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PRESENTATION OF STRUCTURAL COMPONENT DESIGNS FOR THE FAMILY OF COMMUTER AIRPLANES

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PREPARED FOR: NASA GRANT NGT-~~7001~~ 80001

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APRIL 20, 1987

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LIST OF SYMBOLS

Symbol	Definition	Dimension
A	Aspect ratio	-----
b	Wing span	ft
b_t	Tire width	ft
c	Wing chord	ft
$\bar{c}$	Wing mean geometric chord	ft
D_t	Tire diameter	ft
m.g.c.	Wing mean geometric chord	ft
S	Wing area	ft^2
t/c	Thickness ratio	-----

Greek Symbols

λ	Taper ratio	-----
Λ	Sweep angle	deg
Γ	Dihedral angle	deg

Subscripts

c/2	Semi-chord
c/4	Quarter chord
E	Elevator
L.E.	Leading edge
r	Root or rudder
V	Vertical tail

Acronyms

B.L.	Buttock line
F.S.	Fuselage station, or Front spar
PAX	Passenger
R.S.	Rear spar
W.L.	Waterline

1. INTRODUCTION

This is the third report completed on the family of commuter airplanes. Reference 1 contains the preliminary Class I configuration development of the commuter family. References 2, 3, and 4 contain design studies determining the feasibility (or in some cases, the impracticality) of commonality.

The purpose of this report is to present the implementation of structural commonality in the family of commuter airplanes. One of the main goals of the design project is implementation of structural commonality to as high a degree as possible. In this report the structural layouts of those parts of the airplanes in which commonality is possible with all members of the family will be presented. The following airplane sections, which are common on all of the airplanes in the family, will be presented:

Common Nose Cone Design (Chapter 2)

Common Wing Torque Box Design (Chapter 3)

Common Tail Cone Design (Chapter 4)

A proposed production and manufacturing breakdown will be presented in Chapter 5. In Chapter 6 the advantages and disadvantages of implementing structural commonality and recommendations for further work will be discussed.

2. LAYOUT OF THE COMMON NOSE CONE

This section presents the layout of the common nose cone for the commuter family. Included in the common nose cone are the cockpit, nose gear, front pressure bulkhead, and the forward portion of the passenger cabin.

2.1 Structural Layout of the Common Nose Cone

Figure 2.1 presents the structural layout of the common nose cone, which runs from F.S. 62 at the nose to F.S. 346 at the aft end of the main passenger door. The front pressure bulkhead is located at F.S. 126 and the common nose gear attachment point is at F.S. 226. Based on typical values for frame spacings from Reference 5, a frame spacing of 20 inches is chosen.

2.2 Layout of the Common Nose Gear

Since the landing gear is one area in which a significant amount of commonality is to be implemented, the nose gear is sized according to many of the Class II design features of the main landing gear, which are sized in Section 3.2 from methods of Reference 6. The nose gear tire size is the same as that of the main gear, 18 x 5.5 inches. The nose gear dimensions, which are the same as for the main gear, are presented in Table 2.1. Although a slight weight penalty is incurred, the nose gear is sized to the main gear specifically for the purpose of commonality.

The nose gear attachment point is much higher than that for the main gear since the main gear attachment is actually below the fuselage. Thus, a longer strut length of 62.75 inches is needed for the nose gear. The only other difference between the main and nose gear is the fact that the nose gear is a twin wheel configuration while the main gear is a twin tandem bogey configuration. The nose gear doors are sized according to the required clearances of the nose gear layout and are shown in Figures 2.2, 2.3, and 2.4.

Brake spacing for the nose gear arrangement was determined from methods in Reference 7. The allotted room for the brakes is given in Table 2.1.

Similar spacing for the brakes is designed into the main gear bogey also. The purpose of this is to allow for similar design of the brake pads and actuation system.

Table 2.1 Landing Gear Sizing Data

tire diameter = 18 in
tire width = 5.5 in
strut length = 62.75 in
strut diameter = 4.7 in
shock absorber length = 17.3 in
brake width = 2.0 in
clearance between brake and strut = 1.5 in
top clearance = 2.5 in
side clearance = 2.5 in

