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MedJet

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MedJet

Final Report

by

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AE 429
University of Tennessee

submitted to

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April 26, 1990

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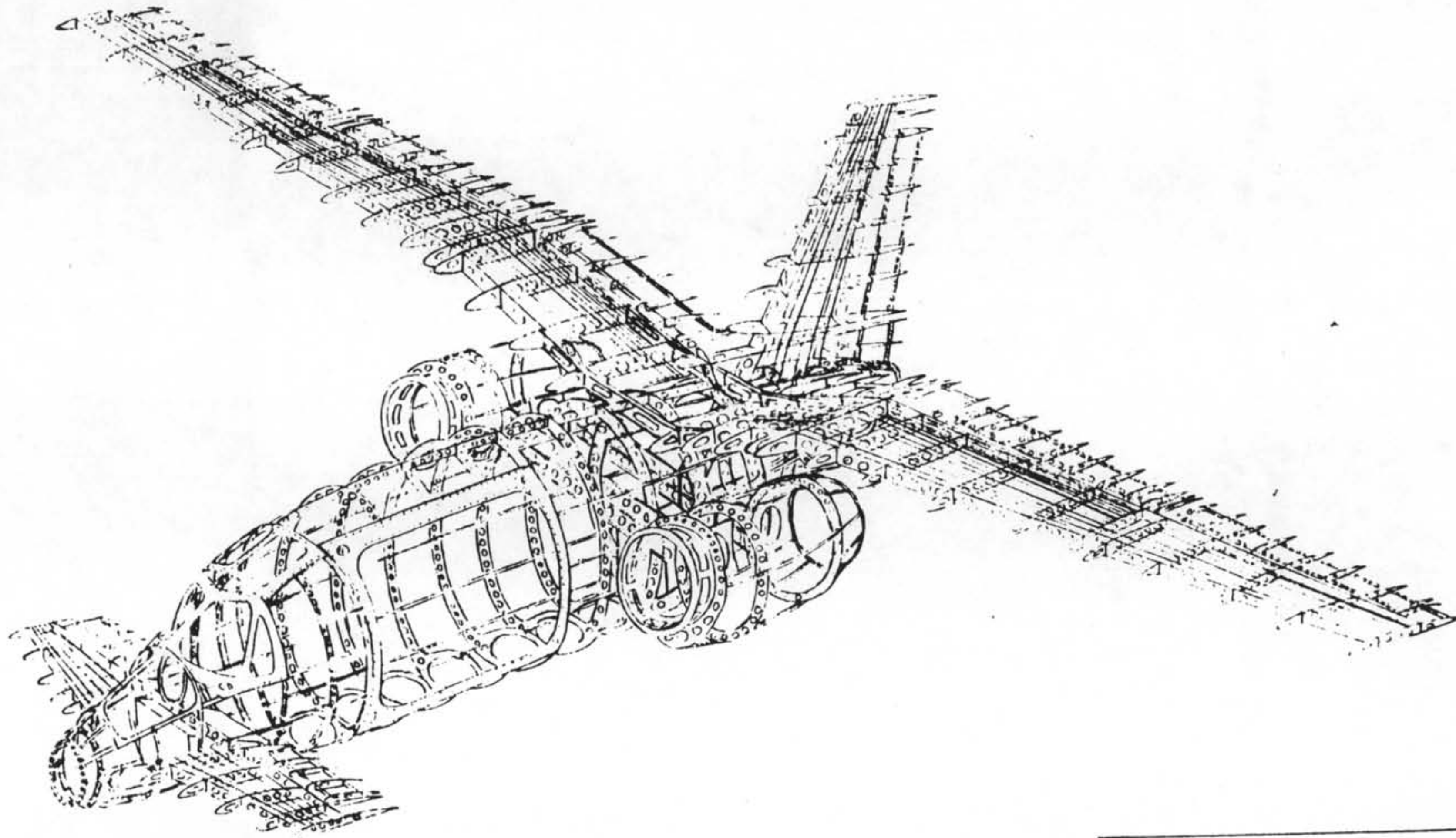

AE 429
Structural Layout - Artist's conception
Steve E. Everett
4/1/90

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a	Length of plate under stress, in
A	Area, in^2
AR	Aspect ratio, b^2/S
A_{ff}	Area of engine fan face, in^2
A_{th}	Area at inlet throat (minimum area), in^2
A_{hi}	Area of the lip of the inlet, in^2
b	Wing span, ft; Width of plate under stress, in
C_d	Coefficient of drag
C_{di}	Induced drag coefficient, $C_L^2/(\pi x AR x e)$
C_{do}	Drag coefficient, neglecting induced effects
C_D	Total drag coefficient
C_l	Section coefficient of lift
C_L	Wing lift coefficient
C_{Lmax}	Maximum lift coefficient
$C_{L\alpha}$	Lift-slope, 1/degree
D	Drag, lb_f
f	Flat-plate areas, ft^2
E	Modulus of elasticity, psi
I	Area moment of inertia, in^4
K	Pressure loss coefficient
L	Lift, lb_f
M	Moment, in(lb_f)
n	Load factor
P	Pressure loss
S	Wing area, ft^2
S_c	Canard area, ft^2
S_v	Vertical tail area, ft^2
t	Thickness, in
$T_{1/2}$	Time to half-amplitude, s
V	Velocity of the fluid
V_{mc}	Minimum controllable airspeed, knots
W	Weight, lb
y	Distance from neutral axis of stresses point, in
α	Angle of attack, degrees
δ	Control surface deflection angle, degrees; Deflection, in
ρ	Density, lb_f/in^3
Θ	Angle of twist, degrees
σ	Compressive or bending stress, psi
τ	Shear stress, psi

Subscripts

cr	Critical (stress)
u	Ultimate (stress)
y	Yield (stress)

Chapter 1
Specifications

1) The aircraft crew and passenger design shall include two pilots, two medical attendants and two/three patients.

2) The aircraft shall include the medical equipment presently installed in UT's Lifestar Bell 412.

3) The aircraft shall be capable of a minimum cruise speed of 350 KTS.

4) The aircraft shall have a range under VFR conditions of 300 Nautical miles.

5) The aircraft shall have VTOL capabilities.

6) The aircraft shall take-off in the STO mode between 300-500 ft.

7) A deicing system shall be available to operate during icing conditions.

8) The aircraft will tolerate a maximum sink rate of 10 ft/sec. to prevent an intolerable deflection of the landing gear.

9) A 3000 ft cabin altitude is designed as the cabin pressure for patient comfort.

10) The interior design and design of the aircraft's door allows for patient unloading within the 90 sec. time frame.

11) The aircraft shall land and take-off on a variety of surfaces, including ones with maximum slopes of 30°.

12) For a gross weight of 18,000 lbs., a load factor of 3 is necessary to meet the requirement of FAR 25.337(b).

13) Aerodynamically, the aircraft shall meet Level I performance characteristics.

Chapter 2
Introduction

During a medical emergency, the injured person's chances of survival are increased dramatically the quicker they can receive the medical attention they require. This is presently accomplished using helicopters to transport the injured to the trauma centers from the accident sites and surrounding hospitals. These air ambulances are second response vehicles, so speed is very important. The problem with these air ambulances is that they were not originally designed for transporting injured people and the medical equipment necessary for their care. They are useful in that they can get into isolated areas or far points from the trauma center and out again before a conventional ambulance could. Medical personnel know that the first hour after the injury has occurred is the most critical.

To accomplish this task better, an aircraft needed to be designed for this specific function. The aircraft needs a range of 300 nautical miles. Due to this range, the aircraft needed to be able to fly at 350 knots to keep the patient in the one hour envelope. This aircraft also should have an interior better suited for in-flight medical attention for the patient. This includes full body access for the patient and enough room for the medical personnel to work without being cramped or put into awkward positions. Also, The aircraft should at least be able to carry 2 traumatized patients and have all the necessary medical supplies and equipment for the care of the patients.

The initial problem encountered when first designing this aircraft was the choice of the general configuration. There are presently several types of VTOL aircraft in use or in the design phase. The design chosen for this aircraft was a vectored thrust type configuration. The wing was chosen to be a gull wing design mounted at the rear of the aircraft. Then a canard was added to aid in keeping the aircraft stable during various flight modes during a typical mission. The weight of the aircraft has always been important in the design phase. The aircraft must carry a number of patients to the trauma center when using the VTOL mode of departure and landing.

The propulsion system chosen to be a vectored thrust configuration. This is accomplished by diverting the fan section flow from the engines to the front of the aircraft and the engine's core flow is vectored down using a rotating basket. A second concern that evolved from the propulsion design was what affect that the exhaust would have on the ground under the aircraft. The heat of the exhaust was found not to be high enough, combined with the weight of the aircraft, to damage the surfaces that the aircraft will land on.

The final design is an aircraft capable of VTOL fully loaded with patients, crew, and fuel. Also, the aircraft is able to reach cruise speeds in a short period of time (with consideration for the traumatized patients) and reach the destination within the time envelope.

Chapter 3
Configuration

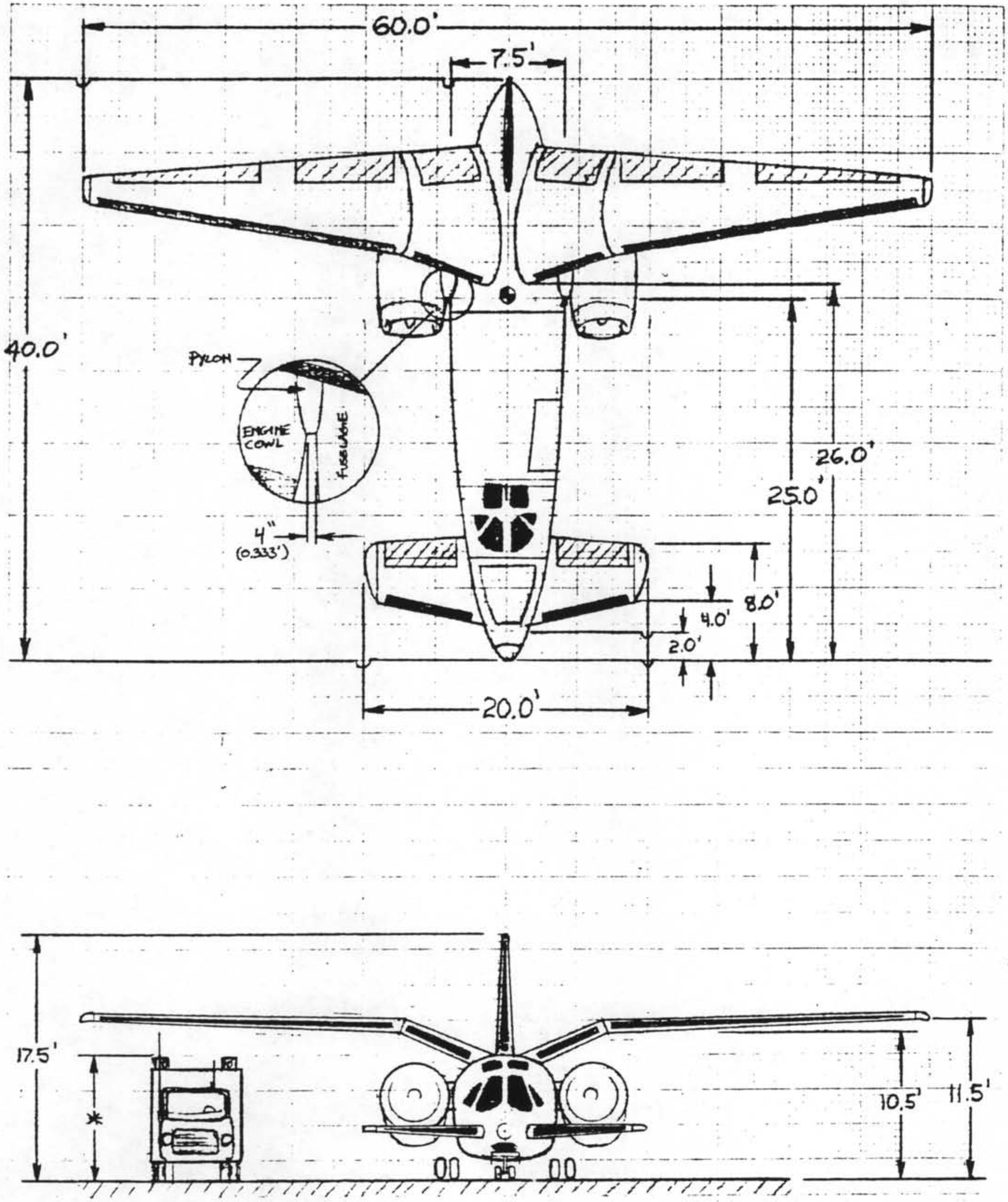
The Design Team I V/STOL Aeromedical Transport is a canard, aluminum alloy, jet propelled aircraft for the purpose of transporting trauma patients to trauma care facilities (see Figures 3.1,2,3). The aircraft will be capable of functioning in a vertical takeoff and landing flight mode for the convenience of landing at an actual accident site. This feature will ensure trauma patients the quickest possible medical attention. The aircraft will also be able to takeoff and land on runway or sod surfaces in a "conventional" flight mode do as most fixed wing aircraft. This feature gives the aircraft a wider range of uses. It can serve as a transport for transplant recipients or other medical emergencies requiring immediate attention.

3.1 Aeromedical Considerations

The aircraft consists of a high wing mounted toward the rear portion of the aircraft designed to handle most of the aircraft's weight loads in the conventional flight mode. The wing's unique high mounted gull shape gives trauma or emergency ground support vehicles necessary clearance. This factor was considered under the assumption that an emergency vehicle could be operating around the aircraft. The wing holds about 40% of the aircraft's fuel requirement for a normal rescue mission. The standard FAA required navigational lighting will be mounted on each wing tip: a red nav light with flashing strobe on the left wing tip and a green nav light with flashing strobe on the right wing tip. The wing will also hold landing lights for both the conventional and vertical flight modes. Necessary flight controls will also be located on the wing in the form of ailerons and flaps.

For lateral axis stability and control, a canard is mounted at the front portion of the aircraft in the vicinity of the nose. This horizontal stabilizer will provide for pitch control when in the conventional flight mode. It will house two elevators at its trailing edge for this purpose. The canard gives the aircraft stall safety features only found in this type of aircraft. Since the transition from a conventional flight mode to a critical-below stall speed vertical flight mode exists, it is necessary to have good flight characteristics at slow flight and at minimum control airspeeds. The canard was chosen for this feature because the canard wing would stall before the rear mounted main wing, thus lowering the nose of the aircraft for a conventional stall recovery technique. The canard also holds a portion of the aircraft's fuel -- about 14% of the necessary amount for a typical mission.

For control about the vertical axis of flight, a rear mounted vertical tail will be utilized. The vertical tail consists of a stabilizer/rudder configuration for yaw control in the conventional flight mode. The tail will house a flashing red beacon atop its



* TYPICAL AMBULANCE CLEARANCE : MINIMUM 7 TO 9 FEET. ADDITIONAL CLEARANCE NECESSARY DEPENDING ON AMBULANCE TYPE. SOURCE - UT LIFESTAR PERSONNEL.

AE 429
DESIGN TEAM I
V/STOL : AEROMEDICAL TRANSPORT VEHICLE
GARIELD. RANDOLPH
DATE: MARCH 28 1990

– CONTROL SURFACES

Figure 3.1. MedJet, Aeromedical Aircraft.

5'

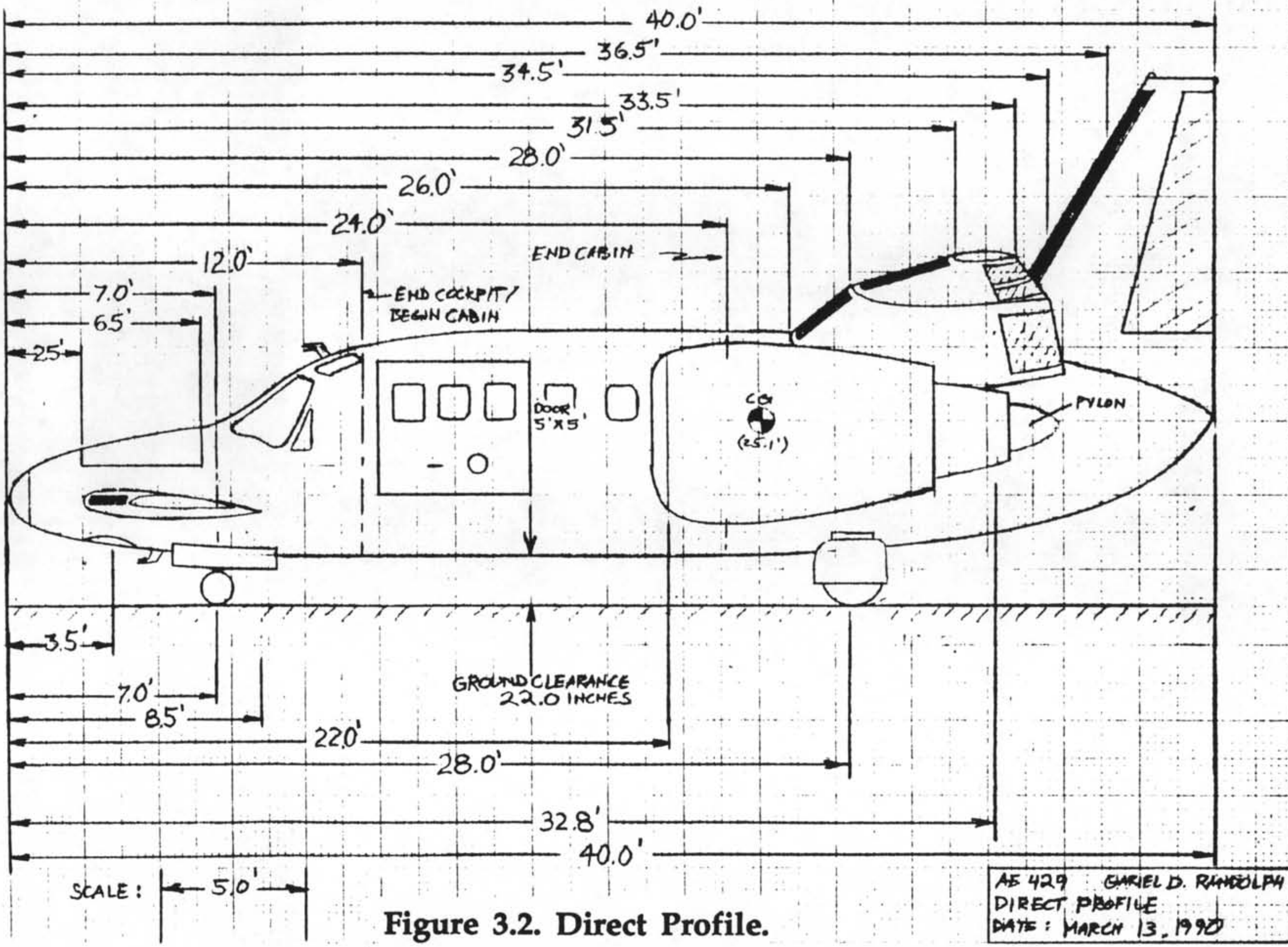


Figure 3.2. Direct Profile.

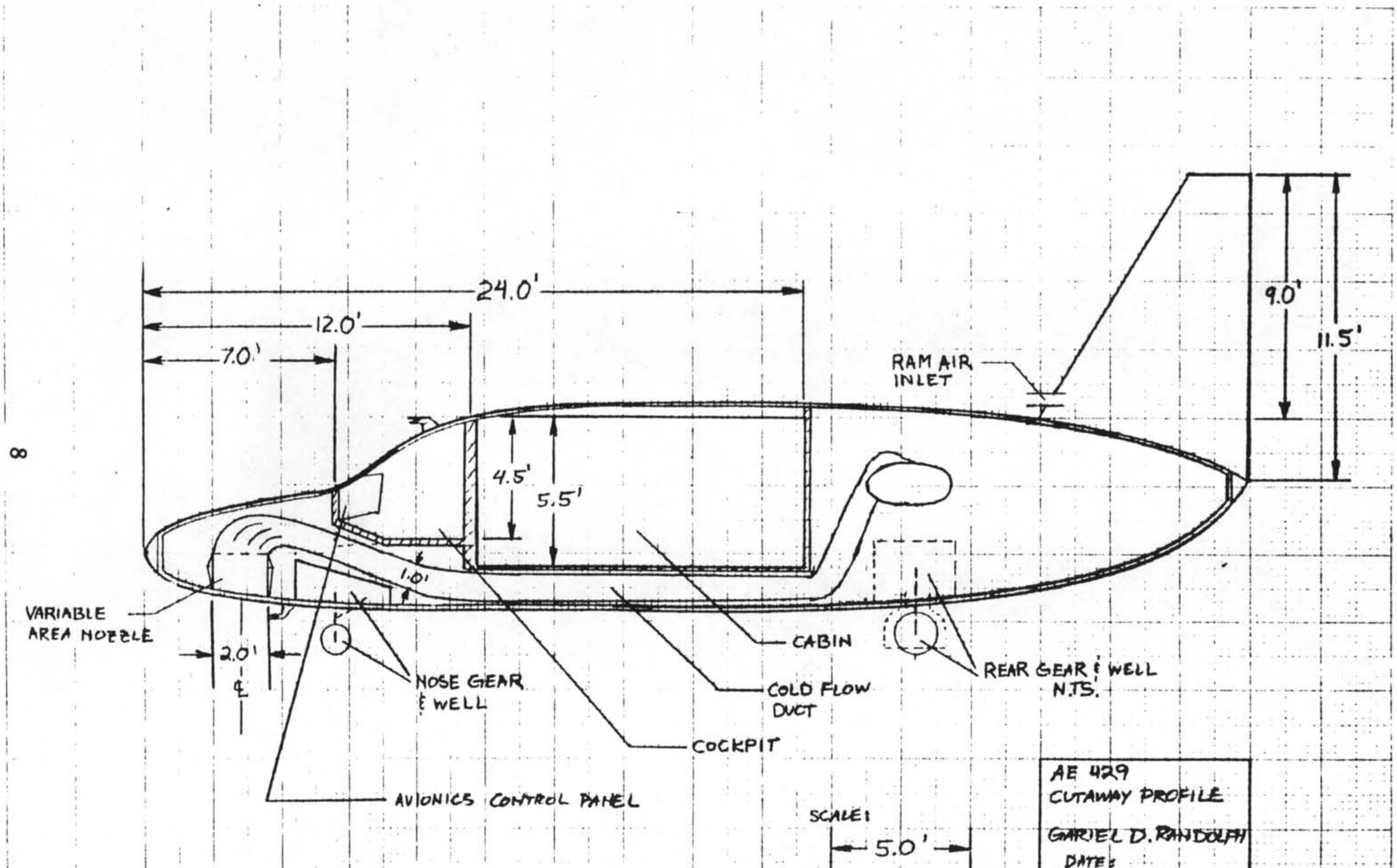


Figure 3.3. Cutaway Profile.

structure with a white anti-collision light mounted on the top-most edge of the tail.

*Note that the wing and all stabilizers are equipped with de-icing equipment of the pneumatic type.

3.2 Stability in the VTOL Mode

The low speed maneuvering of the VTOL mode will not allow the pilot(s) to utilize the rudder, elevators, and ailerons for flight stability. The needed stability control is obtained by using bleed air from the engines in the form of compressed air. Ports will be located at the wing tips, at the nose, and at the tail. The compressed engine air will then be utilized at these ports and form a "puffer" system for VTOL flight stability. VTOL stability will be computer controlled using an electric gyroscopic mechanism to keep the aircraft level while in vertical flight. The system will be complete with a "pilot's manual override" switch in the event the aircraft operator needs control of VTOL stability.

3.3 Propulsion Considerations

The aircraft is propelled by two Pratt & Whitney TF30-P-408 turbofan engines located on the left and right sides of the fuselage, near the rear of the aircraft and under the main wings. In the VTOL mode, the engines are used to provide the necessary thrust to lift the airplane into vertical flight. The "hot" core engine flow is used to provide the required thrust to lift the aircraft weight behind the center of gravity (CG). The "cold" bypass flow is ducted to the front of the aircraft beneath the floor and is used to provide thrust necessary to lift weight in front of the CG.

In conventional flight and STOL modes, the engine ducts are configured are utilized in such a manner that thrust is directed aft of the aircraft to provide for ground roll. This usage saves fuel and is recommended whenever this type of takeoff can be safely performed.

An emergency duct is located within the fuselage of the aircraft connecting in the event an engine fails with one engine remaining fully operational. The duct will be opened, and the remaining engine can provide stability thrust for the opposite side of the aircraft. A variable area nozzle in the front of the aircraft can be adjusted as to provide maximum attainable thrust for the cold flow of the one remaining engine. The aircraft will not remain airborne at this point, but these stability techniques will give maximum impact safety and stability should one engine fail in the VTOL mode.

In the event of engine failure in horizontal cruise flight, techniques used on conventional fixed wing aircraft can be used. These would require the flight crew to find the nearest optimum place to land and landing would be in the conventional mode only; not in VTOL mode.

3.4 Miscellaneous Physical Features

The nose of the aircraft is equipped with a radome for the use of mounting in-flight radars and storm spotting equipment. The radome itself is 0.75 ft in depth and can be expanded to larger sizes if installation of larger equipment is necessary.

Wire cutters are located on the top of the fuselage directly above the pilot seats and on the bottom of the fuselage under the pilot's feet. Overhead cockpit windows provide visibility for the pilot to guide the cutters into wires. Clear floor panels located at the pilot's feet and exterior windows on the fuselage underside provide visibility for the wire cutters. The visibility region passes to the left and right of the cold flow duct mounted beneath the floor and to the sides of the landing gear wills to the outside of the airplane. These floor visibility ports give added safety in checking a landing site before actually touching down.

The landing gear arrangement for the aircraft is of the tricycle type. Centers of axles are located 7.0 and 28.0 ft aft of the nose for the nose gear and the main gear, respectively. Braking mechanisms are available to alleviate ground roll in the event of landing vertically on an inclined surface.

3.5 Weight and Balance

The aircraft has a total gross weight of 18,340 lb and a normal operating CG location of 25.1 ft aft of the nose if it is assumed the aircraft is carrying the following:

1. 2 pilots (220 lb each),
2. 2 medical attendant (220 lb each),
3. 2 trauma victims or patients (220 lb each),
4. the medical equipment listed in Appendix A, and
5. full fuel (3800 lb).

The most forward CG location for the aircraft occurs when the aircraft is loaded with full crew and patients, and the fuel is very low. The gross weight (GW) and CG location for these conditions are 14540 lb and 24.05 ft respectively.

The most aft CG will occur when the aircraft is full of fuel, is being flown by one pilot, and has no other occupants. The GW and CG for this situation are 16,994 lb and 25.79 ft, respectively (see Table 3.1).

Aircraft balance, or CG location, is maintained inflight by the aircraft's ability to draw fuel off of any of five main tank locations while in flight. Either engine can obtain its fuel from either of the five tanks, or a combination of two, three, four, or all five areas at different times. This feature will be a computer controlled system for longitudinal and lateral trim. For lateral trim, the pilot has the option of turning on any of two high speed pumps and moving fuel to and from the canard fuel tanks and the rear tank area. This arrangement will allow the flight operator to trim the aircraft for a desired CG location (see **Fuel System**).

Table 3.1. General Aircraft Information.

Weight and Balance Data

Component	Weight(in pounds)	Moment Arm(feet) (from nose datum)
Engines	= 5204	27
Wing	= 2296	31
Fuselage	= 1480	22
Nacelles	= 920	27
Pylons	= 44	28
Canard	= 338	6
Vertical tail	= 188	37
Landing gear	= 696	22
Controls	= 88	20
Hydraulics	= 510	20
Electrical	= 510	20
De-icing	= 102	24
Avionics	= 470	8
Misc.	= 128	18
Medical equipment	= 246	18
Pilots	= 440	10.5
Patients/ Paramedics	= 880	17.5
Wing Fuel	= 1618	31
Canard Fuel	= 554	6
Fuselage Fuel	= 2028	35

Aircraft Empty Weight = 12974
Total Gross Weight = 18340

CG location (normal) = 25.1 feet aft of nose

CG(most forward) = 24.05 feet aft of nose

CG(most aft) = 25.79 feet aft of nose

Thrust required of front and rear vectored thrust with varied CG location

	Front nozzle thrust requirement	Rear nozzles thrust requirement
Normal CG	= 4440 lbf	13900 lbf
Forward CG	= 4056 lbf	10484 lbf
Aft CG	= 3703 lbf	13291 lbf

Wing Dimensions	Wing area	340 Ft^2
	Wing root chord	9.0 Ft
	Wing tip chord	2.0 Ft
	Wing span	60.0 Ft
	Wing aspect ratio	10.6
Canard dimensions	Canard root chord	6.0 Ft
	Canard tip chord	4.0 Ft
	Canard area	90 Ft^2
	Canard span	20.0 Ft
	Canard aspect ratio	4.4
Vertical tail dim.	Tail height	9.0 Ft
	Root chord	7.5 Ft
	Tip chord	2.2 Ft
	Area	45.0 Ft^2
Other Dimensions	Aircraft length	40.0 Ft
	Aircraft Max. width	7.5 Ft
	Interior wall thickness	3.0 inches
	Cabin height	5.5 Ft
	Cabin length	12.0 Ft
	Aircraft height	17.5 Ft
	Ground clearance	22.0 Inches
	Wing clearance	10.5 Ft

3.6 Cabin Arrangement

The interior configuration of the medical cabin is devoted to maximum patient safety while in route to the trauma center. The initial interior arrangement was the placement patients longitudinally parallel with the flight path. However, after speaking with UT Lifestar personnel, it was determined there were benefits in placing the patients perpendicular to the flight direction (see Figure 3.4). Since this aircraft has an acceleration of 1.4 g's for short field take-off and transition from vertical to horizontal flight, there is considerable force applied to the injured patient. Some conditions that influenced this design include severe back injuries, head injuries, and patients near shock. If in a head forward position during acceleration, shock could be induced in a traumatized patient. For a patient that is placed in a head forward position with closed head injuries, more dangerous pressure results from the acceleration. This perpendicular arrangement has other advantages. First, the force on the patient if in the longitudinal direction could result in the patient sliding out from under the restraints. Second as can be seen from Figure 3.4, the medical attendants have full body access to the patient. In Lifestar the attendants are seated at the head of the patient and have limited access (head to chest only). Finally, this perpendicular arrangement allows for the most critical patient to be placed between two medical attendants.

Lifestar has done a Human Factors Study to determine where medical equipment should be positioned the best efficiency. The same arrangement for equipment availability is included for this cabin design.

Loading and unloading are carried out in the following manner. The door opens on left side of the aircraft. It opens into an up position providing some protection in inclement weather. A screen pulls out of the raised door and drops down to shield patients and personnel from the engine inlets which are two feet away. The (15x18 in) seat C is on tracks and slides to the opposite side of the cabin's open door. The gurney for patient D is loaded first and locked into place. Then the medical attendant C is seated, moving the seat to its middle position. Patient B is loaded and locked into place between attendant A and C. Attendant A is then seated while attendant C puts the engine screen back into the door. Finally, attendant A and C pull down and lock the door (see Figures 3.5 and 3.6).

The cabin is 80.4 to 84 inches wide and is 60 inches high. A cabin width of 82 inches is necessary to accommodate a tall person with a leg splint. The cabin height provides 12 inches more room than Lifestar. A third and fourth stretcher could be stacked 16 inches (as the Bell 412 manual suggests) above the first two patients, if necessary.

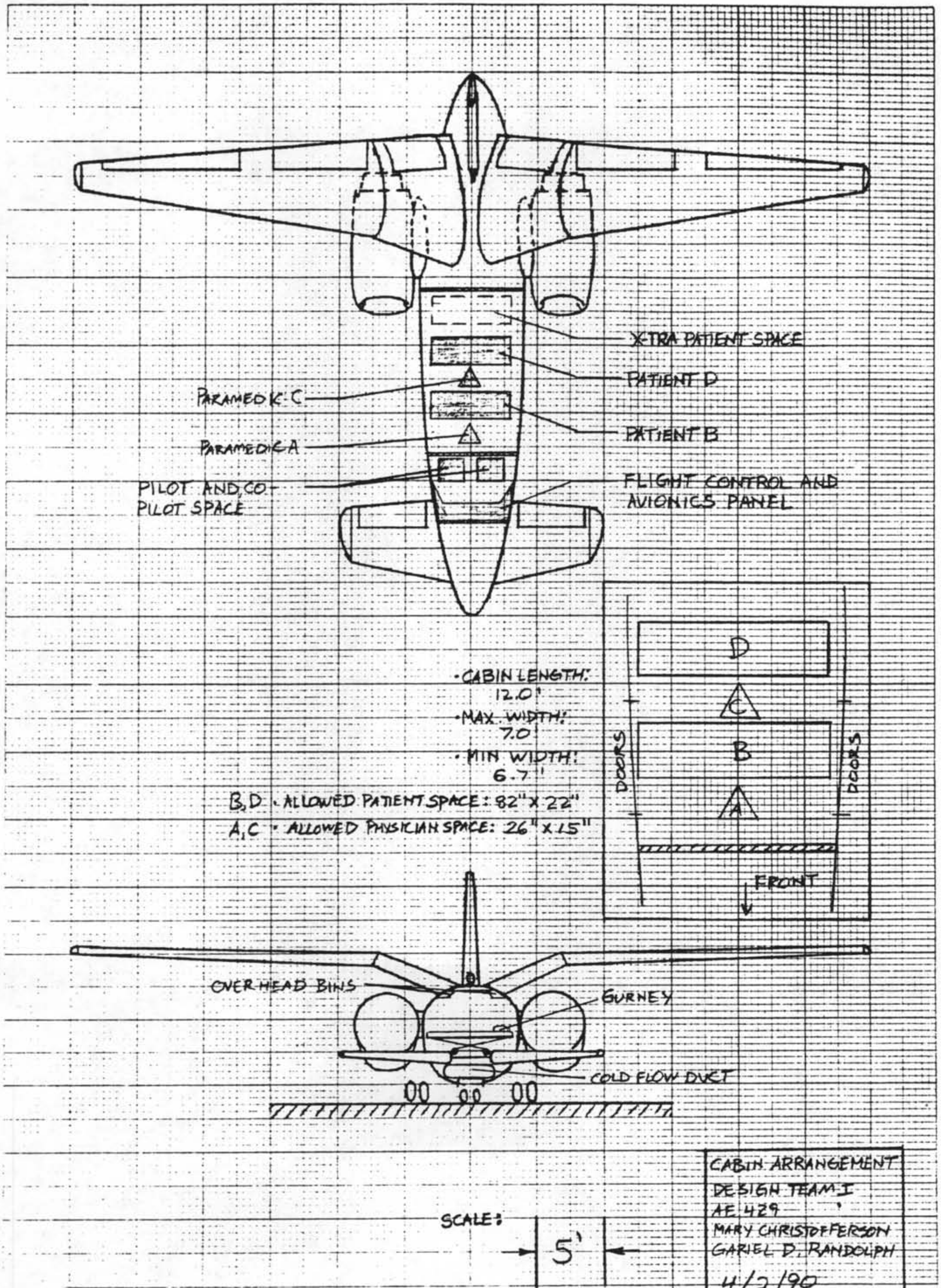


Figure 3.4. Cabin Arrangement.

