4. DESIGN OF COCKPIT AND FUSELAGE LAYOUTS

The purpose of this chapter is to provide a step-by-step guide to the preparation of cockpit and fuselage layouts so that the mission requirements in terms of crew, passengers and payload are met.

For military airplanes this includes the necessary weapons and stores layouts on the fuselage.

The method is presented as part of Step 4 in p.d. sequence I as outlined in Chapter 2.

Section 4.1 presents the step-by-step guide. Example applications are contained in Section 4.2.

4.1 A PROCEDURE FOR THE DESIGN OF COCKPIT AND FUSELAGE LAYOUTS

Step 4.1: Referring to the mission specification, make a list of crew, payload and operational items which need to be located in the fuselage.

Note that this step assumes that the overall configuration is not a flying wing.

Typical items to be included on this list are:

1. number and weight of cockpit crew members
2. number and weight of cabin crew members
3. number and weight of 'special duty' crew members (such as radar and systems operators
4. number and weight of passengers
5. weight and volume of 'carry-on' baggage
6. weight and volume of 'check-in' baggage
7. weight and volume of cargo
8. number, weight and size of cargo containers
9. weight and volume of 'special operational equipment' (such as sensor and computer equipment required by patrol airplanes)
10. weight and volume of military payload (such as: guns, stores, bombs, torpedoes, missiles etc.)
11. weight and volume of fuel carried in fuselage
12. radar equipment
13. auxiliary power unit (APU)
14. beaching requirements such as in the case of flying boats

Step 4.2: Translate the list obtained in Step 4.1 into a dimensioned drawing of a proposed cabin interior layout.

This step includes making a decision on the size and shape of the fuselage cross section to be used, the location of the cabin floor in that cross section and a check of volumetric requirements imposed by any of the items 1-14 in Step 4.1. Part III (Ref.2) contains detailed information on cabin and fuselage layouts used by a number of existing airplanes.

This step involves the definition of access doors, hatches and emergency exits. Depending on the certification base of the airplane, there are very definite minimum requirements for size, placement and number of exits which need to be provided. Part III contains detailed information on these important items.

In passenger/troop transport airplanes and in business airplanes it is important to consider carefully the following choices:

1. Number of persons abreast
2. Number and size of aisles
3. Type of seating to be employed: first class, business class, tourist class or economy class
4. Cabin provisions required in terms of: closets, toilets, overhead storage compartments, galleys
5. Seating provisions for the cabin crew

Part III contains data on all these items.

In certain cargo airplanes there may be a requirement for loading and off-loading from both ends of the fuselage. This usually requires large doors and ramps. These items can dominate the fuselage design of such airplanes and need detailed attention in terms of the structural layout. How to prepare an initial structural layout is discussed in Part III.

In many military applications it is necessary to account for the installation of guns, ammo containers, missiles and other weapons. Data on sizes and volumes for such military items are also included in Part III.

Step 4.3: Add the appropriate distances to the cabin interior layout of Step 4.2, to allow for the required structural depth for fuselage frames, fuselage bulkheads and fuselage skins.

Typical distances which allow for sufficient structural depth are:

for small commercial airplanes: 1.5 inches
for fighters and trainers: 2 inches
for large transports: $0.02d_f$ + 1 inch

Step 4.4: Finish the exterior lines which define the cabin part of the fuselage.

Step 4.5: Translate the cockpit crew requirement into a dimensioned drawing of the cockpit.

Part III (Ref.2) contains detailed data with which civil and military cockpits can be laid out while observing typical requirements for pilot visibility and for pilot ability to reach the essential cockpit controls.

Make certain that the aerodynamic 'fairing' of the cockpit exterior into the fuselage exterior causes as little extra drag as possible.

Step 4.6: Prepare a dimensioned drawing of the entire fuselage, including the rear fuselage cone.

Figure 4.1 defines several important geometric parameters for the fuselage. Table 4.1 shows ranges of these parameters which are currently employed. Unless there is a good reason, these ranges should not be exceeded.

The fuselage cone is normally a smooth transition from the maximum fuselage cross section to the 'end' of the fuselage. When the 'fineness ratio' of this cone is too low, there will be a large base drag penalty although the fuselage weight may be reduced. When the 'fineness ratio' of this cone is too large, there will be a large friction drag penalty as well as a large weight penalty.

It will be obvious to the reader, that a long fuselage cone tends to increase the tail moment arm thereby reducing required tail area and vice versa.

The decision on the fuselage cone fineness ratio is therefore one that involves a number of trade-offs.

