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NASA-CR-197173

NASw-4435

CABIN FUSELAGE STRUCTURAL DESIGN WITH ENGINE INSTALLATION AND CONTROL SYSTEM

S94-1B-3R3
05/03/94

QUEST-3

AE 421-01 BRAVO

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(NASA-CR-197173) CABIN FUSELAGE STRUCTURAL DESIGN WITH ENGINE INSTALLATION AND CONTROL SYSTEM (Embry-Riddle Aeronautical Univ.) 71 p

N95-12639

Unclas

G3/05 0026159

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1. Project Summary:

1.1 Statement of work requirements:

The Statement of Work (SOW) describes requirements for the cabin, cabin system, flight controls, engine installation, and wing-fuselage interface. The design must provide adequate interior volume for occupant seating, cabin ingress and egress, and occupant safety.

The fuselage structure must be sufficient to meet the loadings specified in the appropriate sections of Federal Aviation Regulation Part 23 (FAR 23). The critical structure must provide a safelife of 10^6 load cycles and 10,000 operational mission cycles.

The cabin seating and controls must provide adjustment to account for various pilot physiques and to aid in maintenance and operation of the aircraft. Seats and doors shall not bind or lockup under normal operation. Cabin systems such as heating and ventilation, electrical, lighting, intercom, and avionics must be included in the design.

The control system will consist of ailerons, elevator, and rudders. The system must provide required deflections with a combination of push rods, bellcranks, pulleys, and linkages. The system will be free from slack and provide smooth operation without binding.

Environmental considerations include variations in temperature and atmospheric pressure, protection against sand, dust, rain, humidity, ice, snow, salt/fog atmosphere, wind and gusts, and shock and vibration.

1.2 Design goals:

The following design goals were set to meet the requirements of the statement of work: safety, performance, manufacturing, and cost. To prevent the engine from penetrating the passenger area in the event of a crash was the primary safety concern. Weight and the fuselage aerodynamics were the primary performance concerns. Commonality and ease of manufacturing were major considerations to reduce cost.

1.3. Critical Design Parts:

Table 1.1 shows a summary of stresses, margin of safety, and sources of the critical design loads.

DWG #, Item #	Description	Source of Load	Stress (Load)	Margin of Safety (Type)	Page of Substantiation
S94-1B-301	Fuselage Skin	1670 lb. upward shear	120.5 psi	0.3295	9
S94-1B-301-9	Firewall	1296 in lb. torque	20.37 psi	46.69	13
S94-1B-301-2	Front Bulkhead	1670 lb. upward shear	1310 lb.	2.655	13
S94-1B-302 -12	Thrust Tube Bolt	18 g's	1773 psi	4.7 (Yield)	17
S94-1B-302-8	Thrust Tube Pin	18 g's	3978 psi	3.7 (Yield)	16
S94-1B-302-9	Pin Bolt	18 g's	2004.3 psi	1.8 (Yield)	16
S94-1B-302-2	Thrust Tube	9 g's fwd	459.3 lbs	4.7 (Buckling)	16
S94-1B-302-9	Engine Mount Bolt	+4.4 g's	1137 psi	3.23 (Yield)	15
S94-1B-302-6	Engine Mount	1.5 side	20,235 psi	2.22 (Yield)	15
S94-1B-302- 6	Engine Mount	9 g's fwd	37,033 psi	1.22 (Yield)	13
S94-1B-302- 6	Engine Mount	-2.2 g's	9471 psi	4.8 (Yield)	14
S94-1B-302-6	Engine Mount	+4.4 g's	15,460 psi	2.91 (Yield)	14
S94-1B-303-19	Control Stick	Pilot Input (167lb)	27,744 psi	0.51 (Yield)	17
S94-1B-303-14	Cast Stick Mount	Control Stick	12,323 psi	0.785 (Yield)	18
S94-1B-303-12	Torque Tube	Cast Stick Mount	3959 psi	8.85 (Ult.)	19
S94-1B-303-13	Elevator Pushrod	Control Stick	6927.7 psi	0.547 (Ult.)	19
S94-1B-303-8	Pushrod Coupling	Elevator Pushrod	4351.7 psi	1.154 (Ult.)	20
S94-1B-303-5	Bellcrank (E1)	Elevator Pushrod	21,759.2 psi	0.746 (Yield)	20
S94-1B-303-4	Cable	Bellcrank	(586.5 lb.)	2.00 (Ult.)	21

Table 1.1: Summary of Critical Design Parts.

2. Description of the Design

The general configuration of the aircraft can be seen in Drawing S94-1B-301. The aircraft is a twin boom, mid wing, pusher configuration with tricycle landing gear. The total gross weight and the empty weight are about 2005 and 1200 lbs respectively. The original two-seater preliminary design was modified to accommodate a third person, which resulted in a 200 lbs weight gain. This was done to comply with the Gemini flight training program in use at Embry-Riddle Aeronautical University and other flight training schools. In addition to adding the third seat, the engine was changed from a Lycomming O-320 to Rotax 914. Since the Rotax 914 is smaller in size compared to the Lycomming O-320, the fuselage was reshaped into a more streamlined body. The engine change resulted in a weight reduction of approximately 100 lbs. To account for the net weight increase of about 100 lbs, the wing and tail surfaces were enlarged.

The rear seat was changed from a regular JAARS to a rear JAARS seat to save weight and reduce interior volume. A two door configuration was selected instead of a three door configuration, for ease of manufacturing and reduced cost. The fuel tanks were moved away from the fuselage to eliminate potential fire hazards in the cabin, after a crash.

Other design changes and descriptions are stated below as, the fuselage structure, engine mount & crash tubes, control systems, and instrument panel.

2.1. Fuselage Structure

The cabin-fuselage structure will provide a stiff structure that will maintain shape, carry all flight, landing, and ground loads, and provide occupant safety as specified in the FAR 23. All load bearing structure is an aluminum, semimonocoque construction. Applied loads are carried through longerons, frames, and bulkheads and reacted through the skin.

Cabin-fuselage structure configuration (S94-1B-301 Sheets 2-4) is based upon the continuous spar wing carry through. The 3-piece wing will be designed to have a center section between the tail booms. Both front and rear spars will be continuous in the center section and pass through the fuselage aft of the cabin and forward of the engine. Fuselage bending loads are carried by 4 Z-section floor longerons and 6 C-section side longerons. Overhead structure consists of a single C-section longeron to which the gull-wing doors will be hinged, shoulder harnesses attached, and HVAC air will be ducted. The enclosed floor box consists of the floor panel, floor longerons, panel stiffening stringers, and lower skin. All control linkages are contained within the volume of the floor box. The Z-section floor longerons are spaced to provide a mounting surface for the JAARS seats. The outside longerons extend to the aft end of the fuselage where they attach to the engine mount. The upper side longeron doubles as the door frame in the mid fuselage. The lower side longerons extend to the aft end of the fuselage where they attach to the engine mount.

Cross section shape is maintained by a forward bulkhead, forward, mid, and aft ring frame, and the firewall. The engine is mounted in the pusher configuration to the firewall. Additional support is provided by the floor and side longerons. The nose cone and engine cowling with integral air scoops will be made of weight saving composites. The nose cone will provide high energy absorption when crushed, to aid in occupant protection during an emergency landing. The forward bulkhead is the mounting point of the nose gear. The lower portion of the bulkhead is angled aft to prevent the fuselage from "digging in" during an emergency landing where the nose gear has failed.

2.2. Engine Mount:

The location of the mounting bolts and the arrangement of the exhaust system on the Rotax 914 forced the designers to adapt a beam structure engine mount as opposed to a more conventional dyna focal structure. The engine mount is made of two pieces to ensure fit in the clearance between the mounting bolts of the engine. The mount was attached to the rear longerons as well as the fire wall. This way, its length was kept to a minimum.

For the safety of the passengers during crash conditions, four aluminum tubes were designed to be bolted to the fire wall and extend forward to the aft ring frame. During a crash, the tubes on the starboard side, are designed to buckle before the tubes on the port side. This will cause the engine to displace into the unoccupied starboard fuselage area.

The crash tubes on the port side are connected to the ring frame using steel pins, and bolted pin holders. These tubes are also cut on one side to ensure turning at the time of a crash (See drawings S94-1B-302, Details 1&2). The crash tubes are bolted to the fire wall through tube mounts. The tubes on the starboard side are bolted to the ring frame by tube mounts as well.

2.3 Control System:

The control system for the quest consists of a conventional central stick with torque tube with internal push rod. The rudder assembly also consists of conventional torque tubes with special provisions for staggered seating. Cables were chosen to join the controls primarily because of the limited space in the booms. The rudder and elevator cables are routed through the port side boom, and the rudder cables and trim tab wires are routed through the starboard side boom. Provisions for the longitudinal trim and flaps are provided conceptually. The trim tab functions by an electronic servo motor whose controls are mounted on the control stick. Flaps operate using a servo motor and jack screw device. The flap control is mounted to the center ceiling structure. Steering on the ground is performed by differential braking of the main gear and a castoring nose wheel.

General sizing was done to achieve proper function. The required control surface deflections given in the statement of work are +/-12 deg. for the elevator, +/-15 deg. for the ailerons, and +/-15 deg. for the rudders. The cabin section volume produced a limit to stick travel. The stick was chosen to travel +/-6 inches both forward and sideways. The rudder pedals were chosen to travel +/-5 inches. To minimize the effects of cable stretch, a design goal of +/-2 inches of cable travel was set. These requirements dictated the use of two bell cranks for each system. They also set the gear ratios required for each bell crank. The overall bell crank dimensions were then determined to limit their size and provide proper function. General sizes for the control stick and torque tube were also set by the space below the floor of the aircraft.

2.4. Instrument Panel:

The instruments and radios are mounted on a split sheet metal panel. All instruments required for VFR flight are provided and arranged to allow for additional IFR equipment. The panel is angled to provide a clear view to the pilot and copilot. All radios and engine controls are mounted in the center of the panel to allow easy reach for both pilots.

2.5. Environmental Considerations:

2.5.1 Temperature

A cabin ventilation system is provided for the occupants comfort at temperature extremes. To provide heat in cold weather, a heat exchanger is combined with the engine cooling system. Air is circulated through the cabin by an electronic blower motor located in the engine compartment. The air is ducted through the roof center structure which contains vents over each occupant similar to those found on airliners. Fresh air enters from the engine scoops and is filtered before entering the air ducts.

All structural and control members and joints were designed to account for thermal expansion in the range of -40 °F to +122°F.

2.5.2 Atmospheric Pressure

To fly to 14,000 feet as stated in the statement of work, oxygen must be provided in non-pressurized cabins as stated in FAR 91.211a. A separate oxygen bottle is provided for each occupant beside the seat.

2.5.3 Sand and Dust

The external surface of the aircraft will have a protective corrosion coating to protect the metal from sand and dust. Internal mechanisms and hinges use sealed bearings and washers, so that sand and dust will not degrade their operations.

Filters will be used to keep sand and dust out of the engine ducts. Windows will be sealed using rubber weather-strip, for protection against sand and dust. Sealed bearings or bushings are used on all rotating surfaces for reduced friction and protection against dust and sand. A silicone rubber bootie is used where the control stick protrudes through the floor to protect the system from sand and dirt.

2.5.4 Rain & Hail

Weather-strip rubber sealing will be provided for all windows to prevent leakage. The engine air inlet will be protected from hail ingestion by an air filtration system. Appropriately position drainage holes in the engine cowling and cabin floor will be provided to prevent water collection and damage from icing.

2.5.5 Humidity

To enhance protection against corrosion propagating from humidity, all major components of the aircraft structure and the skin panels will be manufactured using 2024-T4 aluminum. The aircraft windshield will be equipped with a defrost apparatus, to combat the accumulation of humidity. For extended life and safety all mounting hardware is treated to be corrosion resistant.

2.5.6 Ice

Door hinges will be protected against icing by the use of plastic and Teflon washers between the hinging parts. The doors will be sealed using weather-stripping rubber to prevent icing caused by the accumulation of water between the door and the cutout.

2.5.7 Snow

A value of 1.165 slug/ft^3 (taken from The Handbook of Snow, Pergamon Press.) was used to calculate the loading applied by 20 inches of wet snow. The following table shows the calculated snow loads for different parts of the aircraft.

Table 2.1 Snow Loads

Aircraft Section	Mass (slugs)	Weight of Snow (lb.)
	density of wet snow $\rho = 1.164$ sl/ft^3	
Horizontal Tail	79.88	2,570
Booms (2 x)	19.65	632.22
Fuselage	32.37	1,041.5
Wing	271.76	8,743.6

These values were checked during fuselage sizing calculations to ensure that the structure and skin panels would support the applied loading.

2.5.8 Salt & Fog Atmosphere

Corrosion resistant materials will be used in the fuselage structure, skin panels, nuts and bolts to protect against the effects of corrosion bred by salt/fog atmosphere. Plastic washers will be used in the door hinges to reduce the possibility of corrosion in those areas.

2.5.9 Wind and Gust

The aircraft is designed to withstand 50 mph winds with gusts without any degradation in the operations. Tidedowns are provided to secure the aircraft on the ground during 120 mph winds. To prevent control surface flutter during wind gusts on the ground, a control stick lock is used. The lock fits over the stick and extends to the side longeron and control panel like THE CLUB steering wheel lock for automobiles.

2.5.10 Shock and Vibration

The airplane structure and structural joints are designed to withstand shock and vibration loads caused by normal operation and storage described in FAR 23.561 through FAR 23.629.

3. Loads and Loading:

The determination of loads and loading was determined from requirements in the SOW and applicable sections of FAR 23. The individual loads and load paths are stated below for the fuselage, engine mount, and control system.

3.1 Fuselage structure:

Due to the twin tail boom configuration of the aircraft, many of the flight loads are not seen in the fuselage. All loads generated by the empennage are reacted through the booms and into the wing. Engine thrust and torque are not seen by the fuselage because of the pusher configuration. The only loads reacted by the fuselage are the landing loads of the nose gear and inertial loads of the occupants.

The most significant load in the fuselage is the landing load applied to the nose wheel. From FAR Part 23 Appendix C, Basic Landing Conditions, the load experienced by the nose gear was calculated for a level landing condition with inclined reactions. Using a load factor of 2.67 and a maximum landing weight of 2000 lbs., the nose gear load was found to be 1670 lbs. in the vertical direction and 418 lbs. in the fore and aft direction. The fuselage bending moment of 160,000 in-lbs was determined from these loads. With this moment known, the longerons of the floor and side structure were sized.

Sizing of the overhead structure, consisting solely of the single upper longeron, and the supporting ring frames is based upon the required occupant safety in the event of an overturn at maximum gross weight during an emergency landing. No fuselage bending loads are considered to be carried through the ring frames into the upper longeron.

Torque within the fuselage is generated by the inertial loads of the occupants during rolling maneuvers and is reacted through the floor box consisting of the lower skin, floor plate, and longerons. This load is insignificant in magnitude.

3.2 Engine Mount:

The engine mount and the shock absorbing tubing are sized according to FAR Part 23. The engine mount is sized for 4.4 g's upward, 2.2 g's downward according to FAR Part 23.361, 1.5 g's side loading according to FAR Part 23.363, 9 g forward crash condition according to FAR Part 23.561. The shock absorbing tubing is designed according to the regulations of FAR Part 23.561; 9 g forward for emergency landing conditions, and 18 g's for parts that could injure an occupant.

The torque of the engine is transmitted into the firewall through engine mounts. The thrust of the engine is carried through the engine mount into the firewall and the longerons. In the event of a crash, loads produced by the inertia of the engine are carried through the engine mount into the crash tubes.

3.3 Controls

Initial detailed sizing was achieved using simplified structural analysis. The limit loads were provided from FAR 23.397. A maximum stick force of 167 lbs for the elevator, 67 lbs for aileron, and 200 lbs for the rudder pedals were used in the analysis. These loads were found to be the worst case giving higher stresses than forces produced by two opposing pilots exerting minimum forces as stated in FAR 23.399b. The average control surface loads were determined in accordance with FAR A23.13.

The pilot input forces are transmitted through the stick to corresponding torque tubes and push rods shown in Drawing S94-1B-303 Sheet 7. The loads then travel through the cable to the bell cranks where the loads are reacted by the control surfaces and control stops. In the event of opposing pilot forces, the loads from one pilot passes through the stick and torque tube and is reacted by the other pilot's force.

4. Structural Substantiation:

The following calculations substantiate the sizes of the critical load bearing parts.
Complete set of calculations can be found in the internal report. (S94-1B-3R2, Embry-Riddle Aeronautical University, Aerospace Engineering Dept.)

4.1 Fuselage:

4.1.1 Forward Bulkhead

The forward bulkhead is sized to carry the 1670 lbs. shear load of the nose gear. The press formed 0.020 thick 2024-T3 sheet is reinforced by the attached nose gear mount and T-section stiffeners that transfer the load to the longeron (S94-1B-301 Sheet 5).

$$P_{crit} = \frac{\pi^2 \times E \times I}{l^2}$$

$$P_{crit} = \frac{\pi^2 \times 10^7 \times .025}{22.7^2}$$

$$P_{crit} = 4788 lb$$

$$P_{actual} = 1310 lb$$

The shear stress in the bolts used for the nose gear mount is as follows.

$$A = \pi \times r^2$$

$$A = \pi \times .15625^2$$

$$A = .0767 in^2$$

$$f_{shr} = \frac{P}{A}$$

$$f_{shr} = \frac{\frac{1670}{6}}{.0767}$$

$$f_{shr} = 3829 psi$$

The margin of safety for the forward bulkhead is as follows:

$$M.S._{fwd} = \frac{F}{f} - 1$$

$$M.S._{fwd} = \frac{4788}{1310} - 1$$

$$M.S._{fwd} = 2.655$$

4.1.2 Forward and Aft Ring Frames

d The ring frames were designed for excessive support and stiffness since they were the only supporting structure of the cabin roof and doors. A generous thickness of 0.120 inch was chosen for the press formed C-channel frames. For manufacturing considerations, the ring frames are made of 0.060 inch material and then doubled to provide the desired size (S94-1B-301 Sheets 6 and 7).

$$q = \frac{V \times Q}{I}$$

$$q_{max} = \frac{1670 \times .405 \times 2.85}{299}$$

$$q_{max} = 42 lb/in$$

Using a skin thickness of .020 inches and $D=4t_{small}$ the rivet diameter was determined to be 3/32 chosen from Ladesic's notes. Then using a maximum rivet spacing of .75 inches the following bearing stress was determined.

$$P = q \times .75$$
$$P = 30.13lb$$

$$F_{brg} = \frac{P}{t \times D}$$

$$F_{brg} = \frac{30.13}{.255 \times .094}$$

$$F_{brg} = 1257psi$$

4.1.3 Mid Ring Frame

The mid ring frame is not a load carrying member. Its contribution is to allow for the use a commercially standard 4 ft x 8 ft sheet to skin the fuselage.

4.1.4 Upper Longeron

The upper longeron is excessively sized to form the HVAC's air duct and provide ample volume for the attachment of shoulder harness. A brake formed 3.40 x 3.00 2024-T4 C-channel of 0.125 inch thickness provides this volume and support for overturn loads.