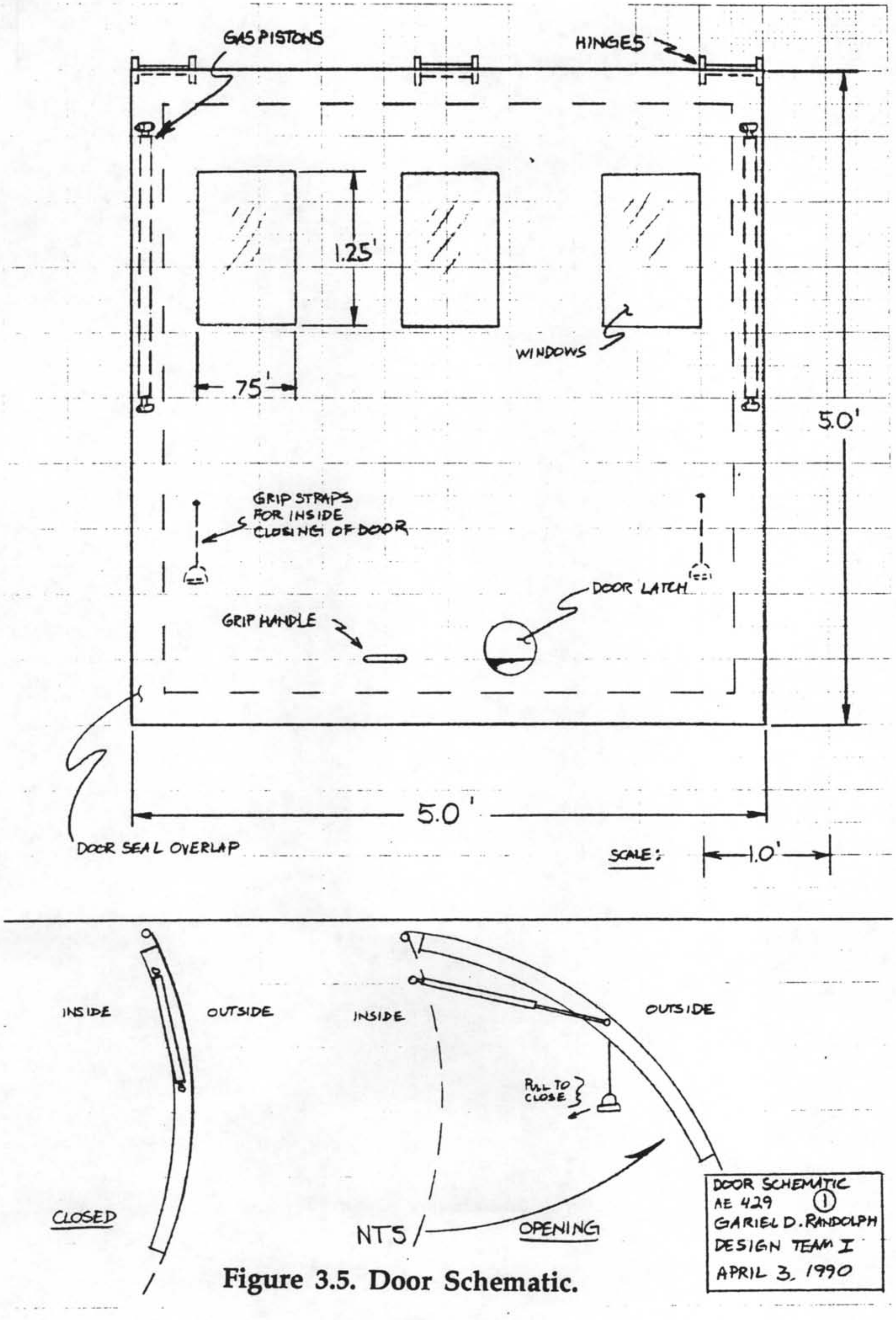


Figure 3.5. Door Schematic.

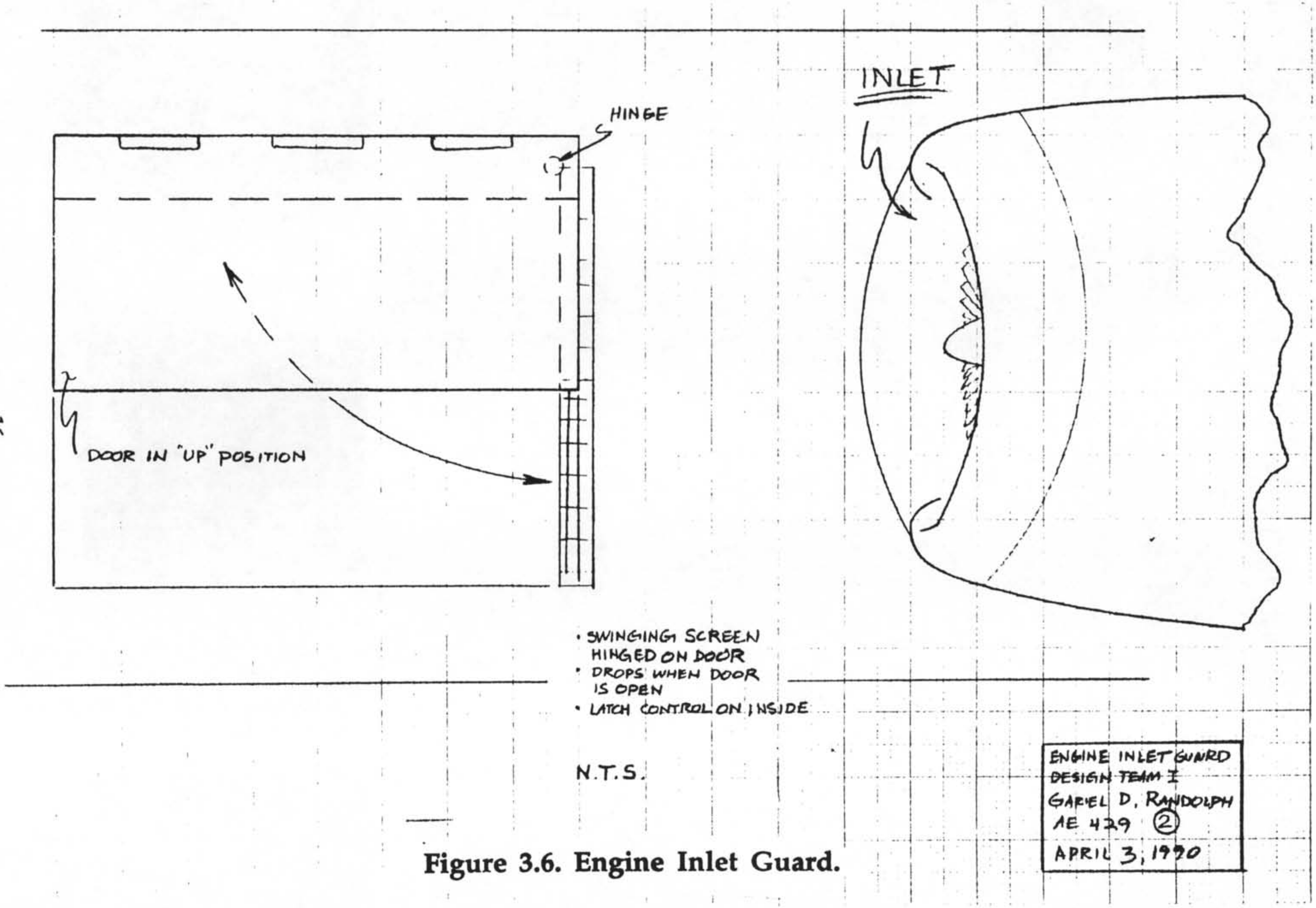


Figure 3.6. Engine Inlet Guard.

3.7 Systems

3.7.1 Fuel System

The fuel system in the V/STOL Aeromedical transport has five major fuel storage areas (see Figures 3.7 and 3.8). The largest of these areas is the fuel storage tank located in the rear of the fuselage. This tank stores 1,628 lb or about 42.8% of the aircraft's required fuel for a 350 mile trip (the 350 mile trip includes 2-vertical takeoffs and 2-vertical landings). The next largest fuel storage area is located in each of the aircraft's wings. These regions hold 1,618 lb or about 42.5% of the required fuel when added together. The last two fuel storage areas are located in each of the two canards in the front of the aircraft. The canards together hold 554 lb of fuel or the remaining 14.7% of the required mission fuel.

The fuel tanks in the wings are vented through surge tanks located at each of the wing tips. The same venting configuration exists for the canards. The wing tanks, however, are equipped with jettison pipes located at the trailing edge of the wings between the ailerons and flaps. These pipes are controlled in the cockpit and enable the crew to dump fuel if the aircraft's weight is too high for safe operation.

The engines can draw their fuel off of any combination of fuel tanks. This procedure enables the aircraft to maintain a desired CG location and prevents the CG from becoming a flight trim problem. A computer controller will regulate the volumetric flow of the fuel from each of the tanks and balance the weight accordingly. The flight crew can automatically set a given pump to pull fuel from any given tank. The fuel levels are read and displayed in the cockpit, and the pilot can select whatever combination of tanks are used for a particular engine, thereby controlling flow rate from each tank.

The CG can be controlled manually in flight by the use of two fuel lines extending **directly from the canard tanks to the rear fuselage tank (see Figure 3.8). By** switching on the appropriate high speed pump, fuel can be transferred from the rear tank to the canard tanks or from the canard tanks to the rear tanks, thereby adjusting the CG (see Figure 3.9). This technique can be used by the flight operator to trim the aircraft.

Filling the tanks prior to flight can be achieved by utilizing fuel filling ports located on the top surface of the main wing. Fuel runs by gravity feed into the rear rank, then fills the wing root tanks, and finally fills the wing tanks themselves. The canard tanks can be filled by two methods. First, they can be directly filled through ports in the top surface, or second, the direct line pumps can be turned on so that fuel is pumped from the rear tank to the canards. Once the canard tanks are full, the pumps would automatically kick off, and the rest of the airplane's tanks would continue to fill with fuel.

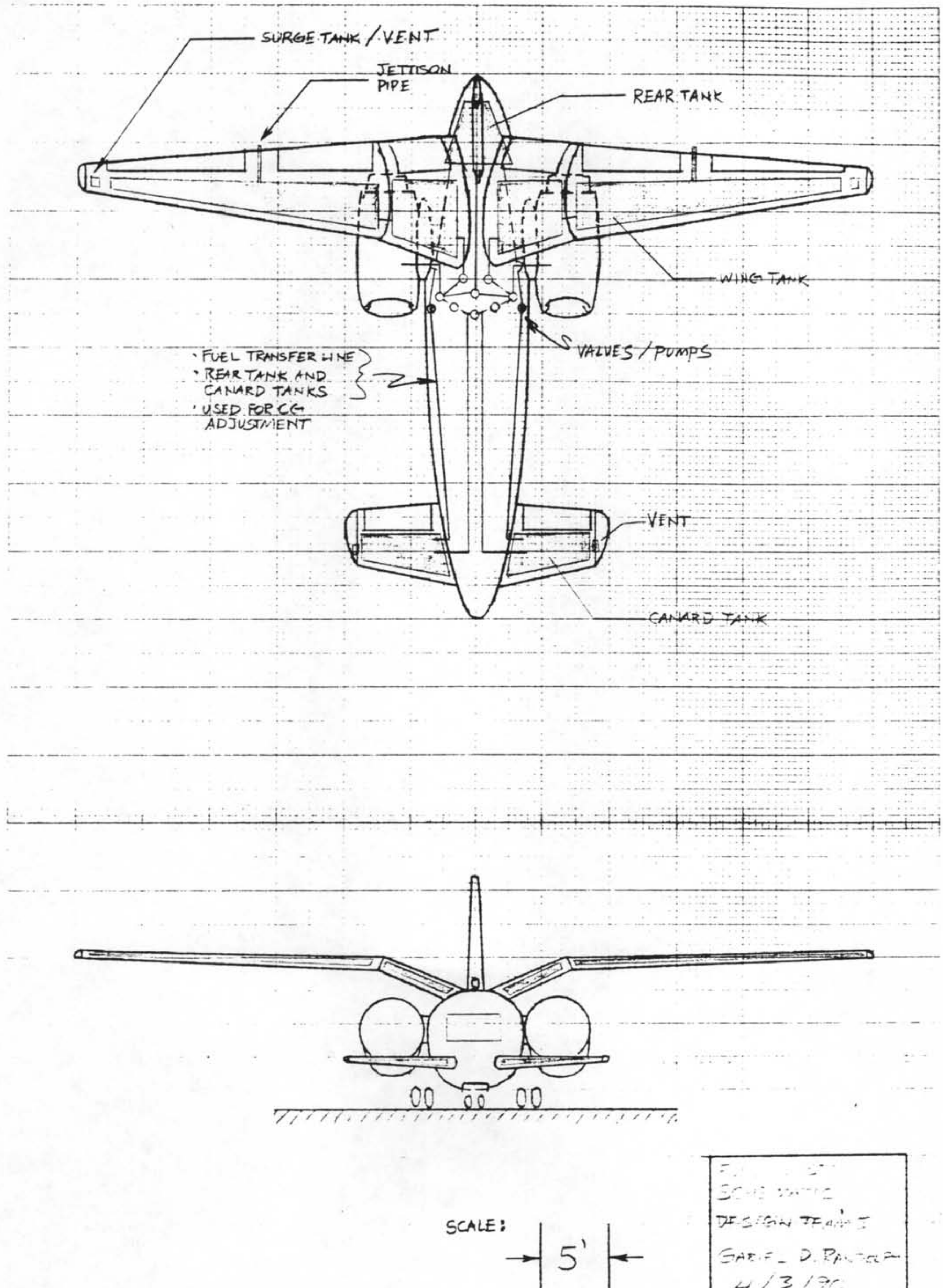
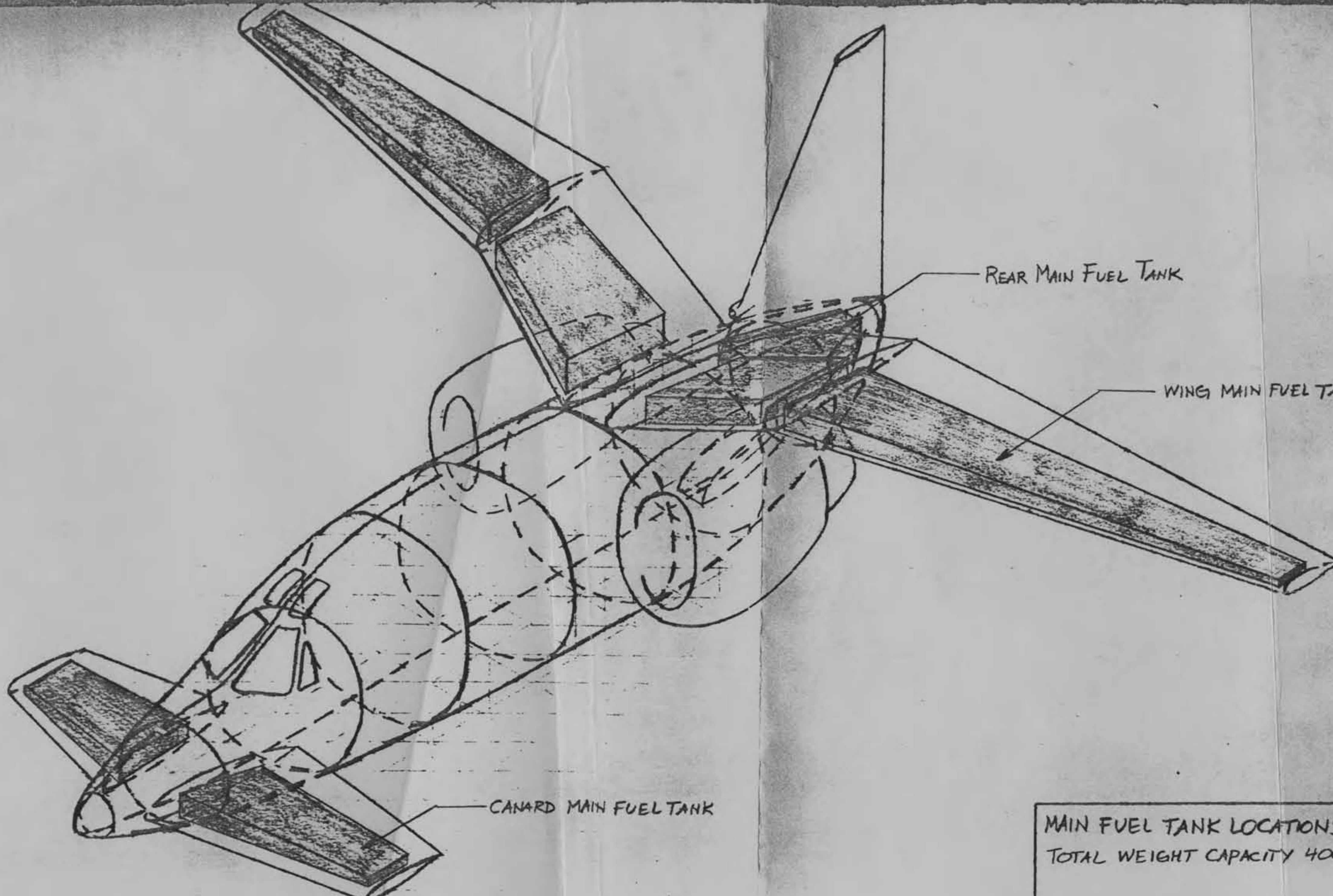


Figure 3.7. Fuel System Schematic.



MAIN FUEL TANK LOCATIONS
TOTAL WEIGHT CAPACITY 4000#

Figure 3.8. Main Fuel Tank Locations (Isometric).

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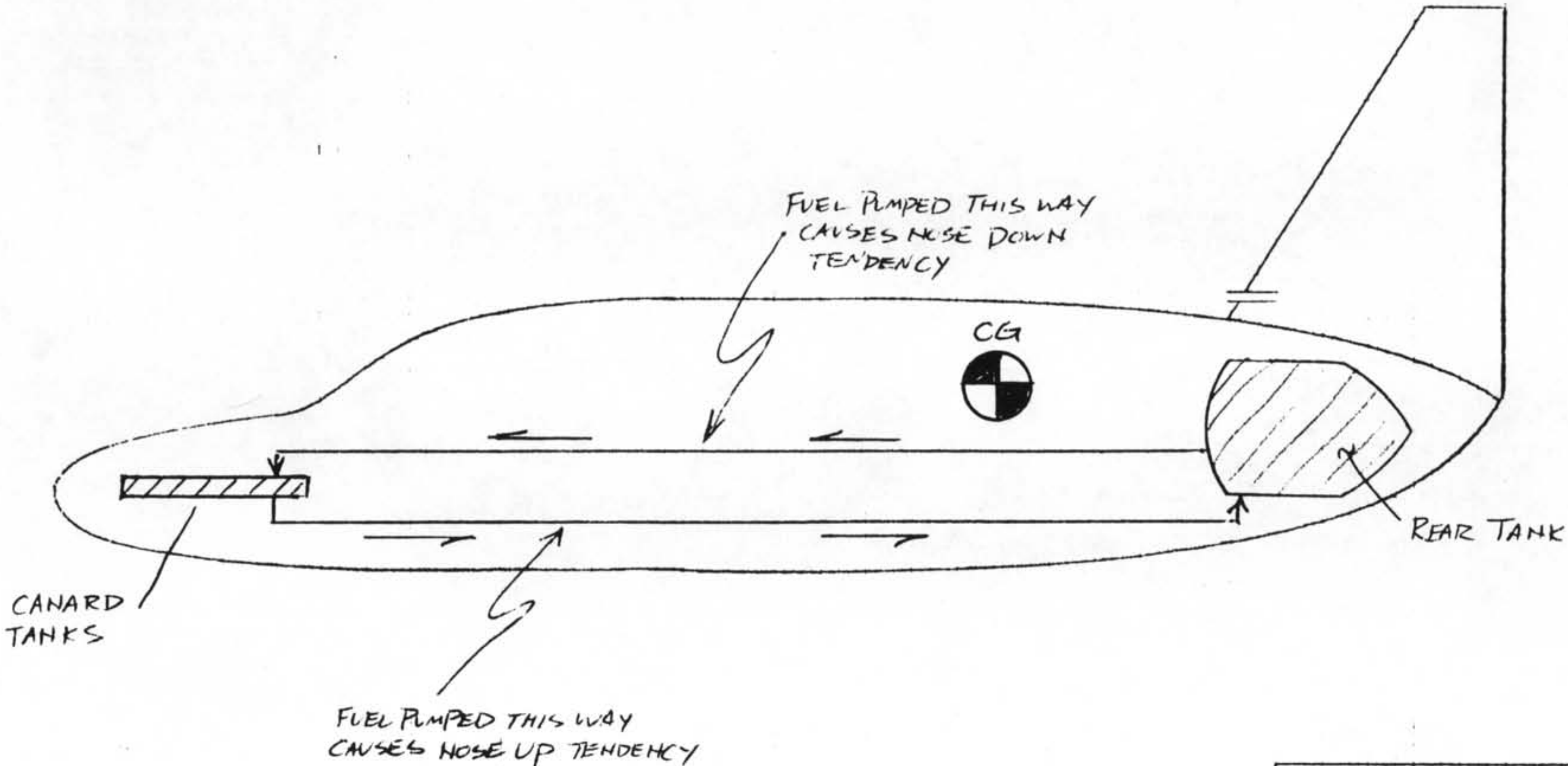
INTERIOR VISIBLE ISOMETRIC AE 429		
DR BY: GARIEL D. RANDOLPH		SEC.
DATE: 4/3/90	SCALE: X	CK BY:



NOT TO SCALE:

Figure 3.9. Fuel Transfer Schematic

FUEL TANKS AND
USE OF FUEL TANK
TRANSFER FOR
PITCH CONTROL
GARIEL RANDOLPH
4/7/90

3.7.2 Deice System

The aircraft's deicing system includes heated Pitot tubes, heated windshields, heated inlets to the engines, and inflatable boots on the leading edges of the wings, canards, and vertical tail.

The Pitot tubes located on both sides of the nose of the aircraft measure total pressure for accurate readings of the airspeed indicator system and are heated by electrical resistance elements. A switch located on the overhead panel with the other switches for the deicing system controls each of the two heating elements.

The cockpit has electrically heated laminate windows in front of, above, and below the cockpit. As in the Bell 412, the wiring and hardware are controlled by an ON/OFF switch located on the overhead panel with the deicing group switches.

The following procedure is used to heat the inlets to the two Pratt & Whitney engines. Pressurized air from the fourth stage of the engine compressor flows to a duct that runs to the front of the engine to a circumferential heating manifold. The manifold air is transported by tubes to the inlet guide vane hub which then heats up to about 100° Fahrenheit (see Figure 3.10). Part of the air then travels to the inlet guide vanes where it is exhausted. The rest of the heated pressurized air travels to the perforated tube that runs around the lip of the engine inlet (see Figure 3.11). On the overhead panel with the deicing group is an ON/OFF switch for this function. Also included is a warning light that will indicate when icing conditions are occurring. This engine inlet heating system is similar to the one on the Rolls-Royce SPEY engine.

The following describes the deicing of the wings, canards, and vertical tail. A recessed deicing inflatable boot has been chosen for this aircraft. The boot has been recessed onto the leading edge of the wings, canards, and vertical tail because not only can ice but the boot itself can cause a deformation of the air foil's characteristic (see Figure 3.12). The boots are necessary to prevent ice accumulation on these surfaces which can result in an increase in the gross weight of the aircraft, destructive vibrations, and changes in trim conditions. Surface drag on the aircraft is significantly increased, and ice accumulation may also result in dangerously raising in the stall speed of the aircraft. Pressurized air from an engine compressor is regulated by a bleed air flow control unit and travels through a distributor valve and an air filter.

Either control unit can supply the surface deice system if one engine becomes inoperative. A pressure/vacuum tube from the distributor valve also goes to the canards and to the vertical tail (see Figure 3.12). A vacuum tube from the distributor valve through a venturi ejector regulates the deflation of the boots to complete the deice cycle.The deicing cycle operates first in the wings, then in the canards, then in the vertical tail. 10 to 18 psi is supplied by the air to the boots. The cycle takes about 30 seconds for each of the three control surfaces.

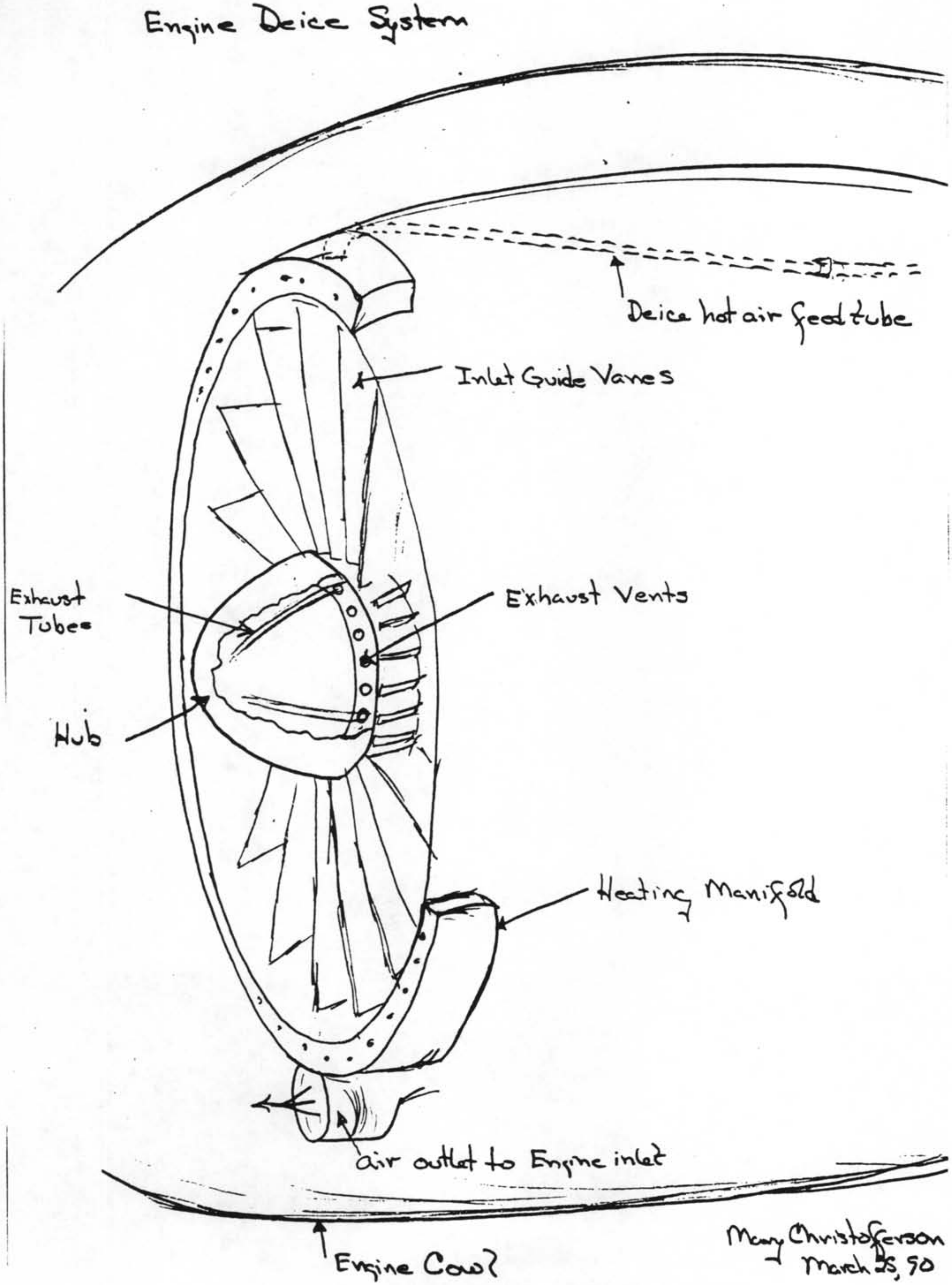


Figure 3.10. Engine Deice System.

Engine inlet de-icing

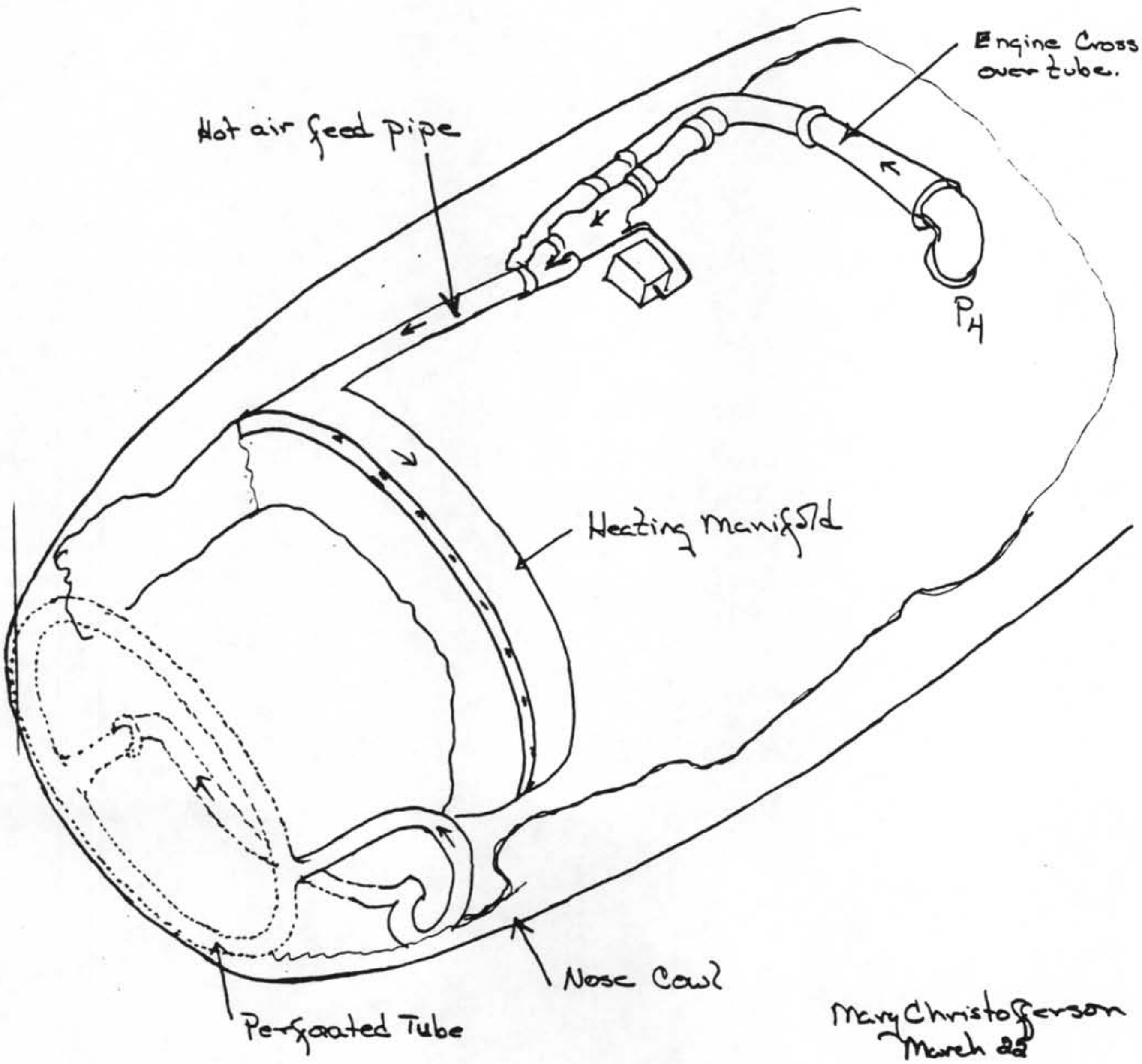


Figure 3.11. Engine Inlet Deicing.

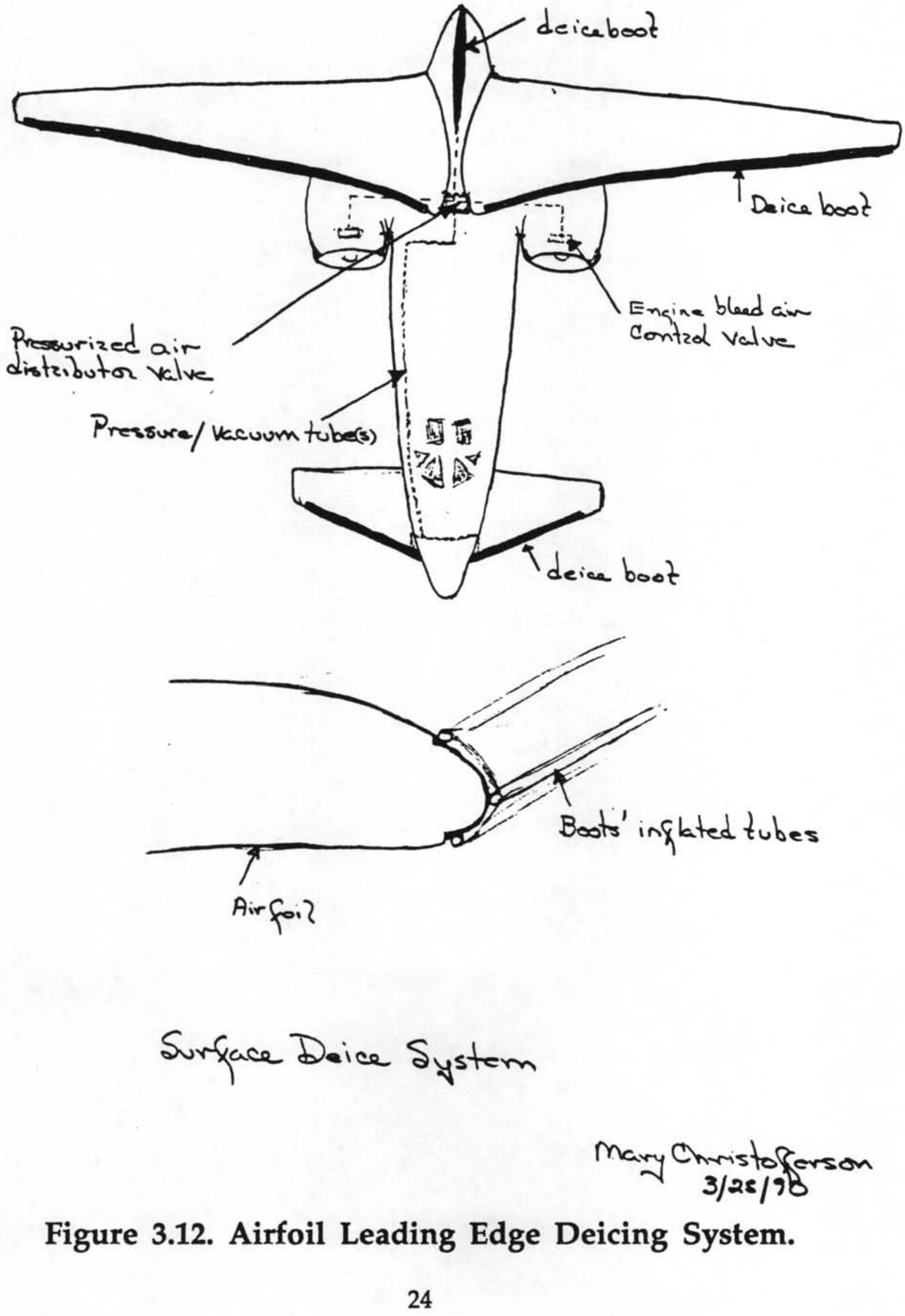


Figure 3.12. Airfoil Leading Edge Deicing System.

3.7.3 Environmental System

The environmental system for this aircraft is state-of-the-art and is made up of an interior pressurization and a heating and air-conditioning system. In order to minimize stress on the trauma victims, a limit of 3,000 ft altitude pressure is regulated for the cabin and cockpit. This aircraft's maximum expected flight altitude is 25,000 ft. This means a fuselage structural capability, a ducting system, and a regulation system must allow for a pressure differential of 7.8 psi (see Figure 3.13).

The pressurization system performs as follows (see Figure 3.14). Bleed air from each engine compressor moves to a flow control unit, where it is combined with ambient air in a ratio suitable for the desired cabin pressure. The control unit is located in each engine nacelle. The environmental air then flows to a heat exchanger in the engine pylon where the temperature is regulated by passing ambient air over it. The environmental air then flows to a single muffler which allows the system to function quietly. The flow is mixed with cabin air in a plenum located in the rear cabin bulkhead. The cabin is pressurized by this air by flowing through a floor and a ceiling-outlet duct running the length of the cabin. The air eventually is expelled through an outflow or dump valve located in the forward bulkhead of the cabin at the same rate it is entering the cabin once the system has stabilized.

The pressure system only functions during flight. A safety or "squat" switch is located on the landing gear. When the aircraft is on the ground, the "squat" switch is closed and the cabin outflow valve is held open to prevent cabin pressurization. A ram air inlet scoop is located at the base of the vertical tail. Air entering here can provide some ventilation while the aircraft is on the ground or during low altitude flight. When the outside air is cold, air may be bled from the compressor for the heating of the cabin.

After take-off the gear is up and the system allows pressure changes to occur incrementally with no sudden changes. Pressure control valves, switches, and indicators are located together on the cockpit panel. Actual aircraft altitude is sensed by the aircraft static pressure port, and the desired cabin pressure is set. If flight altitude exceeds the setting, there will be a warning light, the system will override, and the aircraft's maximum pressure differential will be established. The rate of cabin pressure change may be set and monitored. For descent the desired cabin pressure is reset to what the landing altitude will be. The rate of descent should never be such that the aircraft's altitude is the same as the cabin's indicated altitude.

