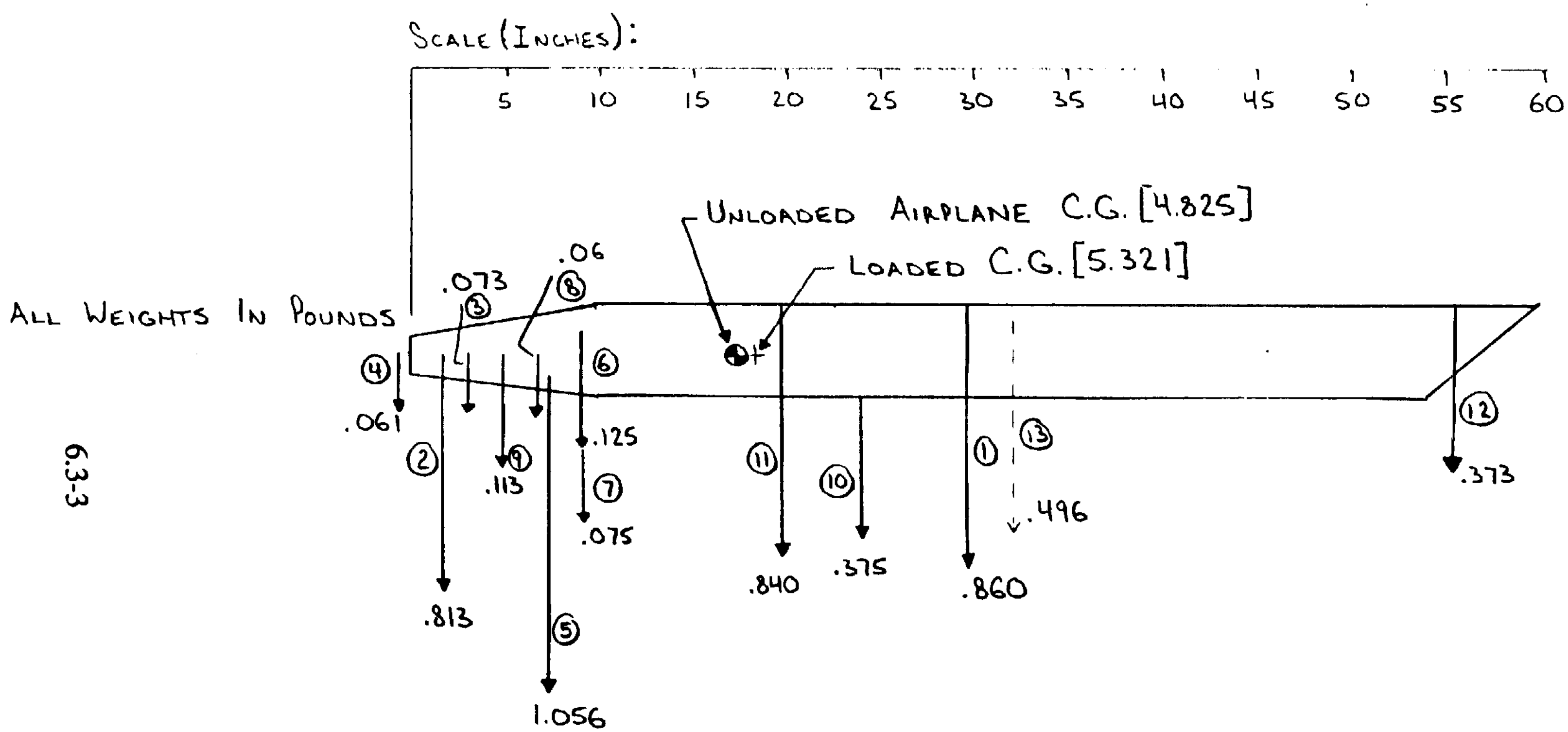
6.3 Center of Gravity

Concerns regarding the center of gravity of GoldRush spanned the areas of weights and stability and control. For stability and control reasons the center of gravity was to be placed in order that the static margin of the aircraft was between 20 to 25%. Knowing the value of the neutral point (see Section 7.2) it was possible to determine where the aircraft c.g should lie. The center of gravity of GoldRush was then computed knowing where the c.g. of each airplane component acted. The weights and positions of these components appear in Table 6.2 and in Figure 6.1. When the airplane was full with passengers the c.g. was located 18.4 inches aft of the fuselage nose, or at 27.7% of the mean aerodynamic chord. This yielded a static margin of 24%, which was within the desired range. Without passengers the center of gravity moved to 17.46 inches aft, or 21.4% of the mean chord. This yielded a static margin of 30%, which was somewhat higher than desired. However, this static margin was deemed acceptable because, although the maneuverability of the airplane would be diminished, it would make the airplane more stable.

Table 6.2 Center of Gravity Estimation

Airplane Component	Weight (pounds)	C. G. Location (inches)
Fuselage	.860	29.54
Motor	.813	1.75
Engine Mount	.073	2.98
Propeller	.061	-.50
Fuel (13 batteries)	1.056	7.35
System Battery	.125	8.75
Servos (2)	.075	8.75
Receiver	.060	7.0
Speed Controller	.113	4.75
Landing Gear	.375	24.0
Wing	.840	19.75
Tail	.373	55.46
Total Unloaded Airplane	4.825	17.46
Passengers/Crew (max)	.496	31.85
Total Loaded Airplane	5.321	18.40

FIGURE 6.1
WEIGHT PLACEMENT DIAGRAM



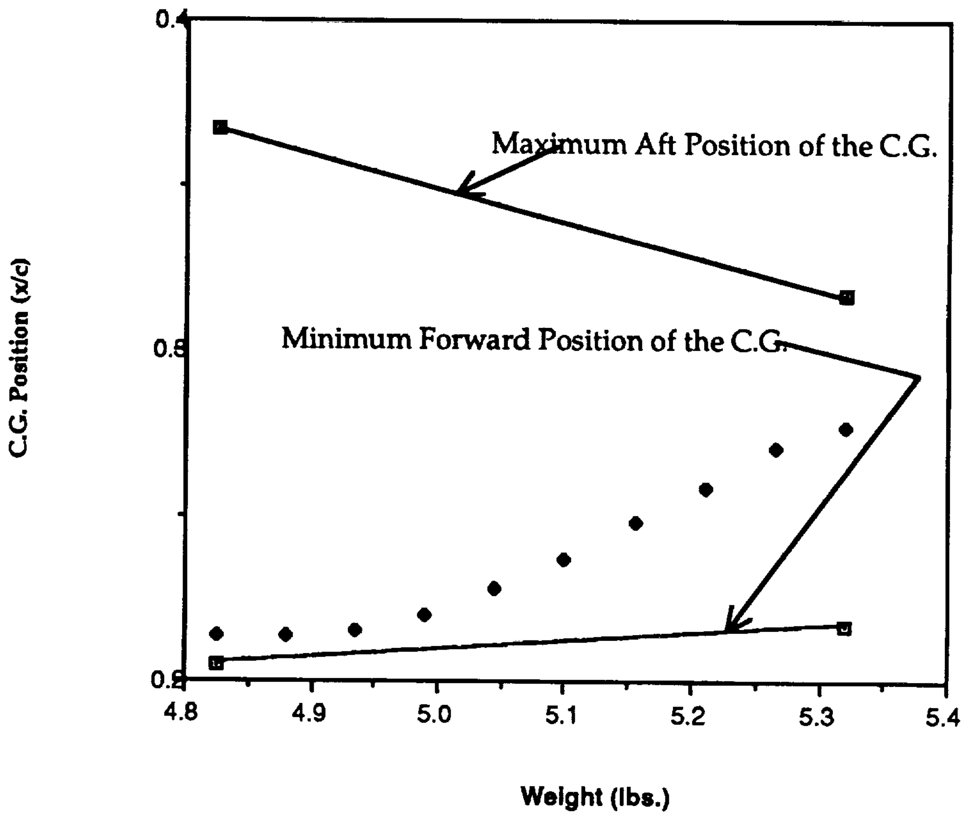
Component:

1 Fuselage
2 Motor
3 Engine Mount
4 Propeller
5 Fuel (13 Batteries)
6 System Battery
7 Servos (2)
8 Receiver
9 Speed Controller
10 Landing Gear
11 Wing
12 Tail
13 Passengers/Crew (max

Note: Center of Gravity measured from the fuselage nose.

After determining the center of gravity positions for the maximum and minimum weight conditions, it was important to produce a weight balance diagram for all passenger seating scenarios. Initially the acceptable static margins for the two extreme configurations were determined. They were to be between 15 and 31% for the case without passengers and between 20 and 30% for the case with a full load of passengers. For the case without passengers the lower limit of the static margin was allowed to drop below 20% because safety was not as important and issue. These limits then yielded the acceptable range of c.g. location for GoldRush. Passenger seating patterns were of concern in determining the c.g. behavior with weight. Because of the probable large amount of business travelers within Aeroworld, and their preference of comfortable accomodations, it was assumed that the first class seating would nearly always be filled. Thus the first eight passengers were assumed to sit in first class. When more people were added the first ten would be placed at the front of the lower deck. The next ten would be placed immediately behind them on the lower deck, and the ten after that would be seated right above these people. This seating pattern would be repeated until the airplane was filled or the passengers were all seated. Knowing where the center of gravity would act for different numbers of passengers it was then possible to determine the variation in the c.g. location (Graph 6.4).

Graph 6.4
Weight Balance Diagram



The center of gravity was found to increase slowly at first, and then more rapidly as the added passengers were placed further aft of the c.g. Finally the curve levelled off because using the passenger seating scenario at the very back the ten people would be placed over both levels, so their center of gravity would not be increased as much over the last passenger location as compared to earlier in the seating. From the graph it was apparent that the center of gravity position was within the acceptable limits of the static margin for all passenger seating types. This would be true no matter how the airplane was filled. Thus GoldRush achieved a design requirement of stable flight for all passenger seating scenarios.

It was noted that the center of gravity position with respect to the mean aerodynamic chord was more forward than the often desired value of 30 percent. This occurred because the relatively heavy avionics and propulsion systems were situated in the nose of the airplane. This caused the c.g. to move forward and neccessitated a larger elevator for control purposes. The trim condition flap deflections of this large elevator would lead to somewhat of a drag penalty. For this reason moving these subsystems aft of the nose was considered. However because this would disrupt the passenger seating scenario, and because the drag penalty would not be very large this consideration was rejected.

SECTION 7: Stability and Control System Design

7.1 Stability and Control Objectives

The stability and control group of GoldTeam wanted to produce for GoldRush a system of control mechanisms which would offer stability, as well as sufficient control for maneuvering in Aeroworld. In addition, the control group had to satisfy several Aeroworld regulations and group objectives:

1) Perform a steady, level turn of R=60′ at 25 ft/s

2) Roll control without ailerons

7.2 Horizontal Control Surface Sizing and Location

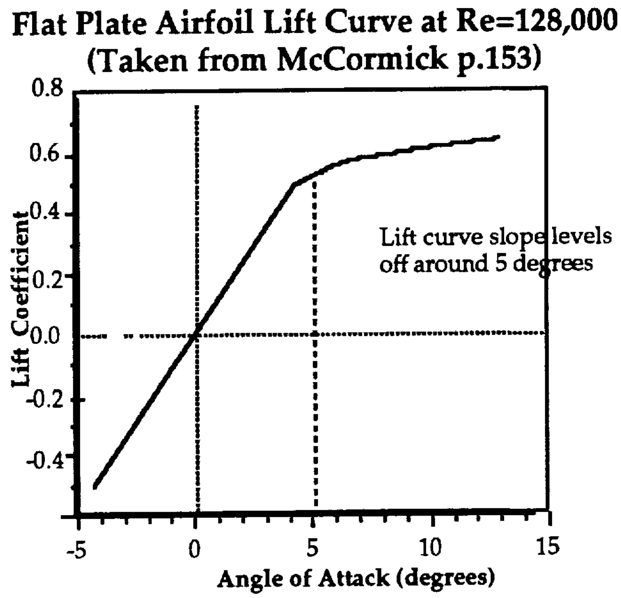
The first step in creating a horizontal tail which would provide static stability for GoldRush was to set a distance between the plane's c.g. and the aerodynamic center of the horizontal tail. Assuming a preliminary tail chord length of 0.7 ft (8.4in), based on previously built aircraft of similar size and type, and that the trailing edge of the tail would remain flush against the rear edge of the fuselage, the tail moment arm was set at l_t=2.942 ft. This would make the cruise Reynolds number of the tail approximately 130,000. In addition, reference 3 suggested a static margin within 20-25% MAC for both the maximum weight and empty weight configurations in RPVs. This static margin was determined using the formula:

$$\frac{X_{np}}{c} = \frac{X_{ac}}{c} - \frac{C_{m_{\alpha_f}}}{C_{L_{\alpha_w}}} + \eta\frac{l_t S_t}{Sc}\frac{C_{L_{\alpha_t}}}{C_{L_{\alpha_w}}}\left(1-\frac{d\varepsilon}{d\alpha}\right)$$

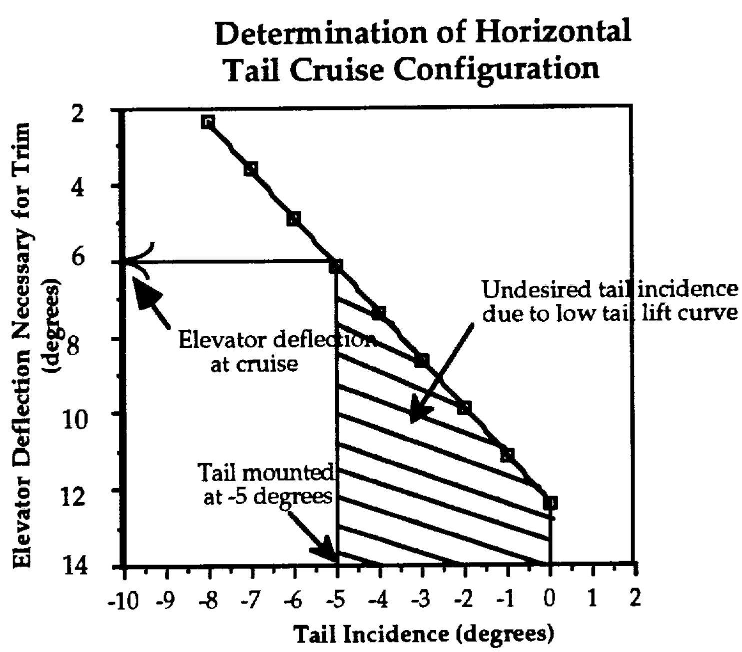
GoldTeam determined that the horizontal tail area necessary for a static margin of approximately 24% was $S_t = 1.6\ ft^2$. Since the c.g. of GoldRush was so far forward, a large downlift was required of the horizontal tail, and for our fixed l_t and tail area, the it was found that a -9.9 degree tail incidence was necessary to produce a trim condition. Unfortunately there were two big disadvantages to this configuration. First, the drag produced by the tail at such a high negative incidence will produce considerably more pressure drag than if it were mounted at a zero angle of incidence. Second, the tail would produce a large negative lift on the craft which would have to be counteracted by the wing. This would increase wing loading and flight cruise speed.