4.1.5 Floor and Side Longerons

All longerons were assumed to carry an equal portion of the 167,000 in-lbs. fuselage bending moment generated by the nose gear landing load. 2024-T4 aluminum was used with a maximum stress of 37620 psi to design the longerons.

At fuselage station (F.S.) 168.75 the following values were determined:

$$S_{*} = \frac{M@F.S. \times L.L.F.}{f_{max}}$$

$$S_{*} = \frac{167000}{37620}$$

$$S_{*} = 4.44$$

$$\frac{I}{c})_{actual} = \frac{I}{c})_{req'd} = S_{*}$$

$$I_{actual} = S_{*} \times c$$

$$I_{actual} = 4.44 \times 12.57$$

$$I_{actual} = 55.81 in^4$$

$$I = \Sigma I_L + \Sigma A d^2$$

The sum of the I_L is very small therefore neglected and assuming all areas are equal.

$$A = \frac{I}{\Sigma d^2}$$

$$A = \frac{55.81}{4(-8)^2 + 2(.36)^2 + 2(6.8)^2 + 2(12.57)^2}$$

$$A = .084 in^2$$

This is the minimum required area for each longeron.

The margin of safety for the fuselage skin is as follows:

$$M.S._{skin} = \frac{F}{f} - 1$$

$$M.S._{skin} = \frac{160.2}{120.5} - 1$$

$$M.S._{skin} = .3295$$

4.1.6 Front Spar Attachment

The three piece wing with a continuous spar carrythrough allows a simple attachment of the spars. Both frames of the aft ring frame pair are joggled to offset the spar flanges and rivet to the spar web (S94-1B-301 Sheet 7). This simple attachment eliminates the weight associated with lugs. A simple shear calculation is all that is required to size for the rivet attachment since the twin boom configuration of the aircraft does not transmit torque through the fuselage.

4.1.7 Firewall and Rear Spar Attachment

The major load consideration for the firewall is the engine torque that is directly applied through the engine mount. Function requirements and safety due to temperature demand the firewall to be made of PH 15-7 Mo stainless steel. With the stiffening effects of the attached engine mount and rear spar, the firewall is 0.032 inch thick.

The rear spar is continuously riveted to the joggled firewall in a similar fashion to the front spar. A shear calculation sizes the attaching rivets here as well (S94-1B-301 Sheet 8).

An applied torque was given to be 1296 in lb. in and using an area of the firewall equal to 995 in^2 return calculating a shear flow as follows:

$$q = \frac{T}{2A}$$

$$q = \frac{1296}{2(995)}$$

$$q = .6519 lb/in$$

The shear flow was then used to calculate the shear stress in the firewall with a thickness (t) of .032.

$$f_{shr} = \frac{q}{t}$$

$$f_{shr} = \frac{.6519}{.032}$$

$$f_{shr} = 20.37 psi$$

The critical stress was calculated using an equation from Nui on page 139 and assuming a simply supported and fixed edge. An a/b value was calculated to be 2.374 resulting in a value of K_s equal to 6.83.

$$E_{st} = 2.9(10^7)$$

$$f_{cr} = K_s E_{st} \left[\frac{t}{b}\right]^2$$

$$f_{cr} = 6.83 \times 2.9(10^7) \times \left[\frac{.032}{14.45}\right]^2$$

$$f_{cr} = 971.4 psi$$

The margin of safety was calculated as follows:

$$M.S._{fire} = \frac{F}{f} - 1$$

$$M.S._{fire} = \frac{971.4}{20.37} - 1$$

$$M.S._{fire} = 46.69$$

4 .2 Engine mount:

4.2.1 Structural Sizing:

The cross section of the engine mount was determined according to FAR A23.13. The engine mount is designed to be machined into I-beams. This way, the weight of the mount was kept to a minimum, while the moments of inertia was maximized. To increase the margin of safety, the engine mount was redundantly attached to the rear longerons. The engine mount was sized for positive 4.4 g's and negative 2.2 g's for performance requirements, for 9 g's forward, 1.5 g's sideways for emergency landing conditions requirements, and for 18 g's for occupant safety regulations . The cross section with the lowest moment of inertia was used throughout these calculations. The natural axis for bending was also taken from this cross section. Structural sizing calculations are summarized below:

4.2.1.a Sizing for Positive 4.4 g's:

The bending stress under this load was calculated and compared to the endurance limit of 2011-T8 aluminum alloy. The maximum moment at 4.4 g's was used to calculate the bending stress. This moment was found by summing forces and moments at this g load. The details of these calculations can be found in the internal report (S94-1B-3R2, ERAU, Asp.Eng.)

$$M_{max}=5100 \text{ in.lbs}, \qquad I_{min}=0.2474 \text{ in}^4, \qquad y_{min}=0.75 \text{ in}$$

$$\sigma = \frac{My}{I} = \frac{5100.0.75}{0.2474} = 15460 \text{ psi}, \qquad \sigma_{endurance} = 18000 \text{ psi}$$

$$\sigma_{yield} = 45000 \text{ psi}, \qquad MS=\frac{45000}{15460} = 2.91$$

4.2.1.b Sizing for Negative 2.2 g's:

The maximum moment for this loading was calculated to be 3124 in.lbs. The bending stress for this value was calculated and compared to the endurance limit and yield strength of aluminum 2011-T8.

$$\sigma = \frac{My}{I} = \frac{3124.0.75}{0.2474} = 9471 \text{ psi}, \qquad MS=\frac{45000}{9471} = 4.8$$

4.2.1.c Sizing for Forward 9 g's:

Both bending stress and the axial compression stress were calculated for this condition. The maximum moment used was calculated to be 8144.1 in.lbs.

$$\sigma = \frac{My}{I} = \frac{8144.1x0.75}{0.2474} = 24689 \text{ psi}, \qquad MS=\frac{45000}{24689} = 1.22$$

$$\sigma_{axial} = \frac{P}{A} = \frac{2121}{0.75} = 2828 \text{ psi}$$

4.2.1.d Sizing for Sideways 1.5 g's:

The moment of inertia about the horizontal axis was calculated and used for this calculation. The maximum moment and the minimum moment of inertia was used to determine the stress.

$$\sigma = \frac{My}{I} = \frac{1789x0.5}{0.04297} = 20285 \text{ psi}, \qquad MS=\frac{45000}{20285} = 2.22$$

4.2.1.e Bolt Sizing of the Engine Mount:

The engine mount bolts were sized for the maximum shear on the engine mount. The mount was sized to hold with 8 bolts. Other 6 bolts on each mount were designed to be redundant, as safety feature.

$$\sigma_{shear} = \frac{P}{A} = \frac{55.5}{0.0487} = 1137 \text{ psi}, \qquad \sigma_{y.shear}=3680 \text{ psi}$$

$$MS=\frac{3680}{1137} = 3.23$$

4 .2.2 Fatigue Considerations

The endurance limit of 20 series aluminum was used for the structural design of the engine mount. No other fatigue evaluation was done.

4.3 Crash/Thrust Tubes

4.3.1 Structural Sizing

Both of the crash tubes were sized for the 9 g forward emergency landing condition. This way, in case the engine failed to turn outside, the tubes will be able to absorb the energy of the impact specified by FAR. The tubes on the starboard side were tapered at the fire wall, for some crippling effect. During a crash, the tubes will fold into themselves, and shear inside out. This will absorb some of the energy during crash and cause the engine to turn outside more smoothly. The pins and the tube mounts were sized for 18 g's for FAR passenger safety regulations.

4.3.1.a <u>Buckling Loads at 9g Forward:</u>

The critical value for buckling was calculated for both of the thrust tubes. Both tubes were designed to hold for 9g's. The appropriate moment of inertia for the tubing and the modulus of elasticity of aluminum was used.

$$P_{critical} = \frac{\pi^2 EI}{l^2} = \frac{\pi^2 10^7 x 0.02898}{36.3^2} = 2171 \text{ lbs}, \qquad P_{applied} = 459.3 \text{ lbs}$$

$$MS = \frac{2171}{459.3} = 4.7$$

4.3.2.b <u>18g Loads for Tube Connections:</u>

The pin that holds the tubing (See DWG S94-1B-302, Item 7) is in transverse shear during this load. The force on the tubes at this loading was calculated and used to calculate the shear stress on the pin.

$$\sigma_{shear} = \frac{P}{A} = \frac{781}{0.1963} = 3978 \text{ psi}, \qquad \sigma_{yield,shear} = 14700 \text{ psi}$$

$$MS = \frac{14700}{3978} = 3.7$$

The bolts were sized to hold at 18g's of shear , since they are completely in shear during this loading. AN4-C3 corrosion resistant steel shear bolts were used for these calculations. These bolts are to be used with AN320-C4 nuts and AN960-C10L light weight washers.

$$\sigma_{shear} = \frac{P}{A} = \frac{97.6}{0.0487} = 2004.3 \text{ psi}. \qquad \sigma_{y,shear} = 3680 \text{ psi}$$

$$MS=\frac{3680}{2004.3} = 1.8$$

4.2.3.c Bolt Sizing for Tube Attachments:

The parts of the thrust tubes that were not pin connected were bolted to the firewall and to the ring frame. (See DWG S94-1B-302, Detail 2) These bolts were also sized to hold at 18g's for occupant safety regulations. AN6-C3 corrosion resistant steel shear bolts were used for these calculations. These bolts are to be used with AN320-C6 nuts and AN960-C616L light weight washers.

$$\sigma_{shear} = \frac{P}{A} = \frac{195.3}{0.11} = 1773 \text{ psi} \qquad \sigma_{y.shear} = 8280 \text{ psi}$$

$$MS=\frac{8280}{1773} = 4.7$$

4.3.2 Fatigue Evaluation

No fatigue evaluation was made, since the crash tubes are designed primarily to be used during crash.

4.4 Control system:

Sizing was performed to prevent yielding and to provide a factor of safety of 1.5 against ultimate failure. Flexural displacement was also a critical component in sizing. The structural substantiation for the critical design parts are shown below. Due to the inconsistent and frequent loads of various magnitudes, the fatigue limits such as safe life were not estimated. It is recommended that the system be rigorously tested to ensure proper resistance to fatigue. The final size of all components is shown in the drawings.

4.4.1 Control Stick:

The control stick is seen in Drawing S94-1B-303, Item 19. The cross section of the stick was determined to provide adequate stiffness. The stick consists of 2024-T3 tubing which has a compressive yield strength of 42,000 psi. The calculations below verify the structural integrity of the control stick. The bending moment is based on the maximum pilot input of 167 lbs. The deflection of the top of the stick was determined to ensure that the controls will be responsive.

Bending moment:

$$M = pl$$
$$M = (167)(28.5)$$
$$\underline{M = 4759.5 \text{ in-lb.}}$$

Stress: $f = \frac{Mc}{I}$

$$f = \frac{4759.5(0.75)}{\frac{\pi}{4}(0.75^4 - 0.625^4)}$$

$$\underline{f = 27,744 \text{ psi.}}$$

Margin of Safety:

$$M.S._{yield} = \frac{F_{cy}}{f} - 1$$
$$M.S._{yield} = \frac{42,000}{27,744} - 1$$
$$\underline{M.S._{yield} = 0.514}$$

Stick Deflection: (Critical Length is the length above the machined fitting-- 25".)

$$\delta = \frac{Pl^3}{3EI}$$

$$\delta = \frac{(167)(25)^3}{3(10x10^6)(\frac{\pi}{4}(0.75^4 - 0.625^4))}$$

$$\underline{\delta = 0.676 \text{ in.}}$$

4.4.2 Cast Stick Mount:

The casting which attaches the control stick to the torque tube is shown in drawing S94-1B-303, Item 14. The loads on the stick mount are transmitted from the stick through the mounting pin. The critical mode of failure is the bending stress developed in the base of the two arms by a 167 lb. pilot input. The load on the arms is the sum of the pilot input and the reaction at the elevator pushrod; (1527 lbs.). The calculations below substantiate the size of these arms. The thickness was determined to be 0.25 in. for bearing and tearout stress in the pin.

Bending Stress:

$$f = \frac{Mc}{I}$$
$$f = \frac{(1527/2(2.7))(1)}{\frac{1}{12}(0.25)(2^3)}$$
$$\underline{f = 12,323 \text{ psi.}}$$

Margin of Safety:

$$M.S._{yield} = \frac{F_{ty}}{f} - 1$$ (Alcoa 220-T4 F_{ty}=22 ksi.)
$$M.S._{yield} = \frac{22,000}{12,323} - 1$$
$$\underline{M.S._{yield} = 0.785}$$

4.4.3 Torque Tube:

The aileron torque tube is shown in drawing S94-1B-303, Item 12 . It was sized according to the torsion produced from a maximum pilot input of 67 lbs. The most critical condition was the twisting of the torque tube. The tube size was determined to provide less than 1° of twist. The following calculations substantiate the size of the torque tube.

Torque in Tube:

$$\tau = Pl$$
$$\tau = 67(32)$$
$$\underline{\tau = 2144 \text{ in-lb}}$$

Twist of Tube:

$$\phi = \frac{\tau l}{JG}$$
$$\phi = \frac{2144(12)}{\frac{\pi}{2}(0.8125^4 - 0.625^4)(3.843x10^6)}\left(\frac{180°}{\pi}\right)$$
$$\underline{\phi = 0.862°}$$

Shear Stress:

$$f = \frac{\tau c}{J}$$
$$f = \frac{2144(0.8125)}{\frac{\pi}{2}(0.8125)^4}$$
$$\underline{f = 3959 \text{ psi}}$$

Margin of Safety: (2024-T4 tubing---F_{su}=38 ksi)

$$M.S._{ult.} = \frac{F_{su}}{f} - 1$$
$$M.S._{ult.} = \frac{39000}{3959} - 1$$
$$\underline{M.S._{ult.} = 8.85}$$

4.4.4 Elevator Pushrod:

The elevator pushrod concentric with the torque tube is shown in Drawing S94-1B-303, Item 13. The pilot input force of 167 lbs. causes a 1359.9 lb. axial load in the pushrod. The critical size was determined to prevent buckling. A bearing was placed within the torque tube as shown in the drawing to give the pushrod a maximum length of 12in. The calculations below substatiate the pushrod size.

Stress:

$$f = \frac{P}{A} = \frac{P}{\frac{\pi}{4}D^2}$$
$$f = \frac{1359.9}{\frac{\pi}{4}0.5^2}$$
$$\underline{f = 6927.7 \text{ psi}}$$

Buckling Strength:

$$F_{crit.} = \frac{\pi^2 EI}{Al^2} = \frac{\pi^2 E(\frac{\pi}{4}c^4)}{(\frac{\pi}{4}d^2)l^2}$$
$$F_{crit.} = \frac{\pi^2(10x10^6)(\frac{\pi}{4}0.25^4)}{(\frac{\pi}{4}0.5^2)(12^2)}$$
$$\underline{F_{crit.} = 10,719 \text{ psi}}$$

Margin of Safety: $$M.S._{ult.} = \frac{F_{crit.}}{f} - 1$$ ($F_{crit} > F_{tu}$ =38 ksi for 2024-T3 rod)
$$M.S._{ult.} = \frac{10,719}{6927.7} - 1$$
$$\underline{M.S._{ult.} = 0.547}$$

4.4.5 Pushrod Coupling:

The pushrod coupling joins the pilot and co-pilot elevator pushrod motions. The pushrod coupling is shown in Drawing S94-1B-303, Item 8. The size of the shear web was determined to prevent buckling. The shear stress is created by the force in the elevator pushrod of 1359.9 lbs.

Shear Stress:
$$f_{shear} = \frac{P}{lt}$$
$$f_{shear} = \frac{1359.9}{(5)(0.0625)}$$
$$\underline{f_{shear} = 4351.7 \text{ psi}}$$

Buckling Strength: (K_s from NUI page 139)
$$F_{crit.} = K_s E(\tfrac{t}{b})^2$$
$$F_{crot.} = 6(10x10^6)(\tfrac{0.0625}{5})^2$$
$$\underline{F_{crit.} = 9375 \text{ psi.}}$$

Margin of Safety:
$$M.S._{ult.} = \frac{F_{crit.}}{f} - 1$$
$$M.S._{ult.} = \frac{9375}{4351.7} - 1$$
$$\underline{M.S._{ult.} = 1.154}$$

4.4.6 Bellcrank:

The first bellcrank in the elevator system had the highest loads transmitted to it from the elevator pushrod coupler. From this bellcrank sizing, the thickness of all bellcranks was found to be 0.25 inch. The bellcrank substantiated below is shown in Drawing S94-1B-303, Item 5. The pushrod load of 1359.9 lbs. is exerted 1.5 inches from the pivot point, and a 510 lb. cable force reacts this at a distance of 4 inches from the pivot. The pivot pin is connection is evaluated for strength and stiffness. Pushrod and cable connections have lower forces applied and are sized accordingly.

Bellcrank:

Bending Stress:
$$f = \frac{Mc}{I}$$
$$f = \frac{(1359.9)(1.5)(\frac{1.5}{2})}{\frac{1}{12}(0.25)(1.5)^3}$$

$$\underline{\underline{f = 21,759.2 \text{ psi.}}}$$

Margin of Safety: $M.S._{yield} = \frac{F_{cy}}{f} - 1$ (2024-T4 plate, F_{cy}=38 ksi.)

$$M.S._{yield} = \frac{38,000}{21,759.2} - 1$$

$$\underline{M.S._{yield} = 0.746}$$

Pivot Connection:

Load: $P = FF(P_{cable} + P_{pushrod})$

$$P = 2(510 + 1359.9)$$

$$\underline{P = 3740 \text{ lbs.}}$$

Margin of Safety: $M.S._{ult} = \frac{P_{allow}}{P_{act}} - 1$ (AN5 bolt, $P_{allowable}$=5750 lbs.)

$$M.S._{ult} = \frac{5750}{3740} - 1$$

$$\underline{M.S._{ult} = 0.537}$$

Bearing Stress: $f_{brg} = \frac{FF(p)}{tD}$ (2024-T4 plate, F_{brg}=64 ksi.)

$$f_{brg} = \frac{3740}{0.25(0.3125)}$$

$$\underline{\underline{f_{brg} = 47,872 \text{ psi.}}}$$

Tearout Stress: $f_{t.o.} = \frac{FF(P)}{2xt}$ (2024-T4 plate, F_{cy}=38 ksi.)

$$f_{t.o.} = \frac{3740}{2(0.625)(0.3125)}$$

$$\underline{f_{to} = 9574.4 \text{ psi.}}$$

4.4.7 Cable:

The cable size of 1/8 in. diameter was chosen to give less than one inch of stretch when the maximum pilot input force is applied since the cables only move +- 2 inches. The highest cable load was for the elevator. A load of 510 lbs was transmitted to the cable from the bellcrank. To prevent the cables from becoming loose, they were preloaded 15% to 586.5 lb. The strength of 1/8 in. diameter 7x19 stainless steel cable from Aircraft Spruce and Specialty was 1760 lbs. The calculations below show the margin of safety and the stretch of the cable assuming it to behave like a solid steel rod in tension. The longest single length of cable is approximately 450 inches.