The aircraft's structure is designed for a positive pressure differential, i.e., the interior pressure should be greater than the exterior pressure.

The air-conditioning and heating systems are an integral part of the pressure system, all making up the environmental system. Heating the cabin means bringing more air from the engine, and less environmental air is mixed with it. A defrost valve is switched on for the cockpit windows when needed.

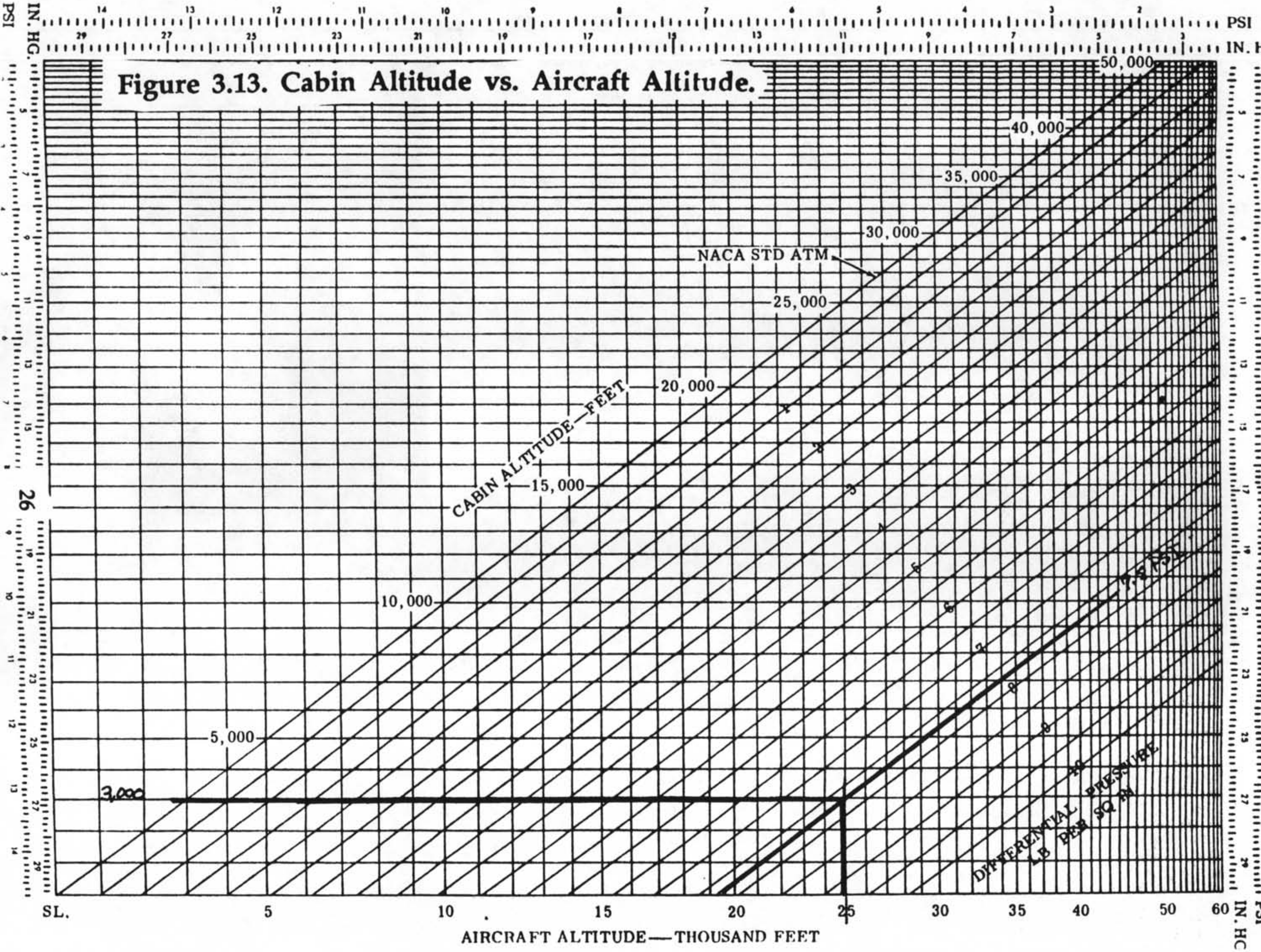


Figure 3.13. Cabin Altitude vs. Aircraft Altitude.

CABIN ALTITUDE Vs AIRCRAFT ALTITUDE

Reference Source: Turbocommander Flight Manual

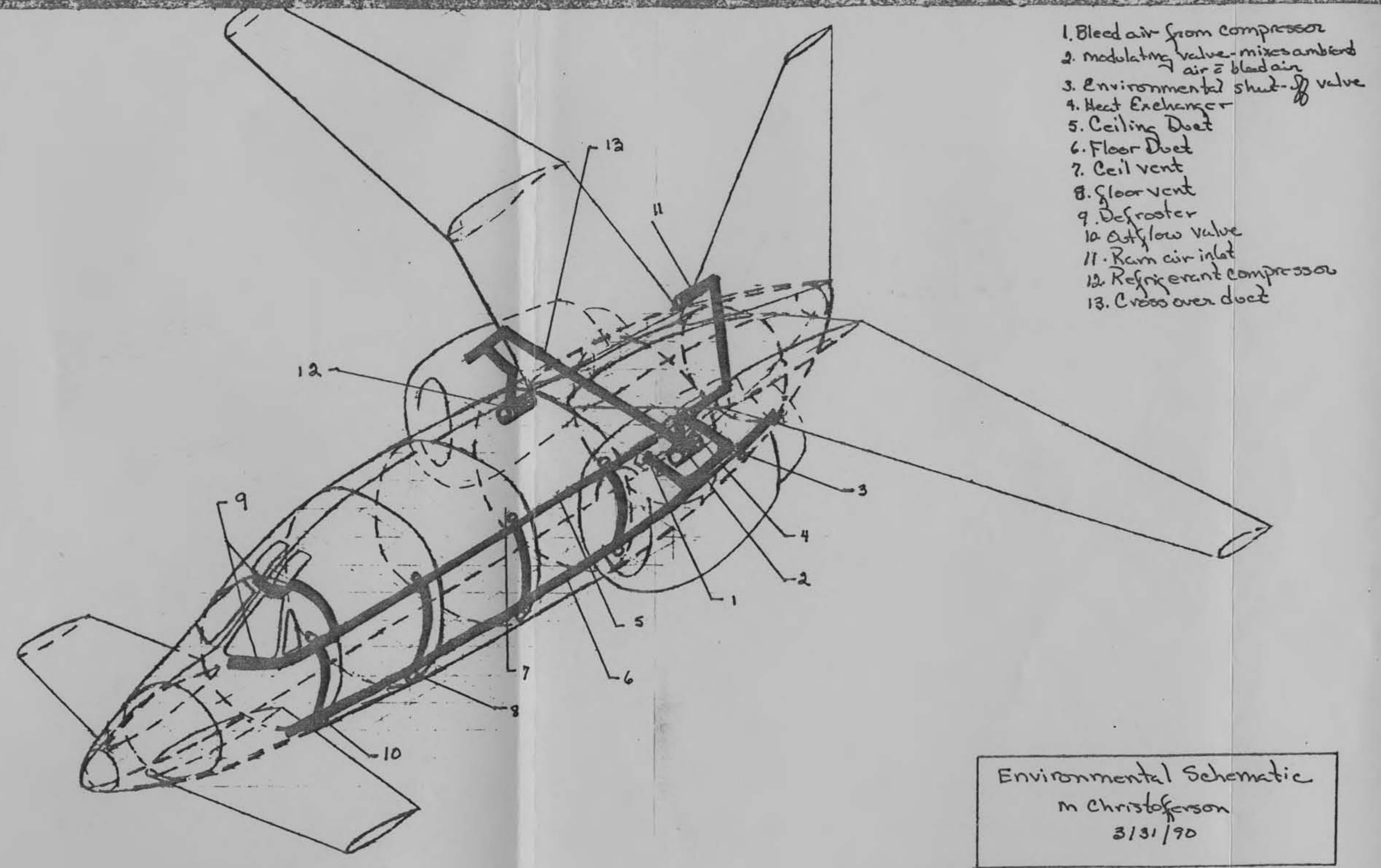


Figure 3.14. Environmental System Schematic.

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INTERIOR VISIBLE ISOMETRIC		AE 429	
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In the nacelle of the right engine is a refrigerant compressor using Freon. The liquid travels to the fore and aft evaporators where the air is cooled, then to the mixing plenum, and, like warm air for the heating system, flows through the floor and ceiling ducts. If the cabin is also being pressurized, warm environmental air will also enter the system. The warmer air travels through the floor ducts and the cool air through the ceiling ducts. When in operation, either heating or cooling or pressurizing, the system should stabilize for the desired temperature and pressure in about 6 minutes.

3.7.4 Avionics

The avionics found in the aircraft are identical to those found in UT Lifestar N412UT. The list of avionics and medical equipment can be found in Appendix A.

The V/STOL Aeromedical transport uses the standard pitot/static system for the purpose of airspeed indication. Pitot and static ports can be found on the front nose portion of the aircraft.

3.7.5 Lighting

The aircraft is lighted with the standard FAA required aircraft anti-collision lighting. A rotating red beacon is mounted atop the tail. Flashing beacons can also be found on the top fuselage and the underside of the fuselage for the purpose of making a beacon visible from all locations around the airplane.A white anti-collision light is mounted on the trailing edge of the vertical stabilizer toward the top. This light is only visible from the rear of the aircraft.

The wing tips have appropriate position lighting consisting of a red light on the lift wing and a green light on the right wing.Taxi and landing lights for both VTOL and conventional flight modes are located on the wings. Landing lights for vertical landings are positioned at different angles for best visibility.Additional anti-collision flashing strobes are mounted on each wing tip. These lights are beneficial since operation will be around fairly densely populated ares that most likely will have a moderately busy airport.

3.8 Mission Profile

3.8.1 Flight Preparation

In the stages before each flight it will be necessary for the pilot to inspect the aircraft for fuel leakage and structural damage. Anti-collision lighting should be checked as well as all other electrical systems. Pitot tubes and static ports should be checked for debris blockage and all foreign objects should be removed prior to flight. Other inspection points and data will be listed in the Operator's Manual with the aircraft.

The designed mission profile consists of a 350 mile flight. The fight contains 2-vertical takeoffs, 2-vertical landings, 2-ascents, and 2-descents to landing. A cruise portion fulfills the demand of the 350 mile range specifications (see Table 3.2).

3.8.2 Takeoff

The aircraft is capable of taking off in two different modes; vertical and conventional. For the vertical takeoff, the pilot would bring the nozzles into a vertical flight configuration then bring the engines to the required VTOL power setting. The pilot would use the controls to adjust nozzle flow areas thereby increasing thrust until vertical flight is attained. The aircraft computer in conjunction with the electrical gyro mentioned in Article adjusts the ratio of rear thrust to forward nose thrust until the aircraft has lateral stability. The pilot adjusts the altitude by increasing or decreasing the exhaust areas. The pilot controls longitudinal stability by utilizing the puffer system. Once an appropriate altitude is attained, the pilot can transition to horizontal flight. If conventional flight is desired, the operator of the aircraft simply adjusts the nozzles aft and the takeoff is just as it would be for any other fixed wing aircraft.

Should an engine fail in the VTOL mode, the pilot maintains control of the aircraft as the computer adjusts flow areas and ducting to accommodate the thrust loss. The pilot then guides the aircraft to a level impact. Should the computer not engage, manual override is available.

If an engine fails during transition and appropriate speed has been reached such that conventional flight can be attained, the pilot may override and continue with transition.

3.8.3 Climb Out

Climb out follows transition, therefore, it is in the conventional or horizontal flight mode. At this point, the pilot maneuvers the aircraft using standard fixed wing aircraft control mechanisms. Roll is attained by using ailerons, pitch by using elevators, and yaw by utilizing the rudder. Even though the aircraft is capable of climbing out at high velocities, lower speeds should be maintained for consideration of the trauma patients. This will require considerable power reduction after the transition phase.

3.8.4 Cruise

The aircraft will cruise at speeds in excess of 350 knots for a wide range of altitudes. Lower altitudes may be more convenient for faster missions, therefore, cruise speeds above 250 knots below 10,000 ft mean-sea-level will need to be approved by the FAA as they would violate FAR Part 91.70. During cruise flight, the paramedics can prepare the cabin for the transportation of trauma patients.

Table 3.2. Mission Profile, Fuel Burned.

	TIME(min)	FUEL BURNED (Lbm)
Vertical Takeoff	.5	105
Short Takeoff	.25	26.25
Climb-out	5.0	455
Cruise(20,000')	42.9	1278
IFR Reg. Cruise (45 min. after reaching destin. at night.)	45	1350
Descent	5.0	75.83
Vertical Landing	.75	150
Short Landing	.25	2.0
TOTAL MISSION	* 110.4/ 108.9	* 4200/3750

* Vertical/Short

Chapter 4
Propulsions

The muscle of thrust behind the aircraft is its two Pratt & Whitney TF30-P-408 engines, rated at 13,400 lb_f each. These engines produce the thrust for both vertical and horizontal flight. The TF30 engines are designed so that the fan section airflow of the engine bypasses the engine core. It is this fan flow which allows the aircraft to make the conversion form horizontal flight to vertical flight. The fan flow is separated from the engine in the vertical mode and ducted forward to the nose of the aircraft, where it helps to stabilize the vehicle. The remainder of the engine flow is vectored down and out the rear of the engines producing the major portion of the vertical thrust for the aircraft. To keep such a vehicle stable in vertical flight it is often necessary to make fine adjustments to the orientation of the aircraft. Since the control surfaces will not function without horizontal velocity it is therefore necessary to install a puffer system which uses engine compressor bleed air to produce thrust for pitch, roll, and yaw moments.

The puffer system is not , however, the only system for which the engines must provide power. The aircraft will need a cabin pressurization system, power for avionics and medical equipment, and pressure for deicing and hydraulic systems. With all these system and the weight of the aircraft being supported by the engines, it is important that considerations be made for engine failures and power losses. For this reason two engines were chosen instead of one. In the event of an engine failure in horizontal flight one engine has enough power to fly the aircraft to the nearest airfield and land safely horizontally with all medical and avionic systems operating normally.

A more dangerous engine failure case involves the vertical landing procedure. In the event of an engine out in vertical takeoff or landing mode, a single engine is not capable of supporting the weight of the entire aircraft. However, an emergency duct has been designed into the system to allow an equal distributions of thrust, thus stabilizing the aircraft so that the landing gear and structure can absorb the impact more effectively. Each of these systems is affected by the operation of the propulsion system, and therefore these and other specifics about the engines and their performance will be discussed in depth in the following paragraphs.

4.1 TF30-P-408 Engine

The TF30-P-408 engine has a long history of use in the A-7B fighter. This long history of service provides the user with detailed performance curves and engine specifications. Data for the engine performance ranging from sea-level to an altitude of 36,000 ft and for a temperature range of 103° to -60° F at sea-level was provided by Pratt & Whitney. Data was also received for flow conditions at various stages in the engine allowing for calculations of internal flow and nozzle variations. The TF30-P-408 engine was designed for a maximum thrust of 13,400 lb_f at sea-level with an air intake of 257 lb_m/s. The engine develops a maximum temperature of 2,072° F. Other variations in flow due to location in the engine and/or altitude changes may be seen in the computer generated results and performance graphs in Appendix B. See Figure 4.1 for the engine envelope and dimensions.

4.2 Rear Nozzle Configuration

One of the major concerns of the propulsions group is to insure that the aircraft has enough thrust to make vertical takeoffs and landings. The thrust must therefore be vectored in a downward direction, which means that some losses will be developed in the stagnation pressure. These losses were estimated using the following equation for internal flow losses:

$$P/\rho = K(V^2/2)$$

where
P = pressure loss
ρ = density
K = loss coefficient
V = velocity.

The internal losses for a 90° elbow with a flow velocity of 1090 ft/s, a stagnation pressure of 36.572 psi, and a loss coefficient of 0.21 is approximately 4%. The flow for the vertical flight mode is diverted in a similar manner to the thrust reversers used in today's aircraft. Clam-shell doors are used to block the flow from exiting through the horizontal flight nozzle. The flow is then turned by letting it strike the clam shell door and allowed to exit through a cascade basket-type nozzle in the bottom of the horizontal flight nozzle. The cascade basket nozzle area may be changed to get maximum thrust out of a variety of different mass flow rates by a rotating cylinder mechanism. This variable area nozzle is especially helpful in the vertical mode, engine failure case, in which half the airflow must be diverted to the failed engine's nozzle. When the flow is diverted to the failed engine the exhaust cone of the failed engine is expanded to block any back-up flow through the failed engine. In the horizontal mode the engine nozzles are to be designed as they are in Pratt & Whitney performance data and should produce the same amount of thrust at the normal TF30-P-408 (see Figure 4.2 for the nozzle configuration).

4.3 Inlet

The inlet areas were matched to a power level of 30% at 20,000 ft. This is due to the fact that the thrust needed for cruise best fits this lowest power level at cruise Mach number. The fan face area , A_{ff}, was measured off of the engine diagrams in Appendix B and is equal to 940.06 in^2. Using the mass flow rate of 108 lb/s, the Mach number at the fan face was determined to be 0.359. The minimum area, or throat area (A_{th}), was determined to be 679.7 in^2 for a Mach number equal to 0.55.

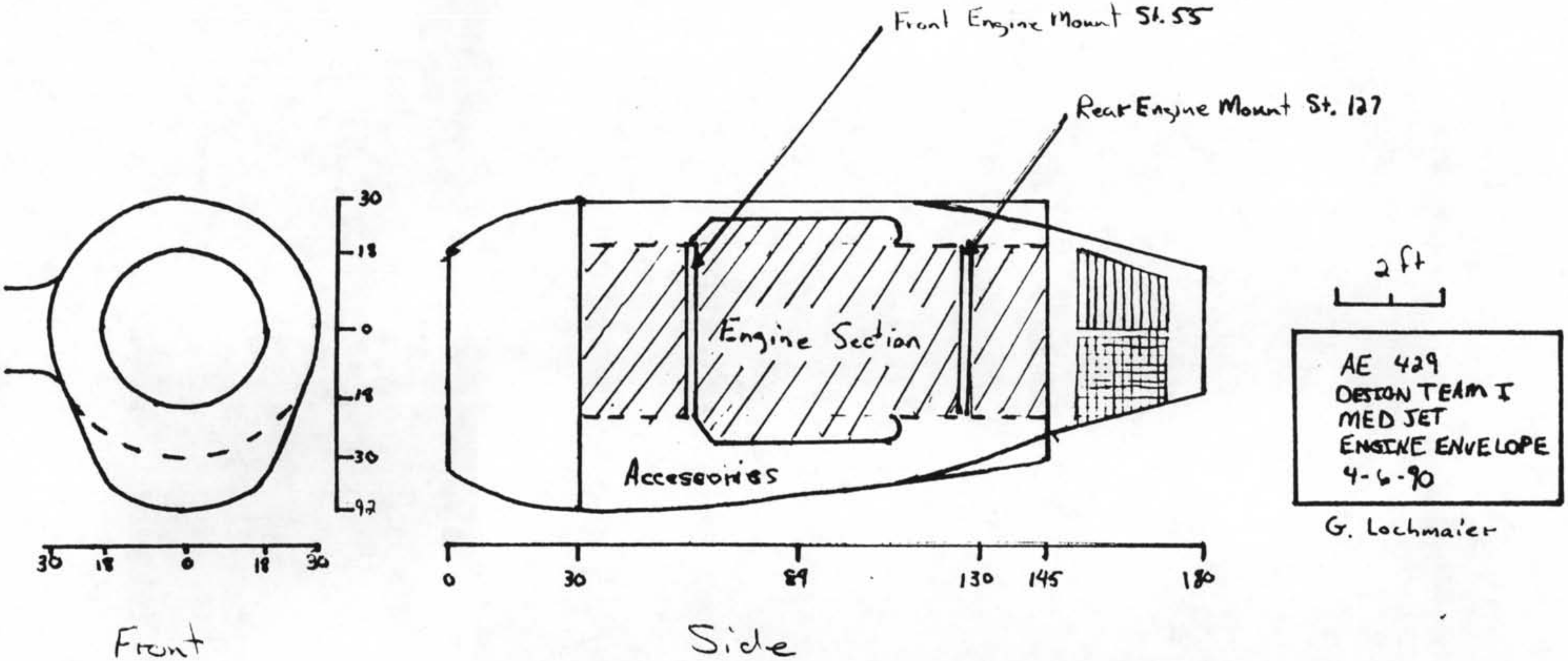


Figure 4.1. Engine Envelope and Dimensions.

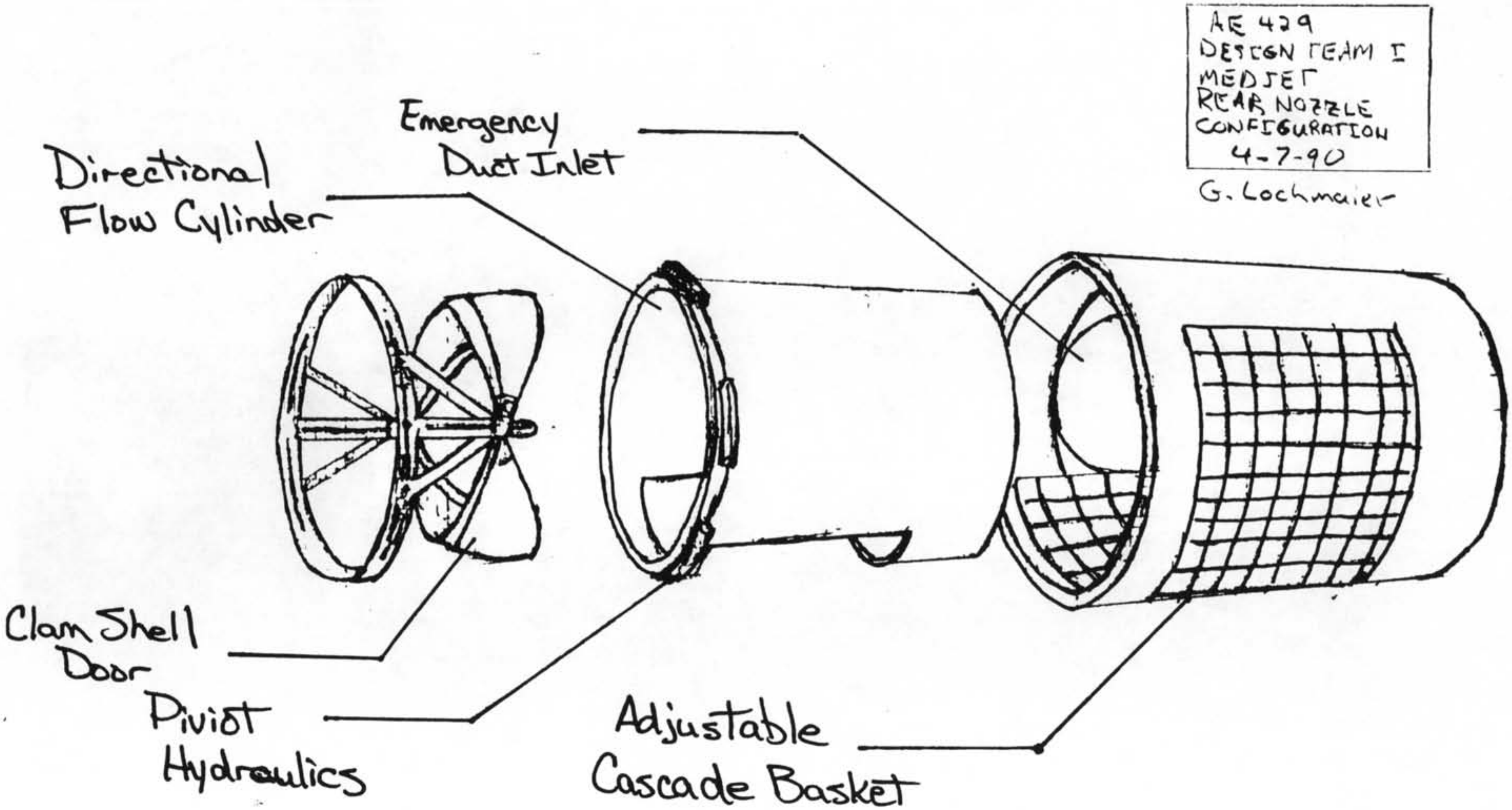


Figure 4.2. Nozzle Configuration.

The highlight area (A_{hl}) was found using the ratio of 1.26 (A_{hl}/A_{th}). A_{hl} is equal to 856.4 in^2 and gives an inlet Mach number of 0.40. This area ratio was used due to the amount of stagnation pressure loss that occurs during static operation. These areas are shown on Figure 4.3.

The mass flow rate at maximum power (as in take off) is such that the inlet will need to be fitted with blow-in doors for takeoff. These blow-in doors are shown in Figure 4.4.

4.4 Forward Variable Area Nozzle

The variable area nozzle located in the nose portion of the aircraft serves two primary functions. The first of these is to provide variable thrust levels while the engines are held at a constant RPM. This feature enables the flight crew to bring the engines to a power setting and lock this value in. Thrust is controlled by varying nozzle exit area size, thereby eliminating the need to induce unwanted accelerations on the engine. The second purpose the nozzle serves is to reduce flow area to a desired size in the event of engine failure. This area reduction prevents the remaining engine from "over-speeding" in the VTOL mode.

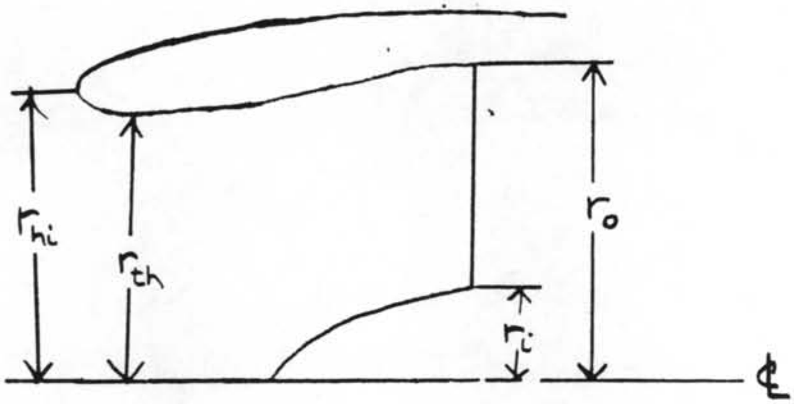
The nozzle is constructed out of a series of overlapping panels hinged into a common circle configuration (see Figure 4.5). Hydraulic pistons attached to the interior of the segments push to close or pull to open the nozzle exit, as shown in Figure 4.6, as is required for various thrust levels. When opening or closing, the overlapping segments slide over one another to allow the area to increase or decrease without causing a great amount of flow disturbance.

The amount of thrust, regulated by the area of the nozzle exit, is controlled be a computer system in direct communication feedback with an electric gyroscope. The gyro will operate such that any fluctuation in pitch attitude during VTOL maneuvers will be sensed and an A/D converter will adjust the nozzle size to regain level pitch attitude. This system will have a manual override such that the aircraft operator can regain control in the event of system malfunction or failure.

The thrust that can be achieved by this nozzle is shown in Figures 4.7 through 4.10. These figures contain thrust for one and two engine operating conditions as a function of both area and Mach number.

4.5 Engine Performance

The engines for horizontal flight must only match the drag of the aircraft and therefore the necessary thrust in the cruise mode is only 3,000 lb_f. At a cruise altitude of 20,000 ft this thrust only requires 30% of the engine's power; therefore all systems in the aircraft may be run without overloading the power requirements for cruise (see Figure 4.11 and 4.12). The vertical takeoff and landing mode, however, requires more thrust since the entire weight of the aircraft must be supported by the



$$A_{FF} = \pi(r_o^2 - r_i^2)$$

$$A_{th} = \pi(r_{th})^2$$

$$A_{hi} = \pi(r_{hi})$$

Figure 4.3. Inlet Areas.

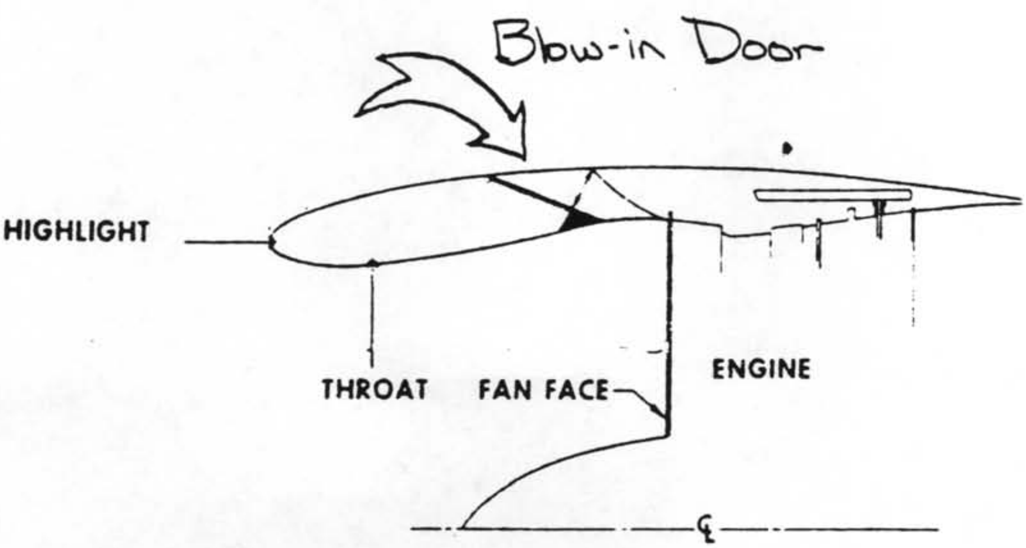


Figure 4.4. Blow-in Door Configuration.

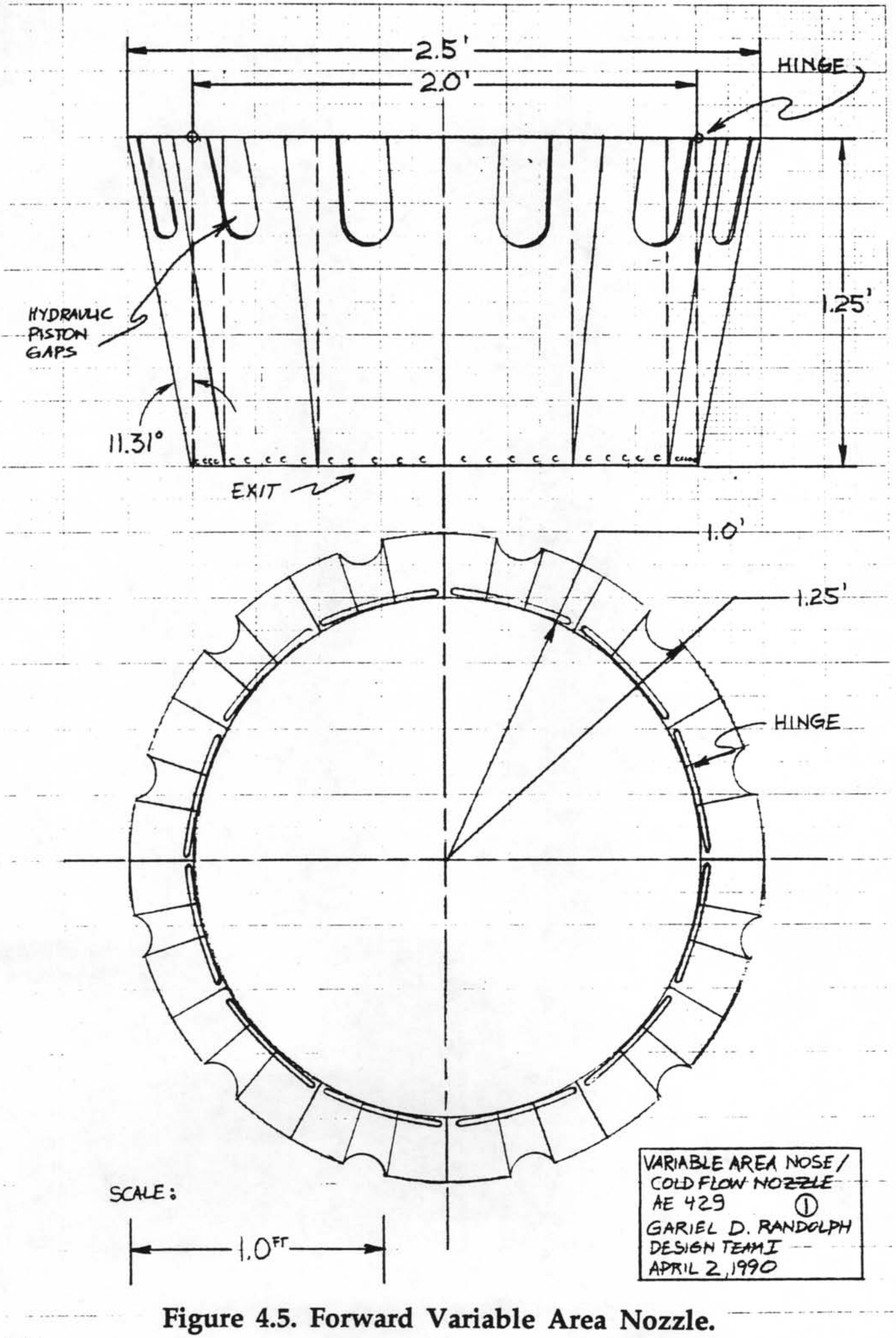


Figure 4.5. Forward Variable Area Nozzle.

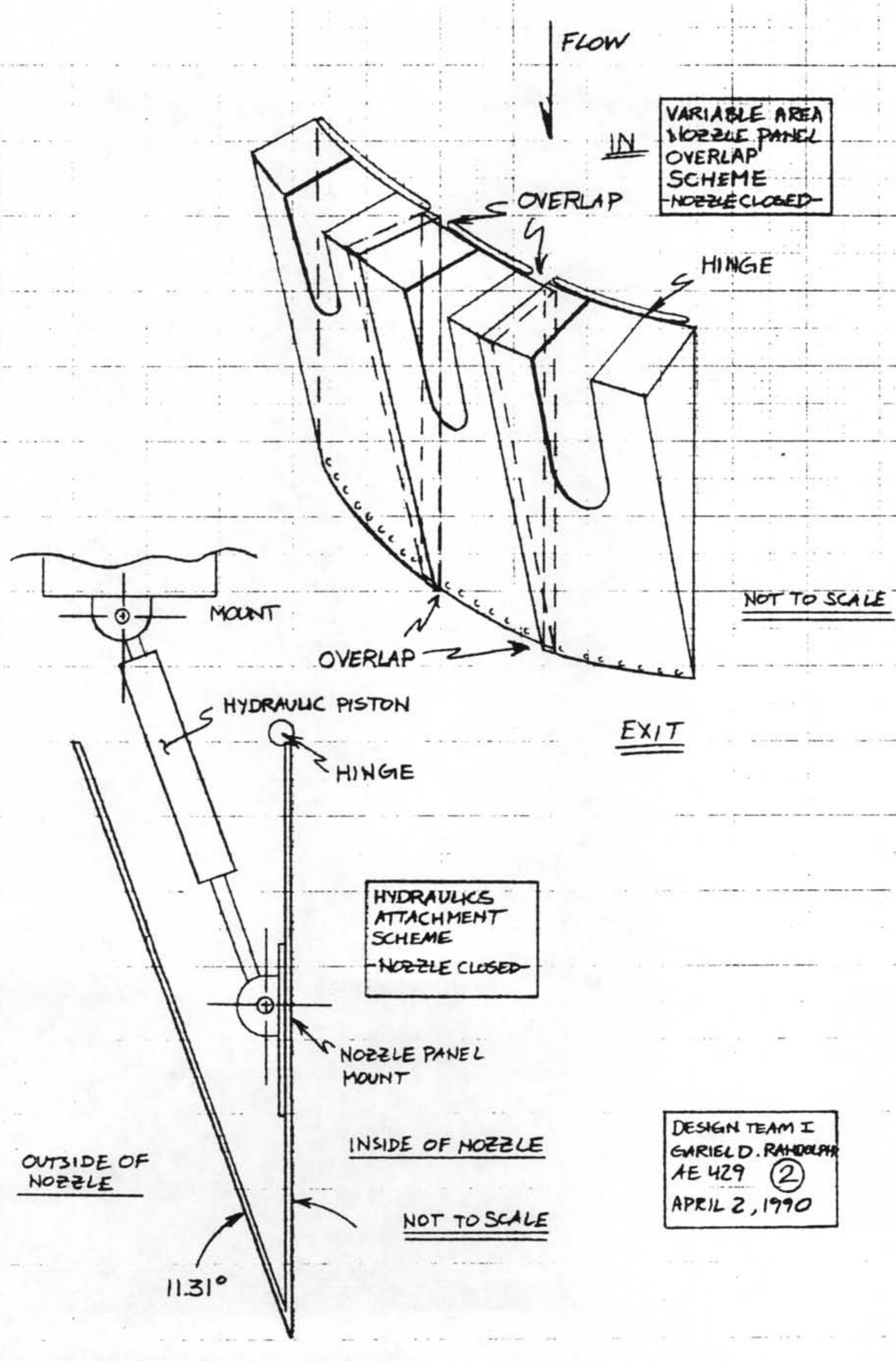


Figure 4.6. Forward Variable Area Nozzle Configurations for the Overlapping Panels and Hydraulic Attachment.

