SYSTEMS ENGINEERING FRAMEWORK TO ASSESS THE EFFECT OF VERY LARGE CAPACITY AIRCRAFT IN AIRPORT OPERATIONS

by

Alceste Venturini

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APPROVED:

Dr. Antonio A. Trani, Chairman

Dr. Donald R. Drew

Dr. Richard D. Walker

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(ABSTRACT)

The purpose of this research thesis is to develop an integrated framework methodology to assess the effects of VLCA operations at existing and future airports. The procedure described here investigates airport, airline and user impacts of VLCA operations using a systems engineering approach to understand the trade-off between economic and technological operational factors. Specific areas included in this systems engineering analysis are: a) the effect of VLCA operations in the airside and runway capacity, b) development of new airfield geometric design guidelines, c) terminal and landside impacts and gate compatibility issues, and d) possible noise and pavement design impacts.

This research defines realistic parametric templates of feasible aircraft design using computer methods [MATLAB, 1992][1] and then explores the impacts of proposed aircraft designs in airport operations, planning, capacity and economics. The analysis focuses on the airside and landside, terminal capacity, geometric design constraints and pavement and noise impacts of VLCA operations using a systems engineering perspective where aircraft design inputs have quantifiable outcomes on airport capacity, infrastructure changes and ultimately in the cost of operations. The main thrust of this effort is to identify cost effective ways to facilitate the operations of VLCA aircraft at existing and future airports including development of new design guidelines.

1. MATLAB is a trademark of The Math Works, Inc., Massachusetts

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1. Introduction

1.1 Background

Several surveys of international airlines have confirmed the future need for a Very Large Capacity Aircraft (VLCA hereon), and have identified the Asia/Pacific region as the first market to require such a very large aircraft. The surveys have also identified that certainly there will be a requirement for an airplane substantially bigger than the existing Boeing 747-400 and several airframe manufacturers are already preparing for the potential launch of a VLCA aircraft later in the decade. Such an aircraft could enter service early in the next century. In addition, various studies have suggested that very large capacity commercial transport aircraft could be operating as early as the year 2003, and they have also indicated that a stretched 800 to 1000-seat version will have a market in about 15 years [Lenorovitz, 1991; Smith, 1992; Sparaco, 1992].

The air carriers surveyed by the airframe manufacturers are generally very clear about what physical and aerodynamic characteristics VLCA airplanes should possess. Their desirable aircraft capacity target is to carry at least 600 passengers in a typical three-class cabin layout configuration. And for future versions, VLCA capacity would be increased in higher-density cabin configurations. For the purpose of this research thesis, a VLCA aircraft is defined here as any of the proposed 600 to 800-seat-passenger commercial transport aircraft being designed by Boeing Commercial Aircraft Group, Airbus Industries Consortium, or McDonnell Douglas Aircraft Corporation.

1.2 Airport and Airway Congestion

It is generally recognized that airport congestion and enroute traffic density are severe constraints on the sound development of civil air transport in the future [Wagenmakers, 1991]. Airport congestion is rapidly becoming the biggest single barrier to growth in several industrialized and developing regions of the world. Since the world's airline passenger traffic is expected to grow at an average rate of 5.5% per year, most large airport hubs will face growing congestion problems, [Gervais, 1994].

One way of increasing the airport capacity and to accommodate the increasing number of passengers in peak hours is to reduce the aircraft operation frequencies by increasing the average passenger capacity of the aircraft. This is in fact another motivation for using VLCA airplanes. In congested city pair corridors with limited runway acceptance rates.This is clearly a current trend. Another way of increasing the airport and terminal area capacity is to ensure that the traffic is divided more evenly over the twenty-four hours of the day. Airlines are already forced in this direction by the slot systems in place at many airports around the world. Although the slot system concept is a controversial subject, it cannot be denied that differentiation in landing charges may be effective and justifiable in dividing the traffic more evenly over the hours of the day. Higher peak hour charges tend to eliminate small and light aircraft. It may be added that smaller aircraft usually have lower approach speeds than the larger jets. This increases the separation problems during final approach, thereby reducing the runway acceptance rate.

One way to accommodate the increasing enroute traffic is by reducing longitudinal, lateral, and vertical separations. Modern technology, including satellite communication and positioning capabilities, may well lead to reduced separations. But a way to increase airway capacity is just by decreasing the enroute traffic density by means of introducing VLCA airplanes in significant numbers.

1.3 The Marketing Approach

The marketing approach developed in order to launch a new-generation very large capacity aircraft program is based on simple facts. Boeing 747 fleet has been the only very long-range, high-density transport aircraft available until today and most likely until the year 2000. McDonnell Douglas introduced its MD-11 into service in 1991 to satisfy airlines with a need to cover long-range medium-density routes and they are being joined by Airbus A340, A330 [Lenorovitz 1992], and Boeing 777 [Ropelewski and Wilson, 1994] in 1994-1995. Furthermore, 80% of the seat-miles produced by the world fleet of more than 900 B747's are devoted to long-range, high-density routes and airlines are now operating 800 long-range routes around the world with 100 of those to be considered high density. The first VLCA potential route survey [Gervais, 1994] shows that about 50 city-pairs in the world could economically justify a 600-seat aircraft by the time the first units are delivered. These routes require the use of two or more Boeing 747 aircraft within a period of three hours or less.

Airframe manufacturers are justifying the VLCA program by explaining that B747's airframe relies on thirty year old technologies and that now new technologies are becoming available. In addition, VLCA airplanes will relieve airport and airways congestion and reduce airline direct operating costs by 15-20%. McDonnell Douglas estimates show that the long-range widebody market will reach nearly 2,500 aircraft during the next 20 years, with a sale value exceeding $300 billion [Smith, 1992]. Also, according to Aerospatiale market forecast, 40% of commercial transport sales over the next 20 years will be in the 400-seat-plus category reaching a 60-aircraft per year production rate in 2010 [Sparaco, 1994].

The main thrust for VLCA acquisitions will come from airlines of the Asia-Pacific region, but not limited to airlines operating to or from Asia. Primary market areas for the VLCA are the Trans-Pacific, Inter-Asia, and Europe-Asia routes. Airports in those primary markets are preparing for VLCA as part of the construction of new airports (i.e., the new Denver International Airport) or the construction of new facilities on existing airports such as London Heathrow, Paris Charles de Gaulle, Tokyo Narita, Frankfurt, etc.

1.4 Research Scope, Objective, and Approach

The purpose of this research thesis is to develop an integrated framework methodology to assess the effects of VLCA operations at existing and future airports. The procedure described in the master thesis investigates airport, airline and user impacts of VLCA operations using a systems engineering approach to understand the trade-off between economic and technological operational factors.

Specific areas included in this systems engineering analysis are:

- The effect of VLCA operations in the airside and runway capacity
- The development of new airfield geometric design guidelines
- The terminal and landside impacts and gate compatibility issues
- The possible noise and pavement design impacts

These aspects or design modules are modeled using a Systems Engineering Approach which permits a blend of technological and socio-economic variables into the same model. This research defines realistic parametric templates of feasible aircraft design using computer methods [MATLAB, 1992] and then explores the impacts of proposed aircraft designs in airport operations, planning, capacity and economics. The analysis focuses on the airside and landside, terminal capacity, geometric design constraints and pavement and noise impacts of VLCA operations using a systems engineering perspective where aircraft design inputs have quantifiable outcomes on airport capacity, infrastructure changes and ultimately in the cost of operations. The main thrust of this effort is to identify cost effective ways to facilitate the operations of VLCA aircraft at existing and future airports including development of new design guidelines.

1.5 Airport Environment Description and Limitations

The overall airport environment may be considered as a system consisting of the following three main components:

- The airside component
- The terminal building component, and
- The Landside component

These three main components are further divided into respective sub components as follows:

Airside Component:

- Airspace
- Runways
- Taxiways
- Terminal aprons
- Aircraft parking positions and Gates
- Air traffic control systems

Main Terminal Building and Concourse Component:

- Ticketing, Central Waiting, and Baggage Claim Lobbies
- Airline Ticket Counter and Support Space Offices (ATO/SS)
- Outbound Baggage Facilities (OBF)
- Public Corridors (PC)
- Departure Lounges (DL)
- Baggage Claim Facilities (BCF)
- Airline Operations Area (AOA)
- Food and Beverage Services (FBS)
- Building Mechanical Systems (HVAC)
- Building Structure (BS)
- Immigration Services

- Customs Services
- Public Health Services, and
- Animal and Plant Health Inspection Services

Landside Component:

- Airport Access Systems
- Terminal Curb Frontage
- Public Parking Facilities

There are obvious concerns and limitations for VLCA airplanes to operate on a daily basis at existing airports. Among some of the airport compatibility problems facing VLCA aircraft are reduced runway acceptance rates, increased passenger flows at terminals, possible geometric design standard conflicts, and pavement design and noise constraints [Trani and Venturini, 1994].

The broad impact of the VLCA; constraints on airport facilities, environmental issues, safety problems must be kept always in mind from the beginning. The future success of VLCA depends on adequate preparation by airports to deal with these ancillary problems created by the operation of VLCA aircraft. This investigation attempts to look at the problem as a complex engineering problem involving variables of technological and economic order. Furthermore, it addresses a very clear trade-off in VLCA operations where airlines are forced to operate a non-optimal aircraft performance design that comply with current airport design standards or where airports face the daunting task to adjust their infrastructure to allow optimal design VLCA aircraft to operate routinely at existing and future airports. It is not clear whether the airport infrastructure of the future will change to allow the use of optimal VLCA aircraft or whether aircraft manufacturers will need to go exotic fixes such as folding wing concepts (offered by Boeing on the 777) or non-optimal aircraft designs (poor performance in the cruise regime).

William A. Fife [Fife, 1994], project manager for the PANY&NJ Aviation Department, said, the reality of the new generation aircraft development program provides both airport capacity relief and airport operational burdens. Also, Mr. Fife states that airport operators are concerned not only with aircraft movements, but more importantly passenger movement and ask the following questions that this research will try to answer:

- Will there be adequate gate capacity considering the wing spans of VLCA
- Will existing terminals, curb frontages, roadways, etc., be able to handle the peak surges of incoming passenger traffic?
- What are the impacts of the VLCA on existing airports?
- If the projected frequency of VLCA movements is low enough, can the VLCA operate safely at current FAA Airplane Design Group V and/or VI airports?

1.6 VLCA Technological Improvements

Airbus Industries engineering managers recently listed major technological gains that must be achieved before an efficient VLCA commercial transport can be launched [Sparaco, 1994]:

- A more flexible structure design associated with a 550-metric-ton (1,210,000-lb.) maximum takeoff weight (MTOW).
- Decreased per-seat empty weight
- Enhanced flight control characteristics for adequate handling
- Airport/runway compatibility and the resulting landing gear complexity
- Ninety-seconds emergency evacuation procedures for 600-plus passengers, in particular for the double deck VLCA concept.

VLCA needs technological solutions that are not available yet, but this is exactly the main motive behind this investigation. Furthermore, all the previous exploratory work and market forecast assumes that direct operating costs will be lower than those of current high capacity transports by at least 15%. Finally, when Boeing 747 entered airline service 22 years ago, airlines and airport authorities were taken by surprise at effects of the large aircraft entering service, and this situation should not be allowed to happen again, so this is another main thrust for this research.

1.7 Typical Airport Scenario

The proposed airport scenario for this VLCA economic impact study is a typical International Airport that serves both domestic and international wide-body high-density aircraft operations. It is clear from the outset that limitations of data collection militated against a satisfactory description and measurement of the various factors affecting VLCA economic impact on airport infrastructure as well as airline total operating costs. It is essential for the potential user of this program to understand the needs for intensive data collection in order to reduce potential margins of errors in the economic impact estimation.

2. Literature Review

2.1 Introduction

The objective of this literature review is to present some background on past and current research on the new-generation VLCA transport aircraft concepts. The new concepts reviewed here are those developed by three of the most well known airframe manufacturers in the world; Boeing Commercial Aircraft Group, Airbus Industries Consortium, and McDonnell Douglas Aircraft Corporation. By 1994 these aircraft manufacturers have undertaken serious studies to identify potential markets where VLCA aircraft could operate efficiently and economically. The same studies have produced sketchy aircraft configurations ranging in mass from 4,000 to 5,500 Kilonewtons (900,000 to 1,250,000 pounds) as shown in Figures 2.1, 2.2, and 2.3 [Sparaco, 1992 & 1994; Smith, 1992; Lenorovitz, 1991; and Gervais, 1994].

2.2 Boeing New Large Aircraft Concepts

The Boeing Corporation, in response to strong interest expressed by Pacific Rim and major customer airlines is beginning to develop either a follow-on to the 747-400 as soon as possible or a new larger aircraft to enter service around the turn of the century. Boeing is focusing its very large commercial transport development plan on three versions that would carry 20-50% more passengers than 747-400's. Two aircraft versions under study are 747 derivatives and the third is an all new large aircraft. The project tentatively has been designated the New Large Aircraft (NLA hereon).

According to Aviation Week & Space Technology, Boeing's first aircraft version option is to stretch the 747-400 about 110 centimeters (280 inches) by using equal-sized fore and aft fuselage plugs [Scott, O'Lone, and Proctor, 1992]. This would add 84 seats. The extra structural weight will be around 138 KN (31,000 lbs.) and would require use of a wing planned for the 747-400F freighter to maintain equivalent wing loadings to existing aircraft. In a typical three-class seating arrangement, the stretched 747 would seat 484, or 12 more passengers on the upper deck and 72 on the main deck.

According to a Boeing document entitled "Airplane Characteristics for Airport Planning, Model 747-400" [Boeing, 1990] the maximum allowable takeoff weight (MTOW) is about 3,870 KN (870,000 lbs.) with a range of 13,000 Kilometers (7,400 nautical miles). In consequence MTOW for the streched 747 version will probably not be extended substantially, so making its fly range only about 80% of current 747-400's. Then, many key routes may not be serviced, including flights from Tokyo to New York, Sydney, Dallas or London.

Boeing's second aircraft version option consists in extending the 747-400's upper deck to the full length of the main-deck passenger cabin. This modification would add 160 seats, to provide a total of 560 in a three-class seating arrangement configuration. As with the stretched version, range of a double-deck 747 would suffer. The upper-floor extension and the additional structural weight will be around 169 KN (38,000 lbs.), so to stay within its maximum takeoff weight limit, the transport would carry less fuel and achieve only about 73% of the range of today's 747-400.

Finally, the third aircraft option will be an entirely new large aircraft with longer and wider wingspan and larger fuselage. However, length and wheelbase will remain similar to those of the 747-400. This mega-transport will be powered by four large-fan engines and will also include bigger vertical and horizontal tails, be configured with full upper and lower passenger decks, and a cockpit located well forward on the aircraft's nose. This new NLA concept would be able to accommodate 650 passengers in a typical Asian airline seating configuration. The NLA's MTOW and range are envisioned to be approximately about 5,345 KN (1.2 million pounds) and 13,000 Km. (7,400 n.m.), respectively.

Advantages of both the stretched and double-decker 747's concepts should include a seat-mile cost lower than the 747 with no major change in aircraft wingspan and length. Furthermore, an additional advantage for the NLA transport will be an even lower seat-mile cost than the previous two versions. Future NLA stretched versions carrying up to 750 passengers could reduce DOC to record braking minimums.

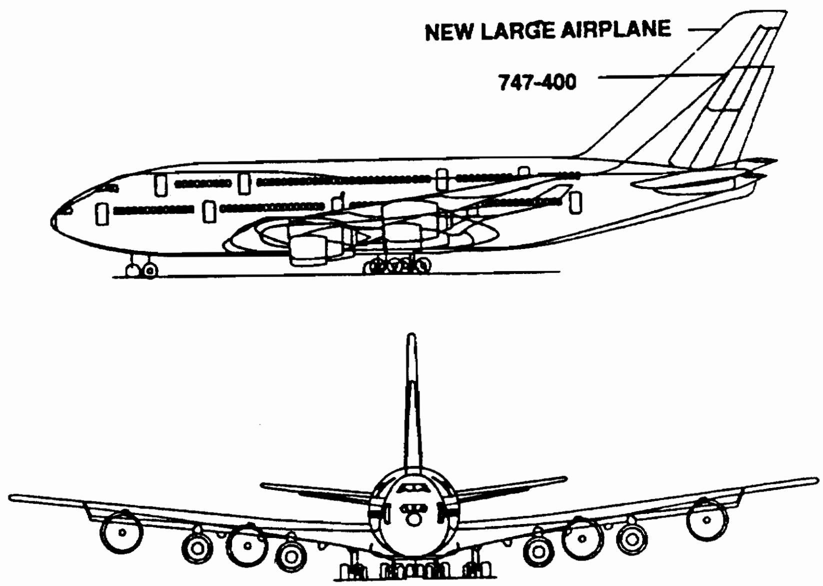


FIGURE 2.1 Boeing New Large Aircraft Concept

2.3 Airbus Ultra High Capacity Aircraft Program

Airbus Industries is actively pursuing exploratory research work and preliminary marketing efforts on its 600-seat Ultra High Capacity Aircraft (UHCA hereon) program. Currently, there are four separate European design teams that are working on various concepts of what could become the consortium's major technical and marketing effort in the coming years. Three of the teams belong to each of the main Airbus Industries partners; Aerospatiale of France, British Aerospace, and Deutsche Airbus of Germany. The fourth team looking to the UHCA concept belongs to Airbus Industries.

Airbus Industries first UHCA aircraft design option is based on "a single-deck horizontal double-bubble configuration with each seating bubble placed side-by-side along the length of the A330/A340 fuselage" when the UHCA fuselage is viewed in cross-section. The Airbus Industries family of UHCA's may offer airline customers a choice of three-class seating layout arrangements with capacities ranging from 500 to 800 seats, based on MTOW's between 443 and 570 metric tons (976,370 to 1,256,200 lbs.) [Sparaco, 1994].

According to Aviation Week & Space Technology, the present preliminary European UHCA design studies are likely to yield two basic models; a 500 to 600-seat 13,427 Km. (7,250 n.m.) range aircraft and a 600 to 800-seat stretched UHCA model with a lower maximum range [Sparaco,1992]. The UHCA european aircraft may be powered by four 278 to 343 KN (62,500 to 77,000-lbs.) thrust turbofans.The three main large engine manufacturers in the world, General Electric [Taverna, 1993], Pratt & Whitney [Kandebo 1993], and Rolls-Royce [Kandebo, 1992] can all offer increased thrust derivatives of existing engine types that will be compatible with Airbus Industries present tentative program schedule.

Aerospatiale's UHCA exploratory work is centered on the 600-seat ASX concept. Its team of engineers hope that by using a double-deck 7.20-meter-diameter (23.6 feet) fuselage will help keep the UHCA dimensions within physical limits of today's airport infrastructures, which is a critical issue from the new generation aircraft-airport compatibility point of view. Wingspan and length should not exceed 79.5 meters (261 ft.), which is the current airport design threshold criteria, still these dimensions will allow for the installation of 11-abreast business class seating arrangement and a six-abreast first-class seating configuration. The main and upper decks of the ASX would accommodate 370 and 230 seats, respectively [Sparaco, 1994].

Another subject under study at Aerospatiale is the freight and passenger baggage capacity for the ASX. Since the UHCA aircraft may have about the same length as a 747 (meaning about same underfloor cargo hold capacity) and since it will carry more passengers, then, there will be more passenger baggage, therefore less volume for cargo. As a result, Aerospatiale is evaluating making the ASX main deck a combi with about half the length for the passenger cabin and the remaining space for freight. The ASX development costs will be about $8 billion, and the aircraft's tag price probably will be in the $200-220-million bracket [Sparaco, 1994].

Deutsche Airbus is also considering a double-deck UHCA aircraft configuration. The German company favors a double-deck arrangement for the 800-seat version.The UHCA will not rely on the A330 or A340 technological standards but will be far more advanced. This aircraft could use laminar flow control, improved wing/nacelle integration, and more composite materials than the present Airbus versions. According to German executives, "composite materials will be more widely used, but the 600-seater should not have a carbon-fiber wing or fuselage, instead it should have conventional or slightly changed aluminum alloys, and perhaps new concepts in the detailed design of the structures. There continues to be a degree of caution on major applications of aluminum lithium, since the alloy's crack propagation characteristics are less predictable than conventional alloys. Also, its cost continues to remain high". In addition, German engineers are interested in looking for new flight control design developments that would allow Airbus Industries to build on the fly-by-wire technology pioneered in its A320. "One approach studied is the integration of the primary, secondary and autopilot computers. Transputers would be use and the number of computers required for the flight control system would be reduced" [Lenorovitz, 1991].

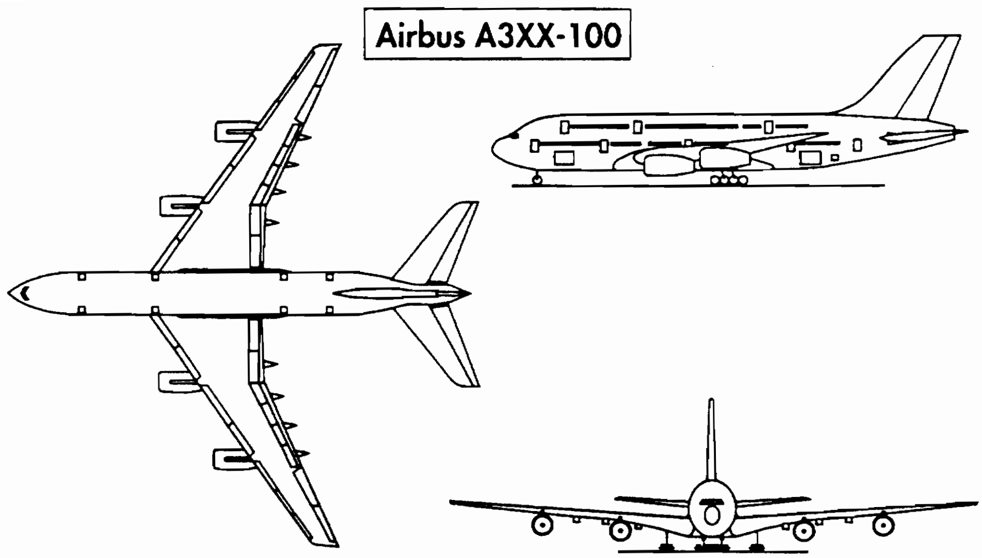


FIGURE 2.2 **Airbus Ultra High Capacity Aircraft Program**

2.4 Douglas High Capacity MD-12 Aircraft Concept

By May 1992, Douglas Aircraft Corporation had frozen the design configuration for the planned High Capacity MD-12 Aircraft concept (HCA hereon), an all new double deck transport with four engines and a cabin seating more than 400 passengers. This new leading design concept could place the new HCA aircraft in competition with the well-entrenched 747, and position Douglas for relatively quick entry into a super jumbo transport competition. Douglas has emphasized economics, range, and performance in a design that can be handled by existing airport terminal facilities [Smith, 1992].

The new HCA aircraft design concept includes an overall length of 62 m. (203 ft.), a maximum fuselage width of 115 cm. (293 in.), and an upper passenger deck that runs along the entire length of the fuselage. The HCA objective is to out-perform Boeing's 747-

400 in payload/range capability through the use of a new advanced wing and the twin passenger decks. Furthermore, Douglas has also envisioned a double-deck HCA MD-12 follow-on that could involve stretching the fuselage by 9.2 m. (30 ft.) in order to increase the payload capability to 650 passengers [Smith, 1992].

Aviation Week & Space Technology has described some features and characteristics that an HCA MD-12 should possess and include [Smith, 1992]:

- A Phase 1 aircraft that should seat 400 to 450 passengers in a typical three-class seating layout arrangement, with a stretched Phase 2 aircraft that should accommodate 600 to 650 passengers.
- The initial aircraft will come in several configurations: a long-range model, a high-capacity version, a combi, and a freighter.
- The length of the upper passenger deck for the long-range version will extend only about two-thirds of the available space. The capacity and range of this long-range option should be about 430 passengers and 14,816 Km. (8,000 n.m.), respectively.
- The length of the upper passenger deck for the high-capacity version will run the full length of the fuselage. The capacity and range of this high-capacity option should be about 511 passengers and 13,334 Km. (7,200 n.m.), respectively.
- Both the long-range and high-density models will have a single-level passenger loading and unloading with the two passenger decks connected by two conventional staircases.
- The HCA fuselage design could be extended to accommodate up to 800 passengers.
- The HCA will also include four main landing gear trucks, ten-foot windup extensions, and four very powerful engines ranging from 276 to 400 KN (62,000 to 90,000 lbs.) of thrust.

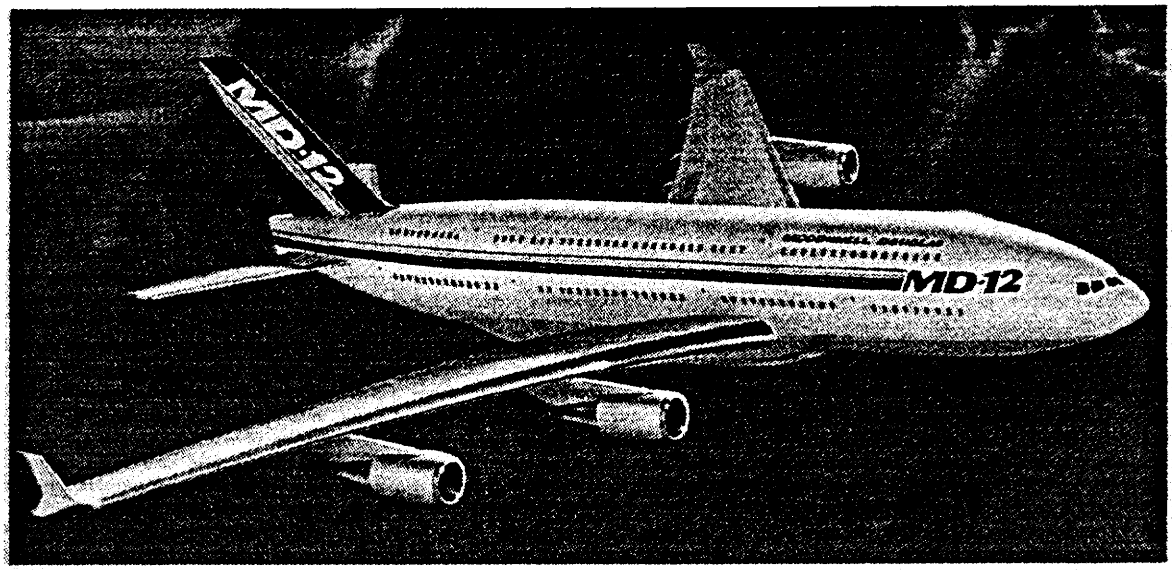


FIGURE 2.3 **Douglas High Capacity MD-12 Aircraft Concept**

2.5 VLCA Aircraft Separation Analysis & Wake Vortex Model

A useful procedure for establishing approach aircraft in-trail separations has been the roll control ratio criteria developed by Andrews et. al. [Andrews et al., 1971]. The procedure estimates the ratio of the roll acceleration produced by a leading aircraft vortex shed on a trailing aircraft and the roll acceleration of the trailing aircraft at maximum aileron deflection. Using Rossow and Tinling nomenclature [Rossow and Tinling, 1988] this parameter is defined mathematically as,

$$\dot{P} = \frac{\dot{p}_v}{\dot{p}_{\delta m}} \qquad \text{(EQ. 2.1)}$$

where, $\dot{p}_v$ (rad/sq.sec.) is the induced roll acceleration on a trailing aircraft due to the wake vortex of a leading aircraft, $\dot{p}_{\delta m}$ (rad/sq.sec.) is the maximum roll acceleration possible with full deflection of the lateral control aerodynamic surfaces, and $\dot{P}$ (rad/sq.sec.) is the roll acceleration quotient.

Flight evaluations conducted by NASA and the FAA in the seventies suggested separation minima between successive aircraft arrivals according to the rolling acceleration quotient principle [Andrews et. al, 1971; Dunham et. al., 1971; Robinson et al., 1972]. In these studies various aircraft were subjected to the wake vorticity of a Lockheed C5-A and a Convair 990 with the dynamic responses of probing (i.e., trailing) aircraft recorded including pilot inputs needed to maintain aircraft control. One point of argument, however, has been the issue of how much roll control is left on an aircraft before a pilot judges the system is unsafe [Rossow and Tinling, 1988]. Several studies have suggested that $\dot{P}$ values of 0.5 to 1.0 are acceptable for most Instrument Meteorological Conditions (IMC) approach conditions [Rossow and Tinling, 1988] but even such guidelines imply a wide range of separation minima between approaching aircraft.

Using a roll acceleration quotient of unity Andrews et al. [Andrews et al., 1971] estimated the separation between three types of aircraft: small, medium size and large transports as they follow large and heavy jet transports. Using the same guiding principle Trani and Venturini [1994] hypothesize expected approach aircraft in-trail separations from VLCA aircraft as shown in Figure 2.4. Using linear interpolation for the few data points available a simple relationship can be found for generalizing aircraft separation criteria. Using W_i and W_j as the approach landing weights (in KN) of a leading and a trailing aircraft, respectively, we define a general in-trail separation expression as,

$$\delta_{ij} = Max\left(L_1 + L_2 W_i, K_1 + K_2 W_i + K_3 \{W_j\}^{K_4}\right) \qquad \text{(EQ. 2.2)}$$

where, δ_{ij} is the recommended separation distance between aircraft i and j in Km. (n.m.), K_1, K_2, K_3, and K_4 are regression constants found to be 6.1000, 0.00378, -0.24593 and -0.44145, respectively. Constants L_1 and L_2 are 4.7000 and 0.00172 and have been derived using empirical roll control flight simulation data [Robinson and Richardson, 1972] with modifications by the authors to reflect possible application to VLCA aircraft. This equation is plotted in Figure 2.5.

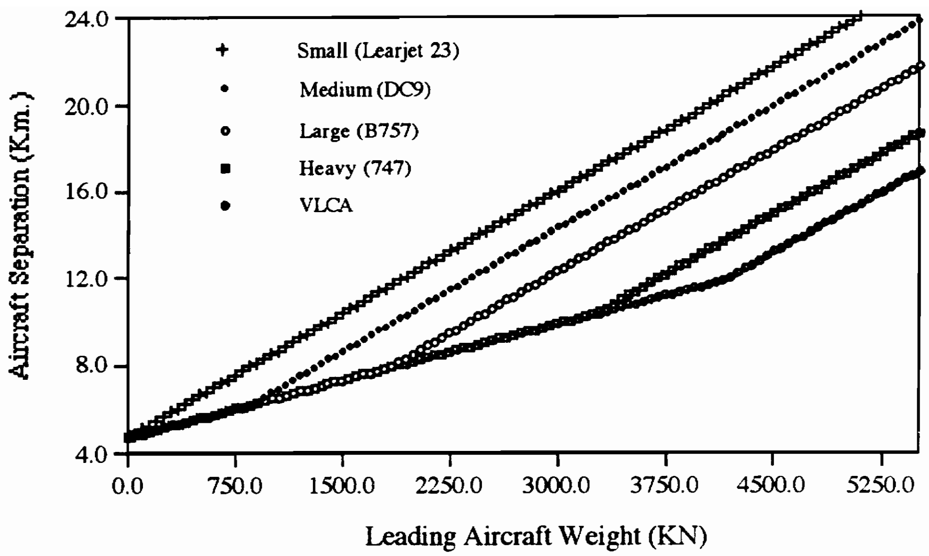


FIGURE 2.4 **Recommended Approach Aircraft In-trail Separation Criteria from VLCA Aircraft**

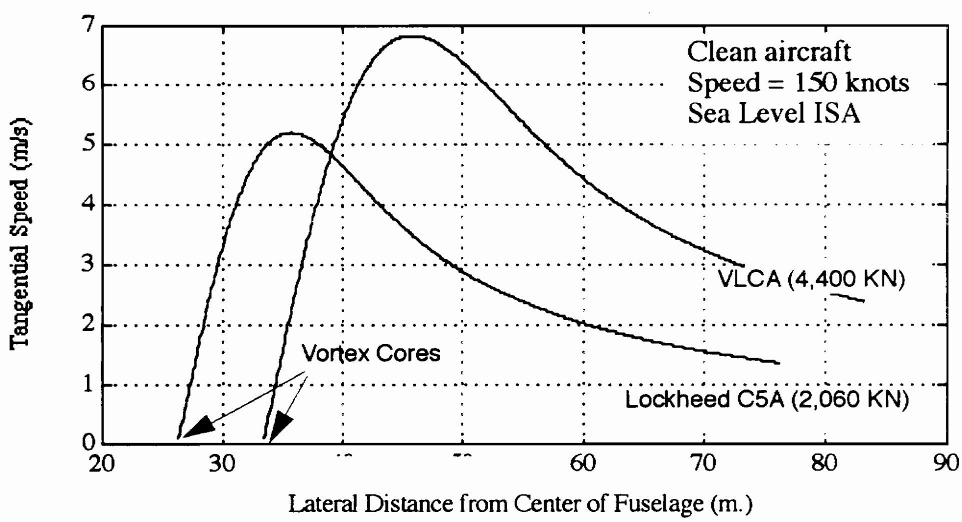


FIGURE 2.5 **Predicted Vortex Wake Tangential Speed Distribution for a VLCA and a Lockheed C5A (8 n.m. Behind the Generating Aircraft)**

Extrapolating these results for a hypothetical VLCA aircraft weighing 4,405 KN in the landing configuration one can see that aircraft separations of up to 20 Km. (11.0 n.m.) might be needed to dissipate the harmful effects of the wake vortex generated against general aviation and small business aircraft. The wake vortex intensity of a VLCA aircraft (i.e., 81.5 m. in wingspan), measured by the maximum tangential component of the vortex, would be around 33% higher than those generated by a Lockheed C5A military transport aircraft approaching at 150 knots at sea level (in the clean aircraft configuration). A plot of the expected tangential spanwise vortex speed distribution in the outboard wing section of both aircraft is shown in Figure 2.5 at a distance of 14.8 Km (8 n.m.) behind the generating aircraft. Note that although the vertical decay of the vortex is also a factor in the probability of penetration under realistic conditions the maximum tangential speeds observed 14.8 Km.behind the generating aircraft are substantial to upset general aviation aircraft including small business jets with sluggish roll control capabilities. The results have been estimated using elliptical wingspan loading distribution and the semi-empirical vortex decay model suggested by Robinson and Larson [Robinson and Larson, 1972].

The results shown in Figures 2.4 and 2.5 clearly illustrate the need for detailed analysis of wake vortex interactions for future transports. Computer simulations and graphical visualization tools could, at this juncture, aid in developing conclusions regarding wake vortex interactions involving VLCA aircraft, which in turn will be applied to the estimation of capacity and delay analysis of various aircraft population mixes. The airport capacity implications of very large in-trail separations are very important in planning airport operations. For example mixing VLCA aircraft with commuters/business jets and even small transport aircraft (i.e., TERP C group) offers significant penalties to the runway capacity as illustrated in Figure 2.6. Using a generic airport scenario with two parallel runways (i.e., > 1,310 m separation and standard radar scan rate of 4.8 seconds) with mixed traffic on both runways a reduction of 18% in the arrival saturation capacity is found when twenty percent of the aircraft mix is VLCA type. These results have been obtained using the saturation capacity formulation of Harris [Harris, 1972, 1976] and quantified using the modified Airport Capacity Model (ACM) [Swedish, 1982]. Figure 2.6 contains a typical saturation capacity plot showing arrivals and departures for cases where the population of VLCA aircraft is varied from zero to twenty percent.