Margin of Safety: $M.S._{ult} = \frac{P_{allow}}{P_{act}} - 1$

$$M.S._{ult} = \frac{1760}{586.5} - 1$$

$$\underline{M.S._{ult} = 2.00}$$

Cable Stretch: $\delta = \frac{PL}{AE}$

$$\delta = \frac{586.5(450)}{(\frac{\pi}{4}0.125^2)(30x10^6)}$$

$$\underline{\delta = 0.717 \text{ in.}}$$

4.4.8 Control Stick Base:

The machined control stick base is sized using lug equations for bearing and tearout. Since this part is solid, the bending capacity is greater than the stick itself and is therefore substantial.

4.4.9 Control Stops:

The stops for the control systems are made of 0.19 in thick 2024-T4 sheet. They are sized to withstand the entire load transmitted to the bellcranks in the event that the pilot exerts the maximum force while the plane is on the ground.

5. Manufacturing and Maintenance Provisions:

The intent of the manufacturing and assembly plan is to avoid complex tooling which can lead to excessive cost. For this reason, standard size parts and fasteners were chosen whenever possible. The manufacturing plan was broken down into three main components; structure, engine mount, and control system.

5.1 Manufacturing Plan:

5.1.1 Fuselage Structure:

All fuselage C-channels longerons are brake formed from 2024-T4 aluminum. Two C-channel longerons are attached in upper half of the fuselage between the rear ring frame and the rear bulkhead for shape of the fuselage skin. The floor Z-channels longerons are extruded from 2024-T4 aluminum, part no. NAS346-47. The floor is stiffened with brake form J-sections made of 2024-T4 aluminum. The two outside Z-channels extend to the rear of the fuselage for attachment to the engine mount. The forward bulkhead is made of 2 extruded T-channels, part no. NAS344-32 riveted to 2024-T4 sheet aluminum. The rear bulkhead (firewall) is press formed from PH15-7Mo stainless steel. Stiffening beads are placed in the forward and rear bulkheads for stiffness. All ring frames are press formed C-channels manufactured with 2024-T4 aluminum and doubled to provide adequate strength. A semi-ring frame is located between the main ring frames located at the front and rear of the door frame. This semi-ring frame allows the use of a standard 4 ft x 8 ft sheet to be used for the skin. Standard 4 ft x 8 ft sheets of 2024-T3 aluminum, .020 inches thick, is used for the skin and can be easily circumphrencially wrapped around the fuselage and attached with AN470 rivets.

A wing interface made of a spar carrythrough section is to be attached by the front spar to the aft ring group frame and to the rear bulkhead by the rear spar. This is to allow the assembly of a three piece wing and decreased reinforcement structure. The booms and main landing gear are attached at the intersection of the wing interface structure and the outboard wing sections. The nose gear is attached with a aluminum machined assembly that is attached to the two T-channels that support the nose gear in the front bulkhead. All landing gear is comprised of oleo strut type systems.

A fiberglass composite nose cone is attached to the front bulkhead using flat head screws. This allows for easy inspection of the nose gear assembly and front bulkhead area. The rear engine cowling is a one piece fiberglass composite attached with flat head screws to the rear bulkhead. This allows for easy access to the engine compartment and surrounding structure.

5.1.2 Engine Mount:

The mounts are designed to be machined out of aluminum. Any type of aluminum alloy can be used for the machining process as long as the alloy is of 20 series and heat treated. It is recommended that 2011-T8 be used for its high machinability, strength and endurance. The crash tubes are to be manufactured by rolling sheet metal into a square tubular shape and welding in the seam. The tubes must be heat treated after they are welded, if this method of manufacturing is decided upon. The crash tubes on the starboard side can be manufactured the same way as the tubes on the port side, except for the sheet metal must be rolled into tapered square tubing , instead of straight. Like the engine mount, the tubes can be manufactured out of any heat treated 20 series aluminum alloy, but 2011-T8 is recommended.

5.1.3 Control System:

The rudder pedal assembly was chosen to be purchased from Aircraft Spruce and Specialty and was therefore omitted from structural sizing. The control stick consists of 2024-T3 aluminum tubing chosen for stiffness and low weight. It has a tight fit over a machined part which provides the locations for pin connections to the torque tube and for the elevator push rod. The stick attaches to the torque tube with a pin through a cast fitting. The cast fitting is riveted to the torque tube. The two pilot's torque tubes are connected by a cable. A push rod with a pin connection joins the tube to a bell crank that moves the control cables. All bell cranks are machined out of 0.250 inch 2024-T3 aluminum plate. The torque tube is attached to the floor by brackets with roller bearings and stops to prevent the tube from moving longitudinally. The elevator push rod attaches to the control stick fitting with a threaded rod end bearing. It then moves through the torque tube and is supported by three sintered bronze bushings located in the cast torque tube fittings. The two pilot's push rods are connected by an aluminum shear web welded to two tubes that fit over the push rods. Thrust bearings are used to decouple the transitional motion of the push rod from aileron related rotation. The shear panel is stiffened to provide an attachment for a push rod to attach to a bell crank which moves the cables.

For commonality and adequate strength, all control cables are 1/8 inch diameter. Stranded stainless steel was chosen for the cables for its corrosion resistance. The cables and pushrods use eye ends purchased from Aircraft Spruce and Specialty for mounting the cables to the bell cranks (Drawing S94-1B-303, Sheet 9). Pulleys sizes correspond to the cable size. They are mounted to various structure using formed and machined sheet metal brackets and rivets. The final connection to the control surface is through aluminum push rods with bearing rod ends. The control surface stops consist of 0.250 inch thick 2024-T4 plate brackets which are mounted beside the final bell crank in each system.

For serviceability and maintenance, inspection panels are provided in the booms, and fuselage floor.

5.2. Order of Assembly:

5.2.1 Third Tier:

Third tier assembly will consists of building the fuselage internal structure from the floor plate up. The longerons, ring frames and bulkheads will be assembled first followed by the installation of controls system brackets and pulleys as well as necessary wiring harnesses. Preliminary routing of the control cables will then be laid-out until further assembly is made. The instrument panel will be installed with many of the instruments already in place.

5.2.2 Second tier:

The second tier assembly begins with the installation of the wing center section assembly and firewall. The nose gear will be attached, at which time the fuselage will have all three wheels in place and the brake system will be installed. Next, all skin panels will then be riveted in place. With the structure now rigid, the engine will be installed and all engine controls assembled.

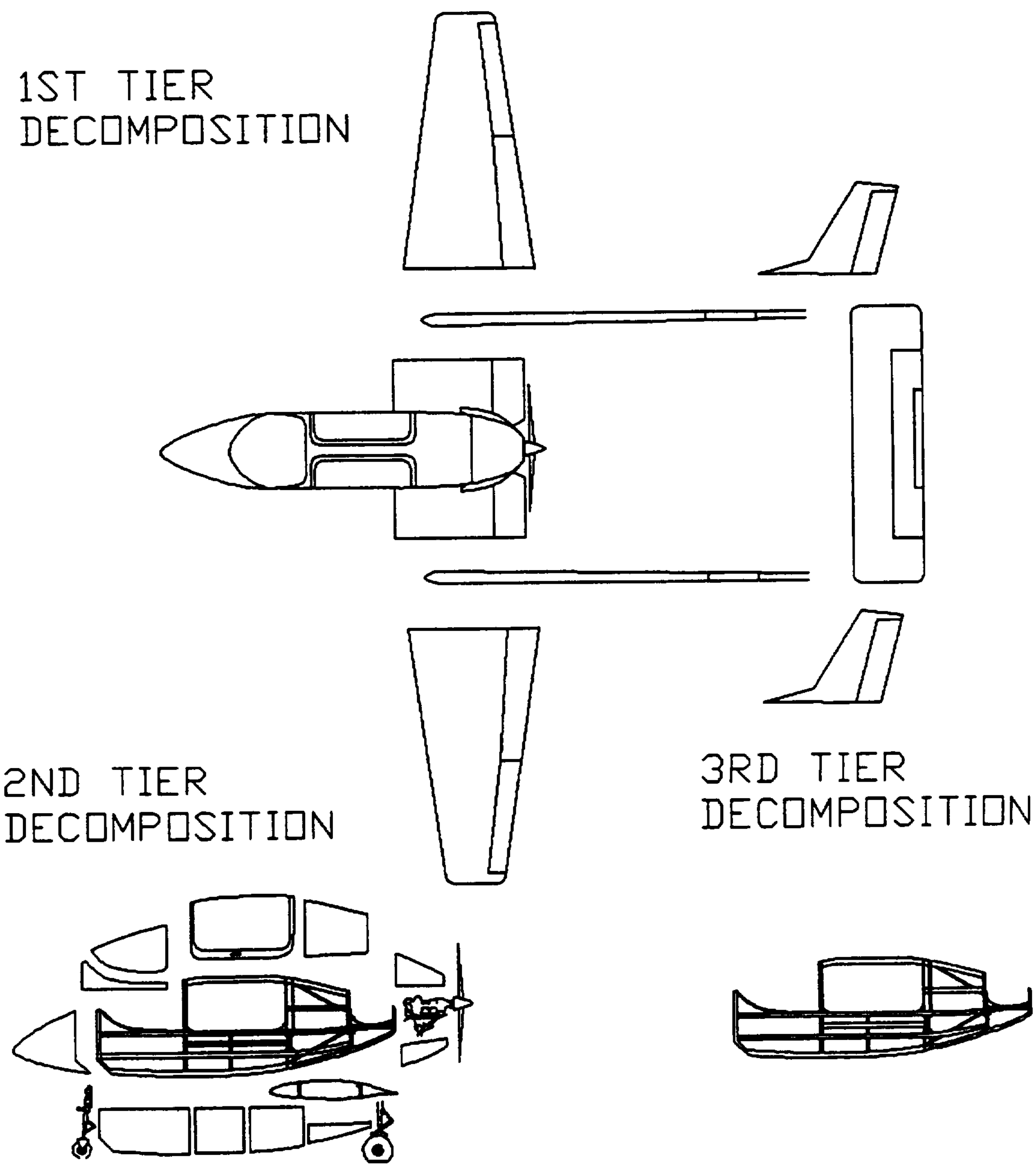


Figure 5.1 - Fuselage Decomposition

The cabin interior will be installed including JAARS seats and safety harnesses. To complete the fuselage structure, the nose cone, engine cowling, and doors will be put in place.

5.2.3 First Tier:

First tier assembly will complete the aircraft with the installation of the outer wings, tail booms, and the horizontal and vertical stabilizer. With all control surfaces now in place, the control cabling and wiring can be completed.

6. Cost Summary:

The total material cost was broken down and is summarized below. The total aircraft material cost was found to be $30,814.30. The target cost of $50,000 can be met if tooling and labor costs are kept below $19,185.70.

6.1 Avionics:

The cost is based on prices in Aircraft Spruce and Specialty Catalog. The total cost was found to be $10,023.30. All the instruments specified are purchased from Aircraft Spruce & Specialty Catalog.

Aircraft Components	Component Cost [$]
Battery	437.25
Airspeed Indicator	150
Horizon Indicator	329
Gyro	229
Clock	40
Fuel Indicator	120
Suction	67.55
Oil Temperature/Pressure Indicator	110
Voltage/Ampere Indicator	120
Engine Temperature Gage	120
HOBBES	60
Altimeter	289
Compass	360
Turn Coordinator	343
Engine RPM gage	56.75
Vertical Airspeed	164
NAV	2,890
ADF	375
Miscellaneous	220
Communication Apparatus	4,000
TOTAL	10,023.30

Table 6.1. Avionics Cost Summary

6.2 Control System:

The cost of the control system is approximated using prices found in the Aircraft Spruce and Specialty Catalog. Table 6.2 summarizes the control system costs.

Components	Component Costs [$]
Control Stick	30
Pushrods	22
Torque Tubes	50
Rudder Assembly	383
Cable	160
Brake System	600
Bellcranks	50
Pulleys	135
Hardware	615
TOTAL	2,045

Table 6.2 Control Cost Summary

The rudder assembly consists of pedals and torque tubes. The cost of hardware includes nuts, bolts, rivets, washers, cotter pins, rod ends, cable ends, bearings, bushings, and mounting brackets. Approximately 300 feet of cable is required for the entire system. The cable chosen was 7x19 stainless cable 1/8" diameter. The total cost was found to be $2,045.

6.3 Structure:

The following is a list of approximate costs for structural material.

SKIN	COMPONENTS	AREA/LENGTH	COST [$]
	Horizontal Tail	2 x 41.16 ft^2	177.2
	Wing	2 x 140 ft^2	602.7
	Vertical Tails	2 x 41.16 ft^2	177.2
	Fuselage	225 ft^2	482.2
	Booms	96 ft^2	206.6
STRUCTURE	Longerons	155 ft	480
	Thrust Tubes	4 x 3 ft	15
	Engine Mounts	2 x 1.5 ft	10
	Wing	----	
	Bulkhead: Aluminum	7.07 ft^2	45.1
	Nose Gear Assembly	cast aluminum	50
	Bulkhead: Stain. Steel	5.33 ft^2	300
	Ring Frames	132.5 ft	400
	Landing Gear	Nose and Main	400.00/1000.00
	Windshield/Window	----	300.00/400.00
ENGINE	Rotax 914	----	10,000
COMPOSITE	Nose Cone	-----	500
	Engine Cowlings	Top & Bottom Halves	600
INTERIOR	Seats	JAARS	2,600
TOTAL	----	----	18,746

Table 6.3. Structural Component Cost

2024-T3 aluminum was used as the material for the skin and front bulkhead at estimated prices of $68.88 for a 4 ft x 8 ft sheet with a thickness of 0.020 inches and $33.10 for a 4 ft x 4 ft sheet with a thickness of .016 inches respectively. 2024-T4 aluminum was used for the structural members material with an estimated cost of $3.00 per foot. PH15-7 Mo stainless steel sheet was used for the rear bulkhead (firewall) at an estimated cost of $300.00 total. All prices were estimated according to the prices shown in Aircraft Spruce and Specialty catalog, 1993-94 edition.

7. Weight Summary:

The sizing of the aircraft components were done to provide adequate stiffness without excessive weight. The weights of the fuselage, engine mount, and control system components are summarized below.

7.1 Fuselage Structure:

Components	Weight [lbs]
UPPER SKIN	4
TAIL CONE	1.5
CARRY THROUGH SKIN	3.92
AFT MID SKIN	7.36
FORWARD MID SKIN	4.6
LOWER FORWARD SKIN	6.81
NOSE SKIN	1
UPPER SKIN RIVET	0.11
AFT LONGERON BRAKE FORM C	1.08
MID LONGERON BRAKE FORM C	4.86
FIREWALL LT CORNER PRESS FORM	0.12
FIREWALL RT CORNER PRESS FORM	0.12
SPAR RIVETS	0.04
FRAME RIVETS	0.6
LOWER SKIN RIVETS	1.18
ATTACHMENT ASSEMBLY	2
NOSE CONE	12
ENGINE COWLING	10
FLOOR PANEL	7.69
LONGERONS BRAKE FORM C	24.3
BUCKLE STIFFENERS BRAKE FORM J	3.6
FLOOR LONGERONS EXTRUDED Z	32.4
WINDSHIELD FRAME	0.75
ENGINE MOUNT	6.24
FIREWALL PRESS FORM	0.68
LOWER ENGINE THRUST TUBE	0.64
UPPER ENGINE THRUST TUBE	0.55
AFT RING FRAME PRESS FORM C	25.03
MID LT RING FRAME PRESS FORM C	1.62
MID RT RING FRAME PRESS FORM C	1.62
FWD RING FRAME PRESS FORM C	25.03
FORWARD BULKHEAD	2.45
UPPER LONGERON BRAKE FORM C	10.41
TOTAL	204.3

Table 7.1. Fuselage Structure Weight Summary

7.2 Engine Mount:

Components	Weight [lbs]
Engine Mount	6.5
Thrust Tubes	2.7
Nuts, Bolts & Washers	1.5
TOTAL	10.7

Table 7.2. Engine Mount Weight Summary

7.3 Control System:

The weight of the control system components are shown in Table 7.3. The weight of the rudder assembly includes the pedals, torque tubes, and master cylinders. The pushrod, cable, bellcrank, and pulley weights include all the components required for each sub-system. The control hardware weight includes all brackets, bolts, washers, nuts, rivets, and bushings for the entire system. The total weight was approximated to be 46.45 lbs.

Components	Weight [lbs]
Control Sticks	4.77
Pushrods	2.54
Torque Tubes	3.05
Rudder Assembly	6.78
Cable	8.96
Bellcranks	1.99
Pulleys	10.5
Control Hardware	7.86
TOTAL	46.45

Table 7.3. Control System Weight Summary

This total weight is less than the preliminary estimate of 48.3 lbs. Possible areas where additional weight can be saved are the control stick and torque tube because of their high margin of safety. It could also be possible to reduce the number of pulleys in the entire system.

7.4 Avionics Panel:

The weight of each instrument and radio were determined as shown in Table 7.4. The total weight was found to be 130 lbs. These weights are based on information found in Aircraft Spruce and Specialty Catalog.

Components	Weight [lbs]
Battery	80
Airspeed Indicator	0.75
Horizon Indicator	2.75
Gyro	4.5
Clock	0.1
Fuel Indicator	0.3
Suction	0.1
Oil Temperature/Pressure Indicator	0.7
Voltage/Ampere Indicator	1
Engine Temperature Gage	0.3
HOBBES	0.3
Altimeter	2.5
Compass	2.5
Turn Coordinator	1.375
Engine RPM gage	1.5
Vertical Airspeed	0.7
NAV	5
ADF	2.3
Miscellaneous	5
Communication Apparatus	18
TOTAL	130.1

Table 7.4 Avionics Weight Summary

7.5 Total Weight Summary:

Table 7.5 below is a summary of the total aircraft weight. All weights excluding the fuselage, engine mount, and control system are based on preliminary design estimates. From preliminary design, the empty weight of the original two seat Quest was estimated to be 1017 lbs. After structural sizing, the empty weight for the three seater was found to be 1282.47 lbs, a gain of 265.5lbs.

Components	Weight [lbs]
Fuselage Structure	204.3
Engine Mount	10.7
Control System	46.45
Avionics Panel	130.1
Wing	269.1
Horizontal Tail	16.69
Vertical Tail	34.65
Main Gear	155.93
Nose Gear	51.56
Engine	165
Fuel System	33.61
Boom	54.28
Furnishings	110.1
TOTAL	1,282.47

Table 7.5 Aircraft Component Weight Summary

8. Conclusions:

The analysis shown in this report indicate that all requirements listed in the SOW are met by this design. In order to reach this final stage, some design modifications were made which were enforced by the calculations performed.

The initial calculations and sizing of the engine mount showed that the mount was too heavy. In order to reduce weight and increase stiffness, I-beam cross sectioned structure was adopted, while the height of the beam was increased. This way, the goal design weight was reached without any compromise from safety. In the control system, the design of the stick and torque tube was changed, because of the flex in the system. There is the possibility of saving weight by more careful analysis of these parts.