The next task was the determination of the best tail angle of incidence/cruise-elevator-deflection combination that would produce the tail moment for trim (corresponds to the -9.9 degree effective tail angle of attack). Upon referencing the data base of previously designed remotely piloted vehicles, it was determined that an appropriate elevator size is 50% of the entire horizontal tail area. Because the maximum elevator deflection was set at 20° and it was determined that GoldRush needed a +/-12° elevator deflection to produce the desired pitch control, the cruise elevator deflection could be no more than 8°. It was desired to have as much elevator deflection as possible available for maneuvering. This would seem to indicate that the tail angle of incidence should be -9.9 degrees. This could clearly not be the case because the lift curve slope of a flat plate airfoil at low Reynolds number decreases drastically beyond α=+/–5° as shown in Graph 7.1.

Graph 7.1

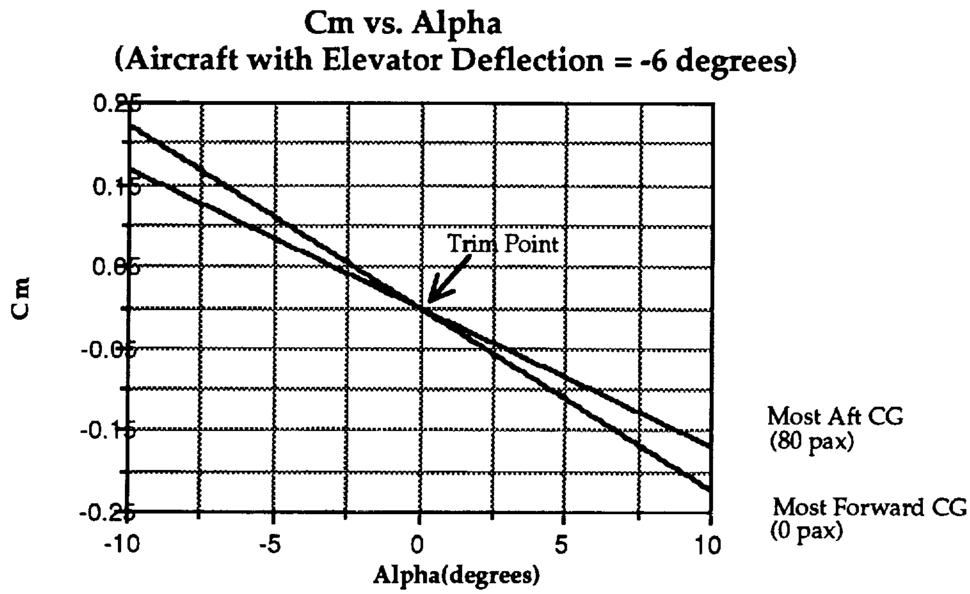


Graph 7.2



For this reason, GoldTeam chose the α_t=-5° because it avoided the area of the flat plate lift curve which levelled off. At the same time, it produced trim with an elevator deflection of -6° as can be seen in Graph 7.2. The combination of this tail incidence and elevator deflection produce trim at a cruise speed of 31 ft/s for GoldRush, and they produce the Cm vs. α for the airplane shown in Graph 7.3.

Graph 7.3



7.3 Vertical Control Surface Sizing and Location

As stated in section 4, the yaw and roll of the airplane are coupled motions. The rudder of the vertical tail provided yaw, which created sideslip. This effect, along with the dihedral of the wing create a roll moment and a coordinated turn can be achieved. Therefore, the design of the wing and the design of the vertical tail were not independent of one another. Figure 4.1 showed a rudder area of 55% of the vertical tail area would provide ample control power. Calculations for the required rudder with the given wing dihedral were done for several rudder sizes. Based on the advice of consultants and the data it was decided that a vertical tail size of 1.0 sq. ft. would provide good lateral stability while also giving reasonable values for the percent rudder. For a more detailed description of the calculations involved in the design of the vertical tail refer to section 4.2.

7.4 Control Mechanisms

Control will be provided to the active surfaces through a control rod assembly from the servos to a control horn and hinge on the flap surfaces. Several control rods are being considered. Commercially available plastic control rods offer smooth operation and are somewhat flexible. Control transfer may also be provided through a straight balsa rod from servo to control horn, but this means of control does not offer as much flexibility as the plastic control rods. Control horns may be purchased which have adjustable attach points so that the control surface deflection can be adjusted.

Section 8: Performance Estimation

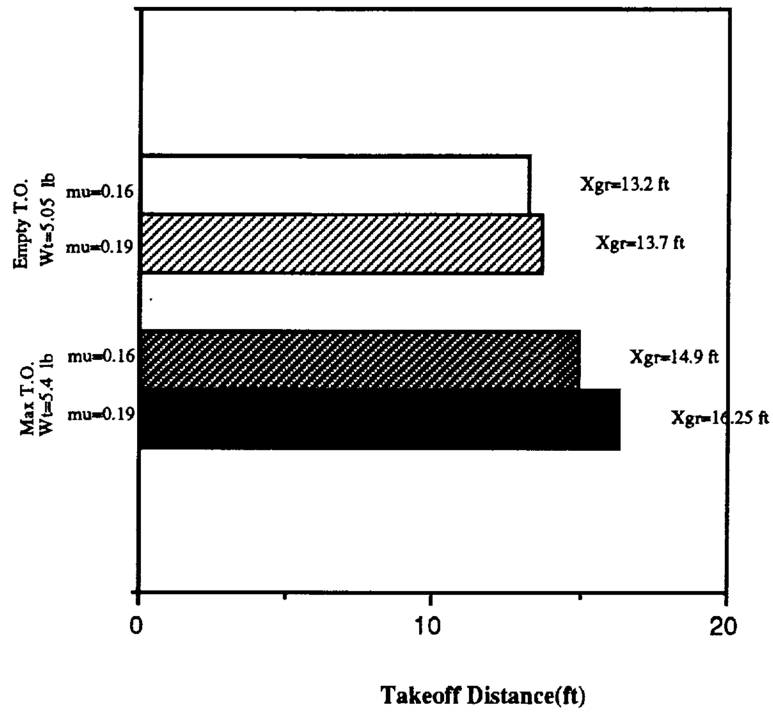
8.1 Takeoff and landing estimates

The takeoff distance was determined using the program TAKEOFF. This program took input on various parameters of the plane, such as propeller size, current draw, weight, and rolling friction, and used these parameters in an iterative process to determine the distance required for the plane's lift to equal its weight. GoldRush's takeoff distance was then determined for a maximum weight of 5.4 pounds and an empty weight of 5.05 pounds. For each of these weights, rolling coefficients of friction of 0.16 and 0.19 were used since they represented the range of values expected in Aeroworld. Graph 8.1 illustrates the results.

The maximum takeoff distance, with a weight of 5.4 lbs and a coefficient of friction of 0.19, was 16.3 feet. This takeoff distance is much lower than the design requirement of 24 feet. If the friction coefficient is lowered to 0.16, the takeoff distance drops to 14.9 feet. When the RPV is empty, i.e., no passengers, the takeoff distances range from 13.2 to 13.7 feet. This gross overshoot on the target design takeoff distance was of concern. Further refinements on the GoldRush design could include a decreased wing area and/or pursuance of a more convenient battery size. Battery choice was extremely limited and forced the designers to choose a battery which was more than adequate for the takeoff and range requirements.

Graph 8.1

Takeoff Distance for Varying Rolling Friction Coefficients



Landing distance was estimated as Xgr=47 ft for the WMTO configuration and Xgr=44 ft. for the WMinTO configuration. Further work should be done to lower these values to below 40 ft, for example, an active braking system could be designed for the production model.

8.2 Range and Endurance estimates

The endurance of the GoldRush was calculated using the battery capacity and the range objective of 10,000 ft with two minute loiter. For a 900 mah capacity battery pack and a cruise current of 5.2 A, the endurance of the pack after takeoff battery drain was calculated to be 618 s.

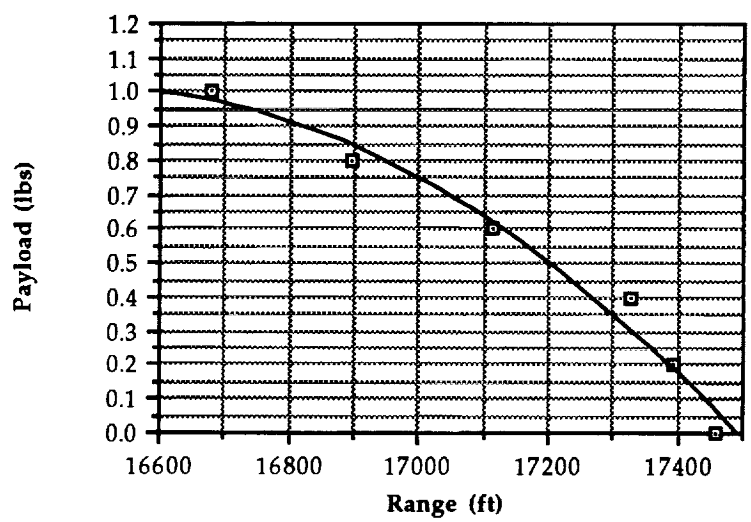
The range of the GoldRush aircraft was based on the following formula.

$$\text{Range} = \text{Vcruise} * \text{Endurance}$$

A Range-Payload diagram was constructed based on the relationship between endurance and aircraft weight. The maximum range for the full payload capacity (1.0 lb) is 16600 feet and the maximum range for the empty condition was 17400 feet. Graph 8.2 was generated based on maximum endurance conditions.

Graph 8.2

Range - Payload Diagram



8.3 Power required and power available summaries

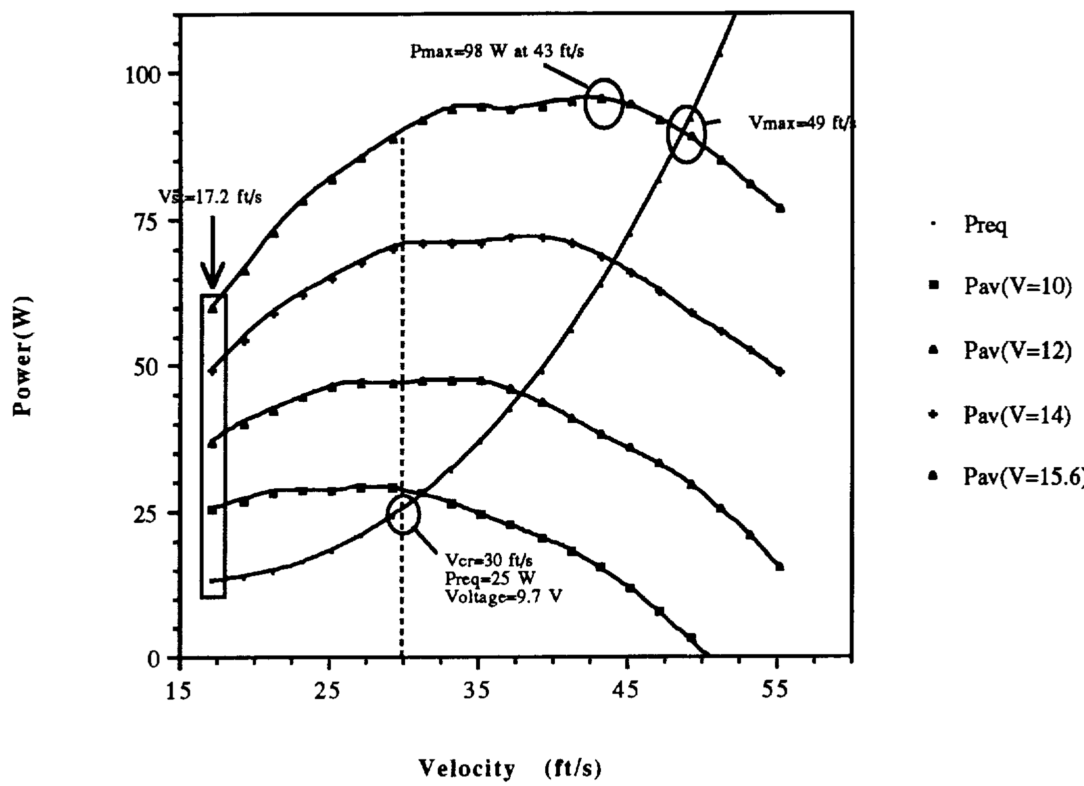
The power required data was determined for level flight as

$$P_{req}=D*V$$

An accurate drag polar estimate was desired and made available for this calculation as $C_d=0.0415 + 0.0547C_L^2$. Power available was also calculated for the electric propulsion system as a function of level flight velocity. This was accomplished using the program PAVAIL. A plot of Pav and Preq vs. Velocity revealed the maximum level flight speed of 49 ft/s. Graph 8.3 was the result.

Graph 8.3

Power Available and Power Required vs. Velocity



8.4 Climbing and Gliding Performance

The rate of climb (R/C) of the aircraft was derived from the aforementioned power curves.

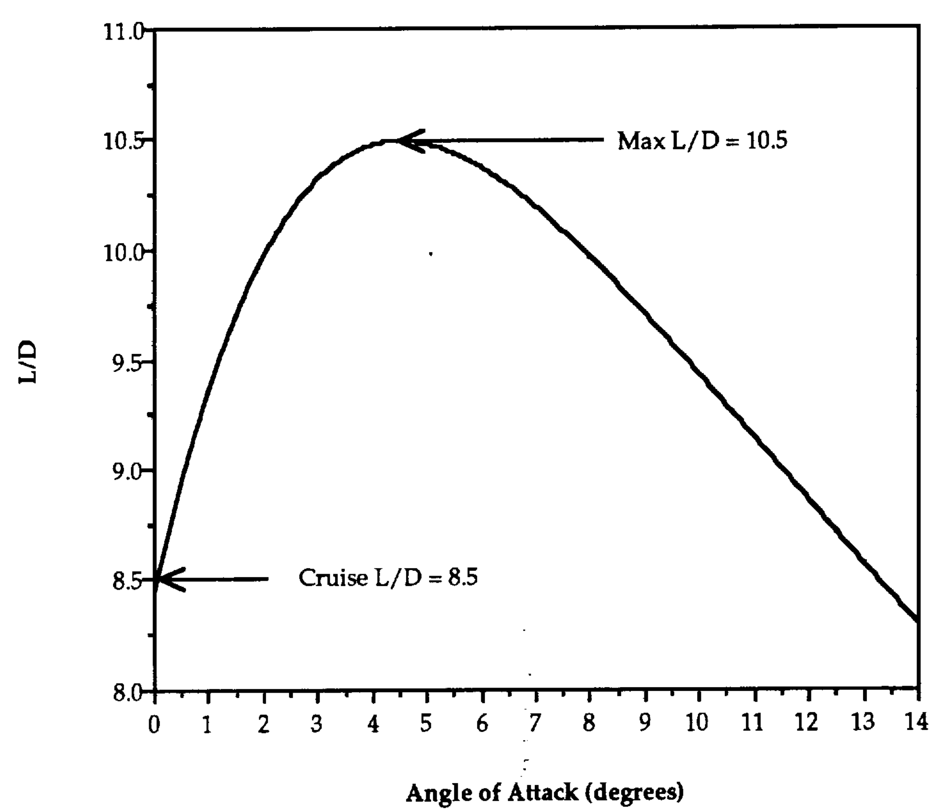
$$R/C = (Pav - Preq)/W$$

Thus it was a simple matter to plot R/C against velocity for the Full and Empty weight conditions. The maximum R/C's were 12.7 ft/s and 12 ft/s for the empty and full conditions respectively.

