HIGH-CAPACITY SUBSONIC TRANSPORT PROJECTS

Professor J P Fielding
College of Aeronautics
Department of Aerospace Technology
Cranfield University
MK43 OAL
UNITED KINGDOM

ABSTRACT

The A-90 project was performed to investigate one of the possible means of alleviating the chronic and worsening congestion at many of the world's airports, by producing a larger aircraft. The aim would be carry 5-600 passengers up to 2000 miles on high density routes in Europe, North America and the Pacific Rim.

The aircraft conceptual design study was performed by the author, to determine the basic shape of the aircraft together with weight, aerodynamics and loading information.

This provided the starting point for twenty-three post-graduate design students, who were allocated responsibility for preliminary/detail designs of major parts of the aircraft such as the forward fuselage, a flying control surface or a mechanical system such as fuel, environmental control, propulsion, landing gear or the active control system. This allowed much more realistic estimates to be made of mass, and showed the construction methods to be feasible. A further 20 flight dynamics students modelled the stability and control characteristics, and found them to be adequate.

The A-90 project utilised may new technologies such as variable-camber flaps, aluminium-lithium structure and fibre-optical signalling and thus had considerable project risk. Many lessons were learned relevant to very large aircraft and are described in the paper. Subsequent individual studies performed alternative A-90 designs with fewer innovations, and economic comparisons were made with the baseline A-90. In common with industrial practice, it was decided to extend the A-90 family using as much as possible of the earlier design. The fuselage was stretched to accommodate 754 passengers in a high density layout, and range extended to compete with 1that of the Boeing 747-400.

The wing position reverted to the more conventional low-wing configuration, from the shoulder-wing A-90, and the aircraft became the A-94. Two versions were designed, one with current technology and one with hybrid laminar flow on wing and nacelles. The A-94 was designed by 28 graduate students, and the flight mechanics checked by a further 15 students.

The A-90 and A-94 projects employed the attention of some 90 graduate students and manpower expended was in the order of 47,000 hours. This lead to some very detailed work in advanced technology concepts and went a considerable way towards validating concepts which initially relied extensively on significant extrapolation of empirical data from much smaller aircraft.

The results make interesting reading for companies involved in designing, or specifying aircraft in this class.

1 INTRODUCTION

Many Universities use group projects as powerful means of pulling together aeronautical teaching programme in realistic applications of design integration. Design is largely taught by "doing" it. This has been Cranfield's Policy since 1946, but it's design course is unique in the magnitude of the student, staff and equipment resources used in the projects. These allow much more detailed studies than elsewhere, and provide useful research investigations. It is important that these resources are well-spent investigating relevant aircraft design topics, and large airliners were chosen as suitable topics. It was felt that such aircraft could be a major element in the alleviation of the chronic and worsening congestion at many of the Worlds's airports. The most important requirement, however, was to provide a means of safe, comfortable travel at costs some 20% lower than current values.

Fig.1. shows a summary of the subsonic airliner market as it was in 1991. Two major project studies were performed in 1990/1 and 1994/5 for short (A-90) and long-range (A-94) aircraft respectively. This paper gives descriptions of both aircraft and draws some conclusion about this class of aircraft.

2 THE A-90 SHORT-RANGE AIRLINER

2.1 Aircraft Performance

It was decide to take the radical approach of aiming for a 2000 n. mile, 500 seat aircraft. This could replace DC10-10 and A300 aircraft over most of their operations and meet growth generated by such aircraft as the 757, 767, and A321. Discussions with a senior British Airways representative suggested there was a significant requirement for a 3,500 n.m. range for trans-Atlantic or trans- U.S.A. routes. The A-90 aircraft requirements therefore included provisions for fuel volume for such a range, although there would have to some reduction in payload, to limit the aircraft size.

The strong predicted growth in cargo led to the requirement for carriage of standard containers above and below the main deck in cargo or COMBI versions of the aircraft and be compatible with military cargo operations, providing that this would not detract from civil operations.

The major features of the specification were:

(a) 500 mixed class passengers
(b) Carriage of under-floor LD3 containers and optional main deck cargo door.
(c) Passenger and bag range of 2000 N.miles with FAR reserves with max cruise speed greater than 340 knots.
(d) All-up mass take off in 8300ft, landing 5660 ft, ISA, sea level.
(e) Runway loading less than that of the A330

The speed and field requirements were based on comparison with the A-330 aircraft.

It was envisaged that the aircraft would use state-of-the art materials and technology. The operational flexibility required for a short/medium range airliner with possible civil/military cargo derivatives prompted the decision to specify the use of variable camber wing flaps to optimise lift/drag ratios over a wide lift coefficient range. It was further decided to use the wing aerofoil and variable-camber (V-C) flaps being developed at Cranfield on an independent research programme. This had the advantage of making use of good data from the computational fluid dynamics work on the aerofoil. The variable-camber research programme would benefit from ideas generated in the A-90 application. One of the benefits of the V-C system was it's ability to be easily adapted to the use of "active control" of surfaces, for wing mass reduction.

The detailed requirements were given in the project specification (ref.1).

2.2 A-90 Configuration

The cross-sections of current aircraft were examined and it was decide to use a double-bubble fuselage, with a lower-lobe of similar width to the Boeing 747, with an upper lobe of similar width to the Airbus A320.

Figure 2 shows a side-view of the final fuselage configuration. All-economy seating has a capacity of 620 passengers. The main deck can accommodate two rows of 8ft x 8ft x 20ft containers in a cargo version.

Figure 3 shows the fuselage cross-section at the wing intersection.

The controversial shoulder-wing arrangement had many advantages, not least being good ground clearance for the large Trent wing-mounted engines. This layout led to some difficulties in the rare event of aircraft landing in water.

Figure 4 shows a CAD model showing the aircraft configuration.

2.3 A-90 Predicted Performance

The detail designs produced by the students allowed a more accurate prediction of aircraft mass than given the original empirical methods. These showed that the Manufacturer's empty mass would be some 5 tonnes lighter than the target, but so many novel features could easily erode this margin.

Performance checks were made and produced a payload-range curve which indicated that the aircraft would exceed the specification requirements, giving a 500-passenger range of 2260N miles, rather than the required value of 2000N miles.

The economical cruise Mach No was predicted to be 0.83 with high speed at 0.86. The optimum performance over the 2000 mm range was cruise at M = 0.81 at 37,000 ft altitude.

It was possible to meet the specified all-up mass take-off field length of 8,300 ft at ISA conditions, but more power would increase climb gradient after the failure of one of the very large engines.