A : ATTENDANT SEAT

E : ENTRANCE

SD: SIDE DOOR

G : NOSE GEAR ATTACH POINT

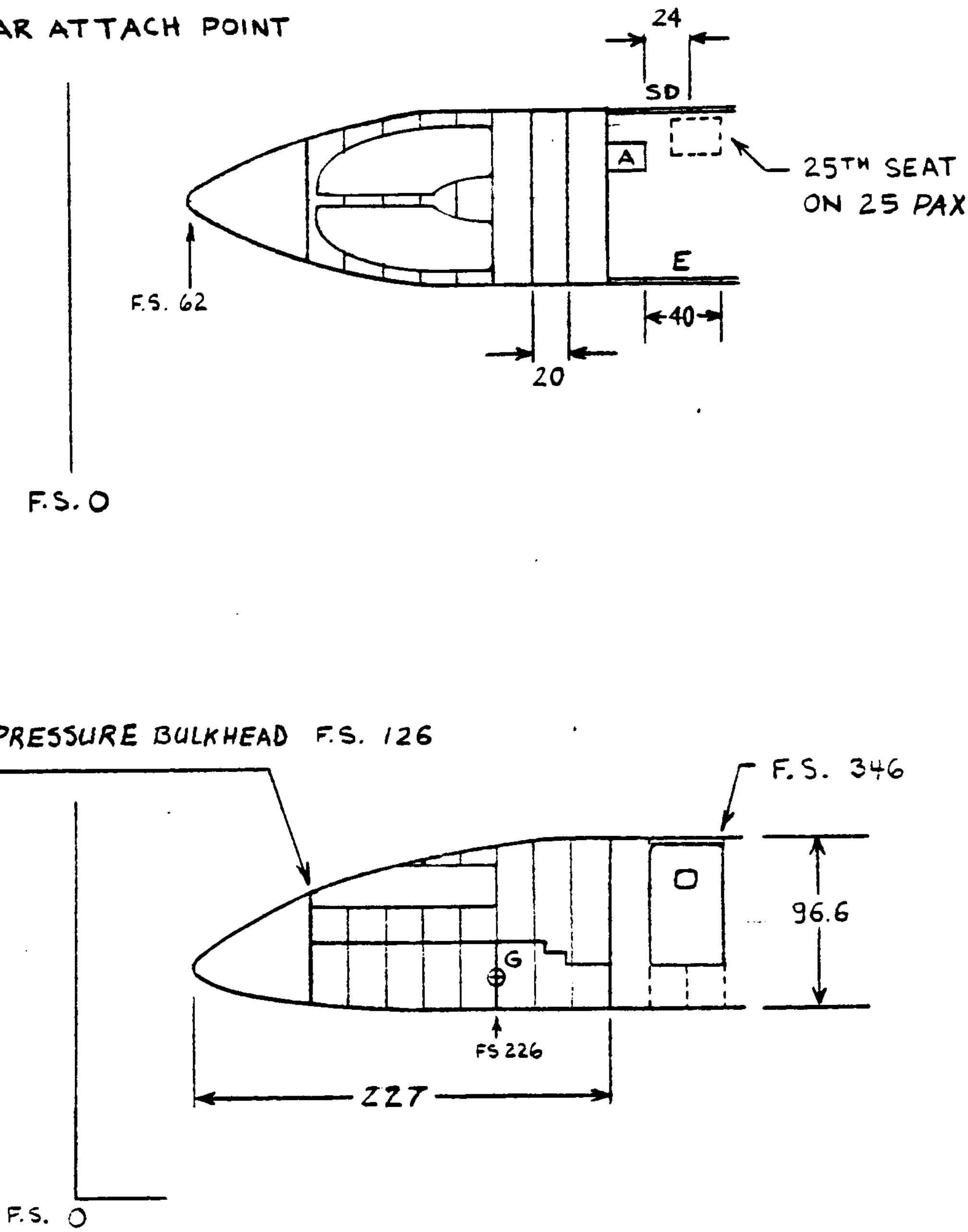

Figure 2.1 - COMMON NOSE CONE

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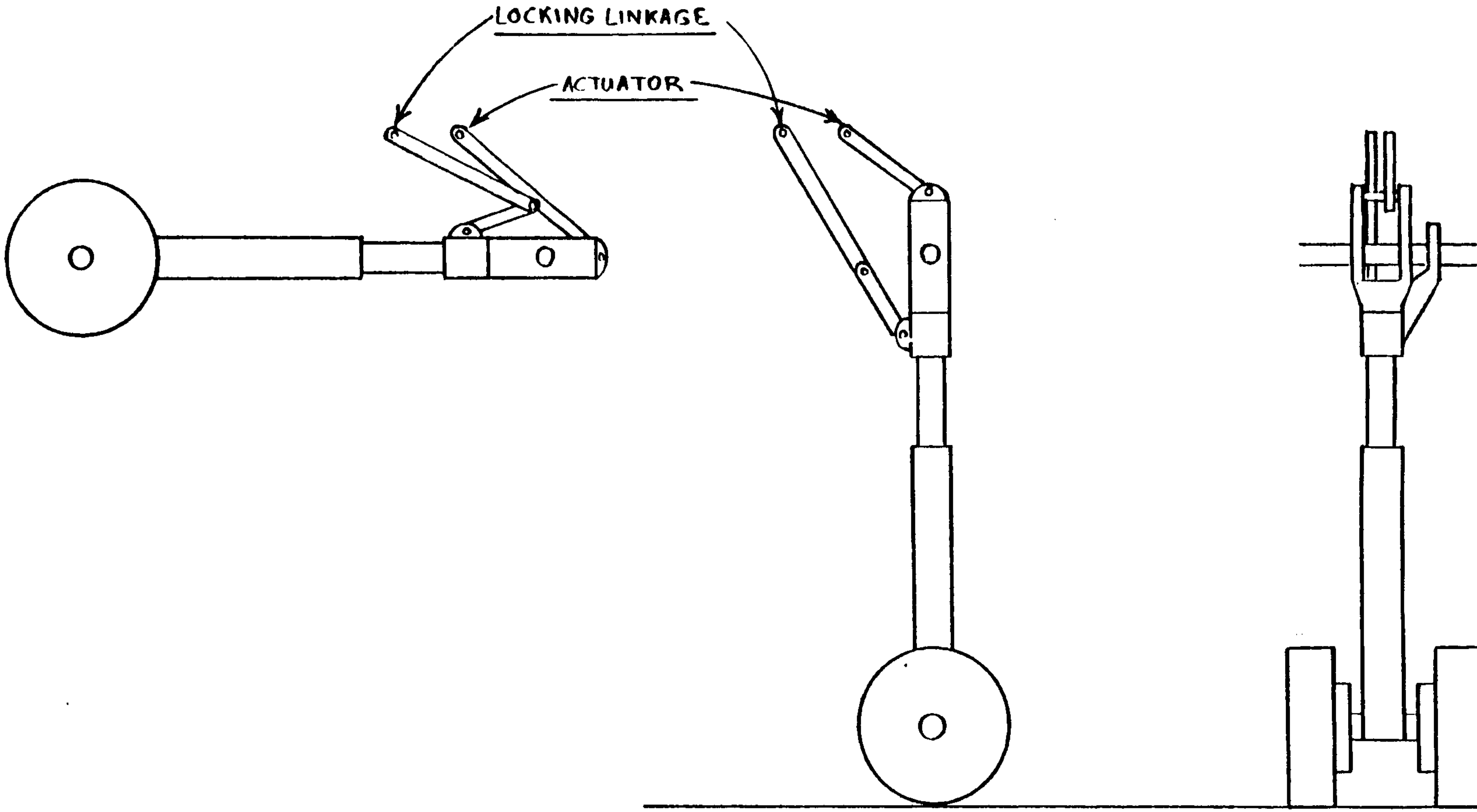

Figure 2.2 - NOSE GEAR RETRACTION KINEMATICS

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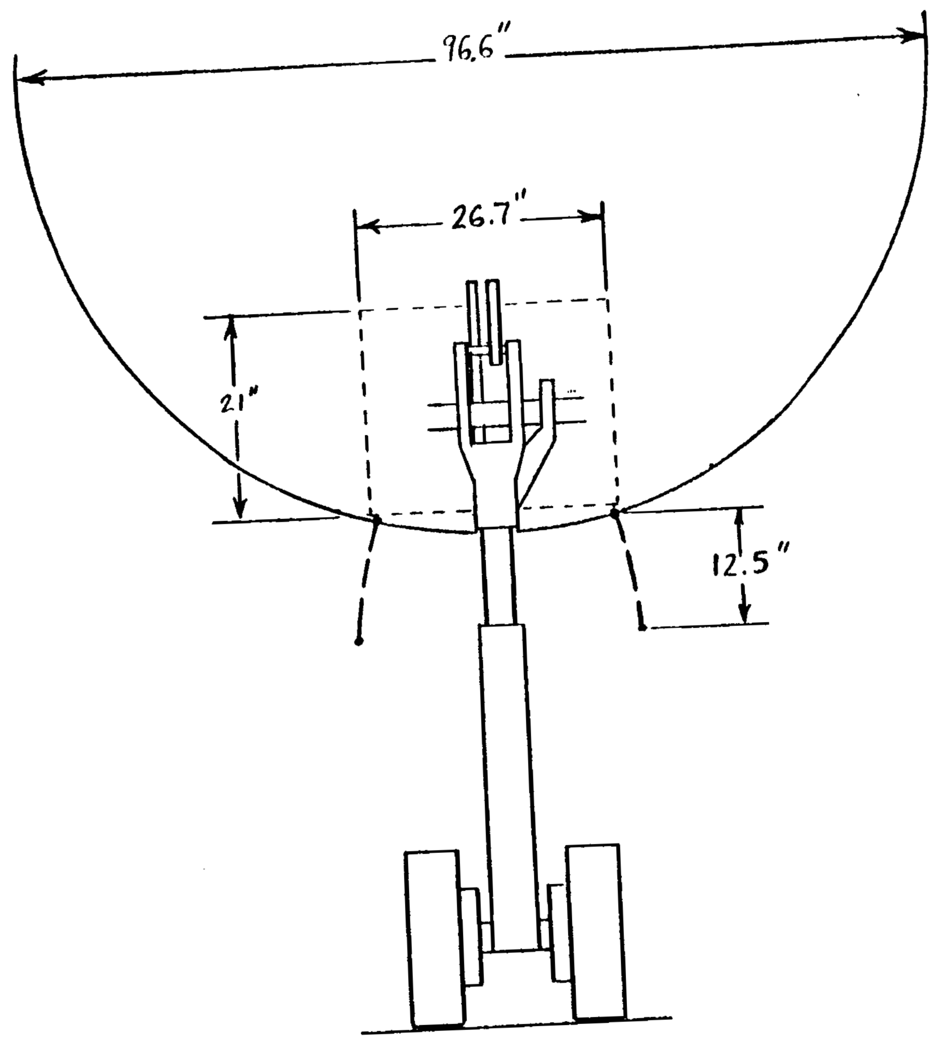

Figure 2.3 - NOSE GEAR STOWAGE (FRONT VIEW)