Caution 1. The geometry of the fuselage cone can also have an impact on the ability of the airplane to

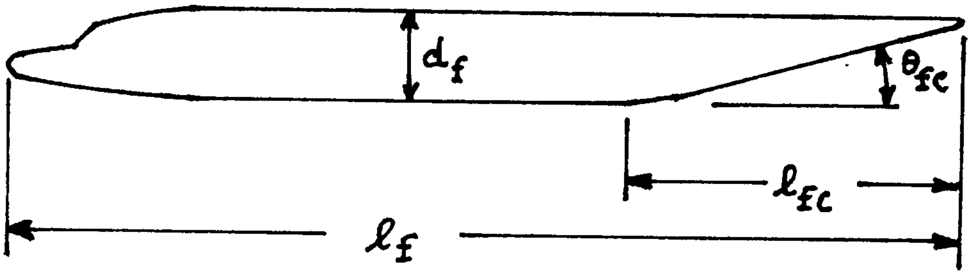

Figure 4.1 Definition of Geometric Fuselage Parameters

Table 4.1 Currently Used Geometric Fuselage Parameters

Airplane Type	l_f/d_f	l_{fc}/d_f	θ_{fc} (deg)
Homebuilts	4 - 8	3*	2 - 9
Single Engine	5 - 8	3 - 4	3 - 9
Twins	3.6** - 8	2.6 - 4	6 - 13
Agricultural	5 - 8	3 - 4	1 - 7
Business Jets	7 - 9.5	2.5 - 5	6 - 11
Regionals	5.6 - 10	2 - 4	15 - 19***
Jet Transports	6.8 - 11.5	2.6 - 4	11 - 16
Mil. Trainers	5.4 - 7.5	3*	up to 14
Fighters	7 - 11	3 - 5*	0 - 8
Mil. Transports, Bombers and Patrol Airplanes	6 - 13	2.5 - 6	7 - 25****
Flying Boats	6 - 11	3 - 6	8 - 14
Supersonics	12 - 25	6 - 8	2 - 9

*Tailcone as defined by Figure 4.1 not easily defined
**Cessna 336 (Fig.3.9c) ***Embraer Brasilia (Fig.3.16d)
****Lockheed Hercules (Fig.3.29d)

rotate about its rear gear during take-off. Make sure that the selected cone geometry does not interfere with take-off rotation.

Table 4.1 shows ranges of rear fuselage angles used on existing airplanes.

Caution 2. In the case of twin boom configurations, the fuselage tends to have a rather small fineness ratio. Examples are the AW Argosy (Ref.14, Section 14.2) and the Fairchild C-119 (Ref.29, Section 14.2). These airplanes all experienced high drag due to the fuselage configuration. The obvious trade-off between a larger fineness ratio for the fuselage to reduce drag and the greater weight caused by such a larger fineness ratio will have to be established and a decision made.

Caution 3. In the case of flying boats it is essential that the lower part of the fuselage (called hull) has the 'correct' hydrodynamic lines. The reader should refer to Part III for data on these shapes.

Step 4.7: Document the decisions made under steps 4.1 - 4.6 in a brief descriptive report including clear, dimensioned drawings.

One of these drawings should be a so-called 'inboard profile'. Examples of inboard profiles may be found in Part III.

4.2 EXAMPLE APPLICATIONS

Three example applications will be presented:

4.2.1 Twin Engine Propeller Driven Airplane: Selene
4.2.2 Jet Transport: Ourania
4.2.3 Fighter: Eris

The applications are all presented in accordance with the Step 4.1 through Step 4.7 sequence presented in Section 4.1.

4.2.1 Twin Engine Propeller Driven Airplane

Step 4.1: Table 2.17 of Part I defines the mission of the Selene. The following items from Table 2.17 need to be carried in the fuselage:

1. Six passengers (this includes the pilot)
2. 200 lbs of luggage

The mission specification does not stipulate the required baggage volume. Comparison with competitive airplanes (Ref.8) shows that a baggage volume of 40 cubic would be acceptable.

Step 4.2: A two abreast layout is selected for the Selene. This type of layout is common to most airplanes in this category. Two cockpit seats and four cabin seats are therefore required, for a total of three rows.

The selection of cabin cross section is critical to passenger comfort and to weight and wetted area. Looking at the fuselage cross sections for this type of airplane in Part III shows most of them to be rather flat sided. For an unpressurized fuselage that is acceptable. It also is easy to manufacture. For a pressurized fuselage the perfect cross section would be circular. The reader should try and prepare a layout of a circular cross section for the Selene. Because of the human anatomy it will be discovered that the fuselage will become rather bulky. This is another reason why the fuselage cross section of most smaller general aviation airplanes is more or less rectangular.

Since it is forseen that future versions of the Selene will have to be pressurized, the double circle cross section of Figure 4.2a was selected. Note the slab sides which connect the two circles. The internal cabin dimensions of the Selene were selected after comparison with four competitors:

Airplane Type	Internal cabin dimensions in ft		
	Length	Max. Width	Max. Height
Beech Duke	11.8	4.2	4.3
Beech Baron M58	12.6	3.5	4.2
Cessna T303	13.6	4.0	4.0
Piper PA-44-180	8.0	3.5	4.0
Selene	18.5	4.25	4.4

Most cabin type twins have an access door in the rear. Because Selene will be configured as a high wing pusher with the propellers behind the wing trailing edge, a rear access door would be awkward: the propellers are to close to the door. Therefore, the cabin access door will be located directly behind the pilot on the left side. This arrangement is also used in several business jets. Figure 4.2b shows the proposed interior arrangement of the cabin.