The landing field length increased to 7,750 ft. This is still reasonable performance, but the specified performance could be achieved by the use of more powerful auxiliary flaps.

The aircraft meets the runway requirement and exceeds the internal space requirements for passengers.

Trans-Atlantic or trans-Continental flights of 3,500 N miles should be possible with 345 passengers.

2.4 Study of modified designs - the A-90A and B

The above design showed considerable potential, but there were many unresolved questions, particularly of a commercial nature. An individual MSc study was performed by Mr P T L Lim (ref.2). The study used the A-90 as a datum, but used the same technology, combined with a conventional high-lift system to arrive at the A-90A. The new flaps could operate at higher lift coefficients, thus the wing could be made smaller with consequent drag and mass changes.

The A-90B retained the conventional flaps, but replaced aluminium-lithium structures, fly-by-light and electrical actuation by more conventional technologies. These changes led to an increase in mass and size, relative to the A-90 and A90A. The three variants were then subjected to acquisition and direct operating cost studies and compared with existing aircraft, using consistent methods. Fig. 5 shows the relative DOCs for the three variants. The A-90 is rather worse then the A-90A and A-90B because the uncertainty about the variable-camber flaps and advanced technology led to higher acquisition costs which were not off-set by the performance improvements of the V-C flaps. The latter were not accurately predicted and are the subject of a current Cranfield study.

3 THE A-94 LONG-RANGE AIRLINER

3.1 A-94 Requirements

It was decided to study developments of the A-90 family on the long-range market because, according to current forecasts, air traffic will more than double by the year 2011. The growth in the Asia/Pacific region is forecast to be 7%, and larger aircraft are required. The aircraft requirements were to match the range and field-length capability of the Boeing 747-400, but to provide a mixed-class capacity of 600 passengers and to reduce the DOC per seat-mile by 20%.

The A-90 fuselage cross-section and nose were retained on the A-94, but the wing was increased in size to that show in fig.6.

The main features of the aircraft requirement are shown, below more details are given in ref.3:-

i) Capacity

600 mixed class passengers at 34"/32" pitch with comfort standards at least as good as those of the Boeing 747.

One attendant's seat per 35 passengers with sufficient galley space per passenger of $0.025m^2$.

One toilet per 50 passengers.

The flight deck shall be designed for a two-person crew.

ii) Performance

600 passenger, mixed class and bag payload range shall be approximately 7300 nautical miles with 200 nm diversion and hold at 1500 ft for 30 minutes.

The maximum design cruise speed will not be less than 340kt. CAS.

Maximum cruise altitude should be at least 41,000ft.

Maximum certificated runway for maximum all up mass take-off is 11,000 ft at ISA sea level + 15°C conditions.

The FAR landing distance at maximum landing mass should not exceed 7000 ft at ISA sea level + 15°C conditions.

Runway loading should not exceed that of a Boeing 747-400 at ramp mass.

3.2 A-94 Description

i) Wings

A modest sweepback combined with a supercritical wing section enable Mach numbers in the region of 0.86 to be achieved. The aspect ratio is 8.4 and there is sufficient fuel tankage at spec. payload for a range of some 7300 miles with reserves. Double slotted flaps, low wing loading and leading edge devices should enable field performance targets to be met for the blue version, whilst the variable camber flaps, in conjunction with a Hybrid Laminar Flow Control system, should enhance the cruise performance for the A-94 Red version.

The wings are mainly constructed from aluminum-alloy with considerable use of composite materials.

ii) Fuselage

The double-bubble fuselage permits twin-aisle, 10 a breast seating on the main deck, and six on the upper deck. Passenger baggage is stored under the cabin floor. The seating arrangements are as in the specification but and alternative layout accommodates some 750 passengers at 32" seat pitch. A quick-change version can accommodate twin rows of 8 ft x 8 ft containers. The fuselage is largely designed to use aluminum-alloy construction.

iii) Powerplant

The configuration consists of a low wing with 4 pod-mounted Trent powerplants. The engine nacelles form part of the Hybrid Laminar Flow Control system s on the A-94 Red Version (FIG.7).

The wing laminar-Flow system provides suction to the upper leading edges, by means of dedicated compressors driven by the secondary power system.

iv) Tail Unit

The aircraft utilises an all-moving fuselage-mounted tail. Trim is obtained by tailplane movement whilst control is provided by the elevators. This powerful arrangement is necessary to trim out the large pitching moments produced by the wing high-lift devices. Fig 8 shows a CAD model of the fin and it's attachment to the fuselages, whilst Fig 9 shows some of the results of structural finite-element analyses.

v) Landing Gear

Such large aircraft led to the expected problems with landing gear. The lighter red aircraft utilised the main gear arrangement of fig 10 with four six wheel bogies. The heavier blue aircraft used five main gears with four wheel bogies (fig 11). Both aircraft use a four wheel in-line axle nose gear.

vi) Operational Aspects

The aircraft both use generally conventional avionic and airframe systems, albeit of higher capacity than current aircraft. The exceptions were the systems associated with laminar-Flow and variable-camber flaps.

Maintainability and reliability prediction showed that the aircraft should meet targets and have a dispatch reliability of better than 97%. Fig 12 shows an estimate of turn-round times, and Fig. 13 shows aircraft servicing using conventional means.

Table 1 shows a summary of aircraft dimensions and masses. These indicate, along with other high-capacity aircraft studies, that such aircraft will have a significant impact on the airport environment. This includes passenger and cargo handling and maintenance, but also impacts on emergency evacuation, Fig 14 shows an initial scheme for escape slide deployment, but further research is required.

3.3 Performance, Costs and Lessons Learnt

Fig 16 shows the payload/range predication for both A94 aircraft, and a version of the blue aircraft with winglets. It can be seen that the latter aircraft meets the requirements but the others are slightly deficient. The red laminar-Flow aircraft was effectively a modified turbulent design and full benefits of new technology can only be realised if the aircraft is optimised with the new technologies at the conceptual design phase. Independent research at the College of Aeronautics has shown significant benefits from aircraft optimised to take account of laminar-flow and variable camber.

Other performance targets were met or exceeded by both designs except for rather disappointing cost predications . Acquisition costs were typically $200m per aircraft depending on build numbers and technology risk factors. Direct operating costs per seat mile costs were at best, some 12% lower than the Boeing 747-400.

The aircraft suffered from significant trim drag penalties at normal centre of gravity conditions. Flight dynamics students suggested flight control system modification to correct this, but an easier solution would be to move the wing forward on the fuselage on the next design iteration.