The aircraft's gliding performance was calculated as a function of the lift to drag ratio. The lift to drag ratio for GoldRush is shown in Graph 8.4. It can be shown that the glide path angle is equal to $\tan^{-1}(D/L)$. The minimum glide angle of 5.5 degrees was calculated for L/D max. If the GoldRush were in level flight at L/Dmax with a 20 ft altitude, it could perform a power off glide, covering a distance of 208 ft. The gliding performance was considered good since the GoldRush was nearly able to match the competition in this performance area (the HB-40 can glide only 20 ft further than the GoldRush in this example calculation.)

Graph 8.4

Aircraft Lift to Drag Ratio



Performance Parameters:

TAKEOFF	
Distance at WMTO	16.3 feet
Distance at OEW	15.6 feet
VELOCITY	
V_{min} at WMTO	17.2 fps
V_{max} at WMTO	49.0 fps
V_{stall} at WMTO	17.2 fps
RANGE	
Maximum at WMTO	16,600 feet
Maximum at E_{max}	19,900 feet
Maximum at W_{min}	20,250 feet
ENDURANCE	
At Maximum Range	618 seconds
At WMTO	618 seconds
GLIDE	
Minimum Glide Angle	5.5 degrees
ROC	
Maximum at WMTO	12 fps

Section 9: Structural Design Detail

The initial concept for the structural design of GoldRush was obtained from the database of previous years' designs. Other sources for structural information and ideas were the actual models in the design room and the discussions with Mr. Joe Mergen. All of these sources together were extremely helpful in the design of the GoldRush structure. The original structure was divided into four parts: the nose, the fuselage, the tail, and the wing. Each of these will be treated separately in the following discussion.

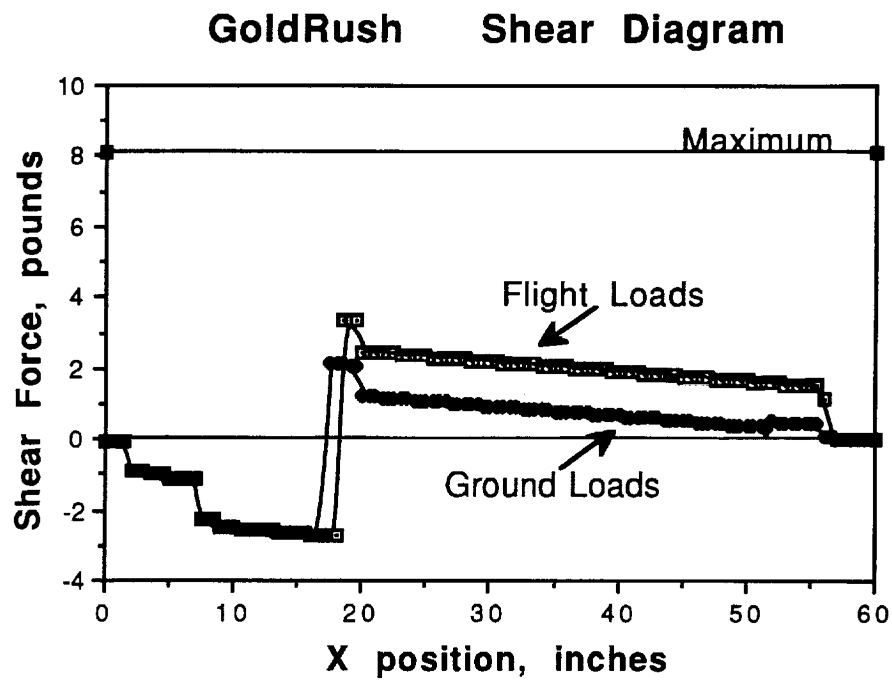
9.1 The Nose

The nose of the fuselage was designed primarily to accommodate the propulsion system, specifically, the motor, receiver, servos, and batteries. The structure consists of four pieces of spruce that define the sides of the nose, with two cross pieces. Behind the motor is plywood firewall to which the back of the motor is attached. The wires leading into the motor pass through a 1" hole in the vertical plywood piece. All of the components in the nose are easily accessible through the hinged door on the top, which is made of thin balsa wood covered in Monokote. The total length of the nose is ten inches, and its cross section varies from 2"x 2" at the front to 5"x 6" where the nose meets the fuselage.

9.2 The Main Fuselage

The main body of the fuselage is a simple truss structure which was designed to carry the 80 or 84 passengers plus crew. The structure consists of four 44" long, 1/4" square spruce beams that are used as the main support for fuselage bending moments. Each side of the main body then has five diagonal balsa cross pieces, and one diagonal spruce cross piece located under the wing. The top and bottom each have four cross pieces, two spruce and two balsa. The two spruce are directly under the wing. The passengers sit on two thin balsa sheets that are 44" long and 6" wide. The high stress areas, directly underneath and behind the wing, are supported by spruce cross pieces, while the rest of the cross pieces are balsa. The following graph shows the shear force exerted on the fuselage section during normal ground and flight loading. As can be seen from the graph, the loads that are expected to be encountered are well below those that can be withstood by the designed fuselage. The factor of safety in the fuselage is approximately 2.2. The calculation of the maximum shear force allowable assumed that the entire shear force was supported by the four long spruce pieces on the edge of the fuselage. Since some of the shear can and will be supported by other pieces, the factor of safety in the fuselage is actually a bit higher.

Graph 9.1



9.3 The Tail

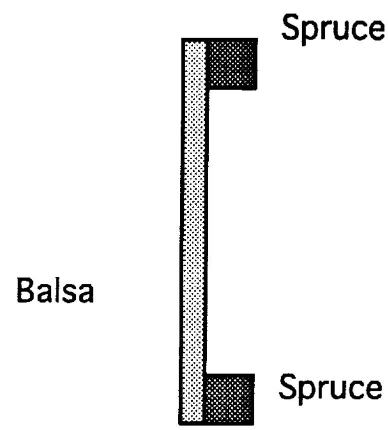
The tail structure begins 54" aft of the fuselage nose. At this point, the 5" by 6" cross section begins to taper to a point, 6" aft. This brings the total length of the plane to 60 inches. The tail also consists of four spruce pieces with a balsa cross piece on each side. The main purpose of the tail fuselage structure is to support the horizontal and vertical tails. Both of these tails are flat plates, made of balsa pieces defining the edges. The horizontal tail is 1.6 square feet and the vertical tail is one square foot. The elevator is divided into two pieces so as to avoid contact with the deflected rudder.

9.4 The Wing

The wing is a three panel polyhedral design. The center, horizontal panel is 36 inches long. It has a wing spar consisting of two 1/4" square pieces of spruce connected by a vertical piece of balsa two inches high (the thickness of the airfoil) and 1/8" thick. This wing spar design is pictured below:

Figure 9.1

Wing Spar Design



This design is capable of supporting a bending moment of 15.2 foot-pounds. In order to determine the maximum bending moment that GoldRush will be required to withstand, it was assumed that the lift on the wing was evenly distributed along the entire span. This assumption led to a calculated bending moment value of 5.8 foot-pounds at the root of the wing. This justifies the use of the above wing spar, as it gives GoldRush's wing a factor of safety of 2.6. One benefit of the polyhedral design lies in the fact that no joint is necessary at the root of the wing, where the shear and bending moment are greatest.

Each end panel has a wing spar similar to the main wing spar, with the only difference being the replacement of the spruce pieces with balsa. Keeping the extremities of the aircraft lightweight will lower the moments of inertia, and thereby provide for a better maneuvering response by decreasing the lag time between the pilot input and the maneuver. The length of the end panels is 2.98' each, and they are each angled up at 15 degrees to provide an effective dihedral.

The end panels are connected to the straight center panel by a plywood elbow joint, as depicted in the accompanying picture(refer to Figure 9.2). The plywood is necessary to support the shear loads concentrated at the joint.

The airfoil shape of the Wortman FX 63-137 airfoil is maintained along the wing by 41 thin balsa ribs. The ribs are evenly spaced at three inch intervals so as to keep the Monokote from sagging in, and thus distorting the shape of the airfoil. The leading edge and trailing edge shapes are maintained by thin balsa spars, which also hold the ribs in their correct positions. The wing is connected to the fuselage by two rubber bands, one on each side of the fuselage. These rubber bands are strung between two spruce dowels protruding from the fuselage, one in front of the wing and one behind it (refer to Figure 9.3). A thin balsa sheet covers the top of the wing directly over the fuselage, as well as one inch to either side of it. This balsa sheet will provide the support needed to prevent the rubber bands from distorting the airfoil shape (refer to Figure 9.4)

9.5 Landing Gear

The placement of the landing gear coincides with the strongest structural points of the fuselage. The front wheels are located at 17.4 inches from the front of the plane, and the rear wheel is located at 51.6 inches. The 2" diameter rubber wheels are attached to the fuselage by 1/8" diameter metal rods. The large wheels were chosen in order to reduce the adverse frictional effects of the Astroturf runways in Aeroworld.

9.6 V-n Diagram

The V-n diagram shown below in Graph 9.2 illustrates the maximum loads that the craft will encounter, and was very helpful in determining the aircraft structure. The maximum load factor expected during normal operations is approximately 1.3 to 1.4. The aircraft was designed using a target factor of safety of 1.5, which yielded a limit load of 2.0. The stall limits for both the loaded and empty aircraft configurations are shown on the diagram.