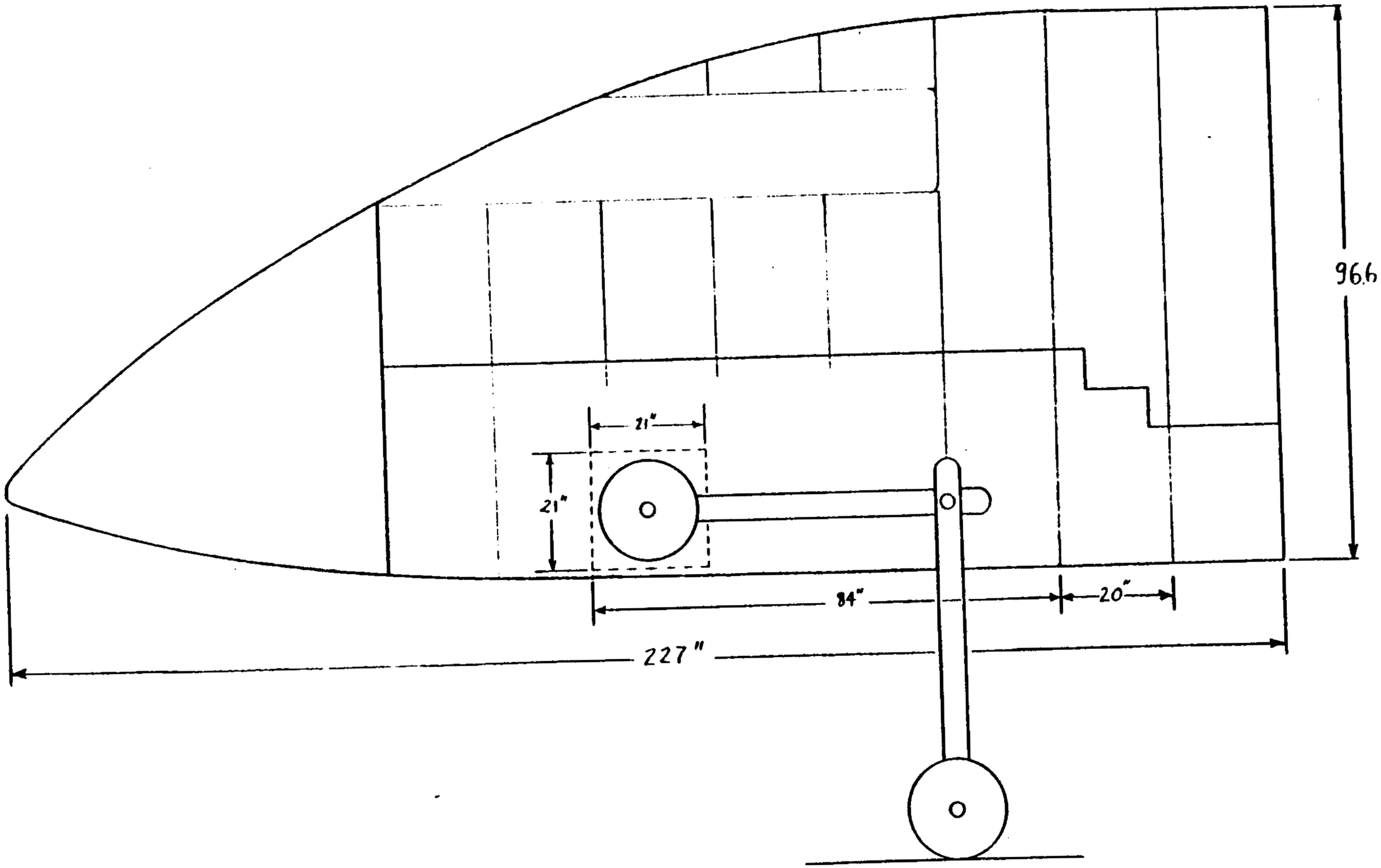

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Figure 2.4 Nose Gear Stowage (side view)

3. LAYOUT OF THE COMMON WING

This section presents the layout of the common torque box, and how this torque box is integrated into each of the wings. The commmon main langing gear design is also presented here with its retraction scheme and wing box integration.

3.1 Structural Layout of the Common Wing Torque Box

The wing spar area required for the critical loading condition (at design dive speed) for the 50 passenger airplane was determined in Reference 4 to be 10.8 in^2. It was also determined that a possible solution for arranging this area is as shown in Figure 3.1. This allows for a standard 4 x 3.5 x 5/8 inch angle to be used for both the spar caps and stringers in the wing box. Also shown in Figure 3.1 is the spacing of the wing spars. The front spar is located at 20% chord, and the rear spar at 70% chord. By placing the spar caps and stringers as shown, an equal frame spacing of 22 inches may be used where the wing torque box intersects the fuselage.

3.2 Layout of the Main Landing Gear

Using the Class II methods from Reference 6, the main landing gear dimensions were sized to the 50 passenger airplane. These dimensions, which will be used on all of the airplanes in the commuter family, are shown in Table 3.1. Except for the strut length, the data in Table 3.1 will apply to both the main gear and the nose gear. The main landing gear brakes were sized according to methods in Reference 7.

The Class II main landing gear layout is shown in Figure 3.3. The main gear disposition is shown such that the outer edge of the outboard tire is 90 inches from the fuselage centerline. This distance was determined from the lateral tip-over criterion in

Reference 1. The main gear doors are sized according to the retraction scheme and are shown in Figure 3.3. The door sizes are 23 x 47 inches and 33 x 47 inches for the inboard and outboard doors respectively. This retraction scheme and gear layout will be used on all members of the commuter family. Figure 3.2 shows the main gear retraction kinematics.

Table 3.1 Landing Gear Sizing Data

tire diameter	= 18 in
tire width	= 5.5 in
strut length	= 43.25 in
strut diameter	= 4.7 in
shock absorber length	= 17.3 in
brake width	= 2.0 in
clearance between brake and strut	= 1.5 in
top clearance	= 2.5 in
side clearance	= 2.5 in

3.3 Wing Box / Wing Integration

The structural layout of the wing for the single-body airplanes is shown in Figure 3.4. From Reference 5 it is determined that a wing rib spacing of 25 inches is sufficient. Wing layouts for the twin body airplanes are basically the same as the single body layout, except that a zero degree sweep center section is needed between the two fuselages. This is shown in Figure 3.5. For the center sections on the twin fuselage airplanes, the torque box will remain the same as at the wing root.

Figures 3.4 and 3.5 show the top view of the common torque box for all of the airplanes. The landing gear is shown attached to a rib located 79 inches away from the fuselage centerline. The entire wing torque box will be common on all of the airplanes in the commuter family, except that on the twin-body configurations the torque box in the center section is an unswept arrangement.

The landing gear attachment point is common for all of the airplanes. The location of the retracted landing gear is shown in Figures 3.4 and 3.5. Note that a 7.5 ft^2 yehoudi is needed to provide adequate space for the retracted landing gear. The wing box and main landing gear integration will be common throughout the entire family. Wing geometry is contained in Table 3.2.

Table 3.2 Wing Geometry

$S = 592\ ft^2$	$t/c = .13$	$S_a = 6.25\ ft^2$
$b = 84.3\ ft$	$\lambda = .40$	$S_{sp} = 7.67\ ft^2$
$A = 12$	$\Lambda_{LE} = 15\ deg$	
$\bar{c} = 7.45\ ft$	$c_f/c = .30$	$c_{sp}/c = .10$

Twin-body wing centerpiece, $S = 590\ ft^2$

3.4 Wing Control Surfaces

3.4.1 Flaps

For generation of high values of maximum lift coefficient for the approach flight condition, it was decided to incorporate Fowler flaps on all of the airplanes in the family. the geometry in Table 3.3 was deemed necessary for the 50 passenger model and will be used on all airplanes in the interest of commonality. The flap system is shown in Figure 3.4.

Table 3.3 Flap Geometry

Model	25, 36, 50	75, 100
flap chord ratio	.30	.30
Inboard Span St.	.10	0
Outboard Span St.	.85	.89
Max. flap delfection	40 deg	40 deg

3.4.2 Lateral Control Devices

A 6.25 ft^2 aileron was placed at the .85-.97 semispan station of the wing. This area was not enough for lateral control, so two spoilers were added. The size of these spoilers is 3.8 ft^2, each with a chord ratio of 0.10. See Figure 3.4 for the layout of these control devices.

3.4.3 Fuel System Volume

Fuel volumes for the family of commuters are contained in Table 3.4. The required fuel volumes are sufficient to carry the necessary fuel to complete the mission requirements.

Table 3.4 Wing Fuel Volumes

Model	Volume ft^3	Fuel Available (lbs)
25	230	11,500
36	230	11,500
50	230	11,500
75	530 *	26,500
100	530 *	26,500

* (fuel necessary in wing centerpiece)