A large half-aircraft wind tunnel model was tested, to investigate the wing fuselage fillet region. Flow-visualisation tests were performed but these need to be continued.

An interesting lesson learnt was the cargo volume limitations posed by this class of aircraft. A consequence of double-deck aircraft is the reduction in the cargo baggage container capacity relative to the number of passengers carried. This is because although the fuselage lengths are little longer than the 747, there is only the space below the main deck for baggage storage for 50% extra passengers. This is compounded by the fact that the new aircraft have bigger wings and landing gear, which further erode under-main-deck space.

The following table shows the number of under-deck LD3 containers that may be carried by some wide-body aircraft:-

TYPE	NO. OF LD3s	NO.OF PASSENGERS/ CONTAINER
Airbus A340-300	32	9.2
Boeing 747-400	30	14
Cranfield A-94	26	23

It can thus be seen that most of the container space is likely to be used for passenger baggage, thus reducing the amount of space available for cargo.

Air cargo carriage is increasing at a higher rate than that for passengers, so large aircraft such as the A-94 may seem a retro-grade step in this context. The large aircraft, however could be modified to combi or dedicated all-cargo aircraft to alleviate this problem. Under-deck and main deck cargo could be handled as for the 747, but upper deck cargo would be more difficult. It would be possible to use 'igloo' standard containers on the upper deck, and a nose docking-port could help loading and also be useful for maintenance access.

4. CONCLUSIONS

The A-90 Short-Range project aircraft has been designed in considerable detail and has the potential of meeting mass, cost and airport requirements. It should exceed the range target of 2000 N miles with 500 passengers or carry 620 passengers 1700 N miles or 345 passengers for 3500 N miles.

The novel shoulder wing arrangement gives good engine clearance and has considerable flexibility for civil or military cargo operations. Ditching characteristics should be adequate, but research is being carried out in terms of emergency evacuation.

The twin-engine arrangement is feasible on such a large aircraft, but leads to potential problems with the provision of bleed-air and secondary power. These were resolved by careful system design.

The A-94 Long-Range project was a detailed study of a type of aircraft of current interest. It showed that such an aircraft is feasible, and should meet market requirements, although a 20% D.O.C. reduction is difficult to achieve. New technologies such as laminar-flow and variable-camber flaps are potentially rewarding but care must be taken to integrate them into a fully-optimised conceptual design.

The new large aircraft designs are potentially attractive in terms of operating costs and appear feasible in terms of design and manufacture. Designers have striven to minimise their impact on airports, but there are several, soluble, problems. The solutions require considerable investment, and careful appraisals must be made to ensure that the entire aircraft system will produce the desired benefits.

The A-90 and A-94 projects provided realistic environments in which students learned how to design practical components, work as team and present their results orally, and in written theses. The theses contain some 400 engineering drawings, produced by tradition and CAD methods. Some 60 theses have been published, giving some 8000 pages of description and analysis.

Students have been gives "hands-on" experience of computer techniques, such as CAD, Finite-Element Analysis, Composite Materials Analysis as well as a wide range of dedicated analysis programs. They have researched up-to-date aeronautical technologies, such as active control, all-electric aircraft, and advanced materials. These activities will provide information of use to other members of the Aerospace Community. Students were drawn from many counties in the World, and many will reach senior positions within their countries and, hopefully, benefit aerospace activities throughout the world.

BIBLIOGRAPHY

[1] J.P. Fielding. *Report of the project design of the Cranfield A-90 short-haul 500-seat airliner project.* CofA Report NFP 9103, Cranfield Institute of Technology, United Kingdom. July 1991.

[2] P.T.L. Lim. *Technical and Commercial Viability of the A-90 500 seat short haul airliner.* MSc thesis, Cranfield Institute of Technology. September 1992.

[3] J.P. Fielding. *600 passenger Long Range Airliner A-94 DAeT 9400 Red* Cranfield University. September 1994.

Table 1:
SPECIFICATION DIMENSIONS AND QUANTITIES FOR THE A94

The blue Aircraft has been designed as a "conventional aircraft", using current materials and systems. The Red Aircraft has been designed to incorporate advanced material with high technology features such as hybrid laminar Flow on the wing and engine nacelles and variable camber flaps on the wing.

Wing		
Gross Wing Area	$672m^2$ Red	$688m^2$ Blue
Span	75.15m Red	76m Blue
Aspect Ratio	8.4 Both	
Quarter Chord Sweep	30° Both	
Tailplane		
Gross Area	$185m^2$ Both	
Span	26m Both	
Aspect Ratio	10.3 Both	
Fin		
Nominal Area	$125.7m^2$ Both	
Effective Aspect Ratio	1.786 Both	
Fuselage		
Length	69m Both	
Maximum Width	6.56m Both	
Maximum Height	7.76m Both	
Main Cabin Length	57m Both	
Powerplant		
Engines Rolls Royce Trent	877 Both	
Sea Level Static Thrust	356.2 kN Both	
Masses		
Maximum Take Off	506,548 kg Red	519,689 kg Blue
Maximum Payload	67,500 kg Both	
Maximum Volumetric Fuel	230,000kg Red	236,000 Blue