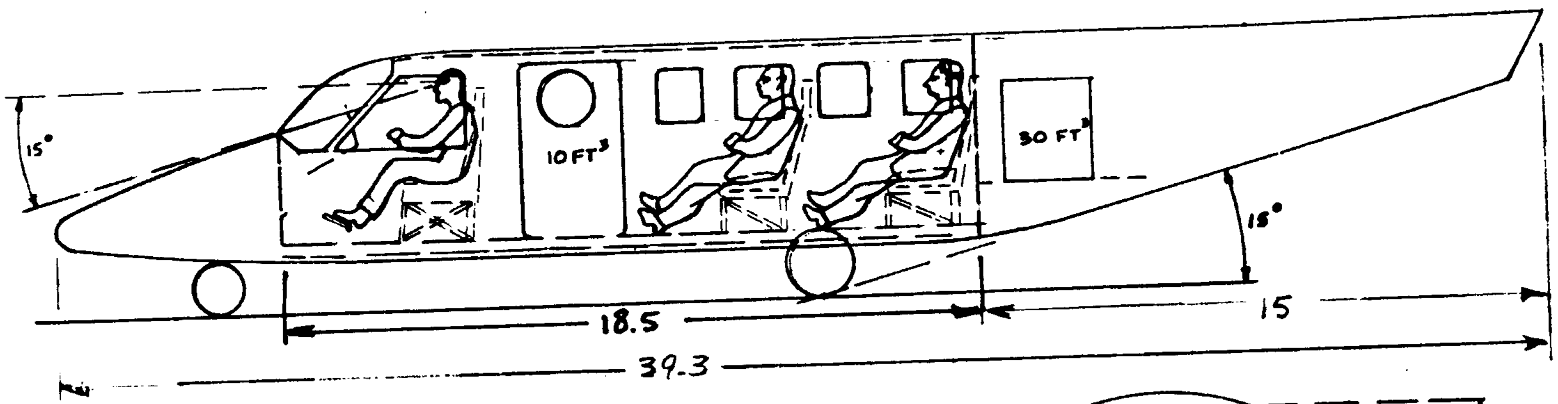

Figure 4.2b Selene: General Arrangement of the Fuselage

ALL DIMENSIONS IN FT.
DO NOT SCALE

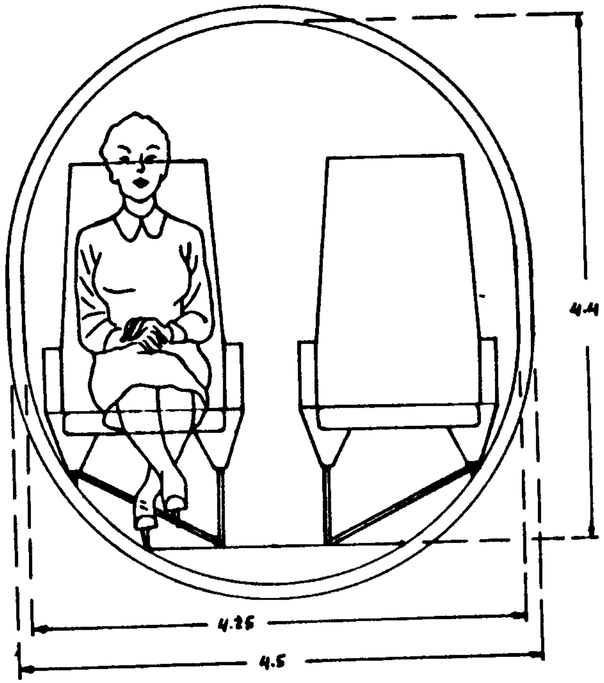

Figure 4.2a Selene: Cabin Cross Section

Step 4.3: Figure 4.2a also shows the proposed structural depth of 1.5 inches.

Steps 4.4 and 4.5: Figure 4.2b shows the general arrangement of the cockpit and the fairing into the exterior lines of the cabin. Note the 15 degree 'over the nose' visibility.

Step 4.6: Figure 4.2b shows the rear fuselage cone. The up-slope of the bottom of the cone is 15 degrees. This is consistent with attached flow and with the requirement for take-off rotation. The length of the cone was selected so that a fineness ratio of 2.7 resulted. The overall fuselage fineness ratio is 7.2. These numbers are consistent with those of Table 4.1.

Step 4.7: To save space this step is omitted. Example inboard profiles for several airplanes are presented in Part III.

4.2.2 Jet Transport

Step 4.1: Table 2.18 of Part I defines the mission of the Ourania. The following items from Table 2.18 must be carried in the fuselage:

1. 150 passengers
2. 150x30 = 4,500 lbs of luggage
3. flight deck crew of two + three cabin attendants
4. 5x30 = 150 lbs of luggage for the crew

There is no specific requirement for cargo containers. It will be assumed, that the total of 4,650 lbs of luggage will be carried in containers located below the cabin floor. Typical luggage density is 12.5 lbs/ft^3. This yields a requirement for 372 ft^3 of baggage volume. Because of the large number of 727's and 737's which are in airline service, interchangeability of cargo containers with these airplanes is felt to be desirable. Typical Boeing 727 belly containers have a volumetric capacity of about 80 ft^3. Therefore five such containers will be necessary.

Data on cargo and luggage containers may be found in Part III.

Step 4.2: According to Ref.8, comparable airplanes to the Ourania have five or six abreast seating. A circular fuselage cross section is required to keep the weight of the pressurized shell down.