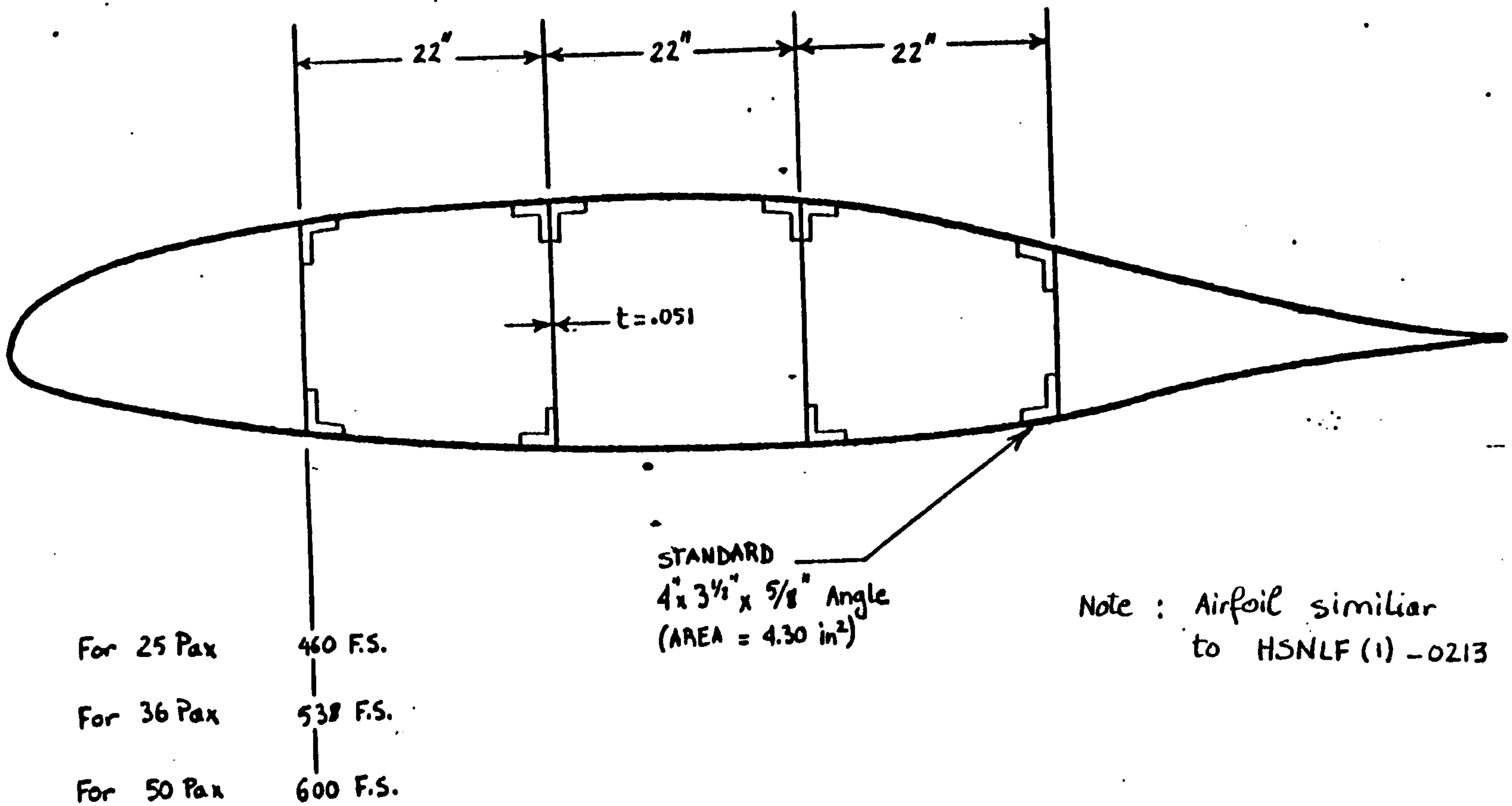

Figure 3.1 - Wing Cross Section

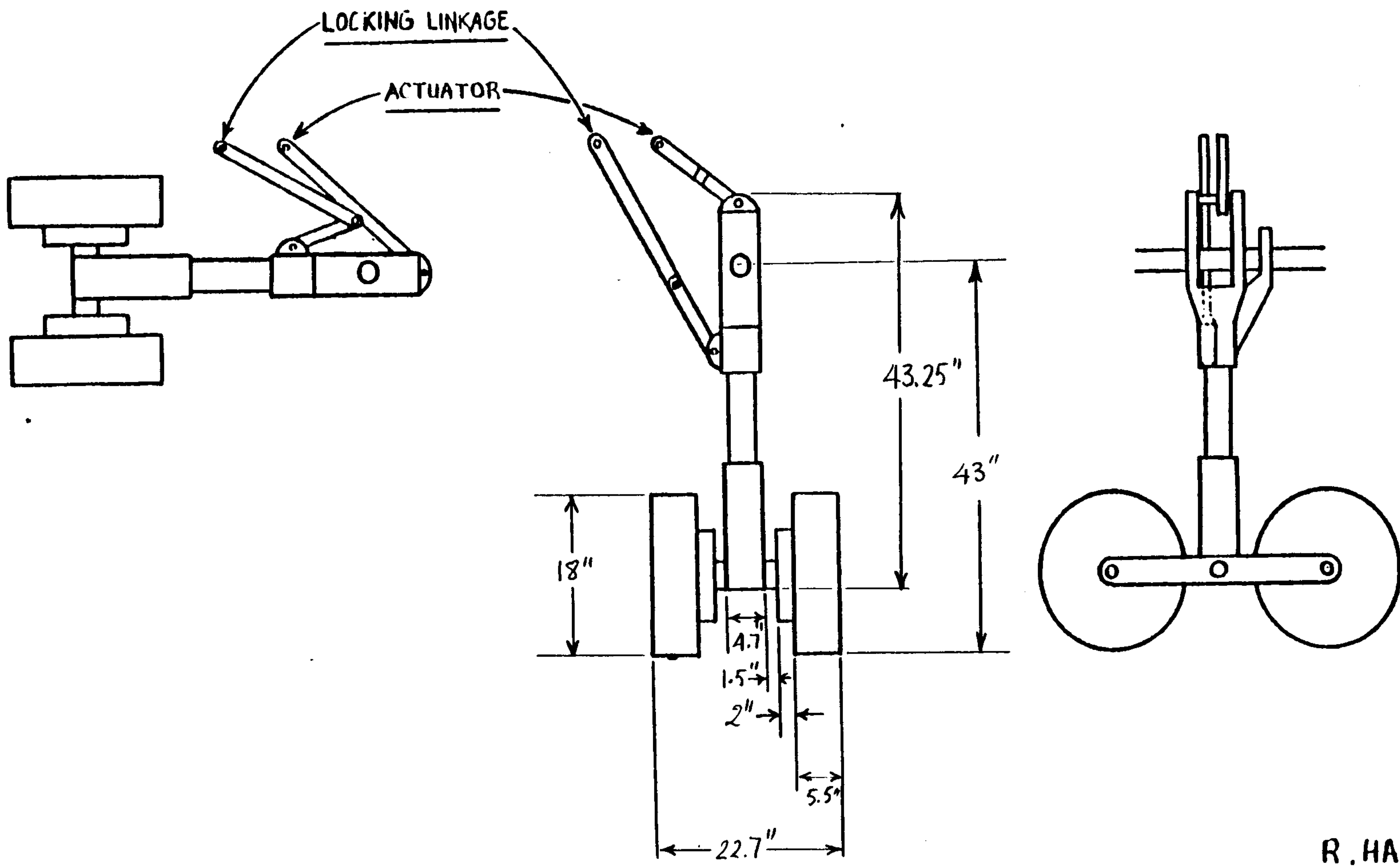

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Figure 3.2 - MAIN GEAR RETRACTION KINEMATICS

(strut length is not to scale)

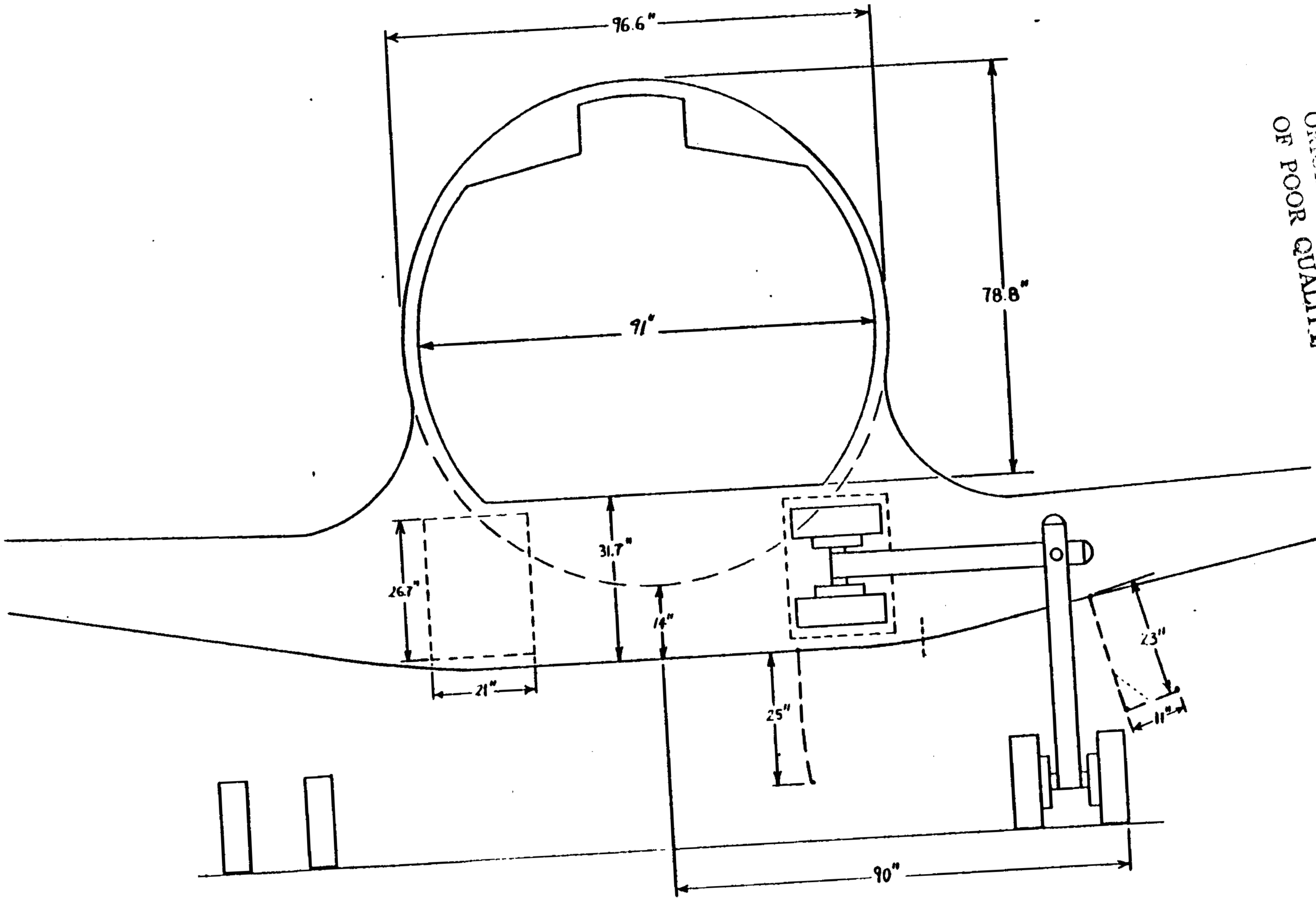

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Figure 3.3 Main Gear Stowage