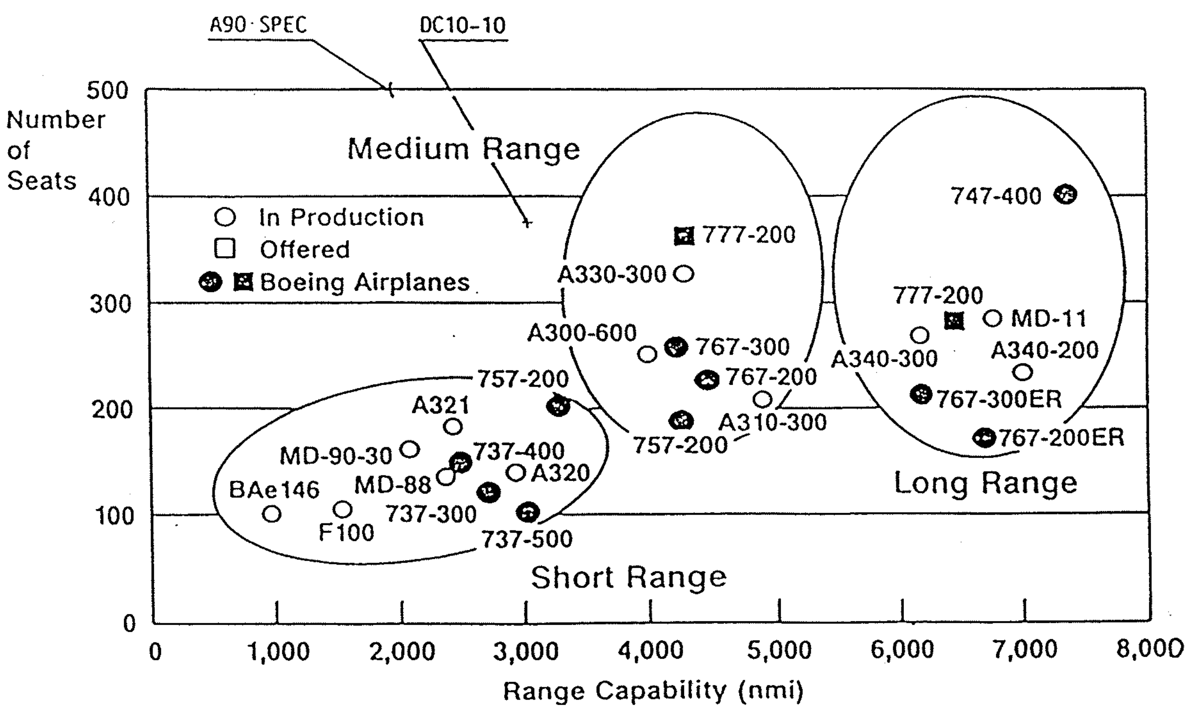


FIG. 1 JET TRANSPORT SEAT/RANGE PERFORMANCE (COURTESY BOEING)