Five abreast seating results in 30 seat rows.
Six abreast seating results in 25 seat rows.

A future problem with a 5-abreast arrangement may be that any growth version will end up with a very long fuselage. This is one reason to opt for 6-abreast seating for the Ourania.

The next question to be decided is the seat and aisle width to be used. Part III contains detailed data on this subject. It is decided here to opt for the seats shown in Figure 4.3 with an aisle of 22 inches. Figure 4.4 shows the proposed seating/aisle arrangement. At this point a circle needs to be drawn such that the aisle height is reasonable and such that the shoulders of passengers seated in window seats do not touch the interior side wall. Figure 4.3 also shows the proposed interior circle.

Airline experience shows that an item high on the list of passenger preferences is easy to reach and liberally sized overhead storage. Figure 4.3 also shows the overhead storage.

The seat pitch needs to be selected next. Part III shows that a 34 inch seat pitch is reasonable for this type airplane. The cabin floor arrangement can now be drawn. Figure 4.5 shows the proposed floor arrangement. Note that provisions are made for door and emergency exits. Part III also contains data on the required number and size of doors and emergency exits in passenger airplanes.

Figure 4.5 also shows the proposed arrangement of galleys, toilets and wardrobes. Part III contains data on the dimensions of these items also.

The following data compare the cabin interior dimensions of the Ourania with those of three competitors:

Airplane Type	Seats Abreast	Internal cabin dimensions in ft Length	Max.Width	Max.Height
Boeing 737-300	6	68.5	11.5	7.2
McDD DC9-80	5	101	10.1	6.8
Airbus 320	6	NA	12.2	7.3
Ourania	6	76.6	12.4	7.5