Graph 9.2

V - n diagram for GOLDRUSH

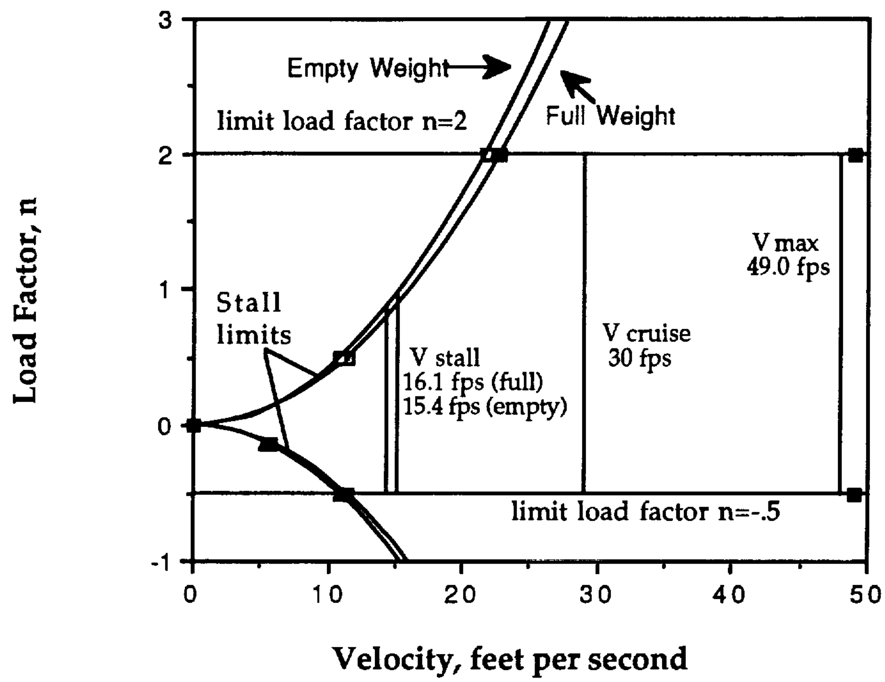


FIGURE 9.1 THE FUSELAGE STRUCTURE

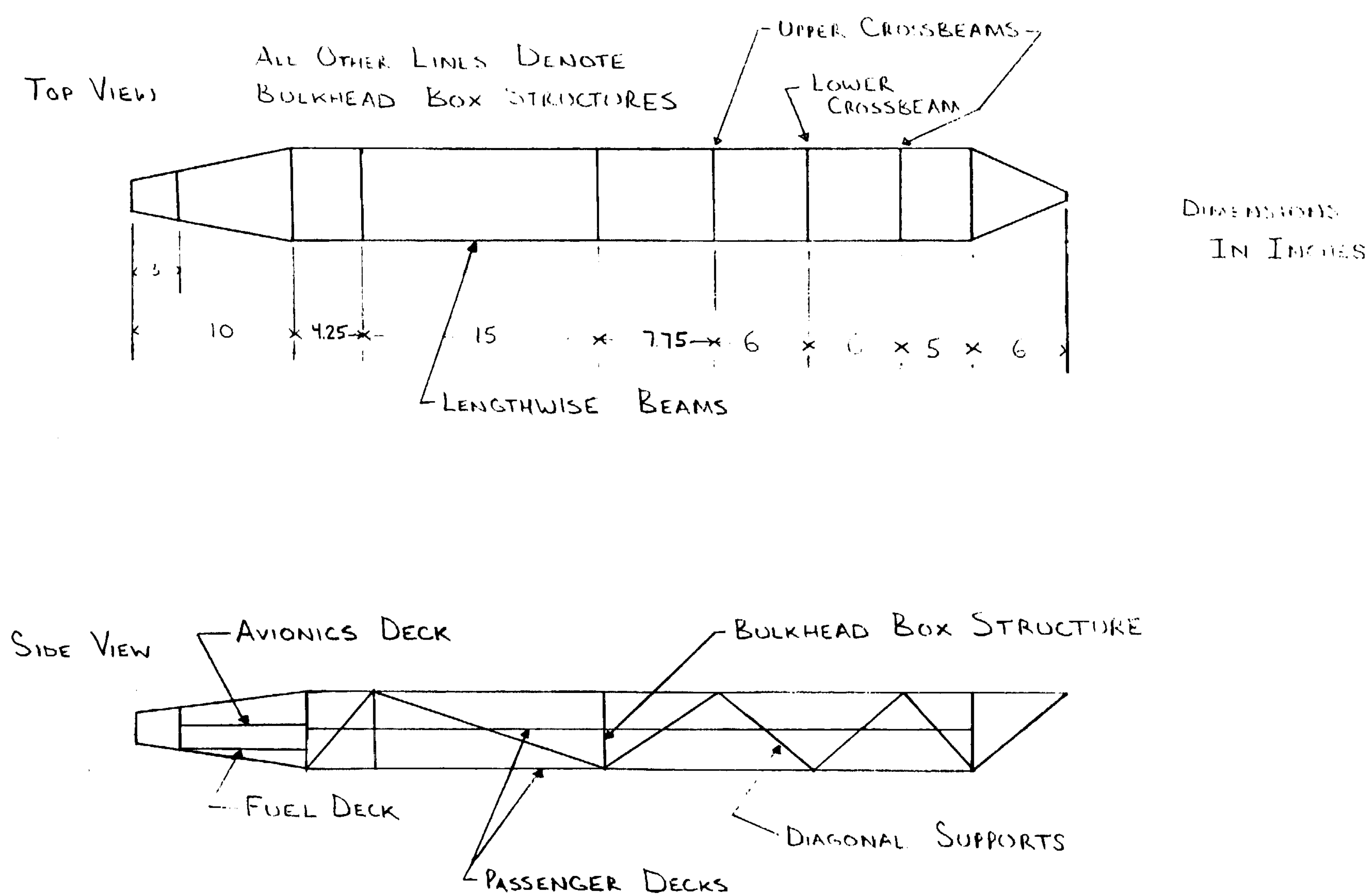


FIGURE 9.2 WING DIHEDRAL JOINT

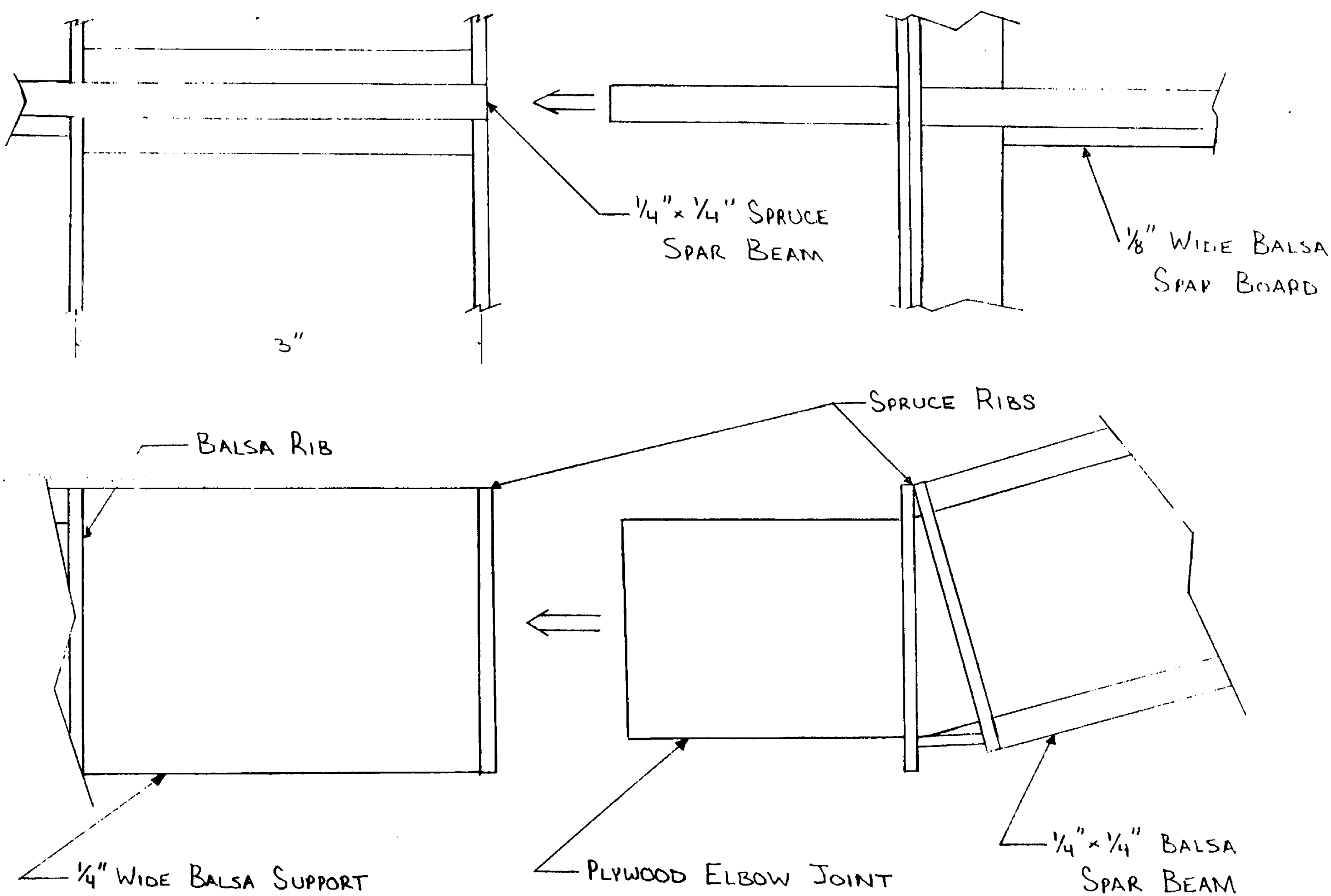


FIGURE 9.3 WING BOX STRUCTURE

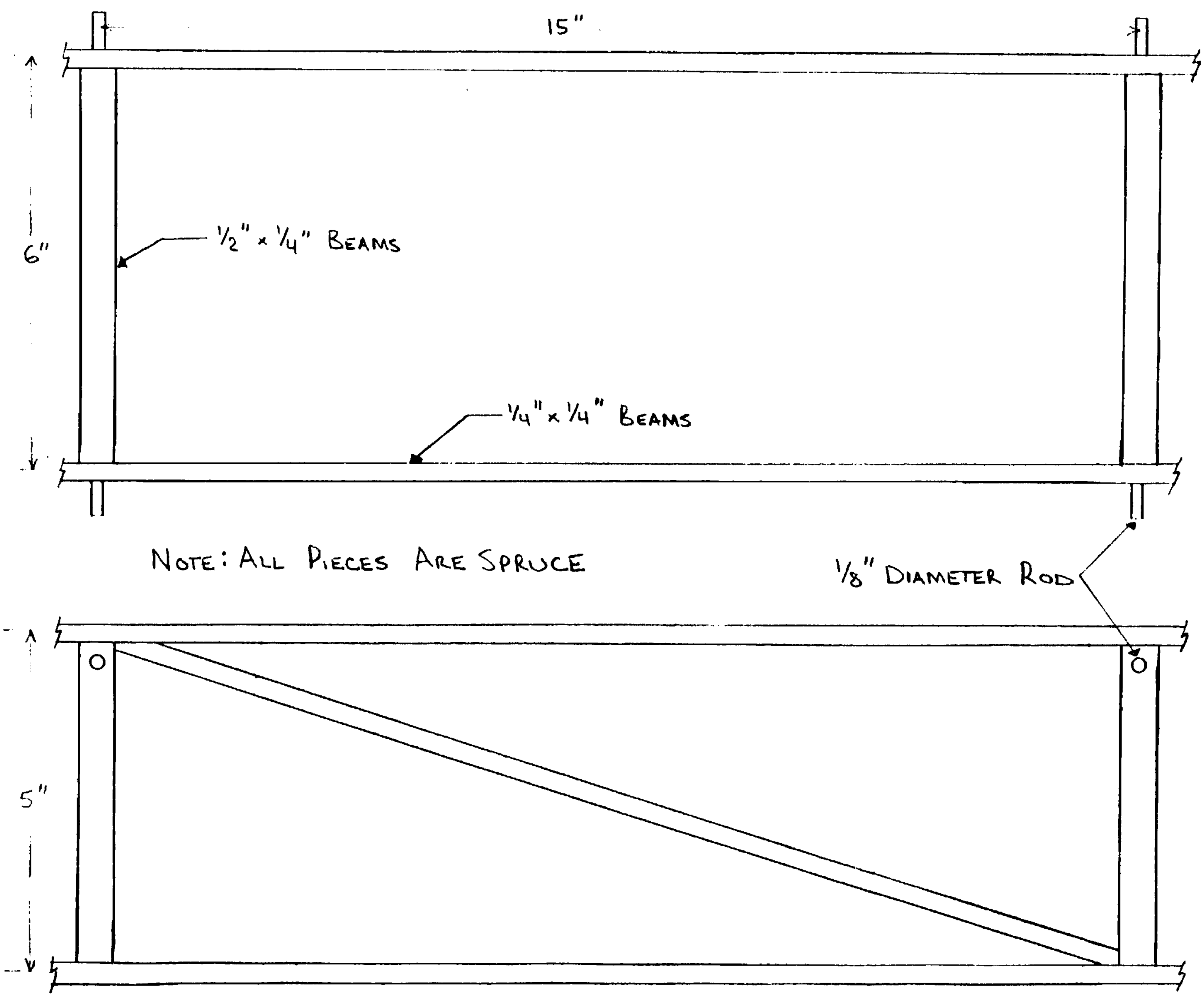
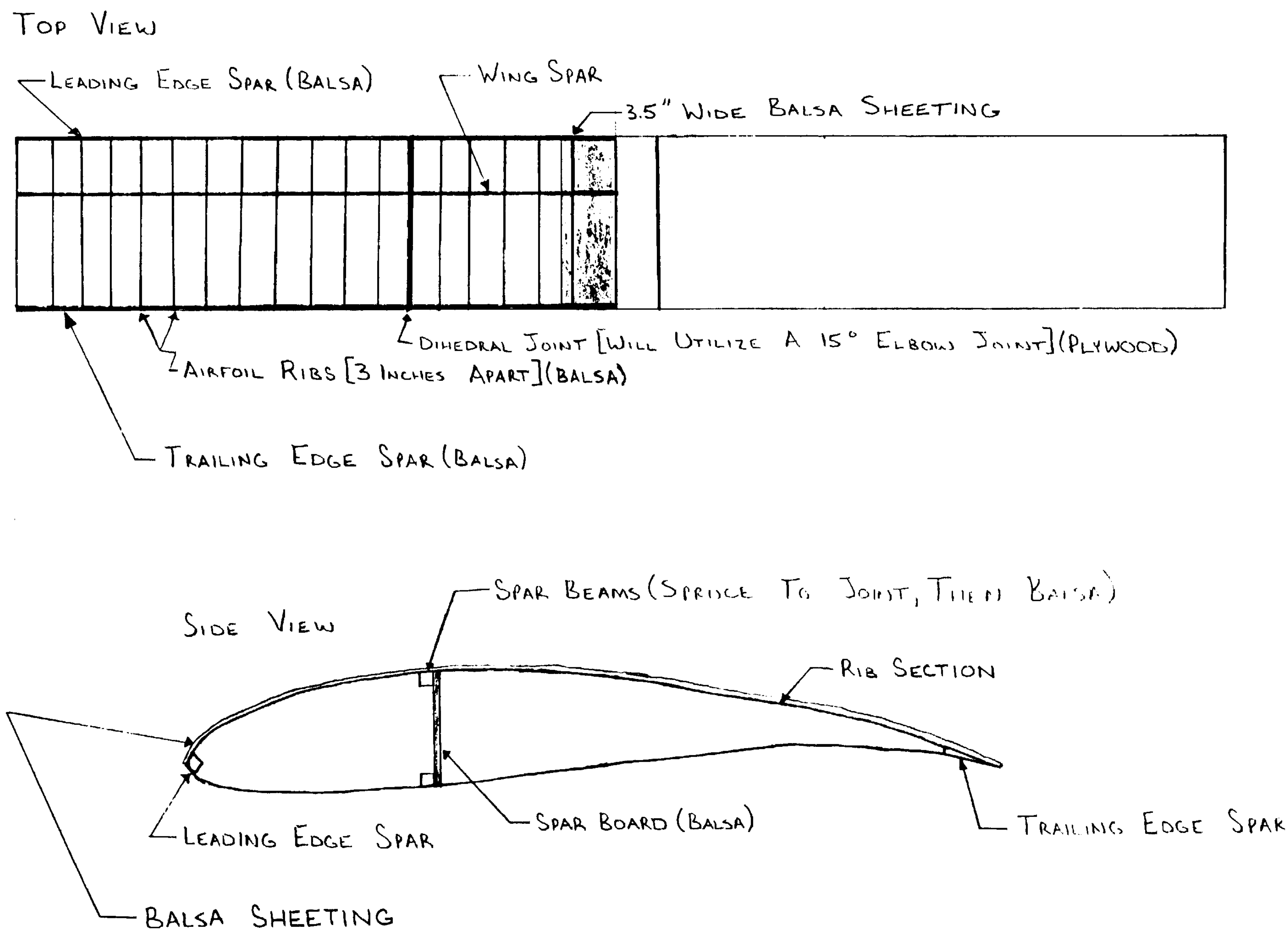


FIGURE 9.4 THE WING STRUCTURE



Section 10: Economic Analysis

10.1 The Major Goal

GoldRush was designed to compete in the Aeroworld travel market against the lone competitor, the HB-40. In order to compete effectively, GoldRush would have to be the more cost efficient aircraft. The measure of cost efficiency in Aeroworld is an aircraft's CPSPK, or cost per seat per thousand feet. Therefore, a major driving force of the design of GoldRush was to better the CPSPK of the HB-40, which was $0.009. This attention to cost efficiency was stressed throughout the design process.

10.2 Costing Factors

CPSPK is a function of the number of passengers on an aircraft, its range, and a term called the direct operating costs, or DOC. Since the number of passengers and range were set to serve a particular market, the only way to lower the CPSPK was to lower the direct operating costs. The DOC is a sum of three separate costs: depreciation costs, operation costs, and fuel costs. Each of these three terms is explained below.

Depreciation Costs

Depreciation costs represent the fact that every machine has a finite life. Therefore, the total cost of a single aircraft must be depreciated over its entire life. In order to do this, it was first necessary to determine the number of flights GoldRush could make in its finite life. With a design range of 10,000 feet (plus a two minute loiter time) and a cruise velocity of 30 feet per second, the design flight time was calculated to be 333 seconds. Assuming a lifetime of 50 hours (the Aeroworld maximum), each GoldRush aircraft could make 540 flights in its lifetime. The depreciation costs were then calculated by dividing the total cost of each aircraft by 540 flights. The total cost of each aircraft was estimated to be $2104. The breakdown of this figure can be seen in the accompanying table. Finally, the depreciation costs were determined to be $3.90 for each flight.

The depreciation cost of GoldRush was impacted bythe choice of the Astro 25 as the propulsion power plant. The increased cost of the Astro 25 raised the depreciation costs by 4%.