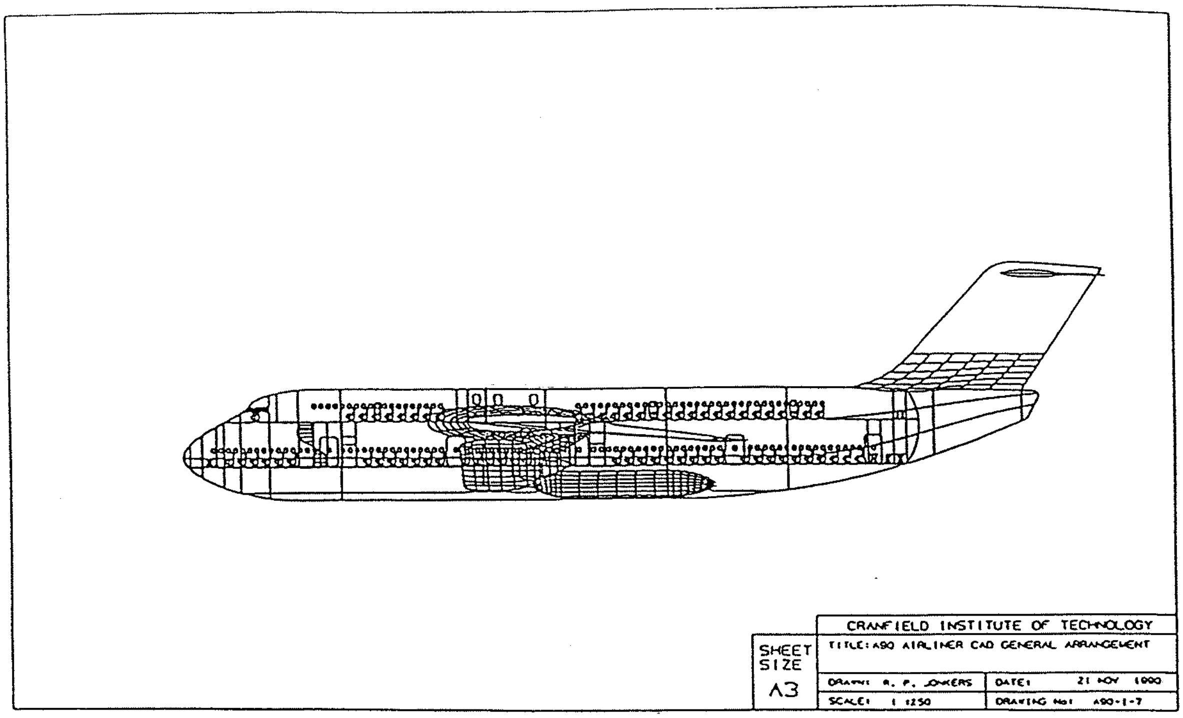


FIG. 2 A-90 FUSELAGE

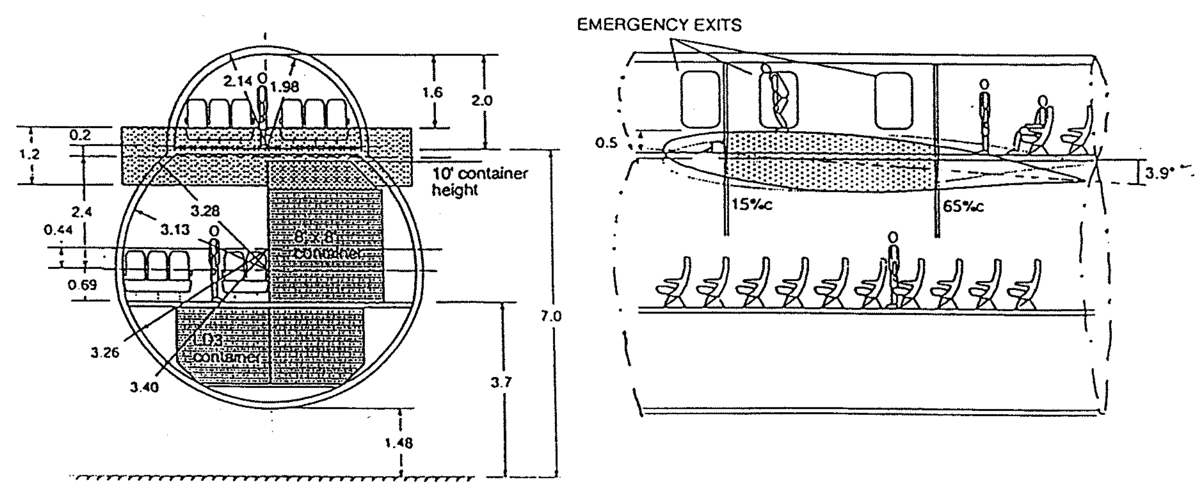


FIG. 3 A-90 CROSS-SECTION AND EMERGENCY EXITS

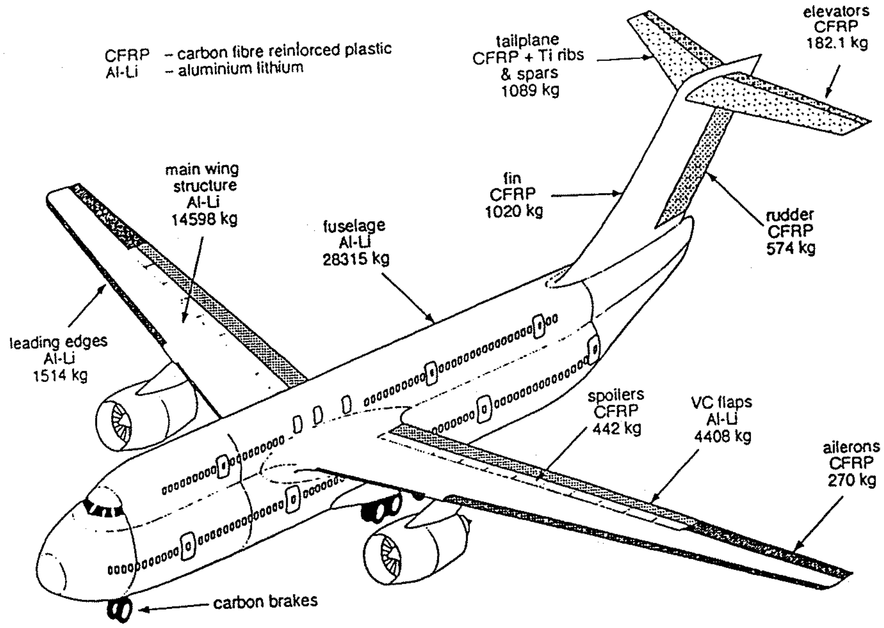


FIGURE 4 A-90 CONFIGURATION

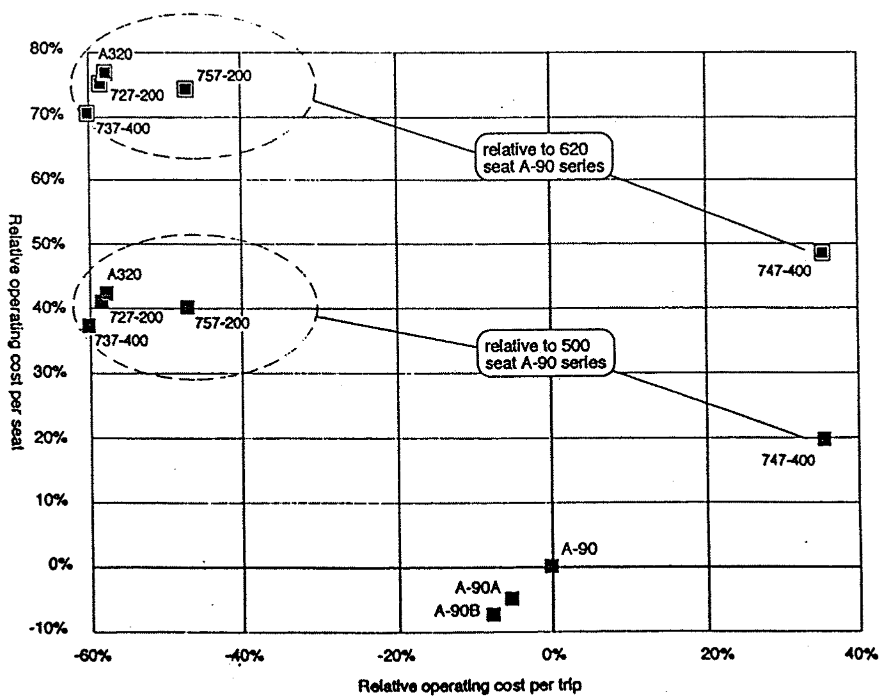