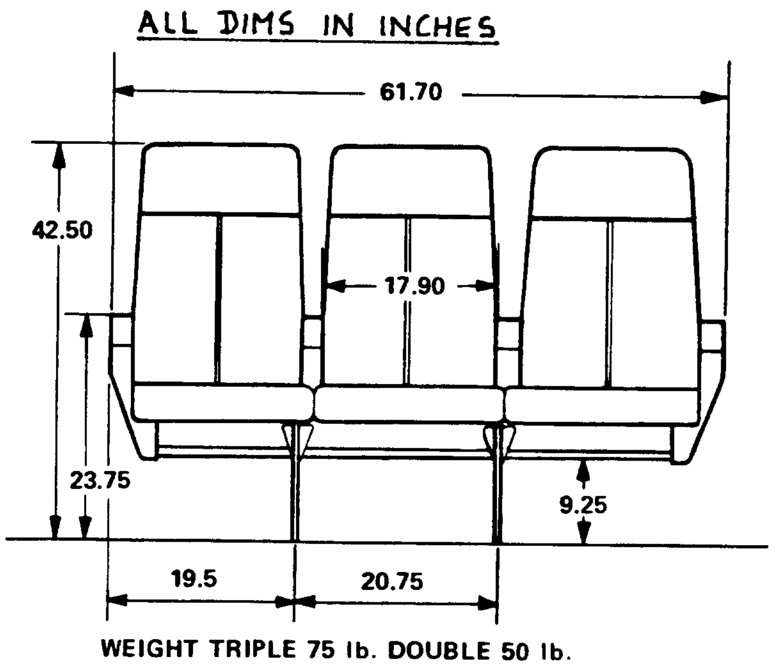

Figure 4.3 Ourania: Proposed Triple Seats

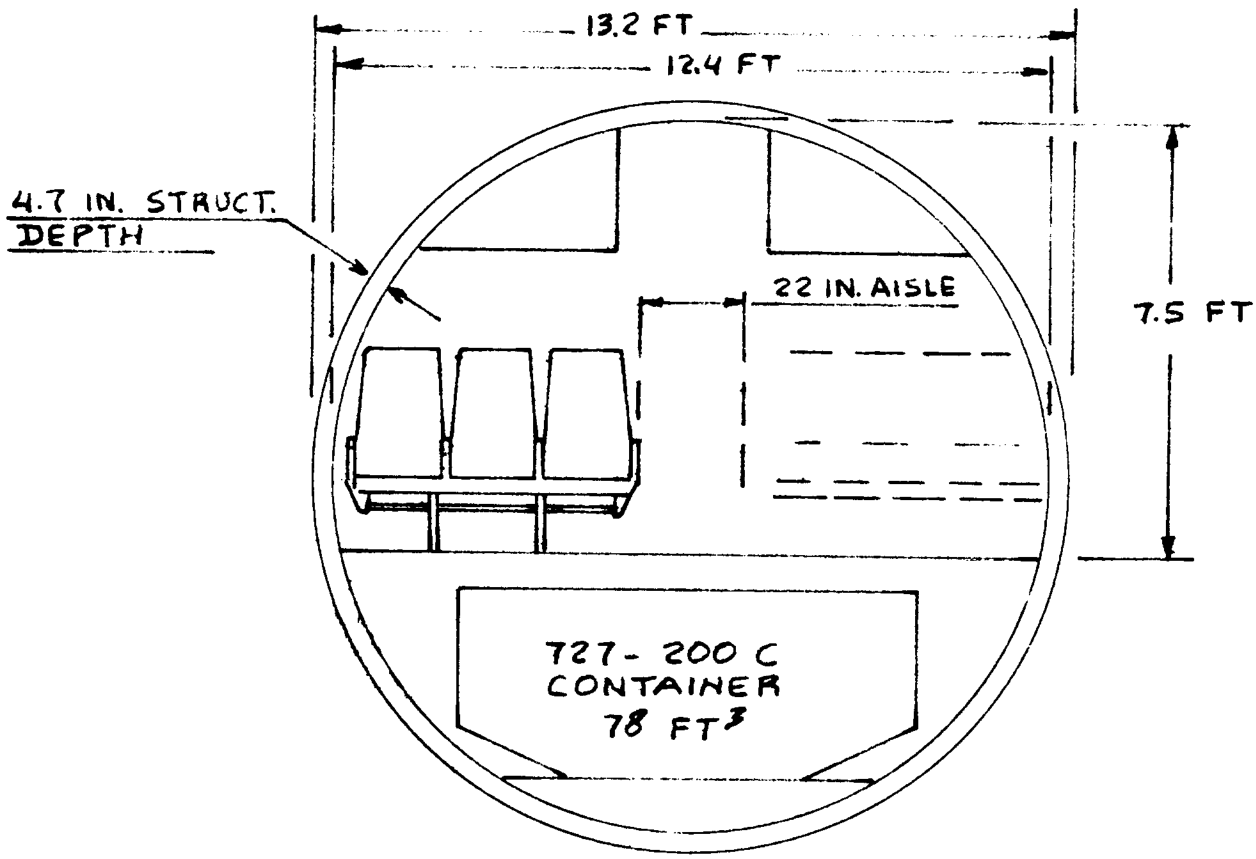

Figure 4.4 Ourania: Cabin Cross Section

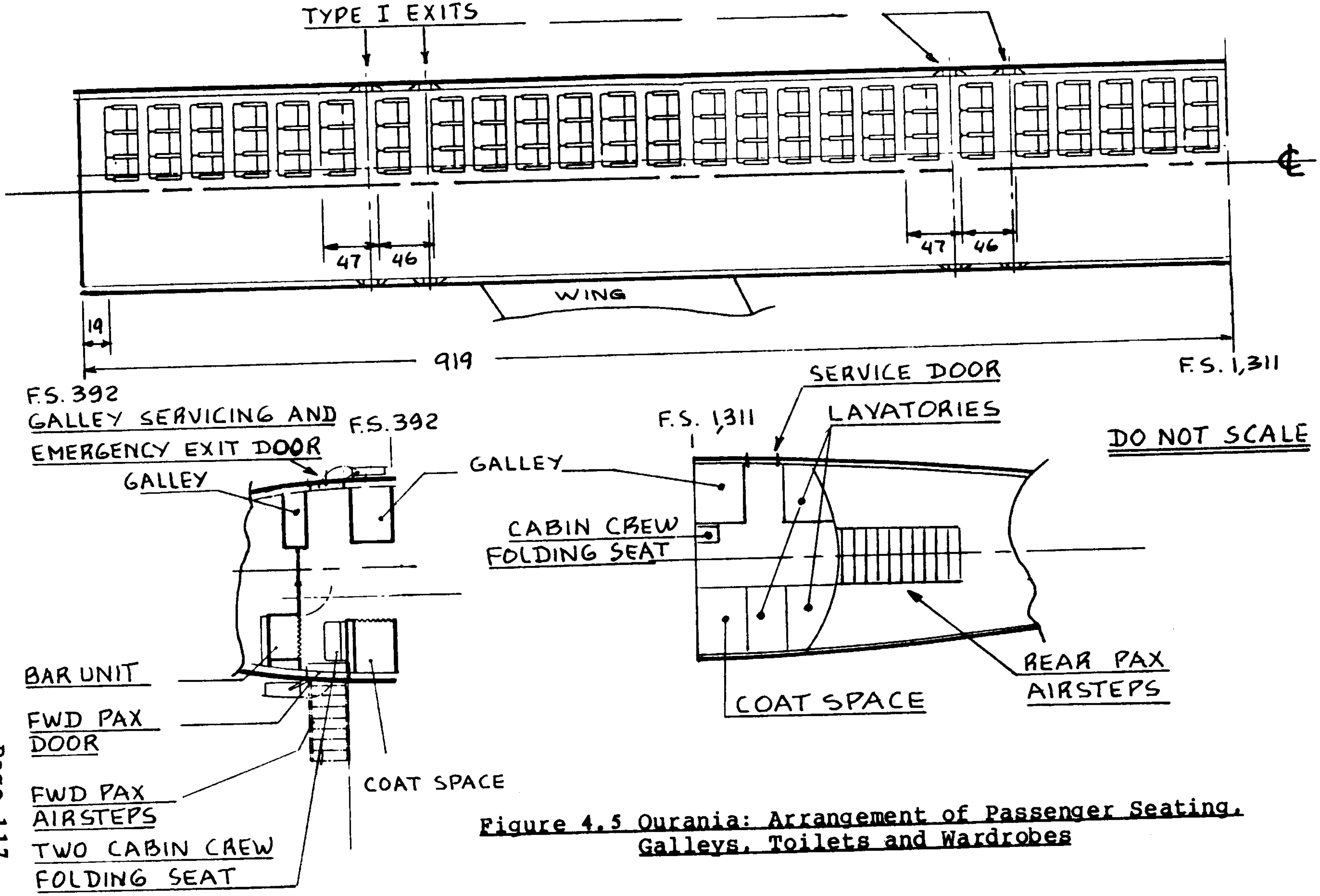

Figure 4.5 Ourania: Arrangement of Passenger Seating, Galleys, Toilets and Wardrobes

Step 4.3: Figure 4.4 also shows the exterior cross section. Note that the structural depth is 4.7 inches. This is consistent with the recommendation of Section 4.1, Step 4.3.