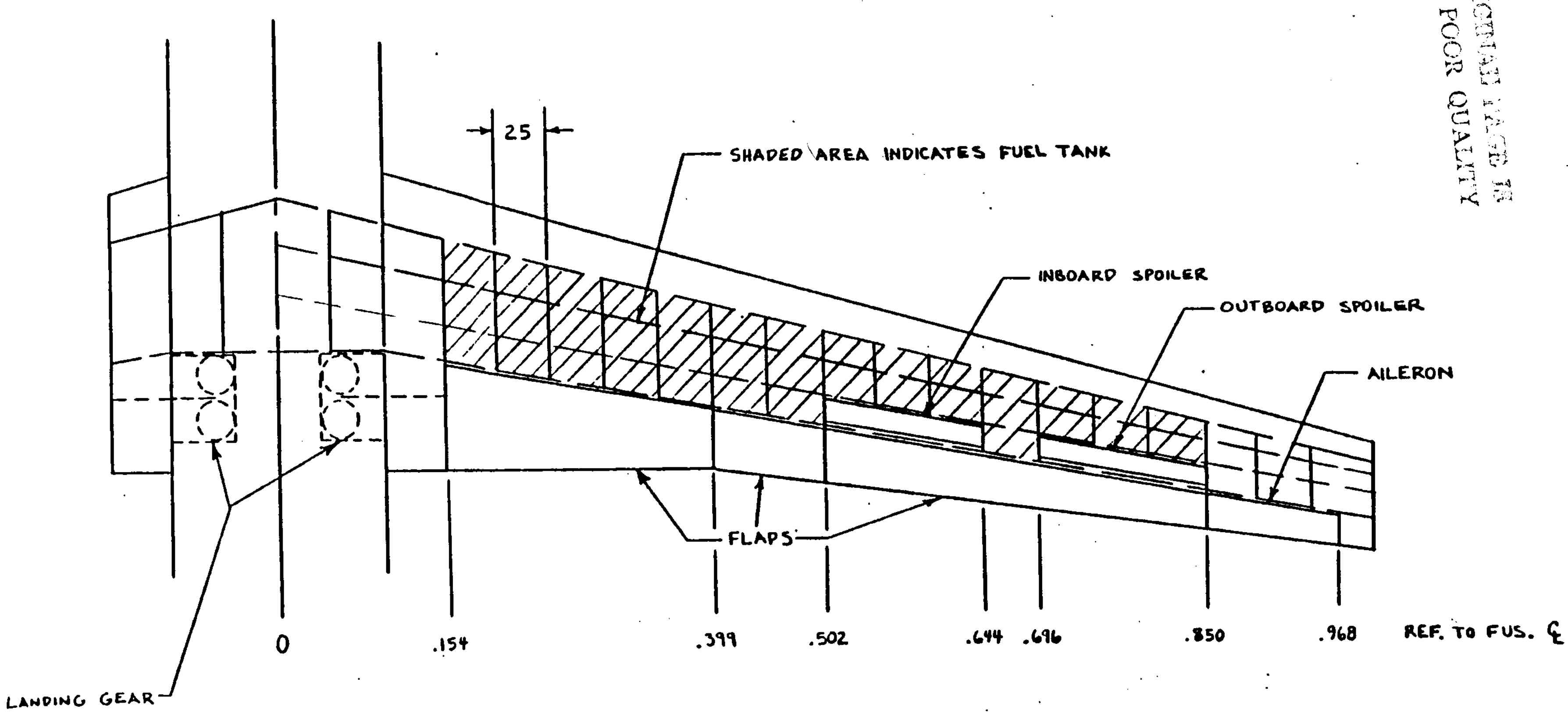

Figure 3.4 Common Wing Layout

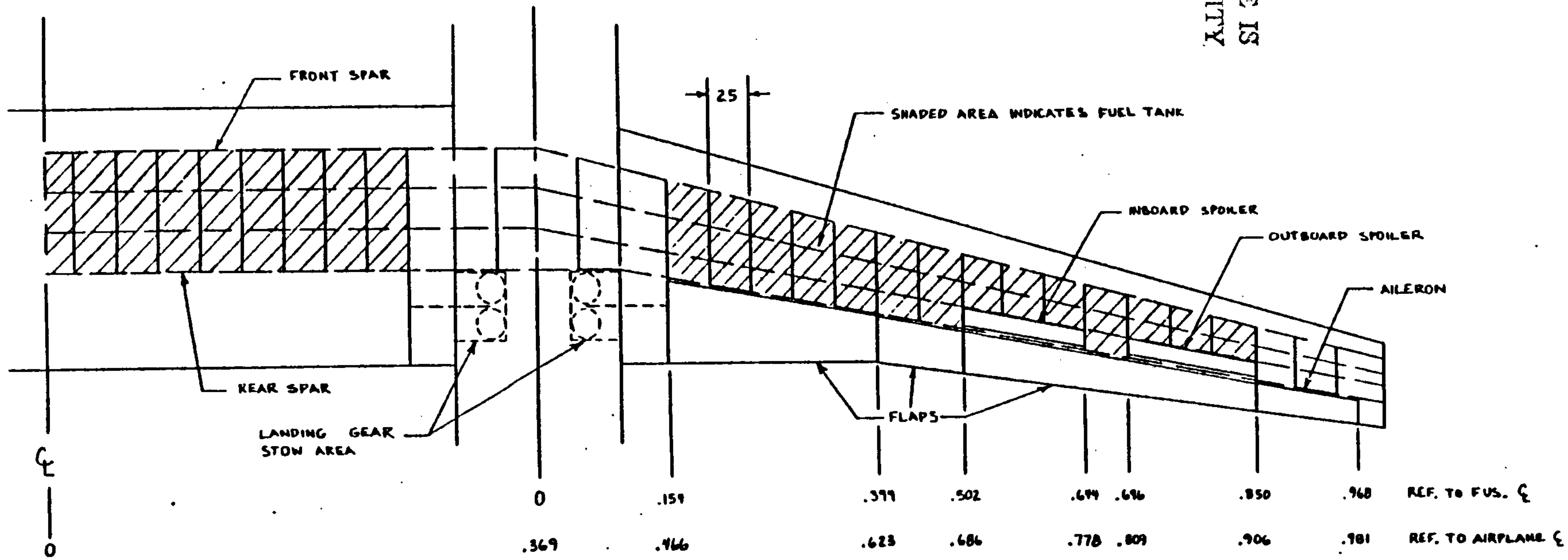

Figure 3.5 Twin-Body Wing Layout

4. LAYOUT OF THE COMMON TAIL CONE

The purpose of this section is to show the structural layout of the common tail cone as well as the common empennage. The tail cone is common on all airplanes of the commuter family.

4.1 Layout of the Common Empennage

A common empennage arrangement is selected for the family of commuters. Table 4.1 contains the geometry of the empennage. Figure 4.1 contains the common tails for the commuter family.

4.1.1 Layout of the Common Horizontal Tail

The horizontal tail was sized from low-speed trim requirements. The 120 ft^2 of surface area was necessary to maintain trimmed flight at minimum control speed. The spars were laid out to connect with the vertical tail. This determined the elevator chord ratio and area (see Table 4.1). The common horizontal tail for the single body airplanes is shown in Figure 4.1a).

The twin body airplanes required a larger tail area of 410 ft^2 to achieve static longitudinal stability. The tail bar of 290 ft^2 was designed to span between the two vertical tails.

Table 4.1 Geometry of the Empennage

	H-Tail	V-Tail
Area, ft^2	120	170
Span, ft	26.6	15.4
Aspect Ratio	5.88	1.4
Taper Ratio	0.50	0.33
M.G.C., ft	4.68	12.0
L.E. Sweep, deg	20.0	40.0
Thickness Ratio	0.11	0.11
Root Chord, ft	6.02	16.6
Spar Box Length:		
root, in	27	88
tip, in	13	27
Elevator Chord Ratio	.35	
Elevator Area, ft^2	42.0	
Rudder Chord Ratio		.35
Rudder Area, ft^2		59.5

4.1.2 Layout of the Common Vertical Tail

One common vertical tail will be used on all members of the commuter family. In order to satisfy the stability and control requirements, particularly the engine-out requirement, a vertical tail area of 170 ft^2 is required. On the 50 passenger airplane 30 degrees of rudder deflection was needed to satisfy the engine-out requirement at take-off thrust. The 50 passenger airplane was the most critical in terms of engine-out flight, and therefore sized the vertical tail for all of the airplanes in the commuter family. This results in the vertical tail geometry given in Table 4.1. The common vertical tail is shown in Figure 4.1b).