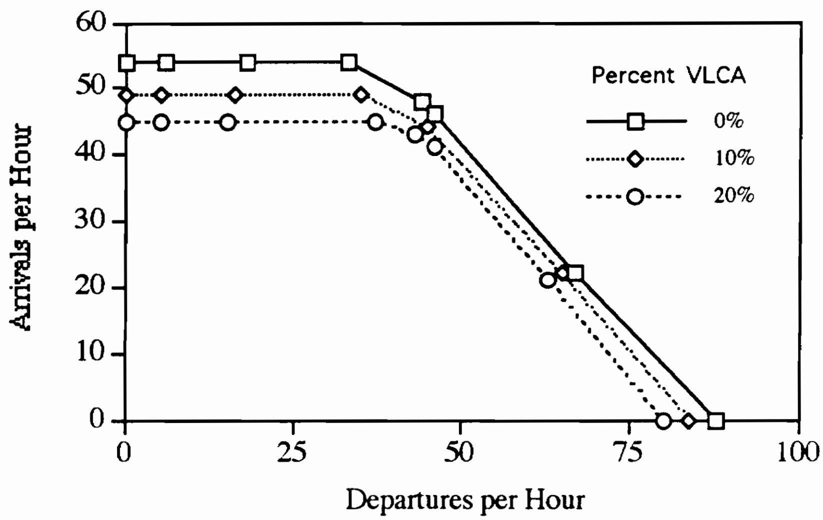


FIGURE 2.6 Runway Capacity Comparison for Various Aircraft Mixes (Parallel Runway Configuration with Mixed Traffic on Both Runways)

Note that a loss of both arrival and departure capacities is present as the VLCA population mix increases due to larger expected in-trail longitudinal separations. From the same figure it is noted that under high VLCA operations (i.e., 20% of the total airport mix) a reduction of up to 10% in the departure saturation capacity is observed due to larger departure-departure separations expected. This, however, is not likely to translate into lower passenger demand levels at the airport terminal given the excessive capacity of each VLCA aircraft compared with those of conventional wide-body aircraft. The ultimate effect is dependent upon the fleet composition operating at the airport.

2.6 Landside Design Model

The most prominent effect of VLCA operations at large airports is the possible increment in passenger flows inside terminals and the gate compatibility problems associated with large wingspans. Analysis of VLCA aircraft/airport terminal compatibility can be executed with the use of computer simulation models such as ALSIM [FAA, 1990] and ALPS [Trani and Kulkarni, 1994]. This involves the modeling of terminals to determine Levels of Service (TLOS) given new passenger demand flows and to identify areas of possible improvement to existing design guidelines such as the FAA advisory circular 150/5360 [FAA, 1993]. To illustrate the point we simulate the passenger flows through a large international concourse using ALPS - a computer simulation model developed at the Transportation Systems Laboratory at Virginia Tech. The results suggest possible reductions in TLOS as shown in Figure 2.7 for this terminal if no improvements are made to the facility. Shown in this figure is the physical representation of an international terminal with five gates for the VLCA scenario and seven gates for current heavy transport technology. In both cases the frontage requirements are the same (thus assuming complete replacement of current wide body technology with new VLCA aircraft to vindicate the effect of VLCA more clearly). Shown in Figure 2.7B are the corresponding transient queueing parameters at the immigration section of this airport. Thirty immigration servers are used in both cases with a normally distributed service time with mean service rate of 1.5 minutes and standard deviation at 0.5 minutes.

Note that in the worst case scenario (i.e., assuming VLCA at 95% load factor) the maximum queue lengths expected are around 15 passengers per station against only 7-8 for the baseline scenario (i.e., current technology aircraft). The passenger flows in the circulation corridor leading to the main terminal are also shown in Figure 2.7C. Note that once again the use of VLCA equipment at this airport terminal will degrade the level of service as indicated by the boundary line in the plot.

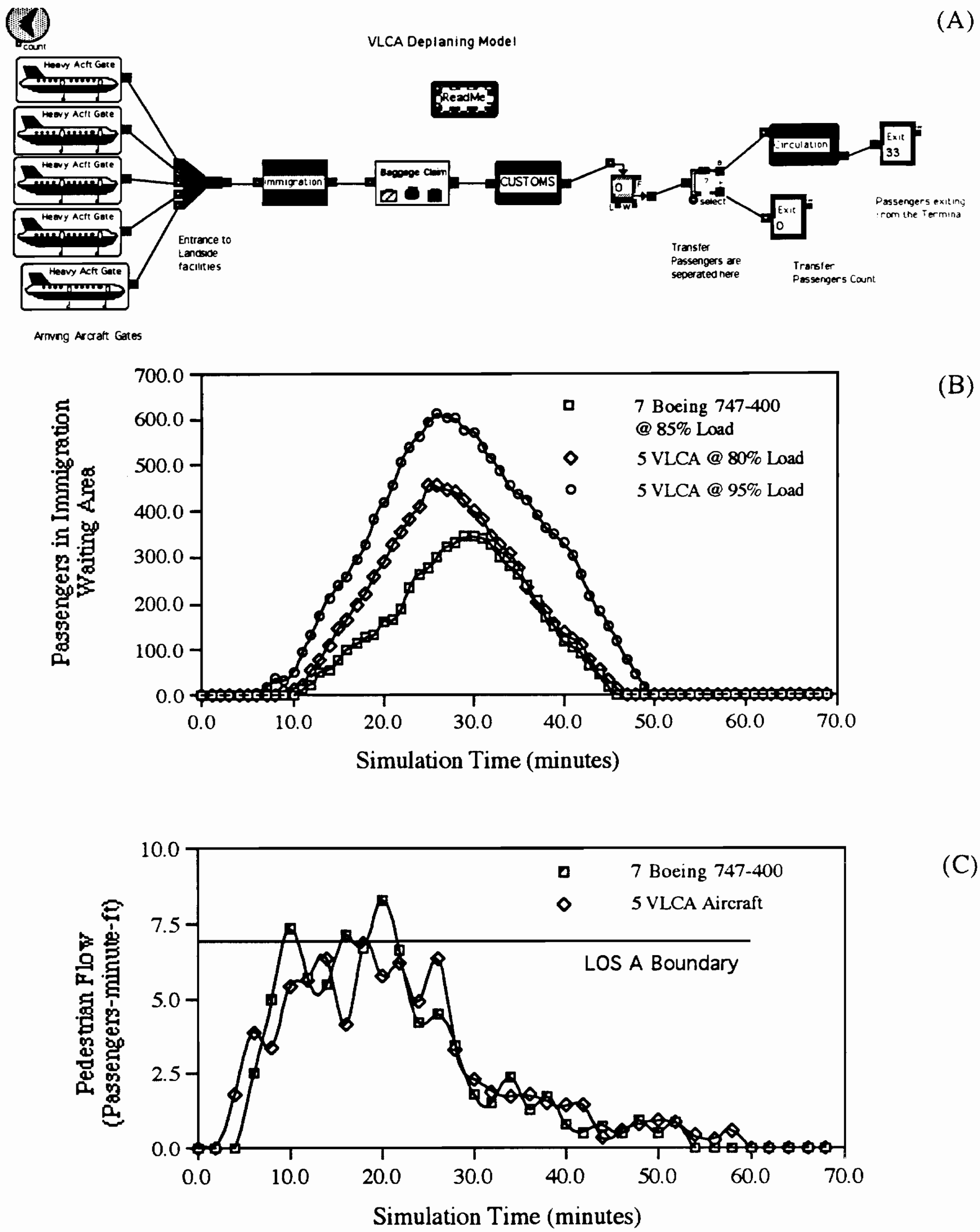


FIGURE 2.7 **VLCA Airport Terminal Operations Using an Airport Terminal Planning Model**

3. Methodology

3.1 Introduction

This chapter briefly discusses the methodology used for conducting this endeavor. As mentioned in Chapter one, the goal of this research is to develop a Systems Engineering Framework to assess the effect of VLCA in airport operations and planning in terms of the airline direct operating cost and airport infrastructure improvement cost. The systems approach consists in making use of an integrated model developed in MATLAB [The Math Works, 1992] which is an interactive system and programming language. Therefore, this chapter is devoted to the definition of systems engineering, perspective, and approach as well as on Systems Dynamics. The software program package MATLAB was used for developing the proposed model while STELLA II[1] helps as a visualization tool to better explain Systems Dynamics cause-effect relationships in the VLCA engineering study.

3.2 Systems Engineering and Analysis

Dean Benjamin S. Blanchard defines a system "as an assemblage or combination of elements or parts forming a complex or unitary whole; or an ordered and comprehensive assemblage of facts, principles in a coordinated field of knowledge, or a coordinated body of methods" [Blanchard, 1981]. While systems are composed of components, attributes, and relationships. A system is described by the interaction between many components (modules) and is created by the particular position and spatial distribution of its components. In our research the system is the VLCA aircraft and its overall impact on the environment (capacity and airport infrastructure), the parts or components are the different modules that make up our program (model) such as the aircraft sizing, wake vortex, pavement design, geometric design, terminal design etc.,. All these elements form a complex

1. STELLA is a trademark of High Performance Systems, Inc., New Hampshire.

engineering problem that requires that the elements be ordered and organized in a comprehensive methodology (systems engineering approach) for useful real-world applications.

Furthermore, Blanchard [1981] defines a systems engineering as a process that involves the application of efforts necessary to 1) transform an operational need (increasing worldwide air transportation demand) into a description of system performance parameters (airline direct operating cost, airport infrastructure improvement cost) and a preferred system configuration (optimal VLCA cruising performance) through the use of an iterative process (use of Matlab) of functional analysis, synthesis, optimization, definition, design, test, and evaluation; 2) integrate related technical parameters (aspect ratio, wingspan, MTOW, fuel fraction, etc.,.), and assure compatibility of all physical, functional, and program interfaces in a manner that optimizes the total system definition and design; and 3) integrate performance, producibility, reliability, maintainability, supportability, and other specialties into the total engineering effort [Blanchard, 1981].

Finally, the basic goal of systems engineering and analysis is to provide a system that will satisfactorily meet some identified need. This system must both perform in a specified manner and must do so effectively and efficiently. While the science of engineering is concerned with the action to be taken in the future, a systems engineering process consists in improving the certainty of decision making with respect to the objectives of engineering applications. In other words, the engineering decision making process is the intent to select the best approach by conducting a series of individual evaluations or analysis, where each evaluation stems from a specific problem definition [Blanchard, 1981].

To illustrate the use of systems engineering for the study of VLCA operations on existing and proposed airports, refer to Figure 3.1 where various fields of interest (i.e., pavement design, airside capacity, landside capacity, etc.) are combined under the umbrella of a single model from where conclusions are taken regarding courses of action to be considered in VLCA operations. In this figure it is seen that various aspects (modules) of VLCA operations are addressed using specific models (micromodels) and then fused into a single macromodel that contains pertinent results that can be modeled at a higher decision level (i.e., only results of specific simulations are included in the decision making VLCA systems engineering model). A simple analogy to this approach can be seen in computer war gaming models where the outcome of individual unit engagements (i.e., air engagements) is later used in campaign models to draw definite conclusions of the outcome of a battle or even the complete campaign [Trani and Drew, 1989].

3.3 Systems Perspective and Approach

To understand the systems approach to solving complex engineering problems it is essential to look at the problems in a systems perspective. According to M.I.T. Professor Jay W. Forrester "Systems awareness is the formal awareness, of the parts of a system, their interactions and the interdependencies between the parts of the system. This interaction and interdependency produces an information feedback which is goal seeking and self correcting. A feedback control system exists whenever the environment causes a decision which in turn affects the original environment" [Forrester, 1975].

In order to describe any system an engineer should be able to describe verbally, graphically, and mathematically the separate parts of the system, their functions, the methods of interconnection between the components and how they interdependent on each other. A dynamic system is one which is changing with the progress of time. The various components of the system interact to create new conditions and alternatives. This kind of systems can be present in all fields of study such as engineering, management, nature, or economics just to mention a few.

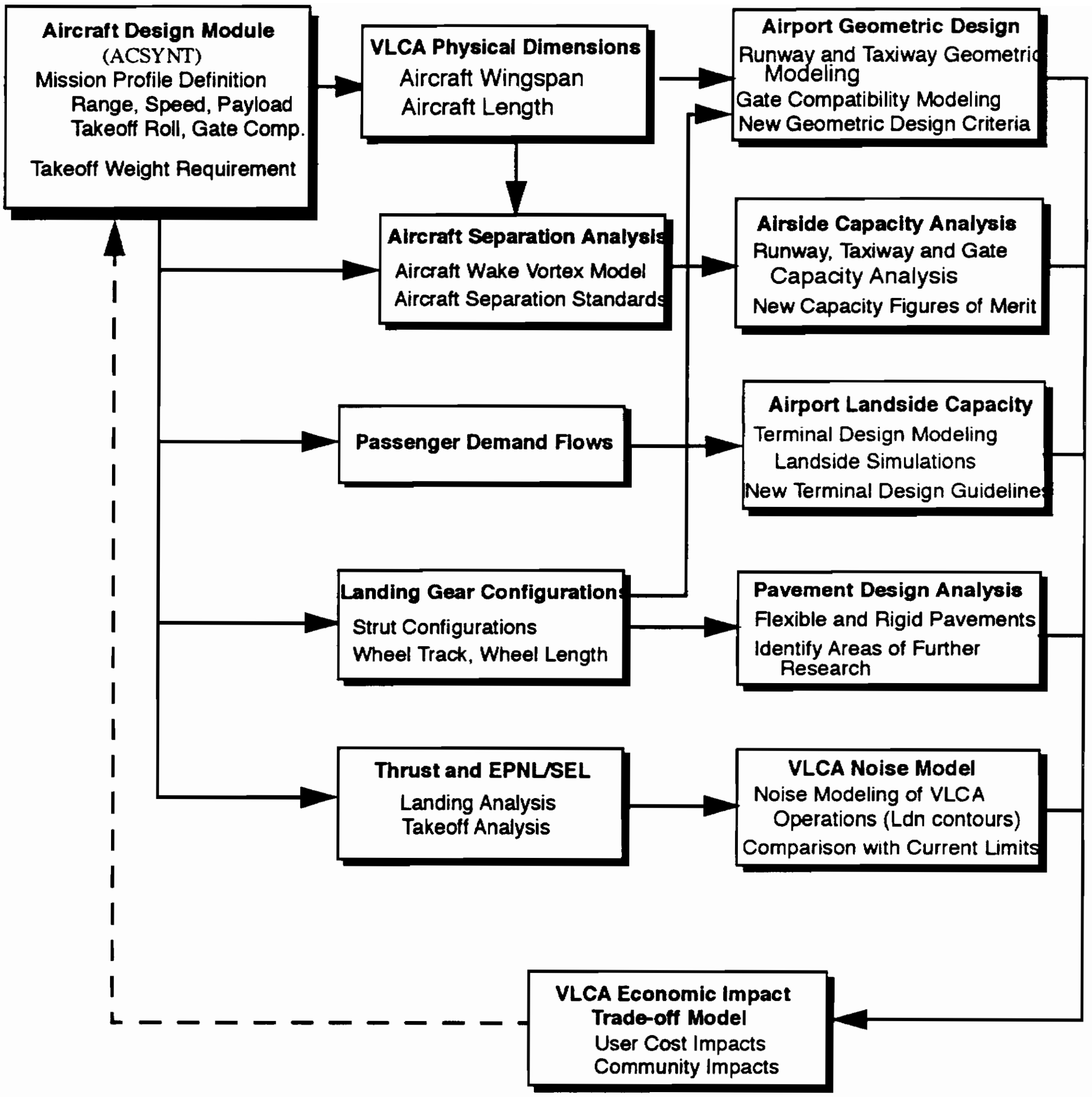


FIGURE 3.1: **Cause-Effect (module) Relationships in VLCA Systems Engineering Study**

Dr. Donald R. Drew writes in his Systems Dynamics: Modeling and Applications "Systems approach is the modus operandi of dealing with complex systems. The systems approach is holistic in scope, creative in manner and rational in execution. Thus it is based, on looking at a total activity, project, design or system, rather than considering the efficiency of the component tasks independently. It is innovative, in that rather than seeking modifications of older solutions to similar problems, new problem definitions are sought, new alternative solutions generated and new measures of evaluation are employed if necessary" [Drew, 1993].

The systems approach strives to be logical, consistent, objective, and quantitative in analyzing systems and solving problems. It recognizes the need to make compromises and trade-off among the system factors. It facilitates the selection of the best approach from the many alternatives. Through the process of model building and scenario analysis it makes possible the prediction of future system performance.

3.4 Systems Dynamics Methodology

Systems Dynamics (SD hereon) was developed at M.I.T. by Professor Jay W. Forrester as a means to enhance decision making capabilities in models involving variables of technological and economic nature. The methodology relies on the use of causal relationships coupled with feedbacks as a means to model complex economic and technological systems. SD makes possible the representation of decision policies and information flows. It provides for a more efficient economic analysis. The form of a SD model should be such as to achieve several objectives.

The SD model should have the following characteristics:

- Be able to describe any statement of cause effect relationship that one wishes to include.
- Be simple in mathematical nature.

- Be closely synonymous in nomenclature to industrial, economic, and social technology.
- Be extendable to large number of variables without exceeding the practical limits of computers.
- Be able to handle continuous interactions in the sense that any artificial discontinuity introduced by solution time intervals will not affect the results.
- Should be able to generate discontinuous changes in decisions when these are needed [Forrester, 1961].

The three basic steps in the Systems Dynamics modeling process are 1) Verbal description, 2) Causal diagram, and 3) Mathematical model. The first step is to describe verbally what one wants to model. The verbal description is then expressed as a flow diagram, also called a causal diagram. The next and final step is to convert this causal diagram into mathematical form. The basic building blocks for drawing a causal diagram is described in Table 3.1.

Table 3.1: Systems Dynamics Variables

Levels or Stocks or State Variables	Represents accumulation of resources in a system, such as goods, number of jobs, population, traffic volume, etc.
Rate Variables or Flows	Represents how the state or level variables change over time such as traffic flow rate, population growth rate etc.
Auxiliary Variables or Flows	These are secondary variables used to complete the mathematical model of interest. Generally are used to estimate the rate variables in the simulation of the system
Constant Parameters or Converters	Used to indicate static variables or the boundaries of the model
Supplementary Variables	Used to represent measures of effectiveness of the model.

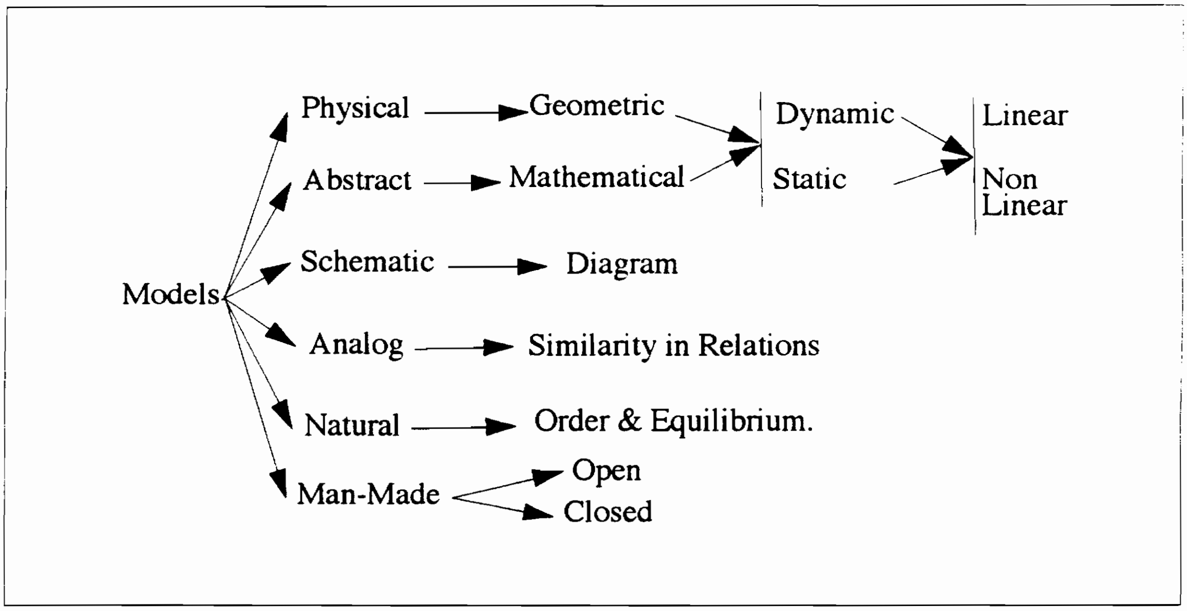
Systems Dynamics modeling can be performed using computer languages such as DYNAMO or by the use of simulation software such as STELLA II [STELLA, 1994]. DYNAMO and STELLA II are problem oriented rather than computer oriented; therefore, little or no knowledge of computer programming is necessary. The SD methodology has been used in the past three decades to address a wide variety of problems where variables of technological order have to be mixed with economic factors in providing optimum answers to complex systems.

3.5 Simulation Models

A model is a substitute for a system, a real structure, or a real equipment. A model is a useful tool for better understanding the behavior and characteristics of a system than the one performed by simply observing the real system. Moreover, models also help to obtain information quickly and for conditions that may not be observable or repeatable in real life and at a much lower cost. All these models are of different types and can be classified as shown in Table 3.2.

Among all the models the mathematical abstract models presents very interesting features, because unlike the physical and verbal models they can be manipulated more easily and tend to produce more clarity in the verbal description of the problem. Mathematical models are written using mathematical symbols to describe the system they represent and are evolved from verbal descriptions, experience, field observations and available data. Mathematical models can be dynamic or static according to whether the model deals with time varying interactions or not.

Table 3.2: Classification of Models



Mathematical models can be solved both analytically and by means of computers. Computers are the preferable choice since they solve models without any simplifications and at low cost. By simulating models on a computer a continuous regeneration process is set in motion leading to new results, which in turn lead to new decisions which in turn keep the system in continuous motion through information feed back loops.

Simulation implies the use of one process or experiment to stand in for and play the role of some other process [Forrester, 1975]. Simulation consists of tracing through step by step, the actual flows of information, and observing the series of new results and new decisions that take place. A great deal more can be learned through simulation than real life as the experimental conditions are fully known, controllable and reproducible, so that changes in system behavior can be trace directly to the causes.

3.6 MATLAB as an Interactive System & Programming Language

MATLAB has become the premier software package for interactive numeric computation, data analysis, and graphics, spanning a broad range of engineering and scientific applications. MATLAB is an interactive system and programming language for general scientific and technical computation. Its basic data element is a matrix that does not require dimensioning. This allows solution for many numeric problems in a fraction of the time it would take to write a program in a language such as Fortran, Basic, or C. Furthermore, problem solutions are expressed in MATLAB almost exactly as they are written mathematically as shown if Table 3.3.

Table 3.3: MATLAB FILE SCRIPT SAMPLE

```
% MAXIMUM TAKEOFF WEIGHT REQUIREMENTS (MTOW)

    Wtogi = 600000;      % Guess initial gross takeoff weight in pounds
    deltaw = 10000;       % Iterate at increments of 10,000 pounds
    for i=1:1:140;
      Woet = Wtogi - Ffrac * Wtogi - wpax*pax;
      Wetent = Woet - Wtogi*.0005;
      We = 10 ^ ( (log10 (Wtogi) - A) / B);
      DeltaW = Wetent - We;
      Wout(i) = Wtogi;
      delta(i) = DeltaW;
      if abs(DeltaW) < deltaw/3;
        Wtogf = Wtogi;            % Final gross takeoff weight in pounds
      end
      Wtogi = Wtogi + deltaw;
    end
    Wtogf;
    %plot (Out, delta)
```

3.7 STELLA-II

STELLA is an acronym for "Systems Thinking, Experimental Learning Laboratory, with Animation". STELLA executes dynamic simulation models. It is a problem oriented software rather than computer oriented. It makes available easy to use computing facilities so that the user can focus his attention on building a useful model undisturbed by complex computer requirements. The software has built in diagramming, model building and simulation capabilities.

The basic building blocks in STELLA are Stocks, Flows, Converters, and Connectors. These are represented as shown in Figure 3.2 and are briefly described as follows:

- Stocks or levels are accumulations or state variables and are represented by rectangles.
- Flows are rates of change and they regulate the flow in and out of stocks. They are represented by a pipe through which the flow takes place.
- Converters can represent auxiliary variables, constant parameters or supplementary variables. They are represented by cycles. Converters can represent either information or material quantities and they are attached to the pipe as a flow regulator which contains the logic that determines the specific flow volume.
- Connectors link stocks to converters and converters to other converters. Connectors do not take on numerical values, they represent inputs.

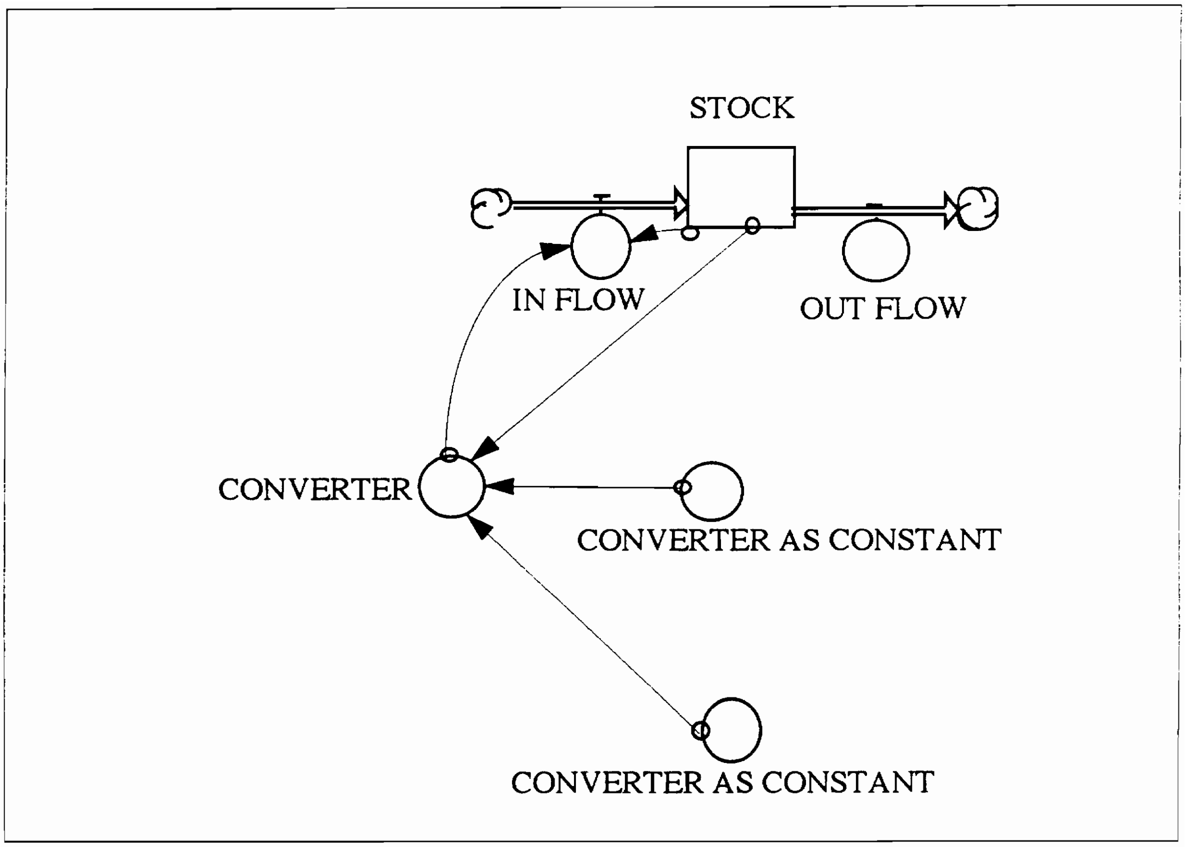


FIGURE 3.2: Basic Building Blocks in STELLA II

4. Model Description

4.1 Introduction

Decision variables in the VLCA study are entered by the analyst in terms of mission profile parameters (i.e., range, cruise mach number, geometric aircraft configuration, etc.) then the program executes a series of computational modules to size a suitable aircraft to meet the given design constraints. Wingspan and wing area are sized according to takeoff, climb, landing and cruise constraints and wake vortex strengths are estimated. Since the wake vortex strength is known a suitable in-trail separation criteria is developed for VLCA aircraft when followed by other groups of aircraft. Airside capacity analysis is then executed. From the aircraft sizing procedure an estimate of the landing gear configuration is made and desirable geometric design standards are developed. Since existing airport infrastructure would not necessarily meet these standards cost estimates of an improved facility are made. A similar approach is used in the estimation of landside facilities needed to accommodate VLCA aircraft at an equal level of service. Noise and pavement design metrics are also evaluated and converted to equivalent costs which in turn are factored against the higher operational costs imposed by a non-optimal design. Measures of effectiveness in the model are the various costs and benefits associated with the operation of optimal VLCA versus non-optimal VLCA configurations that comply with existing airport design guidelines.

4.2 Aircraft Preliminary Design Module

An integrated systems engineering framework analysis of VLCA operations requires an aircraft preliminary design module to ascertain the impacts of mission profile and takeoff weight requirements to airport costs and operations, airline direct operating costs, and their appropriate trade-off cost economics. Using preliminary design procedures stated in the literature it is possible to construct computer models that will converge to a desirable aircraft configuration given a specific mission profile [Roskam, 1986]. There are complete computer models that have been developed through the years to simplify these design procedures and they off course could simplify the analysis [ACSYNT Institute, 1992]. Regardless of which approach is taken here (the approach herein was to develop our own MATLAB computer model) the VLCA aircraft preliminary design procedure starts with the assumption that a mission profile parameters (range, speed, payload, takeoff weight requirements, etc.), takeoff and landing field requirements, and a few details of the geometric configuration of the vehicle are known (decision design variables).

Following standard design procedures the MATLAB program estimates the required fuel fraction (i.e., fraction of the maximum takeoff weight needed in fuel) to complete the given mission profile (stage length). The mission used fuel weight fraction is usually estimated as product of the fuel fractions of all the segments to be flown in the mission profile as shown in Appendix A and the following equation,

$$F_{frac} = W_9 W_8 W_7 W_6 W_{51} W_{52} W_{53} W_{54} W_{55} W_{56} W_{57} W_4 W_3 W_2 W_1 \qquad \text{(EQ. 4.1)}$$

where, F_{frac} is the mission used fuel weight fraction, W_1 through W_9 are suggested fuel weight fractions of phases 1,2,3,4,5,6,7,8 and 9, respectively. These nine mission profile phases are defined as follows:

- Phase 1: Engine start, warm-up, and push-out
- Phase 2: Taxi to takeoff
- Phase 3: Takeoff procedure
- Phase 4: Climb procedure
- Phase 5: Cruise segment (divided into 7 segments to increase accuracy)
- Phase 6: Loiter segment
- Phase 7: Descent segment
- Phase 8: Cruise to alternate, and
- Phase 9: Landing procedure, taxi to gate, and shutdown.

Since little is known about the aircraft in this instance assumptions regarding the various aerodynamic characteristics of the aircraft are made and later refined as the design procedure iterates from initially assumed weight conditions to an equilibrium design point. Because the initial aircraft weight is not known an initial gross takeoff weight, Wtogi, is guessed and iterated until it satisfies the mission constraints (see Appendix A). For long range commercial transport aircraft range and cruise speed are two of the most important design variables sizing the vehicle. Once an equilibrium weight configuration is known aerodynamic characteristics of the vehicle are estimated using standard drag book keeping procedures [Roskam, 1988]. For example, given an specific approach speed, some of the aerodynamic features estimated for this aircraft will be the max. landing weight requirements, wing span and area, and MTOW (see Appendix A).

Takeoff, climb, cruise, approach, and landing analyses are carried out to estimate thrust requirements to satisfy high speed cruise conditions, takeoff, climb and landing roll constraints (see Appendix A). Engine scaling laws are then used to select a powerplant to satisfy the most demanding thrust condition criteria (see Appendix A). If a powerplant in the thrust range required is available table lookup analysis is employed to extract specific fuel consumption values and thrust performance throughout the engine operational flight envelope (see Appendix A). If no existing engine is suitable for the design constraints of the vehicle then a thermodynamic engine module can be invoked to size an engine according to the design constraints specified. This information is fed back to the aircraft sizing procedure until a suitable convergence is achieved between two successive aircraft configurations. Figure 4.1 illustrates this iterative procedure.

Finally, this first module concludes by including computations on takeoff field length requirements as well as approach and climb performance models. For analytical purposes the takeoff consists of ground run, rotation, transition, and climb over a 15 m. (50 ft.) obstacle. Therefore, the total takeoff distance in meters is the sum of the ground, rotation, transition, and climb distances as shown in the following equation,

$$S_{to} = S_g + S_r + S_{tr} + S_{cl} \quad \text{(EQ. 4.2)}$$

where, S_{to} is the takeoff field length required to support VLCA operations, S_g is the ground or takeoff roll distance, S_r is the takeoff rotation distance, S_{tr} is the takeoff transition distance, and S_{cl} is the climb distance. The VLCA climb performance analysis is obtained by applying Roskam's method [Roskam, 1981]. Some of the most relevant parameters estimated by using this method includes; the climb speed, thrust, and weight; rate of climb; and time and distance to climb. The analysis of the VLCA approach performance is more simple in nature and just yield the thrusts required to approach at two different distances from the runway threshold.

4.3 VLCA Aircraft Parametric Study

Figure 4.1 illustrates the general procedure to execute the VLCA aircraft preliminary sizing process. In order to illustrate this aircraft preliminary design module a parametric study of a VLCA aircraft capable of carrying up to six hundred passengers (i.e., typical three-class seating configuration) over various design ranges is shown in Figure 4.2. Note that gross takeoff weight grows rapidly with increments in desired range due to the added fuel fraction needed to accomplish the mission. Table 4.1 contains the expected design requirements of a Very Large Capacity Aircraft (VLCA). Figure 4.2A shows that there is a clear nonlinear relationship between the size of the aircraft and the desired range for constant cruise mach number and payload conditions. Similarly Figure 4.2B shows that higher aspect ratio wings (i.e., a measure of the wing planform slenderness that dictates aerodynamic efficiency) are more efficient in cruise and thus result in slightly lighter aircraft for a given mission profile. This illustrates the trend in current technology aircraft towards higher aspect ratio wings (see Figure 4.3).

The wingspan values in Figure 4.2C are not constrained by airport compatibility issues but primarily dictated by the low and high speed aerodynamic behavior expected for a VLCA to operate from existing runways (i.e., cruise speed, takeoff and landing distance constraints). Historically, few aircraft have been restricted by airport infrastructure constraints. Notable exceptions are Navy aircraft where severe aircraft carrier space constraints dictate innovative approaches to minimize deck space requirements. The Boeing 777 constitutes an example of good airport compatibility planning with an optional folding wing mechanism. However, no airline has yet ordered this aircraft with this option [Swanborough, 1994] reflecting airline concerns on the operational economics rather than gate compatibility issues (i.e., the heavier folding wing represents a loss in payload capability).