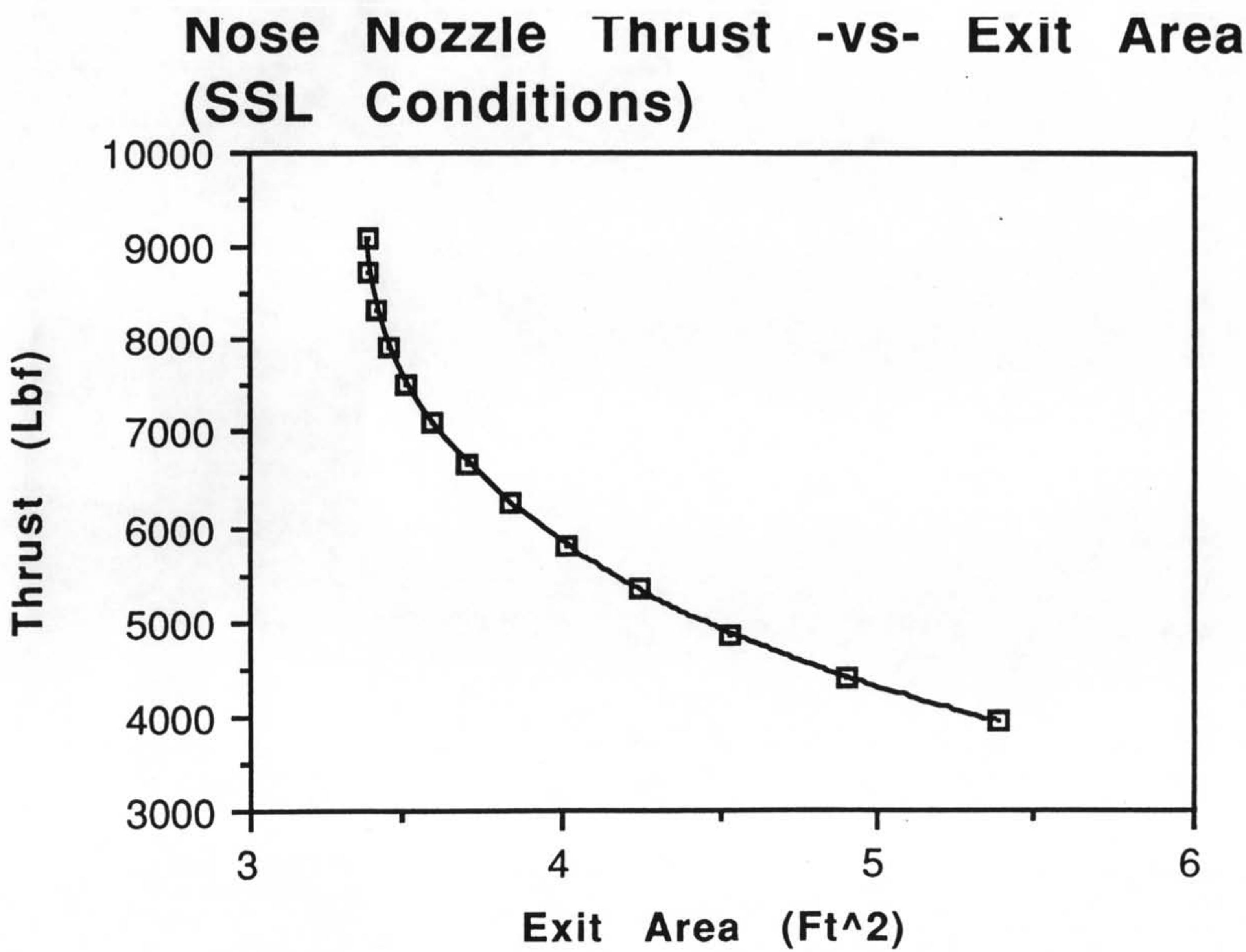


Figure 4.7. Forward Nozzle Thrust vs. Exit Area (SSL)

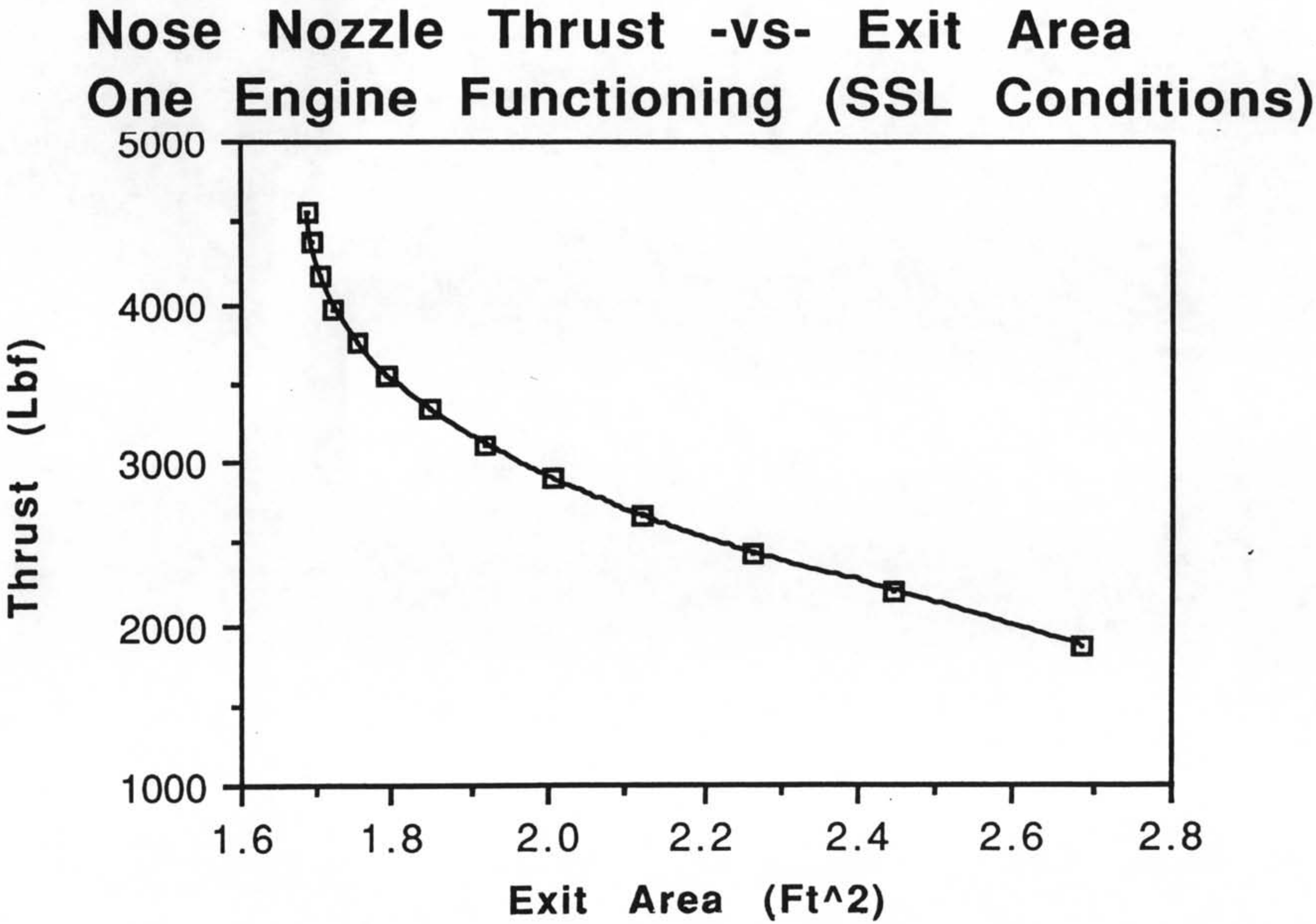


Figure 4.8. Forward Nozzle Trust vs. Exit Area
(One Engine Operating @ SSL)

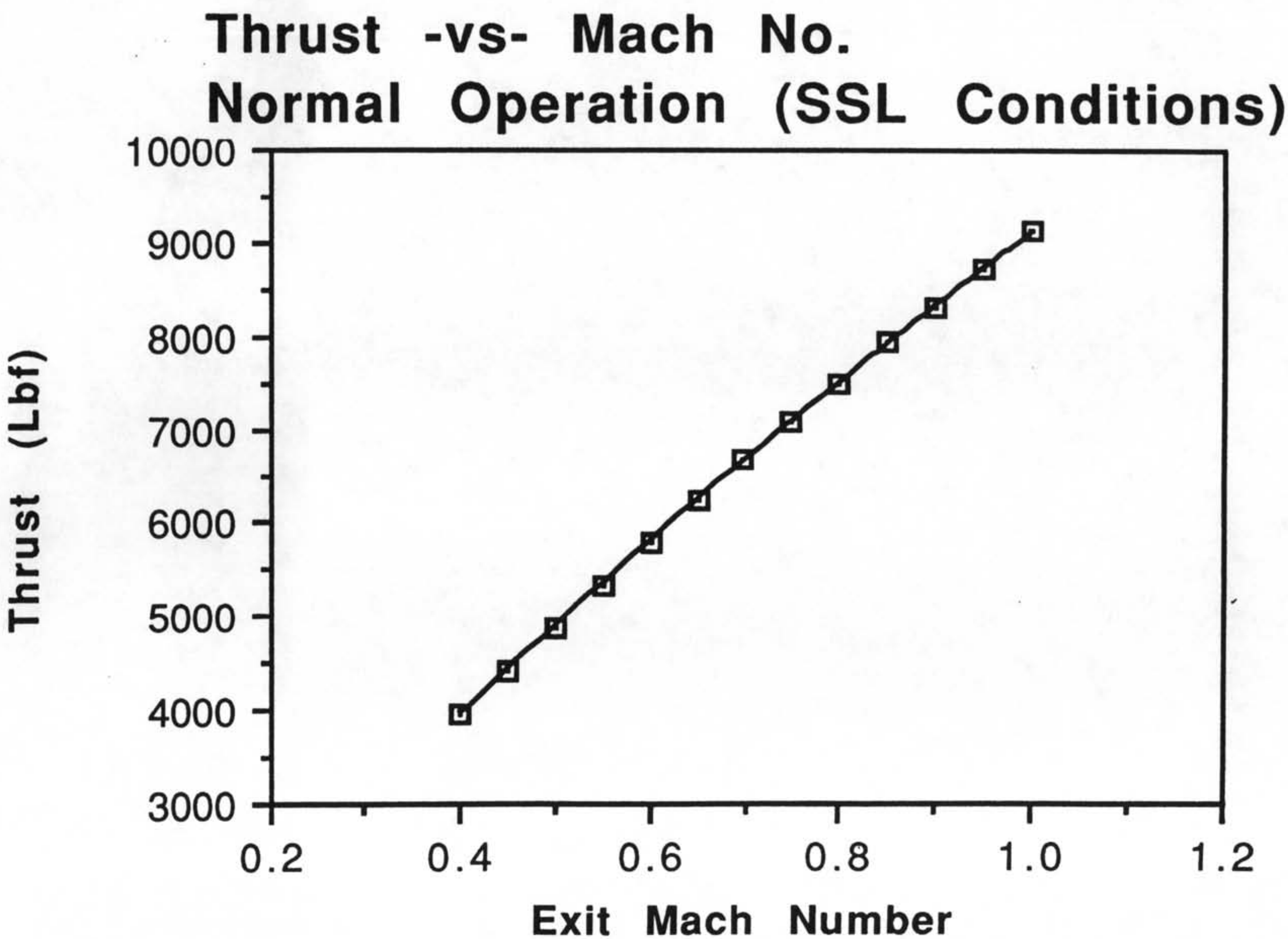


Figure 4.9. Forward Nozzle Thrust vs. Exit Mach No. (SSL).

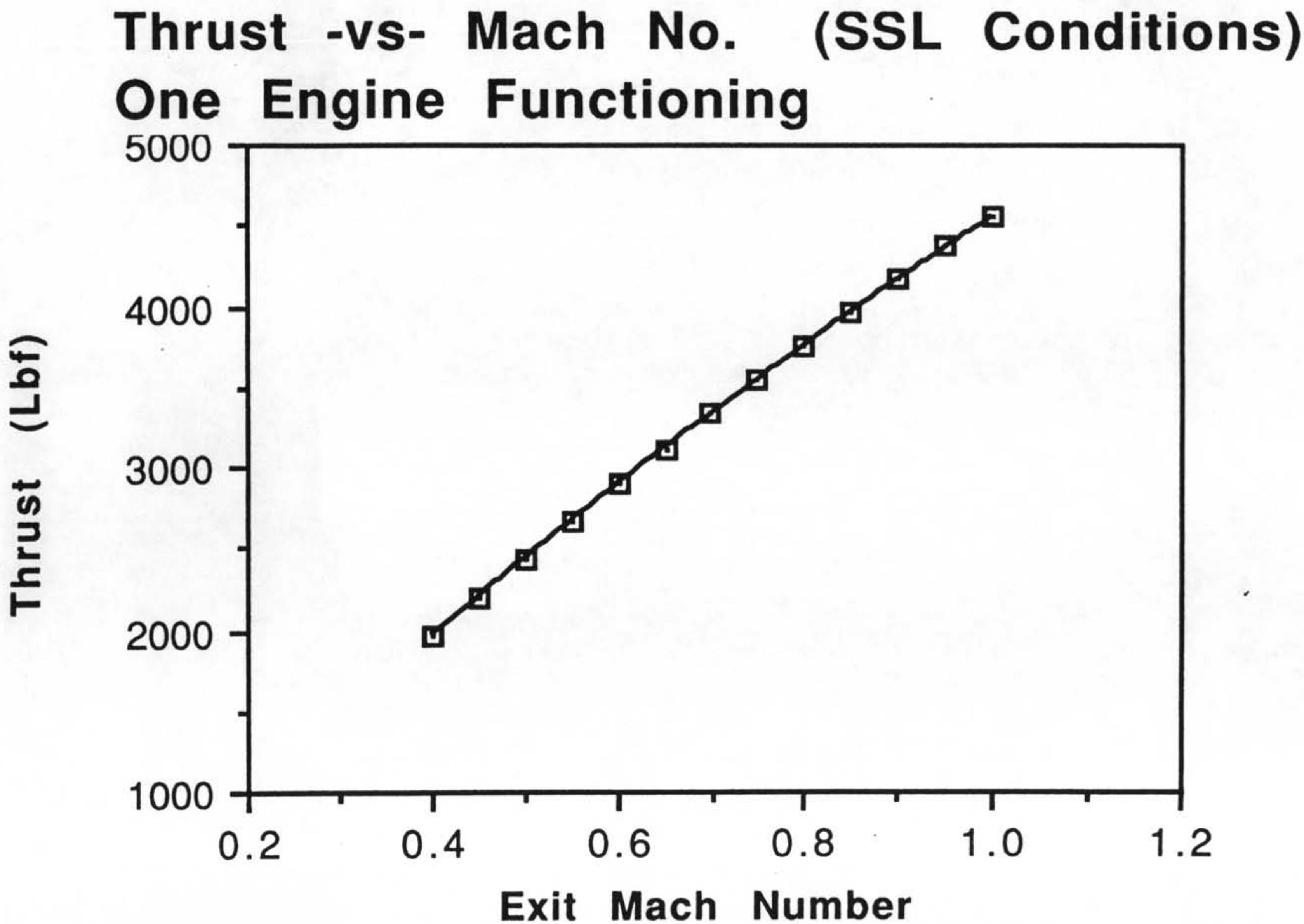


Figure 4.10. Forward Nozzle Thrust vs. Exit Mach No.
(One Engine Operating @ SSL).

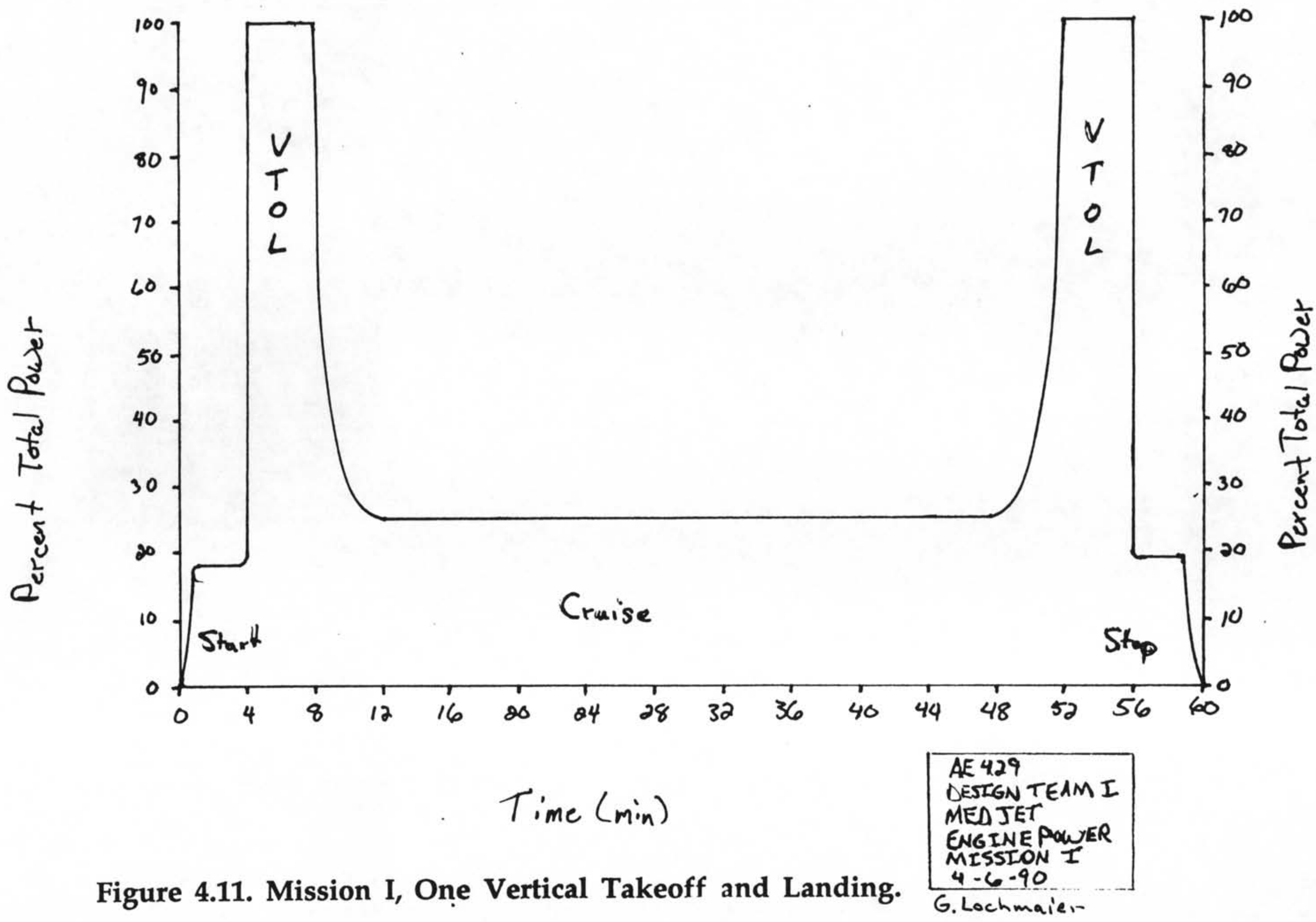


Figure 4.11. Mission I, One Vertical Takeoff and Landing.

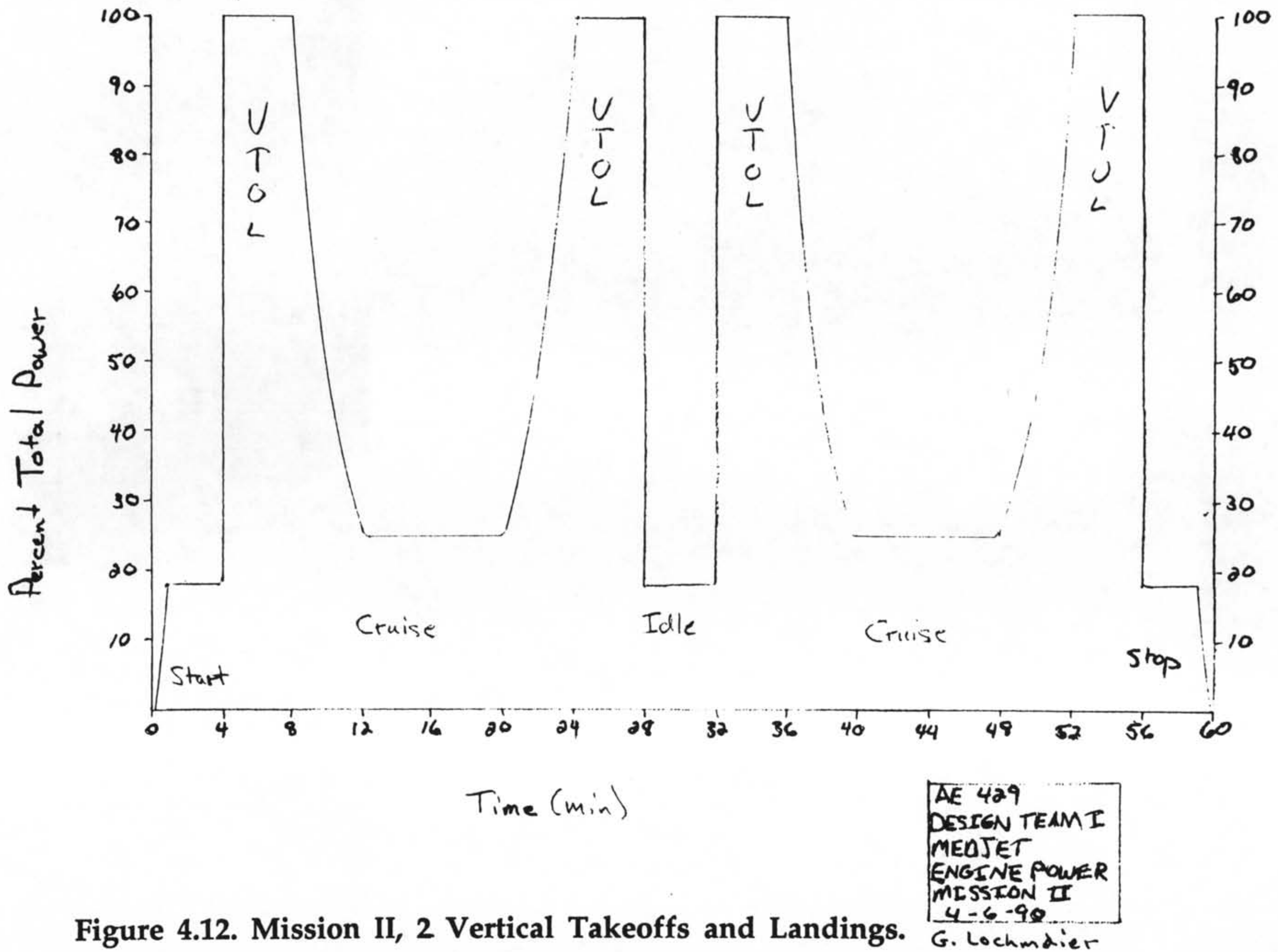


Figure 4.12. Mission II, 2 Vertical Takeoffs and Landings.

engines. The aircraft weighing approximately 18,000 lb must be supported and lifted from the ground. The engines can produce a thrust of 24,000 lb_f for vertical thrust, so that rather than put the engines through unneeded loading cycles by adjusting the throttle, the engines' thrust will simply be diverted at an angle so that only a partial component of the thrust is directed downward. The remainder of the thrust may be used for forward or reverse thrust when it is needed. The TSFC for these two regions of flight are 0.6 for vertical takeoff at sea-level and 0.83 for cruise at 20,000 ft. If one engine were to fail during cruise, the remaining engine would be able to produce the necessary thrust of 3,000 lb_f to maintain cruise at a power level of 45%. An engine failure in vertical mode would leave the other engine at maximum power. The maximum thrust produced by this engine (11,000 lb_f, considering losses) is not enough to keep the aircraft in the air, but it will reduce the deceleration of the impact and will help keep the aircraft stable so that the landing gear may be used more effectively to absorb the impact.

4.6 Emergency Ducting System

The emergency ducting system is used in the vertical flight mode for the engine failure case. Since the main portion of the thrust is provided by the two rear engine nozzles, it is important that the thrust be equal from both nozzles to keep the aircraft from turning upside down. To keep an equal thrust on both sides, a duct was designed to allow airflow from one nozzle to the other. This nozzle would only be open in the event of an engine failure and at all other times would remain closed. In an emergency the area of the working engine nozzle would be closed to slightly less than half of the total airflow. The other half of the airflow would be ducted through the 20 in. diameter duct. The air traveling through the duct would lose 0.6% of its stagnation pressure in the 8.3 ft long duct and another 3% in the other nozzle, resulting in a total loss of 3.5% and a thrust of 3,140 lb_f from each nozzle. Figure 4.13 shows the configuration of this duct.

4.7 Puffer Control System

The puffer control system is used to stabilize the aircraft in the vertical mode while the normal control surfaces are not functional. The puffer system is run from compressor bleed air taken from the 16th stage of the compressor section. The bleed taps on both sides of the engine will remove 6% of the core engine flow from each engine, which is 7.92 lb_m/s per engine. Each puffer is supplied with 1.98 lb_m/s to produce 248 lb_f thrust and all eight puffers may be run at the same time. These puffer systems were designed for pitch, roll, and yaw control. The pitch and roll axes had lower moments of inertia and therefore only require a two puffer system. The yaw axis has a larger moment of inertia and thus uses a four puffer system. Each type of rotation - yaw, pitch, and roll - has an acceleration rate of $14°/s^2$. The location of the puffers can be seen in Figures 4.14 and 4.15. A fuel compensation system is used to help cancel some of the loss in engine performance due to the air bleed.

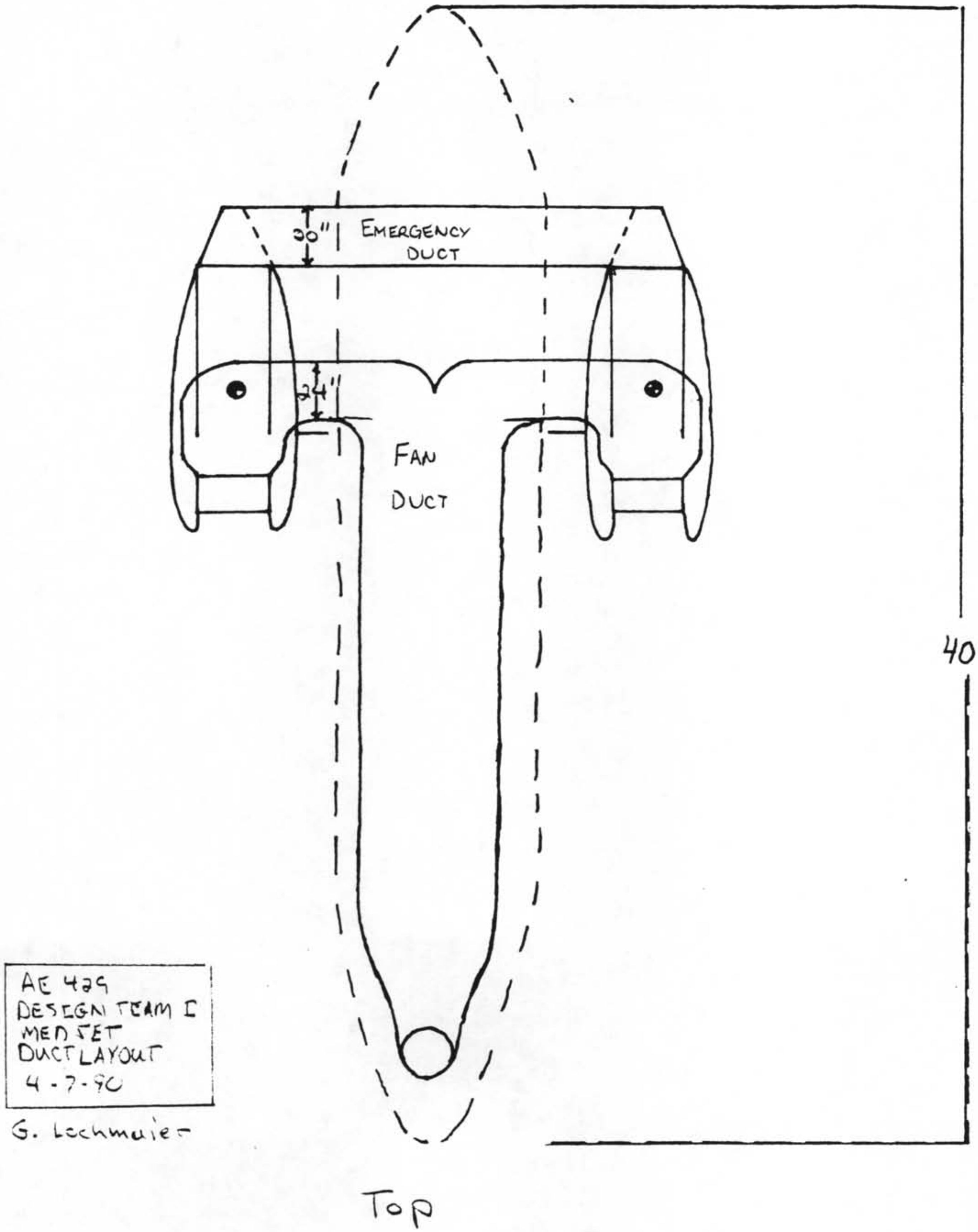


Figure 4.13. Emergency Duct Configuration.

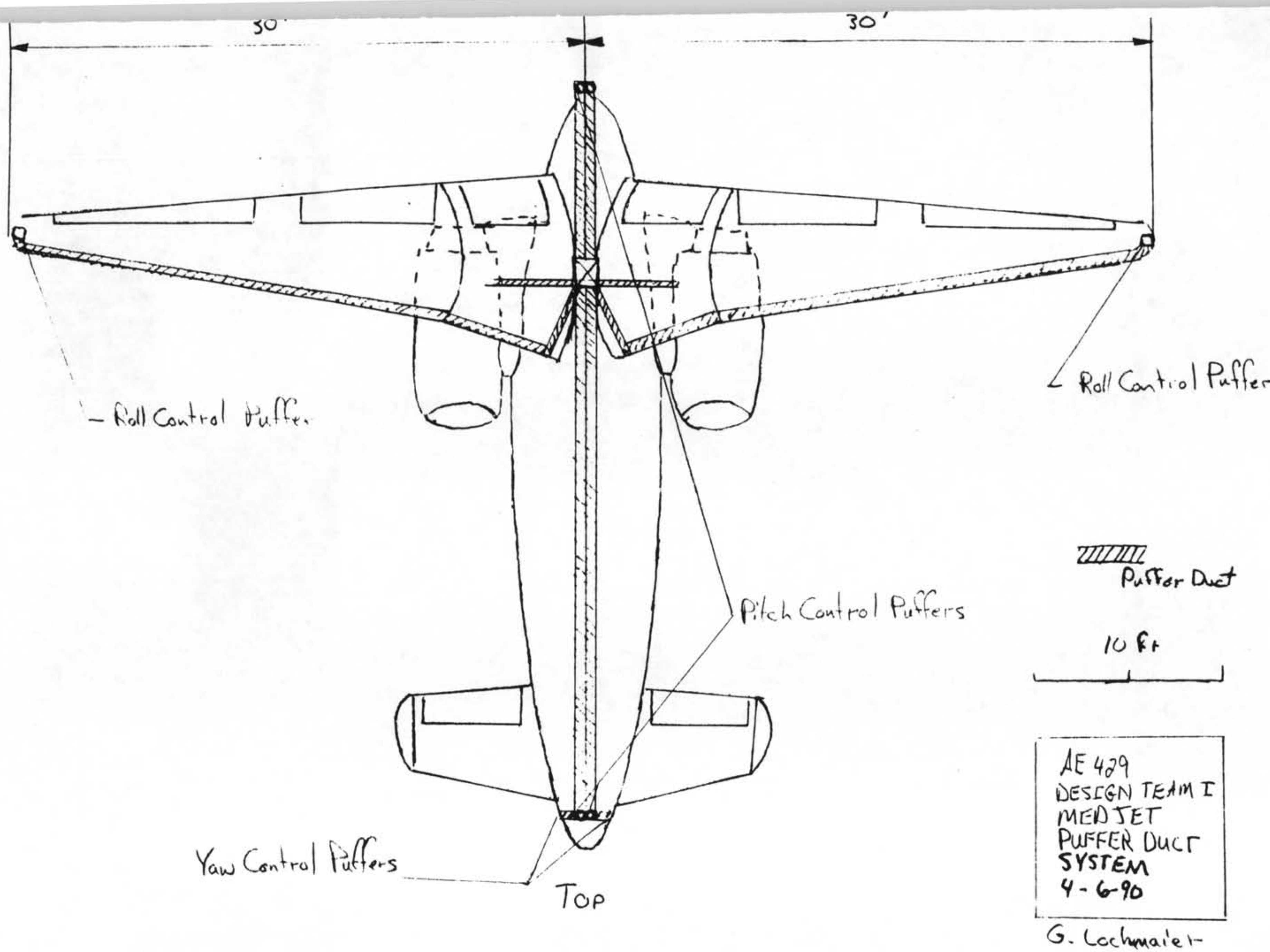


Figure 4.14. Puffer Duct (Top View).