FIGURE 5 A-90 RELATIVE DIRECT OP. COSTS

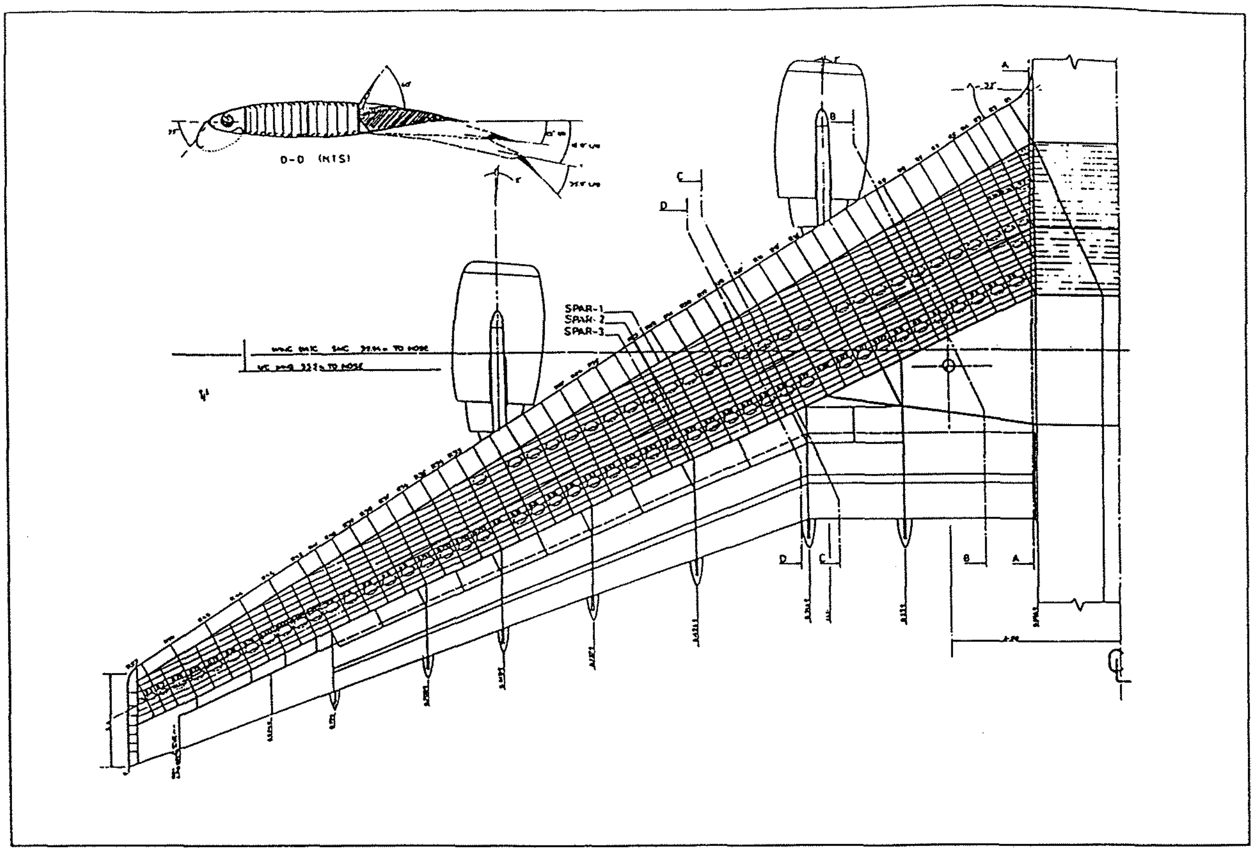


FIGURE 6 A-94 WING

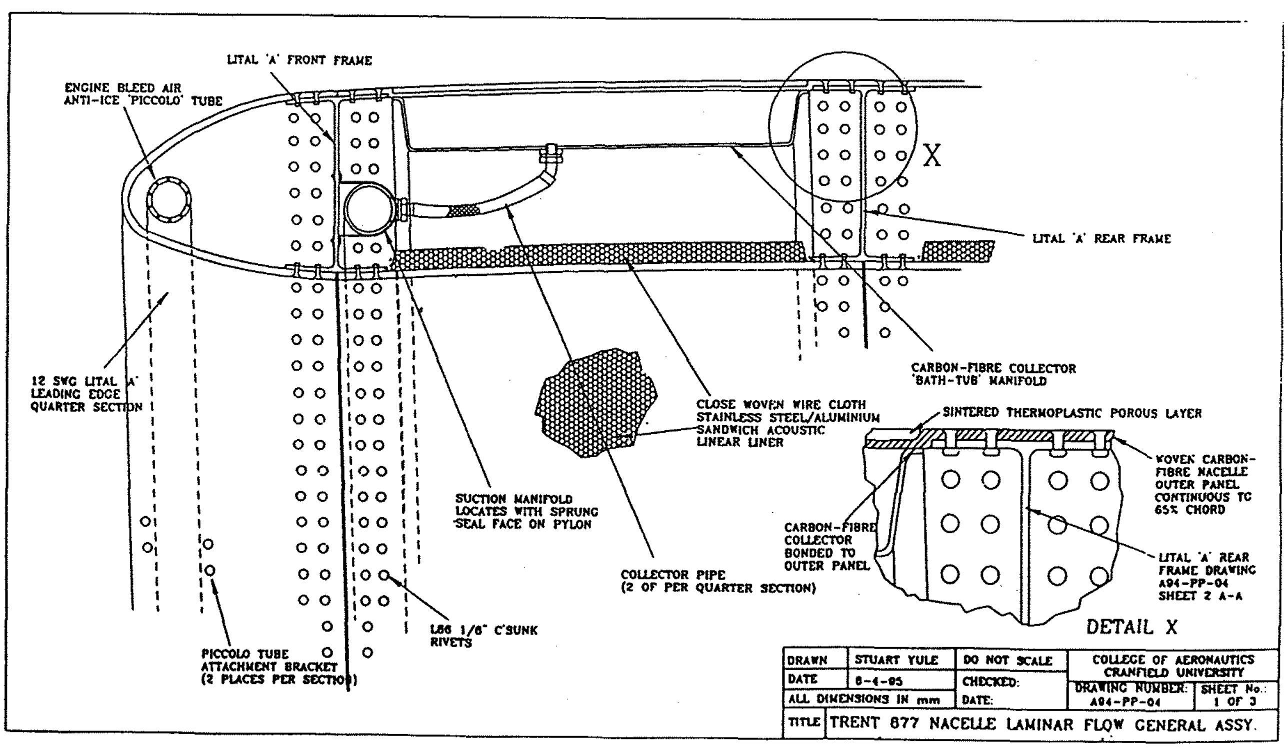


FIGURE 7 NACELLE DETAIL

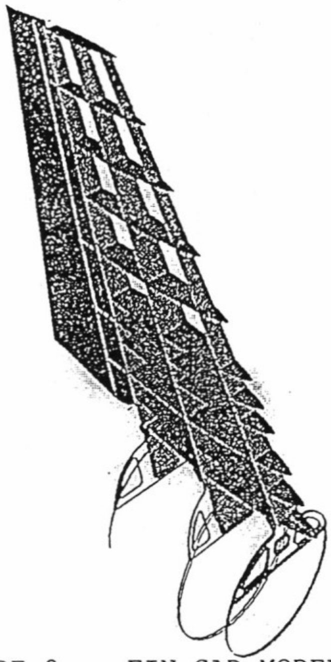
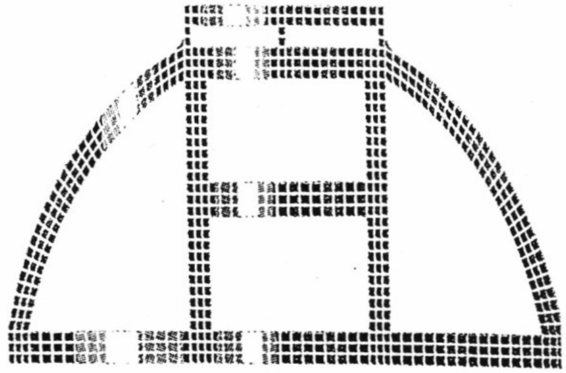