Table 4.1: Relevant Design Parameters for a Future VLCA Aircraft

Parameter	Remarks
Passenger Capacity	600 passengers in a three-class layout plus crew
Desired Range	13,000 Kilometers with 1.50 hour reserve
Speed	Mach 0.85 at 11.0 Km
Runway Length	Use of conventional runways (i.e., 3,200 m at MTOW and Sea Level ISA)

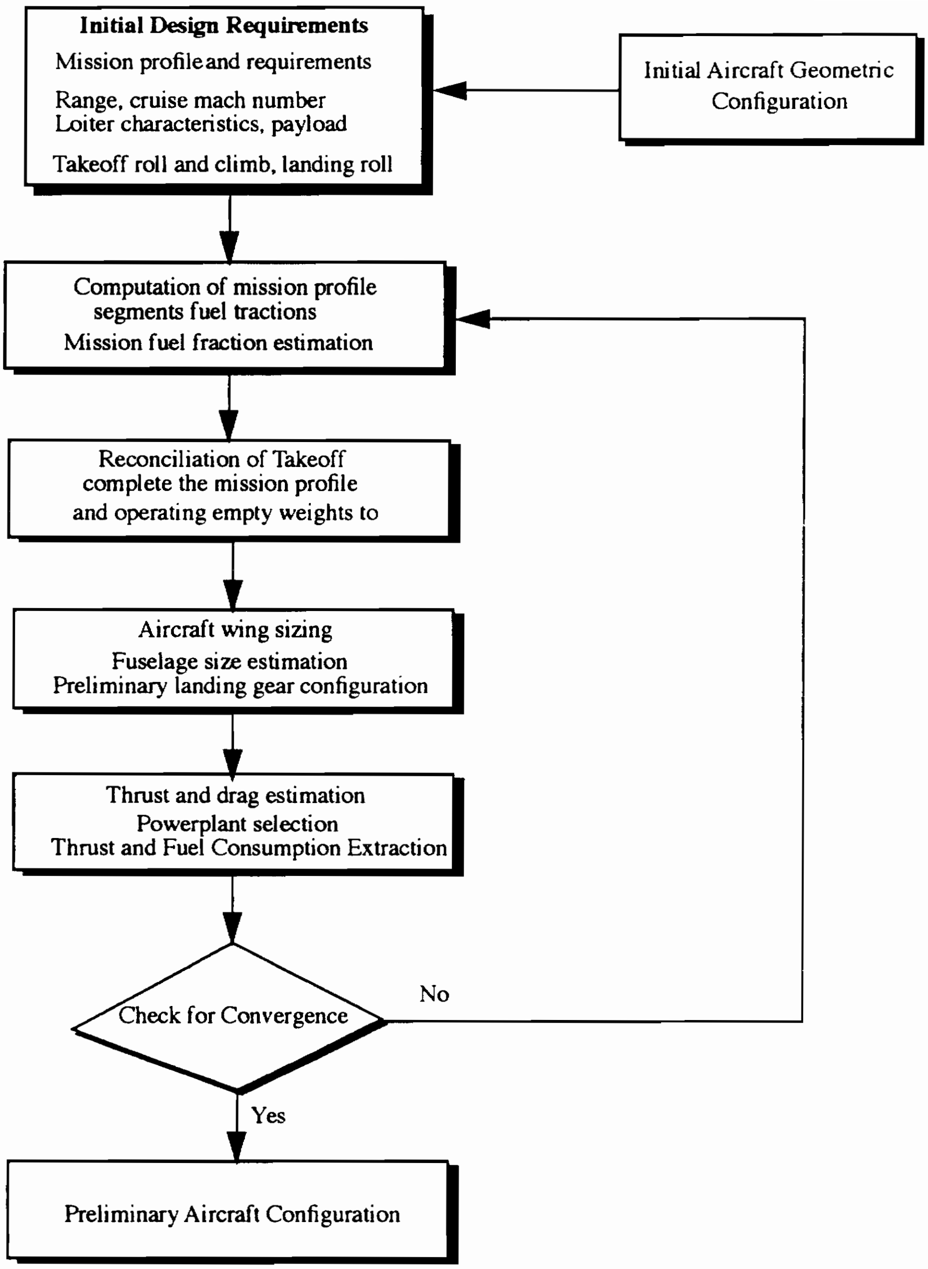


FIGURE 4.1: VLCA Aircraft Preliminary Design Module

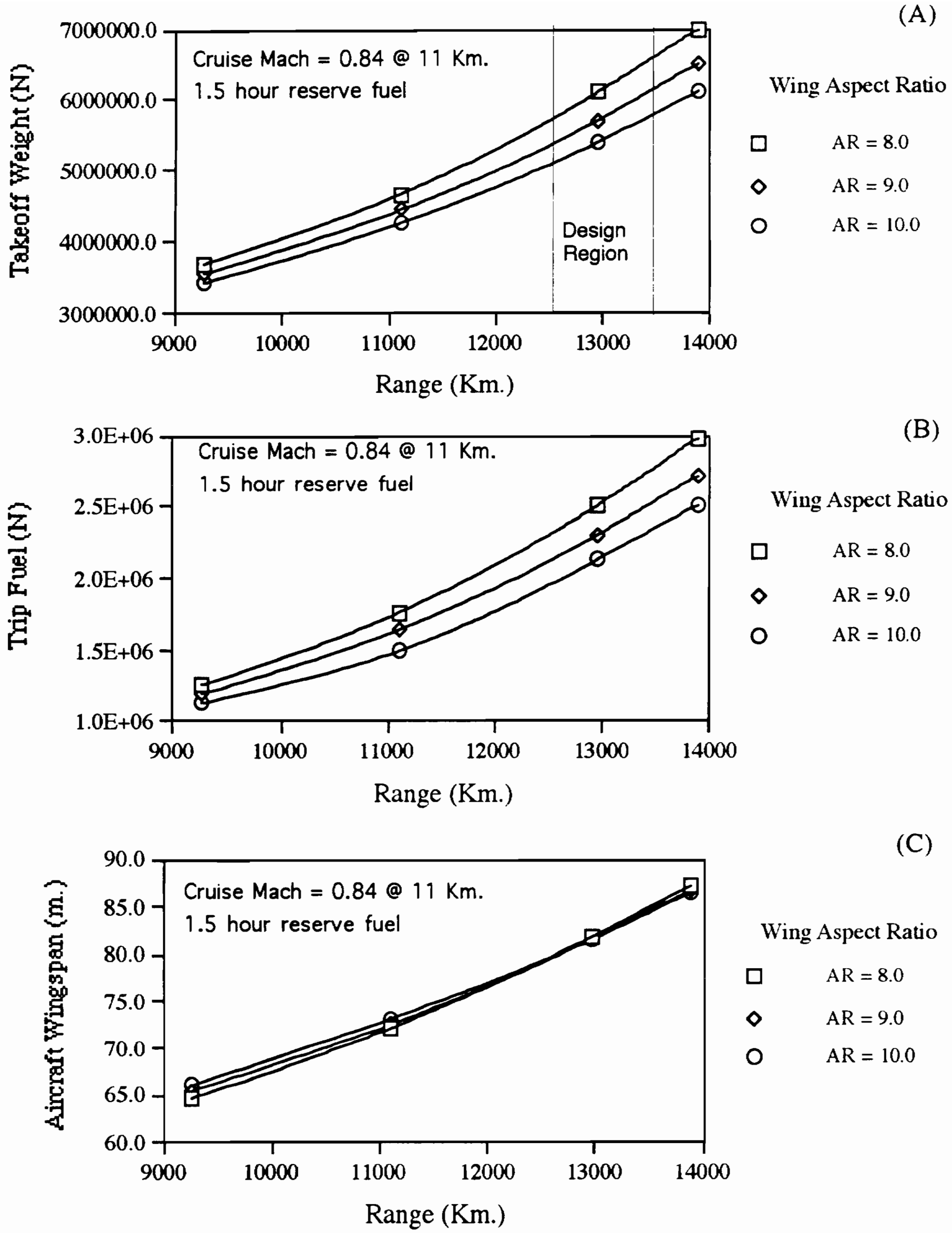


FIGURE 4.2: Preliminary Design Parametric Study of VLCA Aircraft

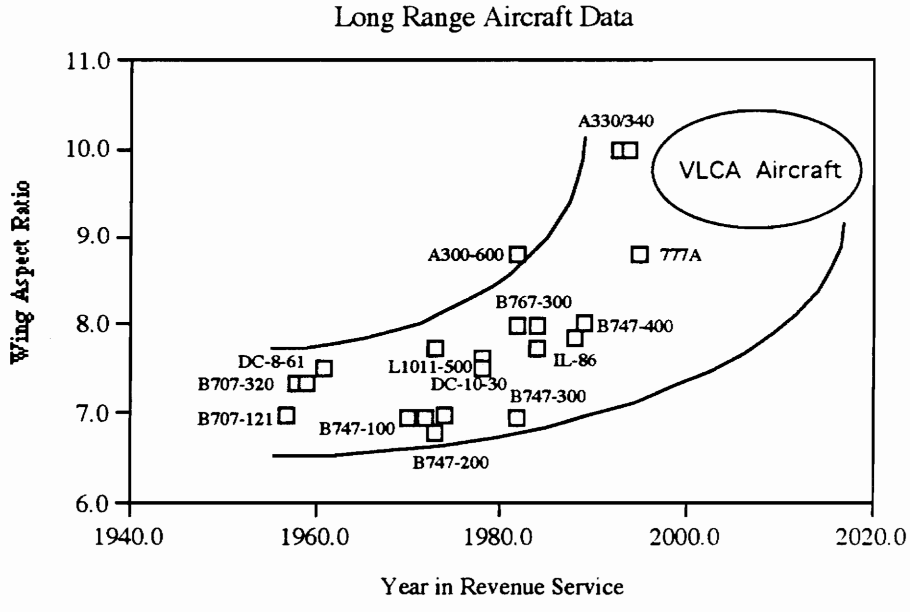


FIGURE 4.3: Historical Development of Aircraft Wing Aspect Ratios for Long Range Transports

Current aircraft operational economics dictate the use of advanced materials for wing construction to minimize weight (i.e., Al-Li alloys and composite materials) and the selection of slender (i.e., high aspect ratio wings) for good high altitude aerodynamic efficiency. Figure 4.3 illustrates the historical development in wing aspect ratio growth over the past four decades for long-range commercial transport aircraft. It can be clearly seen that aspect ratios of the fourth generation aircraft (i.e., those to enter service in the nineties and beyond) are considerably higher than previous aircraft in part to the advances in wing construction technology and availability of stronger, yet lighter, materials. Current FAA design standards contain provisions for large aircraft (i.e., with wingspans up to 79.5 meters), but it is clear that very few airports could actually accommodate such a vehicle if one is to be launched within the next five years unless major improvements to landside and airside facilities are implemented.

The choice of folding wings is a good way to minimize the taxiway and gate compatibility problem but seems an unpopular solution for most airlines due to the moderate weight penalty imposed by the wing hinge mechanism and the higher maintenance cost associated with a folding wing [Swanborough, 1994]. This brings us to the point of whether 79.5 meters is indeed a reasonable wingspan projected for the new generation VLCA aircraft. According to the parametric study of Figure 4.2 the current limit on the design standard could actually be short of the desire of an airline expecting to operate non-stop trips of up to 13,000 Km. (7,000 n.m.) with a full complement of passengers. The obvious trade-off is that if an aircraft planner or designer is willing to constraint the VLCA aircraft design to current FAA airport design standards (i.e., airplane design group VI) the airlines could end up paying a penalty in performance in the long run. This type of trade-off has seldom been estimated from a cost point of view.

Recently certified transport aircraft have wing aspect ratios approaching ten in order to minimize induced drag at cruise conditions thus maximizing lift-to-drag ratios. After all, these aircraft spend 90% of their time in the cruise configuration and thus rightfully so are designed for these set of conditions. It is reasonable to expect that VLCA aircraft will have aspect ratios of between nine and ten thus complicating the airport gate, terminal apron, and taxiway compatibility issue.

4.4 VLCA Aircraft Wake Vortex Model and Separation Analysis

Airside capacity is generally dictated by large in-trail longitudinal separations required between successive aircraft arrivals. For the last two decades, it has been well known that aircraft wake vorticity is the predominant factor that sets the minimum allowable spacings between approaching and departing aircraft. This means that the aircraft vortex wakes persist long enough to force following aircraft to delay their arrival until the vortex wake shed by leading aircraft have either descended below or have been blown out of the flight corridor or have decayed to harmless levels. As a consequence, the vortex wake generated by large and heavy transport aircraft is considerable and thus need to be accounted in the overall capacity of the facility.

Our approach to develop the aircraft separation analysis module consists in dividing it into two components; VLCA aircraft wake vortex and separation analysis models. The wake vortex submodel objective consists in obtaining three main computation-intensive features; vortex profile development, identification of maximum tangential velocities, and estimation of critical lateral distances for a reference aircraft (B747-400) and a VLCA aircraft (see Appendix A). All the above features are performed for three typical scenarios; small, or medium, or heavy aircraft trailing either a heavy aircraft (B747-400) or a VLCA aircraft. In addition to the three previously mentioned features modeling VLCA trailing vortex systems require also the identification of maximum tangential velocities for the wake generated by VLCA aircraft at 100 and 300 seconds of age (see Appendix A) and the computation of headways and separation distances (see Appendix A). These two steps are necessary for developing the VLCA trailing vortex profile from which one can identify the maximum vortex tangential velocities that trailing aircraft may have to experience at different in-trail separation distances. The entire vortex model is based on the following assumption; current in-trail separation distances yield vortex vertical tangential velocities that are considered safe for current trailing approach aircraft operations. By expanding this current separation criteria to also include VLCA operations we want to find what should be the minimum safe in-trail separation distances that small, medium, large, heavy, and VLCA aircraft have to follow behind VLCA aircraft in order not to exceed present vortex tangential velocity distributions.

First of all, before any of the above features are computed the vortex submodel requires estimation of three useful aircraft wake generating parameters. This wake vortex design procedure starts with the assumption that a wingspan, b, and a gross weight, W, of the wake generating aircraft are known (user design variables) and by assuming an elliptical wingspan loading distribution and the semi-empirical vortex decay model suggested by Robinson and Larson [Robinson and Larson, 1972], we can compute the following aircraft wake generating data (see Appendix A):

- The initial midspan total vortex circulation as,

$$\Gamma = \frac{4W}{\pi \rho V b} \qquad \text{(EQ. 4.3)}$$

- The vortex decay value (epsilon) is,

$$\varepsilon = 0.0002\Gamma \qquad \text{(EQ. 4.4)}$$

- The vortex node location with respect to aircraft centerline as,

$$LD_{cr} = \frac{\pi \cdot b}{8} \qquad \text{(EQ. 4.5)}$$

- The vortex profile is obtained for all three scenarios by computing the tangential velocity (vortex vertical velocity) right and left from the vortex node and is given by the following equation as,

$$V_t = \frac{\Gamma}{2\pi b}\left[1 - e^{\frac{-b^2}{4\varepsilon T}}\right] \qquad \text{(EQ. 4.6)}$$

where, Γ is the initial midspan total vortex circulation (in sq.m./sec.), W is the gross weight of generating aircraft (in Kg.), ρ is the air density (Kg./cubic m.), V is the true airspeed (m./sec.), b is the generating aircraft wingspan (in meters), ε is the vortex decay value (in sq.m./sec.), LD_{cr} is the critical lateral distance of the vortex node from aircraft centerline (in meters), V_t is the tangential velocity right or left from vortex node (in m./sec.), and T is the desired in-trail headway between generating and trailing aircraft (in seconds).

The results (outputs) obtained from the wake vortex submodel (in-trail headways and separation distances) become inputs for the separation analysis submodel. The objective of this module component is to develop a new IFR aircraft approach separation distance matrix for five aircraft groups (including VLCA). The five groups included in this analysis are small, medium, large, heavy, and VLCA FAA airplane design groups. In conclusion, the final outcome of the program's second module would be a five by five matrix where each cell (25 in total) represents a minimum safe in-trail separation distance under IFR operating rules expressed in nautical miles.

4.5 Runway Capacity Analysis Module

4.5.1 Pseudo-Graphical Models

Our approach to develop the runway capacity analysis module is to apply Harris' mathematical model that makes frequent use of time-space diagrams. This landing interval model contains some important factors that have significant effect on the capacity of runways accommodating incoming aircraft. These factors are aircraft approach speed characteristics, aircraft group percentage, current air flight rules, and the magnitude of various errors such as speed errors along common approach path, arrival time errors at the entry gate, and landing distance errors from runway threshold.

The goal of the runway capacity module is to find the maximum practical capacity of a typical single runway under both IFR and VFR weather conditions. The inputs of this module are several parameters and user defined variables and include; the new in-trail distance separation matrices which can be extracted from the program's second module (VLCA aircraft wake vortex and separation analysis module), the aircraft mix and approach speed vectors, the aircraft landing and departure runway occupancy time vectors, and various relevant parameters and standard deviations (see Appendix A). The output from this module yields the maximum processing capability of a single runway under three different scenarios: two scenarios are for arrivals only (one is based on the free position error concept which is consider more of an intermediate not realistic step and the other on the real position error concept) and the third is for mixed operations (arrivals and departures mixing in the same runway). These three scenarios have different assumptions and are presented below.

4.5.2 Error-Free Arrivals Only Runway Capacity Model

To illustrate the model let us consider a pair of leading and trailing aircraft entering a final common approach path with speeds V_i and V_j. The leading aircraft belongs to an airplane design group i and the trailing belongs to j where i and j are any of FAA airplane design groups in addition to our own VLCA group. The goal of these approaching aircraft is to maintain a precise safe spacing between them. As a consequence, it is understandable to establish a matrix that represents various minimum in-trail separation times between aircraft of discrete speed classes at the runway threshold (see Appendix A). These matrices are defined as follow [Harris, 1974]:

$$[T_{ij}] = T_j - T_i \qquad \text{(EQ. 4.7)}$$

where, T_{ij} is the error-free aircraft time separation matrix between pairs of landing aircraft (in sec.), T_i is the time when the leading aircraft of group i reaches the runway threshold, and T_j is the time when the trailing aircraft of group j reaches the runway threshold.

Because the percentage of various aircraft groups may differ in the aircraft mix composition probabilities of aircraft of group i followed by aircraft of group j can be obtained and defined as follow [Harris, 1974]:

$$[P_{ij}] = P_j - P_i \qquad \text{(EQ. 4.8)}$$

where, $[P_{ij}]$ is a matrix of probabilities of aircraft of speed class i followed by aircraft of speed class j, P_i is the percentage of aircraft of speed class i, and P_j is the percentage of aircraft of speed class j.

The multiplication of the in-trail separation time matrix by the probability matrix determines the average weighted or expected value of the error-free aircraft time separation matrix at runway threshold [Harris, 1974] which is defined as follows:

$$E[T_{ij}] = \Sigma P_{ij} \times T_{ij} \qquad \text{(EQ. 4.9)}$$

where, $E[T_{ij}]$ is the average weighted separation time matrix at runway threshold for aircraft of various speed classes (in sec.). Finally, the goal is to achieve the maximum practical runway landing capacity without position error as the inverse of the average weighted separation time at threshold which is given below as [Harris, 1974],

$$C = \frac{1}{E[T_{ij}]} \qquad \text{(EQ. 4.10)}$$

where C is the maximum capacity of a single runway for arrivals only with free position error expressed in number of landings per unit of time (no buffer included).

4.5.3 Single Runway Capacity with Arrivals Only and Position Error

The matrix δ_{ij} represents the minimum acceptable spacing between two consecutive landing aircraft along a final common approach path. But it could also mean the in-trail separation distance for the trailing aircraft away from the leading aircraft when no errors in separation are involved. In practice, variations in separation are likely to occur due to human, environmental, or mechanical uncertainties where aircraft are vectored to the final approach. This implies that aircraft positions are randomly located, either ahead or behind of the normal schedule. If the trailing aircraft is ahead of its schedule, or violates the minimum safe separation distance from the one ahead, the situation might be precarious. Therefore air traffic control personnel usually add a buffer time to increase the headway to avoid the possible loss of separation due to position errors. Assuming the position error is normally distributed and the mean value of this normal distribution corresponds to the minimum separation distance. It is easy to find that 50% of the aircraft trailing would violate the separation criteria. To reduce the probability of position violation to an acceptable level, trailing aircraft are inevitably assigned a buffer time to reach a scheduled position later, so that only a small number of aircraft could be ahead of a prescribed position (i.e., 5% is usually acceptable). In general, the real in-trail aircraft time separation matrix with position errors has been demonstrated to be defined as follows [Harris, 1974],

$$E\ [M_{ij}] = E\ [T_{ij} + B_{ij}] \qquad \text{(EQ. 4.11)}$$

where B_{ij} is the buffer time matrix (in sec.) of aircraft of speed class i followed by aircraft of speed class j (see Appendix A).

4.5.4 Single Runway Capacity with Mixed Operations

To illustrate the scenario in which a typical single runway serves both arrivals and departures one needs to compute the following variables (see Appendix A):

- The expected flying time for arriving aircraft to travel the minimum departure-arrival separation distance, δd, (usually this distance to the runway landing threshold is constant at 2 n.m.), $E\left[\frac{\delta d}{V_j}\right]$.
- The expected landing runway occupancy time, $E[LROT_i]$.
- The error term to account for a gap spacing violation, $ERROR = \sigma_g Q_v$
- The expected departure-departure time separation, $E[dd]$.
- The required expected in-trail time separation to release "n" departures between a pair of arrivals, $RE[T_{ij}]$, [Harris, 1972].

$$RE[T_{ij}] > E[LROT_i] + E\left[\frac{\delta d}{V_j}\right] + \sigma_g Q_v + (n-1)E[dd]$$

4.6 Airfield Pavement Section Analysis Module

4.6.1 Landing Gear Configurations

Airfield pavement analysis must also be considered in this systems approach study given the large weights expected for VLCA aircraft. It is expected that the effects of very heavy VLCA on runway, taxiway, and terminal apron pavements can be somewhat alleviated through the use of complex landing gear assemblies with multiple wheels, however, potential weights for VLCA aircraft of up to around 500 metric tons (1.2 million pounds) are certainly important to be neglected. Using current methods of analysis [FAA, 1989] for airfield flexible pavements a CBR versus thickness curve is derived for this type of vehicle using a multi-wheel main landing gear configuration with 24 tires (i.e., four sets of triple-in-tandem gears or struts similar to those used in the Boeing 777).

Overall our interest lies in the possible assessment of maintenance and infrastructure improvement actions that airport authorities should undertake in order to allow routine VLCA operations at specific airports. This interest represents for now a suggested topic for future research. Moreover, recent studies using elastic and inelastic multi-layer methodologies suggest that current design practices overpredict the thickness of airport flexible pavements for multi-wheel aircraft configurations [Preston, 1991; Barker and Gonzalez, 1992]. As a consequence, in this module our approach is to use "the Corps of Engineer Method of design for flexible airport pavements" to ascertain the costs associated with VLCA operations at typical airports. Furthermore, this effort also identifies one additional area of needed research for the FAA which is in the design and evaluation of rigid airport pavements.

4.6.2 The CBR Method of Design for Flexible Airfield Pavements

The goal for applying this method to our VLCA program is to develop a flexible pavement thickness versus CBR curves that enables the user to size airfield flexible pavements of taxiways, terminal aprons, and runway ends that will support VLCA operations. In other words, application of the modified CBR procedure to airfield pavements enables the designer to determine the required thickness of subbasse, base, and surface course by entering a set of design curves with the result of a relatively simple soil test.

To illustrate the procedure (see Appendix A), several relevant loads (i.e., on main landing gears, on a gear assembly, and on a single wheel) and dimensions (i.e., wheel contact area and its radius) must be provided as inputs to the model. Then, the model makes use of a deflection factor matrix developed by the Corps of Engineers and computes several transitional steps. Finally, the output of the model is obtained in terms of CBR vs. thickness curves of the pavement section. The transitional steps (parameters) that are computed by this model are explained and defined as follows [Horonjeff and Kelvey, 1983]:

- Definition of all points of interest (locations) for the investigation of the maximum critical deflection (i.e., A,B,C,D,E, and G)
- Determination of distances from each location to each wheel of the assembly.
- Estimation of all deflection factor contributions of each wheel (1,2,3,4,5, and 6) to each location at different depths (25.4, 50.8, 76.2, 101.6, 127, 152.4, and 177.8 centimeters).
- Summation of deflection factor contributions of all wheels on every position at seven different depths.
- Development of vectors that contain as elements the total deflection factors of all wheels on every location for the same depth.
- Finding the location point that yields the maximum (critical) deflection.
- Estimation of equivalent single-wheel deflection factors at different depths.

- Estimation of equivalent single-wheel loads (ESWL) at different depths.
- Estimation of load repetition factor in terms of aircraft traffic volume (passes or number of operations) and number of tires used to compute ESWL, and
- Estimation of CBR values at different depths.

4.7 Airfield Geometric Design Module

In order to be objective in the analysis of VLCA operations at existing and future airports issues regarding runways, taxiways, terminal aprons, and gates have being analyzed by using the systems approach methodology. Airfield geometric design issues included in the analysis follow; runway length, runway and taxiway widths, runway and taxiway shoulder widths, runway to runway / taxiway / taxilane separations, taxiway to taxiway / taxilane separations, runway obstacle free zones and object free areas, dimensions of holding aprons, and gate positioning and configuration. Most of these geometric parameters require some type of modification or future revision based on the performance and physical characteristics of expected VLCA aircraft. For this reason, it is necessary to envision the new generation VLCA aircraft well before they are conceived.

In this research the airfield geometric design standards contained in the FAA Advisory Circular 150/5300-13-3 [FAA, 1993] was evaluated and modified accordingly to accommodate VLCA operations if very high aircraft wing aspect ratio configurations are used. Overall, our interest lies in running simulations of VLCA movements around the airfield (i.e. using a few representative airports). These simulations would be useful in developing new guidelines for runway and taxiway widths and separations, obstacle free zone (OFZ) dimensions, holding area dimensions, and other geometric design factors [FAA, 1993]. Moreover, using a suitable aircraft configuration suggested by the aircraft design module, aircraft kinematic models can be used to assess the geometric characteristics of runways, taxiways and apron-gate areas. Maneuvering envelopes for aircraft could be studied using computer aided design techniques to realistically represent kinematic maneuvering envelopes. These envelopes in turn are depicted in terms of nomographs that help us to understand the trade-off between aircraft size and possible geometric design infrastructure changes needed to satisfy existing design safety guidelines. This interest represents for now just a suggested topic for future research.

4.8 Airport Terminal Building Design Module

Airside reductions in capacity resulting from the operations of VLCA aircraft could result in longer passenger dwell times at the airport terminals thus resulting in more space requirements per passenger to satisfy the same Terminal Level of Service[1] (TLOS) constraints. Our approach to develop the airport terminal capacity module was to make strong use of FAA charts contained in Advisory Circular 150/5360-13. The intended goal was to facilitate a potential user of this program to easily compare current FAA terminal design standards with ones that support VLCA operations. Otherwise, an alternative and more indicative methodology that could be applied to this module is queueing theory.

This module was divided into two parts. The first part consists in transforming annual demand figures (i.e., enplanements and operations) into typical peak-hour passenger (TPHP) figures by making use of FAA recommended relationships [Ashford and Wright, 1991]. The second part reflects an intensive use of FAA AC150/5360-13: Planning and Design Guidelines for Airport Terminal Facilities [FAA, 1990] which provides guidelines for the planning and design of airport terminal buildings and related access facilities. Furthermore, the modeling of the airport terminal was performed for design standards that support both Group V and VLCA operations in one scenario and Group V operations in the second scenario. Development of both of these scenarios are necessary in order to identify differences in the components that make up an international terminal building. This difference expressed either in surface area or linear footage will become

1.LOS is an indicator of the quality of service perceived by the average passenger. LOS has usually been associated with space requirements per passenger at a terminal very significant when developing the economic costs associated with landside operations.

In developing this module the following terminal building components were included in the analysis either because of their function or influence in the overall economic infrastructure improvement cost:

- Airline ticket counters
- Airline ticket offices and support spaces
- Outbound baggage facilities
- Baggage claim facilities
- Airline operations and support areas
- Departure lounges
- Other airline space
- Ticketing lobby
- Central waiting lobby
- Bag claim lobby
- Food and beverage services
- Concessions and building services
- Other rental areas
- Other circulation areas
- Building mechanical systems
- Building structure
- Immigration area
- Customs area
- Public health area
- Agriculture area
- Visitor waiting rooms area, and
- Circulation, baggage assembly area, utilities, and walls

By adding areas of the above components the total space area of the international airport terminal building that supports VLCA operations is obtained. Another significant parameter estimated by the module is the ratio between airport terminal area and design peak-hour passenger demand. Both of these parameters are obtained for both scenarios.

4.9 Airport Landside Design Module

The most prominent effect of VLCA operations at large airports is the possible increment in passenger flows inside and outside terminals and the gate compatibility problems associated with large wingspans. Analysis of VLCA aircraft/airport landside compatibility can be executed with the use of computer analytical models such as our own Airport Landside Design module. In this simple model only two components were considered; the airport public parking facilities and the required terminal curb frontage capacity. Here again, the modeling of the airport landside was performed for design standards that support both Group V and VLCA operations in one scenario and Group V operations in the second scenario.

Development of both scenarios are necessary in order to identify differences in the components that make up an international terminal building. This difference expressed either in surface area or linear footage will become very significant when developing the last module (VLCA economic impacts). The airport access system represents a major landside component that has been left out of this research, but that clearly will be impacted by the introduction of VLCA operations. This component is proposed as another topic to be considered for future research.

4.10 Noise Module

Acoustical design considerations should also be taken into account in this integrated systems engineering evaluation of VLCA operations. VLCA aircraft are likely candidates to use the new generation of very large by-pass ratio engines in development (i.e., Rolls Royce Trent 800, Pratt and Whitney PW 4086 and General Electric GE90 among others) which although promise better fuel efficiencies in cruise than previous large by-pass engines develop considerably more thrust thus potentially generating more noise (see Figure 4.4).

The analysis here concentrates in the estimation of noise contours that compare VLCA aircraft with existing third generation, wide-body transport aircraft (i.e., Boeing 747-400). Using the FAA Integrated Noise Model [INM v. 3 and 4.11, 1992 and 1993], the aerodynamic and engine performance (thrust requirements) derived in the preliminary design module are used as inputs into INM 4.11 to estimate the noise signature of the VLCA aircraft during takeoff and landing maneuvers. Several economic methods have been proposed in the literature to assess the impact of aircraft noise [Benito, 1986] and these can also be adapted to convert noise measures of merit to annoyance costs. Since the aircraft climb performance has been ascertained in the design module (see Figures 3.1 and 4.1) and using fixed aircraft engine data we can derive the expected acoustic signal of the VLCA and compare it with that of existing wide body aircraft. The noise model shows the changes in noise contours for various designs at maximum takeoff weight operating from sea level ISA conditions. Because the VLCA operates at considerable higher thrust settings than its predecessors it is very likely that the noise contours at any facility where VLCA are expected to operate will increase.

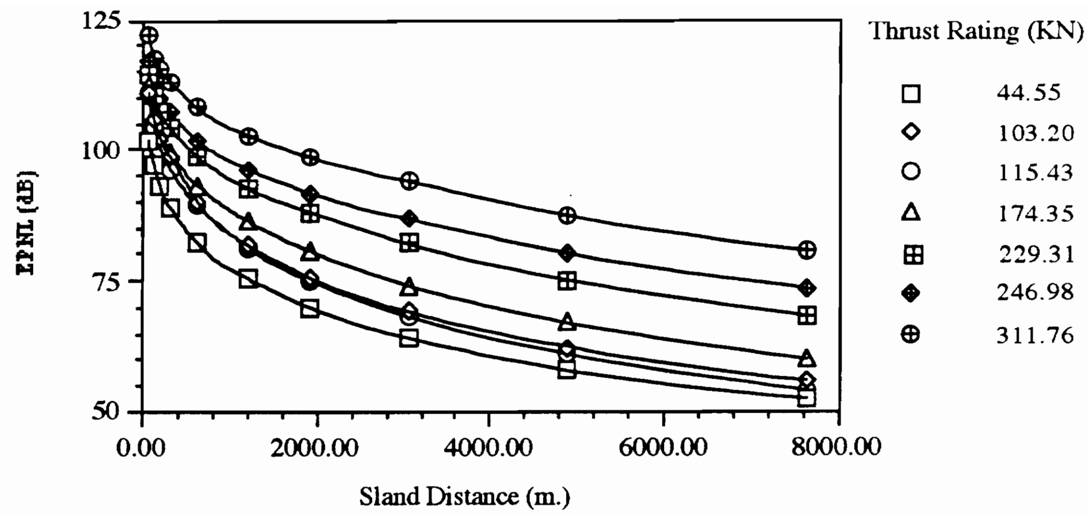


FIGURE 4.4: Expected EPNL Produced by VLCA Engines

4.11 VLCA Economic Impact Module and Trade-off Methodology

The economic decision to operate VLCA aircraft will ultimately rely on airlines and their passenger demand base. However, the operational advantages of VLCA in the future would have to be weighted objectively with a methodology that addresses all technical and economic factors simultaneously and not in isolation. In this context the Systems Engineering methodology is viewed as a tool to estimate the economic outcome of VLCA aircraft operations for users, airport authorities and airlines. The suitability of Systems Dynamics is primarily focused here because of the complex interrelationships between all technical and economic aspects of VLCA operations described.

The method of analysis proposed here integrates the expertise and knowledge of various fields in air transportation engineering to determine best strategies and possible new policies to help VLCA to become an operational reality and minimize negative impacts to existing airports. Figure 4.5 illustrates the integrated Systems Dynamics Model developed using STELLA II. The model takes into account inputs from all the technical disciplines described before and looks the impact of VLCA operations in an integrated fashion. The methodology is site specific in its application since not all cost components are the same for all airports/airlines. Nevertheless, the method establishes a clear trade-off between aircraft design optimization and cost airport authorities are expected to pay for this optimization.

The economic impact module is divided into two components; the airport and the airline cost models. In the first model (see Figure 4.5) one estimates the airport infrastructure improvement cost that will allow to serve VLCA operations by knowing the required infrastructure difference between an airport serving only airplane design group V and the same airport serving also the VLCA group. The following infrastructure improvement cost parameters were estimated in this first cost model:

- Airfield Pavement Section
- Noise Mitigation
- Airfield Geometric Infrastructure
    - Runway length and width and shoulder width
    - Taxiway width and shoulder width
    - 90 Degrees Exits full strength pavement and shoulders
    - Runway Blast Pad Area
    - Terminal Apron Area
    - Taxiway Fillets
- Additional Land Occupancy
    - Runway-taxiway combination

    - Taxiway-taxiway or taxilane combination
- Landside Infrastructure
    - Terminal curb frontage
    - Short and long term parking garage

In the second cost model (see Figure 4.6) one estimates the following parameters for an airline operating an optimized VLCA aircraft vs. one operating current heavy aircraft:

- DIRECT OPERATING COST (DOC)
    - Flight Operations Cost
        - Fuel and oil costs
        - Crew expenses: Pilots and stewards
        - Insurance cost
    - Aircraft Depreciation Cost
    - Aircraft Maintenance Cost
- INDIRECT OPERATING COST (IOC)
    - Maintenance cost
    - Administrative cost
- TOTAL OPERATING COST (TOC)

The goal here is to compare VLCA DOC against DOC of current wide-body aircraft.