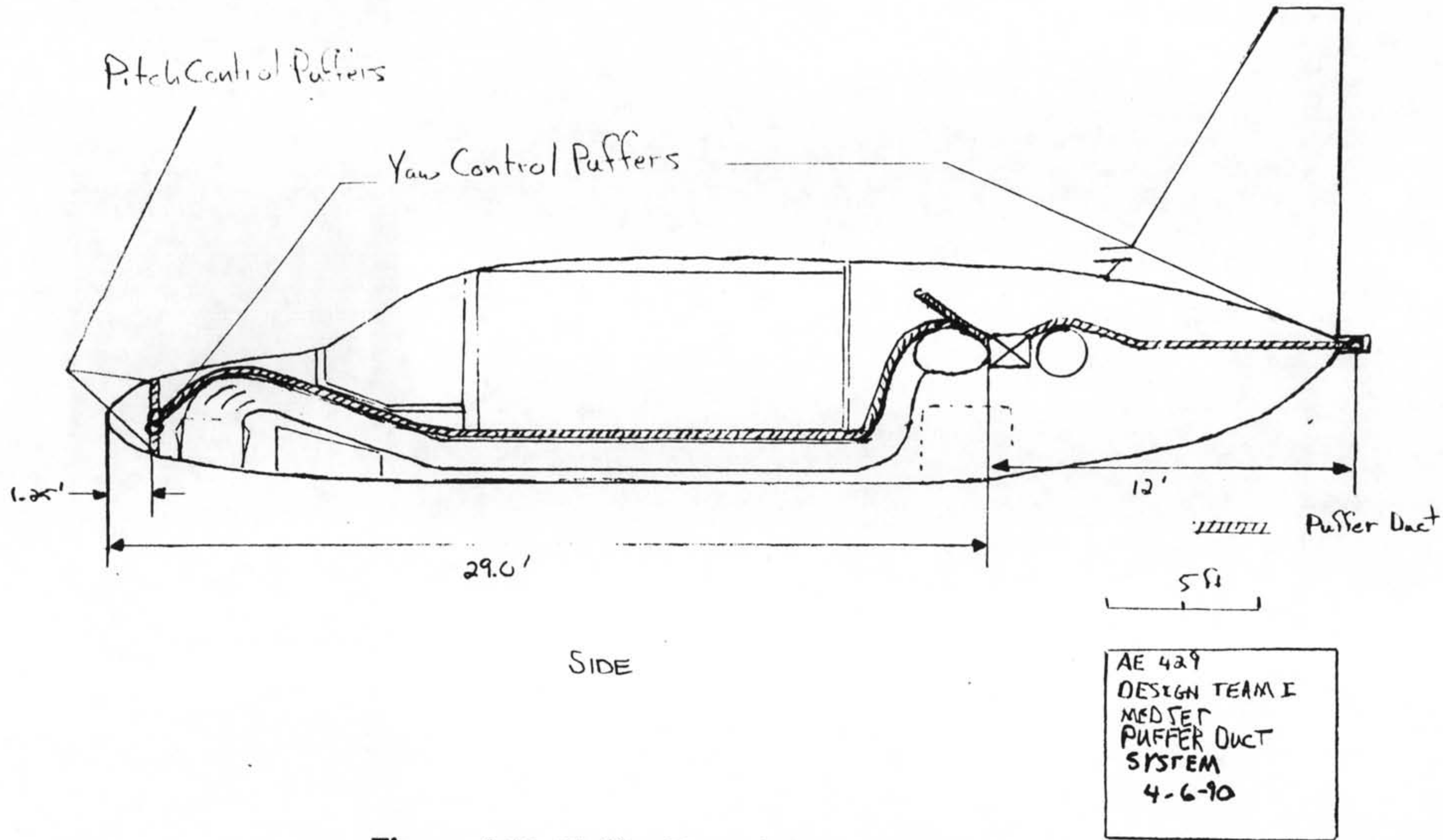


Figure 4.15. Puffer Duct (Side View)

4.8 Fan Section Ducting

The fan flow for the TF30-P-408 engine normally bypasses the engine core and is recombined with the engine's core flow in the nozzle. For use in this aircraft, however, the fan ducting system has been modified. In a normal cruise or horizontal flight mode the fan flow is ducted to the rear of the engine and recombined with the core flow in the nozzle in the same way the original TF30-P-408 engine operates. Since in vertical flight the aircraft must be balanced by the thrust of the engines, it is necessary to separate the fan flow from the engine completely (see Figure 4.16). For this particular aircraft, the fan flow must be ducted to a position 3.5 ft aft of the nose. The separation of the fan flow from the engine was accomplished by annularly dividing the fan flow from the engine (see Figure 4.17). The flow is then ducted from each engine into a common duct which runs from 25 ft aft of the nose to 3.5 ft aft of the nose (see Figure 4.13). Of course the distance which the flow must be ducted is large and the stagnation pressure losses for the ducting systems were estimated at 12%, but these are small prices to pay compared to the weight penalty of another engine for vertical thrust. The flow calculations for the ducting system were done using the minor flow losses formula for bends and turns, discussed in the rear nozzle section, and normal fanno flow analysis for the straight section of the pipe. Figure 4.18 shows the location of this duct in the aircraft, the dimensions of the duct, and the configuration.

4.9 Engine Starting

The starting system for this aircraft consists of two cartridge starters, one in each engine. One starter is used to start a single engine, and then bleed air from the operating engine will be used to start the second engine. The remaining cartridge can then be used to start the engines if the aircraft must be shut down in the field for some reason. The started turbine and the cartridge are located in the accessories section of the engine.

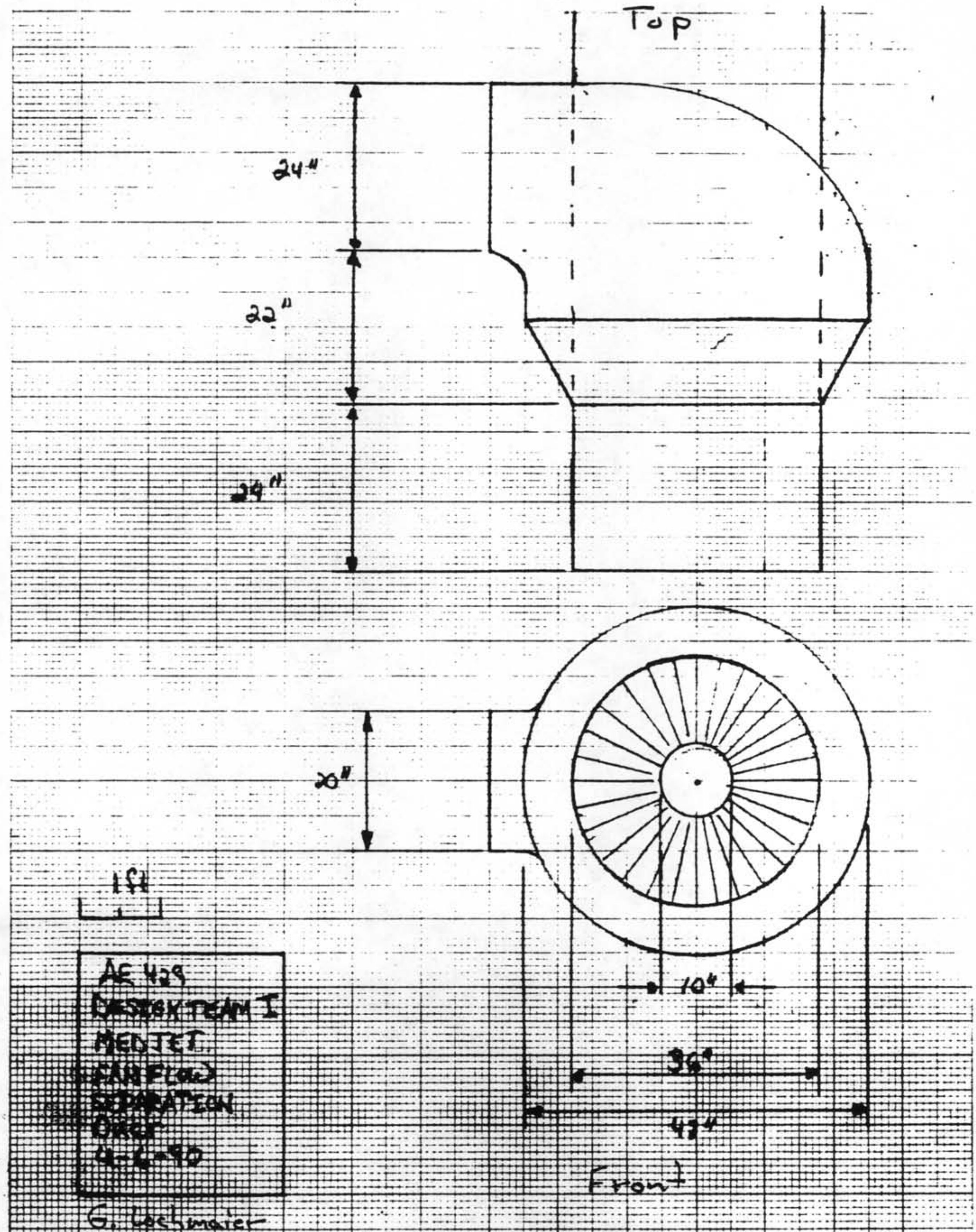


Figure 4.16. Fanflow Separation Duct.

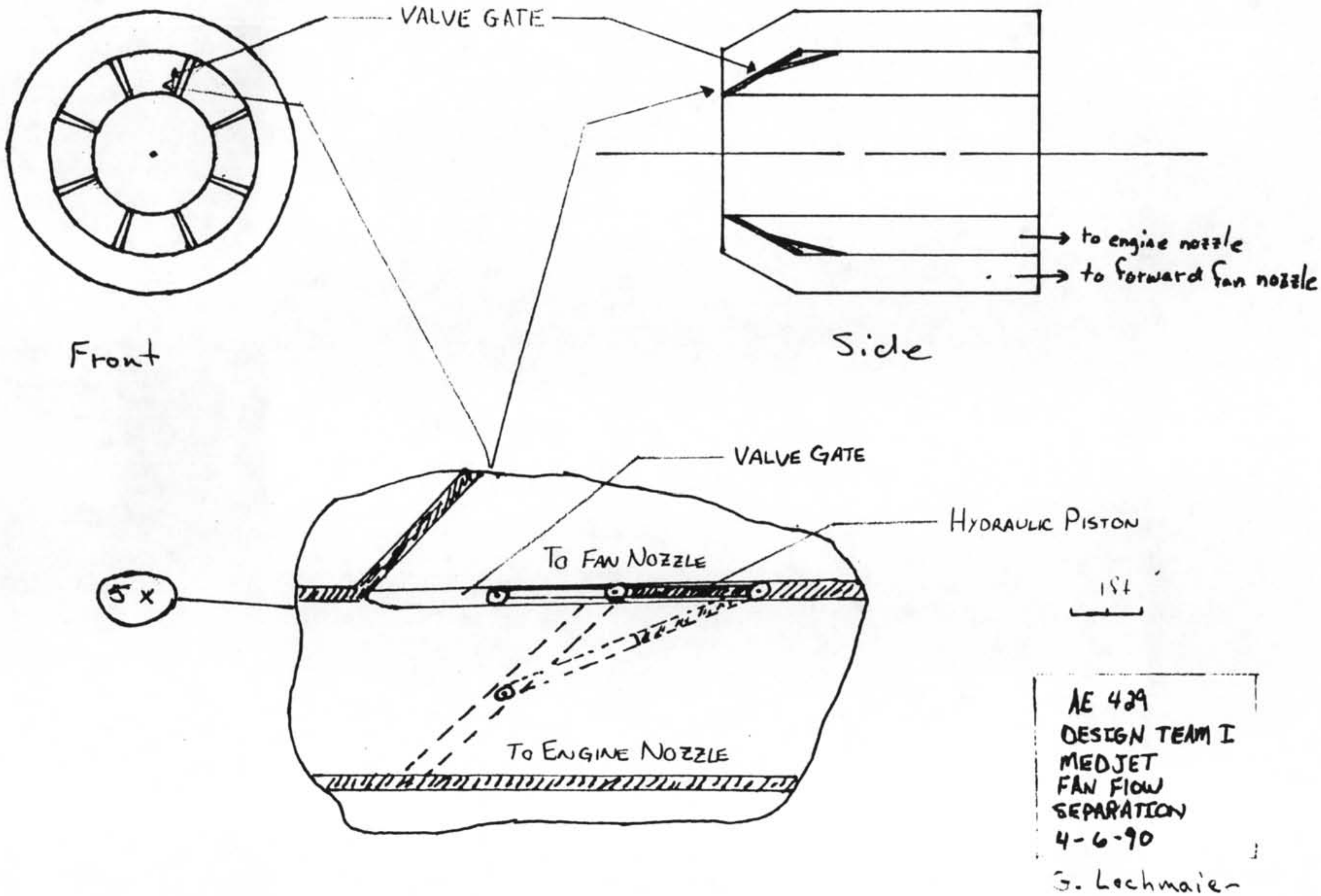


Figure 4.17. Annular Fanflow Separation Configuration.

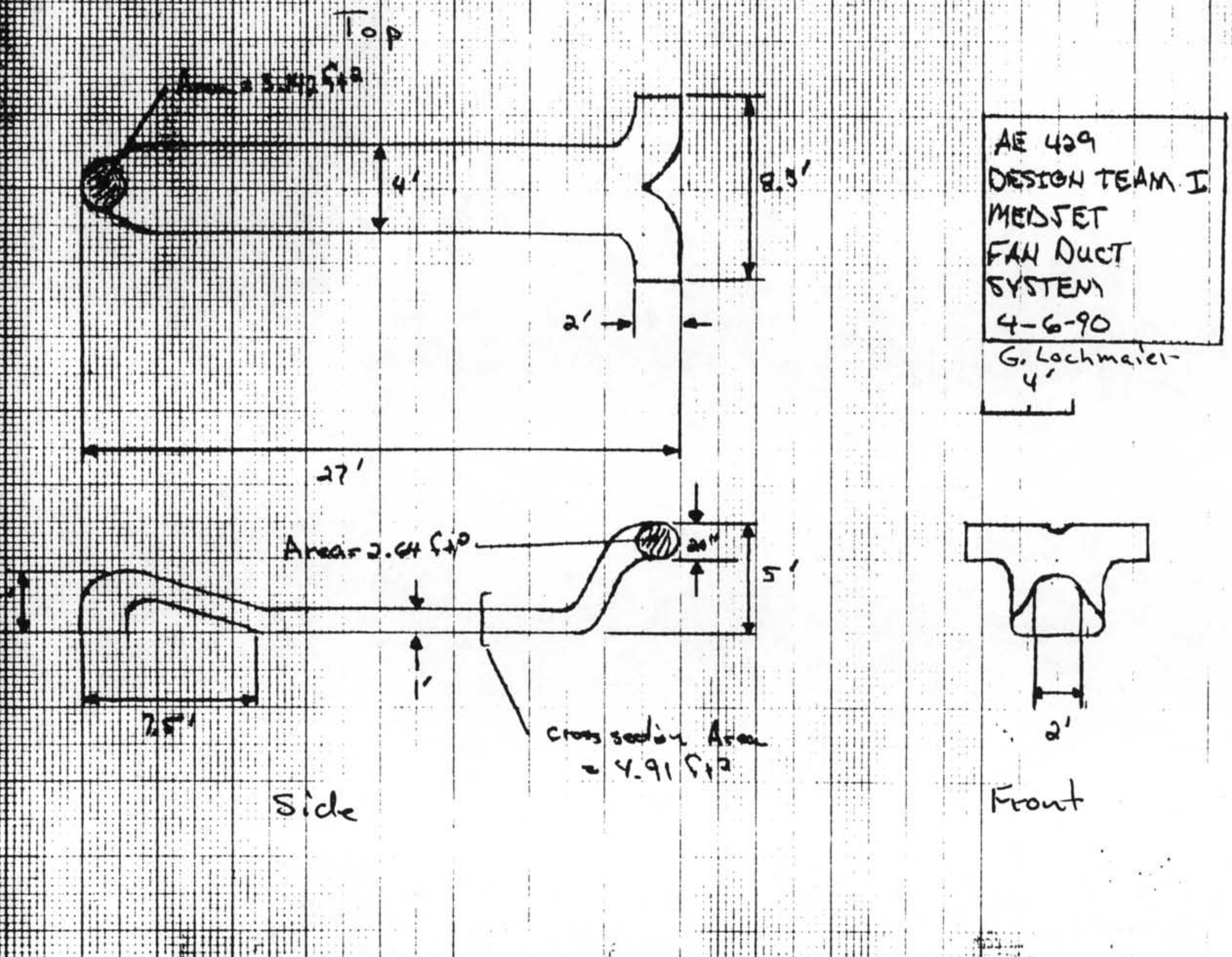


Figure 4.18. Fanflow Duct System and Dimensions.

Chapter 5
Aerodynamics

Aerodynamically, the aircraft consists of a rounded-off rectangular cross-section fuselage, two essentially cylindrical engines mounted on the sides of the aft fuselage, a high-mounted high aspect ratio wing, a low-mounted canard, and a single vertical tail.

A total flat-plate area for the aircraft was calculated to be 7.37 ft^2. This resulted in a drag coefficient (excluding lift induced drag) of 0.0217. The theory calculations were accomplished as follows: first, turbulent boundary layer was used to calculate actual drag on individual components. This number for drag was then divided by q, the dynamic pressure, for the conditions used in the calculation. The number resulting from this is f, the flat-plate area for that component. The flat-plate areas' are summed up for all components and multiplied by 1.20 to account for the following: 5% for trim drag; 5% for interference drag; 5% for pitots, wire cutters, and antennae; and 5% for control surface gaps. In lieu of wind runnel data, this modifications seem fully reasonable. The new, increased flat-plate areas of the aircraft's components are shown in Table 5.1.

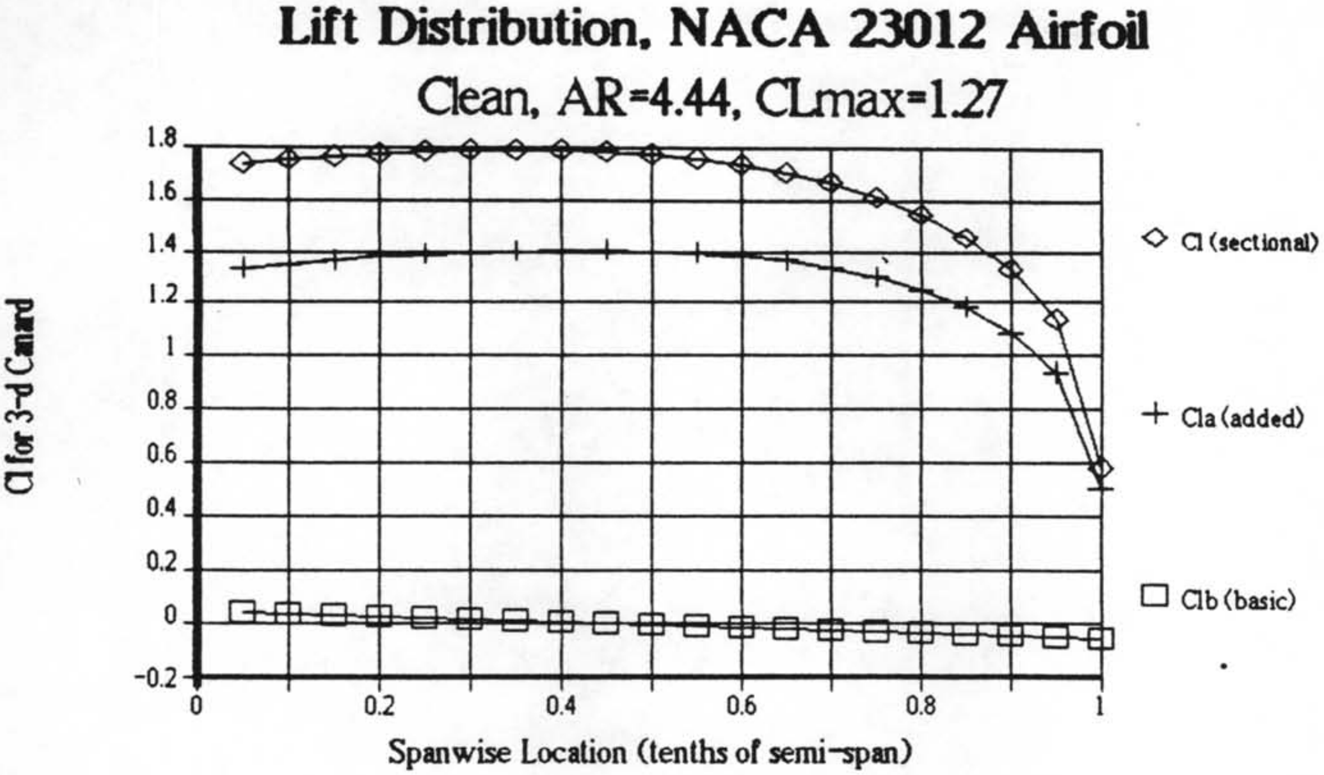
Table 5.1. Component Flat-Plate Areas.

Fuselage:	1.899 ft^2
Wings:	0.269
Canards:	2.730
Vertical Tail:	0.221
Engine Nacelles:	1.020
TOTAL	6.139 x 1.20 = 7.37 ft^2

C_{Lmax}, maximum coefficient of lift, was determined using Schrenk's Approximation. The calculations were performed using a table set up on a personal computer spreadsheet program, and the results are shown in Figure 4.1. This C_{Lmax} was then used to calculate the induced drag.

5.1 Canards

The canards are low-mounted, low aspect ratio wings providing pitch control and greatly improving slow flight performance. Figure 5.2 displays the relevant configuration and Table 5.2 lists the important data. The airfoil used is a NACA 23012. The canard surfaces have full-span elevators for pitch control. In addition to providing pitch control, the elevators act as flaps for low speed , high angle of attack flight phases such as STO and transition to and from vertical flight modes. The elevators have a range of +/- 40° and are gapped to act similarly to slotted flaps.



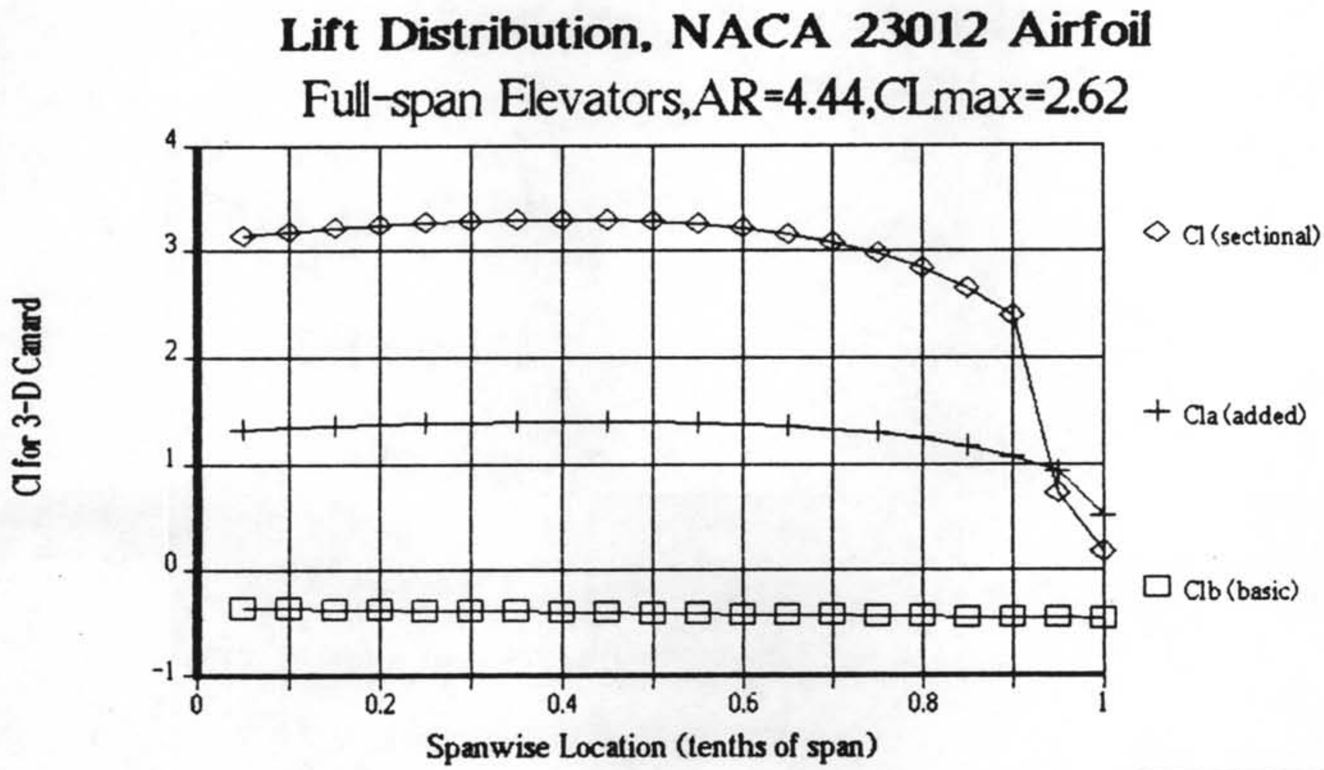


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Figure 5.1. Lift Distribution for the Canard, NACA 23012 Airfoil.

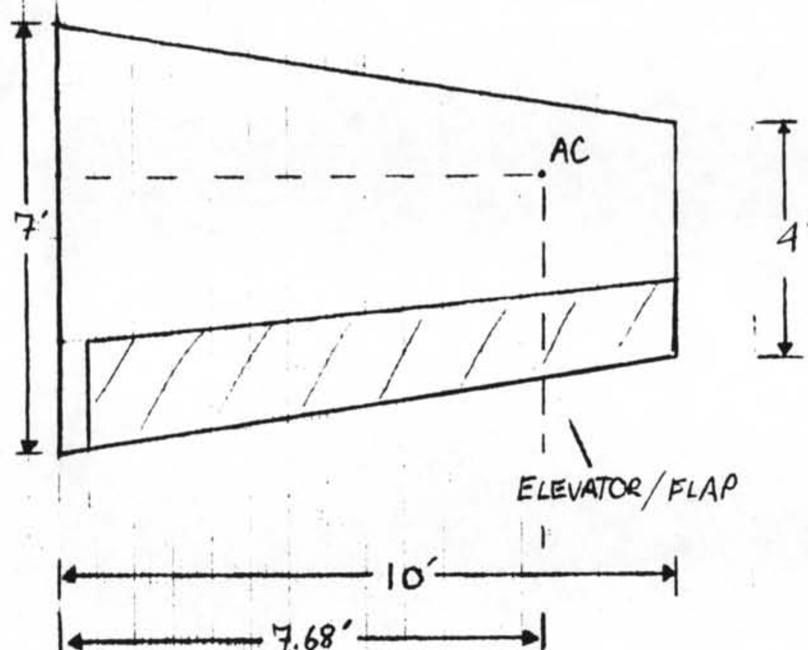
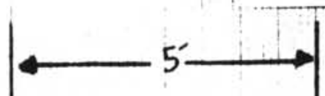


Figure 5.2. Stylized Representation of the Canard.



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The canards are mounted such that the root is at an angle of incidence of 1° relative to the horizontal. This is so that the canard will stall before the wing at high angles of attack. In addition, the canard has 2° of washout to ensure that the flaps/elevators remain unstalled as long as possible. This configuration allows a maximum C_L for the canard of 2.62 with full flap/elevator deflection. Clean, the $C_{L\alpha}$ for the canard is 0.06151/degree.

The span-wise lift distribution was determined using Schrenk's Approximation and is plotted in Figure 5.3. Knowing the C_{Lmax} for the canard allowed the Aerodynamics Group to determine the angle of attack required for vertical/horizontal transition, as well as helped determine aircraft stall speed.

Table 5.2. Physical Data for Aerodynamic Surfaces.

	Canards	Wing	Vertical Tail
Area(ft^2)	90.00	340.0	51.33
Span(ft)	20.00	60.0	9.00
Aspect Ratio	4.44	10.59	2.52(effective)
Root Chord(ft)	7.00	9.00	7.50
Tip Chord(ft)	4.00	2.00	2.11
$C_{l\alpha}$ (/degree)	0.06151	0.08235	0.05213

5.2 Wings

The wings are high mounted, high aspect ratio surfaces (see Figure 5.4). Their geometric data are also listed in Table 5.2. The wings are mounted in a gull wing configuration for three reasons. First, this configuration eliminates much of the concern over interference drag between the engine cowling and the wing. Second, the gull wing eliminates the local loss of lift immediately above the engines when the engines are tucked into the wing itself; raising the lifting surface prevents this. Third, mounting the wing in this fashion allows clearance for a standard size ambulance to drive entirely around the vehicle.

The airfoil shape is that of the NACA 23012, like that of the canards. The wing has a 2° washout and is fitted with inboard, 50% span, 30% chord single-slotted flaps with a maximum deflection of 40°. Outboard, the wing is fitted with 50% span, 30% chord ailerons with maximum travel range of +/- 40°. This configuration allows the wing to achieve a C_{Lmax} of 2.92 at 17.21° angle of attack with full flaps extended. Clean, the $C_{L\alpha}$ for the wing is 0.08235/degree. Schrenk's Approximation was used to find the lift distribution for the wing.

5.3 Vertical Tail

The dimensions of the vertical tail of this aircraft are listed in Table 5.2. The airfoil section used is a 10% thick, symmetrical one with the maximum thickness at the quarter chord. The rudder used is a 40% chord, full-span surface capable of motion

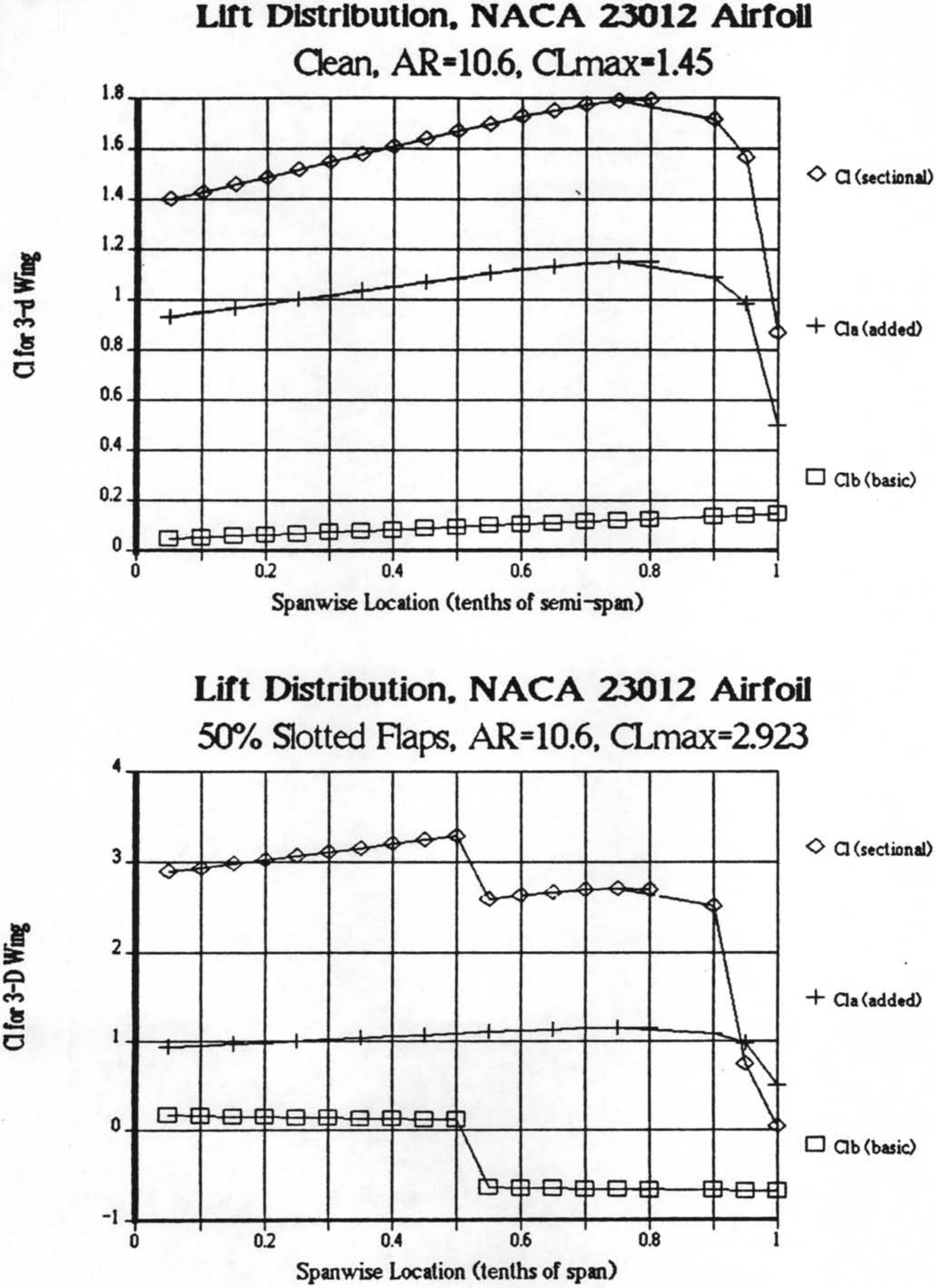

Figure 5.3. Lift Distribution for the Wing, NACA 23012 Airfoil.

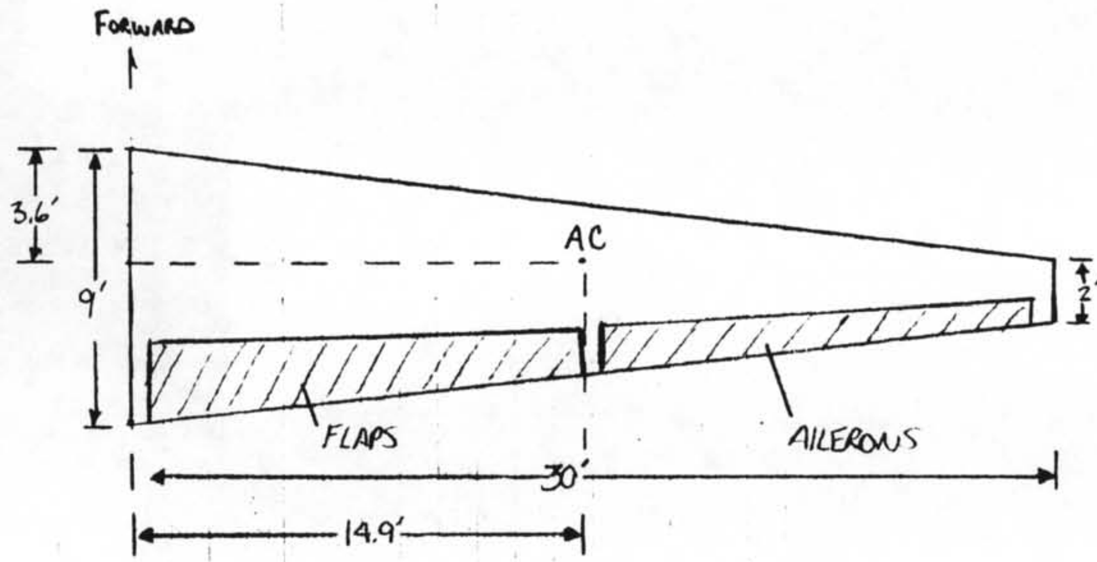

Figure 5.4. Stylized Representation of the Wing.

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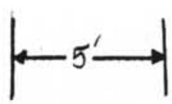

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45° in either direction. This wide range of motion is required to maintain adequate yaw control at low velocities. The $C_{L\alpha}$ for the vertical tail was determined to be 0.05213/degree. The configuration is shown in Figure 5.5.

5.4 Performance and Stability

Short field takeoff data is shown in Table 5.3. Listed there is distance and average acceleration for one and two engine takeoffs using maximum continuous thrust directed fully aft and with no rotation of the aircraft. In determining this data, stall speed was found to be approximately 66 knots at sea-level with an angle of attack of 17.21°. This number assumes a full flap deflectionof 40°. For the no-rotation take-off described above, $V_{lift\ off}$ is 86.3 knots, standard sea-level. Again, this is for full flap deflection.

Table 5.3. Short Takeoff Performance.

Engines:	2	1
Acceleration (ft/s^2):	41.6	20.2
Ground Roll (ft):	127.6	263.2

To maintain straight and level flight, analysis shows that the aircraft's angle of attack at cruise is 2.3° and the elevator angle must be -1.18°; i.e., the elevators must be deflected upward.

V_{mc} is approximately stall speed. The aircraft remains extremely controllable in roll without resorting to puffers below 30 knots at sea-level; calculations indicate that at this velocity, a roll rate of 22°/second is achievable. In pitch, the aircraft remains controllable by the canard elevator/flap until stall speed(i.e., 66 knots). Below this velocity, pitch control is by puffers. In cases of engine out, the aircraft remains controllable in yaw until stall speed. Below this velocity, engine out yaw must be maintained by puffers. For two engine operation, the aircraft is controllable by the rudder down to somewhat below stall speed.

Figure 5.6 shows the rate of climb data for the aircraft at a nominal gross weight of 18,000 lb_f for three different altitudes and for velocities up to 400 knots. Again this performance data is for maximum continuous thrust at the appropriate Mach number and for thrust directed fully aft.

Solution of the longitudinal and lateral stability equations indicates that this aircraft is stable and falls into Level 1 as far as flight control and stability are concerned for all phases of flight. Solving the longitudinal stability equations led to the discovery of the following: for the short period mode, the period is 1.296 seconds with a $T_{1/2}$ of 0.13707 seconds. For the phugoid mode, the period is 82.89 seconds with a $T_{1/2}$ of 127.65 seconds. These results place the aircraft's flying qualities in Level 1. The lateral stability equations were also solved. The mode-shapes of the motion indicated a normal roll-mode with a time to damp to half amplitude of 0.535 seconds. In the spiral mode, the mode shapes indicated an extremely long-period spiral motion; $T_{1/2}$ for this mode is 944.3 seconds. The Dutch-roll mode was relatively normal as well. Analysis of the damping ratios for all lateral modes indicated Level 1 flight quality.