4.2 Structural Layout of the Tail Cone

The structural layout of the common tail cone is given in Figure 4.2. From Reference 5 it is determined that a frame spacing of 22 inches is sufficient for the tail cone, allowing for an equal spacing of the frames. The common tail cone includes the aft pressure bulkhead, which is located at the locations given in Table 4.2.

Table 4.2 Aft Pressure Bulkhead Locations

Airplane	Aft Pressure Bulkhead Location F.S.
25 pax	636
36 pax	729
50 pax	939
75 pax	729
100 pax	939

The rear pressure bulkhead also attaches the rear engine mount to the airframe. Therefore, on all airplanes in the family the tailcone-engine integration is exactly the same. Figure 4.3 shows this arrangement.

Bulkheads are placed at the locations where the vertical tail spars intersect the fuselage, as shown in Figure 4.2. By combining the forward vertical tail spar bulkhead and the aft pressure bulkhead, significant weight savings could be achieved. However, this was not feasible, as it would require that the aft pressure bulkhead be moved 88 inches aft of the current position. As shown in Figure 4.2, the vertical tail torque box at the root is 88 inches in length. The total length of the entire common tail cone is 286 inches.

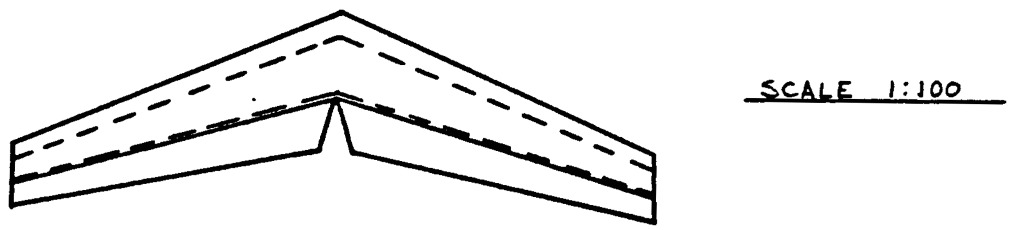

Figure 4.1a) Common Horizontal Tail

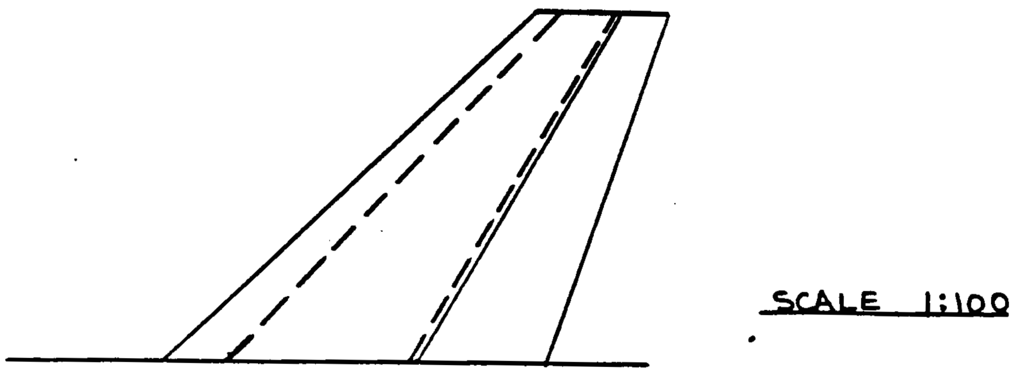

Figure 4.1b) Common Vertical Tail

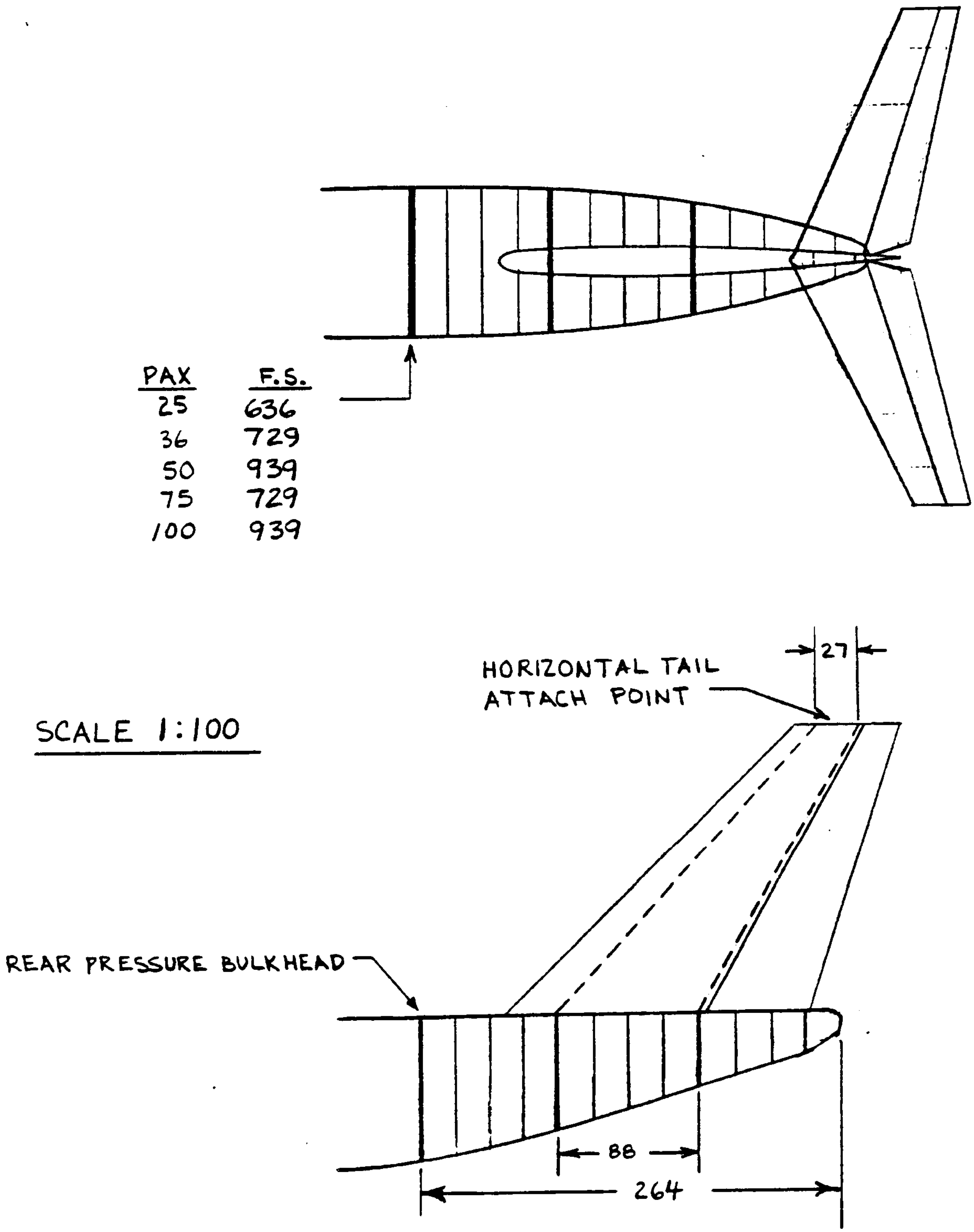

FIGURE 4.2
COMMON TAILCONE

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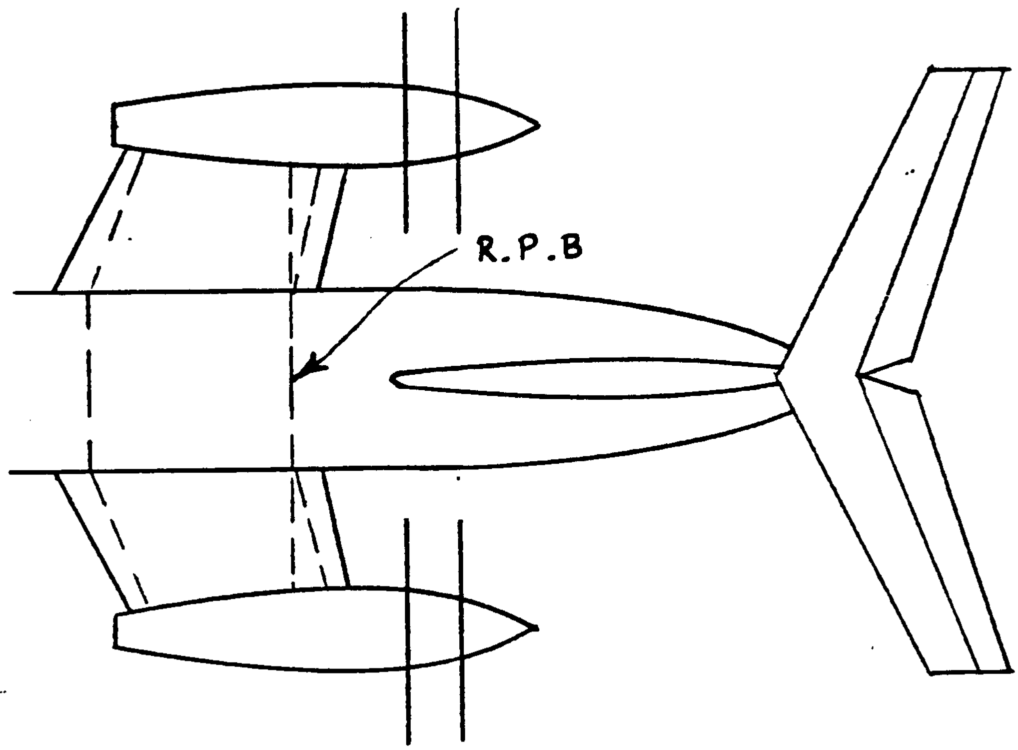