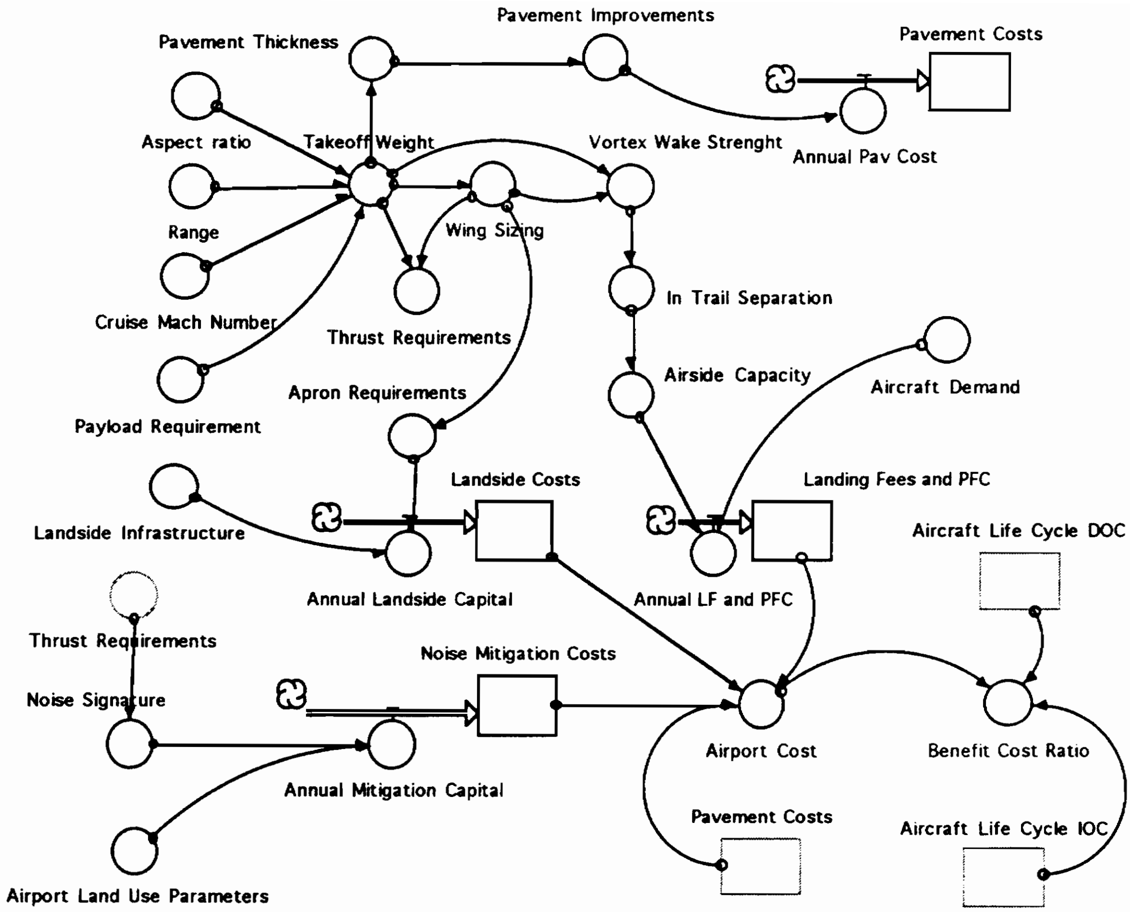


FIGURE 4.5: Life Cycle Airport Component Cost Model

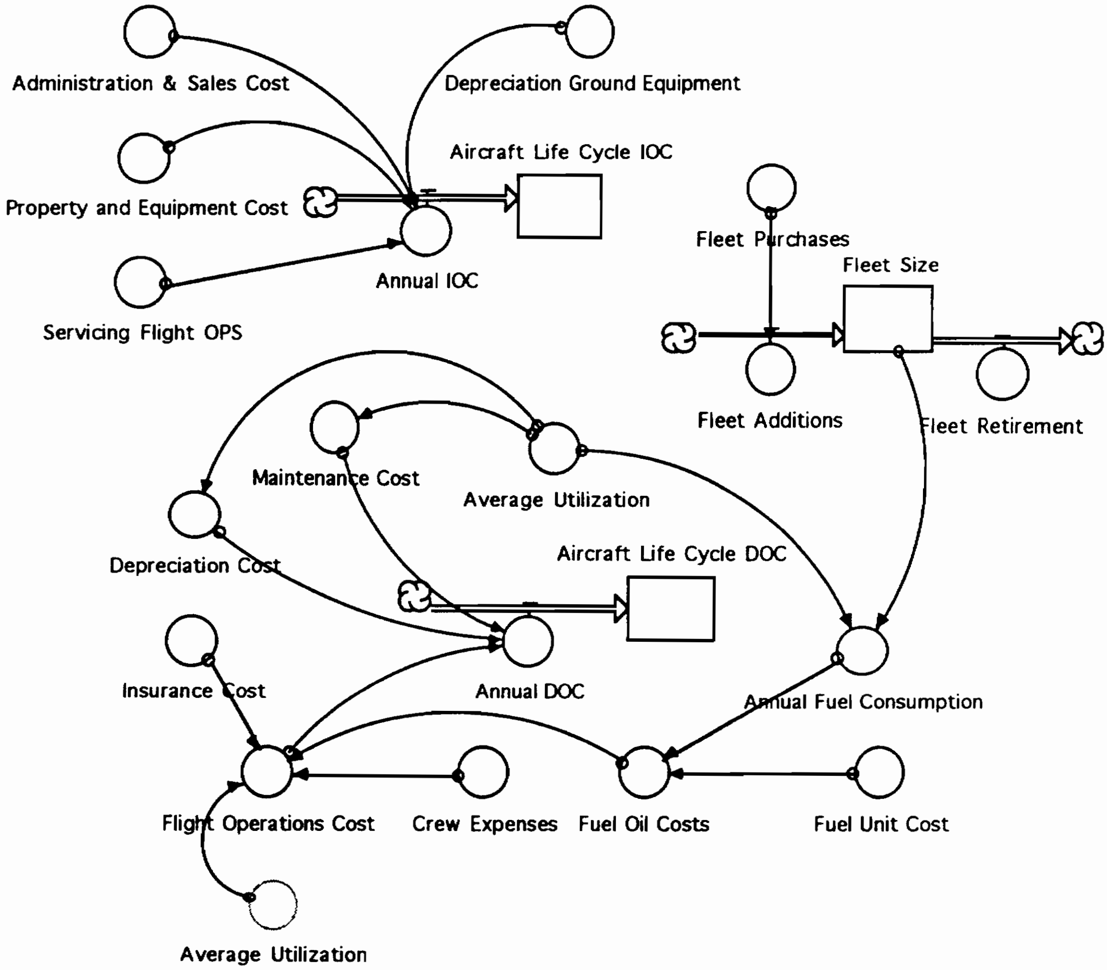


FIGURE 4.6: Life Cycle Airline / User Component Cost Model

5. Model Results and Analysis

5.1 Analysis Description

To demonstrate the versatility and capabilities of the model, a typical International Airport that serves both domestic and international wide-body, high-density aircraft operations was modeled. The model was analyzed by changing input parameters and exploring the changes in various performance parameters. In addition, the model is user friendly making sensitivity analysis an easy task to be performed by just changing certain user-defined variables. Various parametric studies were performed to test the sensitivity of the model. A baseline scenario was developed by using existing representative conditions such as a desired range of 13,000 Km. (7,000 n.m.), an aspect ratio of 9.5, a cruise mach number of 0.85, and a passenger capacity of 600, etc.,. Three scenarios were analyzed by varying the following input parameters:

- Scenario I Desired range and aspect ratio (all other things equal).
- Scenario II Passenger capacity (all other things equal).
- Scenario III Cruise mach number (all other things equal).

The objective of the sensitivity analysis on the preliminary design module is to illustrate the dependencies of all model parameters to aircraft design changes. This is indeed the main goal of this research. Typical questions arising during the preliminary design stage are:

- What is the aircraft wing aspect ratio, capacity, range, and cruising speed for a VLCA to minimize airline direct operating cost.
- What is the aircraft wingspan, fuselage length, and takeoff weight the VLCA should have to minimize airport infrastructure improvement economic cost. The answer to all these questions lies in the model outputs that follows.

5.2 Results

The first scenario involved the change of certain critical design parameters such as those in the preliminary design, wake vortex, in-trail separation, pavement section, noise, and capacity modules, due to changes in VLCA wing aspect ratio and desired range (mission profile) user defined variables. The aircraft preliminary design results are shown in Figures 5.1 through 5.7. Figures 5.1 and 5.2 show VLCA wingspan and wing area, respectively, as they vary with the desired mission range and aspect ratio. It can be observed from Figure 5.1 that for stage lengths greater than 12,500 Km. (6,750 n.m.) the VLCA wingspan will exceed current Airplane Design Group VI upper limit of only 79.5 m. For example, this upper limit will be exceeded by at least 2 m. (6.5 ft.) for a 13,000 Km. (7,000 n.m.) trip range and as far as 7 m. for a trip length of 13,900 Km. (7,500 n.m.).

Figures 5.3 and 5.4 show VLCA max. takeoff weight and landing weight, respectively, as they vary with the mission range and aspect ratio. It can be observed from Figure 5.3 that for various stage lengths VLCA MTOW varies substantially. For example, the takeoff weight would increase up to 60% by increasing the desired range from 10,186 Km. (5,500 n.m.) to 13,890 Km. (7,500 n.m.). These aircraft weight results are significant because of the potential impact on the existing airfield pavement design standards. Figures 5.5 and 5.6 show the used fuel weight fraction sensitivity analysis and the fuel consumed to accomplish the mission, respectively. It can be observed from Figure 5.6 that for various stage lengths the mission fuel consumed varies substantially. For example, the fuel consumed would increase up to 85% by increasing the range from 10,186 Km. (5,500 n.m.) to 13,890 Km. (7,500 n.m.). These required fuel results are significant because of the potential impact fuel cost plays in estimating an airline direct operating costs. Finally, Figure 5.7 shows the max.VLCA engine thrust required to overcome drag in the most critical flying regime. For example, for a desired trip length of 13,000 Km. (7,000 n.m.) the required VLCA engine thrust is at least 333 KN (75,000 lbs.). In addition, Table 5.1 shows runway length sensitivity analysis results for various range and aspect ratio combinations.

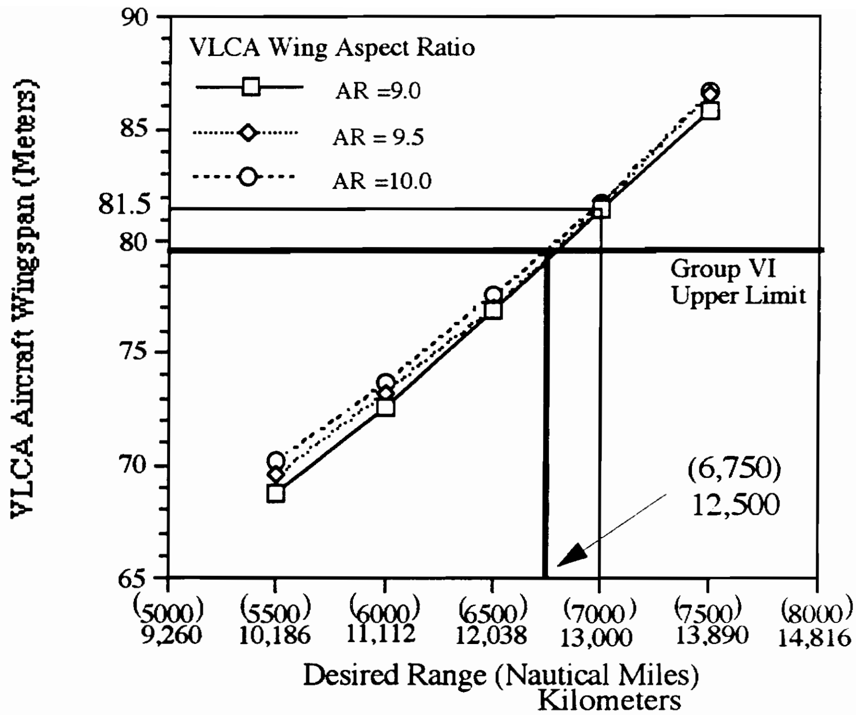


FIGURE 5.1: **VLCA Aircraft Wingspan Sensitivity**

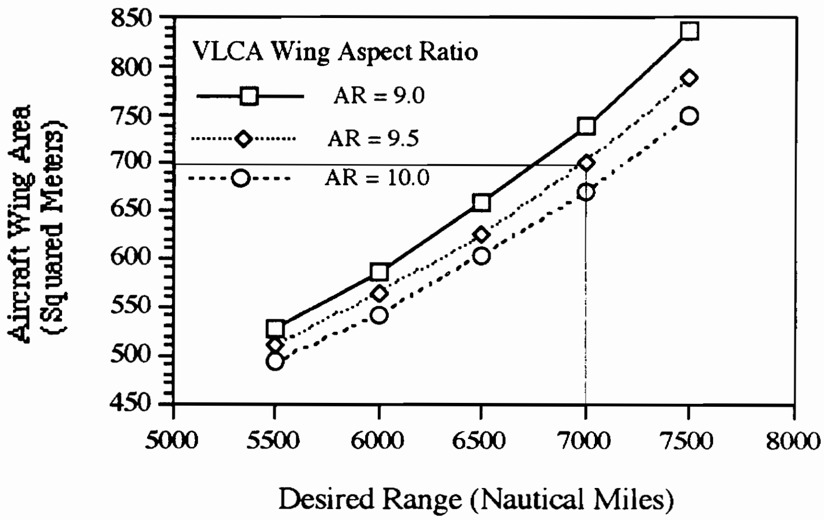


FIGURE 5.2: **VLCA Aircraft Wing Area Sensitivity**

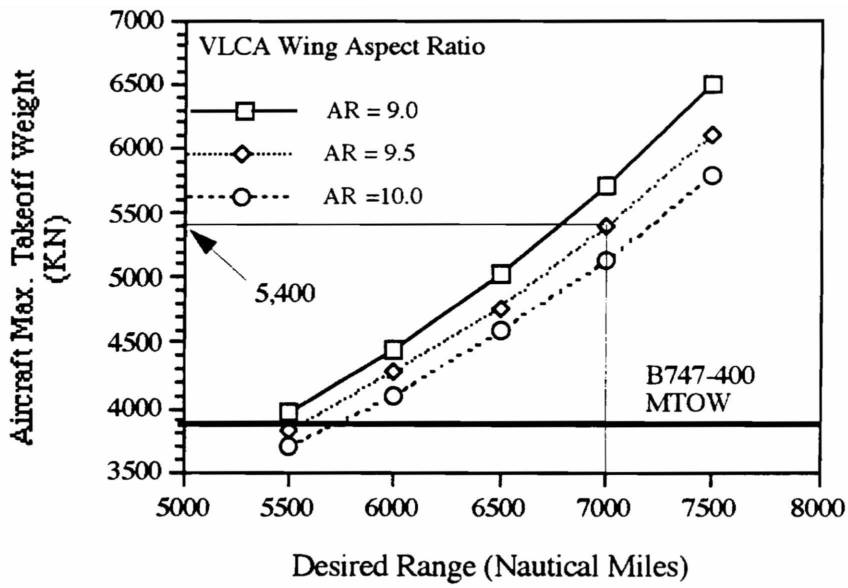


FIGURE 5.3: VLCA Aircraft Takeoff Weight Variations with Mission Range

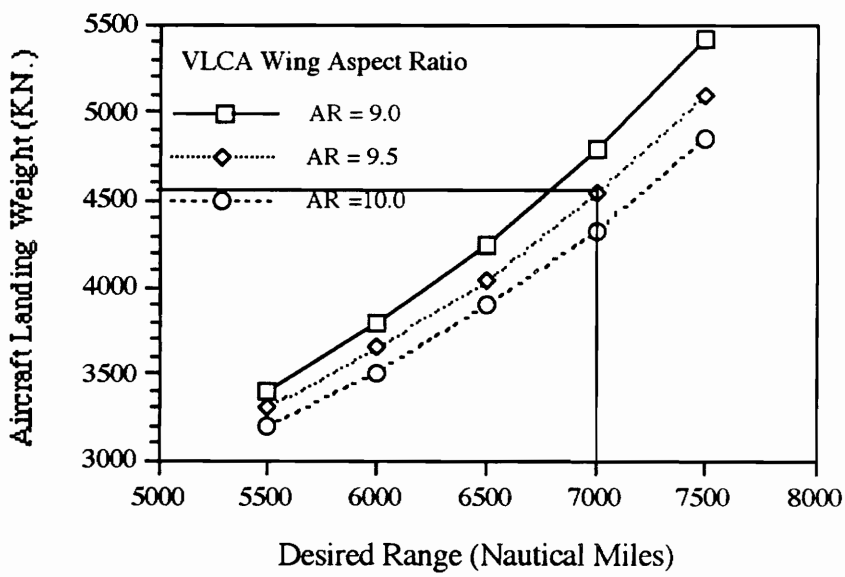


FIGURE 5.4: VLCA Aircraft Landing Weight Sensitivity with Mission Range

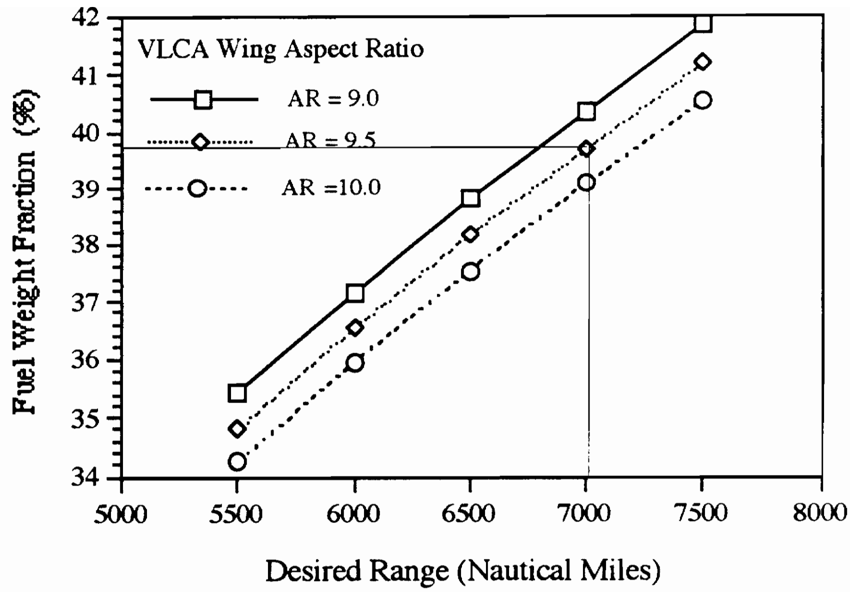


FIGURE 5.5: VLCA Fuel Weight Fraction Sensitivity Analysis

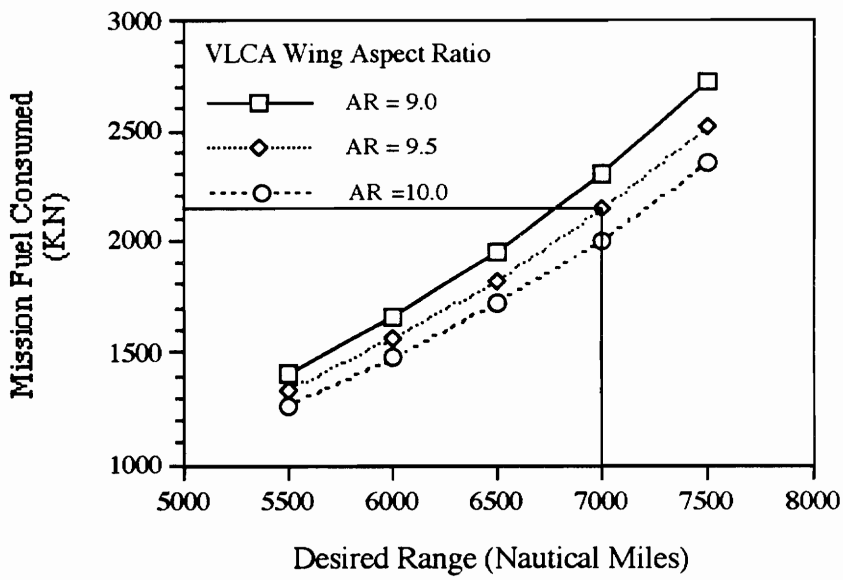


FIGURE 5.6: Mission Fuel Consumed Versus Mission Range

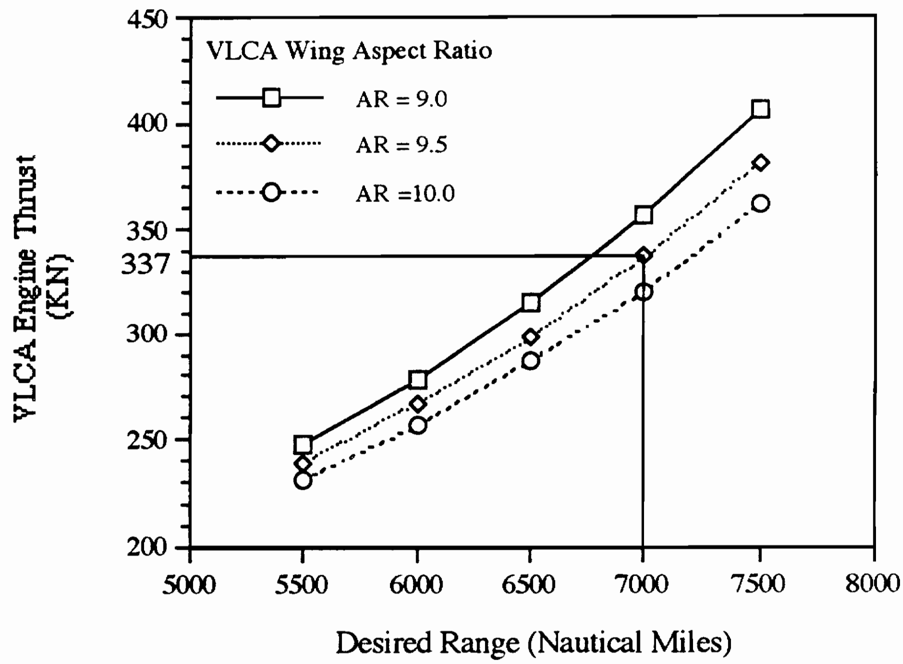


FIGURE 5.7: Required VLCA Engine Thrust (Static ISA Conditions)

Table 5.1: Runway Length (in meters) Parametric Study to Support VLCA Operations For Various Range and Aspect Ratio Combinations

Desired Range in Km. (n.m.)	AR = 9.0	AR = 9.5	AR = 10.0
10,180 (5,500)	3093	3098	3127
11,112 (6,000)	3184	3105	3110
12,038 (6,500)	3191	3196	3116
13,000 (7,000)	3197	3204	3207
13,890 (7,500)	3204	3209	3213

The wake vortex and in-trail separation analysis results are shown in Tables 5.2 through 5.5 and Figures 5.8 through 5.14. Tables 5.2 through 5.4 show the maximum tangential velocity location within a trailing vortex profile. This maximum vortex vertical velocity is located laterally on both sides from the aircraft fuselage centerline and varies according to the aircraft group that follows a VLCA aircraft. In this sensitivity analysis note that three aircraft groups are following a heavy or VLCA aircraft, they are: small, medium or large, and heavy or VLCA groups, defined by the maximum takeoff weight boundaries at 55.6, 267, 1335 KN, (12,500, 60,000, and 300,000 pounds), respectively. For example, for a desired range of 13,000 Km. (7,000 n.m.) and an aspect ratio of 9.5 the trailing vortex wake maximum tangential velocity is located at 11.5, 10.5, 9.4 meters, respectively, from the fuselage centerline. Table 5.5 and Figure 5.8 show the trailing vortex node location within a trailing vortex profile. This vortex node is located laterally on both sides from the aircraft fuselage centerline and again varies according to the aircraft group that follows a VLCA aircraft. For example, for a desired range of 13,000 Km. (7,000 n.m.) and an aspect ratio of 9.5 the node is located at 32 m. from the aircraft centerline.

Furthermore, Figures 5.9 through 5.11 show the predicted vortex wake tangential speed distribution (vortex profile) for a heavy (B747-400) and a VLCA aircraft when followed by a small, medium or large, and heavy or VLCA aircraft groups, respectively. These vortex profiles were developed for the baseline scenario. The critical lateral distances from center of fuselage at which the vortex node and the maximum tangential velocity are located can be graphically found in Figures 5.9 through 5.11 or they can be exactly determined by looking at Table 5.5 (in the case of vortex node) for both B747-400 and VLCA aircraft.

Table 5.2: Lateral Distance From VLCA Fuselage Centerline to Vortex Wake Max. Tangential Velocity Location in meters (Small Follows VLCA)

Desired Range in Km. (n.m.)	AR = 9.0	AR = 9.5	AR = 10.0
10,180 (5,500)	10.2	9.8	9.4
11,112 (6,000)	10.8	10.3	9.8
12,038 (6,500)	11.4	10.8	10.4
13,000 (7,000)	12.1	11.5	10.9
13,890 (7,500)	12.9	12.1	11.6

Table 5.3: Lateral Distance From VLCA Fuselage Centerline to Vortex Wake Max. Tangential Velocity Location in meters (Medium and Large Follow VLCA)

Desired Range in Km. (n.m.)	AR = 9.0	AR = 9.5	AR = 10.0
10,180 (5,500)	9.3	8.9	8.6
11,112 (6,000)	9.8	9.4	9.0
12,038 (6,500)	10.4	9.9	9.5
13,000 (7,000)	11.0	10.5	10.0
13,890 (7,500)	11.7	11.1	10.5

Table 5.4: Lateral Distance From VLCA Fuselage Centerline to Vortex Wake Max. Tangential Velocity Location in meters (Heavy and VLCA Follow VLCA)

Desired Range in Km. (n.m.)	AR = 9.0	AR = 9.5	AR = 10.0
10,180 (5,500)	8.3	8.0	7.6
11,112 (6,000)	8.8	8.4	8.0
12,038 (6,500)	9.3	8.8	8.5
13,000 (7,000)	9.9	9.4	8.9
13,890 (7,500)	10.5	9.9	9.4

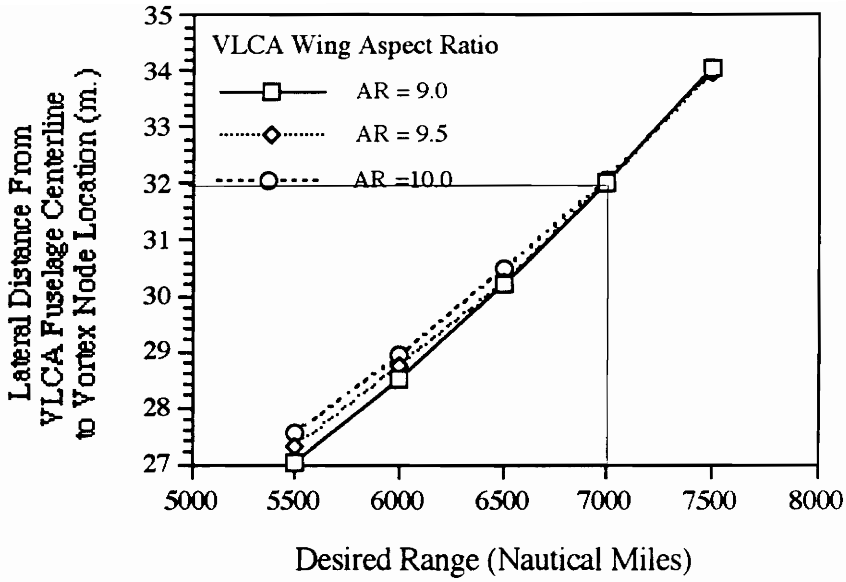


FIGURE 5.8: **VLCA Aircraft Trailing Vortex Node Location**

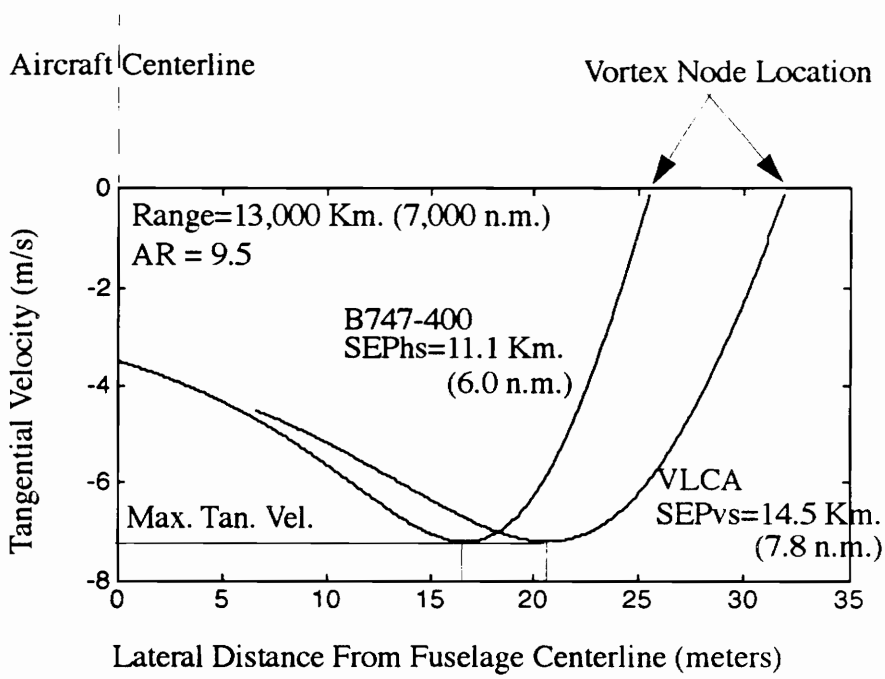


FIGURE 5.9: **Tangential Velocity Profiles (inboard of vortex core) for two Separation Conditions (Small Aircraft Follows Heavy or VLCA)**

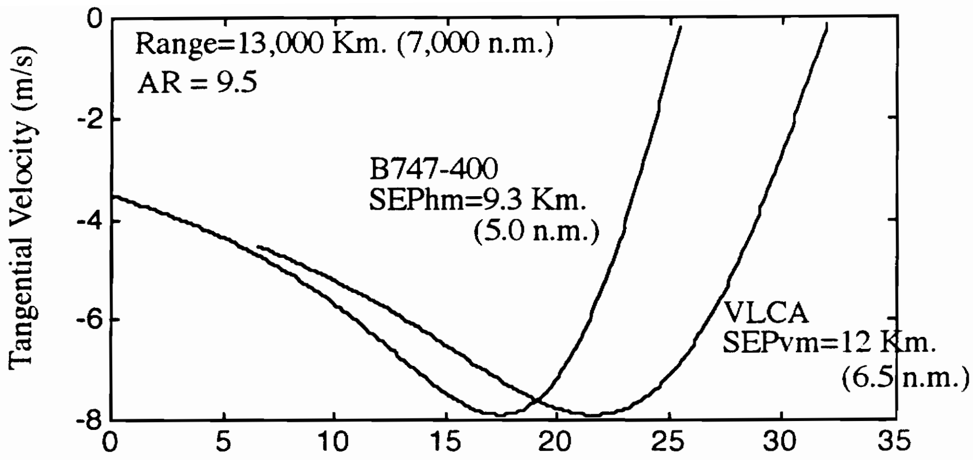


FIGURE 5.10: **Tangential Velocity Profiles (inboard of vortex core) for two Separation Conditions (Medium or Large Follow Heavy or VLCA)**

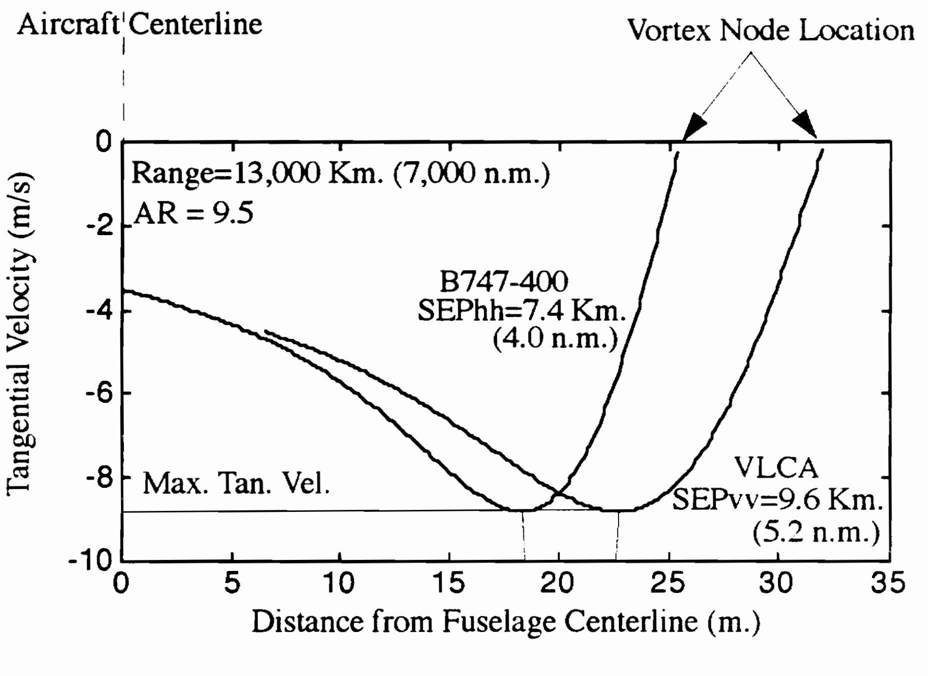


FIGURE 5.11: **Tangential Velocity Profiles (inboard of vortex core) for two Separation Conditions (Heavy or VLCA Follow Heavy or VLCA)**

Results from the wake vortex model are used as inputs to the aircraft in-trail separation analysis model in order to develop new in-trail approach separation distances. This proposed spacing of various aircraft groups from VLCA is clearly indicated in Figures 5.12 through 5.14 where the maximum separation is found for a VLCA designed with a wing aspect ratio of only nine and with a desired maximum stage length of 13,890 Km. (7,500 n.m.). Furthermore, for a desired range of 13,000 Km. (7,000 n.m.) and an aspect ratio of 9.5 the minimum in-trail separation distances when a VLCA is followed by a small, medium or large, and heavy or VLCA aircraft is 14.4, 12.0, and 9.6 Km., (7.8, 6.5, and 5.2 n.m.) respectively. These new spacings represent an increase of 30% from current IFR approach in-trail separation distances. In addition, they represent minimums that are not accounting for buffer times.

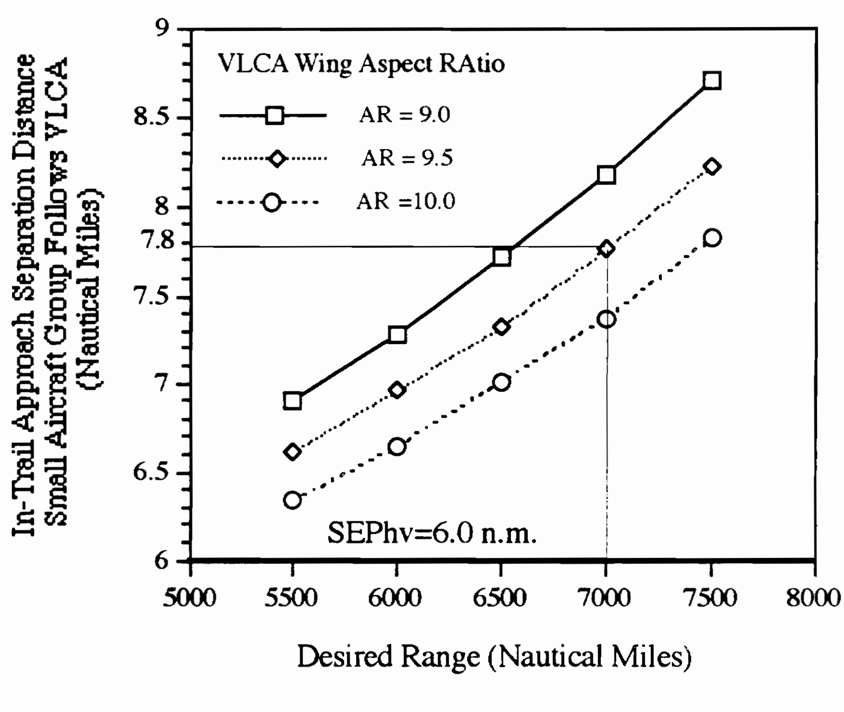


FIGURE 5.12: Minimum Approach Separation Distance for Small Aircraft Trailing VLCA Aircraft

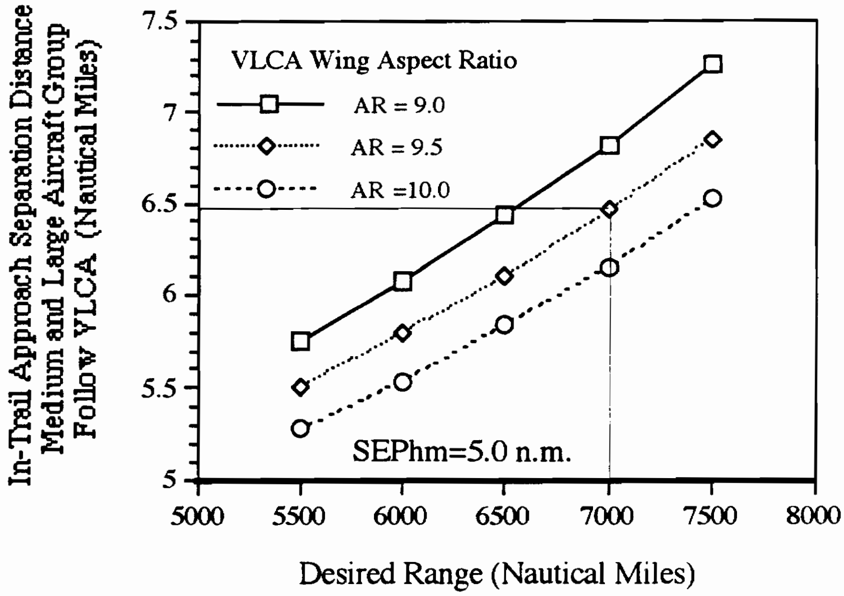


FIGURE 5.13: Minimum Approach Separation Distance for Medium or Large Aircraft Trailing VLCA Aircraft

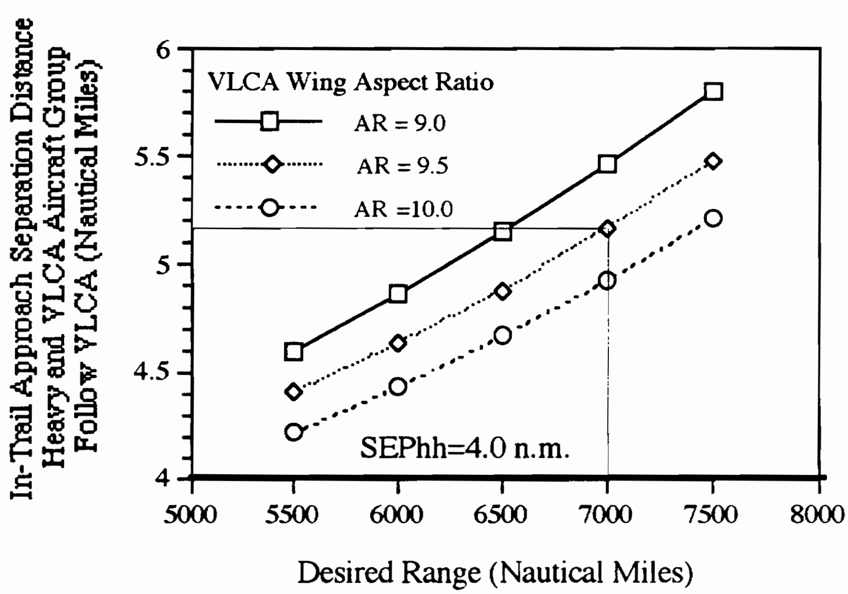


FIGURE 5.14: Minimum Approach Separation Distance for Heavy or VLCA Aircraft Trailing VLCA Aircraft

The airfield pavement module results are shown in Figures 5.15 and 5.16. Figure 5.15 clearly indicates how VLCA wheel track changes according to variations in aspect ratios and desired mission ranges. The wheel track configuration of a Boeing 747-400 is shown in this figure as reference. Figure 5.16 illustrates the results of this sensitivity analysis indicating that existing airfield pavement sections should be capable of accommodating this type of aircraft routinely. A triple, dual wheel configuration has been assumed in our model as this strut configuration will not impact the existing pavement design standards.