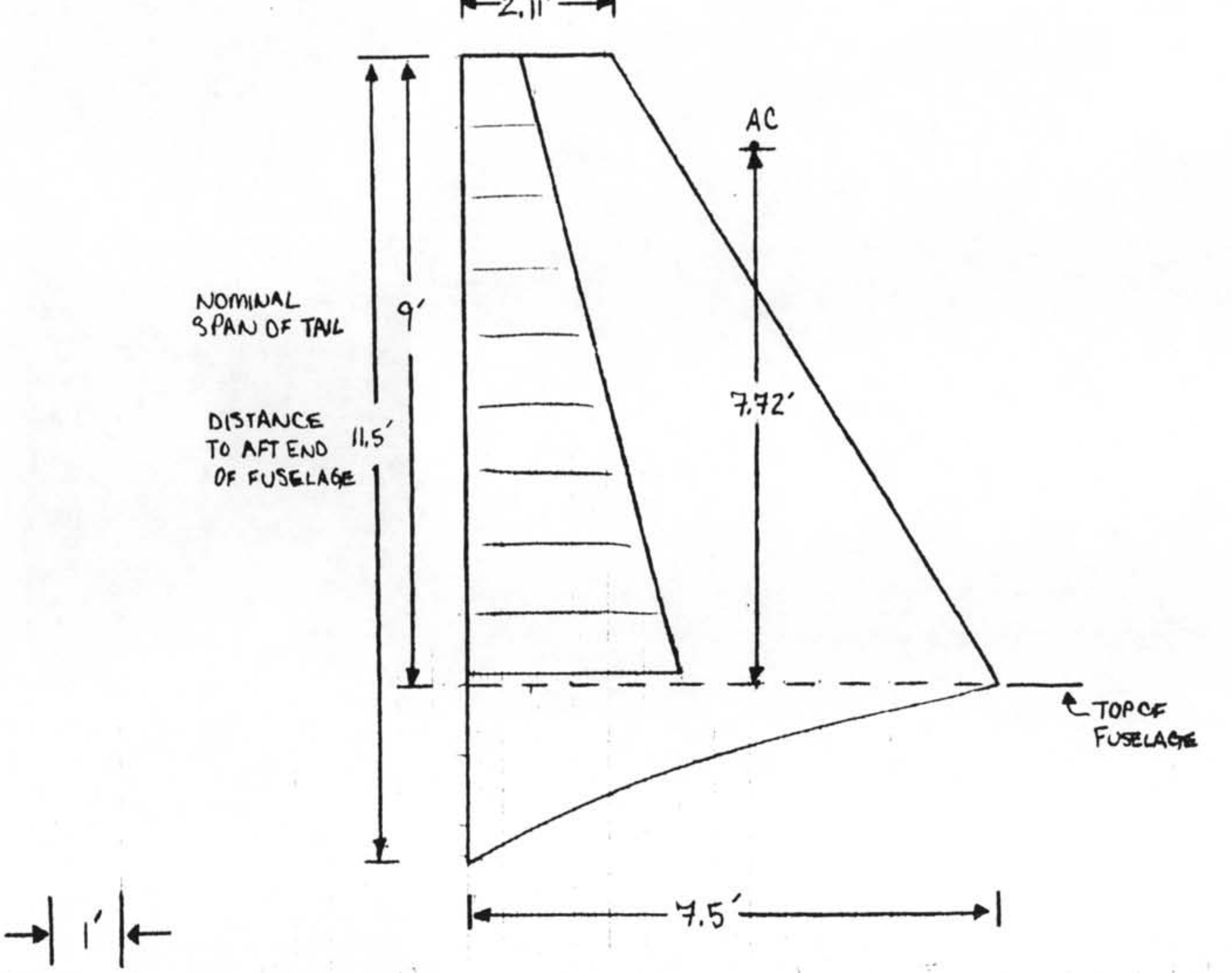

Figure 5.5. Stylized Representation of the Vertical Tail.

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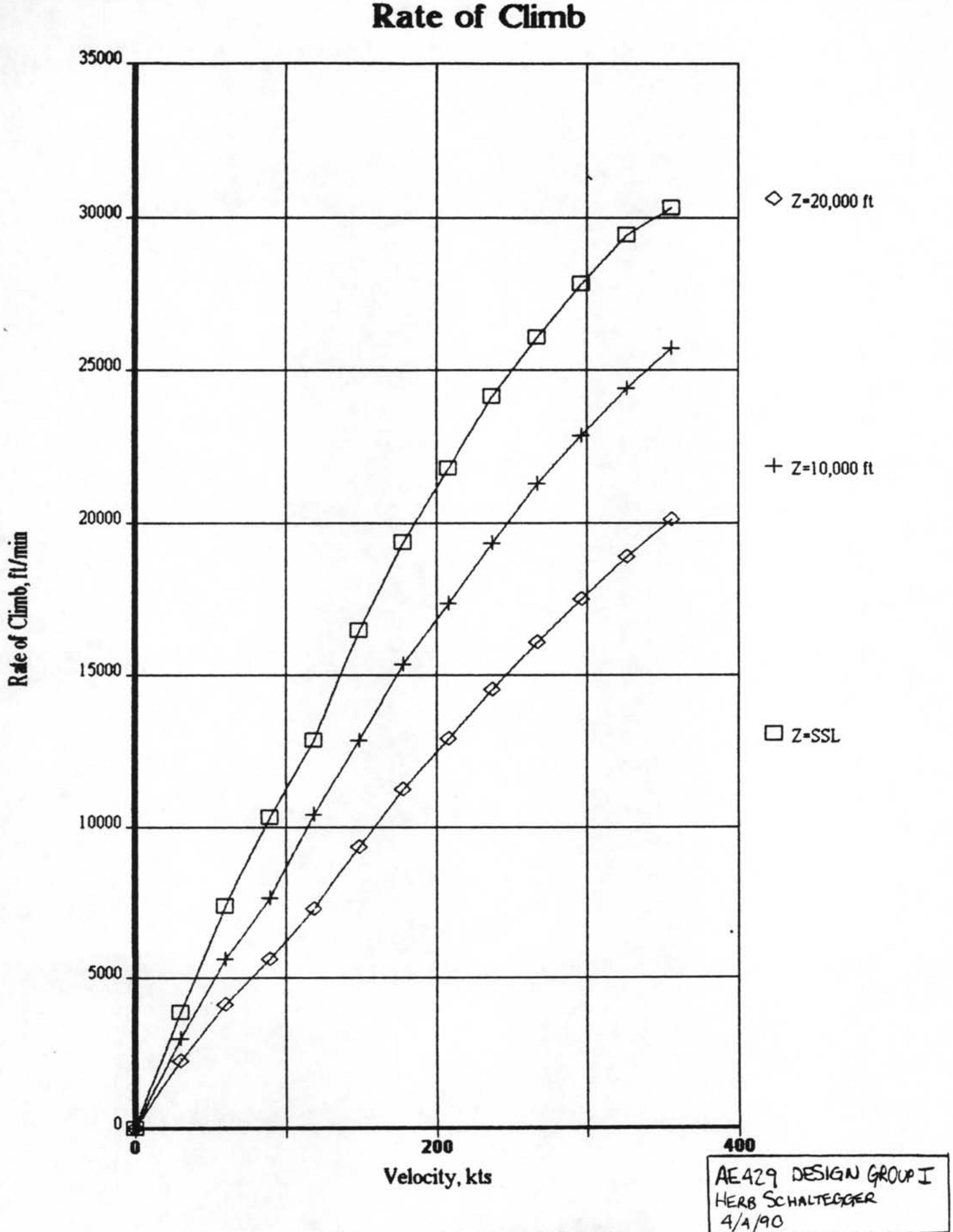

Figure 5.6. Rate of Climb.

Figures 5.7, 5.8, and 5.9 show the calculated rudder deflection, δ_r, for an engine-out case at sea-level, 10,000 ft, and 20,000 ft. As seen, at low velocities, $\delta_r > 45°$. Since 45° is the maximum deflection allowed, flight at these lower velocities would be uncontrollable in yaw without use of the puffer system.

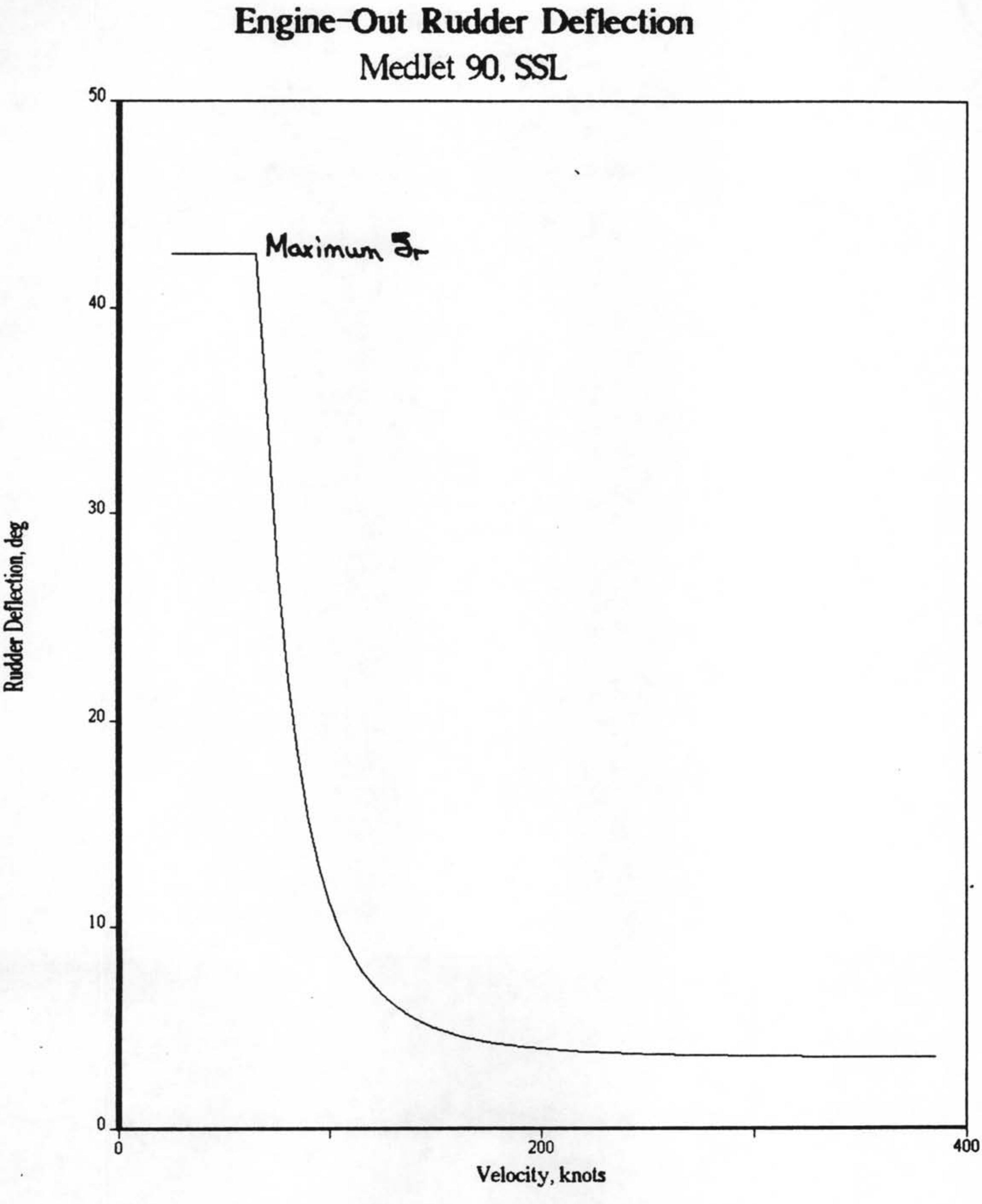

Figure 5.7. Engine-Out Rudder Deflection (SSL).

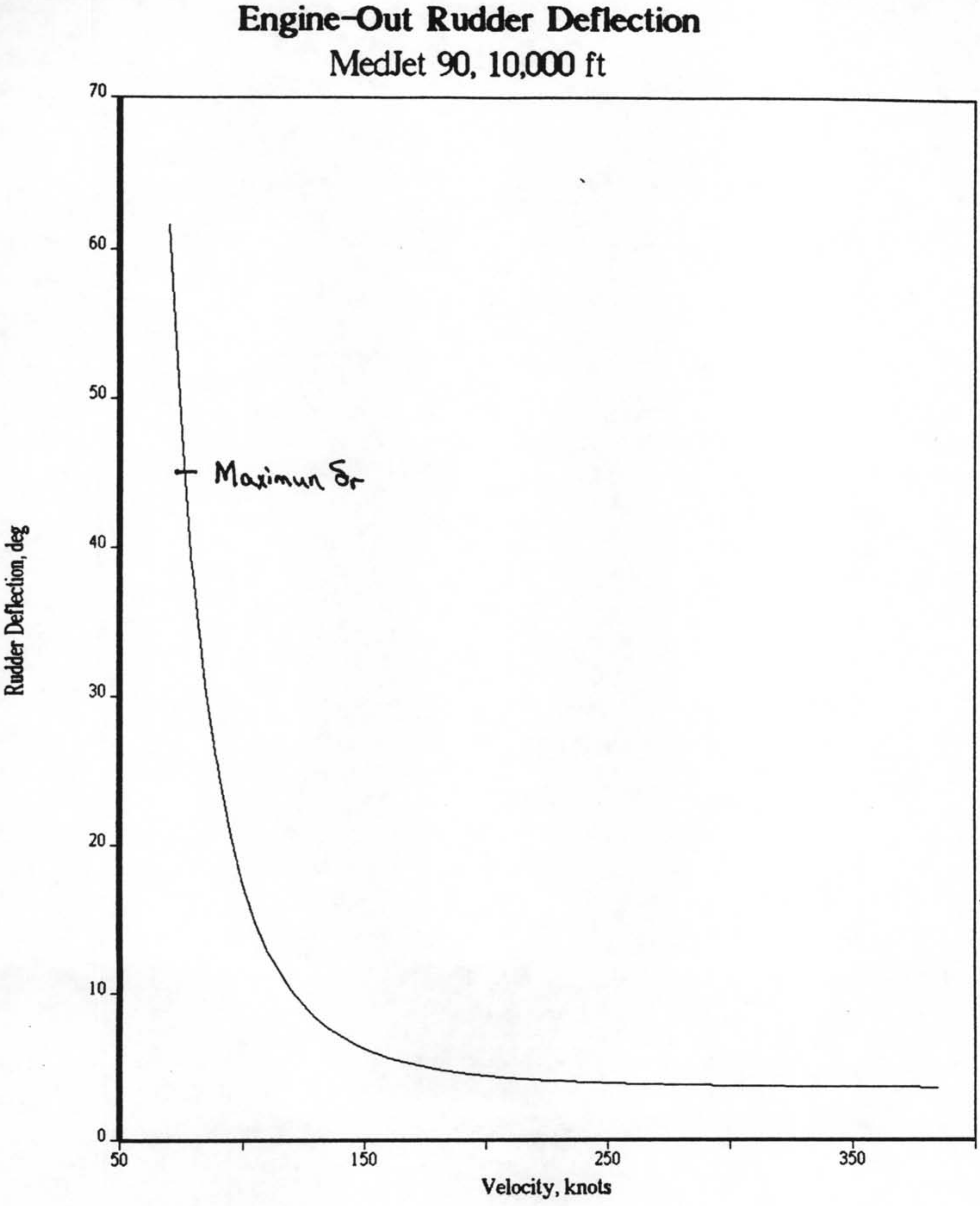

Figure 5.8. Engine-Out Rudder Deflection (10,000 ft).

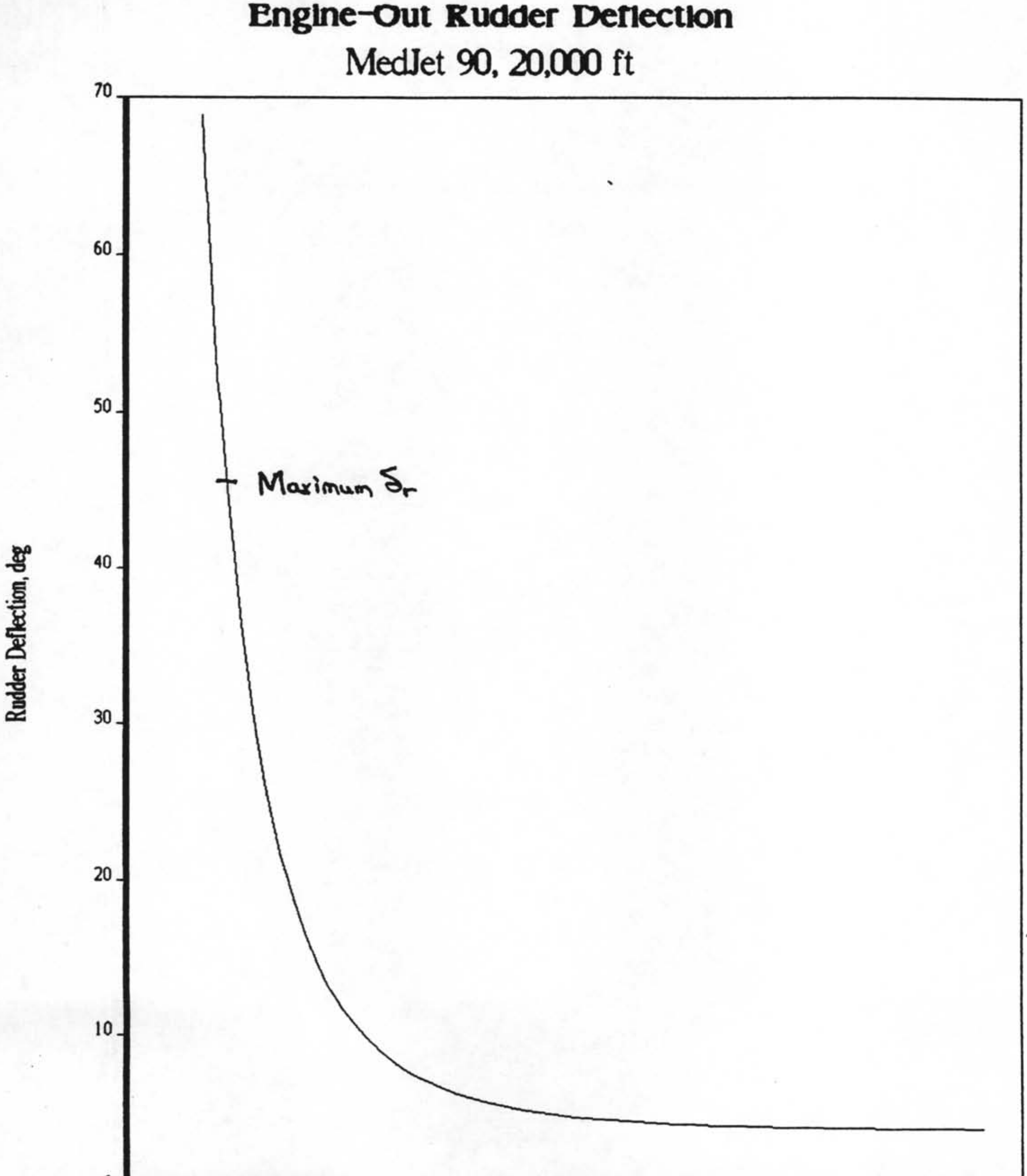

Figure 5.9. Engine-Out Rudder Deflection (20,000 ft).

Chapter 6
Structures

The work of the structures group was divided into six main areas of concern: the wings, vertical tail, canards, engine cowling and pylon, fuselage, and landing gear. Each of these areas was dealt with separately, and then methods of joining them were considered. Results, including component sizing, critical and actual stresses, and safety factors, for each area can be found in Tables 6.1-6.5. Aluminum 2024-T361 ($E=10.5x10^6$, σ_y=57.3 ksi, σ_u=71.8 ksi, ρ=.1 lb_f/in^3) was chosen as the material to be used in the majority of the structure. It is lightweight and strong enough to be suitable for this design.

6.1 Wings

The most critical part of the aircraft, the wing structure, was examined first. In order to choose the load that would be carried by each wing, the required load factor formula given by FAR 25.337 (b) was used: n=2.1 + 2400/(W + 10000). A gross weight of 18,000 lb_f results in n=2.96, so that a factor of 3.00 was used in case subsequent gross weights were less.

Rough estimates were made on the sizing of the stringers, spars, and skin by setting the critical buckling stress in the skin and the stress caused by a bending moment equal while attempting to minimize weight. Note that the moment is worst at the maximum load factor, with no fuel in the wings, at the root of the wing since there are no external forces other than its own lift, weight and drag. Bending stress was given by σ= My/I while the critical buckling stress is $\sigma_{cr}=KE(t/b)^2$. K, the buckling constant, was assumed to be the minimum possible value for the given type of buckling for a plate with clamped edges. The values for K of 6.0 for compressive buckling, 21.0 for bending, and 8.0 for shear were obtained from the graphs shown in Figures 6.1, 6.2, and 6.3. It was found that bending stress was the determining factor in sizing the spars, while buckling due to compressive stress dictated the skin thickness and also the stringer number and spacing. Choices for sizing of these components is seen in Table 6.1, along with their actual stresses, critical stresses,and safety factors, and a cross-section of the wing is seen in Figure 6.4. It was decided to reduce the number of stringers from 30 to 16 at station 180 and then decrease the number again to 12 at station 270. Ending stringers before the wingtip was primarily to reduce weight, but also it was because 30 stringers do not have room to all extend to the tip.

Once these components were sized, a shear flow analysis including taper effects was done on the box beam. The wing box beam was approximated as a rectangle, on which were placed the lift force at the aerodynamic center, the weight on the center

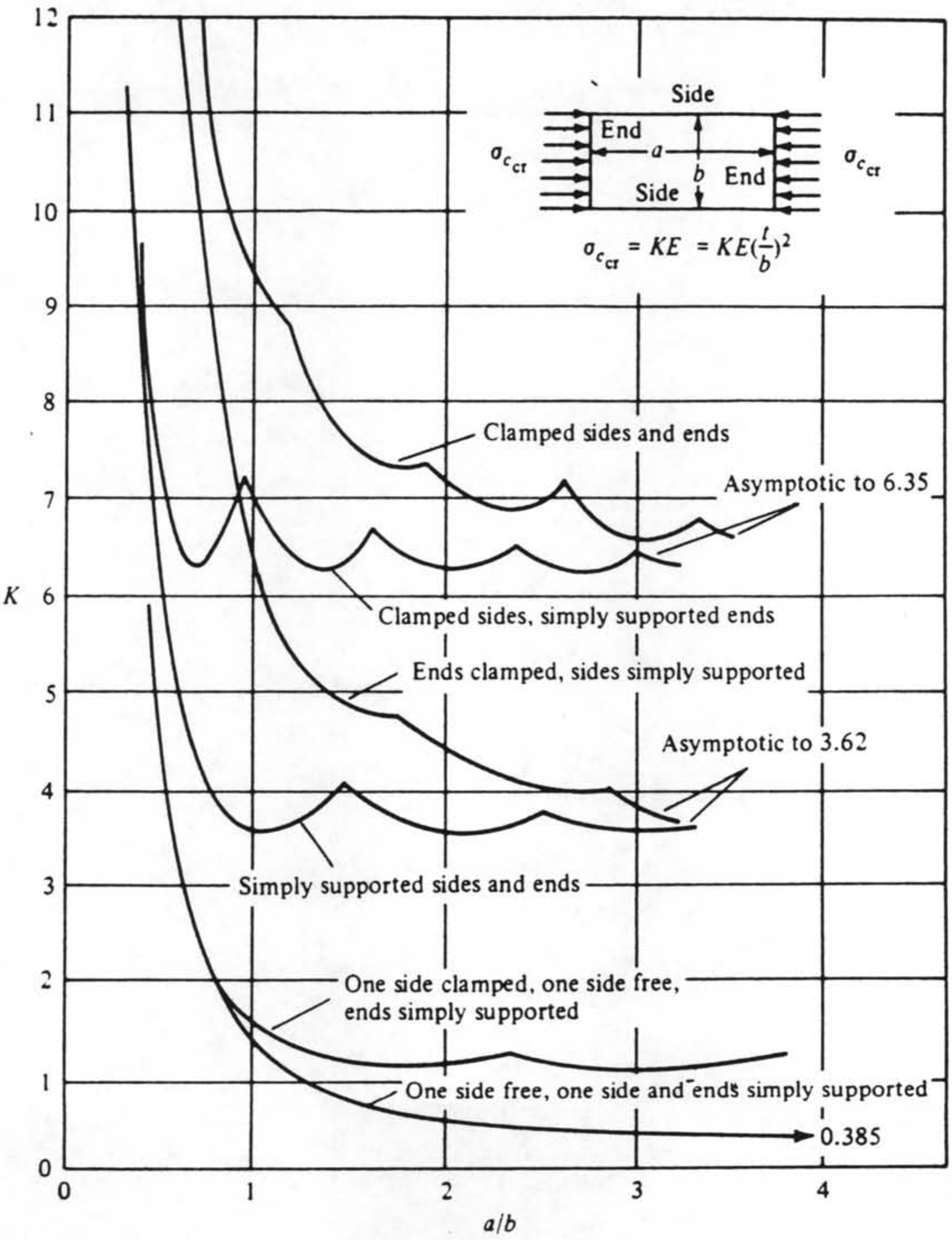

Figure 6.1. K, Constant for Compressive Buckling Stress.

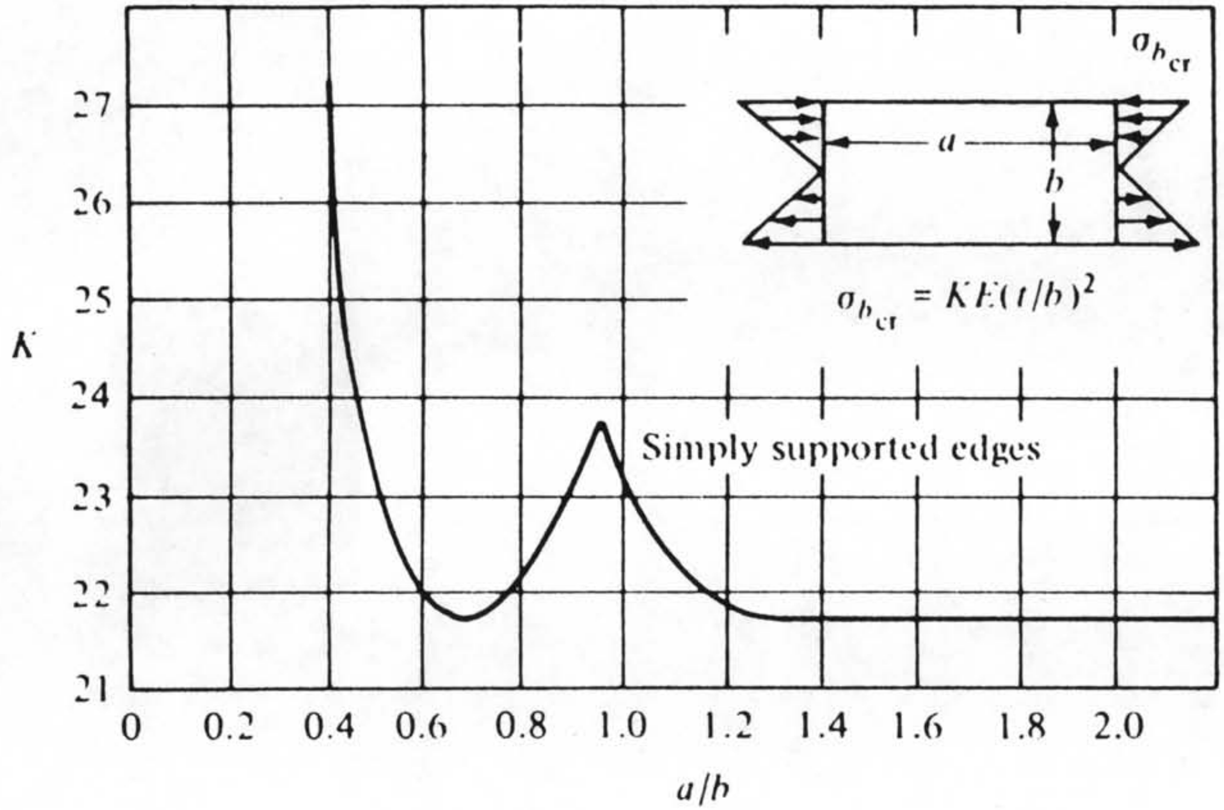

Figure 6.2. K, Constant for Bending Buckling Stress.

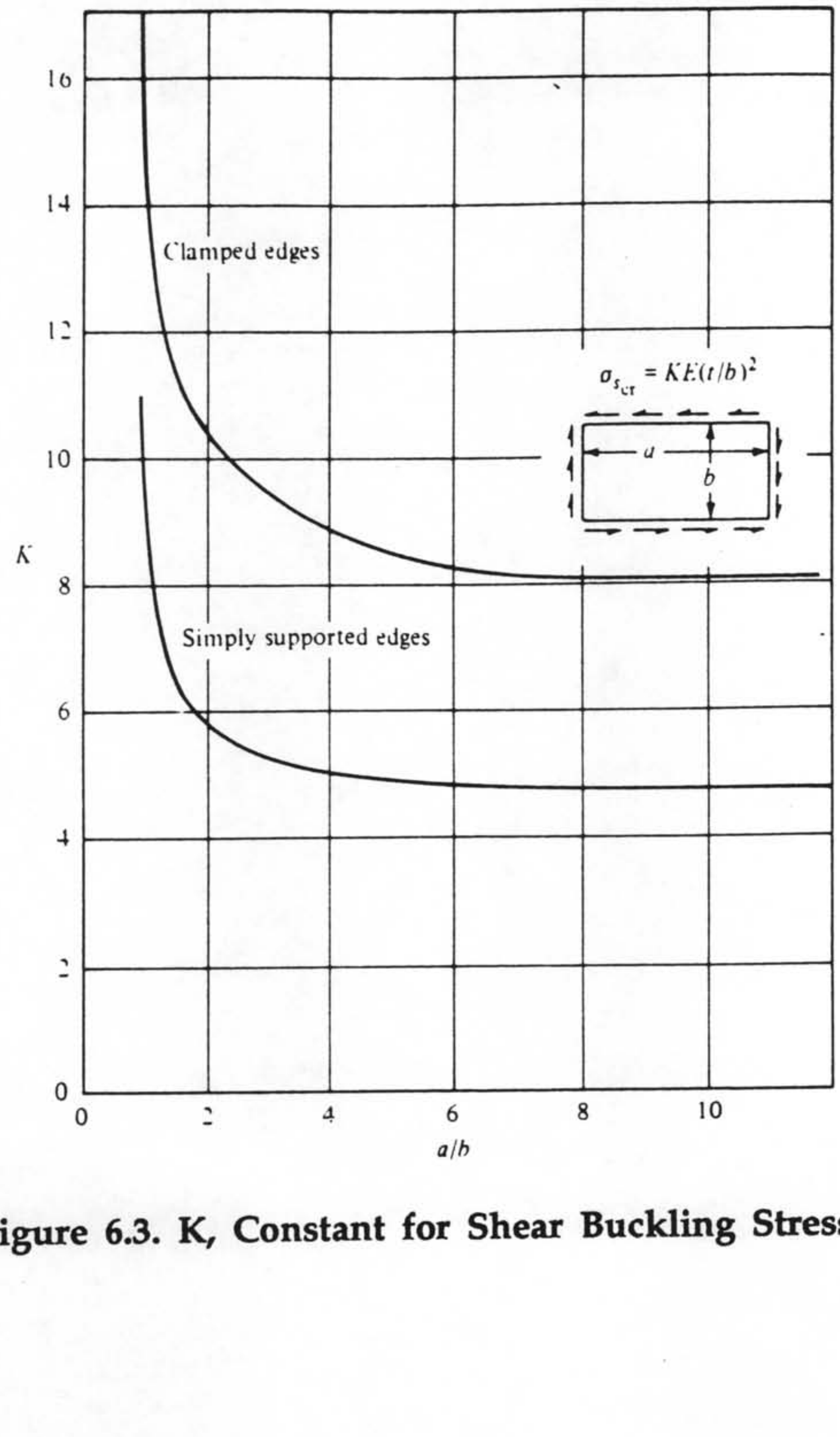

Figure 6.3. K, Constant for Shear Buckling Stress.

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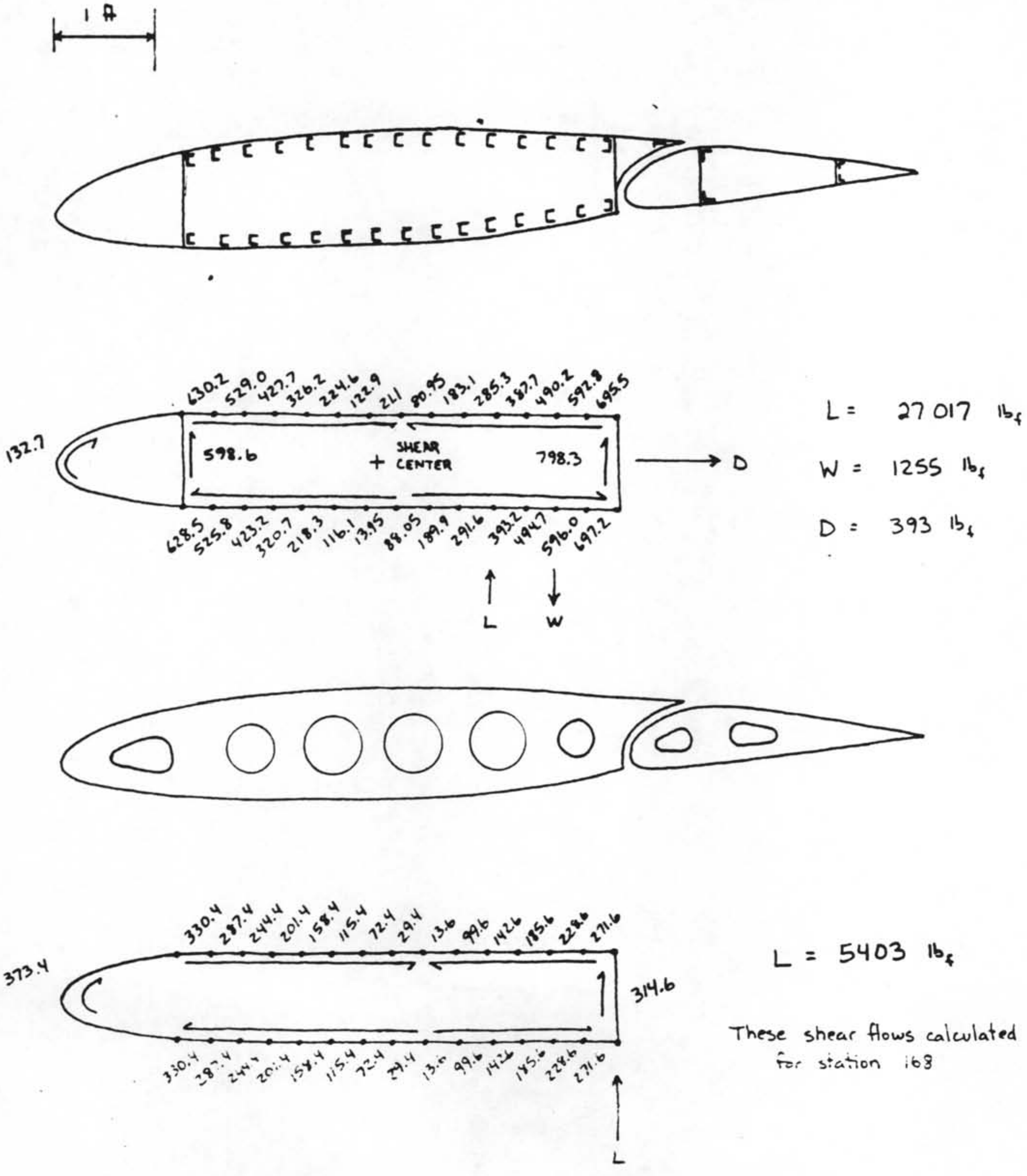

Figure 6.4. Cross-Section of Wing, Example Rib, and Induced Shear Flows.

of gravity, and the drag along the chord line. In order to include the small resistance to bending that the skin would offer, the actual moment of inertia was calculated for the box beam, and an effective area was calculated for the stringers. In this way, it could be said that this effective area resisted bending, while the skin resisted only shear. The resulting shear forces, seen in Figure 6.4, were found to be not as constraining as the buckling and bending forces. The resulting shear flow indicates a twist at the root of the wing of 0.0074°/ft decreased angle of attack. The moment of inertia decreases toward the tip, but the shears acting on the structure decrease also, so that the maximum twist expected at the wingtip is 0.22° decreased angle of attack. Table 6.1 gives maximum actual and critical shears along with the safety factor.