Step 4.4: Figure 4.5 also shows the exterior lines of the cabin.

Step 4.5: Figure 4.6 presents the proposed interior arrangement of the flight deck. Note the added seats for carrying 'check' pilots.

Figure 4.6 also shows that visibility from the cockpit is probably acceptable. To make sure a visibility pattern drawing needs to be made. Part III shows how to prepare such a visibility pattern.

Step 4.6: Figure 4.7 presents a dimensioned drawing of the entire fuselage. The rear fuselage cone has a fineness ratio of 3.5. The entire fuselage has a fineness ratio of 10.1. Note that these numbers are consistent with Table 4.1.

Step 4.7: To save space this step has been omitted. Part III contains example inboard profiles of several airplanes.

4.2.3 Fighter

Step 4.1: Table 2.19 of Part I defines the mission of the Eris. The following items need to be carried in the fuselage:

1. Pilot with ejection seat
2. GAU 8/A multi barrel cannon
3. Two engines

Item three is a result not of the mission specification but of the configuration choice made in sub-section 3.5.3.

Step 4.2 - 4.7: Because a fighter airplane needs to be tightly 'packed' to save weight, wetted area and volume it is not feasible to take these steps individually. Following is a description of how the proposed fuselage arrangement of the Eris was arrived at.

Figure 4.8 shows a dimensioned sketch of the GAU 8/A cannon and its ammunition container. Note the large size of this weapon. It is currently installed also in the