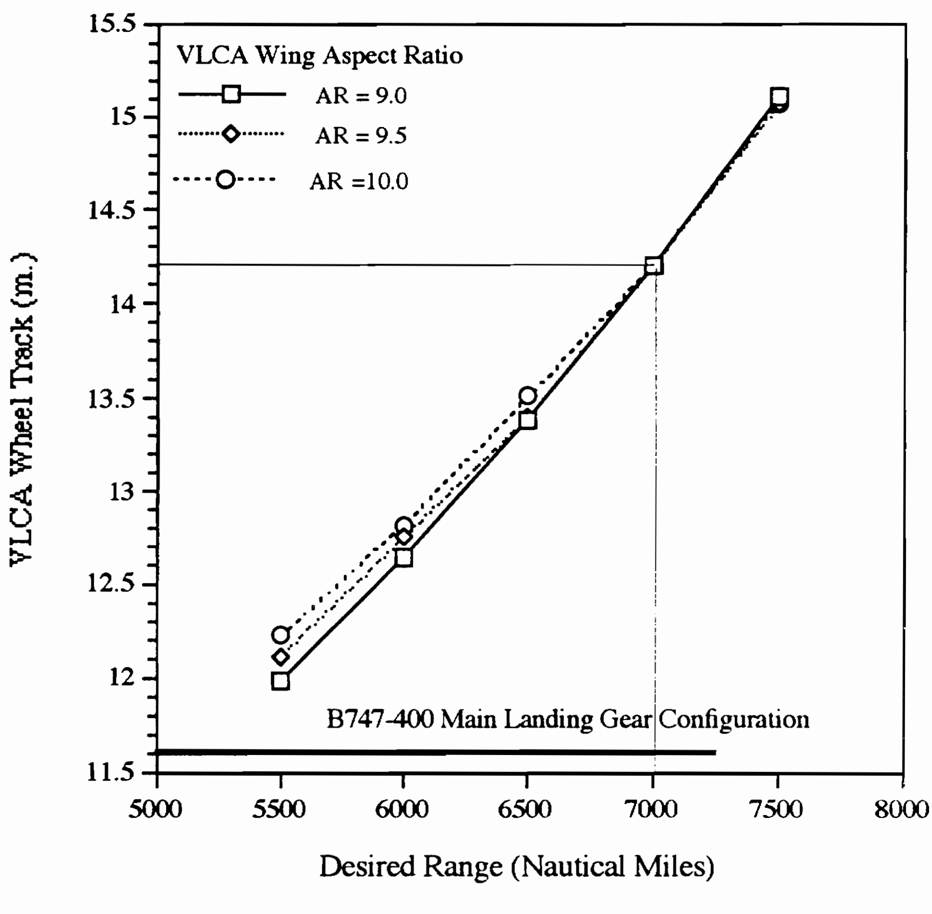


FIGURE 5.15: VLCA Wheel Track Sensitivity Analysis

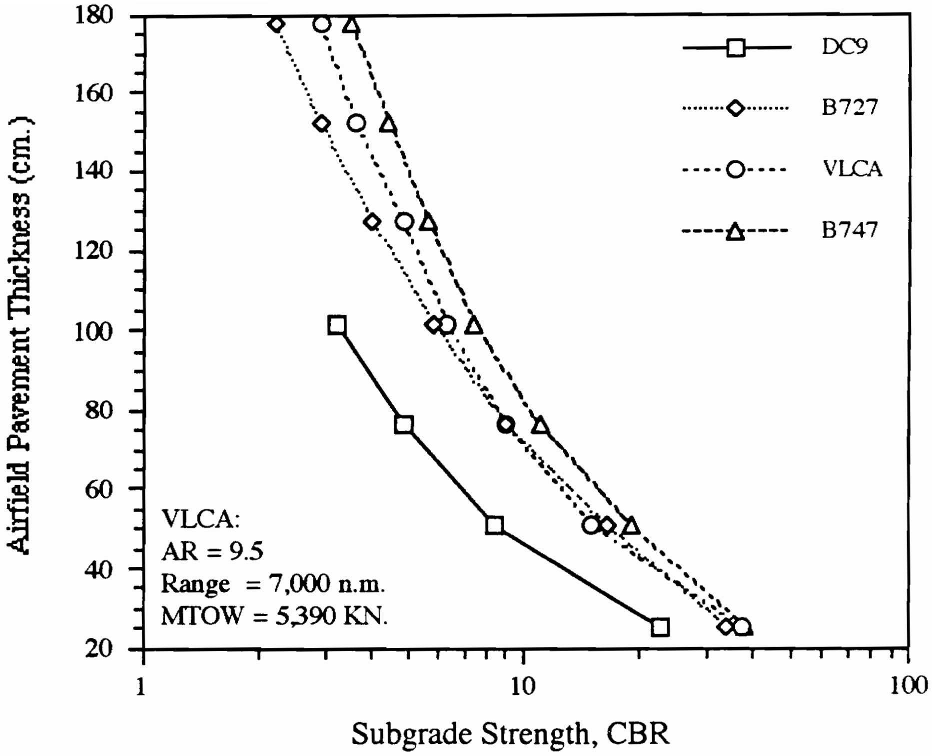


FIGURE 5.16: Airfield Pavement Thickness vs. CBR Curve

The sensitivity analysis of this first scenario concludes accounting also for changes in the airfield geometric design, airport terminal, and landside critical parameters. Table 5.6 shows proposed airfield geometric design guidelines that were developed as a result of supporting VLCA's. Finally, Tables 5.7 through 5.9 show the economic impact of supporting VLCA operations from an airport and airline point of view. Table 5.7 yields the total airport infrastructure improvement cost for four design cases. Table 5.8 shows an airport income parametric study which yields the airport's annual benefit of supporting VLCA's. In Table 5.9, the airline operator will appreciate a parametric study performed to better understand the implications of introducing VLCA aircraft in its own operating costs. The most important results generated in Table 5.9 are the direct operating cost (DOC) and the

DOC per available seat mile (ASM).

Table 5.5: VLCA Trailing Vortex Node Location (lateral distances in m.)

Desired Range in Km. (n.m.) Aspect Ratio	13,000 (7,000) 9.0	13,000 (7,000) 9.5	13,000 (7,000) 10.0
	27.01	27.32	27.57
	28.52	28.75	28.92
	30.20	30.24	30.48
	32.04	32.02	32.09
	34.08	33.97	34.00

Table 5.6: Proposed Airfield Geometric Design Minimum Separations (in meters) in Terms of Desired Range, Aspect Ratio, Cruise Mach Number, and VLCA Passenger Capacity

Range(n.m.) Aspect R.	5500 9.0	5500 9.5	5500 10.0	6000 9.0	6000 9.5	6000 10.0	6500 9.0	6500 9.5	6500 10.0	7000 9.0	7000 9.5	7000 10.0	7500 9.0	7500 9.5	7500 10.0
RW[a] CL[b] to TW[c] CL Spacing (m)	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600
TW CL to TW CL Spacing (m)	281	284	286	296	298	300	313	313	316	331	331	331	352	350	351
TW CL to Object Spacing (m)	168	170	171	177	178	179	187	187	188	197	197	197	209	209	209
TL[d] CL to Object Spacing (m)	145	147	148	153	154	155	161	162	163	170	170	170	181	181	181

a.Runway
b.Centerline
c.Taxiway
d.Taxilane

Table 5.7: Airport Infrastructure Improvement Parametric Study to Support VLCA Operations in Terms of Range and Aspect Ratio (amounts are in dollars and represent overall economic impact to airport authorities and owners)

Desired Range in Km. **Desired Range (n.m.)** **Aspect Ratio** Cruise Mach Number VLCA Capacity in pax. MTOW (lbs.) MTOW in KN Wingspan in meters	**10,186** **(5,500)** **9.5** 0.85 600 (860,000) 3,830 69.58	**13,000** **(7,000)** **9.5** 0.85 600 (1,210,000) 5,385 81.59	**13,000** **(7,000)** **10.0** 0.85 600 (1,150,000) 5,120 81.72	**13,890** **(7,500)** **9.5** 0.85 600 (1,370,000) 6,100 86.51
Airfield Pavement Section Improvement	0	0	0	0
Noise Mitigation	5,000,000	7,872,000	10,000,000	10,000,000
Runway Improvement	19,250,000	19,250,000	19,250,000	24,319,277
Taxiway Improvement	13,663,234	13,663,237	13,663,237	15,413,237
90 Degree Exit Improv.	386,622	276,343	274,952	384,694
Runway Blast Pad Area Improvement	1,200,000	1,200,000	1,200,000	1,589,673
Terminal Apron Area Improvement	0	77,685	78,665	113,207
Land Acquisition	63,869	229,328	231,198	297,101
Airfield Geometric Infrastructure Improvement	39,017,641	48,299,715	48,409,883	59,736,701
Terminal Curb Frontage Improvement	45,900	45,900	45,900	45,900
Parking Garage Improvement	2,653,750	2,653,750	2,653,750	2,653,750
Landside Improv.	2,699,650	2,699,650	2,699,650	2,699,650
International Terminal Infrastructure Improvement	77,523,165	77,523,165	77,523,165	77,523,165
Total Airport Infrastructure Improvement Cost	**124,240,456**	**136,394,530**	**138,632,698**	**149,959,516**

Table 5.8: Airport Income Parametric Study of VLCA Aircraft in Terms of Range and Aspect Ratio (amounts are in dollars and represent airport's additional income received due to new VLCA operations)

Desired Range in Km.	**10,186**	**13,000**	**13,000**	**13,890**
Desired Range (n.m.)	**(5,500)**	**(7,000)**	**(7,000)**	**(7,500)**
Aspect Ratio	**9.5**	**9.5**	**10.0**	**9.5**
Cruise Mach Number	0.85	0.85	0.85	0.85
VLCA Capacity in pax.	600	600	600	600
MTOW (lbs.)	(860,000)	(1,210,000)	(1,150,000)	(1,370,000)
MTOW in KN	3,830	5,385	5,120	6,100
Wingspan in meters	69.58	81.59	81.72	86.51
Passenger Facilities Charge (PFC)	2,295,000	2,295,000	2,295,000	2,295,000
Landing Fees	6,450,000	9,075,000	8,625,000	10,275,000
Annual Airport Benefit	**8,745,000**	**11,370,000**	**10,920,000**	**12,570,000**
Benefit Cost Ratio	**1.00**	**1.19**	**1.12**	**1.20**

The second scenario deals with change in critical output parameters of the airport terminal and landside design modules, due to changes in the passenger capacity of VLCA aircraft. Here, the sensitivity analysis is performed for three design cases, two of which are for a typical airport that operates an aircraft mix that includes VLCA aircraft (for both 600 and 800 passengers, respectively) and the third airport scenario does not include VLCA aircraft. Table 5.10 shows the impact of VLCA aircraft operations on the space requirements of the terminal and landside components for all three study cases. The major outputs of this scenario are represented by the airport terminal space area requirements and the short and long term parking garage space parameters.

Table 5.9: Airline Operating Cost Parametric Study to Support VLCA Operations in Terms of Range and Aspect Ratio (in $per trip)

Desired Range in Km. **Desired Range (n.m.)** **Aspect Ratio** Cruise Mach Number VLCA Capacity in pax. MTOW (lbs.) MTOW in KN Wingspan in meters	**10,186** **(5,500)** **9.5** 0.85 600 (860,000) 3,830 69.58	**13,000** **(7,000)** **9.5** 0.85 600 (1,210,000) 5,385 81.59	**13,000** **(7,000)** **10.0** 0.85 600 (1,150,000) 5,120 81.72	**13,890** **(7,500)** **9.5** 0.85 600 (1,370,000) 6,100 86.51
Capital Cost per unit	150,000,000	220,000,000	200,000,000	235,000,000
Fuel & Oil Costs	75,399	120,962	113,201	142,082
Crew Expenses	23,145	29,553	29,553	31,689
Insurance Cost	20,924	26,717	26,717	28,648
Flight Operations Cost	119,468	177,232	169,469	202,418
Depreciation Cost	21,750	31,900	31,900	34,075
Maintenance Cost	11,310	18,144	16,980	21,312
DIRECT OPERATING COST (DOC)	**152,528**	**227,276**	**218,349**	**257,805**
Available Seat Mile (ASM)	3,300,000	4,200,000	4,200,000	4,500,000
DOC ASM Ratio (in $per-seat mile)	**0.046**	**0.054**	**0.052**	**0.057**
Property & Ground Equipment Maintenance Cost	78,115	99,743	99,739	106,952
Administrative & Sales Cost	19,529	24,936	24,935	26,738
INDIRECT OPERATING COST (IOC)	**97,643**	**124,678**	**124,674**	**133,690**
TOTAL OPERATING COST (TOC)	**250,171**	**351,954**	**343,043**	**391,495**

Table 5.10: Airport Terminal and Landside Infrastructure Improvement Parametric Study to Support VLCA Operations in Terms of Passenger Capacity (areas are in squared meters)

VLCA Capacity in pax. Range in Km. (n.m.) Aspect Ratio Cruise Mach Number MTOW in KN (lbs.) Wingspan in meters	**600** 13,000 (7,000) 0.85 9.5 5385 (1,210,000) 81.59	Without VLCA Operations	**800** 13,000 (7,000) 0.85 9.5 N/A N/A
Peak-Hour Operations	1	0	1
Annual VLCA Operations	1,500	0	1,500
Annual VLCA Enplanements in pax.	765,000	0	1,020,000
Typical Peak-Hour Passenger (TPHP)	6,089	5,400	6,318
Airline Ticket Counter	957 (10,296)	922 (9,918)	957 (10,296)
Airline Ticket Offices & Support Spaces	1285 (13,828)	1234 (13,277)	1285 (13,828)
Outbound Baggage Facilities	4304 (46,300)	4011 (43,150)	4304 (46,300)
Baggage Claim Facilities	2617 (28,159)	2436 (26,210)	2617 (28,159)
Airline Operations & Support Areas	2571 (27,656)	2468 (26,554)	2571 (27,656)
Departure Lounges	9164 (98,585)	8580 (92,285)	9164 (98,585)
Other Airline Spaces	514 (5,531)	494 (5,311)	514 (5,531)
Ticketing Lobby	3605 (38,784)	3589 (38,612)	3605 (38,784)
Central Waiting Lobby Seat Requirements	3,653	3,240	3,791
Central Waiting Lobby	6436 (69,238)	5723 (61,567)	6436 (71,796)
Bag Claim Lobby	8149 (87,674)	7228 (77,760)	8457 (90,979)
Food & Beverage Services	5415 (58,260)	5415 (58,260)	5415 (58,260)
Concessions & Building Services	6228 (67,000)	6228 (67,000)	6228 (67,000)
Other Rental Areas	3425 (36,850)	3435 (36,850)	3425 (36,850)
Other Circulation Areas	17986 (193,498)	16920 (182,032)	17986 (193,498)

VLCA Capacity in pax. Range in Km. (n.m.) Aspect Ratio Cruise Mach Number MTOW in KN (lbs.) Wingspan in meters	**600** 13,000 (7,000) 0.85 9.5 5385 (1,210,000) 81.59	Without VLCA Operations	**800** 13,000 (7,000) 0.85 9.5 N/A N/A
Building Mechanical Systems (HVAC)	10898 (117,249)	10301 (110,818)	10980 (118,128)
Building Structures	4178 (44,945)	3949 (42,480)	4209 (45,283)
Domestic Terminal Building Space	87732 (943,854)	82920 (892,083)	88390 (950,933)
Immigration	5659 (60,885)	5019 (54,000)	5873 (63,180)
Customs	18676 (200,921)	16564 (178,200)	19380 (208,494)
Public Health	8489 (91,328)	7529 (81,000)	8809 (94,770)
Agriculture	1132 (12,177)	1004 (10,800)	1175 (12,636)
Visitor Waiting Rooms	8499 (91,328)	7529 (81,000)	8809 (94,770)
Federal Inspection Services	42445 (456,638)	37645 (405,000)	44045 (473,850)
International Circulation, baggage assembly, utilities, and walls	42445 (456,638)	37645 (405,000)	44045 (473,850)
Airport Terminal Space Area Improvement	172,621 (**1,857,130**)	158 211 (**1,702,093**)	176 479 (**1,898,633**)
Short Term Parking Garage Improv (space vehicle)	4,092	3,850	4,155
Short & Term Parking Garage Improv. (space vehicle)	1,060	942	1,100
Terminal Curb Frontage Capacity (linear m.)	124 (406)	110 (360)	128 (421)

The sensitivity analysis objective of the third and last scenario was to perceive the parametric changes in all the modules to user defined variable changes such as the cruise mach number (that directly affects cruise speed) of the VLCA aircraft. The scenario results are shown in Tables 5.11 through 5.14. Table 5.11 illustrates the economic effect of VLCA operations on the airport infrastructure and its components such as airside, land-side, and terminal components and subcomponents. While Table 5.12 and 5.13 focus on the potential benefits that an airport authority and airline operator can obtain by preparing the introduction of VLCA operations. Finally, Table 5.14 ends this chapter by showing the validity of the model by performing a parametric sensitivity analysis in terms of any chosen variable parameter (i.e., cruise mach number) to obtain any output parameter that airport and airline planners may require for their long term planning efforts.

Table 5.11: Airport Income Parametric Study of VLCA Aircraft in Terms of Cruise Mach Number (amounts are in dollars and represent airport's additional income received due to new VLCA operations)

Cruise Mach Number	**0.80**	**0.85**	**0.88**
Flying Time in hours	**15.1**	**14.25**	**13.78**
Desired Range in Km.	13,000	13,000	13,000
Desired Range (n.m.)	(7,000)	(7,000)	(7,000)
Aspect Ratio	9.5	9.5	9.5
MTOW in KN	5,613	5,390	5,657
MTOW (lbs.)	(1,260,000)	(1,210,000)	(1,270,000)
Wingspan in meters	83.15	81.59	83.47
Passenger Facilities Charge (PFC)	2,295,000	2,295,000	2,295,000
Landing Fees	9,450,000	9,075,000	9,525,000
Annual Airport Benefit	**11,745,000**	**11,370,000**	**11,820,000**
Benefit Cost Ratio	**1.18**	**1.19**	**1.16**

Table 5.12: Airport Infrastructure Improvement Cost Parametric Study to Support VLCA Operations in Terms of Cruise Mach Number (amounts are in dollars and represent overall economic impact to airport authorities and owners)

Cruise Mach Number **Flying Time in hours** Desired Range in Km. Desired Range (n.m.) Aspect Ratio MTOW in KN MTOW (lbs.) Wingspan in meters	**0.80** **15.1** 13,000 (7,000) 9.5 5,613 (1,260,000) 83.15	**0.85** **14.25** 13,000 (7,000) 9.5 5,390 (1,210,000) 81.59	**0.88** **13.78** 13,000 (7,000) 9.5 5,657 (1,270,000) 83.47
Airfield Pavement Section Improvement	0	0	0
Noise Mitigation	10,000,000	7,872,000	10,000,000
Runway Improvement	19,875,721	19,250,000	21,880,939
Taxiway Improvement	15,413,237	13,663,237	15,413,237
90 Degree Exits	345,547	276,343	389,121
Runway Blast Pad Area Improvement	1,235,755	1,200,000	1,450,339
Terminal Apron Area Improvement	88,989	77,685	91,284
Land Acquisition	250,895	229,328	255,273
Airfield Geometric Infra-structure Improvement	45,900,000	48,299,715	54,602,414
Terminal Curb Frontage Improvement	45,900	45,900	45,900
Short & Long Term Parking Garage Improvement	2,653,750	2,653,750	2,653,750
Landside Improvement	2,699,650	2,699,650	2,699,650
International Terminal Infrastructure Improvement	77,523,165	77,523,165	77,523,165
Total Airport Infrastructure Improv. Cost	**142,297,231**	**136,394,530**	**144,825,229**

Table 5.13: Airline Operating Cost Parametric Study to Support VLCA Operations in Terms of Cruise Mach Number (in $per trip)

Cruise Mach Number	**0.80**	**0.85**	**0.88**
Flying Time in hours	**15.1**	**14.25**	**13.78**
Desired Range in Km.	13,000	13,000	13,000
Desired Range (n.m.)	(7,000)	(7,000)	(7,000)
Aspect Ratio	9.5	9.5	9.5
MTOW in KN	5,613	5,390	5,657
MTOW (lbs.)	(1,260,000)	(1,210,000)	(1,270,000)
Wingspan in meters	83.15	81.59	83.47
Capital Cost	250,000,000	250,000,000	250,000,000
Fuel & Oil Costs	127,612	120,962	128,810
Crew Expenses	31,326	29,553	28,578
Insurance Cost	28,319	26,717	25,835
Flight Operations Cost	**187,256**	**177,232**	**183,223**
Depreciation Cost	37,759	35,622	34,447
Maintenance Cost	19,142	18,144	19,321
Direct Operating Cost (DOC)	**244,157**	**230,999**	**236,991**
Available Seat Mile (ASM)	4,200,000	4,200,000	4,200,000
DOC ASM Ratio	**0.058**	**0.055**	**0.056**
Property & Ground Equipment Maintenance Cost	105,724	99,743	96,451
Administrative & Sales Cost	26,431	24,936	24,113
Indirect Operating Cost (IOC)	**132,155**	**124,678**	**120,564**
Total Operating Cost (TOC)	**376,312**	**355,678**	**357,556**

6. Conclusions and Recommendations

6.1 Conclusions

From the sensitivity analysis carried out in this thesis it is evident that operations by VLCA aircraft benefit the airports (benefit over cost ratios ranging between 1.00 to 1.20), the airlines (by offering lower direct operating costs and DOC ASM ratios ranging from 4.8 to 5.8 cents per seat-mile), and the public by offering lower airfares in the high-density routes. Clearly, by looking at Tables 5.1 through 5.14 and Figures 5.1 through 5.15 an obvious VLCA aircraft candidate should have aspect ratios equal or greater than 9.5, Mach 0.85 cruise speed capability, a desirable range of 13,000 Km. (7,000 n.m.), and be capable of carrying 600 passengers. Therefore, as demonstrated in this research study VLCA aircraft transportation is a technically and economically feasible solution to today's problems facing air transportation around the world.

Until now few aircraft have been designed with airport infrastructure compatibility as the primary constraint in this complex aircraft-airport interaction process. However, there is a clear trade-off in designing VLCA aircraft that will comply with existing airport design standards (few or none infrastructure impacts) and those aircraft designs where the vehicle is fully optimized for the mission without airport constraints. If a new VLCA design is constrained by existing airport design guidelines and infrastructure a flying operational performance penalty will be paid by the airlines and ultimately by users as they would have to offset higher operating costs. For example, our envisioned VLCA optimal design shows wingspan ranging from 81 to 87 m., takeoff weights ranging from 5,123 to 6,103 KN (1,150,000 to 1,370,000 pounds), powerful engines ranging from 312 to 401 KN (70,000 to 90,000 pounds) of thrust, and aspect ratios from 9.5 to 10.0. All these parameters exceed today's standards and will without doubts create serious airport compatibility problems and confusion if airport authorities do not prepare and plan ahead of time (now) to support VLCA aircraft.

While it is feasible to minimize the airport infrastructure and economic impact of introducing VLCA aircraft the systems-based methodology presented here shows that airport authorities, airlines and aircraft designers can achieve a common ground by looking at the overall implications of VLCA aircraft operations in an integrated systems engineering fashion. However, until now most of the design strategies adopted by aircraft manufacturers seldom consider airport compatibility issues as a primary constraint. Given the low returns of the aviation industry throughout the years it seems unlikely that non-optimal VLCA designs could be adopted in the near future by the airline industry.

The application of systems engineering modeling in an integrated framework fashion (one programmable package model) for the evaluation of VLCA operations at existing and future airports has proven to be very effective and efficient. The model was also found to be highly flexible so as to meet the needs of airports, airlines, and aircraft manufacturers around the world. As demand for air transportation grows research analysis of this nature using systems approach modeling has great potential. Because, it allows a better insight into the interactions of a complex model, resulting in a better decision making process rather than making judgements based on guess work or intuition. Finally, the use of MATLAB and STELLA II in this effort is clearly compensated because allows the analyst to concentrate on performing sensitivity analysis and obtaining results quickly rather than spending time on complex computer programming and other requirements. The average runtime (in a Macintosh QUADRA 700) of this program ranges from three to five minutes depending on how many or what types of output parameters the analyst would like to obtain.

6.1 Recommendations

The following recommendations are a result of experience and knowledge gained by learning about: aircraft aerodynamics, airport planning, design, and operations; while developing the methodology, the model and its different components; and during the writing of the MATLAB program. The proposed recommendations are as follows:

- The VLCA aircraft configuration should have a wingspan of 81.5 m., a fuselage length of 250 m., four engines producing 334 KN (75,000 pounds) of thrust each, capacity to carry 600 passengers and their baggage, and a maximum takeoff weight of 5,390 KN (1,210,000 pounds).
- The Federal Aviation Administration and its European counterpart should create a seventh Airplane Design Group that will include these Very Large Capacity Aircraft.
- New airport design standards and guidelines must be developed as soon as possible to support operations of these aircraft in just about five to seven years.
- Further research is recommended to address the issue of wake vortex vertical decay. This submodel should be incorporated into our Vortex Wake Module.
- Airline operators should demand from aircraft manufacturers the most optimal VLCA performance design alternative.
- Airline operators should press airport authorities where VLCA will operate to start early infrastructure improvements that will satisfy design standards of this newly created seventh airplane group.

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Appendix A

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%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                    AIRCRAFT PRELIMINARY DESIGN MODULE
%    PRELIMINARY DESIGN PROCEDURE FOR RAPID "WEIGHT AND DIMENSION"
%                         SIZING OF VLCA AIRPLANES
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
format long

%                         MISSION PROFILE DEFINITION

% Estimate or Enter Weight Fractions for Known Mission Profile Phases:

  % Phase 1: Engine start, warmup, and push out
  % Phase 2: Taxi to takeoff
  % Phase 3: Takeoff procedure
  % Phase 4: Climb procedure
  % Phase 5: Cruise segment (unknown)
  % Phase 6: Loiter segment (unknown)
  % Phase 7: Descent segment
  % Phase 8: Cruise to alternate
  % Phase 9: Landing procedure, taxi to gate, and shutdown

  % Suggested weight fractions for above mission phases:

    W1 = 0.990;
    W2 = 0.990;
    W3 = 0.995;
    W4 = 0.980;
    W7 = 0.990;
    W9 = 0.992;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                              RELEVANT VLCA DATA

% Statistically Determined Regression Coefficients for Jet Transport
% Aircraft (per Roskam, 1985 and 1986)

  A = 0.0833;
  B = 1.0383;

% Relevant Constants

  pi = 3.1415926;
  mu = 0.03;                                 % Coefficient of friction

% Relevant Design Parameters for Future VLCA Aircraft

  AR = 9.5;                                  % Aspect ratio
  e = 0.85;                                  % Wing efficiency factor
```

```
neng = 4;                    % No. of engines
pax = 630;                   % Capacity in people (600 pax + 30 crew)
npax = 630;                  % Number of paying passengers
wpax = 200                   % No. of pounds per pax including luggage
pyl = pax * wpax;            % Compute payload in pounds
ran = 7000;                  % Range in nautical m. with max. payload

% To increase accuracy divide the total range in 7 segments

  for h=1:1:7
    range(h) = ran/7;
  end

% Relevant Vectors for Future VLCA Aircraft

 % Speed of sound in m./sec. at different cruise altitudes in meters

  Va =  [   0    340.3
         1000    336.4
         2000    332.5
         3000    328.6
         4000    324.6
         5000    320.5
         6000    316.4
         7000    312.3
         8000    308.1
         9000    303.8
        10000    299.5
        11000    295.1
        12000    295.1
        13000    295.1
        14000    295.1];

 % Air density in Kg./cubic meter at different altitudes in meters

   Rhot = [   0   1.225
            500   1.1673
           1000   1.1116
           1500   1.0581
           2000   1.0065
           2500 0.95686
           3000 0.90912
           3500 0.86323
           4000 0.81913
           4500 0.77677
           5000 0.73612
           5500 0.69711
           6000 0.65970
           6500 0.62384
           7000 0.58950
           7500 0.55662
```

```
          8000 0.52517
          8500 0.49509
          9000 0.46635
          9500 0.43890
         10000 0.41271
         10500 0.38773
         11000 0.36922
         11500 0.33633
         12000 0.31083
         12500 0.28726
         13000 0.26548
         13500 0.24536
         14000 0.22675];

  % Air density ratio in metric system at different altitudes in meters

DENSITYr = [      0    1.0000
               1000    0.9075
               2000    1.0065
               3000   0.91912
               4000   0.81913
               5000   0.73612
               6000   0.65970
               7000   0.58950
               8000   0.52517
               9000   0.46625
              10000   0.41271
              11000   0.36392
              12000   0.31083
              13000   0.26548
              14000   0.22675];

%%_____________________RELEVANT VLCA REGIMES__________________________%%
% TAKEOFF REGIME

  % Define takeoff conditions

    Hfield = 0.0;                     % Airfield elevation in meters
    rhoto = table1(Rhot,Hfield);      % Takeoff air density

  % Relevant lift and drag coefficients for takeoff drag computations

    clmaxland = 2.8;                  % Landing max. lift coefficient
    clmaxto = 2.2;                    % Takeoff max. lift coefficient
    cdl0B = 0.016;                    % Zero lift drag coefficient
    cdg = 0.020;                      % Drag coeff. due to gear config.
    cdf = 0.015;                      % Drag coeff. due to flap config.
    cltogr = 1.0;                     % Takeoff lift coeff. in ground roll
    cdito = cltogr^2/(pi*AR*e);       % Takeoff induced drag coeff.
    cdto = cdl0B+cdito+cdg+cdf        % Takeoff drag coefficient
```

```
  % Compressibility drag coefficient

    Cdoct = [0.70  0.000
             0.76  0.0001
             0.82  0.0003
             0.84  0.0007
             0.86  0.0012
             0.88  0.0025
             0.90  0.0040
             0.95  0.0015];

% CLIMB REGIME

  % Climb speed (as Vcas) in knots at different altitudes in meters

    Vclimb = [    0  200
               1000  220
               2000  250
               3000  250
               4000  270
               5000  280
               6000  280
               7000  280
               8000  280
               9000  280
              10000  280
              11000  280
              12000  280
              13000  280
              14000  280];

% CRUISE REGIME

  % Define cruise mach number, altitude, and speeds

    Mcr = 0.85;                       % Cruise mach number
    Hcrf = 40000;                     % Cruise altitude in feet
    Hcrm = Hcrf / 3.28;               % Cruise altitude in meters
    Vcrm = Mcr * table1(Va,Hcrm);     % Cruise speed (as Vtas) in m./sec.
    Vcrk = Vcrm * 1.94;               % Cruise speed (as Vtas) in knots

  % Define alternate cruise conditions

    Vcral = 300;                      % Alt. cruise speed (as Vtas) in kt
    Dal = 100;                        % Alternate distance in nautical m.

% LOITER REGIME

  % Loiter time in hours
    Enl = 1.0;
```

```
% APPROACH REGIME

  % Define desirable max. approach speeds
    Vappk = 155;                    % In knots
    Vappm = Vappk / 1.94;           % In m./sec.
    clapp = clmaxland/1.69;         % Usable approach lift coefficient

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                     INITIAL LD AND OTHER COMPUTATIONS

% Assume Initial Lift to Drag Ratios, LD, (guess to start computations).

  LDcri = -1.0 + 2.0 * (AR);                  % Initial cruise LD ratio
  LDli = LDcri +.5;                           % Initial loiter LD ratio
  LDali = LDcri - 4.0;                        % Initial alternate LD ratio

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                BIG LOOP

% Start big loop to iterate for various LD ratios, TSFC's, mission
% fuel weight fractions, MTOW's, MALW's, wing span and areas, and cruise
% drag values.

  z = 5;                                             % No. of iterations
  for u=1:1:z;
%%___________________________________________________________________________%%
  % THRUST SPECIFIC FUEL CONSUMPTION COMPUTATIONS, TSFC, PER VLCA ENGINE

  % Forecast Thrust Specific Fuel Consumption Values
  % (from average expected values of new-generation engines)

    TSFCclnew = 0.28;                         % Climb TSFC at maximum power

  % Estimate Initial Thrust Specific Fuel Consumption (from expansion of
  % engine manufacturer curves based on Pratt & Whitney JTD9-7A engine)
  % [McCormick, 1979].
    % Initial climb thrust specific fuel consumption, TSFCcli,
    % in pounds as a function of climb altitude (first row)
    % and climb mach number (first column)

   TSFCcli = [0.00 0.000  5000 10000 15000 20000 25000 30000 35000 40000 45000
              0.00 0.364 0.350 0.340 0.340 0.340 0.34  0.34  0.34  0.34  0.34
              0.05 0.390 0.375 0.365 0.355 0.355 0.35  0.35  0.35  0.35  0.35
              0.10 0.410 0.400 0.390 0.380 0.380 0.38  0.38  0.38  0.38  0.38
              0.15 0.435 0.425 0.420 0.410 0.410 0.41  0.41  0.41  0.41  0.41
              0.20 0.460 0.450 0.445 0.440 0.440 0.44  0.44  0.44  0.44  0.44
             0.25 0.485 0.475 0.465 0.460 0.460 0.46  0.46  0.46  0.46  0.46
              0.30 0.512 0.500 0.495 0.490 0.490 0.49  0.49  0.49  0.49  0.49
              0.35 0.540 0.525 0.520 0.510 0.510 0.51  0.51  0.51  0.51  0.51
              0.40 0.560 0.550 0.545 0.540 0.530 0.51  0.51  0.51  0.51  0.51
              0.45 0.590 0.580 0.570 0.560 0.555 0.55  0.55  0.55  0.55  0.55
              0.50 0.620 0.600 0.595 0.585 0.580 0.57  0.56  0.56  0.56  0.56
```

```
          0.55 0.650 0.630 0.620 0.610 0.600 0.59  0.58   0.58  0.58  0.58
          0.60 0.680 0.660 0.645 0.635 0.620 0.61  0.60   0.60  0.60  0.60
          0.65 0.70  0.68  0.67  0.66  0.64  0.635 0.630  0.62  0.622 0.620
          0.70 0.73  0.71  0.07  0.68  0.67  0.655 0.645  0.64  0.637 0.635
          0.75 0.76  0.74  0.72  0.70  0.69  0.680 0.665  0.66  0.655 0.650
          0.80 0.78  0.76  0.74  0.73  0.71  0.700 0.690  0.68  0.675 0.670
          0.85 0.80  0.78  0.77  0.76  0.74  0.720 0.710  0.70  0.694 0.690
          0.90 0.82  0.80  0.79  0.78  0.765 0.745 0.730  0.72  0.735 0.730];

% Initial cruise thrust specific fuel consumption, TSFCcri, in pounds
%  as a funct. of cruise altitude (first row) and cruise mach number
% (first column)

        TSFCcri = [0      0     10000 20000 25000 30000 35000 40000 45000
                   0.30   0.505 0.50  0.50  0.50  0.50  0.50  0.50  0.50
                   0.35   0.535 0.52  0.52  0.52  0.52  0.52  0.52  0.52
                   0.40   0.565 0.54  0.535 0.535 0.535 0.535 0.535 0.535
                   0.45   0.605 0.57  0.555 0.555 0.555 0.555 0.555 0.555
                   0.50   0.640 0.6   0.575 0.565 0.565 0.565 0.565 0.565
                   0.55   0.660 0.625 0.6   0.59  0.582 0.58  0.579 0.578
                   0.60   0.700 0.65  0.62  0.61  0.605 0.602 0.598 0.596
                   0.65   0.720 0.67  0.64  0.63  0.625 0.62  0.617 0.615
                   0.70   0.750 0.7   0.66  0.65  0.645 0.64  0.636 0.635
                   0.75   0.780 0.74  0.69  0.675 0.662 0.659 0.655 0.652
                   0.80   0.800 0.76  0.72  0.70  0.685 0.68  0.675 0.67
                   0.85   0.82  0.78  0.75  0.73  0.710 0.700 0.695 0.67
                   0.90   0.840 0.81  0.77  0.75  0.73  0.72  0.71  0.71];

% SCALING ENGINE EFFICIENCY

KTSFCcl = TSFCclnew / TSFCcli(2,2) % Engine Eff. const. for climb TSFC

  % NOTE: The improvement in efficiency for new-generation engines
  %       will be the same for all flying regimes

 % Compute Final Cruise Thrust Specific Fuel Consumption per VLCA
 % Engine

  TSFCcrf = KTSFCcl * table2(TSFCcri,Mcr,Hcrf);

% Assume Initial Loiter and Alternate Thrust Specific Fuel Consumption
% Based on the Computed Final Cruise Specific Fuel Consumption

  TSFCloi = TSFCcrf + 0.1;                        % Initial loiter TSFC
  TSFCali = TSFCcrf + 0.2;                        % Initial alt. TSFC
%%________________________________________________________________________%%
% MISSION USED FUEL WEIGHT FRACTION ESTIMATION

% Estimate initial distance (horizontal) to climb in nautical miles

  dclnm = 100;
```

```
% Compute the fuel weight fractions for cruise, loiter and alternate
% segments

W51 = 1/(exp((range(1)-dclnm)*(TSFCcrf/Vcrk)*(1/LDcri)));   % Cruise 1
W52 = 1/(exp((range(2))*(TSFCcrf/Vcrk)*(1/LDcri)));         % Cruise 2
W53 = 1/(exp((range(3))*(TSFCcrf/Vcrk)*(1/LDcri)));         % Cruise 3
W54 = 1/(exp((range(4))*(TSFCcrf/Vcrk)*(1/LDcri)));         % Cruise 4
W55 = 1/(exp((range(5))*(TSFCcrf/Vcrk)*(1/LDcri)));         % Cruise 5
W56 = 1/(exp((range(6))*(TSFCcrf/Vcrk)*(1/LDcri)));         % Cruise 6
W57 = 1/(exp((range(7))*(TSFCcrf/Vcrk)*(1/LDcri)));         % Cruise 7
W6 = 1/(exp((TSFCloi)*(1/LDli)*(Enl)));                     % Loiter
W8 = 1/(exp((Dal)*(TSFCali/Vcral)*(1/LDali)));              % Alt. cr.