Table 6.1. Wing Sizing, Stresses, and Factors of Safety.

stringers	:	0.668 in^2	ribs	:	0.10 in
skin	:	0.10 in	spars	:	0.16 in

Station	Loading Type	Actual Stress (psi)	Critical Stress (psi)	Safety Factor
root	compression	28,930	49,432	1.71
	tension	28,930	57,300	1.98
	shear-skin	6,955	65,909	9.48
	-spars	4,989	17,771	3.56
	-ribs	3,734	6,942	1.86
	bending	28,930	46,651	1.61
180	compression	18,317	32,123	1.75
270	compression	8,325	14,589	1.75

Shear was, however, the determining factor in sizing the ribs. Because their function is the transmission of concentrated shearing loads to the rest of the structure, they were sized by the loads imposed by the control surfaces. The maximum load expected on any rib was chosen as the entire lift on the wing, still with a load factor of 3.0, divided by the number of control surface attachment points. Rib thickness could thus be chosen by performing a shear flow analysis under this load. The worst shear under this load occurs at the smallest rib affected since its moment of inertia is the smallest. A typical rib and estimates of the shear flow imposed are also seen in Figure 6.4. Table 6.1 also gives the rib sizing, actual stresses, critical stresses, and safety factors. In this case, spacing was not considered relevant to buckling of the skin since a minimum possible buckling constant was used.

In considering the gull-type configuration of the wings it was found that only 126 psi extra due to the vertical component of the weight is acting on the base of the wing. This amount is negligible when compared to the total stress on the skin due to bending. However, in order to guard against stress concentration in the bend, extra support was added in this area in the form of extra stringers which are attached to each spar.

Fuel tanks will be placed over most of the span of the wing, with an estimated volume of 18.04 ft^3 (809.4 lb_f of fuel) in each. They will be of the integral type and will contribute very little to weight and essentially none to structure.

A layout of the wing structure, including positioning of ribs and stringers, can be seen in Figure 6.5. An estimate of the wing weight is 1,148 lb_f.

6.2 Canards

The canard structure was analyzed in exactly the same way as the wing structure. A maximum expected lift was gained from the Aerodynamics Group and multiplied by the load factor of 3.0. Compressive and bending stresses caused by this load and the weight were used to size the stringers, skin, and spars. Drag affects were omitted here because they cause a negligible effect on the structure, and their omission simplifies the analysis. A shear flow analysis was performed on this structure, again using a rectangle and including taper effects, and was found to be not very constraining. Rib sizing was also carried out in the same manner again: dividing the maximum load by the number of control surface attachments to get a maximum shearing force on any rib. Sizing for all components along with their actual and critical stresses, and safety factors, can be found in Table 6.2. Figure 6.6 shows cross-sections and shear flows under maximum loading conditions.

Table 6.2. Canard Sizing, Stresses, and Factors of Safety at Root.

stringers	:	0.158 in^2	ribs	:	0.06 in
skin	:	0.10 in	spars	:	0.10 in

Loading Type	Actual Stress (psi)	Critical Stress (psi)	Safety Factor
compression	13,824	24,127	1.74
tension	13,824	57,300	3.54
shear-skin	5,881	32,169	5.47
-spars	5,660	14,933	2.64
-ribs	7,267	14,291	1.97
bending	13,824	39,200	2.84

The twist of the canard box beam at the root was calculated to be 0.0047°/ft decreased angle of attack. Here again, the moment of inertia decreases along with imposed shear flows, so that a maximum twist of about 0.033° decreased angle of attack was expected.

Integral tanks in the canards are expected to hold about 6.18 ft^3 (277.1 lb_f of fuel) each. A complete layout of the canard structure showing rib stringer placement is seen in Figure 6.7. The weight estimated for each canard is 169 lb_f.

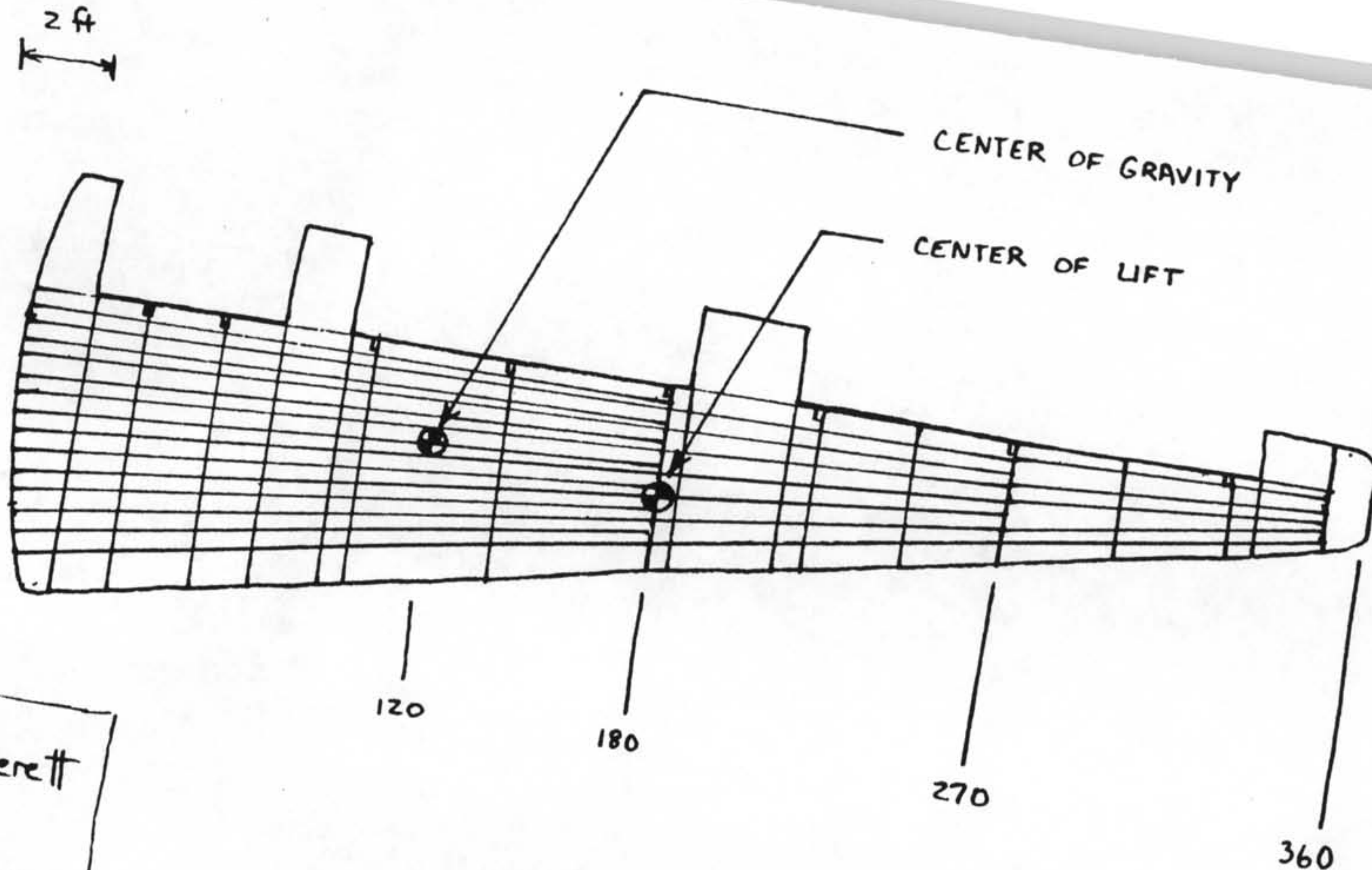

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Figure 6.5. Wing Layout.

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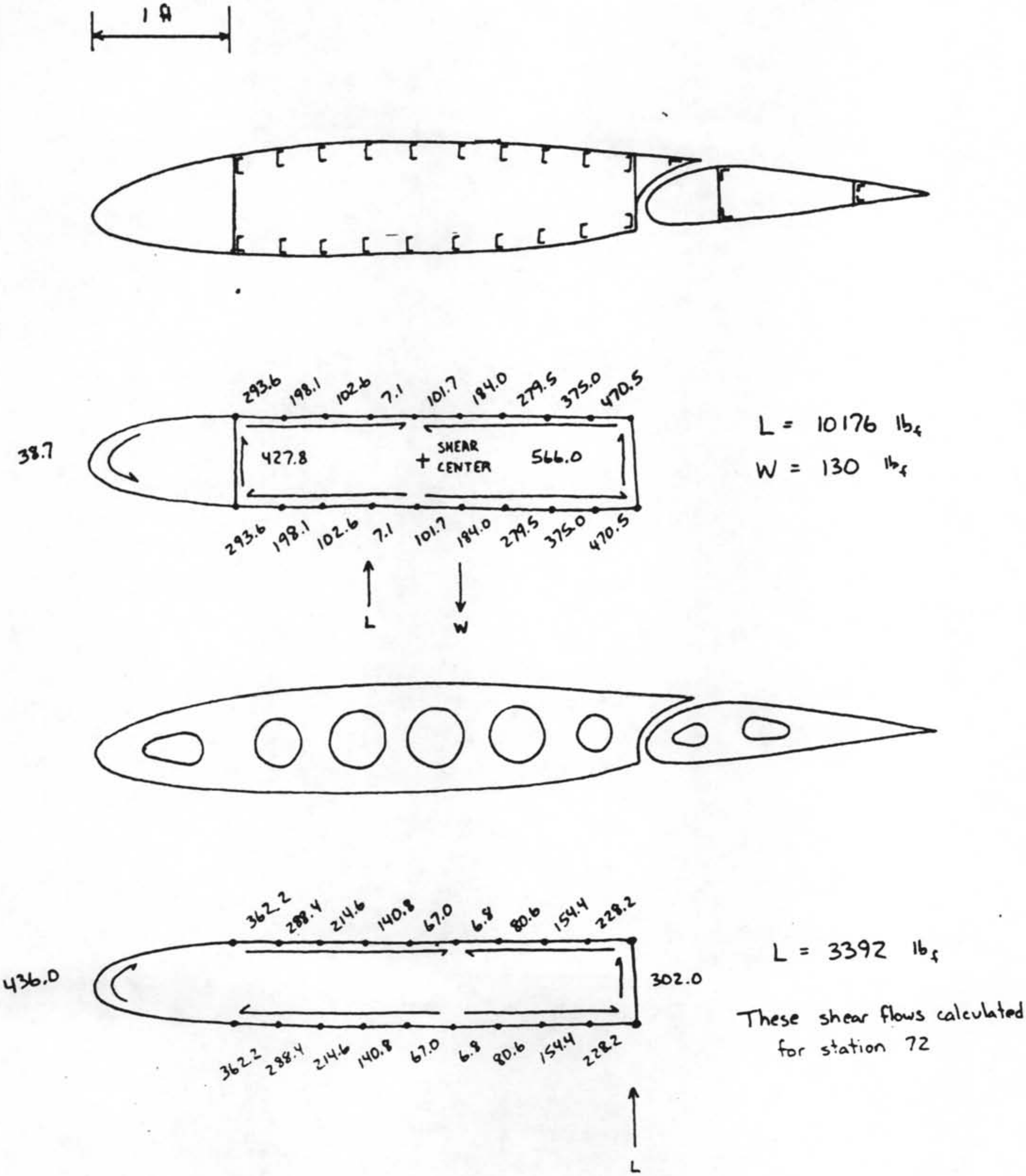

Figure 6.6. Cross-Section of the Canard, Example Rib, and Induced Shear Flows.

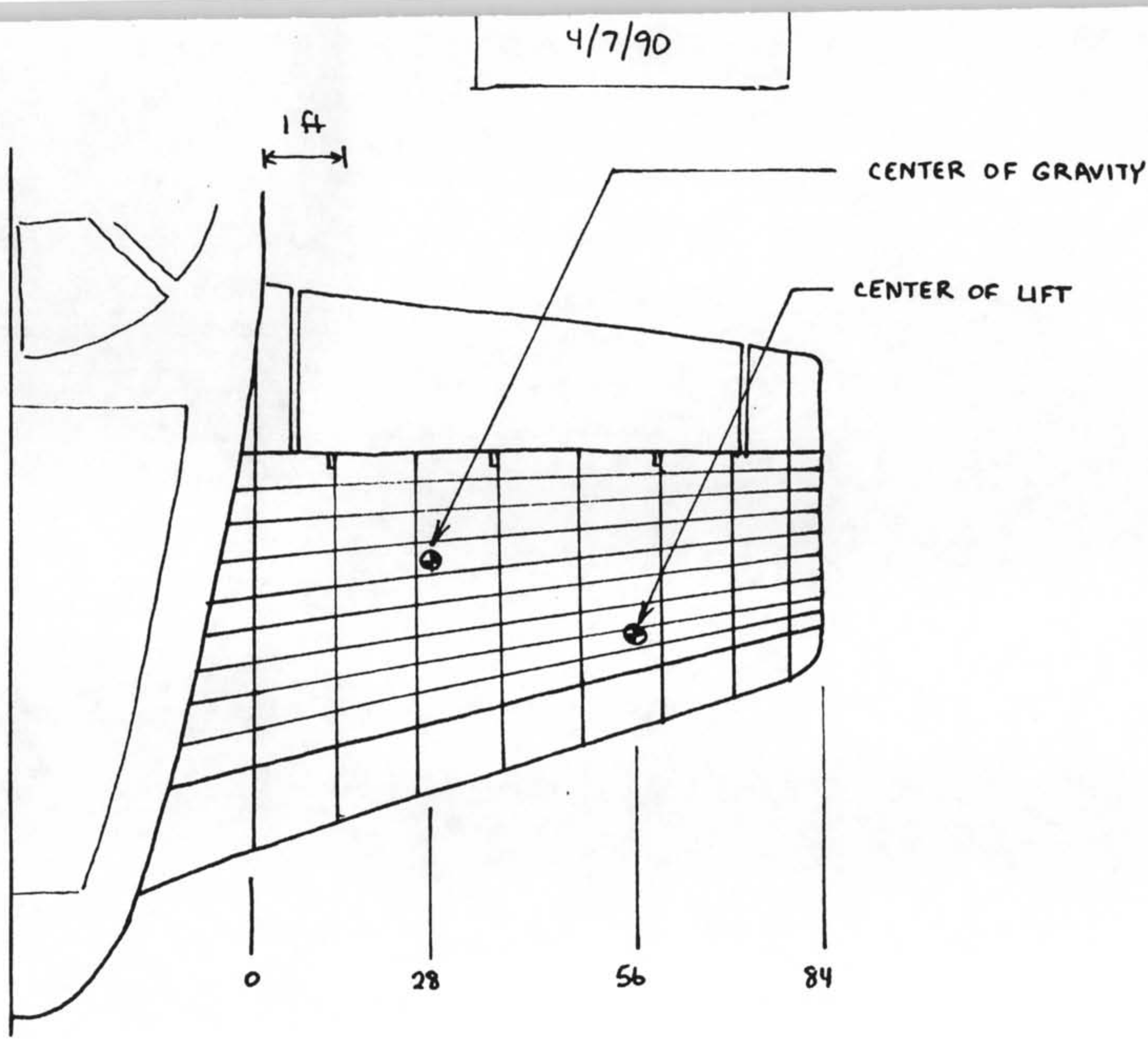

Figure 6.7. Canard Layout.

6.3 Vertical Tail

Analysis of the vertical tail was also carried out in a similar manner as the wing and canard analysis. Bending stresses were calculated using a lift force of 1.5 times the maximum that it will be allowed to produce. The extra compressive stress due to the weight of the tail beyond that caused by bending was found to be only 12.4 psi. The total stresses were used to size stringers, skin, and spars, omitting the negligible drag forces. Shear flow analysis was done for this structure also, using a rectangular box and including taper effects. Rib sizing was also done according to the method outlined for the wing ribs. Table 6.3 gives sizing, actual and critical stresses, and safety factors for all the vertical tail components. Figure 6.8 shows a cross-section along with the shear flows produced on the skin and ribs by the given loads.

Table 6.3. Vertical Tail Sizing, Stresses, and Factors of Safety at Root.

stringers	:	0.158 in^2	ribs	:	0.04 in
skin	:	0.10 in	spars	:	0.10 in

Loading Type	Actual Stress (psi)	Critical Stress (psi)	Safety Factor
compression	10,180	17,500	1.72
tension	10,180	57,300	5.63
shear-skin	1,804	23,333	12.90
-spars	2,628	8,400	3.20
-ribs	9,803	17,902	1.83
bending	10,180	22,050	2.17

Shear in the structure produces a twist of 0.028°/ft decreased angle of attack, which results in a twist of 0.25° maximum at the tip.

Weight for the vertical tail is estimated to be 188 lb_f. A complete layout showing rib and stringer placement can be seen in Figure 6.9.

6.4 Engine Cowling and Pylon

Two loading cases for the engine pylons were analyzed in order to find maximum stresses in all situations. These cases were cruise, in which horizontal thrust and weight act, and vertical mode, in which vertical thrust and weight act. In deciding what kind and arrangements of components to use, the following issues were considered. The pylon must have a long, thin cross-section in order to minimize drag, it must have a very high moment of inertia around the vertical axis in order to counteract the very high cruise thrust force, spars must be wide enough or pylon

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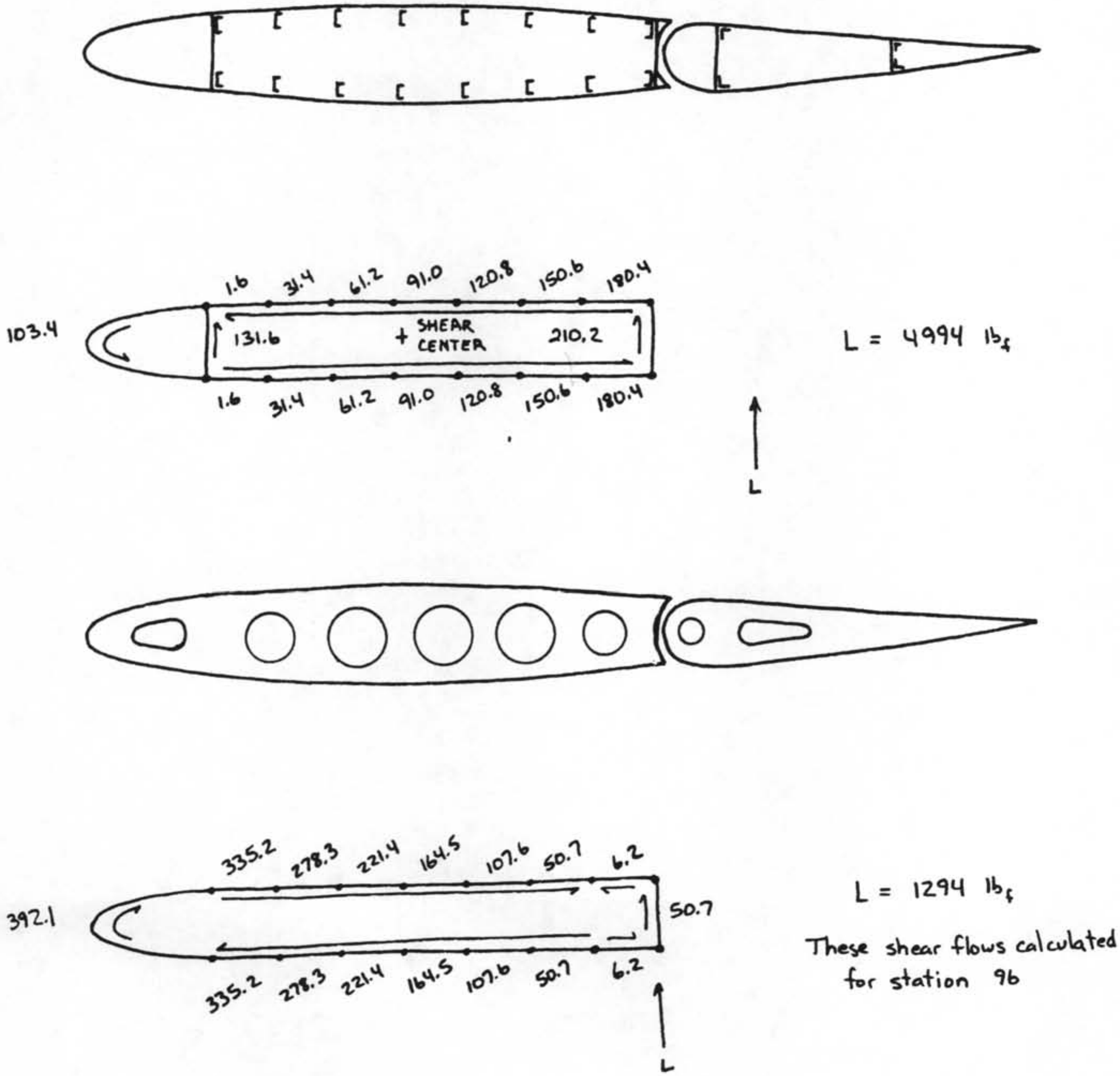

Figure 6.8. Cross-Section of Vertical Tail, Example Rib, and Induced Shear Flows.

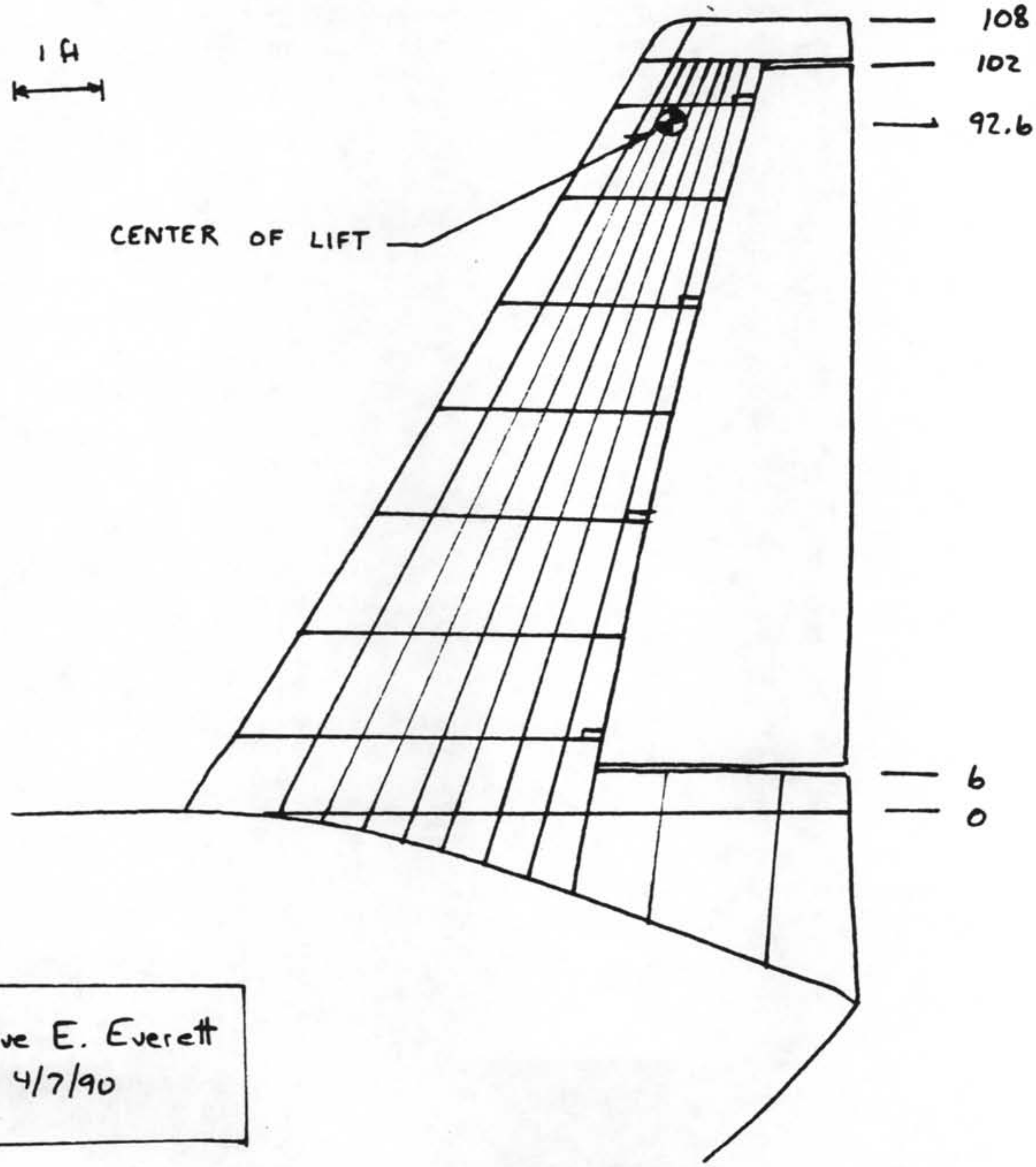

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Figure 6.9. Vertical Tail Layout.

must be thick enough so that the required ducting may pass through, and provision must be made to secure the engine at its specified attachment points. The pylon cross-section in Figure 6.10 was arranged to meet these requirements. The stringers on the skin were placed in order to provide structural integrity as well as attachment points for plates to which the forward and emergency ducts will be attached. Spars were placed at the stations where they could be attached to cowling bulkheads which in turn are secured to the engine at its attachment points. The stringer on the center of each spar was placed to not only increase the moment of inertia, but also to prohibit the front spar from buckling under the moment caused by the cruise thrust. A shear flow analysis was then carried out for both loading cases to ensure that safety factors were met. Sizing of pylon components, along with their actual and critical stresses, and safety factors, can be found in Table 6.4. Figure 6.10 shows the shear flows calculated for both loading cases also.

Table 6.4. Engine Pylon Sizing, Stresses, and Factors of Safety at Root.

stringers on spars :	$0.138\ in^2$	skin :	0.125 in
on skin :	$0.150\ in^2$	spars :	0.080 in

Loading Type		Actual Stress (psi)	Critical Stress (psi)	Safety Factor
compression	(VTOL case)	981	1,709	1.74
	(cruise case)	740	2,800	3.78
tension	(cruise case)	1,203	57,300	47.60
shear	(cruise case)-skin	940	2,279	2.42
	(VTOL case)-spars	968	3,733	3.86
bending	(VTOL case)-spars	981	2,450	2.50

Because the engines are attached almost directly to the spars in the pylon, the engine cowling only needed a minimal structural framework to support the skin protecting the engine. A detailed sketch of the pylon-cowling assembly is shown in Figure 6.11.

6.5 Landing Gear

The landing gear is a tricycle configuration. The nose gear was placed in order that the wheel well would not interfere with the forward duct of the lower part of the cockpit more than could be tolerated. This placement led to the longitudinal positioning of the main gear such that the maximum static loading percentages were close to recommended values. For the nose gear at 7 ft from the nose and the main gear at 28 ft from the nose, the maximum static loading was 19% (3,485 lb_f) and 88% (16,139 lb_f) respectively. Note that the maximum loading on the nose gear occurs with the most forward position of the center of gravity, while that on the main gear is from the most aft position.

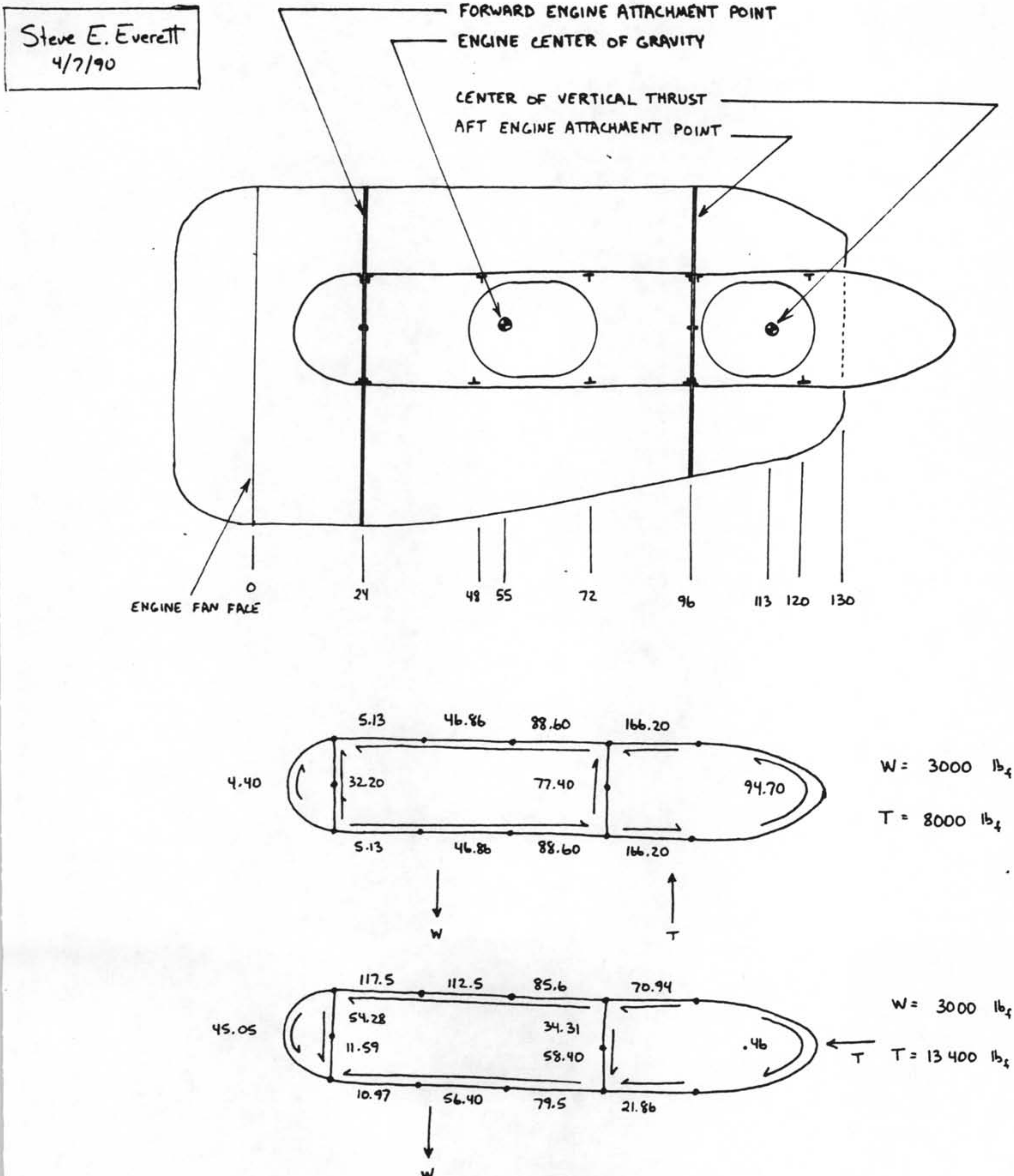

Figure 6.10. Pylon Cross-Section and Induced Shear Flows for Two Loading Cases.

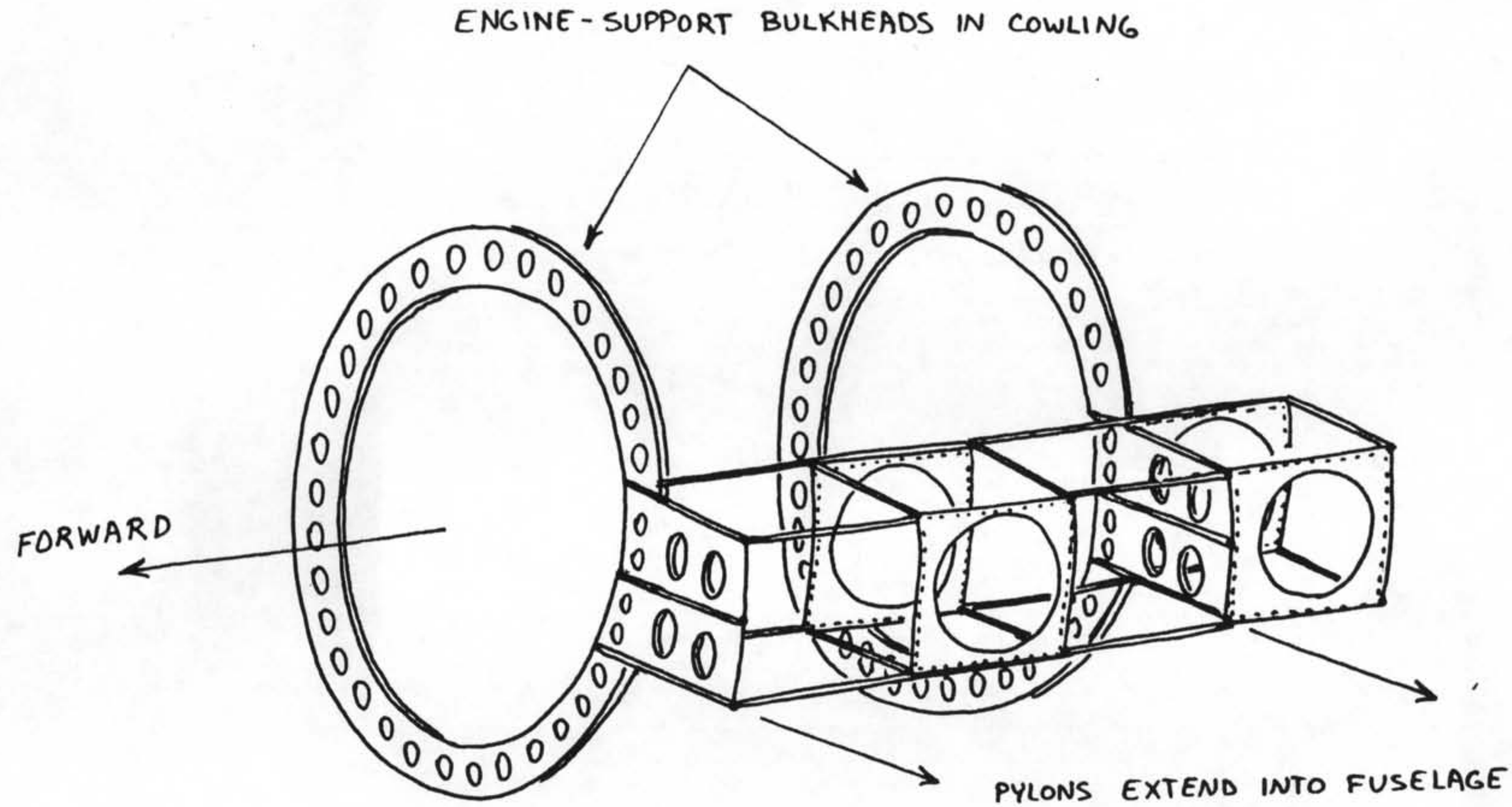

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Figure 6.11. Pylon and Engine Cowling Assembly.

It was decided to use two tires per gear in order to lessen wear and improve safety in case of a blowout in one. In order that the nose wheels would not occupy too much room when stowed, relatively small 12 in. diameter tires were chosen. Tires with diameters of 28 in. were chosen for the main gear so that both sets could be folded inward toward the center of the aircraft.

The main gear was then placed laterally on the aircraft so that the turnover angle, i.e., the angle between the horizontal and the plane connecting the nose gear, main gear, and center of gravity, was less than 60°. At a placement of the main gear of 5 ft from the center-line, this angle was 59°. With this positioning, in order for the aircraft to pivot around its wingtip while taxiing, the nose gear must be turned at 35°.

Once the positioning of the gear was completed, stick figures were drawn to represent the stowed and deployed configurations. It was also made possible for these arrangements to deflect upon landing. It is assumed that a civilian aircraft will touch down at a vertical velocity not exceeding 10 ft/sec under normal conditions. Oleo struts are used in the assembly to absorb the kinetic energy not taken in by the tire deflection. The folded, deployed, and deflected configurations for the nose gear are shown in Figure 6.12 and for the main gear in Figure 6.13. For the deflected geometry, the nose wheels have deflected 2.7 in. and the remaining energy is absorbed by an oleo strut deflection of 4.9 in. The resulting total vertical travel is 7.6 in. and forward travel is 7.0 in. In the same way, the rear tires deflect 6.3 in., while their supporting struts deflect about 1 in., i.e., most of the energy is absorbed by the tires. The total vertical travel is 8 in. while the outward travel is 4 in.