Operation Costs

The cost to operate GoldRush was a sum of flight crew costs and maintenance costs. The flight crew costs were simply the number of mechanical servos times the cost per servo per flight, $0.10. GoldRush, having two mechanical servos, had a flight crew cost of $0.20 per flight. The formula used to calculate the maintenance costs was number of passengers times design flight time times cost per passenger per hour. For the GoldRush's 80 passengers, the cost per passenger per hour was $0.005. As mentioned earlier, the design flight time was 333 seconds. Knowing all of this, the maintenance costs came out to be $0.037. Therefore, the operation costs were found to be $0.237.

Once the decision to use only two servos was made, the operation costs of GoldRush could not be changed. The operation costs also had less than a 4% impact on the DOC, so its impact was negligible.

Fuel Costs

The fuel cost per flight is a function of the current draw, the flight time, and the cost per amphour of battery usage. Finding the current draw involved a rather complicated formula, taking into account such factors as the maximum weight, 5.4 pounds, the cruise speed of 30 feet per second, the design L/D of 10.5, a propulsive efficiency of .59, and a throttle voltage of 9.7 volts. The current draw was calculated to be 5.2 amps. The flight time, again, was 333 seconds, and the cost per amphour of battery usage was $1.50. From these figures, the fuel costs were calculated as $0.72.

Finally, GoldRush's direct operating cost was determined to be $4.88. Knowing the DOC, it was a simple matter to compute the CPSPK. Carrying 80 passengers a distance of 10,000 feet, GoldRush has a CPSPK of $0.006. This figure is 33% less than that of the HB-40. It should be noted that the major cost of the aircraft is in the manufacturing labor costs. With proper planning, Gold Design Team should be able to lower the cost of GoldRush substantially. Gold Design Team's goal of designing a cost efficient aircraft has most definitely been met.

Choosing the Astro 25 as the motor for GoldRush actually saved 30% in fuel costs per flight due to its lower current draw at cruise and in turn reduced the DOC by a total of 8%. This is believed to be the chief advantage of GoldRush.

COST ESTIMATE TABLE

Propulsion		
	batteries	$ 39
	motor	$ 150
	propeller	$ 5
	motor speed control	$ 50
Controls		
	radio transmitter	$ 75
	radio receiver	$ 35
	switch harness	$ 5
	miniature servo	$ 35
	wiring	$ 20
Structures		
	balsa	$ 25
	spruce	$ 35
	plywood	$ 10
	landing gear struts	$ 12
	wheels	$ 8
Construction		
	labor costs	$ 1100
	tooling costs	$ 500
Total Cost		$ 2104

Depreciation costs	$ 3.90
Operation costs	$ 0.26
Fuel Costs	$ 0.72 to $ 1.44
DOC	$ 4.88 to $ 5.60
CPSPK	**$ 0.006 to $ 0.007**

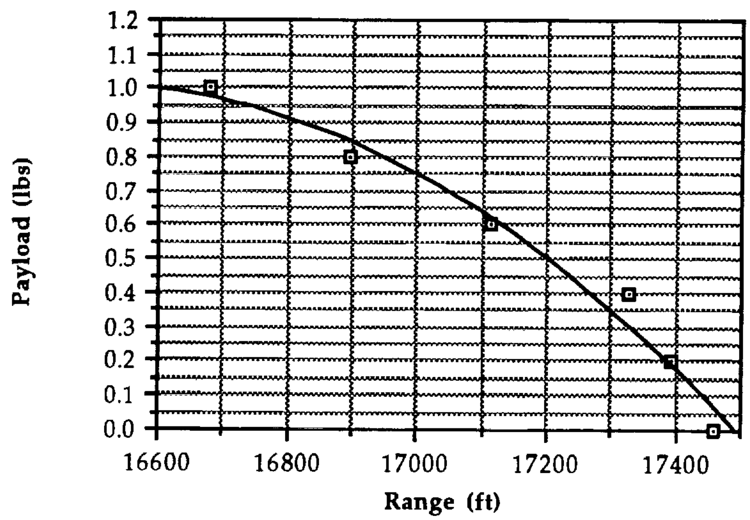
References:

McCormick, Barnes W., Aerodynamics, Aeronautics, and Flight Mechanics, John Wiley and Sons, New York, 1979.

Nelson, Robert C., Flight Stability and Automatic Control, McGraw-Hill, Mexico, 1989.