Figure 4.3 Common Tailcone-Engine Integration for the 25, 36, and 50 Pax Models

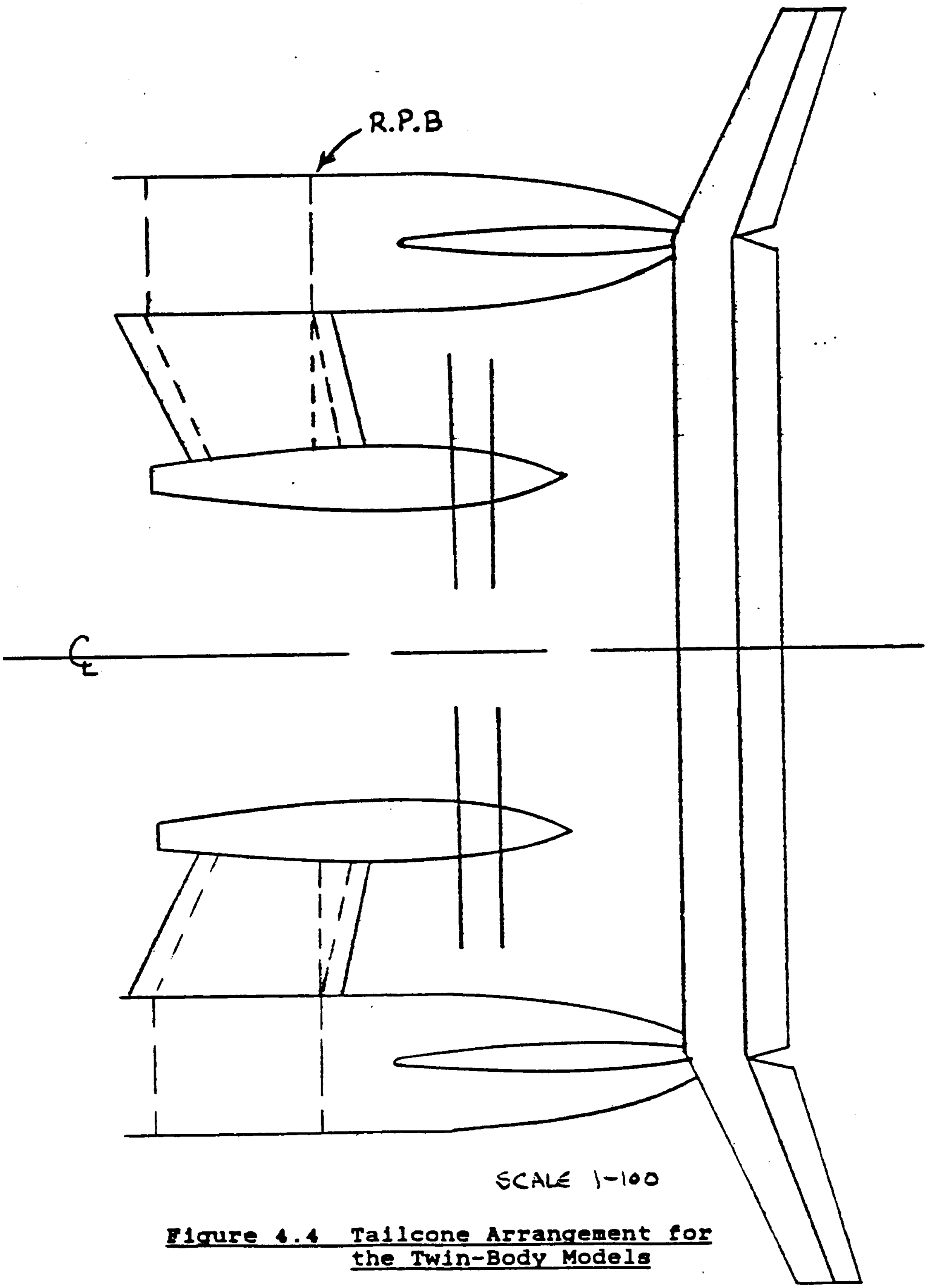

Figure 4.4 Tailcone Arrangement for the Twin-Body Models

5. PRODUCTION AND MANUFACTURING BREAKDOWN

The purpose of this chapter is to present a possible production breakdown for the family of commuter airplanes. The common structural sections of the commuter family provide the ability to easily divide the airplanes into several independent sections. Figures 5.1 and 5.2 show the production and manufacturing major assemblies of the 25 and the 100 passenger airplanes. These two models were chosen since they represent the widest range of the five possible configurations.

For the single body configurations, such as that shown in Figure 5.1, the airplane is broken up into 10 sections:

1. Common Nose Cone
2. Forward Cabin Section of Variable Length
3. Common Wing Box Section
4. Common Wing
5. Aft Cabin Section of Variable Length
6. Common Tail Cone
7. Common Vertical Tail
8. Common Horizontal Tail
9. Engine Pylons
10. Powerplant

For the twin body configurations, as shown in Figure 5.2, the following sections are added:

11. Center Wing Section
12. Center Horizontal Tail

The landing gear are not shown in Figures 5.1 and 5.2, however they are another common section in the manufacturing and production breakdown.

It should be noted that cabin sections 2 and 5 must be manufactured to the proper length for the desired configuration.

Table 5.1 presents the locations of the leading edge of the major fuselage sections on all of the different airplanes in the family.

Table 5.1 Locations of Major Fuselage Sections

Section	25 pax	36 pax	50 pax	75 pax	100 pax
1	62	62	62	62	62
2	346	346	346	346	346
3	460	538	600	538	600
5	568	646	708	646	708
6	646	742	950	742	950

Refer to Figures 5.1 and 5.2.

1. Common Nose Cone
2. Forward Cabin Section of Variable Length
3. Common Wing Box Section
4. Common Wing
5. Aft Cabin Section of Variable Length
6. Common Tail Cone
7. Common Vertical Tail
8. Common Horizontal Tail
9. Engine Pylons
10. Powerplant