FIGURE 8 FIN CAD MODEL

FIGURE 9



FINITE ELEMENT MODEL OF FIN PICK-UP FITTING

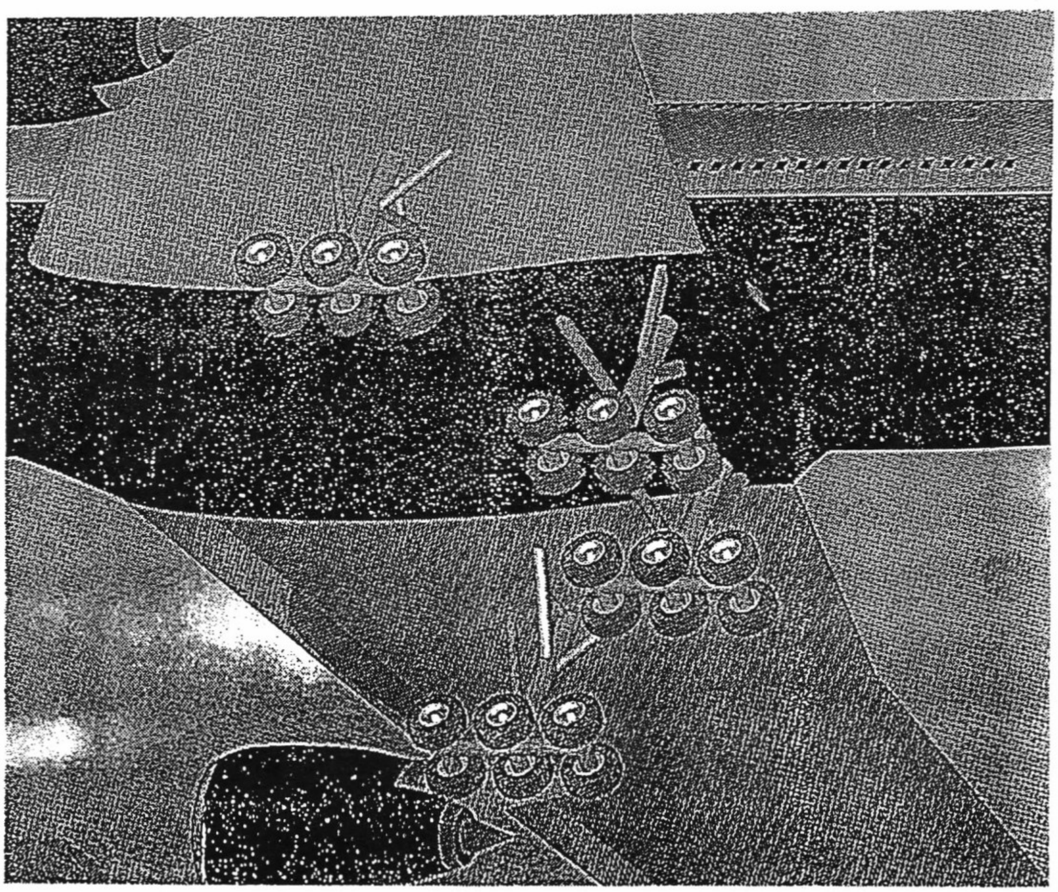


FIGURE 10 MAIN LANDING GEAR OF LIGHTER A-94 VERSION

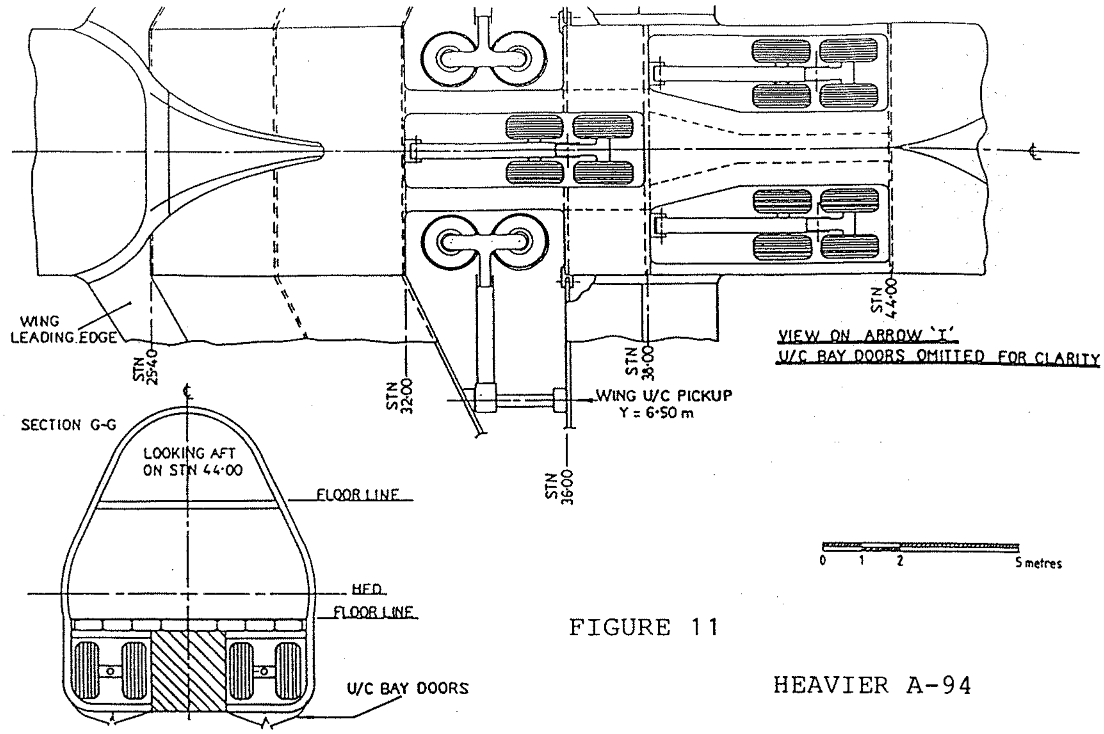
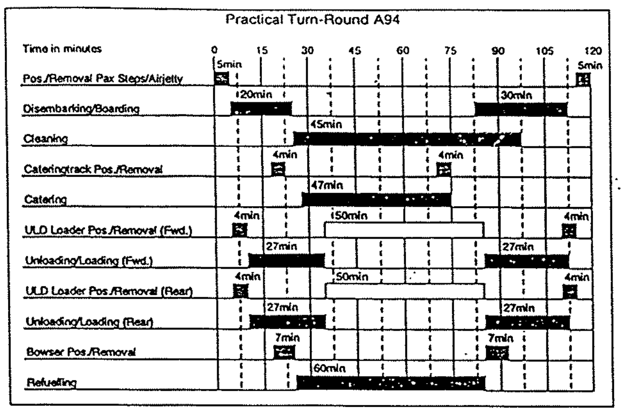