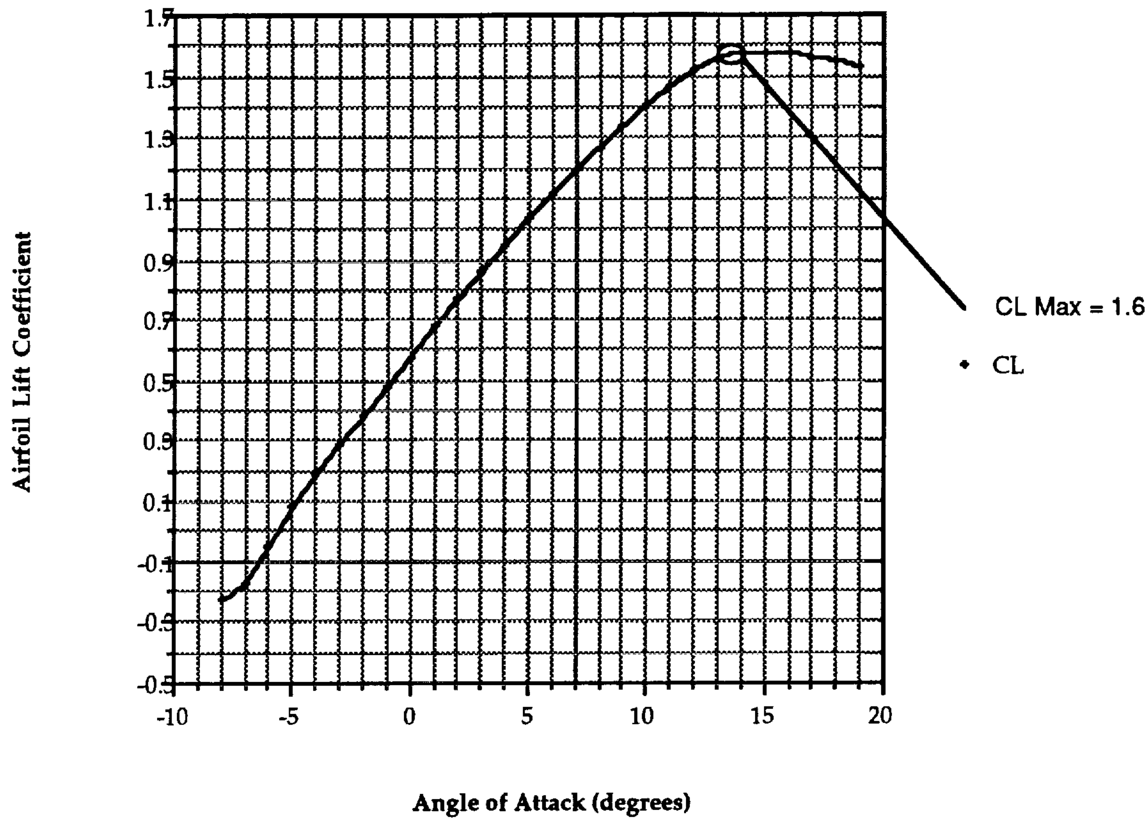
Graph 8.2

Range - Payload Diagram

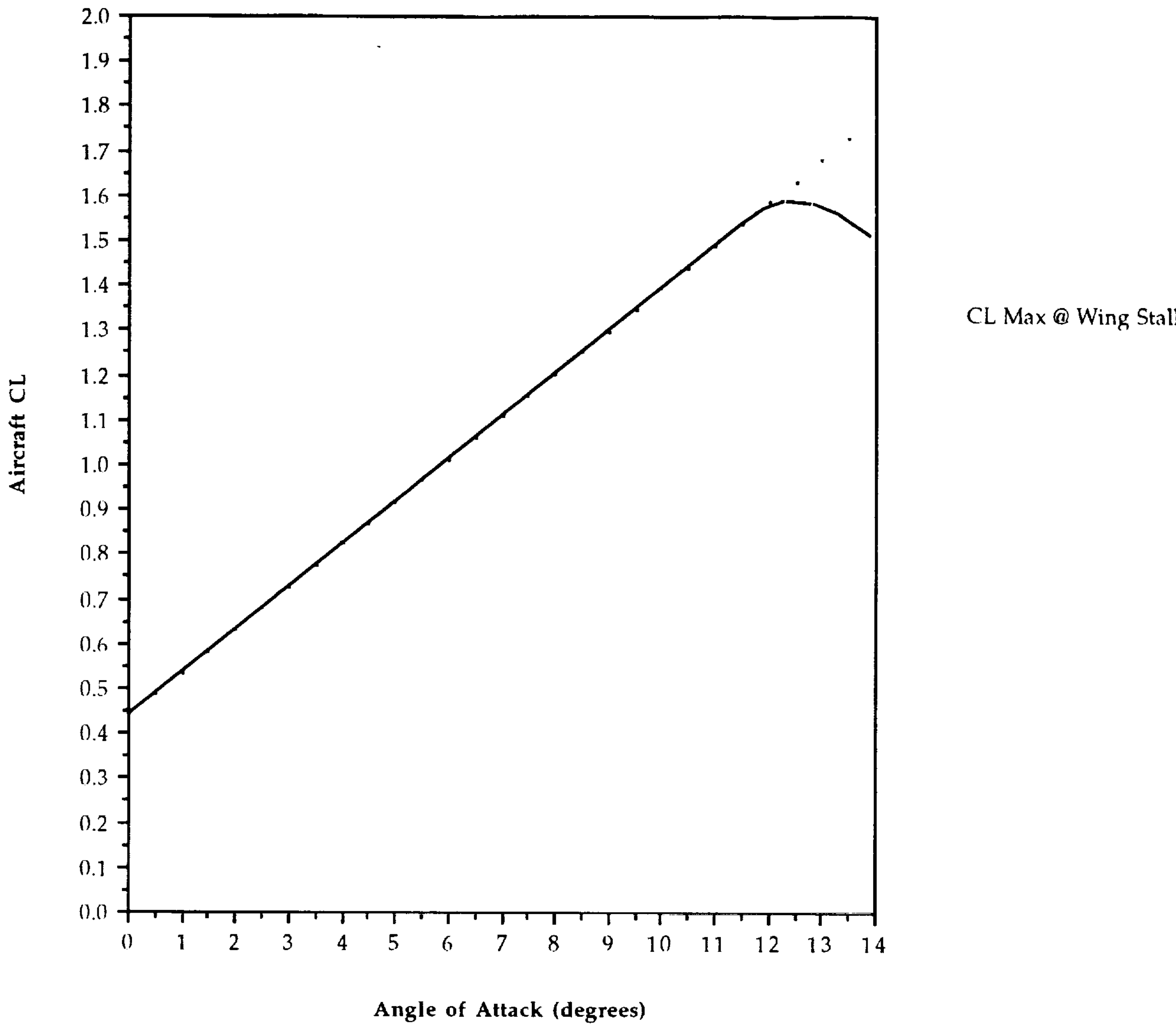


Graph 4.1

FX 63-137 Airfoil Lift Curve at Re=200,000



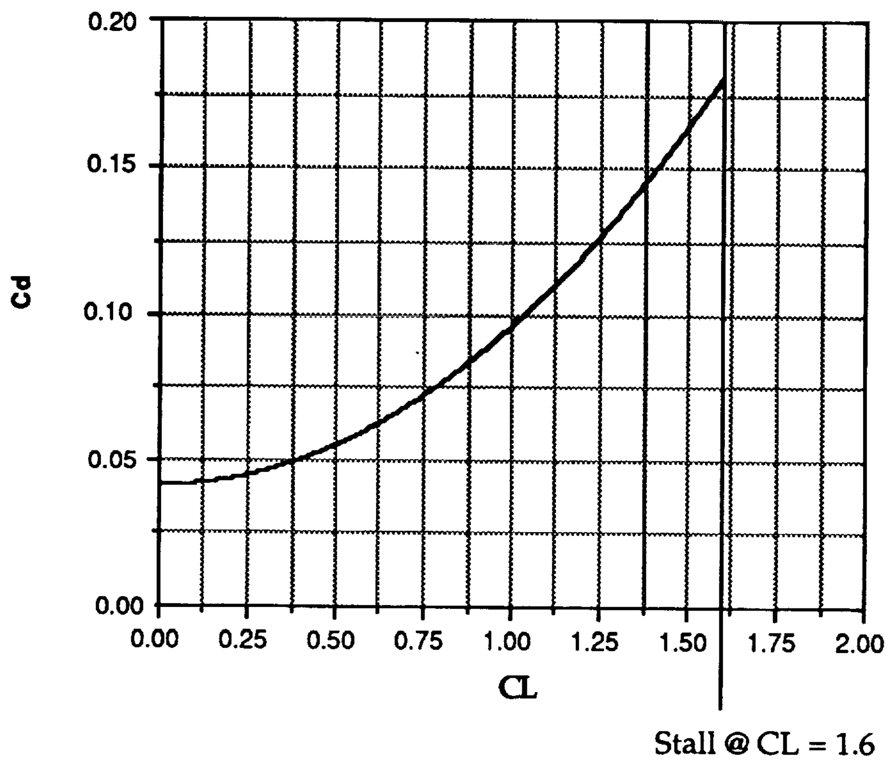
Aircraft Lift Curve



Graph 4.5

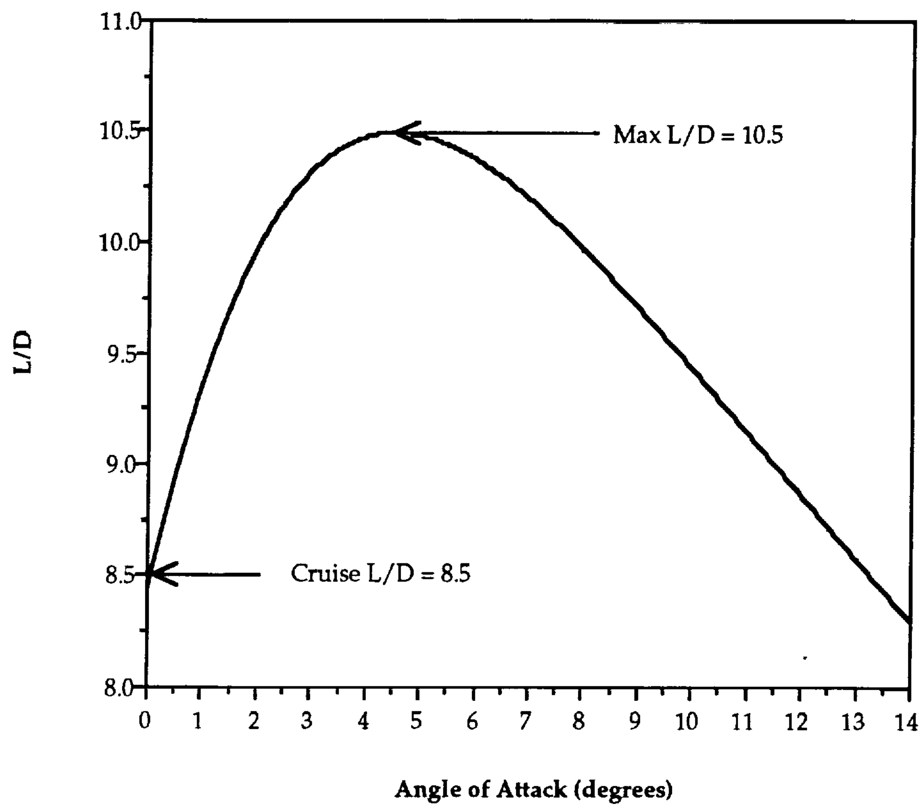
Drag Polar: GoldRush

CD = 0.0415 + 0.0547CL^2

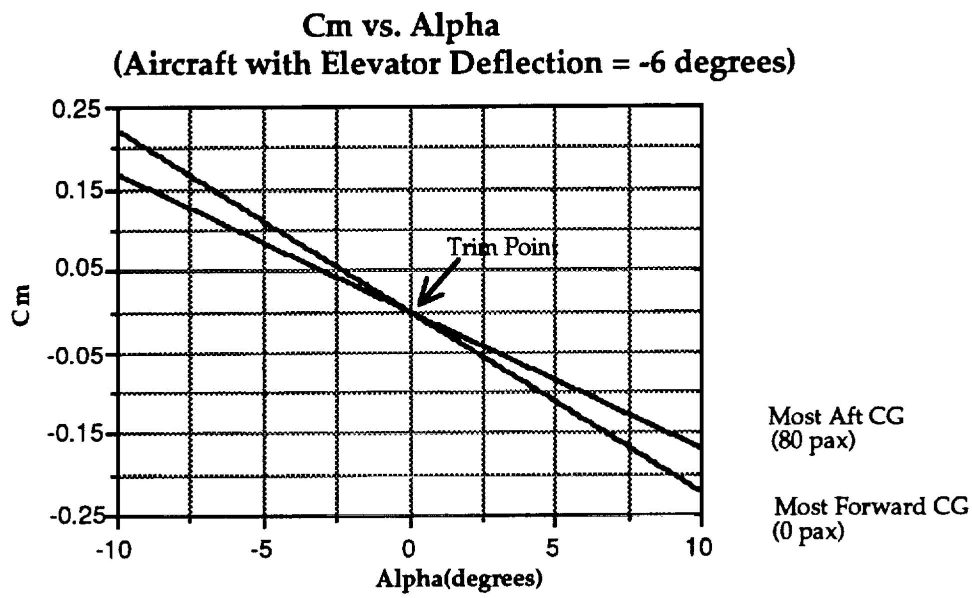


Graph 8.4

Aircraft Lift to Drag Ratio



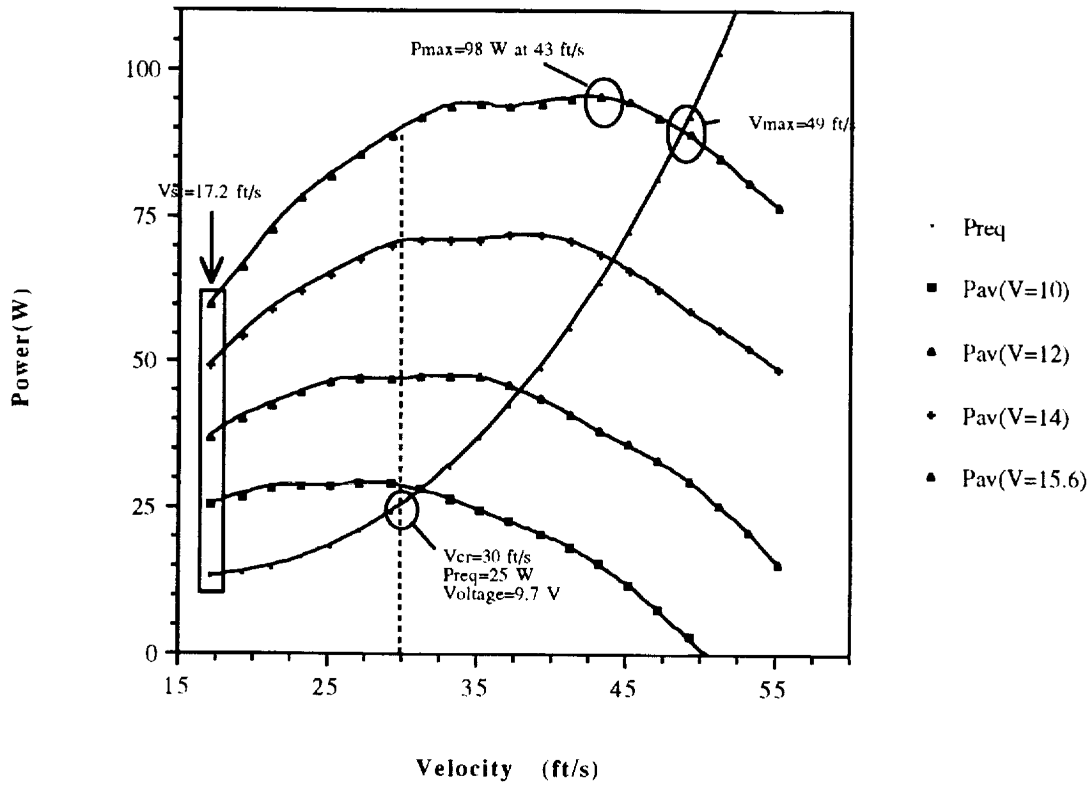
Graph 7.3



Cm vs. Alpha
(Aircraft with Elevator Deflection = -6 degrees)
0.25
0.15
0.05
-0.05
-0.15
-0.25
Cm
Trim Point
-10
-5
0
5
10
Alpha(degrees)
Most Aft CG
(80 pax)
Most Forward CG
(0 pax)

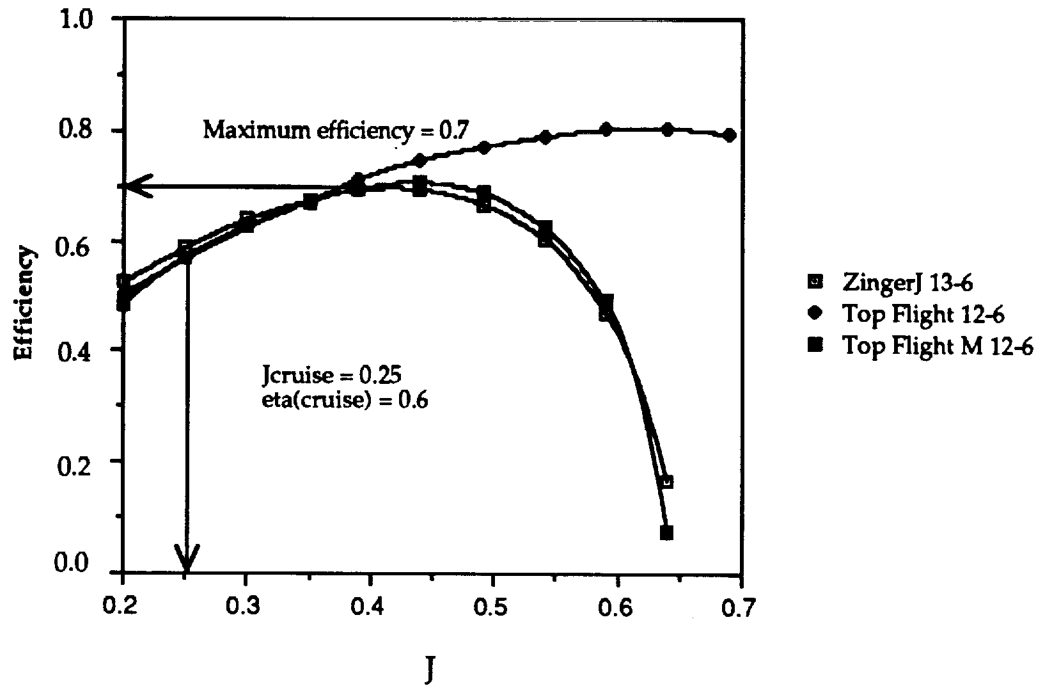
Graph 8.3

Power Available and Power Required vs. Velocity



Graph 5.3

Propeller Efficiency vs Advance Ratio for Various Propellers



Graph 6.4
Weight Balance Diagram

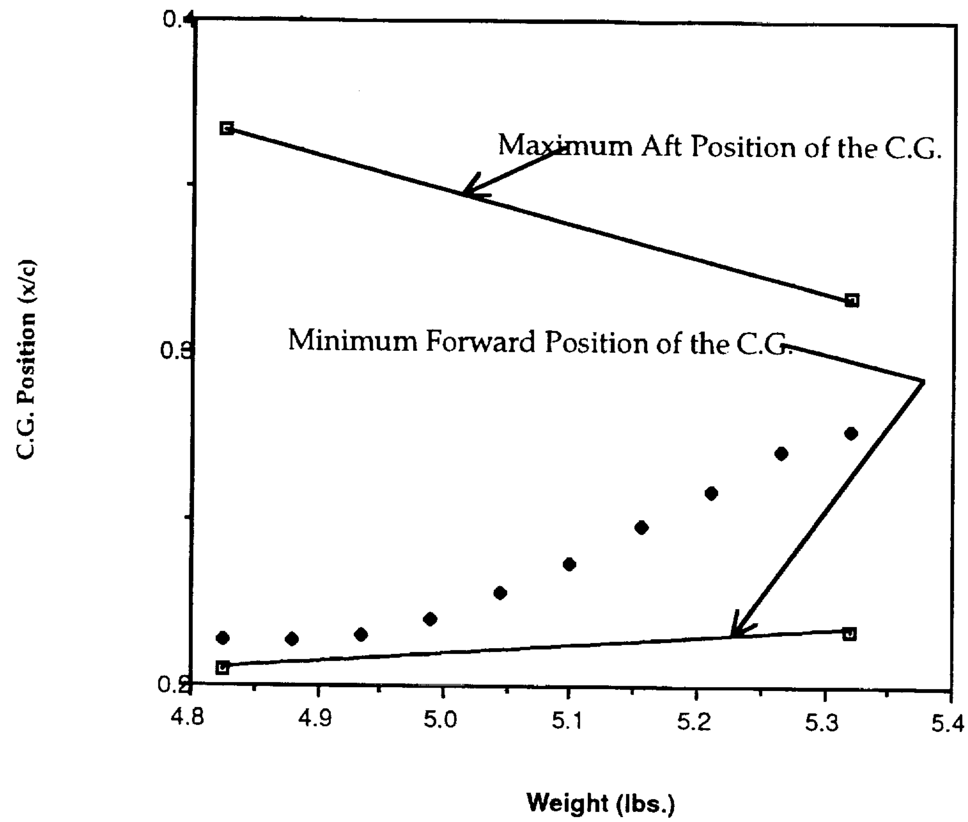
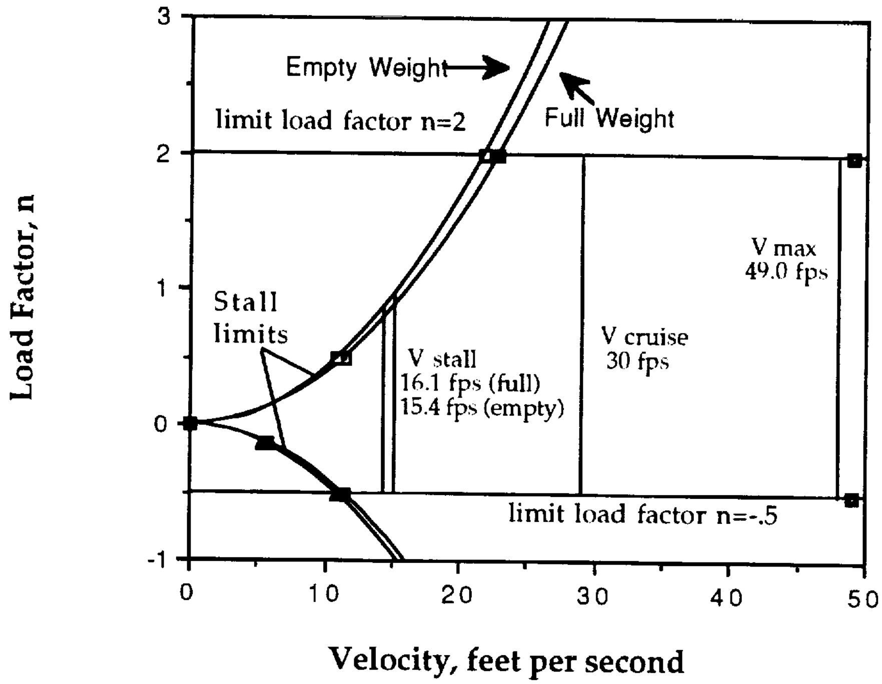


Table 6.1 Weight Estimation

Airplane Component	Weight (pounds)	% of Aircraft Weight
Fuselage	.860	17.8
Propulsion System	.946	19.6
Motor	.813	16.8
Engine Mount	.073	1.5
Propeller	.061	1.3
Fuel (13 batteries)	1.056	21.9
Avionics	.375	7.8
System Battery	.125	2.6
Servos (2)	.075	1.6
Receiver	.060	1.2
Speed Controller	.113	2.3
Landing Gear	.375	7.8
Wing	.840	17.4
Tail	.373	7.7
Total Unloaded Airplane	4.825	-
Passengers/Crew (max)	.496	(9.3)
Total Loaded Airplane	5.321	-

Graph 9.2

V - n diagram for GOLDRUSH



GoldTeam Design Proposal Certification:

Amanda Clarke

Chris Degiorgio

Edmund Galka

Albert Stumm

Lisa Valenta

Thomas Winter

Appendix A : Manufacturing Plan

A.1 Primary Structural Components

The primary structural components of GoldRush are the fuselage, the wing, the empennage, and the landing gear. The fuselage consists first of the cowling and cockpit, which extends 10 inches from the nose of the plane to the first fuselage bulkhead. Within the cowling and cockpit are housed the motor, avionics, and motor and radio batteries. Extending 44 inches from the first bulkhead is the main cabin which has a cross section 6 inches wide and 5 inches high. Finally, the main cabin tapers to a point 6 inches behind the rear fuselage bulkhead to complete the fuselage.

The wing is of polyhedral design and consists of a 3 foot span flat cross section with two 3 foot long polyhedral sections mounted at a 15 degree dihedral angle. It rests on top of the fuselage and is fastened with rubber bands attached to dowels running across the main cabin.