 % Compute Mff and used fuel weight fraction, Ffrac.

   Mff = W9*W8*W7*W6*W51*W52*W53*W54*W55*W56*W57*W4*W3*W2*W1;

   Ffrac = (1 - Mff);                % Mission used fuel weight fraction
%%____________________________________________________________________%%
 % MAXIMUM TAKEOFF WEIGHT REQUIREMENTS (MTOW)

   Wtogi = 600000;       % Guess initial gross takeoff weight in pounds
   deltaw = 10000;            % Iterate at increments of 10,000 pounds
   for i=1:1:140;
     Woet = Wtogi - Ffrac * Wtogi - wpax*pax;
     Wetent = Woet - Wtogi*.0005;
     We = 10 ^ ( (log10 (Wtogi) - A ) / B );
     DeltaW = Wetent - We;
     Wout(i) = Wtogi;
     delta(i) = DeltaW;
     if abs(DeltaW) < deltaw/3;
       Wtogf = Wtogi;              % Final gross takeoff weight in pounds
     end
     Wtogi = Wtogi + deltaw;
   end
   Wtogf;
   %plot (Wout, delta)

%%____________________________________________________________________%%
 % VLCA PHYSICAL DIMENSIONS: SIZING AIRPLANE WING FOR A GIVEN APPROACH
 % SPEED

 % Compute Max. landing Weight Requirements, MALW, in pounds

   WLAND = Wtogf - Wtogf * Ffrac * (4/10);

 % VLCA Aircraft Wing Sizing

   % Compute wing area and wingspan

 rhosl = table1 (Rhot, 0);
```

```
 Sm = (2*9.81*WLAND)/(2.2)/(rhosl*Vappm^2*clapp); % Wing area in sq. m.
 Sft = Sm * (3.28^2);                             % Wing area in sq.ft.
 Bm = sqrt (AR * Sm);                             % Wingspan in meters
 Bft = Bm * 3.28;                                 % Winspan in feet

% VLCA Aircraft Weight Sizing

  % Compute MTOW and MALW in different dimensional units
  WTOl = Wtogf;                          % Takeoff weight in pounds
  WTOmt = WTOl / 2200;                   % Takeoff weight in metric tons
  WTOkg = WTOmt * 1000;                  % Takeoff weight in Kilograms
  WTOkn = (9.8) * WTOl / 2200;           % Takeoff weight in Kilonewtons
  WTOn = WTOkn * 1000;                   % Takeoff weight in Newtons

  WLAND;                                 % Landing weight in pounds
  WLANDmt = WLAND / 2200;                % Landing weight in metric tons
  WLANDkg = WLANDmt * 1000;              % Landing weight in Kilograms
  WLANDkn = (9.8) * WLAND / (2200);      % Landing weight in Kilonewtons
  WLANDn = WLANDkn * 1000;               % Landing weight in Newtons
%%_______________________________________________________________________%%
 % DRAG COMPUTATIONS IN CRUISE CONDITIONS

   % VLCA aircraft cruise weight at top of climb (point 1 or TOC)
   % and top of descent (point 7 or TOD) in newtons.

     wcr1N = WTOn - (1-W4*W3*W2*W1) * WTOn;          % Cruise wt. at TOC
     wcr2N = WTOn - (1-W51*W4*W3*W2*W1) *WTOn;
     wcr3N = WTOn - (1-W51*W52*W4*W3*W2*W1) *WTOn;
     wcr4N = WTOn - (1-W51*W52*W53*W4*W3*W2*W1) *WTOn;
     wcr5N = WTOn - (1-W51*W52*W53*W54*W4*W3*W2*W1) *WTOn;
     wcr6N = WTOn - (1-W51*W52*W53*W54*W55*W4*W3*W2*W1) *WTOn;
     wcr7N = WTOn - (1-W51*W52*W53*W54*W55*W56*W4*W3*W2*W1) *WTOn;
     % Cr. wt. at TOD

     wcr1l = wcr1N / 4.45;               % Cruise wt. at TOC in pounds
     wcr7l = wcr7N / 4.45;               % Cruise wt. at TOD in pounds

   % Compute cruise lift coefficients

     rhocr = table1 (Rhot,Hcrm);          % Cruise air density in metric
     clcr1 = (2*wcr1N)/(rhocr*Sm*Vcrm^2);          % Cruise lift coeff
     clcr2 = (2*wcr2N) / (rhocr*Sm*Vcrm^2);
     clcr7 = (2*wcr7N) / (rhocr*Sm*Vcrm^2);        % Cruise lift coeff

   % Compute zero lift drag coefficient of complete aircraft

     % Compute wetted area and friction factor

       C = 0.0199;
       D = 0.7531;
       Swet = 10^ (C + D * log10 (Wtogf) );
```

```
      H1 = -2.5229;
      J1 = 1.0000;

      f = 10^ (H1 + J1 * log10 (Swet) );
      Cdob = f / Sft;                         % incompressible Cdo value
      Cdoc = table1(Cdoct,Mcr);               % Compressibility correction
      Cdo = Cdob + Cdoc                       % Corrected Zero lift drag

   % Compute cruise induced drag coefficient (lift dependent drag
   % coefficient) by using parabolic drag

     cdi1 = clcr1^2 / (pi*AR*e);         % Induced drag coefficient at TOC
     cdi7 = clcr7^2 / (pi*AR*e);         % Induced drag coefficient at TOD


   % Compute cruise drag coefficient

     cdcr1 = Cdo + cdi1;                 % Cruise drag coefficient at TOC
     cdcr7 = Cdo + cdi7;                 % Cruise drag coefficient at TOD

   % Compute cruise drag

     DRAGcr1N = 0.5*rhocr*(Vcrm)^2*Sm*cdcr1;  % Cruise drag at TOC in N
     DRAGcr7N = 0.5*rhocr*(Vcrm)^2*Sm*cdcr7;  % Cruise drag at TOD in N
     DRAGcr1l = DRAGcr1N / 4.45;             % Cruise drag at TOC in lb.
     DRAGcr7l = DRAGcr7N / 4.45;             % Cruise drag at TOD in lb.
%%___________________________________________________________________%%
  % COMPUTE LD RATIOS AND RECONCILE WITH THEIR INITIAL VALUES

  % Compute Lift to Drag Ratios, LD's, at TOC and TOD

    LDcr1 = wcr1N / DRAGcr1N;           % Cruise LD at TOC
    LDcr7 = wcr7N / DRAGcr7N;           % Cruise LD at TOD

    LDcr = 0.666 * LDcr1 + 0.333 * LDcr7;      % Average cruise LD ratio

  % Reconcile computed LD ratios with initial LD values

    LDcri = LDcr;                       % Set a new cruise LD ratio
    LDli = LDcri + 1.0;                 % Set a new loiter LD ratio
    LDali = LDcri - 2.0;                % Set a new alt. airport LD ratio

  end                                   % End of big loop

  LDcri;
  LDli;
  LDali;

  plot (Wout, delta);
  pause
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% THRUST COMPUTATIONS IN CRUISE CONDITIONS

  % Compute the Required Thrust in Cruise Conditions in newtons (N)
  % and pounds (l)

    THCRreq1N = DRAGcr1N;            % Req'd cruise thrust at TOC in N
    THCRreq7N = DRAGcr7N;          % Required cruise thrust at TOD in N
    THCRreq1l = THCRreq1N / 4.45   % Required cruise thrust at TOC in lb
    THCRreq7l = THCRreq7N / 4.45;  % Required cruise thrust at TOD in lb
    THCReng1l = THCRreq1l/neng; % Req cruise thrust at TOC in lb per eng
    THCReng7l = THCRreq7l/neng  % Req cruise thrust at TOD in lb per eng
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% DRAG AND THRUST COMPUTATIONS IN TAKEOFF CONDITIONS

  % Drag Computations at Takeoff Conditions
    % They are located inside "takeoff field length loop"

  % Thrust Computations at Takeoff Conditions

    % Compute the required thrust to achieve a desired takeoff run
    % by assuming average historical data values

    THTOreqN = 0.25 * WTOkn * 1000;    % Assumed req takeoff thrust in N
    THTOengN = THTOreqN/neng;           % Assd req to thrust per eng in N
    THTOengl = THTOreqN/(4.45*neng);  % Assd req to thrust per eng in lb
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                         POWERPLANT SELECTION

% THRUSTS PROVIDED BY PRATT & WHITNEY JTD9 ENGINE

  % Estimate Initial Climb Thrust and Cruise Thrust (from expansion of
  % engine manufacturer curves based on Pratt & Whitney JTD9-7A engine)
  % [McCormick, 1979].
   % Estimate the initial max. climb thrust in pounds provided by the
   % JTD9 engine as a function of climb altitude (first row) and climb
   % mach number (first column)

THCLli =  [1     0      5000  10000 15000 20000 25000 30000 35000 40000 45000
           0     39650 35400 32000 28400 23500 19000 15700 13000 11000  9000
           0.05  37900 33700 30500 26900 22500 18500 15200 12500 10500  8500
           0.10  35900 32100 29000 25700 21700 18000 14700 12000 10000  8000
           0.15  34300 30800 27900 24800 21000 17500 14500 11800  9700  7800
           0.20  32500 29400 26700 23700 20300 17000 14000 11600  9300  7500
           0.25  31100 28200 25800 23000 19800 16700 13700 11300  9200  7400
           0.30  29700 27000 24900 22300 19200 16300 13500 11000  8800  7200
           0.35  28600 26100 24100 21700 18700 16000 11300 10800  8600  7000
           0.40  27500 25200 23300 21200 18300 15700 13000 10700  8500  6900
           0.45  26500 24400 22700 20700 18000 15500 12900 10600  8450  6800
           0.50  25600 23700 22000 20200 17700 15300 12800 10500  8400  6700
           0.55  24800 22900 21600 19800 17500 15200 12700 10500  8350  6600
           0.60  23900 22100 21000 19400 17400 15100 12650 10450  8350  6500
```

```
        0.65   23200 21600 20500 19000 17300 15000 12650 10500  8300  6400
        0.70   22500 20900 20000 18700 17200 15000 12700 10550  8350  6500
        0.75   22000 20500 19600 18400 17000 15000 12700 10600  8350  6500
        0.80   21500 20000 19000 18100 16800 15000 12750 10700  8400  6550
        0.85   20800 19700 18700 17800 16400 14900 12950 10900  8600  6700
        0.90   20200 19300 18300 17600 16300 14900 13000 11100  8750  6800
        0.95   19800 19000 17900 17200 16000 14800 13200 11200  8800  6900];

  % Estimate the initial max. cruise thrust in pounds provided by the
  % JTD9 engine as a function of cruise altitude (first row) and
  % cruise mach number (first column)

THCRli= [1      0     10000 20000 25000 30000 35000 40000 45000
        0.0     37100 30150 24000 20000 16000 12000  9700  7700
        0.05    35300 28900 22500 19000 15500 11700  9400  7500
        0.1     33150 27300 21500 18000 14800 11400  9000  7300
        0.15    31700 26200 20500 17500 14300 11000  8700  7100
        0.2     29900 25000 19800 16500 13800 10700  8500  7000
        0.25    28600 24000 19300 16000 13300 10400  8300  6900
        0.3     27300 23300 18550 15850 13200 10300  8100  6800
        0.35    26300 22500 18100 15400 12800 10200  8050  6700
        0.4     25100 21700 17700 15100 12600 10100  8000  6600
        0.45    24200 21000 17300 14800 12400 10050  7950  6500
        0.5     23350 20500 17000 14700 12300 10000  7900  6400
        0.55    22400 19900 16700 14600 12200 10050  7950  6350
        0.6     21600 19400 16500 14500 12200 10100  8000  6300
        0.65    21000 19000 16200 14400 12200 10150  8000  6250
        0.7     20200 18500 16000 14400 12200 10200  8050  6200
        0.75    19500 18000 15800 14350 12250 10250  8100  6250
        0.8     19000 17700 15650 14300 12300 10400  8150  6300
        0.85    18700 17300 15500 14200 12350 10500  8300  6350
        0.9     18300 17000 15400 14050 12400 10550  8400  6400
        0.95    18000 16500 15300 14000 12500 10650  8450  6500];
%____________________________________________________________%
 % Scaling Engine Power (cruise thrust)

  Mcrmax = 0.90;                               % Mach 0.90 maximum speed
  Kengcrth = THCRengl1/table2(THCRli,Mcrmax,Hcrf);    % Powe rconstant

 % Compute the Final Cruise Thrust Provided by VLCA Engine in Pounds

  THCRlf = Kengcrth * table2(THCRli,Mcrmax,Hcrf);
  THCResl = Kengcrth * table2(THCRli,0.0,0.0);
%______________________________________________________________________%
 % Scaling Engine Power (takeoff thrust)

  Kengtoth = THTOengl / table2(THCLli,0,0);          % Power constant

% Compute the Final Takeoff Thrust Provided by VLCA Engine in Pounds

% Loop to take the critical scaling factor to be used in future comput.
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                     TAKEOFF FIELD LENGTH REQUIREMENTS

  % Enter Desired Takeoff Field Length in Meters at Sea Level

    DTOL = 3700;          % Based on B747-400 takeoff length requirements
                          % [FAA AC 150/5325-4A, 1990].
  % Compute Ground Distance, Sg, also called takeoff roll distance

    % Compute takeoff relevant velocities

      Vs = sqrt((2*WTOn)/(rhoto*clmaxto*Sm));    % Stall speed in m./sec
      Vlof = 1.1 * Vs;                          % Lift-off speed in m./sec.

    % Initial state variable values

      Vrg = 0.001;                        % Ground run velocity in m./sec.
      Sg = 0.0;                           % Ground run distance in meters
      deltat = 1.0;                       % Iteration time increments

    % Start iteration loop for Sg

      for t = 0:1:50;

        % Compute dynamic pressure in newtons per squared meters

          q = 0.5 * rhoto * Vrg^2;

        % Compute takeoff mach number

          Mto = Vrg / table1 (Va,Hfield);

        % Interpolate the "initial climb thrust matrix", THCLli, to
        % obtain the final takeoff thrust, THTOlf, provided by VLCA eng
        % at the appropriate mach number Mto and airfield elevation.

          THTOlf = Kengtoth * table2 (THCLli, Mto, Hfield);
          THTOnf = THTOlf * 4.45;

        % Compute ground run acceleration in meters per squared seconds
        % per sec.

          a = ((THTOnf*neng - mu*WTOn)-(cdto - mu*cltogr)*q*Sm)/WTOkg;

        % Vrg and Sg computations

          Vrg = Vrg + a * deltat;     % State variable for speed
          Vrgk = Vrg * 1.94;
          Sg = Sg + Vrg * deltat;     % State variable for distance
          Sgf = Sg * 3.28;
          if abs (Vrg - Vlof) < 1.0;
```

```
        Vrgfinal = Vrg;
        Sgfinal = Sg;
      end
  end
  Vrgfinal;                  % Ground run speed in m./sec. at end of Sg
  Vrgkfinal = Vrgfinal*1.94;      % Ground run speed in kt at SG end
  Sgfinal;                        % Ground run distance in meters
  Sgf = Sgfinal * 3.28;      % Ground run distance in feet
  Mto;                       % Takeoff mach number
  THTOlf;                    % Takeoff thrust provided by VLCA engine
  a;                         % Ground run acceleration in m./sq.sec.

% Takeoff Rotation Distance Computation, Sr.

  tr = 3;                                % Rotation time in seconds
  Sr = tr * Vlof;                        % Rotation distance in meters

% Takeoff Transition Distance Computation, Str

  % Compute the change in lift coefficient

    deltacl = ((Vlof/Vs)^2-1)*(clmaxland*((Vs/Vlof)^2-0.53)+0.38);

  % Compute the radius, R, of the circular arc flare in meters

    R = (2 * (WTOn / Sm) ) / (rhoto * 9.81 * deltacl);

  % Compute takeoff drag

    DRAGtoN = 0.5 * rhoto * Sm * (Vlof^2) * cdto;         % In newtons
    DRAGtol = DRAGtoN / 4.45;                             % In pounds

  % Compute climb angle in radians

    angleCL = (THTOnf * neng - DRAGtoN) / WTOn;

  % Compute transition distance in meters

    Str = R * sin (angleCL);

% Climb Distance Computation

  % Compute transition height in meters

    Htr = Str * (angleCL/2);

  % Compute climb distance in meters

    if   Htr > 16;
         Scl = 0;
    else
```

```
          Scl = (50-Htr) / tan (angleCL);
     end

% The Total Takeoff Field Lenght

  Stom = Sgfinal + Sr + Str + Scl;                                  % In meters
  Stof = Stom;                                                      % In feet

% NOTE:If desired TO field length is less than Sto then increase thrust
%      iteratively
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                       VLCA CLIMB PERFORMANCE

% Apply Roskam's method and iterate back to initial sizing phase

  % Initial state variable values

    Hclm = Hfield;
    Hclf = 3.28 * Hfield;              % Initial climb altitude in ft.
    tclsec = 0.0;                      % Initial time to climb in sec.
    dclm = 0.0;                        % Initial distance to climb in m.
    WClil = WTOl;                      % Initial climb weight in pounds

  % Start iteration loop for climb performance for a fixed no. of steps

    roc = 25;                          % Initial rate of climb in m./sec
    nsteps = 100;                      % No. of steps in climb
    step_size = round(Hcrm/nsteps);
    for c = 0:1:nsteps;

  % Compute climb speed in knots at different climb altitudes in meters

      Vclk = table1(Vclimb,Hclm);

    % Compute climb mach number as a function of Vclk (as Vcas) and
    % density ratio (altitude)

      deltap = table1(DENSITYr,Hclm);
      M=5*((1/deltap*((1+0.2*(Vclk/661.5)^2)^3.5-1)+1)^0.286-1);
      Mcl = sqrt(M);

    % Compute climb speed (as Vtas) in m./sec.

      Vcltas = Mcl * table1(Va,Hclm);
      Vcltask = Vcltas * 1.94;
      deltac = step_size / roc;

    % Compute lift and drag coefficients:
    % Compute climb lift coefficient

      rhocl = table1 (Rhot,Hclm);          % Climb air density in metric
      clcl = (2 * WClil) / (rhocl * Sm * Vcltas^2);
    % Compute zero lift drag coefficient of complete aircraft

      Cdoc = table1 (Cdoct, Mcr);          % Compressibility correction
      Cdo = Cdob + Cdoc;                   % Corrected Zero lift drag

  % Compute climb induced drag coefficient (lift dependent drag
  % coefficient) by using parabolic drag

      cdicl = clcl^2 / (pi*AR*e);
```

```
   % Compute climb drag coefficient

  cdcl = Cdo + cdicl;     % Compute climb drag

  DRAGclN = 0.5 * rhocl * (Vcltas)^2 * Sm * cdcl;        % In newtons
  DRAGcll = DRAGclN / 4.45;                              % In pounds

% Compute climb thrust provided by one VLCA engine at sea level
% static cond.

  THCLl = Kengtoth * table2(THCLli,Mcl,Hclf);            % In pounds
  THCLn = THCLl * 4.45;                                  % In newtons

% Compute total climb thrust provided by all engines at SL static
% conditions

  TTHCLl = THCLl * neng;                                 % In pounds
  TTHCLn = TTHCLl * 4.45;                                % In newtons

% Compute final climb thrust specific fuel consumption

  TSFCcl = KTSFCcl * table2(TSFCcli,Mcl,Hclf);

% Compute fuel consumed

  Fcl = TSFCcl * TTHCLl;     % In lbs of fuel per hr per lb of thrust

% Compute climb weight

  FF = (Fcl / 3600) * deltac;     % Fuel flow in pounds per step size
  WCll = WClil - FF;                                   % In pounds
  WCLkg = WCll / 2.2;                                  % In kilograms
  WCLn = WCll * 4.45;                                  % In newtons

% Compute rate of climb in m./sec. and altitude state variable

  roc = ( ( TTHCLn - DRAGclN ) * Vcltas ) / WCLn;
  Hclm = Hclm + roc * deltac;
  Hclf = 3.28 * Hclm;

% Compute the time to climb
  tclsec = tclsec + deltac;% In seconds
  tclmin = tclsec / 60;                                  % In minutes
  tclhr = tclsec / 3600;                                  % In hours

% Compute the distance to climb;
  dclm = dclm + deltac * Vcltas;                          % In meters
  dclkm = dclm / 1000;                                    % In km.
  dclnm = dclkm * 1.852;                                  % In n.m.
  dclft = dclm * 3.28;                                    % In ft.
```

```
  if abs(Hclm - Hcrm) < 100
     tfinal = tclmin;
     dcfinal = dclkm;
  end
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                       VLCA APPROACH PERFORMANCE

  % Compute approach thrust near runway threshold (point 1)

   rhoapp = table1(Rhot,Hfield);      % Approach air density in metric

   Vsapp = sqrt((2*WLANDn)/(rhoapp*clmaxland*Sm));    % App stall speed
   Vappm1 = 1.3 * Vsapp;                 % Approach speed in m./sec.
   Vappk1 = Vappm1 * 1.94;               % Approach speed in knots

   cdiapp1 = (clmaxland/1.69)^2/(pi*AR*e);     % App induced drag coeff
   CDOapp = Cdob+cdg+cdf;                % Corrected zero lift drag coeff.
   CDapp1 = CDOapp + cdiapp1;            % Approach drag cofficient

   DRAGappN1 = 0.5*rhoapp*(Vappm1)^2*Sm*CDapp1;   % App drag in N
   DRAGapp11 = DRAGappN1 / 4.45;         % Approach drag in lbs

   THAPP11 = DRAGapp11;                  % Total approach thrust in lb
   THAPP11eng = THAPP11 / 4;             % App thrust per VLCA engine

  % Compute approach thrust further away from runway threshold (2)

   Vappm2 = 1.4 * Vsapp;                 % Approach speed in m./sec.
   Vappk2 = Vappm2 * 1.94;               % Approach speed in knots

   cdiapp2 = (clmaxland/1.96)^2/(pi*AR*e);  % App induced drag coeff
   CDapp2 = CDOapp + cdiapp2;                % Approach drag coff

    DRAGappN2 = 0.5*rhoapp*(Vappm2)^2*Sm*CDapp2;  % Approach drag in N
   DRAGapp12 = DRAGappN2 / 4.45;        % Approach drag in pounds

   THAPP12 = DRAGapp12;                 % Total app thrust in pounds
   THAPP12eng = THAPP12 / 4;            % App thrust per VLCA engine
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
                    SUGGESTED VLCA PARAMETRIC STUDY
 % Given a defined mission profile

   ASPECTr = AR                               % Wing aspect ratio
   RANGE = ran                                % In nautical miles
   PAXcap = npax                              % Passenger capacity
   MACHcr = Mcr                               % Cruise mach number

 % The VLCA aircraft wingspan in meters is:

   WINGSPAN = Bm

 % The VLCA aircraft wing area in meters is:

   WINGAREA = Sm

 % The maximum (gross) takeoff weight to accomplish the mission is:

   MTOW = WTOl                                        % In pounds
   WTOn;                                              % In Newtons
   MATOW = WTOkn                                      % In Kilonewtons

 % The max. allowable landing weight is:

   WLAND                                              % In pounds
   WLANDn;                                            % In Newtons
   MALW = WLANDkn                                     % In Kilonewtons

 % The mission used fuel weight fraction is:

   Ffrac

 % The total fuel consumed in the mission is:

   TOTfcl = Ffrac * WTOl                              % In pounds
   TOTfcn = Ffrac * WTOn;                             % In Newtons
   TOTfc = TOTfcn / 1000                              % In Kilonewtons

 % Equivalent thrust at SL required to cruise at Mach 0.9

   THCResl;   % In pounds
   THCResln = THCResl * 4.45;                         % In Newtons

 % The takeoff thrust provided by one VLCA engine

   THTOengl                                           % In pounds
   THTOengn = THTOengl * 4.45;                        % In Newtons
   THRUSTeng = THTOengn / 1000                        % In Kilonewtons
 % Runway field length for Takeoff at sea level ISA
   RWL = Stom                                        % Inmeters
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                   AIRCRAFT SEPARATION ANALYSIS MODULE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                     VLCA AIRCRAFT WAKE VORTEX MODEL

% Define Global Variables

  % Enter aircraft approach altitude

    Happm = Hfield;                  % Given by airfield elevation in m.

  % Enter aircraft approach speed (as constant Vcas) in knots

    VAPPcask = 155;                                          % In knots
    VAPPcasm = VAPPcask / 1.94;                              % In m./sec.

  % Compute approach mach number as a function of VAPPcask and
  % density ratio (altitude)

   deltav = table1(DENSITYr,Happm);
   SQMapp = 5*((1/deltav*((1+0.2*(VAPPcask/661.5)^2)^3.5-1)+1)^0.286-1);
   Mapp = sqrt(SQMapp);

  % Compute aircraft approach speed as Vtas

    VAPPtasm =  Mapp * table1(Va,Happm);                     % In m./sec.
    VAPPtask = VAPPtasm * 1.94;                              % In knots

  % Compute approach air density in Kg./cubic meter

    rhoapp = table1(Rhot,Happm);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% REFERENCE AIRCRAFT WAKE GENERATING DATA

  % Define Variables for B747-400 Airplane

    bB747 = 65;              % Wingspan of generating aircraft in m.
    wB747 = 2800000;         % Gross weight of generating aircraft in N.

  % Compute initial midspan total vortex circulation in squared meters
  % per sec. and assume elliptic spanwise lift distribution

    lambdaB747 = 4 * wB747 / (pi * rhoapp * VAPPtasm * bB747);

  % Assume epsilon value

    epsB747 = 0.0002 * lambdaB747;

  % Compute vortex node location with respect to aircraft centerline

    crB747 = pi/8*bB747;
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% B747 VORTEX VERTICAL VELOCITY PROFILE DEVELOPMENT

  % Small Aircraft Trailing Heavy Aircraft (B747) Scenario

    % Enter min. separation distance (in-trail distance)
    % between generating (B747) and trailing (small) aircraft

      Dnm = 6.0;                                    % In nautical miles
      Dmi = Dnm * 1.15;                             % In statute miles
      Dkm = Dnm * 1.852;                            % In kilometers

    % Compute desired in-trail headway between generating (B747) and
    % trailing (small) aircraft in sec.

      Tsec6 = Dnm / (VAPPtask) * 3600;

    % Start iteration loops to develop B747 trailing vortex system

      for a=1:1:500;
          b=a/10.0;

    % Compute tangential velocity (vortex vertical velocity) right
    % from vortex node for B747 at 6 n.m.

      vtrB7476(a) = lambdaB747/(2*pi*b)*(1-exp(-b^2/(4*epsB747*Tsec6)));
      jrB7476(a) = b + crB747;
      end

      for k=1:1:255;
          m=k/10.0;

    % Compute tangential velocity (vortex vertical velocity) left
    % from vortex node for B747 at 6 n.m.

      vtlB7476(k) =-lambdaB747/(2*pi*m)*(1-exp(-m^2/(4*epsB747*Tsec6)));
      jlB7476(k) = crB747 - m;
      end

  % Plot B747 trailing vortex system to the right & left of vortex node
  % plot (jrB7476,vtrB7476)
  % pause
  % plot (jlB7476,vtlB7476)
  % pause
  % plot (jrB7476,vtrB7476,jlB7476,vtlB7476)
  % pause
%%_____________________________________________________________________%%
  % Medium or Large Aircraft Trailing Heavy Aircraft (B747) Scenario

    % Enter min. separation distance (in-trail distance) between
    % generating (B747) and trailing (medium or large) aircraft
```

```
      Dnm = 5.0;                                      % In nautical miles
      Dmi = Dnm * 1.15;                               % In statute miles
      Dkm = Dnm * 1.852;                              % In kilometers

    % Compute desired in-trail headway between generating (B747) and
    % trailing (medium or large) aircraft in sec.

      Tsec5 = Dnm / (VAPPtask) * 3600;

    % Start iteration loops to develop B747 trailing vortex system

      for a=1:1:500;
          b=a/10.0;

    % Compute tangential velocity (vortex vertical velocity) right from
    % fuselage

      vtrB7475(a) = lambdaB747/(2*pi*b)*(1-exp(-b^2/(4*epsB747*Tsec5)));
      jrB7475(a) = b+crB747;
      end

      for k=1:1:255;
          m=k/10.0;

    % Compute tangential velocity (vortex vertical velocity) left from
    % vortex node for B747 at 5 n.m.

      vtlB7475(k) =-lambdaB747/(2*pi*m)*(1-exp(-m^2/(4*epsB747*Tsec5)));
      jlB7475(k) = crB747 - m;
      end

   % Plot B747 trailing vortex system to the right & left of vortex node

% plot (jrB7475,vtrB7475);
% pause
% plot (jlB7475,vtlB7475);
% pause
% plot (jrB7475,vtrB7475,jlB7475,vtlB7475);
% pause
%%______________________________________________________________________%%
  % Heavy Aircraft Trailing Heavy Aircraft (B747) Scenario

    % Enter min. separation distance (in-trail distance) between
    % generating (B747) and trailing (heavy) aircraft

      Dnm = 4.0;                                      % In nautical miles
      Dmi = Dnm * 1.15;                               % In statute miles
      Dkm = Dnm * 1.852;                              % In kilometers

    % Compute desired in-trail headway between generating (B747) and
    % trailing (heavy) aircraft in sec.
```

```
     Tsec4 = Dnm / (VAPPtask) * 3600;

   % Start iteration loops to develop B747 trailing vortex system

     for a=1:1:500;
         b=a/10.0;

    % Compute tangential velocity (vortex vertical velocity) right from
   % fuselage

     vtrB7474(a) = lambdaB747/(2*pi*b)*(1-exp(-b^2/(4*epsB747*Tsec4)));
     jrB7474(a) = b + crB747;
     end

     for k=1:1:255;
         m=k/10.0;

   % Compute tangential velocity (vortex vertical velocity) left from
   % fuselage

     vtlB7474(k) =-lambdaB747/(2*pi*m)*(1-exp(-m^2/(4*epsB747*Tsec4)));
     jlB7474(k) = crB747 - m;
     end

  % Plot B747 trailing vortex system to the right & left of vortex node

% plot (jrB7474,vtrB7474);
% pause
% plot (jlB7474,vtlB7474);
% pause
% plot (jrB7474,vtrB7474,jlB7474,vtlB7474);
% pause
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% IDENTIFY MAX. TANGENTIAL VELOCITIES AND THEIR CRITICAL LATERAL
% DISTANCES FROM B747 VORTEX VERTICAL VELOCITY PROFILE

  % Small Aircraft Trailing Heavy Aircraft (B747) Scenario

    % Initial max. tangential velocity

     VTmax = 0.0;

    % Iterations along wingspan (lateral distance y) begining at vortex
    % node

     for y = 0.5:0.1:20;

    % Compute tangential vel., change in vel., max. tangential vel.,
    % and critical lateral distance at VTmax

     vtrB7476(y) = lambdaB747/(2*pi*y)*(1-exp(-y^2/(4*epsB747*Tsec6)));
```

```
      delvel = vtrB7476(y) - VTmax;
      if  delvel > 0.0;
        VTmax = vtrB7476(y);
        latdist = y;
      end
    end
    VTMAXhs = VTmax;
    LATDISThs = latdist;
%%____________________________________________________________________%%
  % Medium or Large Aircraft Trailing Heavy Aircraft (B747) Scenario

    % Initial max. tangential velocity

      VTmax = 0.0;

    % Iterations along wingspan (lateral distance y) begining at vortex
    % node

      for y = 0.5:0.1:20;

    % Compute tangential vel., change in vel., max. tangential vel.,
    % and critical lateral distance at VTmax

      vtrB7475(y)=lambdaB747/(2*pi*y)*(1-exp(-y^2/(4*epsB747*Tsec5)));
      delvel = vtrB7475(y) - VTmax;
        if  delvel > 0.0;
         VTmax = vtrB7475(y);
         latdist = y;
        end
      end
      VTMAXhm = VTmax;
      LATDISThm = latdist;
%%____________________________________________________________________%%
  % Heavy Aircraft Trailing Heavy Aircraft (B747) Scenario

    % Initial max. tangential velocity

      VTmax = 0.0;

    % Start iterations along wingspan (lateral distance y) begining at
    % vortex node

      for y = 0.5:0.1:20;

    % Compute tangential vel., change in vel., max. tangential vel.,
    % and critical lateral distance at VTmax

      vtrB7474(y)=lambdaB747/(2*pi*y)*(1-exp(-y^2/(4*epsB747*Tsec4)));
      delvel = vtrB7474(y) - VTmax;
        if  delvel > 0.0;
          VTmax = vtrB7474(y);
```

```
       latdist = y;
      end
    end
    VTMAXhh = VTmax;
    LATDISThh = latdist;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% VLCA AIRCRAFT WAKE GENERATING DATA

  % Define Variables for VLCA Airplane

    bVLCA = Bm;                    % Wingspan of generating aircraft in m.
    wVLCA = WLANDn;                % MALW of generating aircraft in N.