FIGURE 11

HEAVIER A-94

FIGURE 12



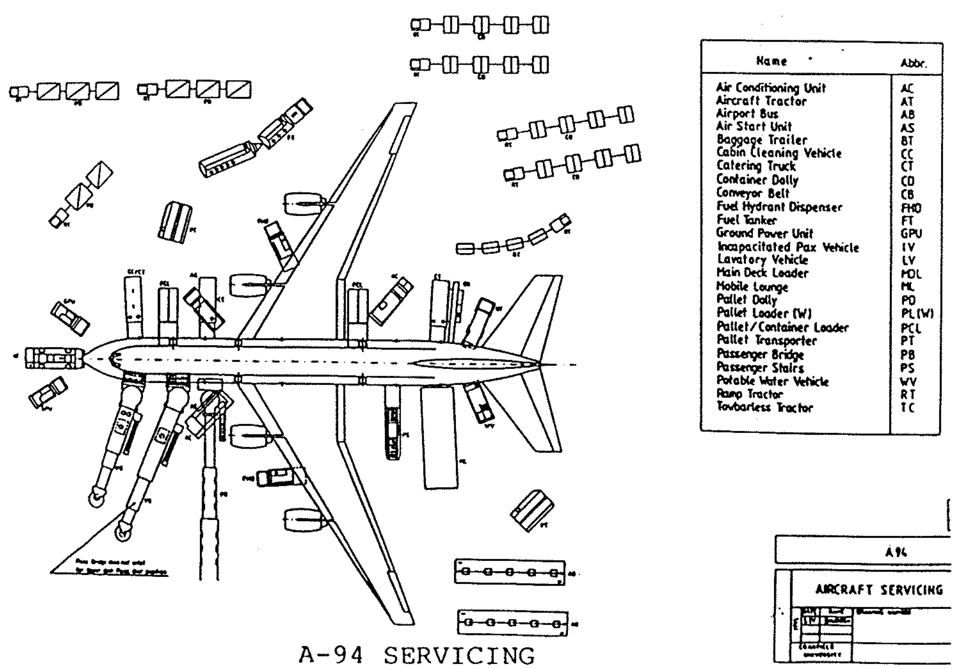


FIGURE 13

A-94 SERVICING

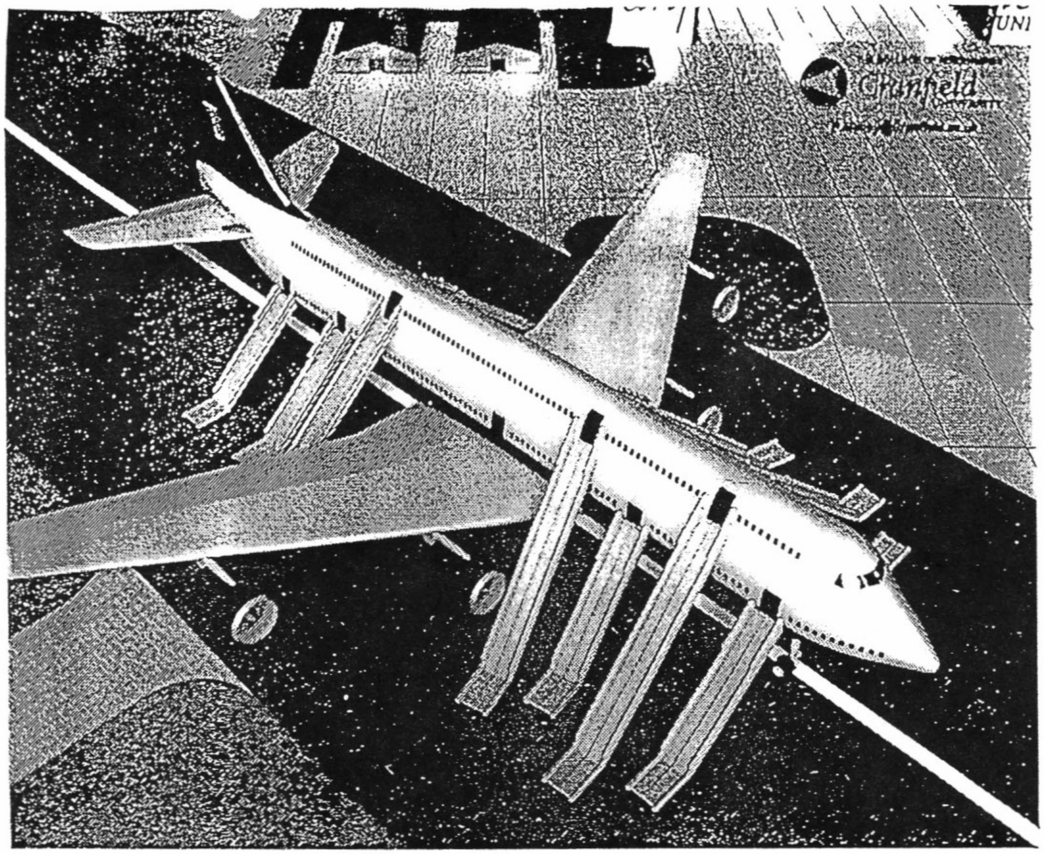


FIGURE 14 ESCAPE SLIDES

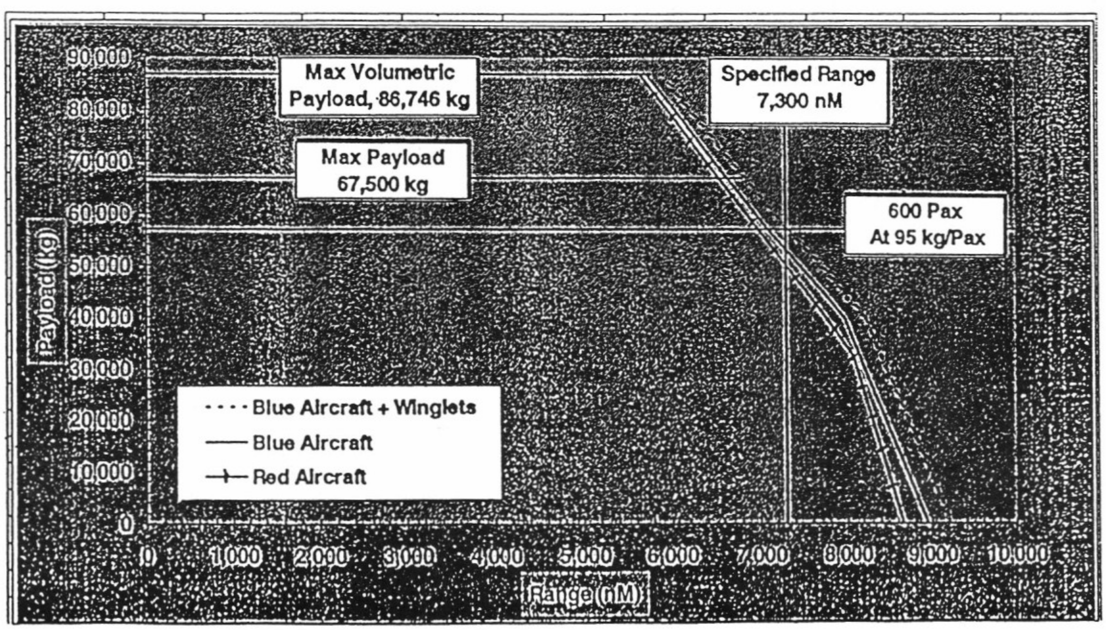


FIGURE 15 A-94 PAYLOAD RANGE DIAGRAM