No fatigue considerations were done for the control systems. This was due to the fact that it was impossible to determine the cyclic life of the control system without testing. Testing or in depth analysis is recommended for determining the endurance limit of the control system. The thrust tubes were estimated to be in use only during crash, although some loading due to the engine thrust will be experienced by these tubes. The out come of this cyclic loading is unknown. Testing and/or in-depth fatigue analysis is recommended on this part of the aircraft as well. Further testing should be done on the fuselage's top longeron. Experimental testing for the top longeron should include simulation of a turnover with the use of different materials for the top longeron.

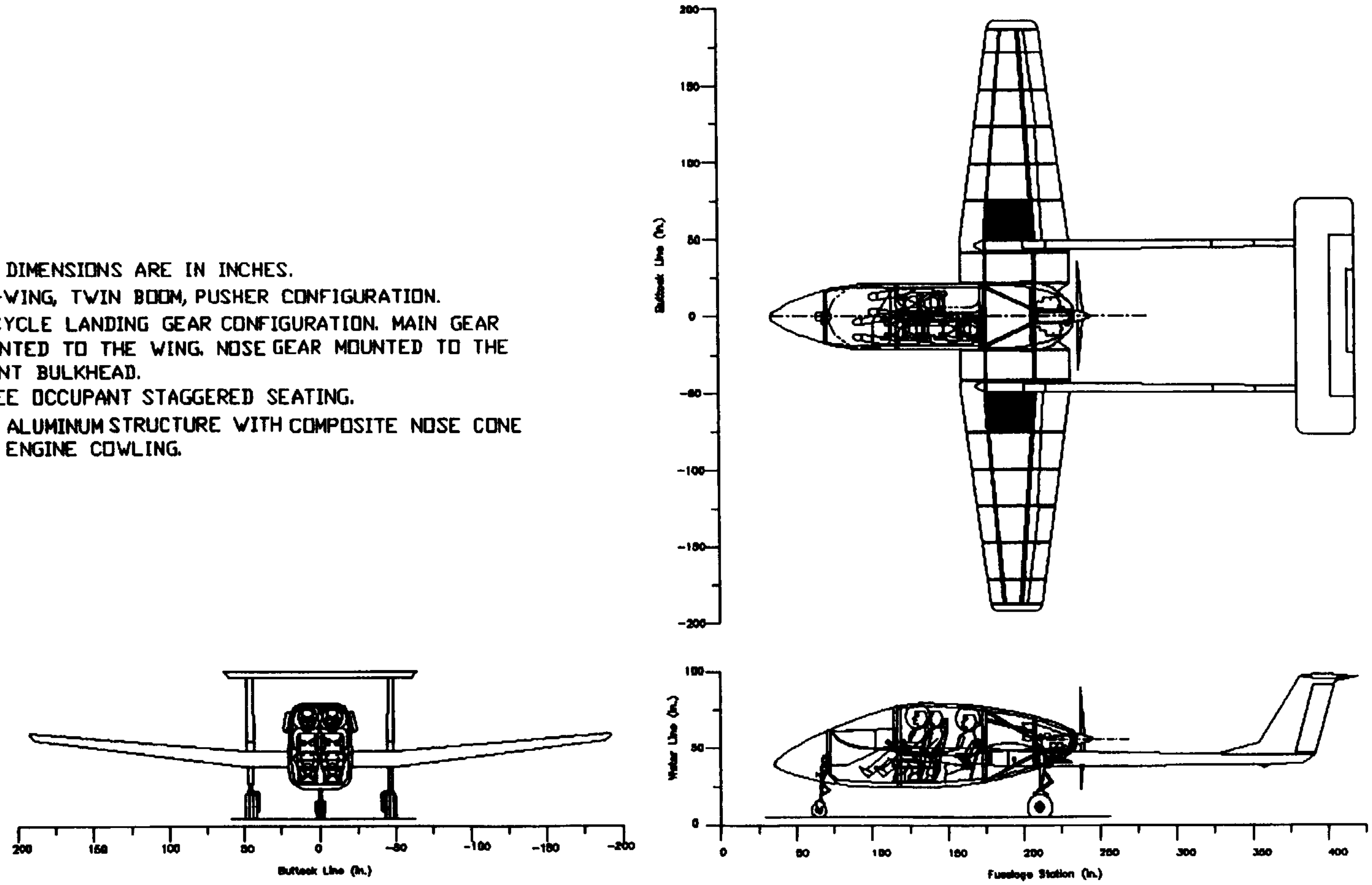
Compared with the original two seat version of this aircraft, adding a third passenger and changing to a lighter engine produced an increase of 265.5 lbs. With more careful structural analysis, the empty weight of 1282.47 lbs. should be reduced.

9. Appendices:

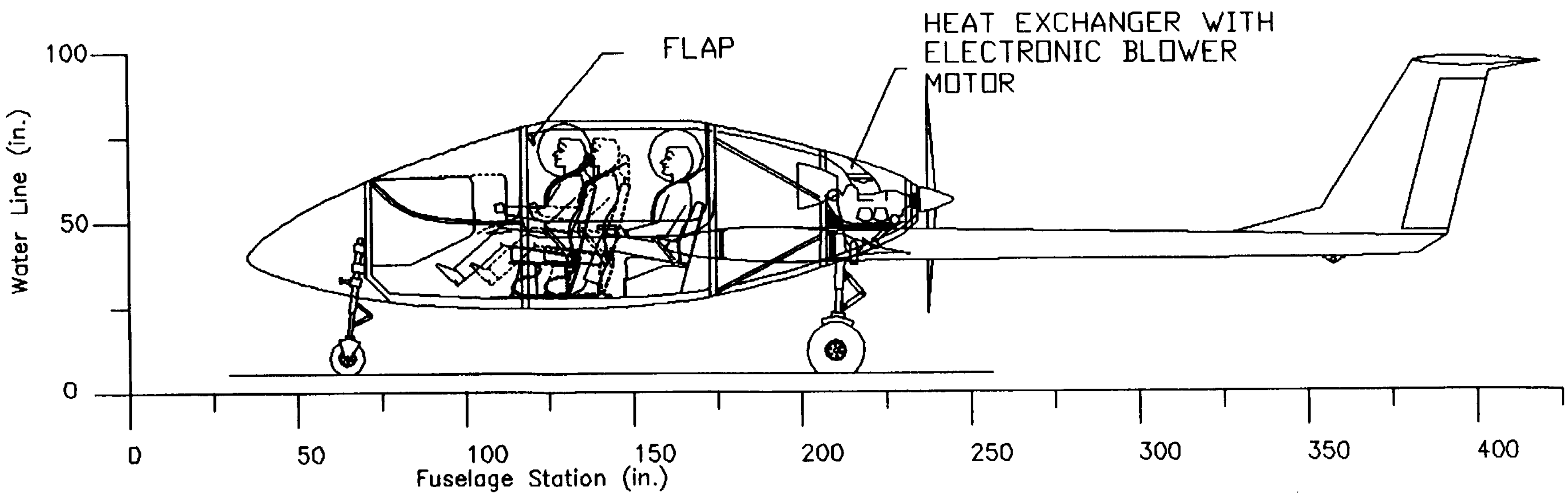
9.1. Drawings

NOTES :

1. ALL DIMENSIONS ARE IN INCHES.
2. MID-WING, TWIN BOOM, PUSHER CONFIGURATION.
3. TRICYCLE LANDING GEAR CONFIGURATION. MAIN GEAR MOUNTED TO THE WING. NOSE GEAR MOUNTED TO THE FRONT BULKHEAD.
4. THREE OCCUPANT STAGGERED SEATING.
5. ALL ALUMINUM STRUCTURE WITH COMPOSITE NOSE CONE AND ENGINE COWLING.



DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED DECIMAL .XX ± .01 .XXX ± .001 ANGULAR ± 1/2°	EMBRY-RIDDLE AERONAUTICAL UNIVERSITY DAYTONA BEACH FLORIDA SIZE A | DATE 04.27.94 | SCALE 1/120 | DRAWN BY BALAKRISHNAN TITLE GENERAL ARRANGEMENT DRAWING NO. S94-1B-304 | SHEET 1/2



DATE	SCALE	DRAWN BY	DRAWING NO.	SHEET
5.03.94	1/50	BALAKRISHNAN	S94-1B-304	2/2

ITEM	QUANTITY	DESCRIPTION	MATERIAL
14	24	THRUST TUBE WASHERS	AN960-C616L
13	24	THRUST TUBE NUTS	AN320-C6
12	24	THRUST TUBE BOLTS	AN6-C3
11	40	WASHERS	AN960-C10L
10	40	NUTS	AN320-C4
9	40	BOLTS	AN4-C3
8	2	THRUST TUBE PIN HOLDER	AMS 5643-H1100
7	2	THRUST TUBE PIN	AMS 5643-H1100
6	1	ROTAX 914 ENGINE	
5	2	ENGINE MOUNT	2011-T8
4	1	FIREWALL	PH15-7MO
3	1	RING FRAME	2024-T4
2	2	THRUST TUBE	2011-T8
1	2	TAPERED THRUST TUBE	2011-T8