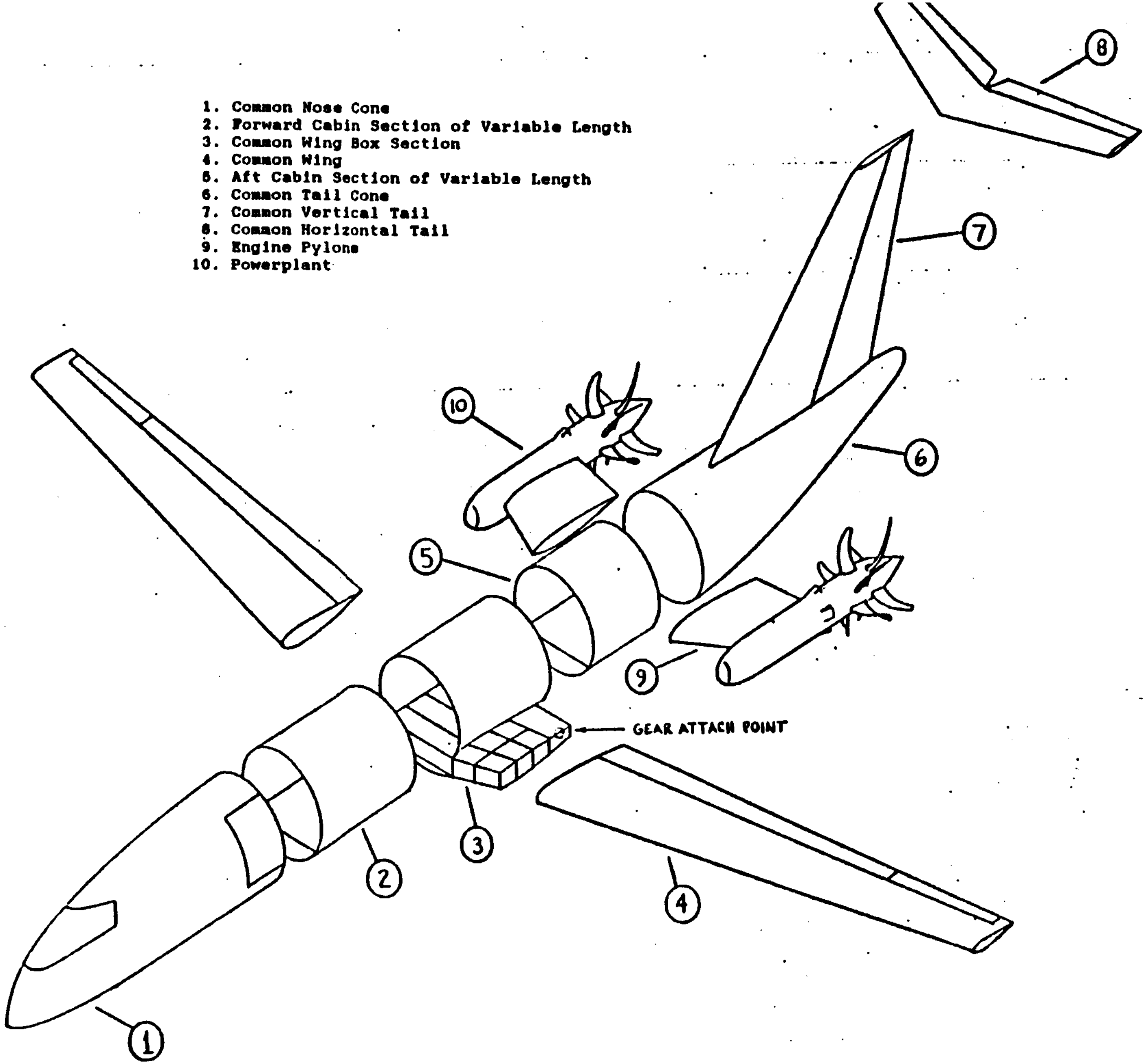

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Figure 5.1 Production and Manufacturing Breakdown Example

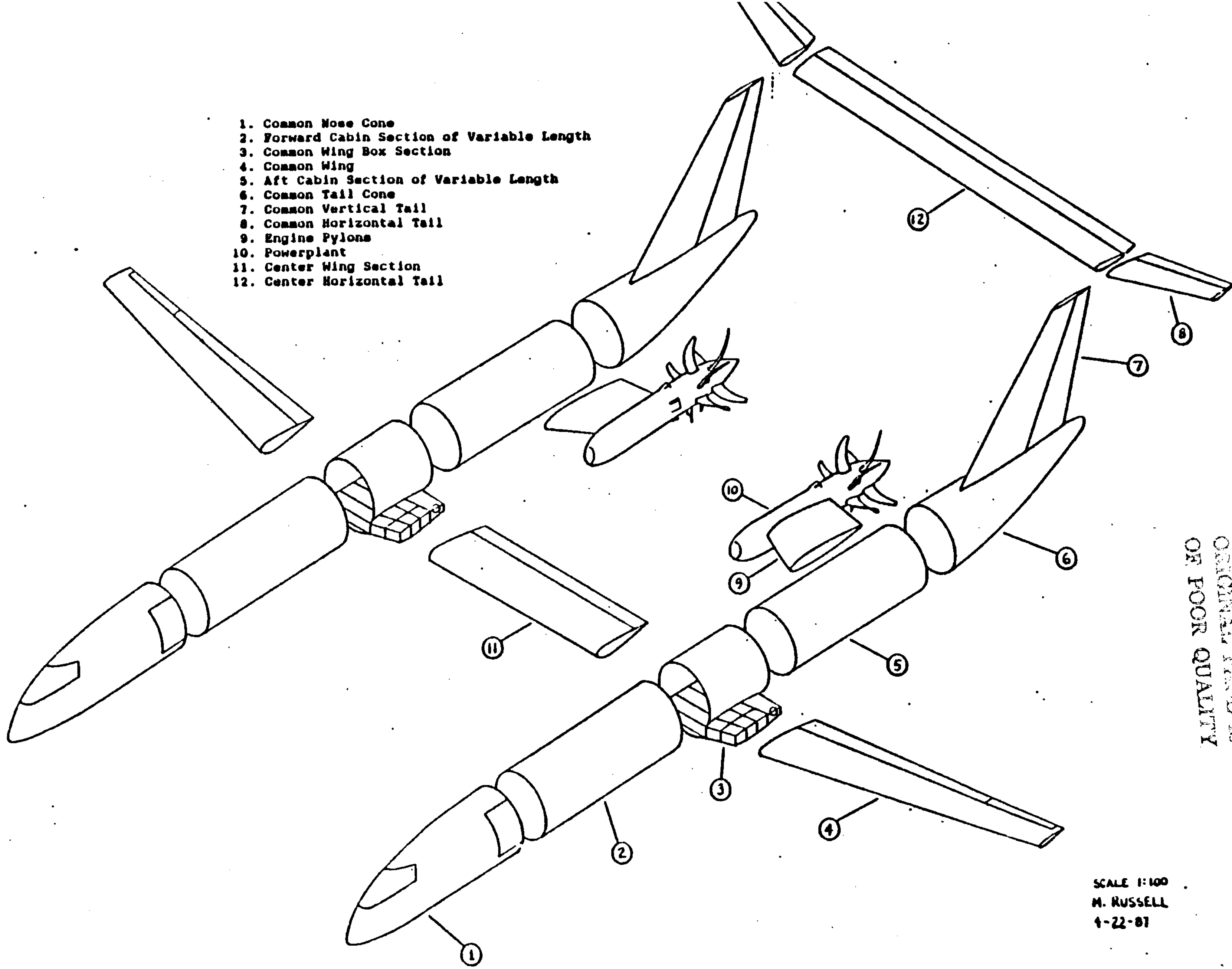

Figure 5.2 Production and Manufacturing Breakdown Example

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The conclusions for this report consist of comments on the advantages and disadvantages of implementing structural commonality. The following advantages result from the implementation of common structural components in the commuter family:

1) Significant savings in production and tooling costs could be achieved through the implementation of a common nose cone, such as that shown in Figure 2.1. This would include common structure and parts, such as common frames, stringers, skins, a common cockpit, front pressure bulkhead, nose gear, entrance door, and windshield. In addition, a common nose cone and cockpit would ease cross-certification of pilots in all the different airplanes of the commuter family.

2) By having a common torque box, significant savings in production and tooling costs could be realized with the common carry through wing box structure, which would include common spars and eight common ribs. In addition, this allows for a common main landing gear attachment point.

3) By having numerous common parts on the family of commuter airplanes, the maintaining and servicing of the airplanes should become much easier and less complex, simply because there would be fewer parts with which to become familiar. Significant savings in production costs could be achieved since the number of different spare parts will be less, requiring fewer suppliers. This would also help avoid delays in obtaining parts.

4) By using two engines instead of five, a reduction in engine acquisition cost could be achieved.

5) Production costs could be cut by using a common tail cone on all of the airplanes. Major structure, including the aft pressure bulkhead, frames, stringers, and the vertical tail will greatly simplify production. Having a common attachment for the horizontal tails will also reduce the complexity of final assembly.

6) Another advantage of common parts is the ability to divide the production amongst several contractors. The numerous major structural pieces can be produced at different locations, then can be shipped to one location for final assembly. Having a high number of common parts on the different airplanes will simplify this process. In addition, less major investment will be required by one company if the production can be divided.

The following disadvantages result from implementing a high degree of structural commonality:

1) There will be weight penalties on the smaller airplanes, since the majority of the common parts are sized to the larger airplanes.

2) The lateral placement of the main landing gear on the smaller airplanes is much wider than it has to be. This results in a larger fairing than necessary, as well as more drag than if the airplane was sized without considering commonality with the other airplanes.

3) By dividing the airplanes up into more sections, additional joints will be required for assembly. This will increase the complexity and cost of assembly. Additional fasteners required for the joints will also increase the weight of the airplanes.

4) The vertical tail is now slightly oversized on some of the airplanes, resulting in a higher weight and drag than necessary, but increasing the directional stability.

6.2 RECOMMENDATIONS

The following recommendations are made:

1) After sizing the main gear struts and tires, it has become apparent that the wing could be moved up 11 inches. This should reduce the area of the wheel well exposed below the fuselage, thereby reducing the drag.

2) A trade study should be done to determine the relationship between the increased cost of tooling separate wing planforms versus the possible reduction in cost by using a common major structure with the wing torque box.

3) A detailed study should be done to determine the relationshiop between the savings in tooling costs, servicing, and parts versus the increased operating costs due to compromised performance, resulting from the implementation of commonality.

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