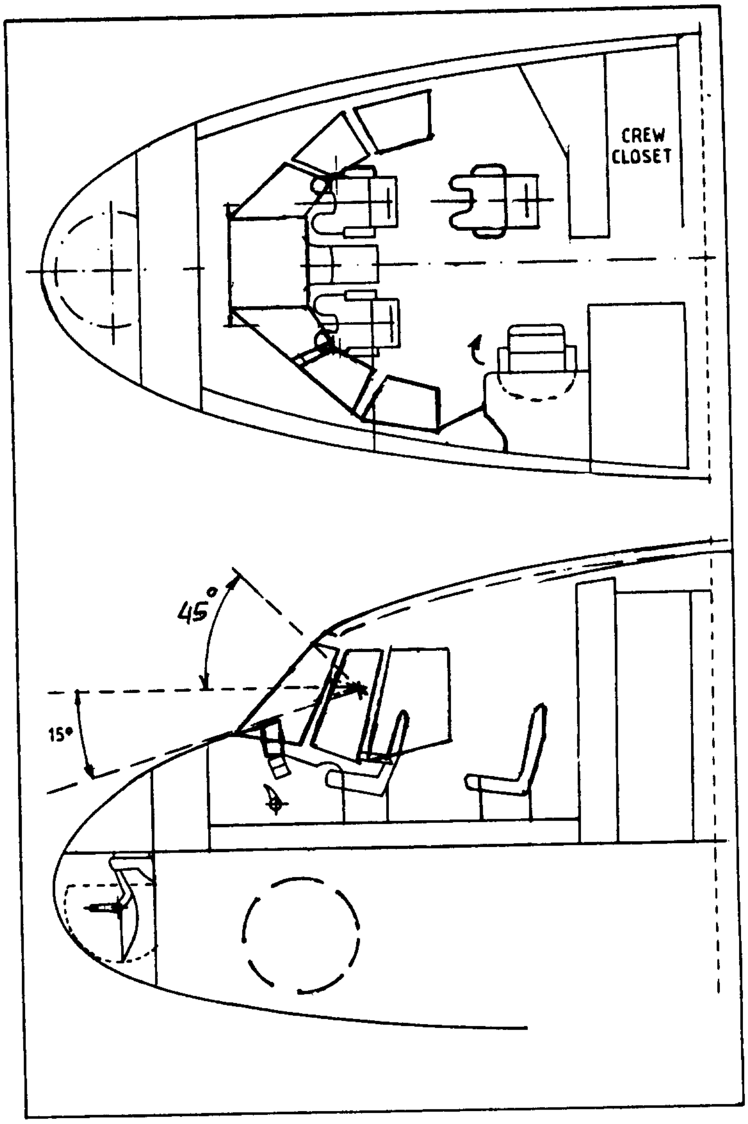

Figure 4.6 Ourania: Flight Deck Arrangement

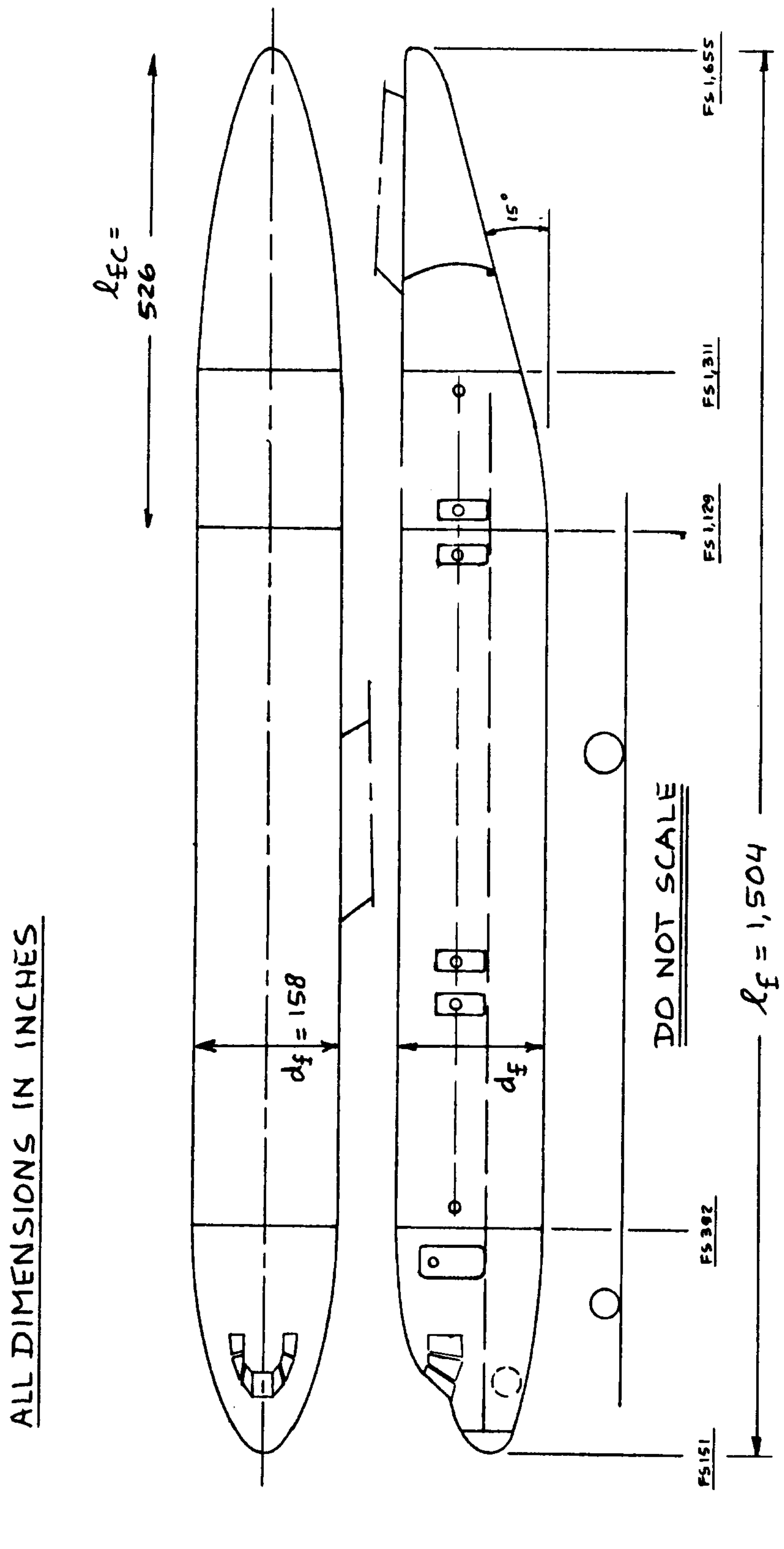

Figure 4.7 Ourania: General Arrangement of the Fuselage

Fairchild Republic A10 attack airplane.

Figure 3.61 shows the threeview of the DeHavilland DH110 SeaVixen. The overall configuration of this airplane is the one selected for the Eris. It can therefore be used as a guide.

To keep the length of the fuselage within reasonable bounds, the large ammo container will be placed behind the pilot. The cannon itself will be placed forward of and below the pilot. The nose gear will be retracted forward into the nose. Because nosegear and cannon compete for the same space, they will be separated laterally. This results in the cannon being on the right side and the nose gear on the left side.

The engines will be mounted as closely behind the ammo container as possible.

The wing torque box must pass through the fuselage above or below the ammo container. To reduce fuselage depth as much as possible it was decided to mount the wing on the fuselage above the ammo container. This results in a high wing configuration. In turn this forces the inlet ducts to be of the so-called 'armpit' type. A potential problem is that the exhaust gasses from the cannon can enter the inlets. To prevent this a special exhaust gas deflector is installed on the nose of the fuselage.

Figure 4.9 shows the proposed fuselage arrangement. Note the 15 degree downward visibility over the nose.

The mission specification of the Eris also calls for twenty 500 lbs bombs to be carried externally. It is decided to try the following arrangement:

- 8 bombs mounted conformally under the fuselage
- 12 bombs mounted in racks under the wings at the same spanwise station which carries the tail-booms.

Example inboard profiles for fighters and trainers are contained in Part III.