  % Compute initial midspan total vortex circulation in squared meters
  % per sec. and assume elliptic spanwise lift distribution

    lambdaVLCA = 4 * wVLCA / (pi * rhoapp * VAPPtasm * bVLCA);

  % Assume epsilon value

    epsVLCA = 0.0002 * lambdaVLCA;

  % Compute vortex node location with respect to aircraft centerline

    crVLCA = pi/8*bVLCA;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% IDENTIFY MAX. TANGENTIAL VELOCITIES FOR WAKE VORTEX GENERATED BY VLCA
% AT 100 AND 300 SECONDS OF AGE

  % Initial max. tangential velocity

    VTmax = 0.0;

  % Iterations along wingspan (lateral distance y) begining at vortex
  % node

    for y = 0.5:0.1:20;

  % Compute tangential vel., change in vel., max. tangential vel.,
  % and critical lateral distance at VTmax

    Tsec100 = 100;
     vtrVLCA100(y)=lambdaVLCA/(2*pi*y)*(1-exp(-y^2/(4*epsVLCA*Tsec100)))
    delvel = vtrVLCA100(y) - VTmax;
        if  delvel > 0.0;
          VTmax = vtrVLCA100(y);
          latdist = y;
        end
      end
    VTMAXvlca100 = VTmax;
    LATDISTvlca100 = latdist;
```

```
%%_____________________________________________________________________%%
  % Initial max. tangential velocity

    VTmax = 0.0;

  % Iterations along wingspan (lateral distance y) begining at vortex
  % node

    for y = 0.5:0.1:20;

  % Compute tangential vel., change in vel., max. tangential vel.,
  % and critical lateral distance at VTmax

    Tsec300 = 300;
     vtrVLCA300(y)=lambdaVLCA/(2*pi*y)*(1-exp(-y^2/(4*epsVLCA*Tsec300)))
        delvel = vtrVLCA300(y) - VTmax;
        if  delvel > 0.0;
          VTmax = vtrVLCA300(y);
          latdist = y;
        end
      end
      VTMAXvlca300 = VTmax;
      LATDISTvlca300 = latdist;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%               VLCA HEADWAY AND SEPARATION DISTANCE COMPUTATIONS

  % Small Aircraft Trailing VLCA Aircraft Scenario

    % Initial max. tangential velocity

      headmax = 0.0;

  % Start iterations along wingspan (lateral distance y)

      for d = LATDISTvlca100:0.1:LATDISTvlca300;
headway(d)=-(d^2/(4*epsVLCA))*(1/log(1-((2*pi*VTMAXhs*d)/lambdaVLCA)));
        delhead = headway(d) - headmax;
        if delhead  > 0.0;
          headmax = headway(d);
          Dvs = (headmax * VAPPtasm) / 1852;
        end
      end
      HEADWAYvs = headmax;
      Dvs;
%%_____________________________________________________________________%%
  % Medium or Large Aircraft Trailing VLCA Aircraft Scenario

    % Initial max. tangential velocity

      headmax = 0.0;
```

```
 % Start iterations along wingspan (lateral distance y)

      for d = LATDISTvlca100:0.1:LATDISTvlca300;
 headway(d)=-(d^2/(4*epsVLCA))*(1/log(1-((2*pi*VTMAXhm*d)/lambdaVLCA)));
        delhead = headway(d) - headmax;
        if delhead  > 0.0;
          headmax = headway(d);
          Dvm = (headmax * VAPPtasm) / 1852;
        end
      end
      HEADWAYvm = headmax;                 % HEADWAYvm = HEADWAYvl  in sec.
      Dvm;                                 % Dvm = Dvl  in n.m.
%%_____________________________________________________________________%%
  % Heavy Aircraft Trailing VLCA Aircraft Scenario

    % Initial max. tangential velocity

      headmax = 0.0;

  % Start iterations along wingspan (lateral distance y)

      for d = LATDISTvlca100:0.1:LATDISTvlca300;
headway(d)=-(d^2/(4*epsVLCA))*(1/log(1-((2*pi*VTMAXhh*d)/lambdaVLCA)));
        delhead = headway(d) - headmax;
        if delhead  > 0.0;
          headmax = headway(d);
          Dvh = (headmax * VAPPtasm) / 1852;
        end
      end
      HEADWAYvh = headmax;
      Dvh;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% VLCA VORTEX VERTICAL VELOCITY PROFILE DEVELOPMENT

  % Small Aircraft Trailing VLCA Aircraft Scenario

    % Enter min. separation distance (in-trail distance)
    % between generating VLCA and trailing small aircraft

      Dvs;                                          % In nautical miles

    % Compute desired in-trail headway between generating VLCA and
    % trailing small aircraft in sec.

      HEADWAvs = Dvs / (VAPPtask) * 3600;

    % Start iteration loops to develop VLCA trailing vortex system

      for a=1:1:500;
          b=a/10.0;
```

```
  % Compute tangential velocity (vortex vertical velocity) right
  % from vortex node for VLCA at Dvs

  vtrVLCAs(a)=lambdaVLCA/(2*pi*b)*(1-exp(-b^2/(4*epsVLCA*HEADWAYvs)))
  jrVLCAs(a) = b + crVLCA;
   end

   for k=1:1:255;
       m=k/10.0;

  % Compute tangential velocity (vortex vertical velocity) left
  % from vortex node for VLCA at Dvs.

 vtlVLCAs(k)=-lambdaVLCA/(2*pi*m)*(1-exp(-m^2/(4*epsVLCA*HEADWAYvs)))
 jlVLCAs(k) = crVLCA - m;
   end

  % PlotVLCA trailing vortex system right & left of vortex node
 % plot (jrVLCAs,vtrVLCAs);
 % pause
 % plot (jlVLCAs,vtlVLCAs);
 % pause
 % plot (jrVLCAs,vtrVLCAs,jlVLCAs,vtlVLCAs);
 % pause
%%____________________________________________________________________%%
% Medium or Large Aircraft Trailing VLCA Aircraft Scenario

 % Enter min. separation distance (in-trail distance) between
 % generating VLCA and trailing small aircraft

   Dvm;                                            % In nautical miles

 % Compute desired in-trail headway between generating VLCA and
 % trailing small aircraft in sec.

   HEADWAvm = Dvm / (VAPPtask) * 3600;

 % Start iteration loops to develop VLCA trailing vortex system

   for a=1:1:500;
       b=a/10.0;

 % Compute tangential velocity (vortex vertical velocity) right
 % from vortex node for VLCA at Dvs

  vtrVLCAm(a)=lambdaVLCA/(2*pi*b)*(1-exp(-b^2/(4*epsVLCA*HEADWAYvm)))
  jrVLCAm(a) = b + crVLCA;
   end

   for k=1:1:255;
       m=k/10.0;
```

```
 % Compute tangential velocity (vortex vertical velocity) left from
 % vortex node for VLCA at Dvs.

  vtlVLCAm(k)=-lambdaVLCA/(2*pi*m)*(1-exp(-m^2/(4*epsVLCA*HEADWAYvm)))
  jlVLCAm(k) = crVLCA - m;
    end

 % Plot VLCA trailing vortex system right & left of vortex node
 % plot (jrVLCAm,vtrVLCAm);
 % pause
 % plot (jlVLCAm,vtlVLCAm);
 % pause
 % plot (jrVLCAm,vtrVLCAm,jlVLCAm,vtlVLCAm)
%%______________________________________________________________________%%
 % Heavy Aircraft Trailing VLCA Aircraft Scenario

  % Enter min. separation distance (in-trail distance) between
  % generating VLCA and trailing small aircraft

    Dvh;                                               % In nautical miles

  % Compute desired in-trail headway between generating VLCA and
  % trailing small aircraft in sec.

    HEADWAvh = Dvh / (VAPPtask) * 3600;

  % Start iteration loops to develop VLCA trailing vortex system

    for a=1:1:500;
        b=a/10.0;

  % Compute tangential velocity (vortex vertical velocity) right
  % from vortex node for VLCA at Dvs

   vtrVLCAh(a)=lambdaVLCA/(2*pi*b)*(1-exp(-b^2/(4*epsVLCA*HEADWAYvh)))
   jrVLCAh(a) = b + crVLCA;
    end

    for k=1:1:255;
        m=k/10.0;

  % Compute tangential velocity (vortex vertical velocity) left from
  % vortex node for VLCA at Dvs.

 vtlVLCAh(k)=-lambdaVLCA/(2*pi*m)*(1-exp(-m^2/(4*epsVLCA*HEADWAYvh)))
 jlVLCAh(k) = crVLCA - m;
    end
% Plot VLCA trailing vortex system right & left of vortex node
% plot (jrVLCAh,vtrVLCAh);
% pause
```

```
  % plot (jlVLCAh,vtlVLCAh);
  % pause
  % plot (jrVLCAh,vtrVLCAh,jlVLCAh,vtlVLCAh)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% IDENTIFY MAX. TANGENTIAL VELOCITIES AND THEIR CRITICAL LATERAL
% DISTANCES FROM VLCA VORTEX VERTICAL VELOCITY PROFILE

  % Small Aircraft Trailing VLCA Aircraft Scenario

    % Initial max. tangential velocity

      VTmax = 0.0;

   % Iterations along wingspan (lateral distance y) begining at vortex
   % node

      for y = 0.5:0.1:20;

    % Compute tangential vel., change in vel., max. tangential vel.,
    % and critical lateral distance at VTmax

      vtrVLCAs(y)=lambdaVLCA/(2*pi*y)*(1-exp(-y^2/(4*epsVLCA*HEADWAvs)))
        delvel = vtrVLCAs(y) - VTmax;
        if  delvel > 0.0;
          VTmax = vtrVLCAs(y);
          latdist = y;
        end
      end
      VTMAXvs = VTmax;
      LATDISTvs = latdist;
%%_________________________________________________________________________%%
 % Medium or Large Aircraft Trailing VLCA Aircraft Scenario

    % Initial max. tangential velocity

      VTmax = 0.0;

    % Iterations along wingspan (lateral distance y) begining at
    % vortex node

      for y = 0.5:0.1:20;

    % Compute tangential vel., change in vel., max. tangential vel.,
    % and critical lateral distance at VTmax

     vtrVLCAm(y)=lambdaVLCA/(2*pi*y)*(1-exp(-y^2/(4*epsVLCA*HEADWAvm)));
        delvel = vtrVLCAm(y) - VTmax;
        if  delvel > 0.0;
          VTmax = vtrVLCAm(y);
          latdist = y;
        end
```

```
      end
      VTMAXvm = VTmax;
      LATDISTvm = latdist;
%%______________________________________________________________________%%
 % Heavy Aircraft Trailing VLCA Aircraft Scenario

    % Initial max. tangential velocity

      VTmax = 0.0;

   % Iterations along wingspan (lateral distance y) begining at vortex
   % node

      for y = 0.5:0.1:20;

   % Compute tangential vel., change in vel., max. tangential vel.,
   % and critical lateral distance at VTmax

      vtrVLCAh(y)=lambdaVLCA/(2*pi*y)*(1-exp(-y^2/(4*epsVLCA*HEADWAvh)))
        delvel = vtrVLCAh(y) - VTmax;
        if  delvel > 0.0;
          VTmax = vtrVLCAh(y);
          latdist = y;
        end
      end
      VTMAXvh = VTmax;
      LATDISTvh = latdist;

%%__________________________________________________________________________%%
% VORTEX PROFILE PLOTS FOR B747-400 AND VLCA

% Small Aircraft Trailing Heavy (B747) and VLCA Aircraft Scenario

% plot(jlB7476,vtlB7476,jlVLCAs,vtlVLCAs)
% pause
% Medium (or Large) Aircraft Trailing Heavy (B747) and VLCA Aircraft
Scenario

% plot(jlB7475,vtlB7475,jlVLCAm,vtlVLCAm)
% pause
% Heavy (or VLCA) Aircraft Trailing Heavy (B747) and VLCA Aircraft
Scenario

% plot(jlB7474,vtlB7474,jlVLCAh,vtlVLCAh)
% pause
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%              IN-TRAIL AIRCRAFT SEPARATION STANDARD MODULE

% NEW IFR AIRCRAFT APPROACH DISTANCE SEPARATION MATRIX

  % The following distance separation matrix elements represent
  % the new approach in-trail min. separation distances In n. miles
  % among the proposed five aircraft groups:

  %                  Leading Aircraft
  %            Small Medium Large Heavy VLCA
  DELTAifr = [2.5   4.0    5.0   6.0   Dvs       % S
              2.5   2.5    4.0   5.0   Dvm       % M
              2.5   2.5    2.5   5.0   Dvm       % L       Trailing ACFT
              2.5   2.5    2.5   4.0   Dvh       % H
              2.5   2.5    2.5   4.0   Dvh]      % VLCA
pause
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                    LANDING GEAR CONFIGURATIONS MODULE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                    VLCA MAIN LANDING GEAR CONFIGURATION

% Use a multi-wheel main landing gear configuration
  % Alternative 1: Triple-In-Tandem Strut Configuration
  %                with four sets of triple-in-tandem gears or 24 tires

  % Wheel dimensions and spacing [Currey, 1988].

    STRUTn = 4;         % No of struts of main landing gear configuration
    Tn = 6;             % Number of wheels per strut
    Td = 49;            % Tire length (diameter) in inches
    Tw = 20;            % Tire width in inches
    Twf = Tw/12;        % Tire width in feet
    Tp = 200;           % Tire inflation pressure in psi
    lat = 25;           % Inside lateral dis. between two adjacent tires
    latf = lat/12;      % Inside lat. dist. b/t two adjacent tires in ft
    lon = 10;           % Inside longitudinal dist b/t two adjacent tires

  % Enter relevant dimensions for B747400 and VLCA in ft [Currey, 1988].

    WS747 = 213.0;                      % B747-400 wingspan (group 5)
    WSv = Bft;                          % VLCA wingspan (>group 6)
    WSr = WSv / WS747;                  % Wingspan ratio

    WT747 = 37.08;                      % B747-400 wheel track
    WTv = WSr * WT747;                  % VLCA wheel track
    WT = WTv / 3.28                     % VLCA wheel track in m.
    WTdif = WTv - WT747;                % Wheel track difference

    UCW747 = 37.08 + latf + 2*Twf;     % B747-400 undercarriage width
    UCWv = WSr * UCW747;              % VLCA undercarriage width
    UCW = UCWv / 3.28               % VLCA undercarriage width in m.
    UCWdif = UCWv - UCW747;          % Undercarriage width difference

    L747 = 231.84;                          % B747-400 length
    Lv = 250;                               % VLCA length (estimated)
    Lr = Lv / L747;                         % Length ratio

    WB747 = 84.0;                           % B747-400 wheel base
    WBv = Lr * WB747;                       % VLCA wheel base
    WB = WBv / 3.28                         % VLCA wheel base

    CL747 = 25.42;                          % B747-400 cockpit length
    CLv = Lr * CL747;                       % VLCA cockpit length

    d2 = (CLv/2) + WBv;             % Main undercarriage/cockpit
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                     PAVEMENT DESIGN ANALYSIS MODULE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%   FLEXIBLE PAVEMENT DESIGN ANALYSIS FOR TAXIWAYS, TERMINAL APRONS, AND
%                      RUNWAY ENDS (first 1000 feet).

% EQUIVALENT SINGLE WHEEL LOAD (ESWL) COMPUTATION [Horonjeff, 1983].

  % Compute relevant loads in pounds

    TLOADm = 0.9*MTOW;  % Total load on main landing gears (90% of MTOW)
    LOADmg = TLOADm / STRUTn;   % Load per main landing gear assembly
    LOADw = LOADmg / Tn;        % Load on a single wheel of the assembly

  % Compute tire contact areas in squared inches

    TA = LOADmg / Tp;           % Total contact area (for six tires)
    Aw = TA / Tn;               % Contact area of each wheel

  % Compute radius of (loaded circular) contact area in inches

    r = sqrt(Aw / pi);

  % Develop Deflection Factor matrix as a function of depth (rows) and
  % offset (columns) per Waterways Experiment Station, Corps of Eng's

F=[1   0*r  0.25*r 0.5*r 0.75*r 1*r  1.25*r 1.5*r 2*r  2.5*r 3*r  4*r  5*r  6*r  8*r  15*r 17*r
   0*r 1.50 1.48   1.40  1.26   0.95 0.67   0.52  0.39 0.30  0.26 0.19 0.14 0.12 0.08 0.01 0.01
   1*r 1.08 1.05   0.98  0.90   0.79 0.65   0.55  0.41 0.32  0.27 0.20 0.16 0.13 0.09 0.01 0.01
   2*r 0.67 0.67   0.65  0.62   0.57 0.53   0.48  0.38 0.32  0.28 0.20 0.16 0.14 0.09 0.01 0.01
   3*r 0.47 0.47   0.46  0.45   0.44 0.41   0.38  0.34 0.30  0.27 0.20 0.16 0.14 0.10 0.01 0.01
   4*r 0.36 0.36   0.35  0.34   0.34 0.33   0.32  0.29 0.27  0.25 0.20 0.16 0.14 0.10 0.01 0.01
   5*r 0.30 0.30   0.30  0.28   0.28 0.28   0.28  0.25 0.24  0.23 0.18 0.16 0.14 0.11 0.01 0.01
   6*r 0.25 0.25   0.25  0.24   0.24 0.24   0.24  0.22 0.20  0.19 0.17 0.15 0.14 0.12 0.01 0.01
   7*r 0.22 0.22   0.22  0.21   0.21 0.21   0.21  0.19 0.18  0.17 0.16 0.14 0.13 0.12 0.01 0.01
   8*r 0.19 0.19   0.19  0.18   0.18 0.18   0.18  0.17 0.16  0.15 0.15 0.14 0.13 0.11 0.01 0.01
   9*r 0.17 0.17   0.17  0.16   0.16 0.16   0.16  0.15 0.14  0.13 0.13 0.13 0.11 0.10 0.01 0.01];

  % Define all points of interest (A,B,C,D,E, and G) for the
  % investigation of the max. (critical) deflection
  % Determine the distances (expressed in terms of radius r) from each
  % location (point of interest) to each wheel of the assembly

    E = lat + Tw;         % Lateral distance from c/l to c/l in inches
    ek = E / r;           % Lateral distance multiplier
    er = ek * r;          % Lateral distance, E , as a function of r
    G = lon + Td;         % Longitudinal distance from c/l to c/l in
    fk = G / r;           % Longitudinal distance multiplier
    fr = fk * r;          % Longitudinal distance, G , as a function of r

    A1 = 0;
    B1 = fr / 2;
    C1 = fr;
    D1 = er / 2;
```

```
E1 = sqrt( (er/2)^2 + (fr/2)^2 );
G1 = sqrt( (er/2)^2 + (fr)^2 );

A2 = fr;
B2 = fr / 2;
C2 = 0;
D2 = sqrt( (er/2)^2 + (fr)^2 );
E2 = sqrt( (er/2)^2 + (fr/2)^2 );
G2 = er/2;

A3 = 2 * fr;
B3 = 1.5 * fr;
C3 = fr;
D3 = sqrt( (er/2)^2 + (2*fr)^2 );
E3 = sqrt( (er/2)^2 + (1.5*fr)^2 );
G3 = sqrt( (er/2)^2 + (fr)^2 );

A4 = er;
B4 = sqrt( er^2 + (fr/2)^2 );
    C4 = sqrt( er^2 + fr^2 );
D4 = er/2;
E4 = sqrt( (er/2)^2 + (fr/2)^2 );
G4 = sqrt( (er/2)^2 + (fr)^2 );

A5 = sqrt( er^2 + fr^2 );
B5 = sqrt( er^2 + (fr/2)^2 );
C5 = er;
D5 = sqrt( (er/2)^2 + (fr)^2 );
E5 = sqrt( (er/2)^2 + (fr/2)^2 );
G5 = er/2;

A6 = sqrt( er^2 + (2*fr)^2 );
B6 = sqrt( er^2 + (1.5*fr)^2 );
C6 = sqrt( er^2 + fr^2 );
D6 = sqrt( (er/2)^2 + (2*fr)^2 );
E6 = sqrt( (er/2)^2 + (1.5*fr)^2 );
G6 = sqrt( (er/2)^2 + (fr)^2 );

 % Find deflection factor contributions of each wheel (1,2,3,4,5, and 6)
 % to points A,B,C,D,E, and G at different depths 10,20,30,40,50,60, and
 % 70 in.
  for d = 1:1:7;
    v = d * 10;
    FA1(d) = table2(F,v,A1);
    FB1(d) = table2(F,v,B1);
    FC1(d) = table2(F,v,C1);
    FD1(d) = table2(F,v,D1);
    FE1(d) = table2(F,v,E1);
    FG1(d) = table2(F,v,G1);
  end;
  for d = 1:1:7;
```

```
  v = d * 10;
  FA2(d) = table2(F,v,A2);
  FB2(d) = table2(F,v,B2);
  FC2(d) = table2(F,v,C2);
  FD2(d) = table2(F,v,D2);
  FE2(d) = table2(F,v,E2);
  FG2(d) = table2(F,v,G2);
end;

for d = 1:1:7;
  v = d * 10;
  FA3(d) = table2(F,v,A3);
  FB3(d) = table2(F,v,B3);
  FC3(d) = table2(F,v,C3);
  FD3(d) = table2(F,v,D3);
  FE3(d) = table2(F,v,E3);
  FG3(d) = table2(F,v,G3);
end;

for d = 1:1:7;
  v = d * 10;
  FA4(d) = table2(F,v,A4);
  FB4(d) = table2(F,v,B4);
  FC4(d) = table2(F,v,C4);
  FD4(d) = table2(F,v,D4);
  FE4(d) = table2(F,v,E4);
  FG4(d) = table2(F,v,G4);
end;

for d = 1:1:7;
  v = d * 10;
  FA5(d) = table2(F,v,A5);
  FB5(d) = table2(F,v,B5);
  FC5(d) = table2(F,v,C5);
  FD5(d) = table2(F,v,D5);
  FE5(d) = table2(F,v,E5);
  FG5(d) = table2(F,v,G5);
end

for d = 1:1:7;
  v = d * 10;
  FA6(d) = table2(F,v,A6);
  FB6(d) = table2(F,v,B6);
  FC6(d) = table2(F,v,C6);
  FD6(d) = table2(F,v,D6);
  FE6(d) = table2(F,v,E6);
  FG6(d) = table2(F,v,G6);
end

% Sum deflection factor contributions of all wheels on every position
% at seven different depths (10,20,30,40,50,60, and 70 in.)
```

```
for d = 1:1:7;
  SFAi(d) = FA1(d)+FA2(d)+FA3(d)+FA4(d)+FA5(d)+FA6(d);
  SFBi(d) = FB1(d)+FB2(d)+FB3(d)+FB4(d)+FB5(d)+FB6(d);
  SFCi(d) = FC1(d)+FC2(d)+FC3(d)+FC4(d)+FC5(d)+FC6(d);
  SFDi(d) = FD1(d)+FD2(d)+FD3(d)+FD4(d)+FD5(d)+FD6(d);
  SFEi(d) = FE1(d)+FE2(d)+FE3(d)+FE4(d)+FE5(d)+FE6(d);
  SFGi(d) = FG1(d)+FG2(d)+FG3(d)+FG4(d)+FG5(d)+FG6(d);
end

% Develop vectors by having as elements the total deflection factors
% of all wheels on every location for the same depth, then find the
% point of interest that yields the max. (critical) deflection

SFi10 = [SFAi(1) SFBi(1) SFCi(1) SFDi(1) SFEi(1) SFGi(1)];
SFi10max = max( SFi10 );

SFi20 = [SFAi(2) SFBi(2) SFCi(2) SFDi(2) SFEi(2) SFGi(2)];
SFi20max = max( SFi20 );

SFi30 = [SFAi(3) SFBi(3) SFCi(3) SFDi(3) SFEi(3) SFGi(3)];
SFi30max = max( SFi30 );

SFi40 = [SFAi(4) SFBi(4) SFCi(4) SFDi(4) SFEi(4) SFGi(4)];
SFi40max = max( SFi40 );

SFi50 = [SFAi(5) SFBi(5) SFCi(5) SFDi(5) SFEi(5) SFGi(5)];
SFi50max = max( SFi50 );

SFi60 = [SFAi(6) SFBi(6) SFCi(6) SFDi(6) SFEi(6) SFGi(6)];
SFi60max = max( SFi60 );

SFi70 = [SFAi(7) SFBi(7) SFCi(7) SFDi(7) SFEi(7) SFGi(7)];
SFi70max = max( SFi70 );

% Find equivalent single-wheel deflection factor, Fe, at various
% depths

Fe10 = table2(F,10,0);
Fe20 = table2(F,20,0);
Fe30 = table2(F,30,0);
Fe40 = table2(F,40,0);
Fe50 = table2(F,50,0);
Fe60 = table2(F,60,0);
Fe70 = table2(F,70,0);

% Compute the equivalent single wheel load (ESWL) at various depths

ESWL10 = (LOADw * SFi10max) / Fe10;
ESWL20 = (LOADw * SFi20max) / Fe20;
ESWL30 = (LOADw * SFi30max) / Fe30;
ESWL40 = (LOADw * SFi40max) / Fe40;
```

```
  ESWL50 = (LOADw * SFi50max) / Fe50;
  ESWL60 = (LOADw * SFi60max) / Fe60;
  ESWL70 = (LOADw * SFi70max) / Fe70;
%%______________________________________________________________________%%
% DEVELOPMENT OF CBR VS. THICKNESS CURVE FOR VLCA

  % Find load repetition factor, alphai

    % Develop Load Repetition Factor matrix as a function of
    % aircraft traffic volume or passes or No. of operations (rows) and
    % number of tires used to compute ESWL (columns)

  alphai = [1       6    8    12   18   24
            1       0.22 0.22 0.22 0.22 0.22
            10      0.38 0.38 0.38 0.38 0.38
            100     0.55 0.55 0.55 0.55 0.55
            1000    0.68 0.67 0.66 0.65 0.64
            10000   0.74 0.72 0.71 0.70 0.68
            100000  0.76 0.74 0.72 0.71 0.69
            1000000 0.79 0.76 0.74 0.72 0.69];

     ALPHAi = table2(alphai,100000,Tn);

  % Compute CBR at various depths(10,20,30,40,50,60, and 70 inches)

    CBR10 = ESWL10 / ( 8.1 * ( (10^2/ALPHAi^2) + (Aw/pi) ) )
    CBR20 = ESWL20 / ( 8.1 * ( (20^2/ALPHAi^2) + (Aw/pi) ) )
    CBR30 = ESWL30 / ( 8.1 * ( (30^2/ALPHAi^2) + (Aw/pi) ) )
    CBR40 = ESWL40 / ( 8.1 * ( (40^2/ALPHAi^2) + (Aw/pi) ) )
    CBR50 = ESWL50 / ( 8.1 * ( (50^2/ALPHAi^2) + (Aw/pi) ) )
    CBR60 = ESWL60 / ( 8.1 * ( (60^2/ALPHAi^2) + (Aw/pi) ) )
    CBR70 = ESWL70 / ( 8.1 * ( (70^2/ALPHAi^2) + (Aw/pi) ) )

  % Plot thickness versus CBR curve for VLCA

    plot(CBR70,70,CBR60,60,CBR50,50,CBR40,40,CBR30,30,CBR20,20,CBR10,10)

% Use this curve to size flexible pavements for taxiways, runway ends
% and terminal aprons

pause
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                          VLCA NOISE MODULE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% THRUST AND EPNL/SEL TAKEOFF ANALYSIS

% Consider noise curve data and develop an EPNL(db) matrix for
% existing engines such as
% GE 2CF68D, this effective perceived noise level is found per FAA
% INM411 system
  EPNLdbee = [1      200   400   630   1000  2000  4000 6300 10000 16000 25000
             10020  101.6 97.0  93.0  89.0  82.1  75.5 70.1 64.3  58.1  52.3
             23190  110.9 106.0 102.2 98.7  90.1  81.7 75.7 69.3  62.5  55.9
             25940  110.7 104.2 100.2 96.2  89.5  81.2 75.2 68.4  61.2  54.2
             39180  112.2 106.7 103.2 99.5  93.2  86.2 80.7 74.2  67.2  60.2
             51530  114.7 110.2 107.2 104.2 98.7  92.4 88.0 82.0  75.2  68.5
             55500  117.2 112.7 110.0 107.2 101.8 96.2 91.7 86.7  80.2  73.7];

% Construct two vectors that represent EPNL perceived by an observer
% when existing engine is developing 10,020 and 55,500 pounds of
% thrust respectively

  T10020 = [10020  101.6 97.0  93.0  89.0  82.1  75.5 70.1 64.3  58.1  52.3];
  H = T10020;
  T55500 = [55500  117.2 112.7 110.0 107.2 101.8 96.2 91.7 86.7  80.2  73.7];
  J = T55500;

  THv = THTOengl;                    % Max. VLCA engine thrust in pounds
  changeth = THv - 55500;
  THnew = changeth + H(1,1);

% Start iterations to compute:
% EPNL(db) at THnew pounds of thrust
% EPNL(db) at THv pounds of thrust

  for g = 1:1:10;
    s = g + 1;

    E(s)=((((THnew)-H(1,1))/(J(1,1)-H(1,1)))*(J(1,s)-H(1,s)))+H(1,s);
    difference = E(s) - H(1,s);
    F(s) = J(1,s) + difference;

  end

% Note: E(s) stands for EPNL(db) at "THnew" pounds of thrust and
%       F(s) stands for EPNL(db) at "THv" pounds of thrust

% EPNL(db) for VLCA aircraft engine

    EPNLdbv = [1      200   400   630   1000  2000  4000 6300 10000 16000 25000
              10020  101.6 97.0  93.0  89.0  82.1  75.5 70.1 64.3  58.1  52.3
```

```
23190   110.9 106.0 102.2 98.7   90.1   81.7 75.7 69.3   62.5   55.9
 25940   110.7 104.2 100.2 96.2   89.5   81.2 75.2 68.4   61.2   54.2
 THnew  E(2)  E(3)  E(4)  E(5)  E(6)  E(7) E(8) E(9)  E(10) E(11)
 39180   112.2 106.7 103.2 99.5   93.2   86.2 80.7 74.2   67.2   60.2
 51530   114.7 110.2 107.2 104.2 98.7   92.4 88.0 82.0   75.2   68.5
 55500   117.2 112.7 110.0 107.2 101.8 96.2 91.7 86.7   80.2   73.7
THv     F(2)  F(3)  F(4)  F(5)  F(6)  F(7) F(8) F(9)  F(10) F(11)]

% Proposed Further Research:

% Noise Modeling of VLCA Operations (Ldn contours)
% Comparison with Current Limits (MD11GE)
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                    AIRSIDE CAPACITY ANALYSIS MODULE
%     RUNWAY CAPACITY MODEL PER RICHARD HARRIS  (GRAPHICAL METHOD)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Find the Maximum Airport Airside Capacity under IFR/VFR Weather
% Conditions with the Following Operating Conditions

% RELEVANT DATA

% Enter the Following Relevant Matrices/Vectors:

  % New IFR/VFR aircraft approach distance separation matrices (in n.m.)
  % under current ATC (Air Traffic Control) manual control conditions

    %                 Leading Aircraft
    %           Small Medium Large Heavy VLCA
        Difr = [2.5   4.0    5.0   6.0   Dvs        % S
                2.5   2.5    4.0   5.0   Dvm        % M
                2.5   2.5    2.5   5.0   Dvm        % L    Trailing Acft
                2.5   2.5    2.5   4.0   Dvh        % H
                2.5   2.5    2.5   4.0   Dvh];      % VLCA

    %                 Leading Aircraft
    %           Small Medium Large Heavy VLCA
        Dvfr = [1.9   3.0    3.7   4.0   Dvs-1.75        % S
                1.9   1.9    3.0   3.7   Dvm-1.50        % M
                1.9   1.9    1.9   3.7   Dvm-1.50        % L    Trailing
                1.9   1.9    1.9   3.0   Dvh-1.25        % H    Acft
                1.9   1.9    1.9   3.0   Dvh-1.25];      % VLCA

  % Aircraft mix vector during busy hour (peak-hour design) in perc.