The empennage consists of the horizontal and vertical tail mounted at the back end of the fuselage. The integration of the two surfaces in close proximity required splitting the elevator into two sections and connecting them with a dowel to coordinate control.

The front landing gear struts are made of steel 1/8" diameter wire and are mounted to the fuselage on a plywood sheet. The rear strut is made of the same wire but is mounted directly into the leading edge of the rudder in order to provide maneuverability on the ground. The front wheels are 1.75" diameter rubber and the rear wheel is 1" diameter rubber.

The primary structural components of GoldRush can be seen in Figures A.1, A.2, A.3, and A.4. A listing of all parts needed in the construction of Gold Rush is given in Table A.1.

A.2 Pertinent Design Requirements and Objectives

The original set of design requirements and objectives dictated several strategies for the manufacturing plan. The most pertinent requirements and objectives to manufacturing were the objective to have a CPSPK lower than $0.009, to have ground manueverability, and to have the plane be transportable.

1) **Lower the CPSPK:** Since the man hours involved in production of the technology demonstrator make up about 35% of the CPSPK, reductions in construction and fabrication time were sought. There were several methods which were employed to achieve this:

a) Detailed Manufacturing Plans: Full scale drawings were developed to promote easy, quick, and repeatable construction of the components. There were separate plans for each component so they could be fabricated simultaneously. The plans will be such that wood pieces may be pinned directly to the plans and glued to their adjacent parts.

b) No Mistakes : Attempts will be made to ensure that all pieces are cut correctly the first time. The detailed manufacturing plans are hoped to help achieve this. Each piece on the plans will be labeled with its size and wood type, and pieces may be sized directly on the plans to guarantee that they will fit snugly with adjoining pieces. Lowering the number of construction errors lowers the number of man hours as well as sparing the need for excess materials cost penalties.

c) Unique Manufacturing Methods : Some time consuming tasks such as wing rib cutting are targeted for more efficient production. Wing rib sheeting will be stacked so that several identically shaped ribs will be cut at the same time. The leading and trailing edges of the wing were purchased pre-shaped from subcontractors.

2) **Ground Maneuverability** : The tail wheel configuration of GoldRush required consideration of several methods of achieving ground maneuverability. Plastic control mechanisms could have been purchased which would offer ground control, but would require the installation of a heavy plywood bulkhead at the rear of the plane. GoldTeam opted to mount the rear strut directly into the rudder hinged edge to avoid the addition of a bulkhead or the complexity of splitting control from one servo to two applications. This will be a crucial region during construction. The wheel strut must pass through the back end of the cabin and near several fuselage bulkheads. This is further complicated by the fact that the horizontal tail is also acting in the same region and must be accounted for.

A.3 Critical Issues

Several areas of GoldRush's construction will crucially influence the success of its maiden voyage.

1) **Fuselage joints** : The length of the fuselage is 44" while the longest piece of available spruce is 36". This requires a splice joint at some point along

the length of the fuselage. Failure to properly join these pieces could result in failure of the fuselage truss structure.

2) **Elevator Dowel** : The elevator is split into two halves so that its deflection does not interfere with the deflection of the rudder. This required the transfer of control from one half of the elevator to the other through a dowel at the elevator leading edge. Another connection may be required at the trailing edge of the elevator to ensure that the two halves move in unison.

3) **Rear wheel connection to rudder** : This region will experience high stress upon landing. It is hoped that the hinge of the vertical tail will support this stress. The rear landing strut will be bent so it will absorb some of the impact of landing.

4) **Airfoil rib cutting** : Since the ribs are being manufactured several at a time, extra care will have to be taken as not to make a mistake. In addition, possible sanding required to smooth the ribs' shape may change the effective airfoil shape. Care will have to be taken to avoid this if at all possible.

5) **Balsa sheeting at wing root** : The rubber bands which attach the wing to the fuselage will rest over a reinforced airfoil section at the wing root. This will be reinforced by covering the top of the root with 1/16" thick balsa sheeting.

A.4 Construction Sequence

GoldTeam will be split into two-person teams which will attack the individual components of GoldRush. Simultaneous construction of the wing, fuselage, and empennage should be possible with the use of the manufacturing drawings, the efficient use of allotted space in the construction facilities, and proper scheduling. The following sequence is planned for fabrication of GoldRush:

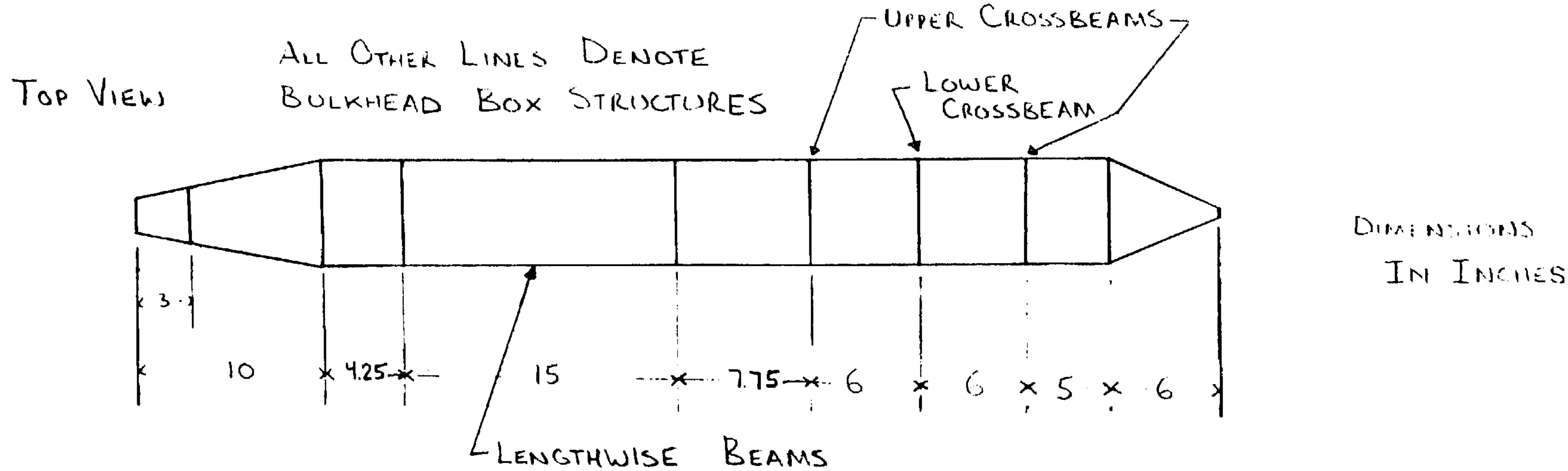
Tues. Apr. 13	Materials purchased
Thu. Apr. 15	Manufacturing drawings completed
Tues. Apr. 20	Wing root section completed Fuselage completed Vertical Tail completed
Fri. Apr. 23	Wing Tips completed Cockpit completed Horizontal tail completed
Sat. Apr. 24	Apply Monokote
Sun. Apr. 25	Install landing gear Integrate empennage to fuselage Install avionics and propulsion systems
Tues. Apr 27	TAXI TEST!

A.5 Materials Costs Table

As of the Manufacturing Plan Review the following materials had been purchased for GoldRush's fabrication:

Spruce	$17.16
Balsa	$44.57
Control Items	$ 5.39
Monokote	$35.16
Rubber Bands	$ 2.65
Wheels	$ 5.27
Propeller	$ 4.19
Glue	$ 7.98
Misc.	$ 4.13
TOTAL	$ 126.50

FIGURE A.1 THE FUSELAGE STRUCTURE



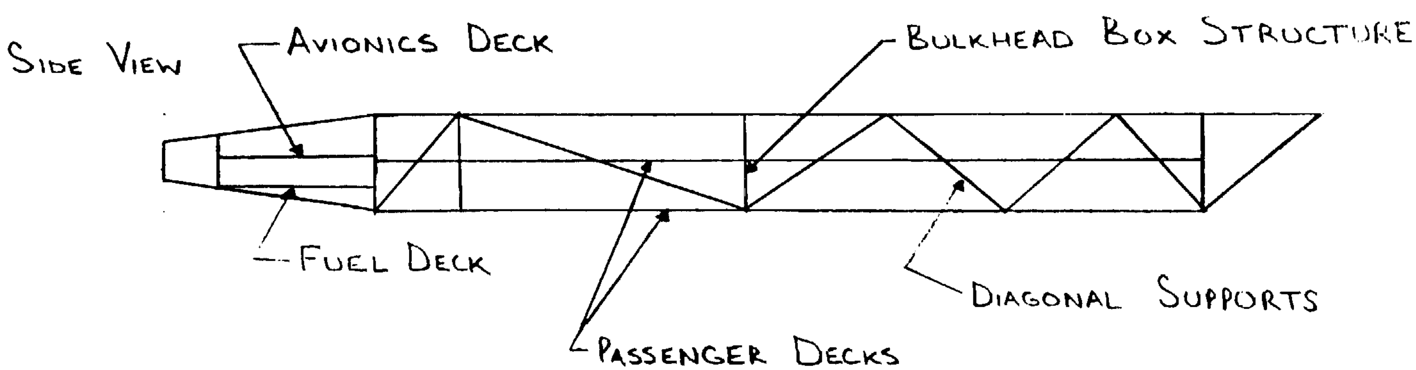


FIGURE A.2 WING BOX STRUCTURE

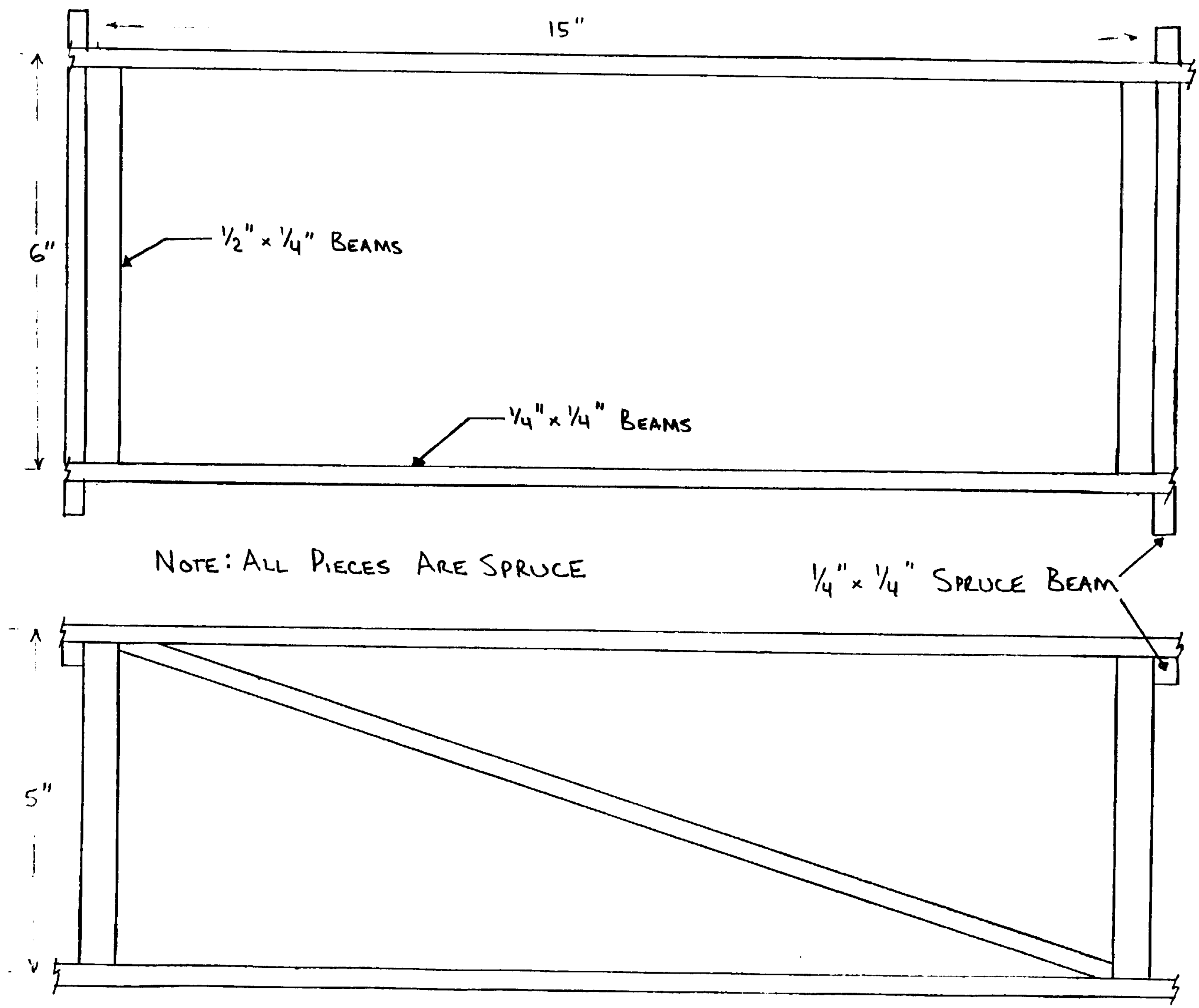
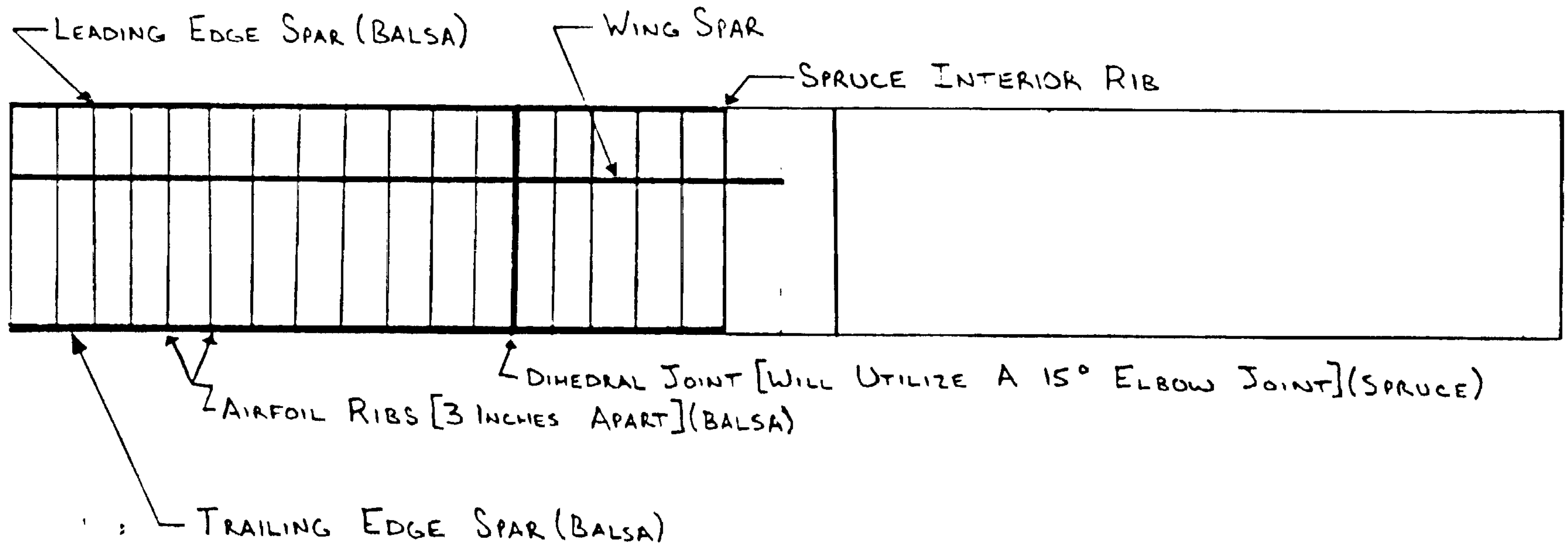