DIMENSION TOLERANCES
UNLESS OTHERWISE SPECIFIED
DECIMAL

.XX ± .01
.XXX ± .001

ANGULAR

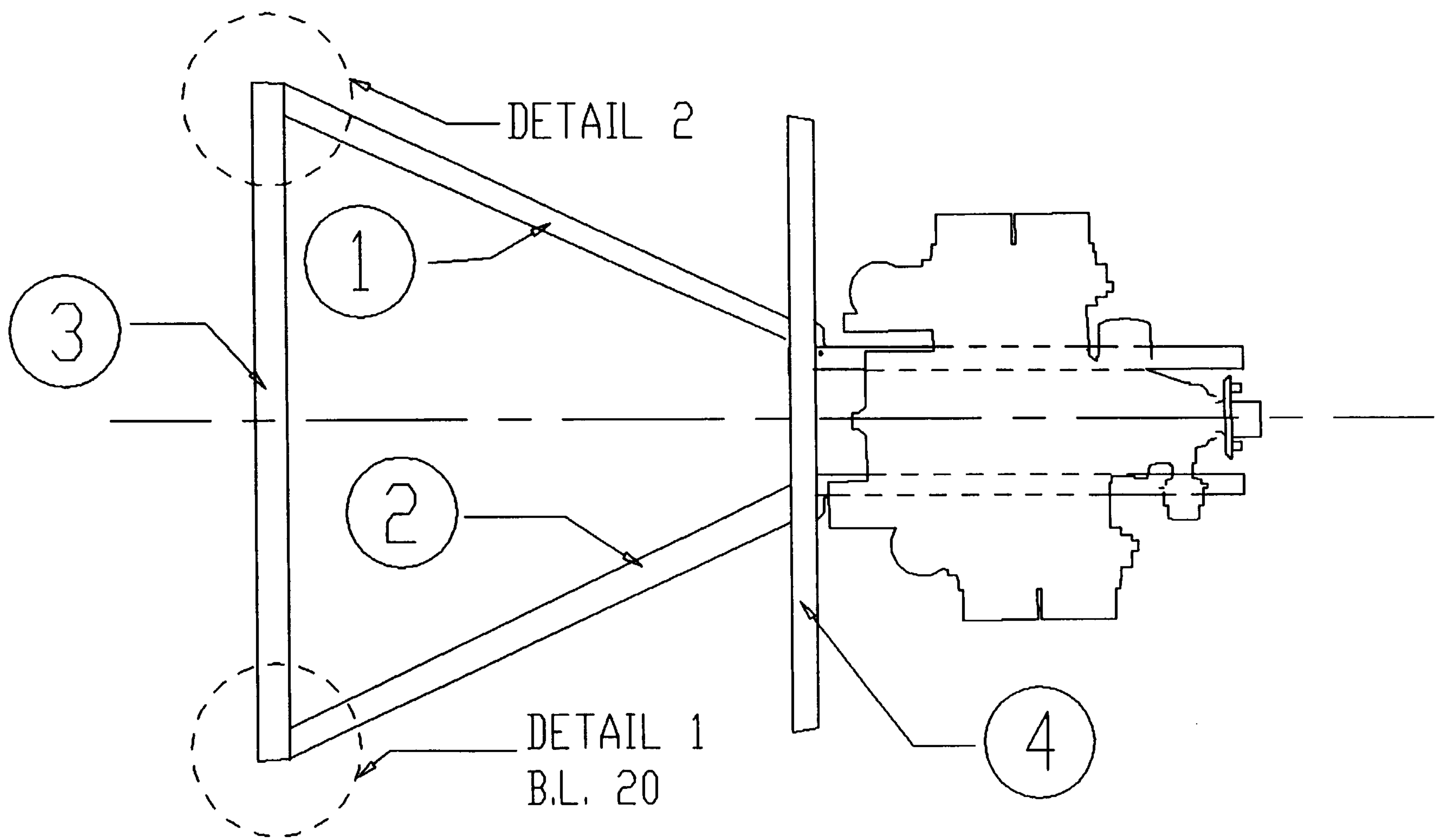
± 1/2°

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY
DAYTONA BEACH FLORIDA

SIZE	DATE	SCALE	DRAWN BY
A	04/30/94	1/10	GUMUS

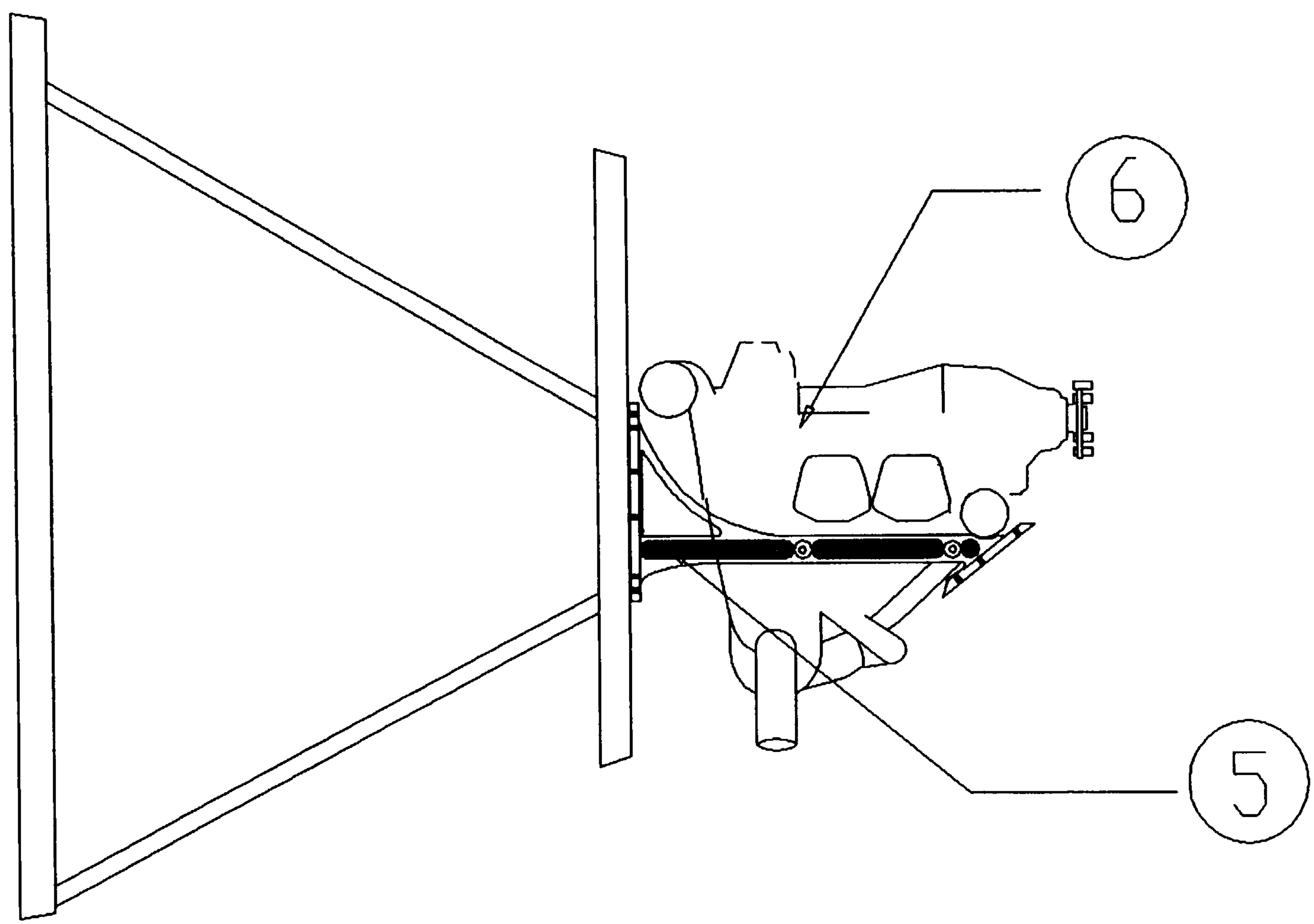
TITLE
ENGINE MOUNT ASSEMBLY

DRAWING NO.	SHEET
S94-1B-302	1/5



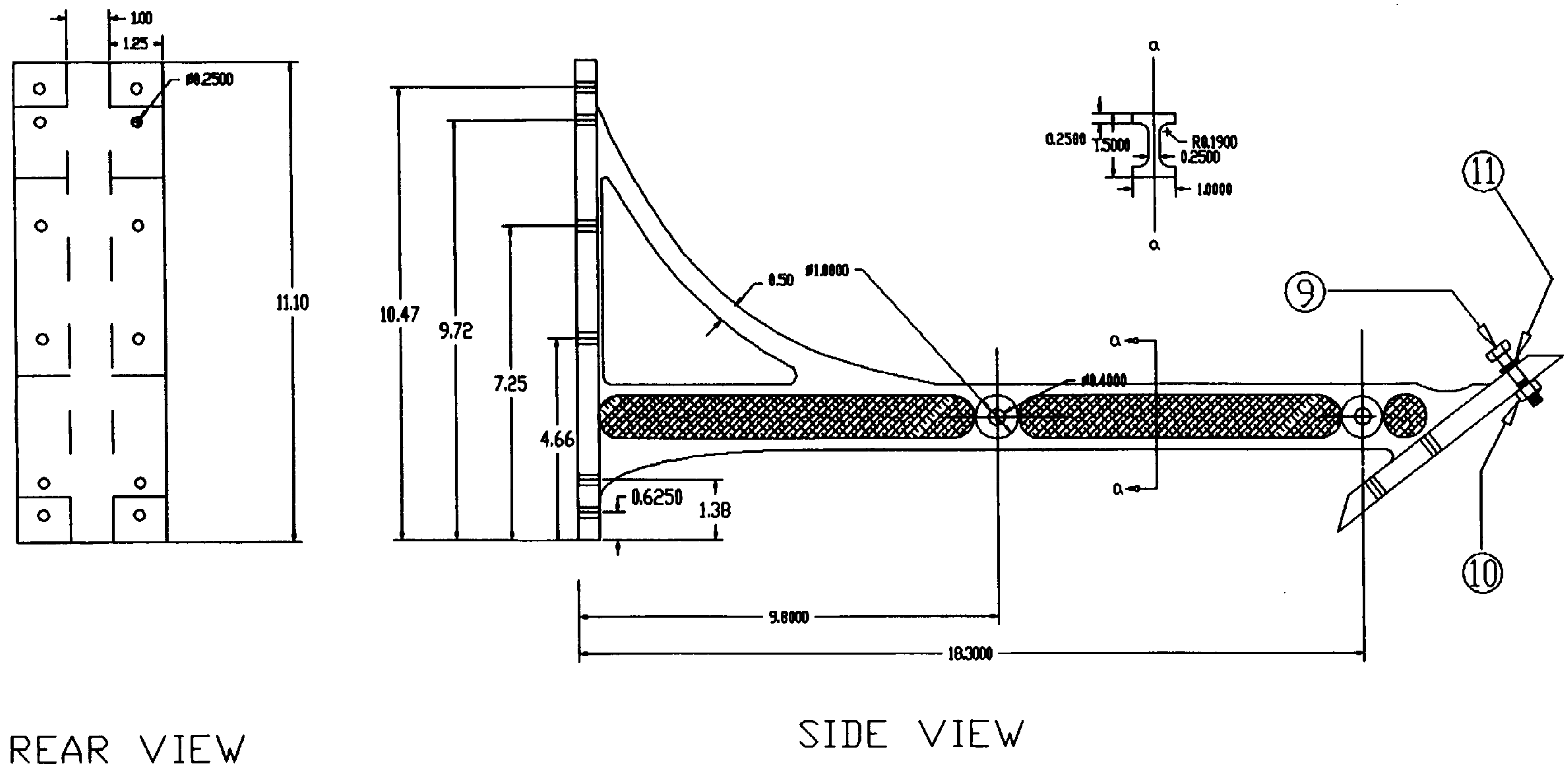
TOP VIEW

DATE	SCALE	DRAWN BY	DRAWING NO.	SHEET
04/30/94	1/10	GUMUS	S94-1B-302	2/5

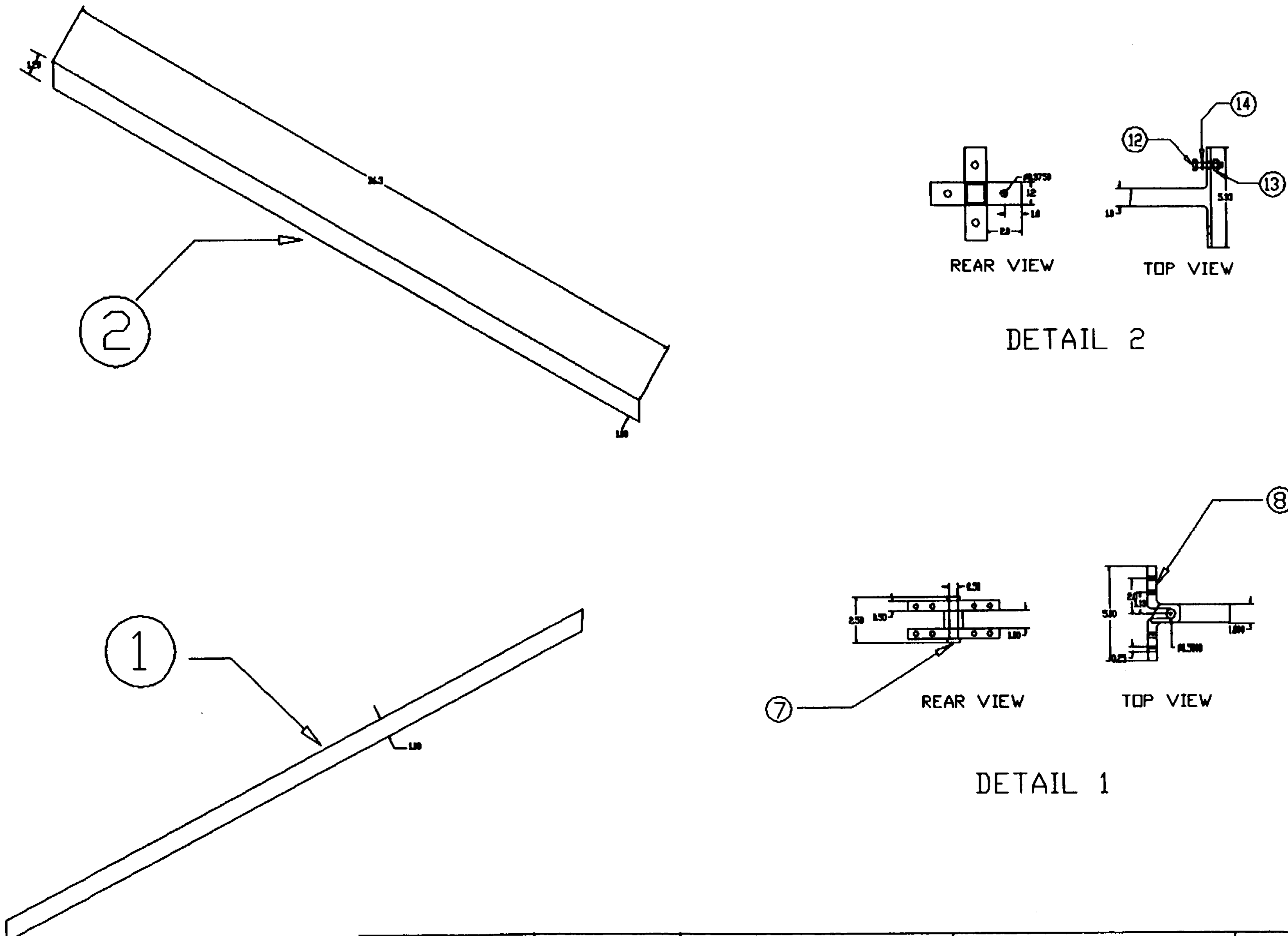


SIDE VIEW

DATE	SCALE	DRAWN BY	DRAWING NO.	SHEET
04/30/94	1/10	GUMUS	S94-1B-302	3/5



DATE	SCALE	DRAWN BY	DRAWING NO.	SHEET
04/30/94	1/4	GUMUS	S94-1B-302	4/5



DATE	SCALE	DRAWN BY	DRAWING NO.	SHEET
04/30/94	1/8	GUMUS	S94-1B-302	5/5

CONTENTS OF DISKETTES

DISKETTE # 1

1. SRSD REPORT >>>>>> AE421SRD.DOC (WORD DOCUMENT)
2. INTERNAL REPORT >>> INTERNAL.SAM (AMIPRO)
3. FINAL REPORT >>>>>> FINALREP.SAM (AMIPRO)
4. EXECUTIVE REPORT >>> EXECTIT.SAM(AMIPRO)

DISKETTE # 2

1. ENGINE MOUNT >>>>>> QUE3ENG.DWG (ACAD10)
2. GENERAL ARRANGEMENT >>> QUE3.DWG (ACAD10)

DISKETTE # 3

1. STRUCTURE DRAWINGS >>>>> A-SIZE ----- Q3STRA.DWG (ACAD10)
   B-SIZE ----- Q3STRB.DWG (ACAD10)

DISKETTE # 4

1. CONTROLS SYSTEM >>>>>>> QUE3CONS.DWG (ACAD10)

NOTE:
1. QUANTITIES SHOWN ARE FOR ONE ASSEMBLY

ITEM	QTY	DESCRIPTION	MAT'L OR PART#
18	8	BOLT	AN4C-10
17	1	ATTACHMENT ASSEMBLY	2024-T3
16	1	NOSE CONE	FIBERGLASS
15	1	FLOOR PANEL	2024-T3
14	4	LONGERONS BRAKE FORM C	2024-T4
13	6	BUCKLE STIFFENERS BRAKE FORM J	2024-T3
12	4	FLOOR LONGERONS EXTRUDED Z	NAS346-47
11	2	WINDSHIELD FRAME	2024-T4
10	2	ENGINE MOUNT	2024-T4
9	1	FIREWALL PRESS FORM	PH15-7MO
8	2	LOWER ENGINE THRUST TUBE	2024-T4
7	2	UPPER ENGINE THRUST TUBE	2024-T4
6	2	AFT RING FRAME PRESS FORM C	2024-T4
5	1	MID LT RING FRAME PRESS FORM C	2024-T4
4	1	MID RT RING FRAME PRESS FORM C	2024-T4
3	2	FWD RING FRAME PRESS FORM C	2024-T4
2	1	FORWARD BULKHEAD	2024-T3
1	1	UPPER LONGERON BRAKE FORM C	2024-T4

DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED
DECIMAL
.XX ± .01
.XXX ± .001
ANGULAR
± 1/2°

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY
DAYTONA BEACH FLORIDA

SIZE	DATE	SCALE	DRAWN BY
A	5-1	AS INDICATED	MICHAEL TRIGGS

TITLE: STRUCTURAL LAYOUT AND DETAIL

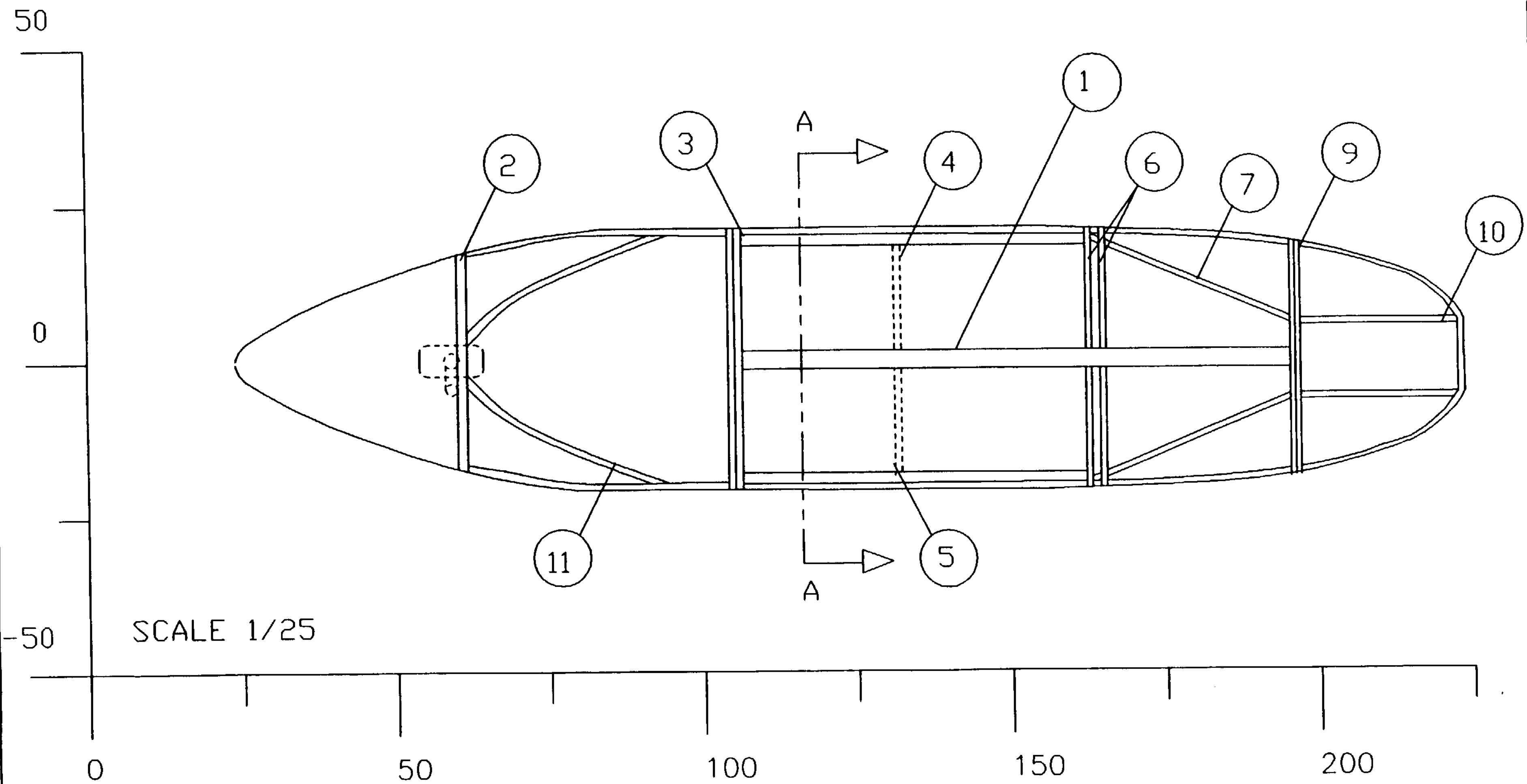
DRAWING NO. S94-1B-301

SHEET 1/9

ITEM	QTY	DESCRIPTION	MAT'L OR PART #
41	2	BULKHEAD STIFFENER EXTRUDED T	NAS344-32
40	16	WASHER	MS20002-10
39	8	NUT	AN315-10
31	440	UPPER SKIN RIVET	AN479-DD3-5
30	2	AFT RING FRAME PRESS FORM C	2024-T3
29	2	AFT LONGERON BRAKE FORM C	2024-T4
28	2	MID LONGERON BRAKE FORM C	2024-T4
27	2	REAR SPAR CAP	NAS-344-33
26	2	FRONT SPAR CAP	NAS-344-69
25	1	REAR SPAR WEB	2024-T3
24	1	FRONT SPAR WEB	2024-T3
23	1	FIREWALL LR CORNER PRESS FORM	2024-T3
22	1	FIREWALL RT CORNER PRESS FORM	2024-T3
21	70	SPAR RIVETS	AN470-DD3-6
20	1700	FRAME RIVETS	AN470-DD3-7
19	3940	LOWER SKIN RIVETS	AN470-DD3-6

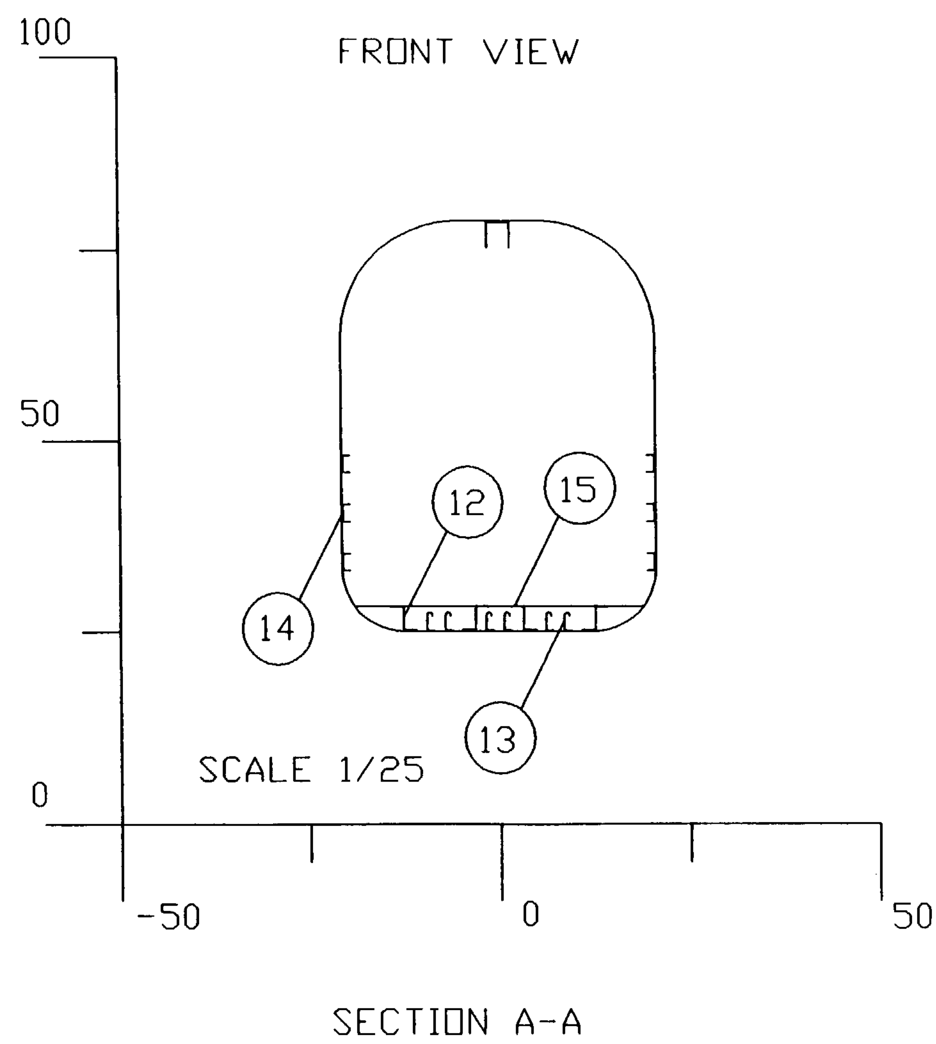
DATE	BY	DWG. NO.	SHT.
5-1	TRIGGS	S94-1B-301	2/9