The plate attached to the hub of the main gear and the fuselage is a section of the outer skin which folds into a clean surface on the bottom of the aircraft. This piece of metal was left attached to the main gear when deployed to help protect the rubber tires from the hot flow being directed downward in that vicinity in the vertical mode. A metallic brush or cloth can also be hung on the bottom of this plate to protect the remaining exposed area of the tire without being damaged extensively by the ground.

6.6 Fuselage

The fuselage was the final main area analyzed, since stresses on it depended on the stresses on all the other lifting surfaces. It was necessary in its design to ensure that it could not only support the hoop stresses from pressurization but also withstand the compressive forces due to bending without buckling.

In determining what the bulkhead minimum spacing would be, a cross-sectional area of 0.64 in^2 was chosen. The force on this area at the top and bottom of the fuselage plus the unknown distance of skin of thickness 0.125 in. between each bulkhead had to equal the pressure differential of 7.8 psi times the projected area over the cross-section of the fuselage. Although the areas were chosen arbitrarily, the pressure differential was given to this group by Configurations. The maximum distance they

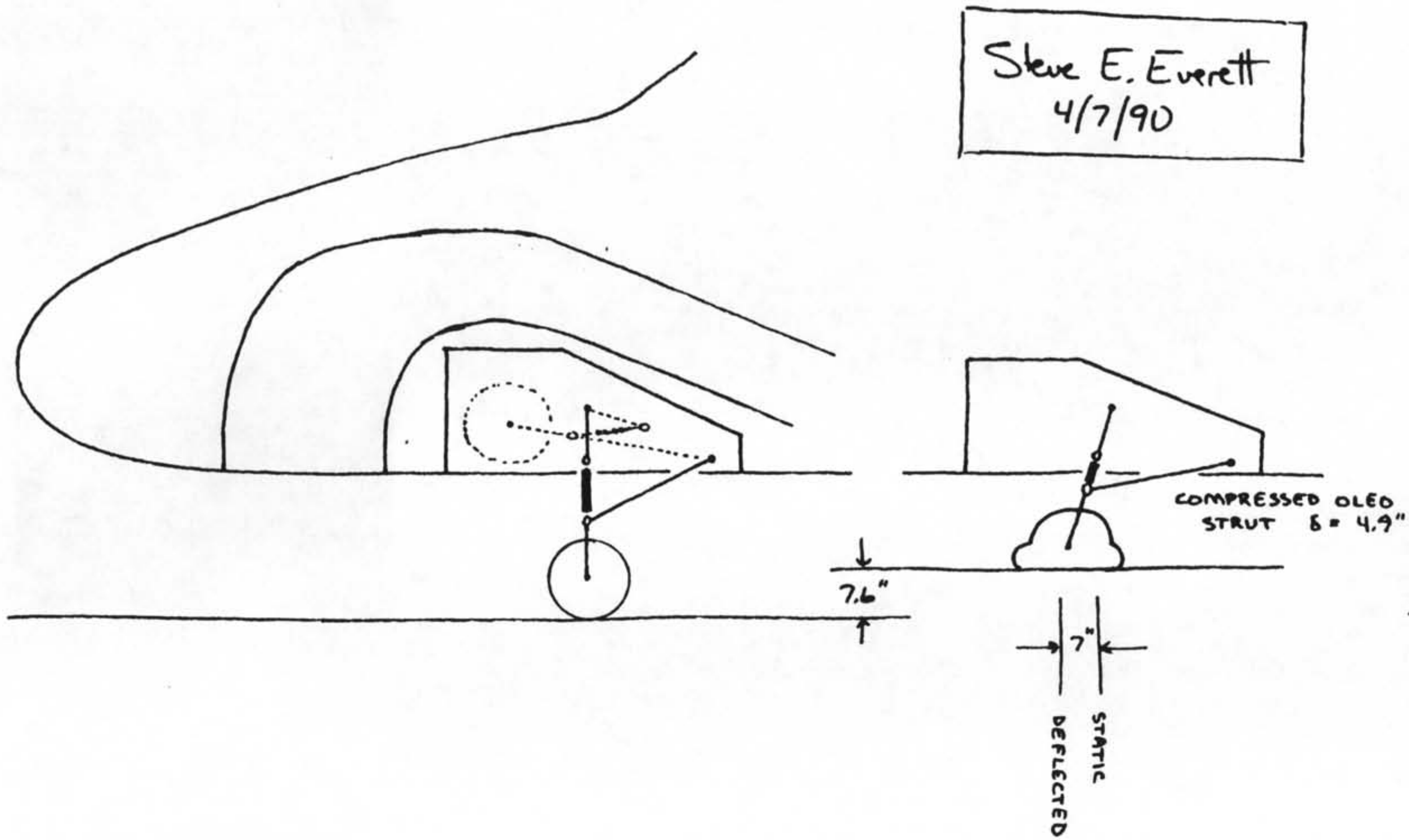

Figure 6.12. Folded, Deployed, and Deflected Configurations of Nose Gear.

could be placed apart was 55 in. in order to maintain a safety factor of 1.5 on the yield stress of the material. For reasons of convenience as attachment points, most were placed at about 21 in. apart, yielding a 4.7 factor of safety.

It was then necessary to choose the stringer spacing around the fuselage. For the three major loading cases - static, vertical flight, and cruise - the highest moment is placed on the fuselage in cruise under the highest load factors. Using the FAR recommended load factor of 3.0 for the wing's lifting force on the fuselage and assuming the canard supports about 20% of the weight, the moment diagram in Figure 6.14 was constructed. The maximum moment on the fuselage is 42,364 ft-lb_f at a distance of 19 ft from the nose. Assuming 16 stringers equally spaced around the fuselage and 0.125 in. thick skin, a stress was found in the upper part of the fuselage with $\sigma = My/I$. This stress added to the compressive stress due on the fuselage due to drag will give a worst case. Note that the stress due to pressurization was not included since it will lessen the compressive stress. A maximum stress of 1,129 psi compared to the critical buckling stress of 2,785 psi was at a safety factor of 2.5. The maximum tensile stress on the bottom was found by using the bending stress again and adding the pressure differential times the projected cross-sectional area of the fuselage. This stress was 1,418 psi as compared with the material strength of 57,300 psi.

Since the duct which runs to the nose leaves very little room for structure under the floor, it was decided to enlarge one of the holes in the bulkhead so that the duct could be passed through it. An example of this design, used in bulkheads 8 through 14, can be seen in Figure 6.15. In this way, the cross-sectional area of the bulkhead was not changed and the duct is supported well.

To compensate for the structural weakening caused by cutouts for the door, windows, and duct exits, the area of skin around them has been thickened to twice normal. A possible assembly configuration for the windows is seen in Figure 6.16.

6.7 Structural Integration

To firmly affix the lifting surfaces and engine pylons to the fuselage, they must be attached to bulkheads or other major structural components. Since only the maximum allowable bulkhead spacing was determined, these supports could be placed at stations where they could be used as attachment points. The arrangement of stringers and bulkheads seen in Figure 6.17 shows the way in which the wings, canards, vertical tail, and engine pylons may be secured.

In order to ensure the attachment of the canards, their rear spar extends completely through the nose of the aircraft. It is affixed to bulkhead 5 and also to the nose gear well and a structural ring around the duct. The forward spar ends at the surface, but is attached to bulkhead 3 at both sides. Figure 6.18 shows details of this arrangement.

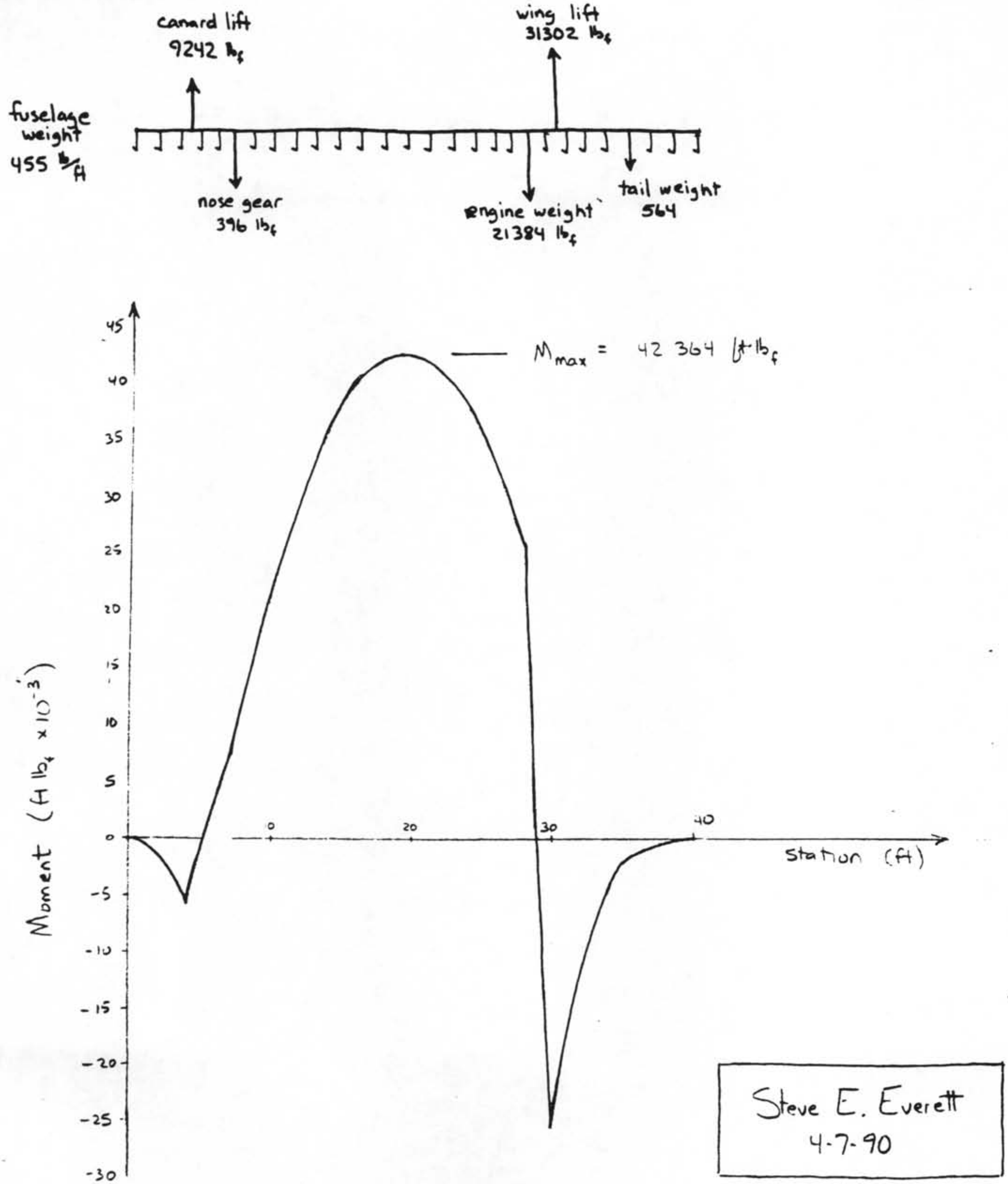

Figure 6.14. Fuselage Moment Distribution Under a Load Factor of 3.0.

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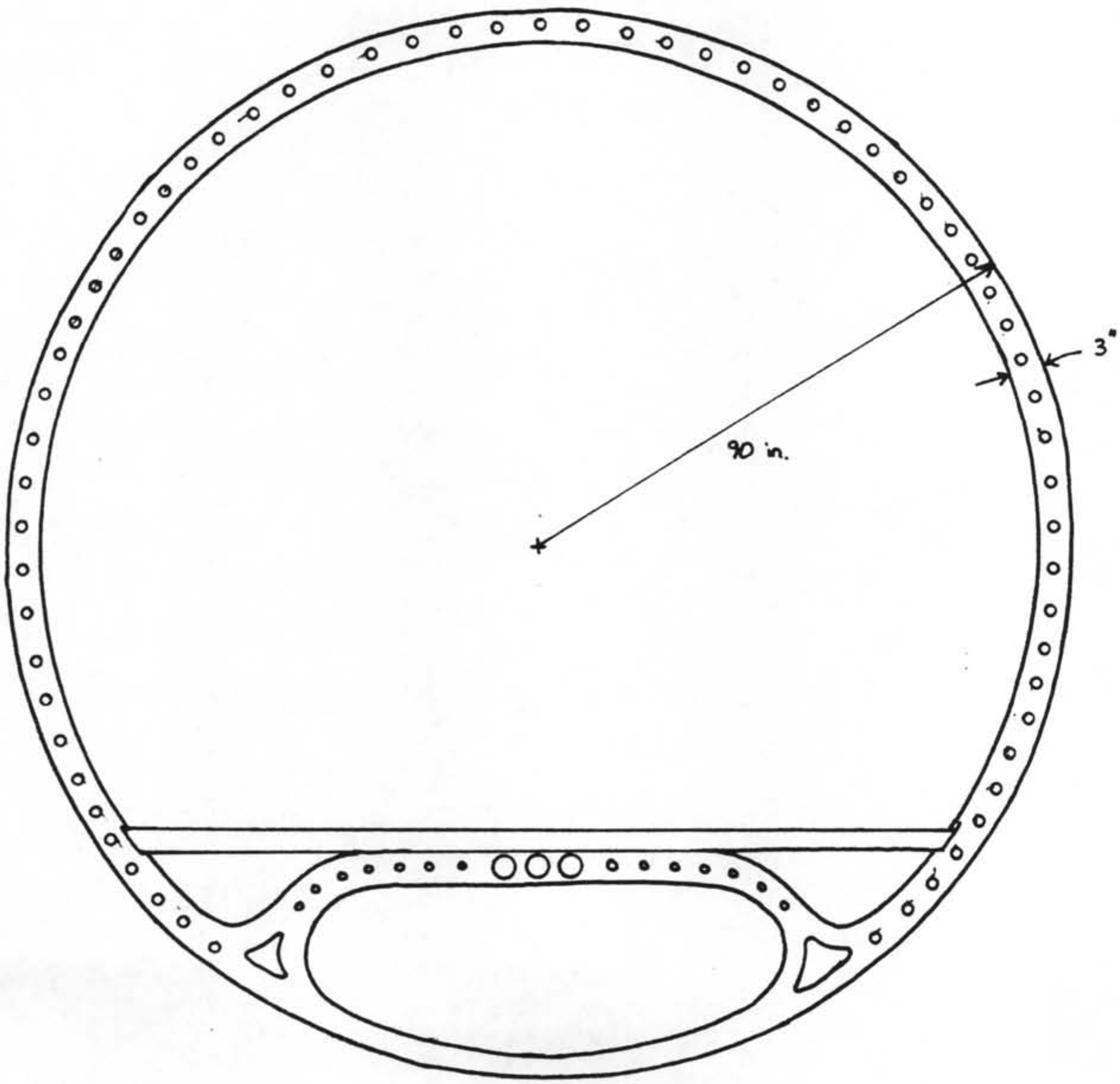
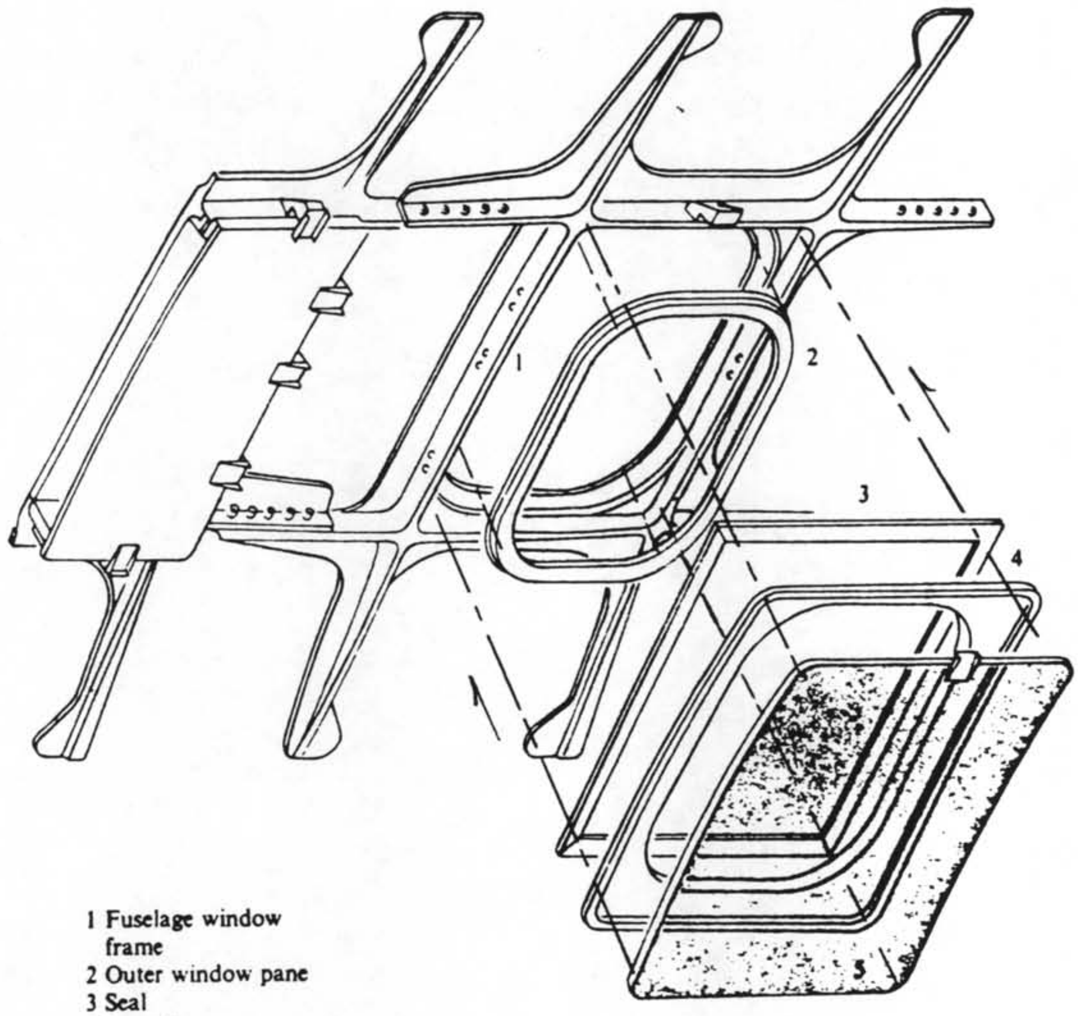


Figure 6.15. Typical Bulkhead.



CONSTRUCTION OF PRESSURIZED CABIN WINDOWS

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* SOURCE: THE LORE OF FLIGHT

DESIGN TEAM I AE 429

APRIL 7, 1990

Figure 6.16. Cabin Window Construction.

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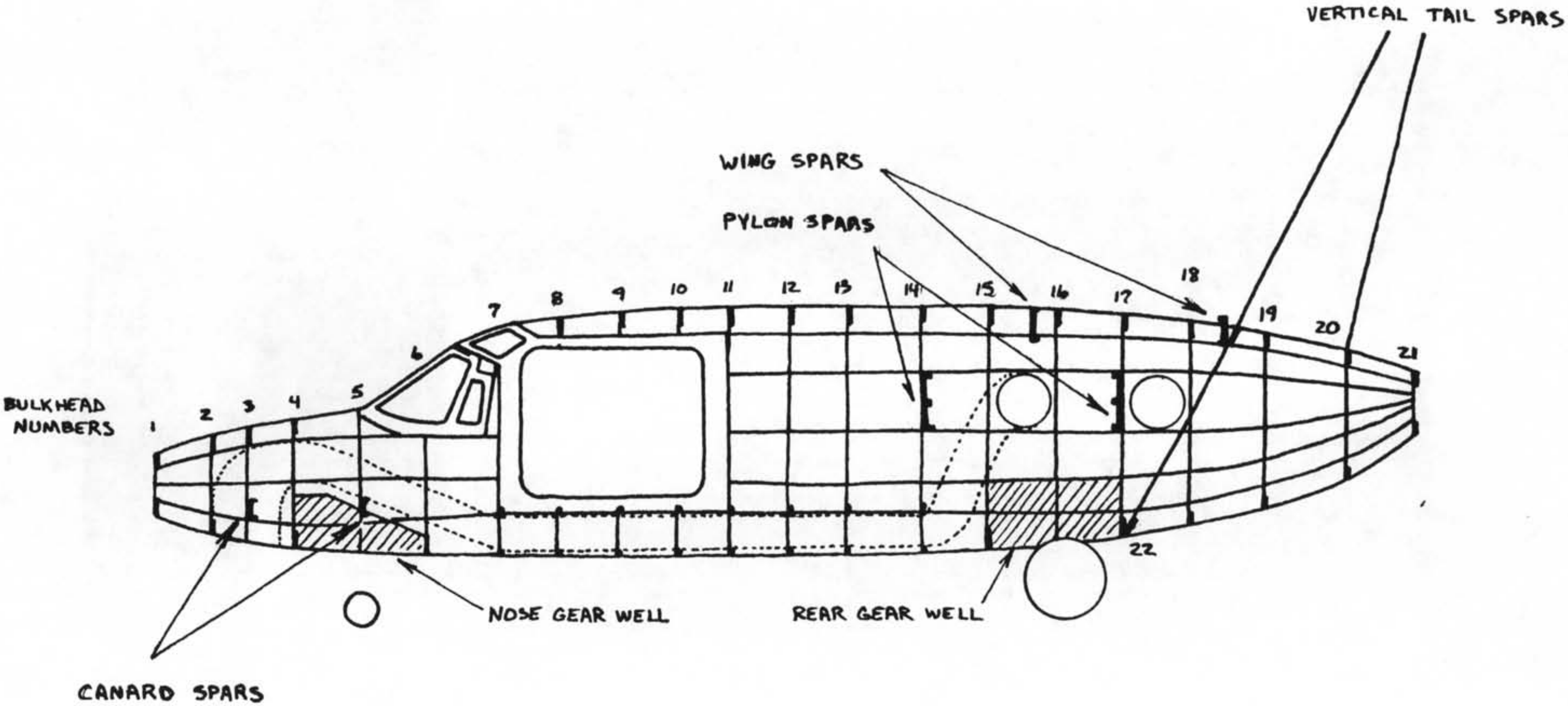

Figure 6.17. Fuselage Layout.

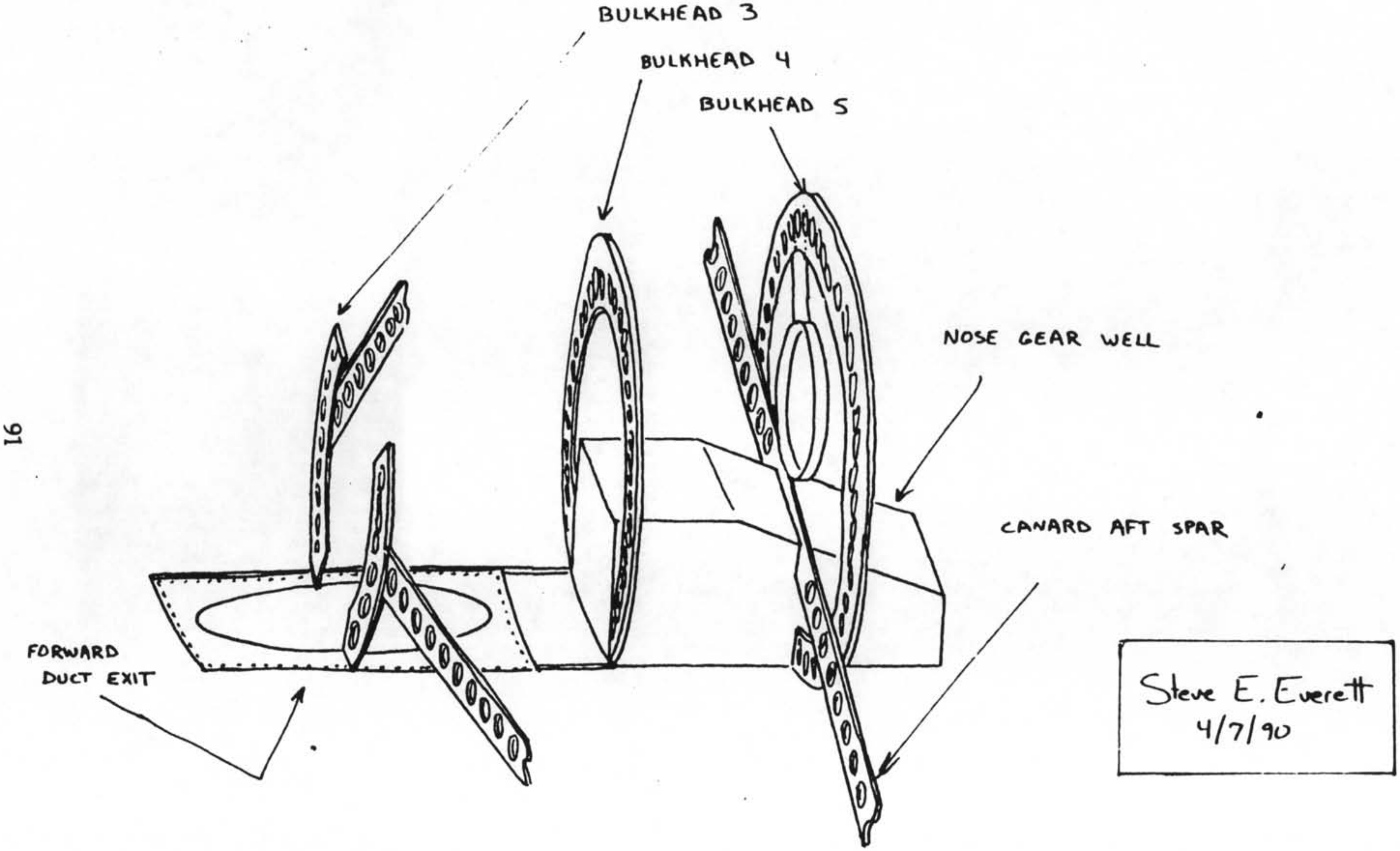

Figure 6.18. Canard Attachment Assembly.

Both wing spars extend through the aircraft and are thicker at the center. Since bulkheads could not be placed to coincide with these spars, the three stringers passing through this spar have been strengthened from bulkhead 15 to 19. The wing rear spar has also been attached to the vertical tail forward spar. This spar extends from the tip of the tail all the way to the bottom of the aircraft and is supported by a special tilted bulkhead 22. The vertical tail rear spar is attached to bulkhead 20. The spars in the engine pylon both extend through the fuselage also and are attached to bulkheads 14 and 17. A diagram of the entire assembly of the pylon, wing and tail spars can be seen in Figure 6.19. Whenever possible, a structural ring around the duct was added to unify the entire structure and to support the duct.

Figure 6.20 shows an approximation of how the entire integrated structure would appear without skin or systems added.

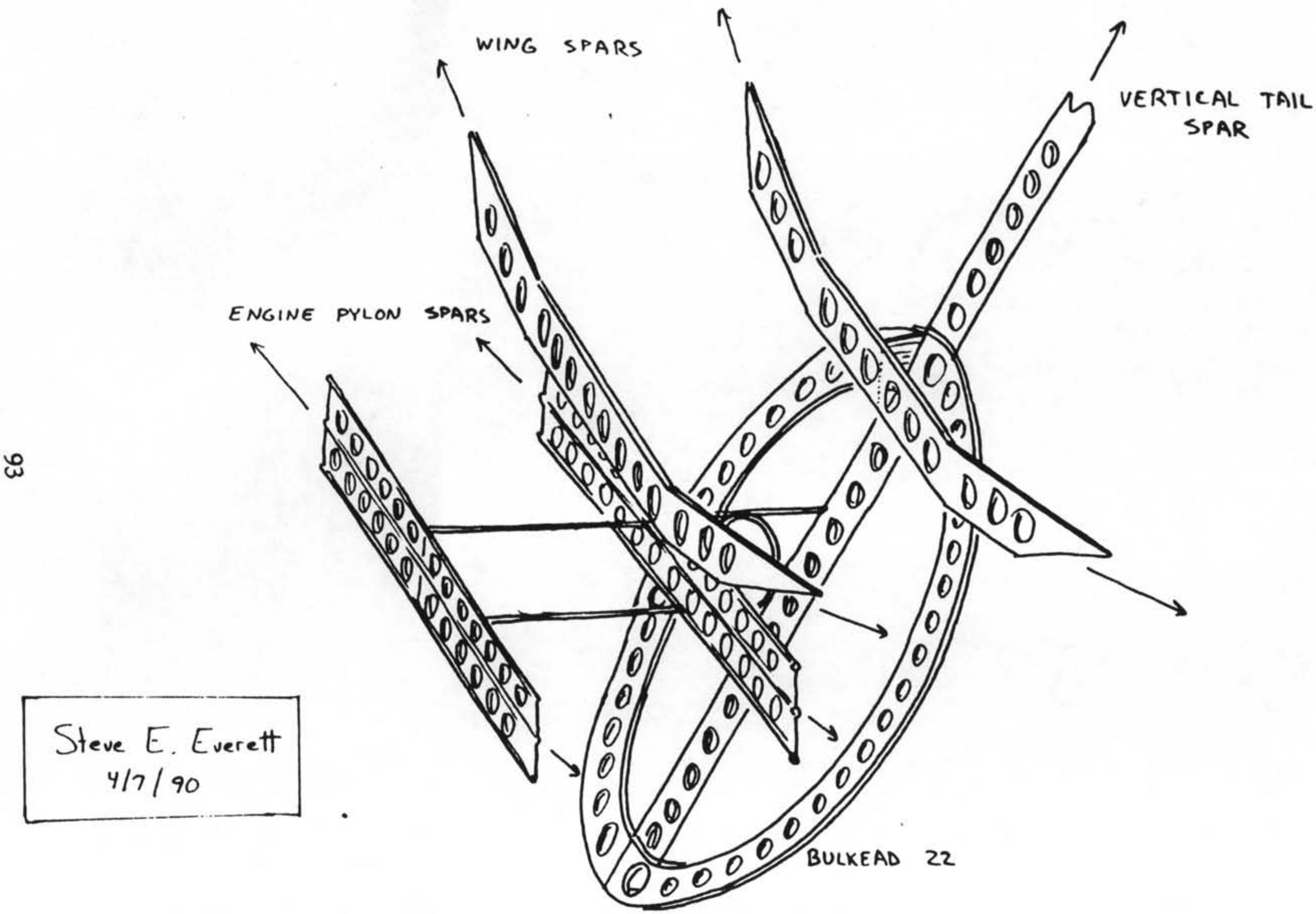

Figure 6.19. Wing and Vertical Tail Attachment Assembly.

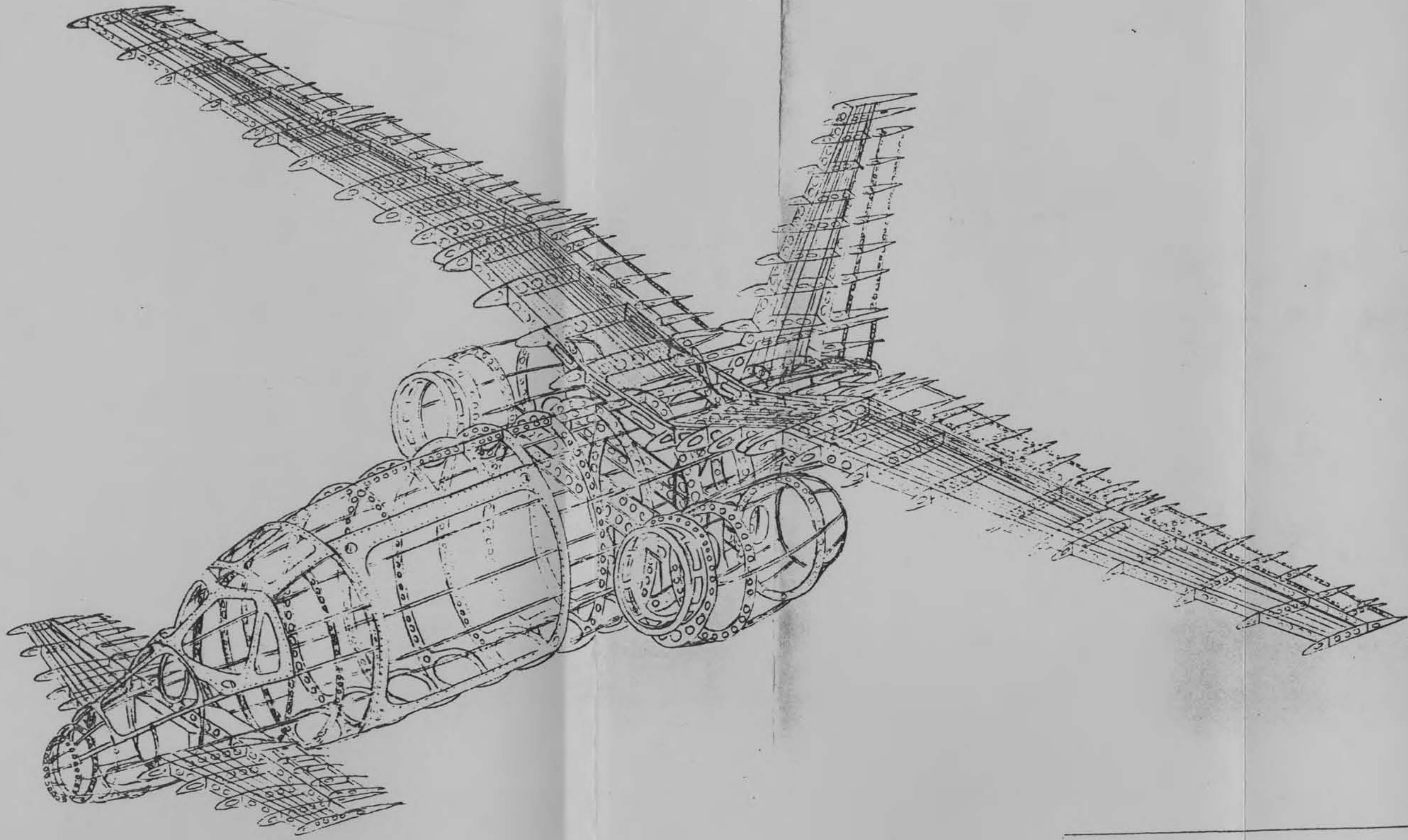

Figure 6.20. Complete Integrated Structural Layout.

AE 429
Structural Layout - Artist's conception
Steve E. Everett
4/1/90

Chapter 7
Future Refinements

7.1 Configurations

Future considerations of the Configurations Group will focus on a more involved design of the systems in the aircraft. This will require a more in depth analysis of engine losses and a detailed definition of required system performance.

The design of the interior of the aircraft will also be resolved in greater detail. This would involve maximizing space efficiency and comfort. Also, as the design is refined, the performance data will be updated to more accurately show the capabilities of the aircraft.

7.2 Propulsions

Future considerations will go to cleaning up these systems and integrating them over the full range of the mission (start to shutdown). The integration of the systems will include a possible combination of the deicing and puffer systems and of an auxiliary power generator and starter. Specifying the actual control mechanisms for the puffer and nozzle controls would also be done in the another iteration. These calculations would include the correct variations in vertical thrust and horizontal thrust for transition. Also, the inlet areas would be corrected for the added work needed by the engine for cruise. Contouring inlet diffuser would also be examined.

7.3 Aerodynamics

In the future development of this design, it would be highly desirable to obtain good quality modeling facilities in order to perform wind tunnel tests and obtain more accurate drag estimates. Barring this, a good computations fluid dynamics program would be desirable to address this modeling. In addition, further attention should be given to such areas as mission profile, stability mode shapes, and performance.

Also, further development of this design would require analysis of control forces and gearing for all aerodynamic control systems. Since this aircraft will have either hydraulic or electric actuators, any stick force required can be achieved. It is simply a matter of designing the control system to meet the required force.

7.4 Structures

In future development, it will be necessary to study the landing gear structure in more detail. Given landing and take off accelerations, it should be possible to size the struts on the nose and landing gear. The types of tires being used should also be researched more thoroughly. In order to get more accurate estimates of the stresses in the box beams, analysis should be done using the actual shapes of the lifting surfaces and their stringers. It should also be possible to do a more detailed analysis in specific areas of the fuselage. By gaining a better estimate of control surface forces, it would be possible to reduce rib thickness and design detailed methods of control surface attachments.

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