FIGURE A.3 THE WING STRUCTURE

Top View



Side View

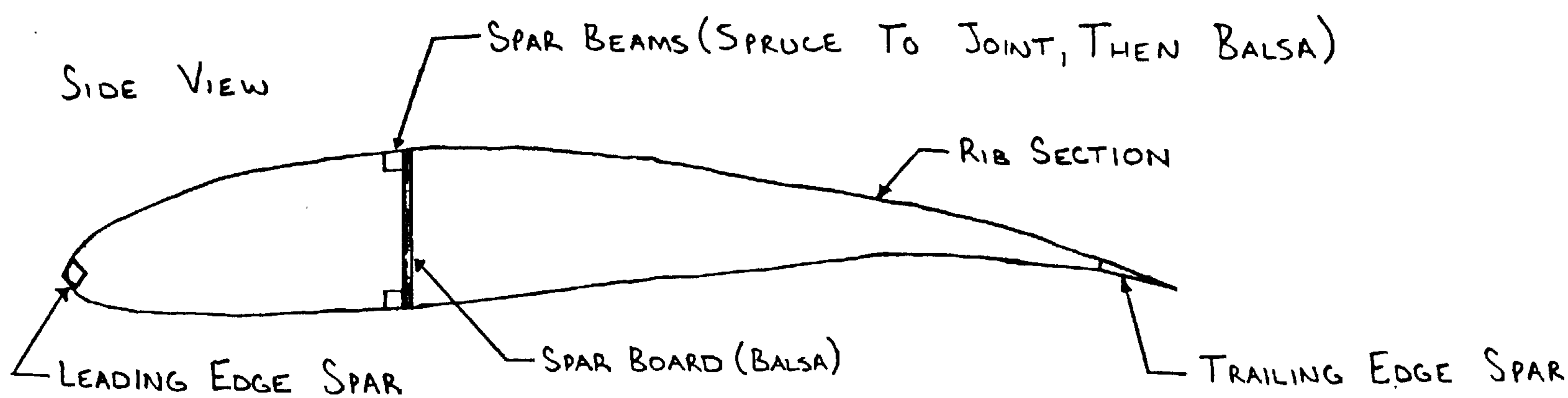


FIGURE A.4 WING DIHEDRAL JOINT

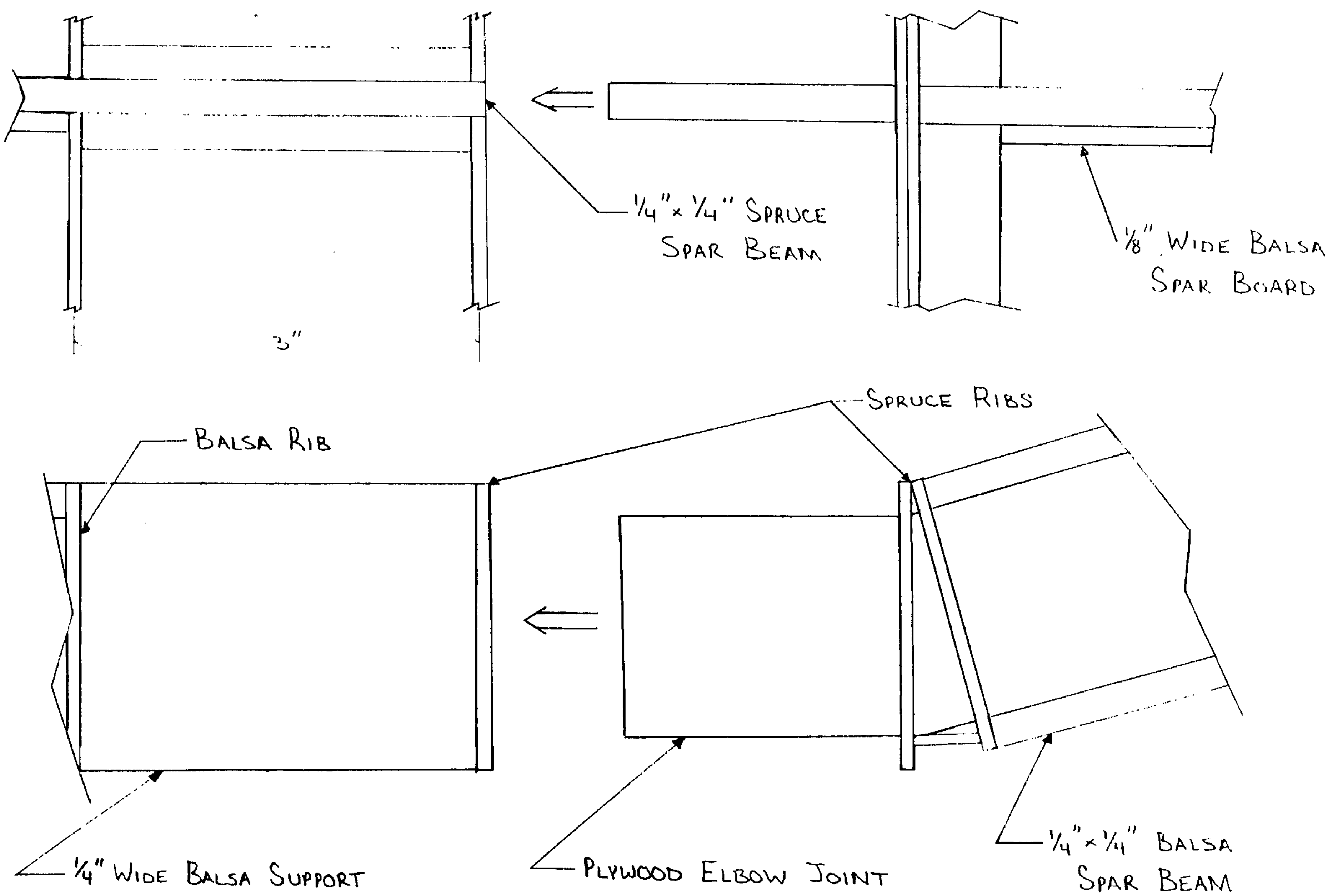


Table A.1 Complete Parts Count for GoldRush

NOTE: Abreviations or symbols are explained at the end of the table.

COMPONENT AREA	MATERIAL	QUANTITY	LENGTH	AREA
FUSELAGE				
NOSE:				
Front Box	B	4	2	(1)
Cowling Edge	S	4	10.3	(1)
Horizontal Bulkhead 1	S	2	3.2	(1)
Vertical Bulkhead 1	S	2	2.9	(1)
Horizontal Bulkhead 2	S	2	6	(1)
Vertical Bulkhead 2	S	2	5	(1)
Fuel Deck	B	1	7	3.2 x .125
Avionics Deck	B	1	7	3.2 x .125
Servo Deck	B	1	5.5	1.5 x .125
Aft Deck Supports	B	2	5.5	(1)
Forward Deck Supports	B	2	3.2	(1)
Diagonal Deck Supports	B	2	7.7	(1)
MAIN BODY:				
Fuselage Edge	S	4	44	(1)
Horizontal Wing Bulk.	S	4	5.5	(2)
Vertical Wing Bulkhead	S	4	4.5	(2)
Wingbox Diagonal	S	2	15.8	(1)
Wingbox Dowels	S	2	7	(1)
Fuselage Diagonal 1	B	2	6.6	(1)
Fuselage Diagonal 2	B	2	9.2	(1)
Fuselage Diagonal 3 & 4	B	4	7.8	(1)
Fuselage Diagonal 5	B	2	7.1	(1)
Horizontal Cross Pieces	B	3	5.5	(1)
Horizontal Rear Bulk.	S	2	5.5	(1)
Vertical Rear Bulkhead	S	2	4.5	(1)
Passenger Decks	B	2	44	5.5 x .031
Upper Deck Supports	B	3	5.5	(1)
TAIL:				
Upper Diagonals	S	2	6.7	(1)
Lower Diagonals	S	2	8.2	(1)

COMPONENT AREA	MATERIAL	QUANTITY	LENGTH	AREA
WING				
SPAR:				
Midpanel Beams	S	2	36	(1)
Outerpanel Beams	B	4	35.7	(1)
Webbing	B	34	3	2.1 x .125
RIBS:				
Regular Ribs	B	35	15	Airfoil
Dihedral Joint Ribs	S	6	15	Airfoil
MISCELLANEOUS:				
Leading Edge	B	1	36	Semicircle
		2	35.7	r=.125
Trailing Edge	B	1	36	Triangle
		2	35.7	h=1 b=.25
Elbow Joints (15°)	S	2	4	t=.125
Joint Webbing Support	B	4	3	2.1 x .25
Root Sheeting	B	1	15	7 x .031
EMPENNAGE:				
HORIZONTAL TAIL:				
Leading Edge	B	1	27.6	(1)
Tail Rear Spar	B	1	27.6	(1)
Tail Rear Edge	B	1	6.5	(1)
Lengthwise Braces	B	4	2	(1)
	B	2	6.25	(1)
Elevator Front Spar	B	2	9.25	(2)
Elevator Trailing Edge	B	2	9.25	(1)
Elevator Braces	B	6	6.25	(1)
VERTICAL TAIL:				
Leading Edge	B	1	17	(1)
Spar	B	1	17	(1)
Braces	B	4	5.45	.25 x .125
Bottom Brace	B	1	5.45	(1)
Rudder Leading Spar	S	1	11	(2)
Rudder Trailing Edge	B	1	11	(1)
Rudder Braces	B	4	6.55	.25 x .125

COMPONENT AREA	MATERIAL	QUANTITY	SIZE or TYPE
LANDING GEAR			
Forward Wheels	Rubber	2	d= 1.75
Tail Wheel	Rubber	1	d= 1
Struts	Steel Wire	2	d= .125
Reinforcement	Plywood	1	6 x 3 x .125
Mounts	Nylon	2	-
AVIONICS AND PROPULSION			
Engine	-	1	Astro 25
Propeller	Wood	1	Zinger 13-6
Batteries	-	13	900 mah P90SCR
Servos	-	2	-
Control Rods	Plastic	2	-
System Battery	-	1	-
Speed Controller	-	1	-
Receiver	-	1	-

NOTE:

MATERIALS:	B	denotes balsa
	S	denotes spruce
AREA	(1)	denotes .125 x .125 inch cross section
	(2)	denotes .125 x .5 inch cross section

All dimensions given are in inches.

Appendix B: Technology Demonstrator

B.1 Introduction

Often the manufactured product is not exactly the same as the designed product because, due to unforeseen manufacturing difficulties, the design can not be easily made into a product. The manufacturers of GoldRush were faced with a few of these problems. Although some difficulties did arise, the problems were kept to a minimum by a well-thought-out and detailed manufacturing plan. In addition to reducing the number of necessary changes, the GoldRush manufacturing plan also made the process run smoothly and quickly, which allowed ample time for final adjustments before the test date for the demonstrator. The following paragraphs will discuss some of the major changes and difficulties encountered during the process.

B.2 Technical Issues

Just before the manufacturing process was about to begin, members of GoldRush Design Team were informed by experienced designers that the elevator size was too large for its type of remotely piloted vehicle. Because of its inordinately large area, the elevator would be too sensitive to small deflective inputs from the pilot, and thus the airplane might be difficult to fly and possibly be in danger of crashing. Therefore, in order to avoid these disasters, utilizing the advice of the previously mentioned experts, the elevator was reduced to one-third the size of the horizontal tail and the entire horizontal tail was moved 4 inches aft. This will allow the aircraft to trim, but a larger elevator deflection than originally planned will be necessary to do so. This also avoided a conflict between elevator and rudder deflection paths.

Also, after construction was complete, it was necessary to move the center of gravity aft by adding dummy weights in the tail in order to obtain the static margin desired. The total weight added to the tail section was 3.2 ounces. In addition, to aid in this endeavor, the battery pack was shifted 3 inches aft. These adjustments located the center of gravity at the quarter chord.

Also, during a post-construction test, the craft was lifted by supports located at 70% of the span length on both sides. During this test, the dihedral joint failed. This joint was reinforced by replacing the balsa supports with spruce supports. In addition to this replacement, the joints were reinforced with packing tape. The packing tape served two purposes. It not only strengthened the joints of the wing, but it also properly aligned the trailing edges of each wing segment.

Other unsuspected difficulties that arose during the manufacturing process involved the movable tail wheel. Integration between the wheel and the rudder was difficult, but was accomplished successfully. Since the vertical tail must absorb a large impact load upon landing through the tail wheel, it was necessary to 'beef up' the vertical tail's attachment to the fuselage.

Another problem involved the front landing gear which is made of one-eighth inch diameter steel rod. When this gear supported the aircraft's weight, it flexed more than was originally anticipated. This factor jeopardized the desired takeoff angle of attack, as well as put the propeller perilously close to the ground. Also, it was feared that the gear would collapse completely upon exposure to a severe landing load. Thus, in order to combat the dangerous situation, a thirty pound fishing line was used to reinforced the gear.

B.3 Manufacturing Costs:

The actual manufacturing time of 81.25 man-hours was 19% lower than the predicted time of 100 man-hours. This was judged to be due to several factors. First, the original estimation was somewhat arbitrary. Second, because of the manner in which the wing and tail were attached to the fuselage, the simultaneous manufacture of all three components was possible. Also, because of this, the integration of the components was simplified and required very little time. Third, several members of GoldTeam are experienced with the techniques employed during construction.

Component	Man-hours	Percent of Total
Fuselage	15.25	19%
Wing	23.5	29%
Tail	5.75	7%
Systems Installation	17.0	21%
Covering	19.75	24%

The total cost associated with fabricating GoldRush consisted of materials costs, labor costs, systems costs and tooling costs.

Materials Costs	$135
Systems Costs	$425
Tooling Costs:	$81
Labor Costs:	$812
Total:	**$1453**

These values produce a DOC of $5.43 per flight and a CPSPK of $0.005. This actual value of GoldRush's CPSPK is lower than the predicted value of $0.006.