TOP VIEW

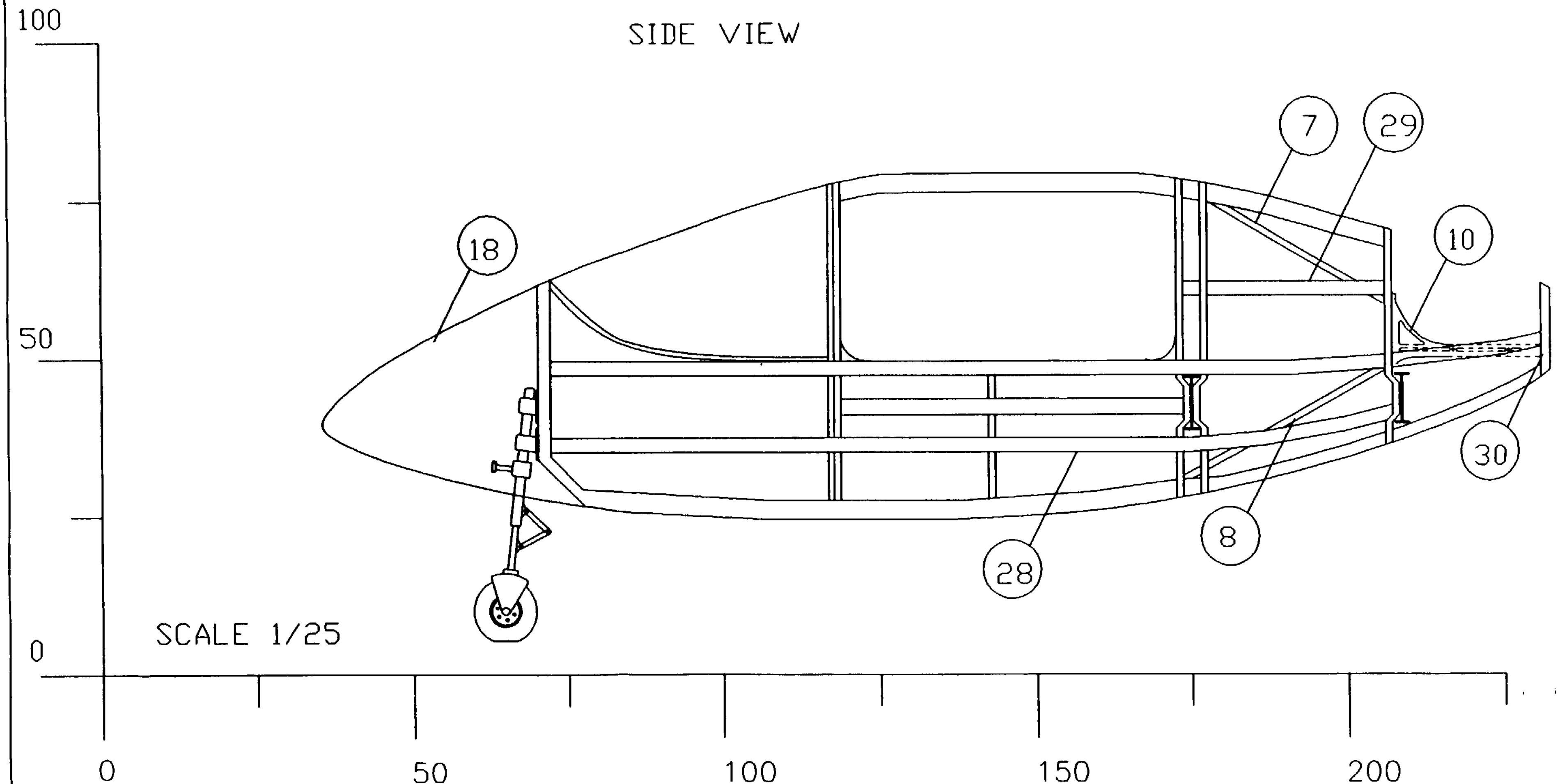


SCALE 1/25

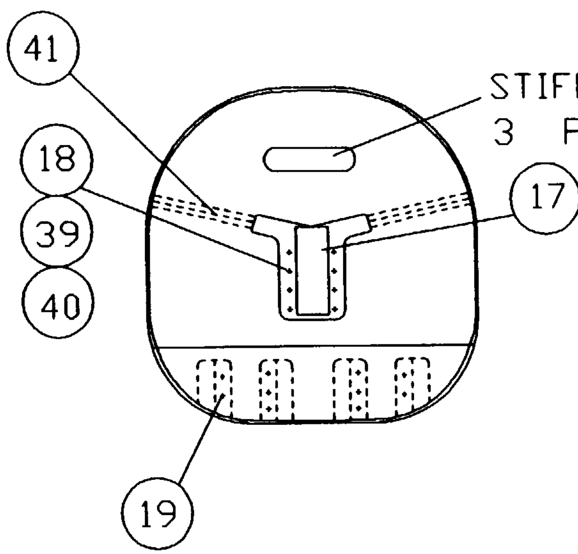
DATE	BY	DWG. NO.	SHT.
5-1	TRIGGS	S94-1B-301	3/9



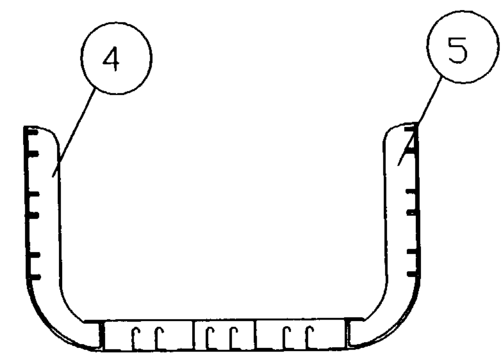
DATE	BY	DWG. NO.	SHT.
5-1	TRIGGS	S94-1B-301	4/9



DATE	BY	DWG. NO.	SHT.
5-1	TRIGGS	S94-1B-301	5/9



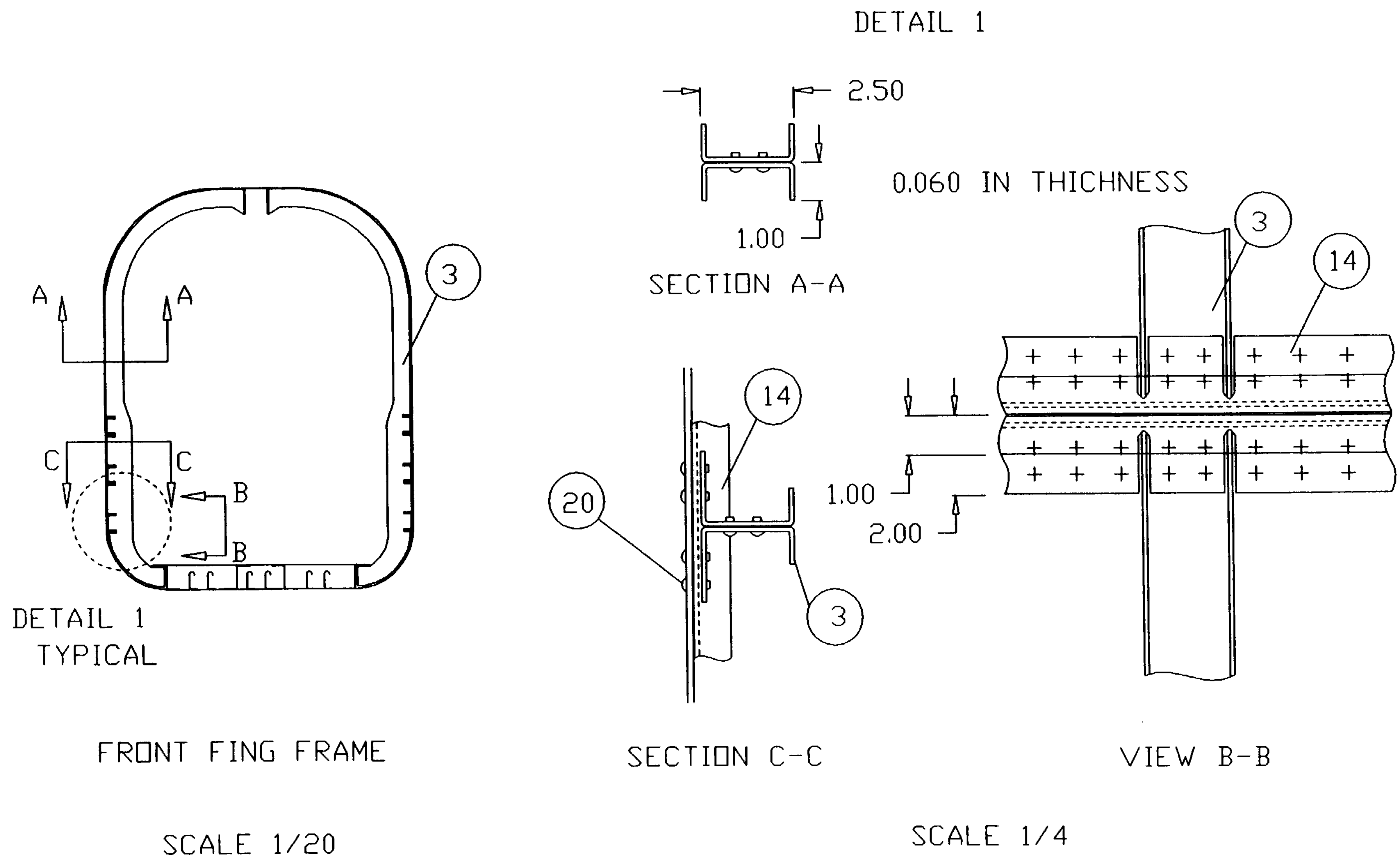
FORWARD BULKHEAD



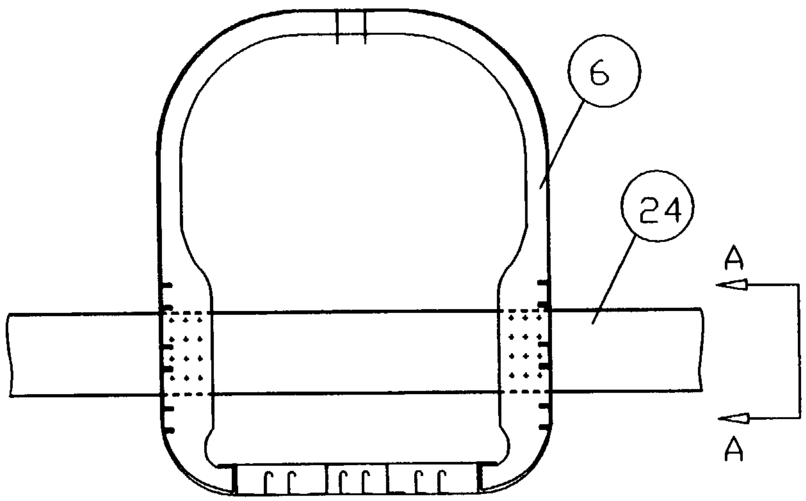
MID RING FRAME

SCALE 1/20

DATE	BY	DWG. NO.	SHT.
5-1	TRIGGS	S94-1B-301	6/9

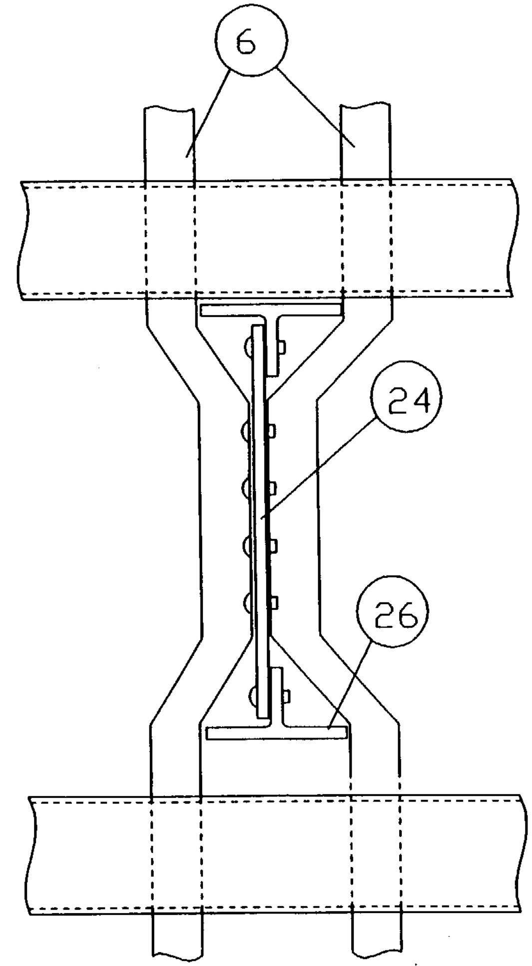


DATE	BY	DWG. NO.	SHT.
5-1	TRIGGS	S94-1B-301	7/9



REAR RING FRAME

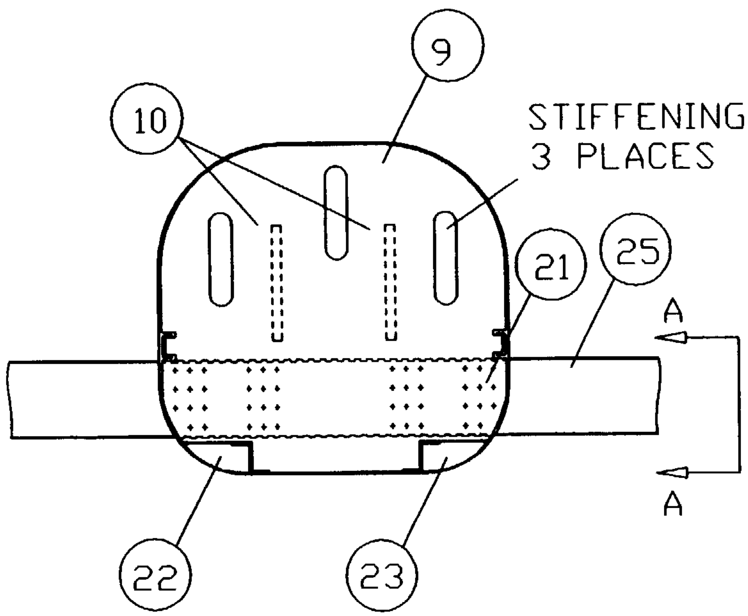
SCALE 1/20



VIEW A-A

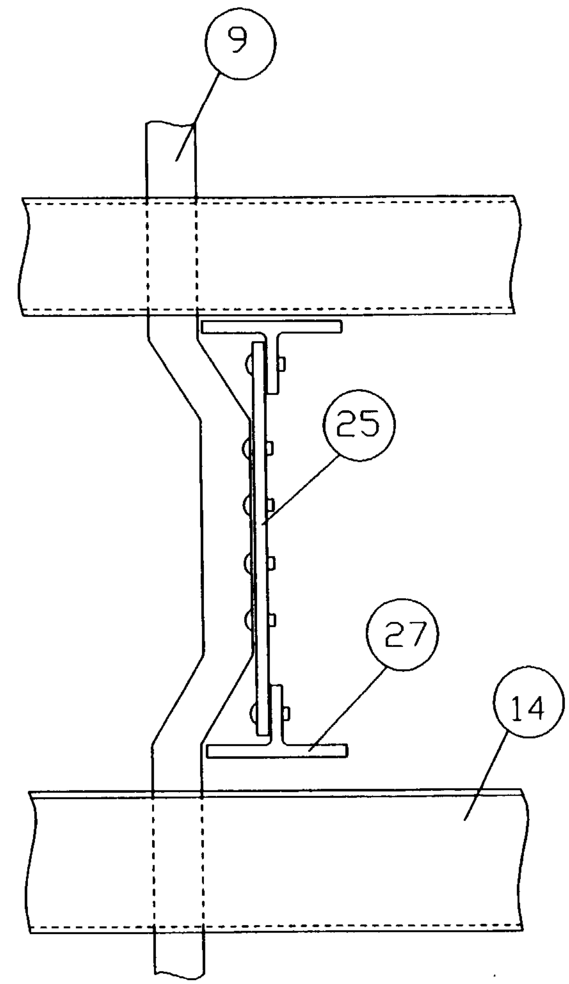
SCALE 1/4

DATE	BY	DWG. NO.	SHT.
5-1	TRIGGS	S94-1B-301	8/9



FIREWALL/REAR BULKHEAD

SCALE 1/20



VIEW A-A

SCALE 1/4

DATE	BY	DWG. NO.	SHT.
5-1	TRIGGS	S94-1B-301	9/9

NOTE:

1. QUANTITIES SHOWN ARE FOR ONE ASSEMBLY

ITEM	QTY	DESCRIPTION	MAT'L OR PART#
8	1	NOSE CONE	2024-T3
7	1	UPPER SKIN	2024-T3
6	1	TAIL CONE	2024-T3
5	1	CARRY THROUGH SKIN	2024-T3
4	1	AFT MID SKIN	2024-T3
3	1	FORWARD MID SKIN	2024-T3
2	1	LOWER FORWARD SKIN	2024-T3
1	1	NOSE SKIN	2024-T3

DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED

DECIMAL

.XX ± .01

.XXX ± .001

ANGULAR

± 1/2°

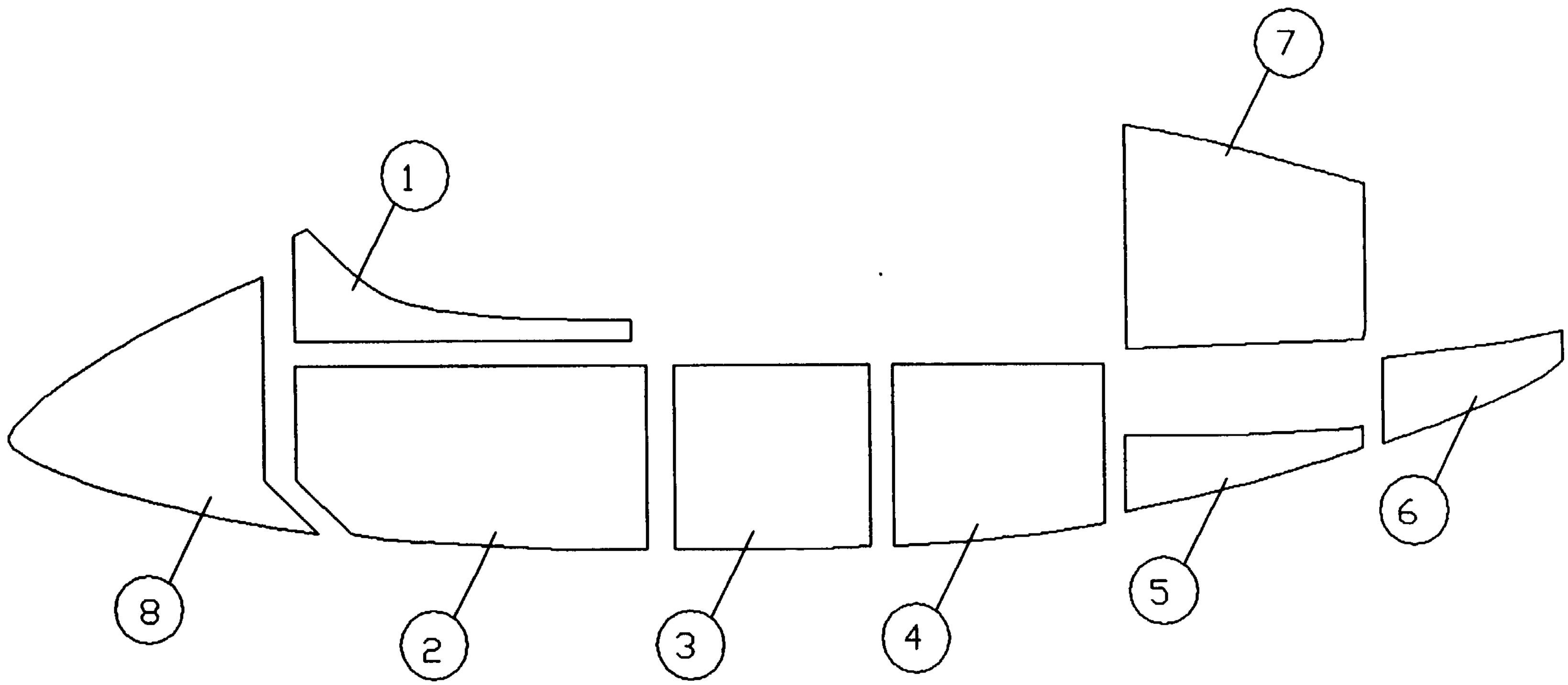
EMBRY-RIDDLE AERONAUTICAL UNIVERSITY
DAYTONA BEACH FLORIDA

SIZE	DATE	SCALE	DRAWN BY
A	5-1	AS INDICATED	MICHAEL TRIGGS

TITLE: SKIN PANEL LAYOUT

DRAWING NO. S94-1B-302

SHEET 1/2



NOTE:

1. ALL SKIN PANELS 0.020 IN
2. ALL SKIN PANELS CIRCUMPHRENCIALLY WRAPPED

DATE	BY	DWG. NO.	SHT.
5-1	TRIGGS	S93-1B-302	2/2

ITEM	QUANTITY	DESCRIPTION	MATERIAL
22	36	CABLE END CONNECTOR	MS 20668-4
21	38	PULLEY & BELL CRANK MOUNT	AL 2024-T4
20	6	SPECIAL WASHER	STEEL
19	2	CONTROL STICK	AL 2024-T4
18	4	AN 936 TOOTHLOCK WASHER	ALUMINUM
17	58	AN BOLT AND NUT	STEEL
16	122	AN WASHER	STEEL
15	2	CONTROL STICK CONNECTOR	AL 2024-T4
14	2	CAST STICK MOUNT	AL 2024
13	2	ELEVATOR PUSH-PULL ROD	AL 2024-T4
12	2	AILERON TORQUE TUBE	AL 2024-T4
11	5	BUSHINGS	
10	150	BLIND RIVETS	
9	2	CONTROL STICK HANDLE	PLATIC
8	1	PUSH-PULL ROD COUPLING	AL 2024-T4
7	19	PUSH-PULL END CONNECTOR	FL35-14/STEEL
6	1	TRIM-TAB CABLE	ELECTRIC CABLE
5	8	PUSH-PULL ROD	AL 2024-T4
4	200 FT	CABLES	7X19 STAINLESS
3	50	PULLEYS	AN210-3B/ PHENOLIC
2	2	FLAP SERVO MOTOR	
1	1	INTRUMENT PANEL	WOOD/PLASTIC

DIMENSION TOLERANCES UNLESS OTHERWISE SPECIFIED

DECIMAL

.XX ± .01

.XXX ± .001

ANGULAR

± 1/2°

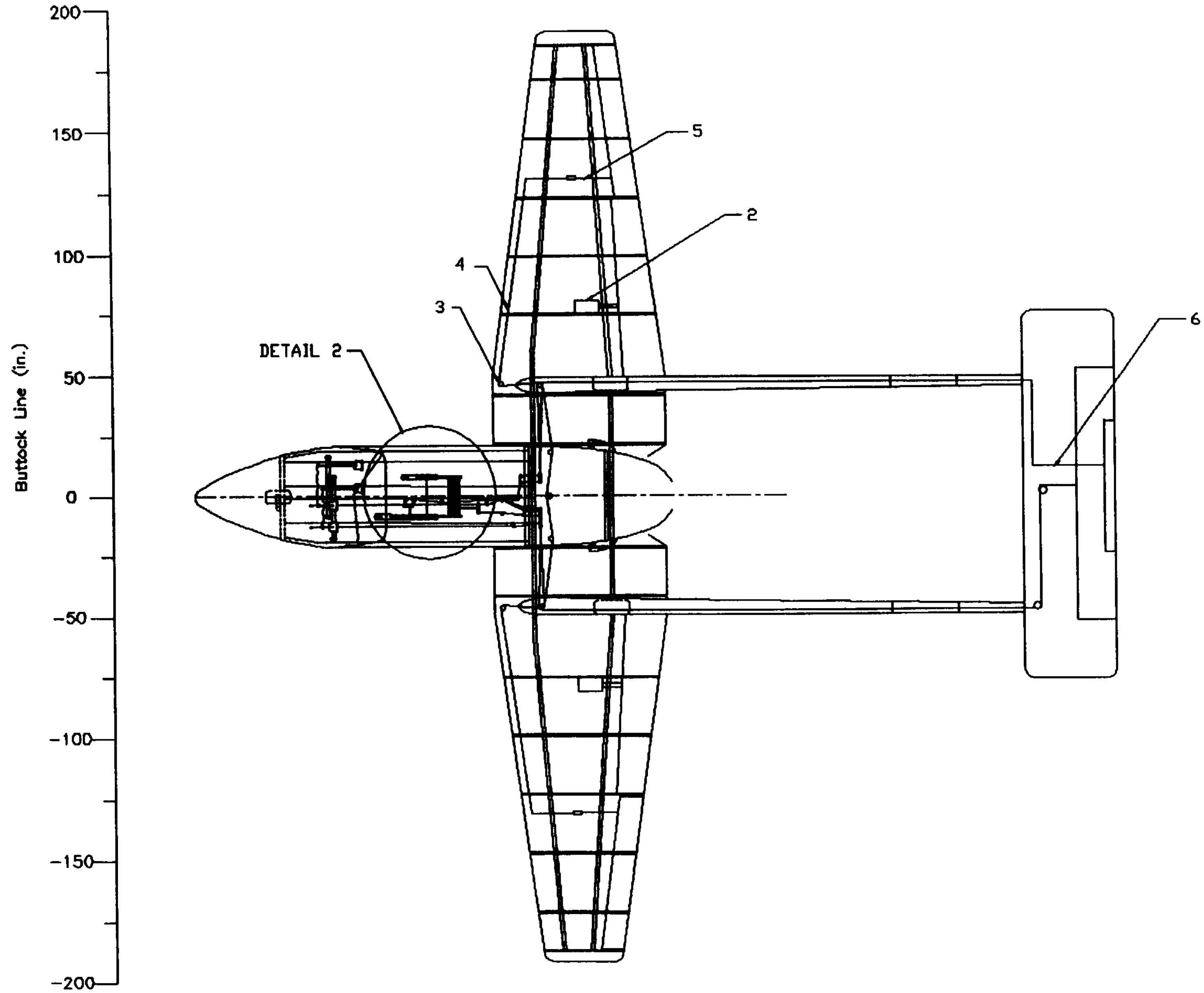
EMBRY-RIDDLE AERONAUTICAL UNIVERSITY
DAYTONA BEACH FLORIDA

SIZE	DATE	SCALE	DRAWN BY
A	5.03.94	1/10	BALAKRISHNAN

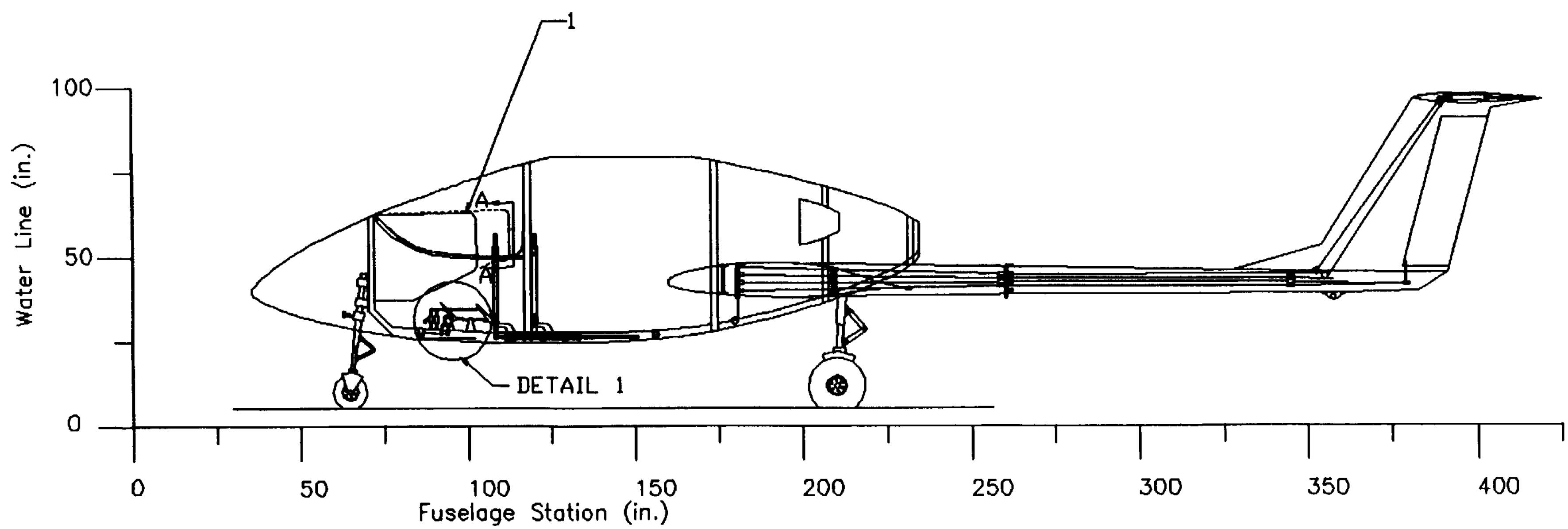
TITLE
CONTROL SYSTEMS

DRAWING NO.
S94-1B-303

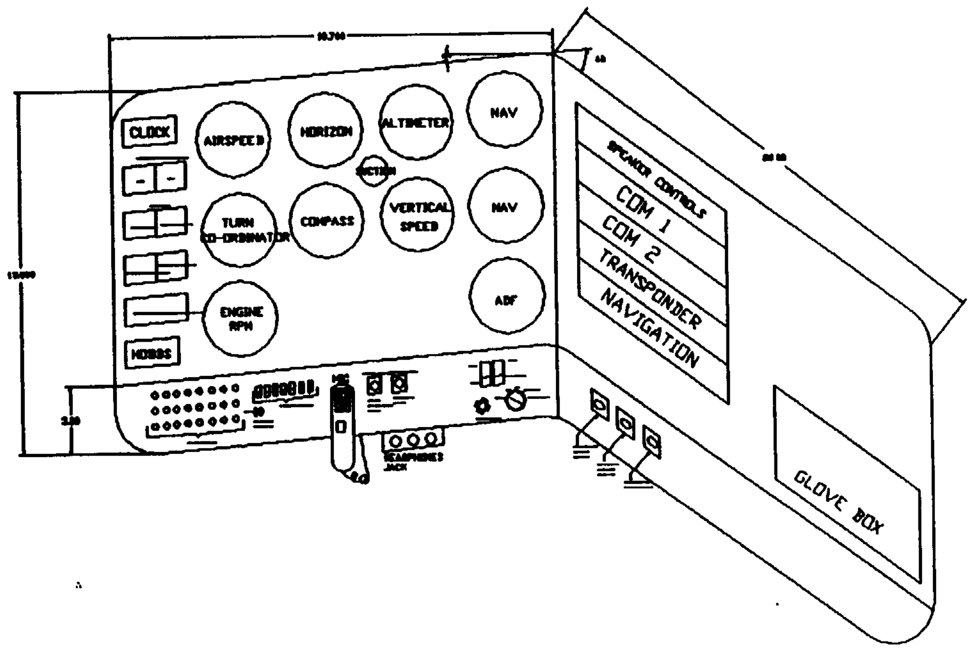
SHEET
1/12



DATE	SCALE	DRAWN BY	DRAWING NO.	SHEET
5.03.94	1/65	BALAKRISHNAN	S94-1B-303	2/12



DATE	SCALE	DRAWN BY	DRAWING NO.	SHEET
5.03.94	1/50	BALAKRISHNAN	S94-1B-303	3/12

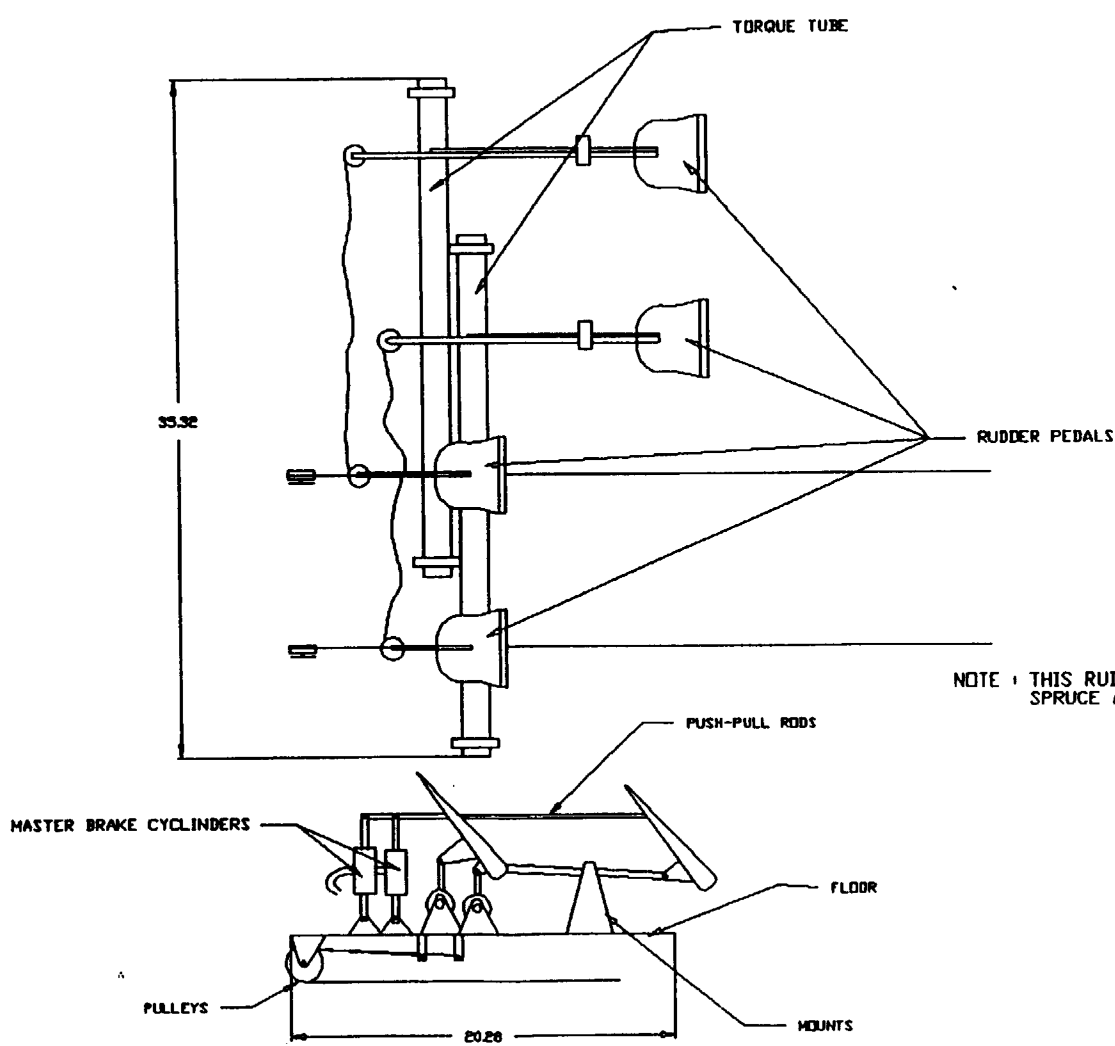


NOTES :

1. THE CONCOLE IS EQUIPED WITH VFR INSTRUMENTS. BUT SPACES ARE PROVIDED FOR IFR INSTRUMENTS.
2. THE FACE OF THE CONSOLE ARE TILTED TO PROVIDE BETTER VIEW FOR BOTH PILOTS AND TO REDUCE GLARE.
3. ALL INSTRUMENTS ARE PURCHASED FROM AIRCRAFT SPRUCE AND SPECIALTY COMPANY.

VIEW AA : INSTRUMENT PANELS

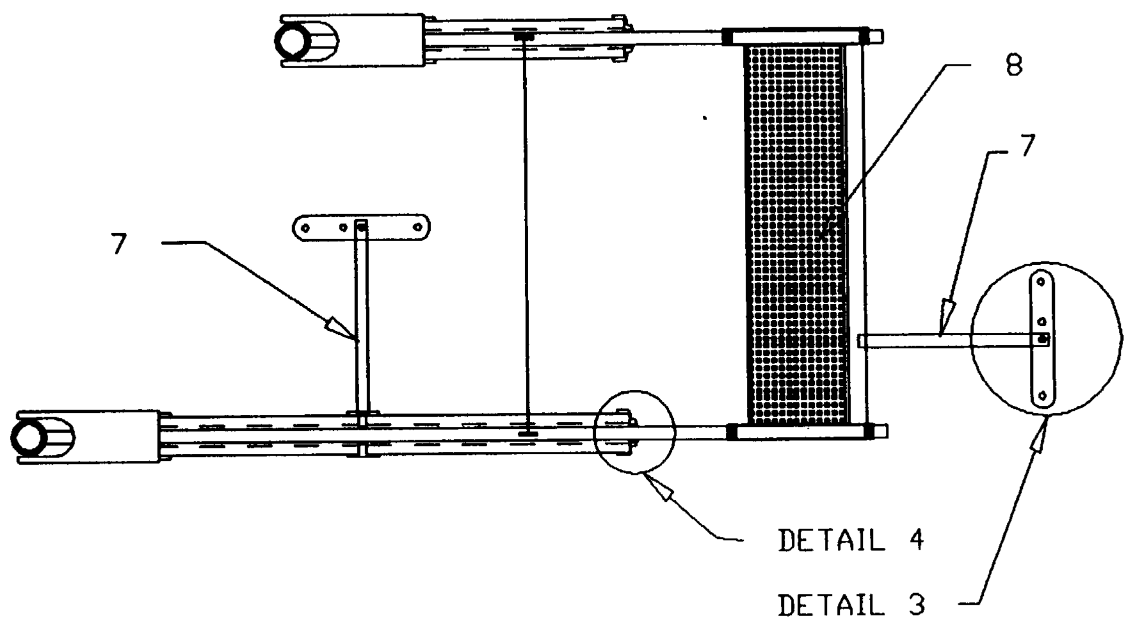
DATE	SCALE	DRAWN BY	DRAWING NO.	SHEET
5.03.94	1/8	BALAKRISHNAN	S94-1B-303	4/12



NOTE : THIS RUDDER ASSEMBLY WILL BE PURCHASED FROM AIRCRAFT SPRUCE AND SPECIALTY COMPANY.