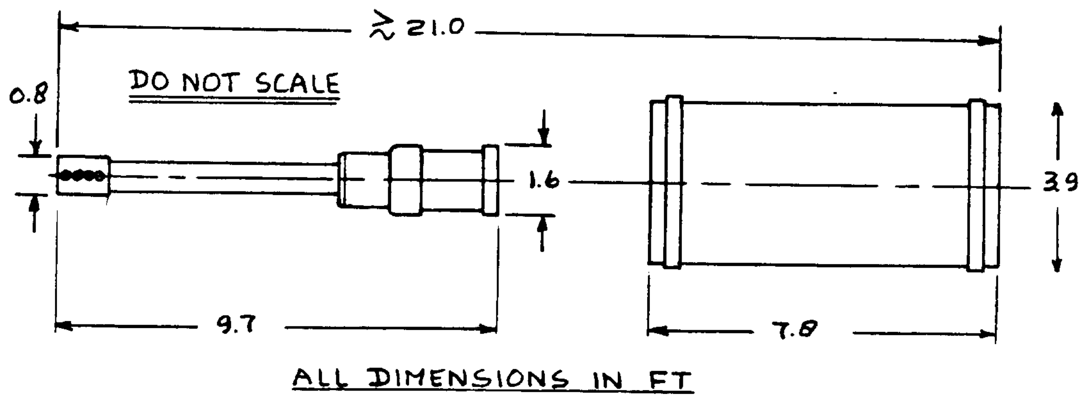

Figure 4.8 Eris: GAU 8/A Cannon Dimensions

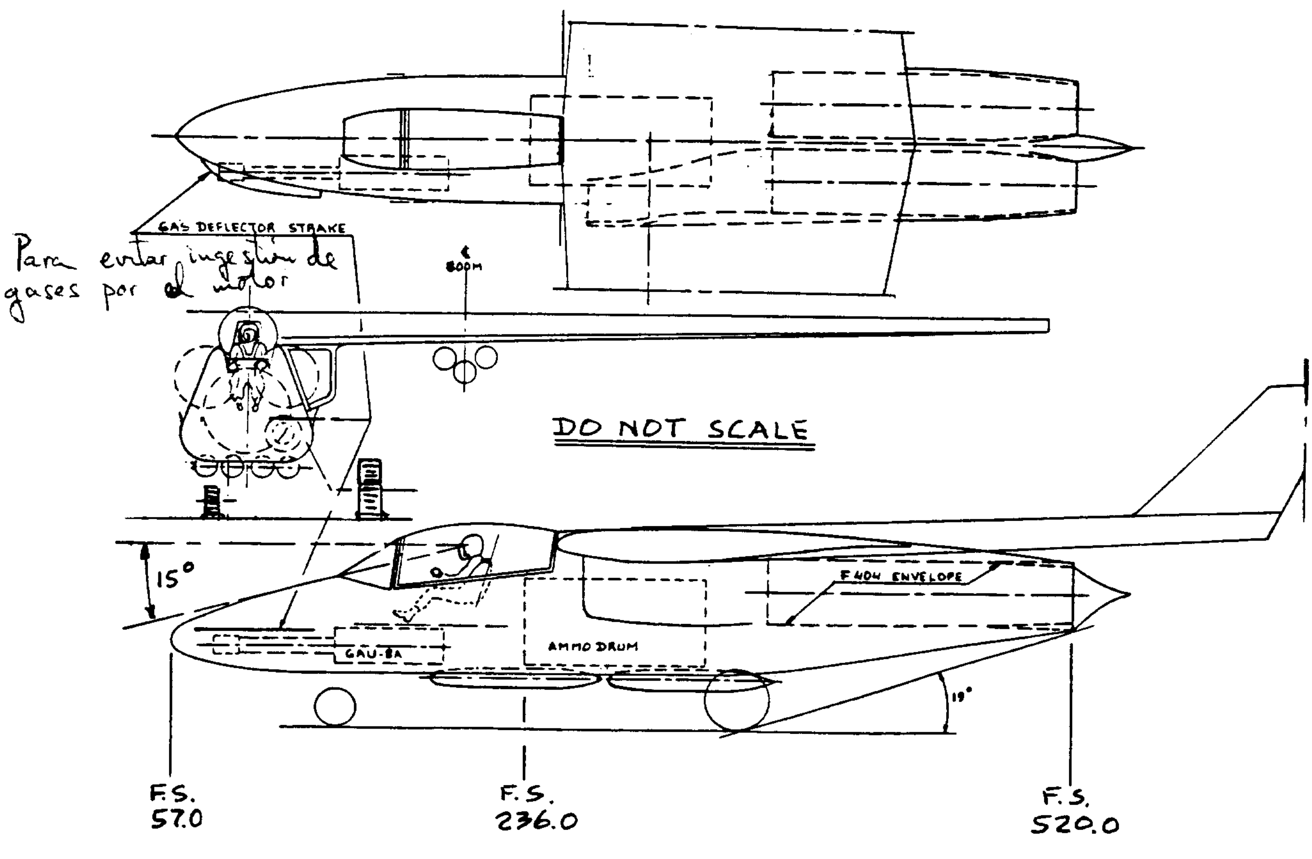

Figure 4.9 Eris: General Arrangement of the Fuselage