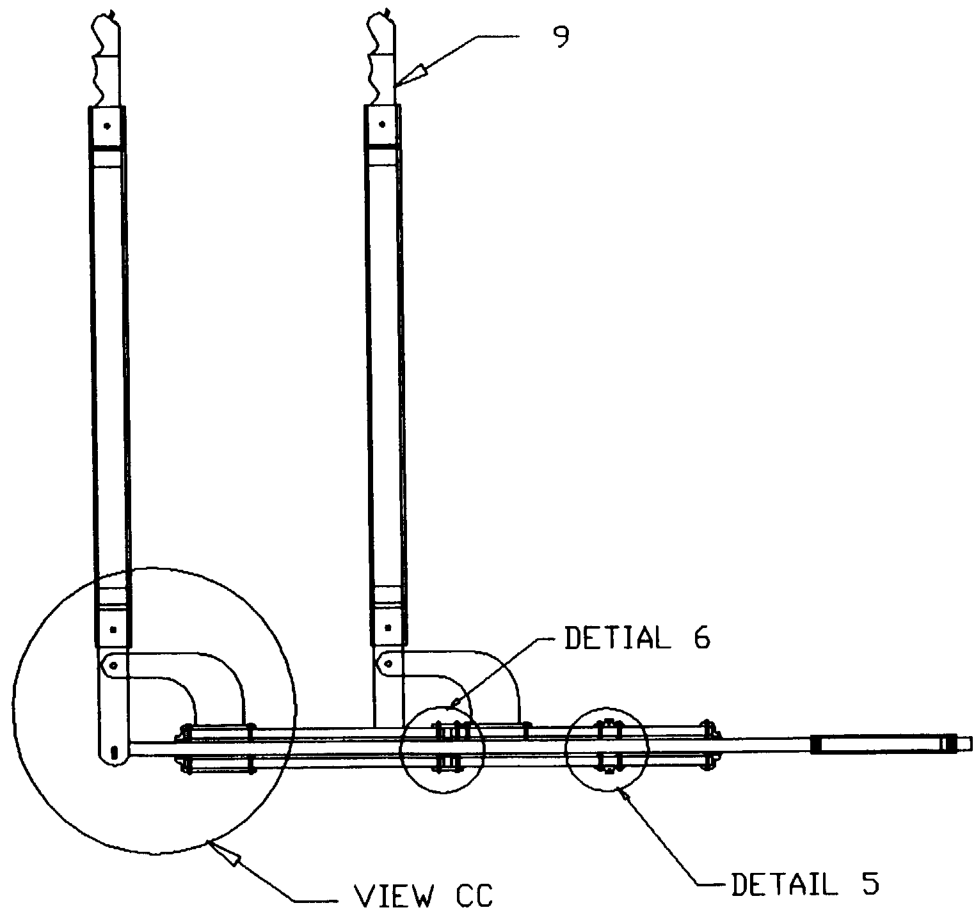
DETAIL 1 : RUDDER PEDEL ASSEMBLY

DATE	SCALE	DRAWN BY	DRAWING NO.	SHEET
5.3.94	1/10	BALAKRISHNAN	S94-1B-301	5/12



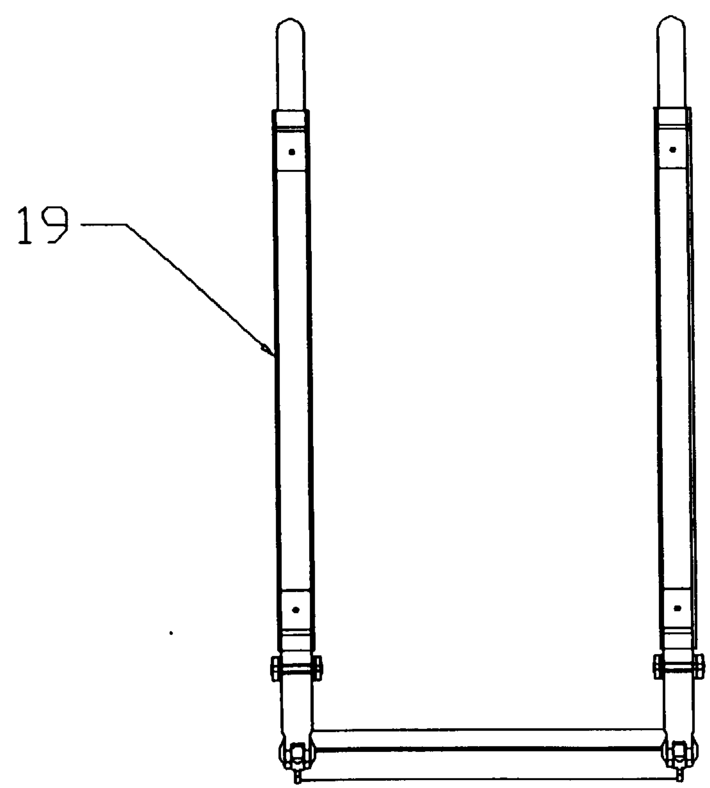
VIEW CC : CONTROL STICK (TOP VIEW)

DATE	SCALE	DRAWN BY	DRAWING NO.	SHEET
5.03.94	1/8	BALAKRISHNAN	S94-1B-303	6/12



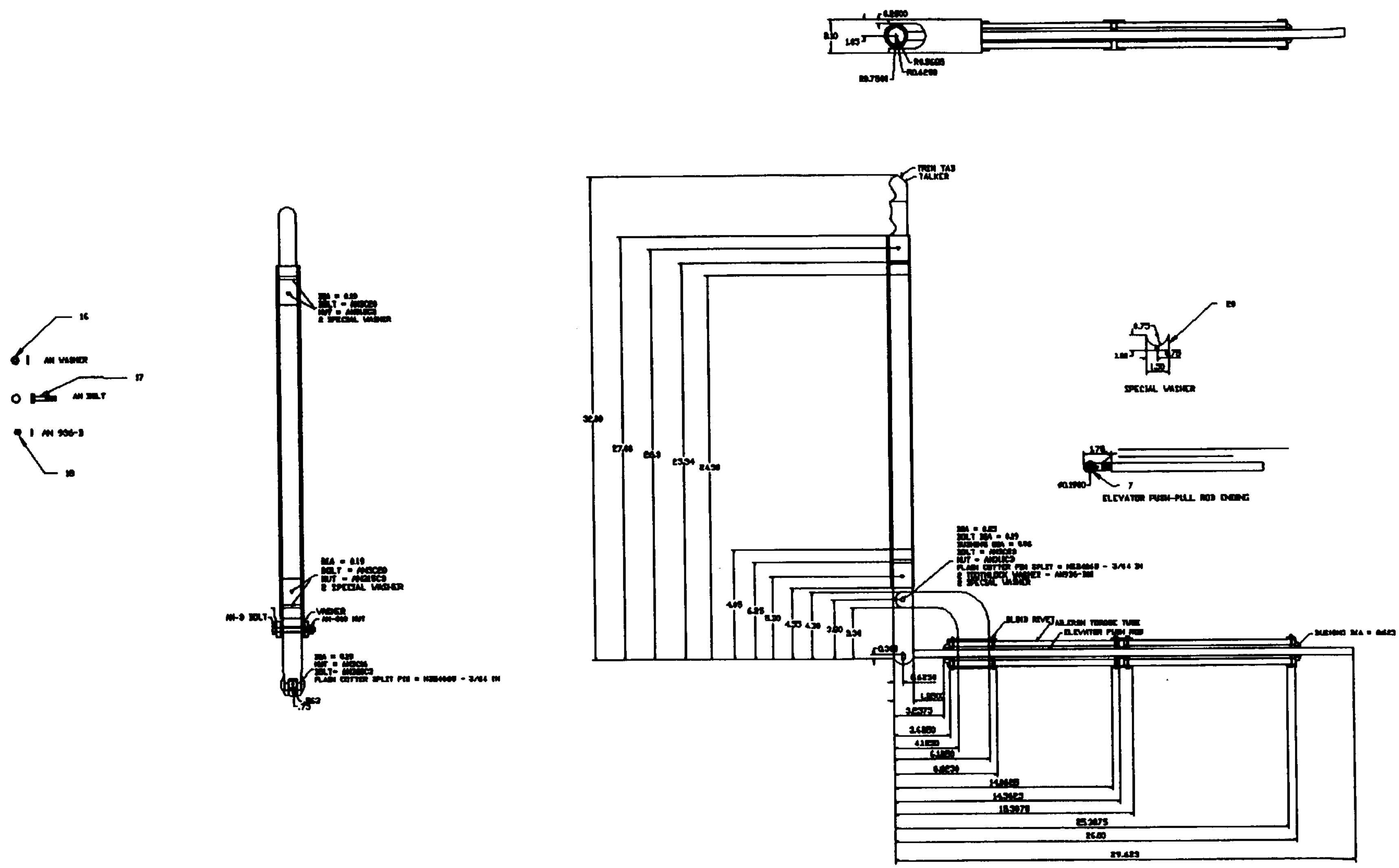
VIEW CC : CONTROL STICK (SIDE VIEW)

DATE	SCALE	DRAWN BY	DRAWING NO.	SHEET
5.03.94	1/8	BALAKRISHNAN	S94-1B-303	7/12



VIEW CC : CONTROL STICK (FRONT VIEW)

DATE	SCALE	DRAWN BY	DRAWING NO.	SHEET
5.03.94	1/8	BALAKRISHNAN	S94-1B-303	8/12

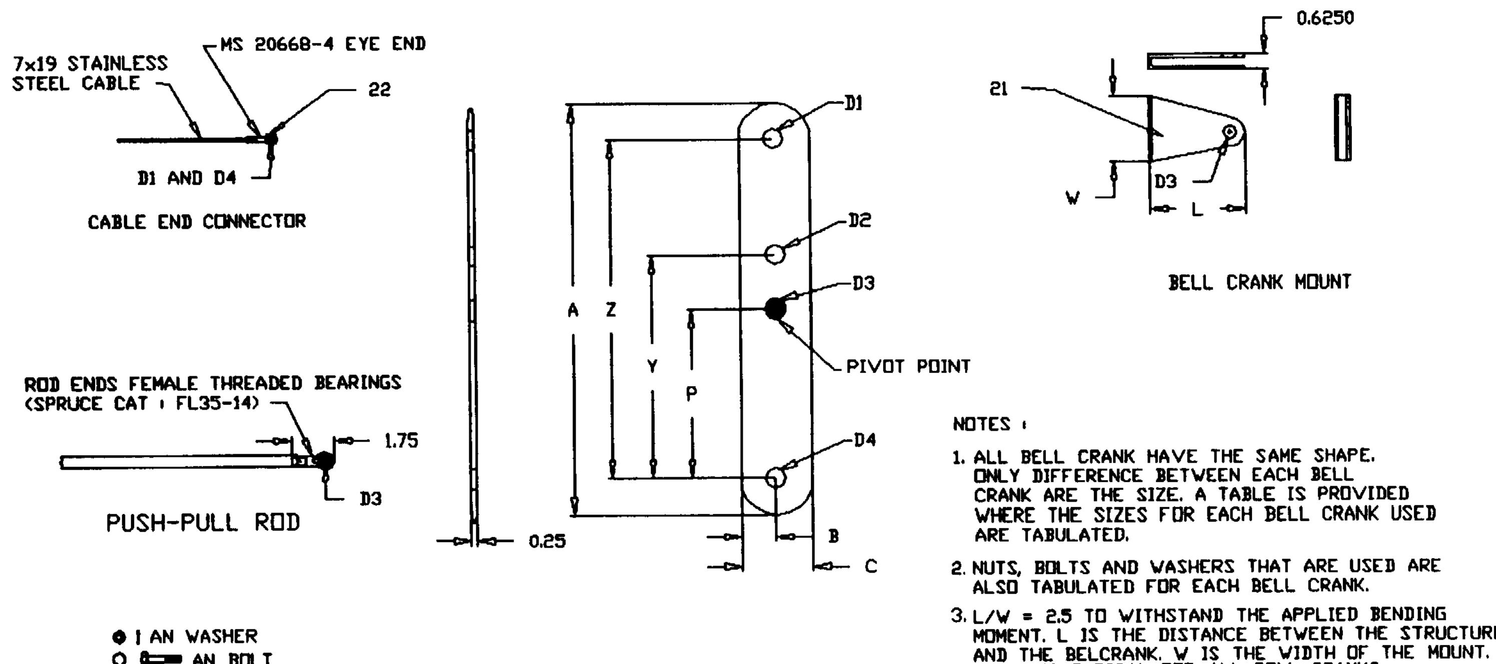


DATE	SCALE	DRAWN BY	DRAWING NO.	SHEET
5.3.94	1/10	BALAKRISHNAN	S94-1B-301	9/12

Bell Cranks

Components	A	B	C	D1	D2	D3	D4	P	Y	Z
Elevator										
Bell Cranck #2	6.78	0.625	1.25	0.19	0.19	0.19	0.19	2.2	1.2	6.4
Bellcranck #1	8.38	0.75	1.5	0.19	0.25	0.3125	0.19	4	5.5	8
Rudder										
Bell Cranck #2	4.88	0.75	1.5	0.25		0.3125	0.25	1.5		4.5
Bellcranck #1	5.96	0.625	1.25	0.19	0.19	0.25	0.19	2.785	4.785	5.57
Aileron										
Bell Cranck #2	6.58	0.5	1	0.19	0.19	0.19	0.19	3.1	5.1	6.2
Bellcranck #1	10.98	0.625	1.25	0.19	0.25	0.3125	0.19	5.33	6.33	10.66

DIA	BOLTS	NUTS	WASHER
0.19	AN3C	AN320C3	AN960B10
0.25	AN4C	AN320C4	AN960B416
0.3125	AN5C	AN320C5	AN960B516

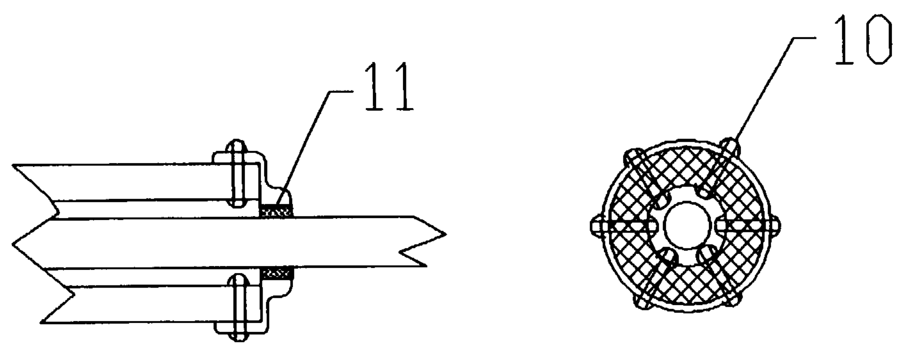


NOTES :

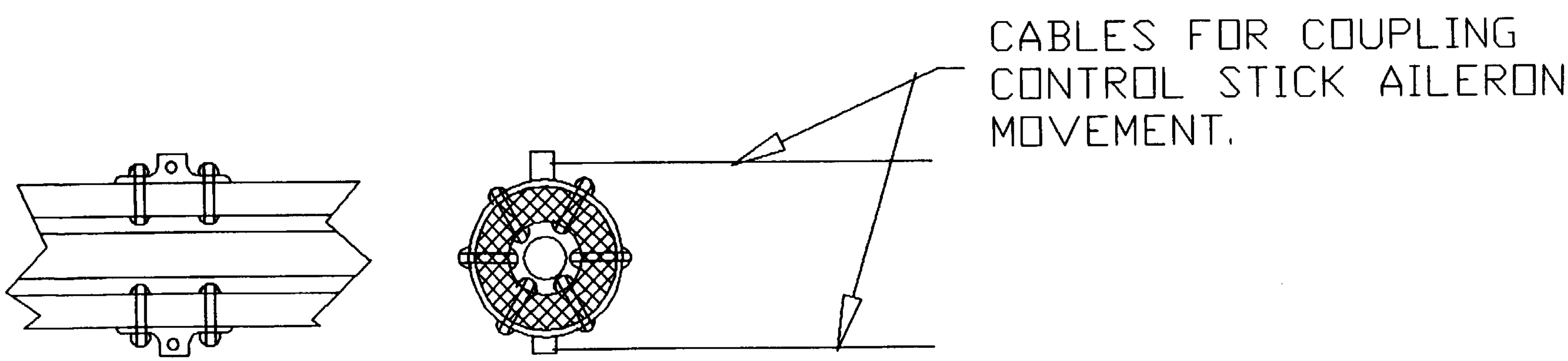
1. ALL BELL CRANK HAVE THE SAME SHAPE. ONLY DIFFERENCE BETWEEN EACH BELL CRANK ARE THE SIZE. A TABLE IS PROVIDED WHERE THE SIZES FOR EACH BELL CRANK USED ARE TABULATED.
2. NUTS, BOLTS AND WASHERS THAT ARE USED ARE ALSO TABULATED FOR EACH BELL CRANK.
3. L/W = 2.5 TO WITHSTAND THE APPLIED BENDING MOMENT. L IS THE DISTANCE BETWEEN THE STRUCTURE AND THE BELCRANK. W IS THE WIDTH OF THE MOUNT. MOUNT IS TYPICAL FOR ALL BELL CRANKS.
4. ALL PARTS ARE MADE FROM ALUMINUM 2024-T4.
5. BOLTS AND NUTS ARE AN SERIES AND THE WASHER USED IS OF AN960 SERIES.

DETAIL 3 : BELL CRANK

DATE	SCALE	DRAWN BY	DRAWING NO.	SHEET
5.03.94	1/8	BALAKRISHNAN	S94-1B-303	10/12

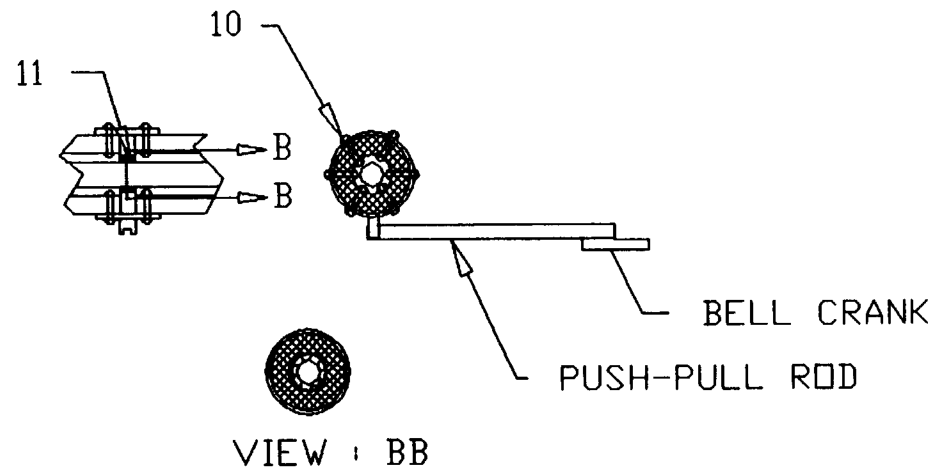


DETAIL 4

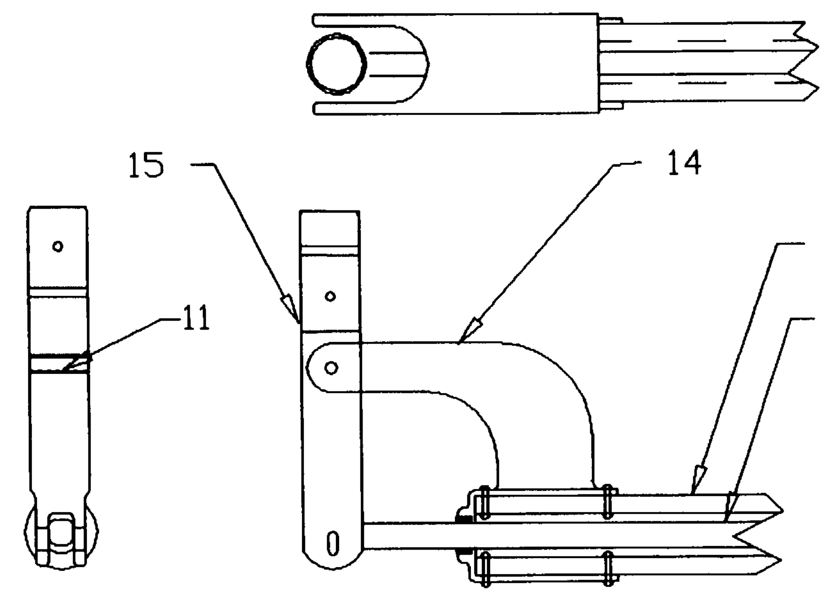


DETAIL 5

DATE	SCALE	DRAWN BY	DRAWING NO.	SHEET
5.03.94	1/2	BALAKRISHNAN	S94-1B-303	11/12



DETAIL 6 : AILERON CONTROL



DETAIL 7

DATE	SCALE	DRAWN BY	DRAWING NO.	SHEET
5.03.94	1/4	BALAKRISHNAN	S94-1B-303	12/12