    %          Small   Medium   Large   Heavy   VLCA     Operation Rule
      Pifr =  [0.05    0.20     0.35    0.25    0.15];   %      IFR
      Pvfr =  [0.05    0.20     0.35    0.25    0.15];   %      VFR

  % Aircraft approach speed vector in knots
  % Aircraft landing runway occupancy time vector in seconds
  % Aircraft departure runway occupancy time vector in seconds

    %            Small   Medium   Large   Heavy   VLCA
      V     =    [100    110      140     150     155 ];
      lrot  =    [40     45       55      60      70  ];
      drot  =    [35     40       45      50      60  ];
```

```
  % IFR/VFR time separation matrix for departure procedures under radar
  % control (departure departure time separations are in seconds)
    %                Leading Aircraft
    %        Small Medium Large Heavy VLCA
      dd = [60     90     120    130    150      % S
            60     60     90     120    150      % M
            60     60     60     90     120      % L   Trailing Aircraft
            60     60     60     60     90       % H
            60     60     60     60     80];     % VLCA

  % Enter the following standard deviations in seconds:

    sigmal = 8;       % Std. deviation of landing runway occupancy times
    sigmad = 6;       % Std. dev. of departure runway occupancy times
    sigmaroll = 0;    % Std. dev. of clear aircraft to takeoff roll
    sigmao = 20;      % Std. dev. of in-trail interarrival time
                        % delivery   error
    sigmag = 20;      % Standard deviation of gap delivery error

  % Enter the following relevant parameters:

    Pv = 0.05;     % Probability of violation according to ATC
    Qv = 1.65;     % Cumulative value of standard normal for Pv violation
    gamma = 7;     % Final common approach path length in n.m, which is
                     % the Lower Outer Marker location from threshold,LOM
    da =2;         % Min dist b/t departing acft and following arrival
                     % (min. departure-arrival separation dist in n.m.)
    RADARasr = 4.6  % Scan time in sec.(airport equipped with ASR radar)
    RADARprm = 3    % Scan time in sec.(airport equipped with PRM radar)

  % Compute aircraft mix index

    MI = (Pifr(3) + 3 * (Pifr(4) + Pifr(5))) * 100;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% FIND CAPACITY OF A SINGLE RUNWAY (TYPICAL RUNWAY SCENARIO)

% IFR ARRIVALS ONLY

  % Estimate the following variables:
  % Error-free aircraft time separation matrix, [Tij], in sec.
  % Probability matrix, [Pij]
  % Expected value of error-free aircraft time separation matrix,
    % E[Tij], in sec.
  % Error-free single runway capacity with arrivals only, CARRIVALSef
  % Buffer time matrix, [Bij], in seconds
  % Real in-trail aircraft time separation matrix, [Mij], in sec.
  % Expected value of real in-trail time separation matrix, in seconds
  % Real (includes buffer) single runway capacity with arrivals only,
    % CARRIVALSreal
    sumE = 0.0;                % Initialize iterations
    sumM = 0.0;
```

```
    for l = 1;                    % Iteration to define column
      for n = 1:1:5;              % Iteration to define rows, closing case
        T(n,l) = Difr(n,l) / V(n) * 3600;
        P(n,l) = Pifr(l) * Pifr(n);
        ET(n,l) = T(n,l) * P(n,l);
        sumE = sumE + ET(n,l);
        B(n,l) = sigmao * Qv;
        M(n,l) = T(n,l) + B(n,l);
        EM(n,l) = M(n,l) * P(n,l);
        sumM = sumM + EM(n,l);
      end
    end

    for l = 2;                    % Iteration to define column
      for n = 2:1:5;              % Iteration to define rows, closing case
        T(n,l) = Difr(n,l) / V(n) * 3600;
        P(n,l) = Pifr(l) * Pifr(n);
        ET(n,l) = T(n,l) * P(n,l);
        sumE = sumE + ET(n,l);
        B(n,l) = sigmao * Qv;
        M(n,l) = T(n,l) + B(n,l);
        EM(n,l) = M(n,l) * P(n,l);
        sumM = sumM + EM(n,l);
      end
      for n= 1;                   % Iteration to define rows, opening case
        T(n,l) = Difr(n,l)/V(n)*3600+gamma*(1/V(n)-1/V(l))*3600
        P(n,l) = Pifr(l) * Pifr(n);
        ET(n,l) = T(n,l) * P(n,l);
        sumE = sumE + ET(n,l);
        if B(n,l) >= 0;
          B(n,l) = sigmao * Qv - Difr(n,l) * (1/V(n) - 1/V(l)) * 3600;
          else 0;
        end
        M(n,l) = T(n,l) + B(n,l);
        EM(n,l) = M(n,l) * P(n,l);
        sumM = sumM + EM(n,l);
      end
    end
for l = 3;                        % Iteration to define column
  for n = 3:1:5;                  % Iteration to define rows, closing case
    T(n,l) = Difr(n,l) / V(n) * 3600;
    P(n,l) = Pifr(l) * Pifr(n);
    ET(n,l) = T(n,l) * P(n,l);
    sumE = sumE + ET(n,l);
    B(n,l) = sigmao * Qv;
    M(n,l) = T(n,l) + B(n,l);
    EM(n,l) = M(n,l) * P(n,l);
    sumM = sumM + EM(n,l);
  end
```

```
  for n= 1:1:2 ;                % Iteration to define rows, opening case
    T(n,l) = Difr(n,l) / V(n) * 3600 + gamma * (1/V(n) - 1/V(l)) * 3600;
    P(n,l) = Pifr(l) * Pifr(n);
    ET(n,l) = T(n,l) * P(n,l);
    sumE = sumE + ET(n,l);
    B(n,l) = sigmao * Qv - Difr(n,l) * (1/V(n) - 1/V(l)) * 3600;
    if B(n,l) >= 0;
      B(n,l);
    else B(n,l) = 0;
    end
    M(n,l) = T(n,l) + B(n,l);
    EM(n,l) = M(n,l) * P(n,l);
    sumM = sumM + EM(n,l);
  end
end

for l = 4;                      % Iteration to define column
  for n = 4:1:5;                % Iteration to define rows, closing case
    T(n,l) = Difr(n,l) / V(n) * 3600;
    P(n,l) = Pifr(l) * Pifr(n);
    ET(n,l) = T(n,l) * P(n,l);
    sumE = sumE + ET(n,l);
    B(n,l) = sigmao * Qv;
    M(n,l) = T(n,l) + B(n,l);
    EM(n,l) = M(n,l) * P(n,l);
    sumM = sumM + EM(n,l);
  end
  for n= 1:1:3;                 % Iteration to define rows, opening case
    T(n,l) = Difr(n,l) / V(n) * 3600 + gamma * (1/V(n) - 1/V(l)) * 3600;
    P(n,l) = Pifr(l) * Pifr(n);
    ET(n,l) = T(n,l) * P(n,l);
    sumE = sumE + ET(n,l);
    B(n,l) = sigmao * Qv - Difr(n,l) * (1/V(n) - 1/V(l)) * 3600;
    if B(n,l) >= 0;
      B(n,l);
    else B(n,l) = 0;
    end
    M(n,l) = T(n,l) + B(n,l);
    EM(n,l) = M(n,l) * P(n,l);
    sumM = sumM + EM(n,l);
    end
  end

for l = 5;                      % Iteration to define column
  for n = 5;                    % Iteration to define rows, closing case
    T(n,l) = Difr(n,l) / V(n) * 3600;
    P(n,l) = Pifr(l) * Pifr(n);
    ET(n,l) = T(n,l) * P(n,l);
    sumE = sumE + ET(n,l);
    B(n,l) = sigmao * Qv;
    M(n,l) = T(n,l) + B(n,l);
```

```
    EM(n,1) = M(n,1) * P(n,1);
    sumM = sumM + EM(n,1);
  end
  for n= 1:1:4;                   % Iteration to define rows, opening case
    T(n,1) = Difr(n,1) / V(n) * 3600 + gamma * (1/V(n) - 1/V(1)) * 3600;
    P(n,1) = Pifr(1) * Pifr(n);
    ET(n,1) = T(n,1) * P(n,1);
    sumE = sumE + ET(n,1);
    B(n,1) = sigmao * Qv - Difr(n,1) * (1/V(n) - 1/V(1)) * 3600;
    if B(n,1) >= 0;
      B(n,1);
    else B(n,1) = 0;
    end
    M(n,1) = T(n,1) + B(n,1);
    EM(n,1) = M(n,1) * P(n,1);
    sumM = sumM + EM(n,1);
  end
end

iCARRIVALSef = 3600 / sumE
iCARRIVALSreal= 3600 / sumM
%%_______________________________________________________________________%%
% IFR MIXED OPERATIONS (ARRIVALS/DEPARTURES)

  % Estimate the following variables:

  % Expected time for arriving aircraft to travel final "da" n.m.
  % to runway threshold, E[da/Vj], in seconds
  % Expected landing runway occupancy time, E[lrot], in seconds
  % Error term to account for gap spacing violation, ERROR
  % Expected departure departure time separation , E[dd], in sec.
  % Required expected in-trail time separation to release "n"
  % departures between a pair of arrivals, RE[Tij]

    sumdavj = 0.0;                               % Initialize iterations
    sumrot = 0.0;
    sumddt = 0.0;

    for w = 1:1:5
      davj(w) = da / V(w) * 3600;
      davjp(w) = davj(w) * Pifr(w);
      sumdavj = sumdavj + davjp(w);
      Edavj = sumdavj;

      ROT(w) = Pifr(w) * lrot(w);
      sumrot = sumrot + ROT(w);
      Elrot = sumrot;
    end

    ERROR = sigmag * Qv;
```

```
  for l = 1:1:5;
    for n = 1:1:5;
      ddt(n,l) = P(n,l) * dd(n,l);
      sumddt = sumddt + ddt(n,l);
      Eddt = sumddt;
    end
  end

  for x = 1:1:5
    RET(x) = Edavj + Elrot + ERROR + (x-1) * Eddt;
  end

% Estimate expected aircraft departure matrix expressed in No. of
% operations per cell

  for l = 1:1:5
    for n = 1:1:5
      M(n,l);
      if M(n,l) < RET(1);
      D(n,l) = 0;
      elseif M(n,l) < RET(2);
      D(n,l) = 1;
      elseif M(n,l) < RET(3);
      D(n,l) = 2;
      elseif M(n,l) < RET(4);
      D(n,l) = 3;
      elseif M(n,l) < RET(5);
      D(n,l) = 4;
      end
    end
  end

% Estimate No. of departures with 100% arrivals priority
  sumdepa = 0.0;
  for l = 1:1:5
    for n = 1:1:5
      depa(n,l) = P(n,l) * D(n,l) * (iCARRIVALSreal - 1);
      sumdepa = sumdepa + depa(n,l);
    end
  end
  iCdep100arr = sumdepa

% Estimate real departure headway in seconds and
% max. No. of departures (no arrivals) in departures per hour
  sumdep = 0.0;
  for l = 1:1:5
    for n = 1:1:5
      DEP(n,l) = P(n,l) * dd(n,l);
      sumdep = sumdep + DEP(n,l);
    end
  end
```

```
   iDEPheadway = sumdep;
   iDEPmax = 3600 / iDEPheadway;
   iCDEPARTURESreal = iDEPmax

 % Estimate total real single runway capacity in No. of op's per hour

   iCtotal = iCARRIVALSreal + iCdep100arr
%%______________________________________________________________________%%
 % VFR ARRIVALS ONLY

   sumE = 0.0;                  % Initialize iterationS
   sumM = 0.0;

   for l = 1;                   % Iteration to define column
     for n = 1:1:5;             % Iteration to define rows, closing case
       T(n,l) = Dvfr(n,l) / V(n) * 3600;
       P(n,l) = Pvfr(l) * Pvfr(n);
       ET(n,l) = T(n,l) * P(n,l);
       sumE = sumE + ET(n,l);
       B(n,l) = sigmao * Qv;
       M(n,l) = T(n,l) + B(n,l);
       EM(n,l) = M(n,l) * P(n,l);
       sumM = sumM + EM(n,l);
     end
   end

   for l = 2;                   % Iteration to define column
     for n = 2:1:5;             % Iteration to define rows, closing case
       T(n,l) = Dvfr(n,l) / V(n) * 3600;
       P(n,l) = Pvfr(l) * Pvfr(n);
       ET(n,l) = T(n,l) * P(n,l);
       sumE = sumE + ET(n,l);
       B(n,l) = sigmao * Qv;
       M(n,l) = T(n,l) + B(n,l);
       EM(n,l) = M(n,l) * P(n,l);
       sumM = sumM + EM(n,l);
     end
     for n= 1;                  % Iteration to define rows, opening case
     T(n,l) = Dvfr(n,l)/V(n)*3600+gamma*(1/V(n)-1/V(l))*3600;
     P(n,l) = Pvfr(l) * Pvfr(n);
     ET(n,l) = T(n,l) * P(n,l);
     sumE = sumE + ET(n,l);
     if B(n,l) >= 0;
       B(n,l) = sigmao * Qv - Dvfr(n,l) * (1/V(n) - 1/V(l)) * 3600;
     else 0;
     end
     M(n,l) = T(n,l) + B(n,l);
     EM(n,l) = M(n,l) * P(n,l);
     sumM = sumM + EM(n,l);
   end
 end
```

```
  for l = 3;                        % Iteration to define column
    for n = 3:1:5;                  % Iteration to define rows, closing case
      T(n,l) = Dvfr(n,l) / V(n) * 3600;
      P(n,l) = Pvfr(l) * Pvfr(n);
      ET(n,l) = T(n,l) * P(n,l);
      sumE = sumE + ET(n,l);
      B(n,l) = sigmao * Qv;
      M(n,l) = T(n,l) + B(n,l);
      EM(n,l) = M(n,l) * P(n,l);
      sumM = sumM + EM(n,l);
    end
    for n= 1:1:2;                   % Iteration to define rows, opening case
      T(n,l) = Dvfr(n,l)/V(n)*3600+gamma * (1/V(n) - 1/V(l)) * 3600;
      P(n,l) = Pvfr(l) * Pvfr(n);
      ET(n,l) = T(n,l) * P(n,l);
      sumE = sumE + ET(n,l);
      B(n,l) = sigmao * Qv - Dvfr(n,l) * (1/V(n) - 1/V(l)) * 3600;
      if B(n,l) >= 0;
        B(n,l);
      else B(n,l) = 0;
      end
      M(n,l) = T(n,l) + B(n,l);
      EM(n,l) = M(n,l) * P(n,l);
      sumM = sumM + EM(n,l);
    end
  end

for l = 4;                          % Iteration to define column
  for n = 4:1:5;                    % Iteration to define rows, closing case
    T(n,l) = Dvfr(n,l) / V(n) * 3600;
    P(n,l) = Pvfr(l) * Pvfr(n);
    ET(n,l) = T(n,l) * P(n,l);
    sumE = sumE + ET(n,l);
    B(n,l) = sigmao * Qv;
    M(n,l) = T(n,l) + B(n,l);
    EM(n,l) = M(n,l) * P(n,l);
    sumM = sumM + EM(n,l);
  end
  for n= 1:1:3;                     % Iteration to define rows, opening case
    T(n,l) = Dvfr(n,l)/V(n) * 3600 + gamma * (1/V(n) - 1/V(l)) * 3600;
    P(n,l) = Pvfr(l) * Pvfr(n);
    ET(n,l) = T(n,l) * P(n,l);
    sumE = sumE + ET(n,l);
    B(n,l) = sigmao * Qv - Dvfr(n,l) * (1/V(n) - 1/V(l)) * 3600;
    if B(n,l) >= 0;
      B(n,l);
    else B(n,l) = 0;
    end
    M(n,l) = T(n,l) + B(n,l);
    EM(n,l) = M(n,l) * P(n,l);
    sumM = sumM + EM(n,l);
```

```
  end
end

for l = 5;                         % Iteration to define column
  for n = 5;                       % Iteration to define rows, closing case
    T(n,l) = Dvfr(n,l) / V(n) * 3600;
    P(n,l) = Pvfr(l) * Pvfr(n);
    ET(n,l) = T(n,l) * P(n,l);
    sumE = sumE + ET(n,l);
    B(n,l) = sigmao * Qv;
    M(n,l) = T(n,l) + B(n,l);
    EM(n,l) = M(n,l) * P(n,l);
    sumM = sumM + EM(n,l);
  end
  for n= 1:1:4;                    % Iteration to define rows, opening case
    T(n,l) = Dvfr(n,l) / V(n) * 3600 + gamma * (1/V(n) - 1/V(l)) * 3600;
    P(n,l) = Pvfr(l) * Pvfr(n);
    ET(n,l) = T(n,l) * P(n,l);
    sumE = sumE + ET(n,l);
    B(n,l) = sigmao * Qv - Dvfr(n,l) * (1/V(n) - 1/V(l)) * 3600;
    if B(n,l) >= 0;
      B(n,l);
    else B(n,l) = 0;
    end
    M(n,l) = T(n,l) + B(n,l);
    EM(n,l) = M(n,l) * P(n,l);
    sumM = sumM + EM(n,l);
  end
end

vCARRIVALSef = 3600 / sumE
vCARRIVALSreal = 3600 / sumM
%%_______________________________________________________________________%%
% VFR MIXED OPERATIONS (ARRIVALS/DEPARTURES)

  % Estimate the following variables:

  % Expected time for arriving aircraft to travel final "da" n.m.
  % to runway threshold, E[da/Vj], in seconds.
  % Expected landing runway occupancy time, E[lrot], in seconds.
  % Error term to account for gap spacing violation, ERROR
  % Expected departure departure time separation, E[dd], in sec.
  % Required expected in-trail time separation to release "n"
  % departures between a pair of arrivals, RE[Tij]

    sumdavj = 0.0;                              % Initialize iterations
    sumrot = 0.0;
    sumddt = 0.0;
```

```
  for w = 1:1:5
    davj(w) = da / V(w) * 3600;
    davjp(w) = davj(w) * Pvfr(w);
    sumdavj = sumdavj + davjp(w);
    Edavj = sumdavj;

    ROT(w) = Pvfr(w) * lrot(w);
    sumrot = sumrot + ROT(w);
    Elrot = sumrot;
  end

  ERROR = sigmag * Qv;

  for l = 1:1:5;
    for n = 1:1:5;
      ddt(n,l) = P(n,l) * dd(n,l);
      sumddt = sumddt + ddt(n,l);
      Eddt = sumddt;
    end
  end

  for x = 1:1:5
    RET(x) = Edavj + Elrot + ERROR + (x-1) * Eddt;
  end

% Estimate expected aircraft departure matrix expressed in No. of op'ns
% per cell

 for l = 1:1:5
   for n = 1:1:5
     M(n,l);
     if M(n,l) < RET(1);
       D(n,l) = 0;
     elseif M(n,l) < RET(2);
       D(n,l) = 1;
     elseif M(n,l) < RET(3);
       D(n,l) = 2;
     elseif M(n,l) < RET(4);
       D(n,l) = 3;
     elseif M(n,l) < RET(5);
       D(n,l) = 4;
     end
   end
 end
```

```
% Estimate No. of departures with 100% arrivals priority

  sumdepa = 0.0;
  for l = 1:1:5
    for n = 1:1:5
      depa(n,l) = P(n,l) * D(n,l) * (vCARRIVALSreal - 1);
      sumdepa = sumdepa + depa(n,l);
    end
  end
  vCdep100arr = sumdepa

% Estimate real departure headway in seconds and
% max. No. of departures (no arrivals) in departures per hour

  sumdep = 0.0;
  for l = 1:1:5
    for n = 1:1:5
      DEP(n,l) = P(n,l) * dd(n,l);
      sumdep = sumdep + DEP(n,l);
    end
  end
  vDEPheadway = sumdep;
  vDEPmax = 3600 / vDEPheadway;
  vCDEPARTURESreal = vDEPmax

% Estimate total real single runway capacity in No. of op's per hour

  vCtotal = vCARRIVALSreal + vCdep100arr
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                    AIRFIELD GEOMETRIC DESIGN MODULE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                 RUNWAY AND TAXIWAY GEOMETRIC MODELING

% This model includes the following geometric design issues:

% Runway Length (see sizing module)

  % Runway length requirements is determined by F.A.R. takeoff runway-
  % length requirements of the most critical fully loaded aircraft, so
  % let's determine which aircraft may be the critical for runway length
  % estimation, B747-400 or VLCA [FAA AC 150/5325-4A].

  % Enter B747-400 F.A.R. takeoff runway-length requirements
  % in meters at standard day & sea level conditions

    RL747 = 3500;
    RL747f = RL747 * 3.28;

  % Now, VLCA takeoff runway-length requirements in m. at standard day
  % and sea level conditions is given by Stom

    Stof = Stom * 3.28;
    if Stof > RL747f
      RLv = Stof;
      else
      RLv = RL747f;
    end

%%____________________________________________________________________%%
% VLCA Taxiway Fillet Design

% FAA Airfield Taxiway Fillet Design For Airplane Design Group VI

  % Apply FAA methodology either for judgmental oversteering and
  % maintaining cockpit over centerline method to verify if VLCA belongs
  % to airplane design group VI

  % Enter airplane design group VI taxiway fillet dimensions in feet:

    TW6 = 100;          % Taxiway width
    R = 170;            % Radius of taxiway turn
    L = 250;            % Length of lead-in to fillet
    Ftc = 85;           % Fillet radius for tracking CL
    Fsw = 110;          % For judgmental oversteering symmetrical widening
    Fosw = 100;         % For judgmental oversteering one side widening
    M = 20;             % Acceptable taxiway edge safety margine or min.
                          % pavement edge clearance
```

```
% JUDGMENTAL OVERSTEERING CASE (1)

 % Calculate airplane datum length, dosw, one side widening:
   dosw = (R^2 - (R + 0.5*TW6 - 2*M)^2 + WBv^2)^0.5;
 % Calculate AMAXosw
   AMAXosw = asin(dosw/R) * (360/(2*pi));
 % Calculate BMAXosw
   BMAXosw = atan((WBv/dosw)*tan(AMAXosw*((2*pi)/360)))*(360/(2*pi));
 % Calculate provided M
PMosw=(R^2+dosw^2-2*R*dosw*sin(AMAXosw*((2*pi)/360)))^0.5-0.5*UCWv-Fosw
 % Calculate airplane datum length, dsw, symmetrical widening:
   dsw = (R^2 - (2*R - Fsw - 2*M)^2 + WBv^2)^0.5;
 % Calculate AMAXsw
   AMAXsw = asin(dsw/R) * (360/(2*pi));
 % Calculate BMAXsw
   BMAXsw = atan((WBv/dsw)*tan( AMAXsw*((2*pi)/360)))*(360/(2*pi));
 % Calculate provided M
   PMsw = (R^2+dsw^2-2*R*dsw*sin(AMAXsw*((2*pi)/360)))^0.5-0.5*UCWv-Fsw

 % MAINTAINING COCKPIT OVER CENTERLINE (2)

 % Calculate Amax2
   Amax2 = asin(d2/R) * (360/(2*pi));
 % Calculate Bmax2
   Bmax2 = atan((WBv/d2) * tan( Amax2*((2*pi)/360) )) * (360/(2*pi));
 % Calculate Fmax
   Fmax = (R^2+d2^2-2*R*d2*sin(Amax2*((2*pi)/360)))^0.5-0.5*UCWv-M;
 % Calculate At
   At = Amax2;
 % Calculate Lmin
   Lmin = d2*(log(4*d2*tan(0.5*At*((2*pi)/360))/(TW6-UCWv-2*M)))-d2;

%%_________________________________________________________________%%
% Runway/Taxiway Widths:

% The runway/taxiway width estimation is based on the concept that VLCA
% main landing gear must stay on full strength pavement almost all the
% time (Very high probability). All dimensions are in feet.

  RW5 = 150;                   % Group V runway width
  RW6 = 200;                   % Group VI runway width
  TW5 = 75;                    % Group V taxiway width
  TW6 = 100;                   % Group VI taxiway width

  TWv = UCWv + 2 * PMsw;       % VLCA taxiway width based on UCW & Msw,
  if TWv > TW5                   % (> group six)
    TWv;
  elseif TWv > TW6
    TWv
  end
```

```
  engd747 = 10;                  % B747-400 engine diameter in ft.
  engdv = 11;                    % VLCA engine diameter in ft.

  CL2ENG747 = 69.5 + engd747/2  % B747-400 cl to second eng. axis dist
  CL2ENGv = WSr * CL2ENG747;     % VLCA cl to second engine axis distance
  EEv = 2 * CL2ENGv + engdv;     % VLCA outside eng. to outside eng. dist
  RWv = max(EEv, RW6);           % Min. VLCA runway width (group six)

%%_____________________________________________________________________%%
% Runway/Taxiway Shoulder Widths

% The runway/taxiway shoulder is provided to reduce the possibility of
% jet blast erosion and engine ingestion problems associated with jet
% engines which overhang the edge of the taxiway pavement.  This width
% estimation is based on the concept that jet engine exhaust velocity
% contours should not reach 35 MPH at the taxiway edge.
% Consider B747 takeoff thrust for runways and low breakway for taxiways
  RSW5 = 35;                      % Group V runway shoulder width
  RSW6 = 40;                      % Group VI runway shoulder width
  TSW5 = 35;                      % Group V taxiway shoulder width
  TSW6 = 40;                      % Group VI taxiway shoulder width

  RCLEDGE747=RW5/2+RSW5;          % B747 rw cl to rw shoulder edge dist
  RCLEDGEv=RWv/2+RSW6            % VLCA rw cl to rw shoulder edge dist
  RCLEDGEr=RCLEDGEv/RCLEDGE747;   % RW cl to rw shoulder edge dist ratio
  CL2ENGr=CL2ENGv/CL2ENG747;      % Acft cl to second eng axis dist ratio
  if RCLEDGEr > CL2ENGr
    RSWv = RSW6;                  % VLCA runway shoulder width (group VI)
    RPWv = RWv + 2*RSWv;          % VLCA runway pavement width (gr. VI)
  end

  TCLEDGE747 = TW5/2+TSW5;        % B747 tw cl to tw shoulder edge dist
  TCLEDGEv = TWv/2+TSW5;         % VLCA tw cl to tw shoulder edge dist
  TCLEDGEr=TCLEDGEv/TCLEDGE747    % TW cl to tw shoulder edge dist ratio
  if TCLEDGEr > CL2ENGr
    TSWv = TSW5;                  % VLCA taxiway shoulder width
    TPWv = TWv + 2*TSWv;          % VLCA taxiway pavement width
  end

%%_____________________________________________________________________%%
% Runway to Taxiway Separation

% Runway c/l to parallel taxiway/taxilane centerline separation must
% be greater than the distance to satisfy the requirement that no part
% of an aircraft (tail tip, wing tip) on taxiway/taxilane c/l is above
% the runway safety area or penetrates the obstacle free zone (OFZ).
```

```
% For airplane design group VI and using VLCA taxiway width

  % Relevant data in ft.

    RTsep6 = 600;           % RW CL to parallel TW CL or TL CL separation
    RSA = 500;             % Runway safety area width for all groups

  % Estimate offset lateral distance when airplane's outer main wheels
  % is on TW edge (worst case scenario)

    old = (TWv - UCWv) / 2;

  % Add half of VLCA wingspan to obtain critical distance

    dcr = old + 0.5 * WSv;

  % Estimate distance between the difference of RW/TW separation and RSA

    diff = RTsep6 - 0.5 * RSA;

  % Check runway to taxiway wing tip clearance

    if (diff - dcr) > 0
      RTsepv = RTsep6;                                  % Satisfy group VI
    end
    WTclearv = RTsep6 - WSv - old;

% Airplane design group V

  % Relevant data in ft.

    RTsep5 = 400;    % RW CL to parallel TW CL or TL CL separation in ft.

  % Estimate offset lateral distance when airplane's outer main wheels
  % is on TW edge (worst case scenario)

    old = (TWv - UCWv) / 2;

  % Add half of VLCA wingspan to obtain critical distance

    dcr = old + 0.5 * WSv;

  % Estimate distance between the difference of RW/TW separation and RSA

    diff = RTsep5 - 0.5 * RSA;
```

```
 % Check runway to taxiway wing tip clearance

   if (diff - dcr) > 0
     RTsepv = RTsep5;
   else
     RTsepv = dcr + 0.5 * RSA;                              % > group V
   end
   WTclear5 = RTsep5 - WSv - old;

%%________________________________________________________________%%
% Taxiway To Taxiway/Taxilane Centerline Separation

  TTv = 1.2 * WSv + 10;
  TTwtc = 0.2 * WSv +10;          % Wingtip clearance for parallel tw's

% Taxiway Centerline To Fixed Or Movable Object Separation

  TOBJv = 0.7 * WSv + 10;
  TOBJwtc = TTwtc;                % Wingtip clearance from taxiway

% Taxilane Centerline To Fixed Or Movable Object Separation

  TLOBJ5 = 0.6 * WS747 + 10;      % Airplane design group five
  TLOBJv = 0.6 * WSv + 10;        % VLCA airplane design group
  TLOBJwtc = 0.1 * WSv + 10;     % Wingtip clearance from apron taxiway

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% NEW GEOMETRIC DESIGN CRITERIA

  % Current geometric design standards are contained in the FAA Advisory
  % Circular AC 5300-13-3.
  % Development of new geometric design guidelines follows:
%%________________________________________________________________%%
% VLCA Taxiway Dimensional Standards

  TWv;                            % Taxiway width
  TM = PMsw;                      % Taxiway edge safety margin
  TSWv;                           % Taxiway shoulder width
  TSAWv = WSv;                    % Taxiway Safety Area Width
  TOFAWv = 1.4 * WSv + 20;        % Taxiway object free area (OFA) width
  TLOFA1v = 2 * TLOBJv;           % Taxilane OFA for a single lane width
  TLOFA2v = 2.3 * WSv + 30;       % Taxilane OFA for a dual lane width
%%________________________________________________________________%%
% VLCA Runway Dimensional Standards

  RLv = RL747;                    % Runway length
  RWv;                            % Runway width
  RSWv;                           % Runway shoulder width
  RBPWv = 280;                    % Runway blast pad width
  RBPLv = 400;                    % Runway blast pad length
  RSAWv = 500;                    % Runway safety area width
```

```
  RSALv = 1000;                   % R/W safety area length beyond rw end
  ROFAWv = 800;                   % Runway object free area (OFA) width
  ROFALv = 1000;                  % Runway OFA length beyond runway end
  % Obstacle free Zone Dimensions (OFZ) for Precision Instrument Runway
  % Runway OFZ
    ROFZend = 200;                % Runway OFZ length beyond runway end
    if (180 + WSv + 0.02 * Hfield) > 400            % Runway OFZ width
      ROFZwidth = 180 + WSv + 20 * Hfield;
    else
      ROFZwidth = 400;
    end
  % Inner-approach OFZ (50:1)
  % Inner-transitional OFZ (3:1)

%%____________________________________________________________________%%
% Taxiways & Runway Exits Overall Lengths

% Consider one parallel taxiway running along entire runway and 90
% degrees exits only as a basic airport scenario

  Tlv = RLv;                                  % VLCA taxiway length in feet

  L90exit5=RTsep5-.5*RW5-RSW5-TSW5-.5*TW5;    % Gr. V 90 deg exit length
  L90exitv=RTsepv-.5*RWv-RSWv-TSWv-.5*TWv;    % VLCA 90 deg exit length

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% AIRCRAFT GATE COMPATIBILITY MODELING

% Gate positioning and configuration

  % Comparative Parking Envelopes: Push-out vs. Taxi-out

    po747L = L747 + 10;                             % In feet
    po747W = WS747 + 2;                             % In feet
    po747A = po747L * po747W / 9;                   % In squared yard
    to747L = 328;
    to747W = 240.8;
    to747A = to747L * to747W / 9;

    poVL = Lv + 10;
    poVW = WSv + 2;
    poVA = poVL * poVW / 9;
    toVL = 1.3 * poVL;
    toVW = 1.15 * poVW;
    toVA = toVL * toVW / 9;
pause
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                    AIRPORT TERMINAL CAPACITY MODULE
%     INTERNATIONAL AIRPORT TERMINAL DESIGN MODELING (USING FAA CHARTS)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%        TERMINAL DESIGN STANDARDS TO SUPPORT VLCA OPERATIONS

% FAA recommended relationships for typical peak-hour passenger (TPHP)
% computations from annual figures. TPHP as a percent. of annual flows
% [Ashford and Wright, 1992].
  TPHP1 = 0.2;         % Total annual passengers under 100,000
  TPHP2 = 0.13;        % Total annual passengers (100,000 to 499,999)
  TPHP3 = 0.08;        % Total annual passengers (500,000 to 999,999)
  TPHP4 = 0.05;        % Total annual passengers (1,000,000 to 9,999,999)
  TPHP5 = 0.045;       % Total annual pax (10,000,000 to 19,999,999)
  TPHP6 = 0.04;        % Total annual pax (20,000,000 to 29,999,999)
  TPHP7 = 0.035;       % Total annual passengers (30,000,000 and over)

% Collect all airport traffic activity and obtain acft mix in pk-hr as
% in the following tabulation:

% Acft   Acft   Seat Range    Equivalent
% Type    No.                 Acft Factor
%   A     15    up to 80          0.6
%   B     16     81-110           1.0
%   C     15    111-160           1.4
%   D      4    161-210           1.9
%   E      5    211-280           2.4
%   F      3    281-420           3.5
%   G      2    421-500           4.6
%   V      1      630             6.3         (VLCA)

% Enter the number of VLCA operations during design peak-hour
% in the noac5 vector

  OPERpkhr = 1;

%        A  B  C D E F G    V                 Acft type
noac = [15 16 15 4 5 3 2 OPERpkhr];           % Departures per design pk-hr

eaf =   [0.6                                  % Equivalent acft factor
         1.0
         1.4
         1.9
         2.4
         3.5
         4.6
         6.3];

EQA = noac * eaf;                    % Equivalent acft
```

```
% Passenger Demand Flows

  pkhryr = 1500;                 % Pk-hr to annual demand oper's factor
  OPERyr = OPERpkhr*pkhryr;      % Total VLCA operations per year
  aVLCAenp = OPERyr*npax*0.85;   % Annual VLCA pax enplanements

  aenpl = 6000000;               % Basic annual pax enpl's
  tenpl = aenpl+aVLCAenp;        % Total annual pax enpl's
  tapax = tenpl*2;               % Total annual passengers

% Determination of design peak-hour demand (in pax per peak-hour)

  TPHP = TPHP5 / 100 * tapax
%%_____________________________________________________________________%%
% GROSS TERMINAL BUILDING AREA ESTIMATES

  GTBar = 250;     % Gross terminal building area rule of thumb for
                   % rough estimation in SF per design peak-hour pax
                   % (international operations)

  GTBa = TPHP * GTBar      % Overall gross terminal building area in SF

% Gross terminal building area space distribution

  rentable = 0.55;
    aline = 0.38;
    other = 0.17;
  nonrentable = 0.45;
    public = 0.30;
    services = 0.15;

% Estimated breakdown of terminal building space by functional areas

  RENTABLEa = rentable * GTBa;
    ALINEa = aline * GTBa;
    OTHERa = other * GTBa;
  NRENTABLEa = nonrentable * GTBa;
    PUBLICa = public * GTBa;
    SERVICEa = services * GTBa;
%%_____________________________________________________________________%%
% COMPUTATION OF TERMINAL COMPONENT AREAS

% Airline Ticket Counters:

  % Develop terminal counter frontage matrix, TCF, in feet as a function
  % of equivalent aircraft,EQA (first column), and other characteristics
  % such as:
  % 5 = Orig.>80% of annual enplan. & gate util. w/ high perc. of depar
  % 4 = Orig. > 80% & gate utilization with equal arrivals and depar
  % 3 = Orig. < 80% & gate util. w/ high perc. of departures
  % 2 = Orig. < 80% & gate utilization with equal arrivals and depart
```

```
  TCF = [ 1    2   3   4   5
         20  180 200 220 240
         30  240 270 300 330
         40  300 330 370 420
         50  330 390 430 480
         60  370 440 500 540
         70  400 500 550 600
         80  450 540 600 640
         90  480 580 550 680
         100 510 610 670 720];

  ATCOUNTERf = table2(TCF,EQA,5);      % Linear feets of counter frontage
  ATCOUNTERd = 15;                     % Depth of counter area in ft.
  ATCOUNTERa = ATCOUNTERf*ATCOUNTERd % Airline ticket counter area in SF

% Airline Ticket Offices and Support Spaces:

  % Develop ATO/SUPPORT SPACE area matrix, ATOSS, in SF as a function
  % of EQA and above characteristics

    ATOSS = [ 1     2     3     4     5
             20  4400  4800  5200  5800
             30  5500  6300  7000  7700
             40  6500  7500  8200  9200
             50  7200  8300  9400 10300
             60  7900  9000 10200 11200
             70  8400  9800 11000 12000
             80  9000 10600 11800 12800
             90  9800 11400 13300 13700
            100 10300 12000 13200 14500];

    ATOSSa = table2(ATOSS,EQA,5);

% Outbound Baggage Facilities:

  % Develop outbound baggage room matrix, OBR, in SF as a funct of EQA
  % and the above charact., also based on the basis of an average of 1.3
  % bags checked per passenger.

    OBR = [ 1     2     3     4     5
           20  7500  8500     0 11000
           30 10000 13000 14000 15500
           40 14000 17000 18000 20500
           50 18000 21000 22000 25500
           60 22000 25000 26000 30500
           70 26000 29000 30000 35500
           80 30000 33000 34000 40500
           90 34000 37000 38000 45500
          100 38000 41000 42000 50500];

    OBFa = table2(OBR,EQA,5);
```

```
% Baggage Claim Facilities

  % First, compute equivalent acft arrivals to approximate deplaning pax
    % in a 20 min.peak period, assuming an average of 1.3 bags per
    % deplaning pax., EQAA20.
  % Second, identify percent of arriving pax terminating locally, terpax
  % Third, develop inbound baggage claim frontage matrix in ft., IBCF,
    % as a function of EQAA20 (first column) and terpax (first row).
  % Compute the claiming frontage requirements in feet
  arrpax = 0.50;              % Arrival passengers
  arrpax20 = 0.5;             % Percentage of arrival pax in peak 20 min

  EQAA20 = EQA*arrpax*arrpax20;
  terpax = 80;

  IBCF = [ 1    50   60   70   80   90  100
           5    50  100  150  200  250  300
          10   200  250  300  350  400  450
          15   360  410  460  520  575  630
          20   520  575  625  675  735  780
          25   675  740  780  845  900  950
          30   840  900  950 1000 1060 1110
          35  1000 1060 1120 1170 1220 1280
          40  1170 1230 1280 1340 1380 1440];

  BAGGAGECLAIMf = table2(IBCF,EQAA20,terpax);

  % Then, select one of the following devices:
  % 7 = Round sloping bed/remote feed or flat bed/direct feed
  % 6 = Flat bed/direct feed (tee & U-shape alternating at 75 ft.)
  % 5 = Oval flat bed/direct feed or oval sloping bed/remote feed
  % 4 = Flat bed/direct feed (Tee & U-shape alternating at 60 ft.)
  % 3 = U-shape flat bed/direct feed
  % 2 = Fixed shelf

 % Finally, develop baggage claim area matrix, BC, in SF as a funct of
 % BAGGAGECLAIMf (first column) and the above mechanical claim devices

   BC =[   1     2      3      4      5      6      7
         100  2777      0   2980      0   3360   3640
         200  5554   5560   5960   6280   6720   7280
         300     0   8331   8940   9420  10080  10920
         400     0  11108  11920  12562  13440  14560
         500     0  13885  14900  15700  16800  18200
         600     0  16680  17880  18840  20160  21840
         700     0  19460  20860  21980  23520  25480
         800     0  22240  23840  25120  26880  29120
         900     0  25020  26820  28260  30240  32760
        1000     0  27800  29800  31400  33600  36400];

   BAGGAGECLAIMa = table2(BC,BAGGAGECLAIMf,7);
```

```
% Airline Operations and Support Areas

  AOSa = 2 * ATOSSa;

% Departure Lounges

  % First, develop departure lounge area space requirements matrix,
  % DLSR, in SF on the basis of acft seating capacity and load factors
    % (75-85%).
  % Then, compute total area for all departure lounges,TDEPLOUNGEa, as a
  % function of DLSR and no. of gates (nogates).

    DLSR = [ 675     % A
            1110     % B
            1500     % C
            2000     % D
            2500     % E
            3800     % F
            5000     % G
            6300];   % V

    nogates = noac;

    TDEPLOUNGEa = nogates * DLSR;

  % VLCA Departure Lounge Space Area:
    % Two levels required
    % Double Level Loading Bridges
    % Sizing

% Other Airline Space in SF

  OASPACEa = 0.2 * AOSa;

% Ticketing Lobby in SF

  % Develop ticket lobby and counter area matrix, TL&C, in SF as a
  % function of EQA and the following characteristics:
  % 2 = For transfer stations &/or high no. of gates per airline
  % 3 = For originating/terminating stations or low no. of gates

    TLC = [ 1      2     3
           10      0  8000
           20  13000 15000
           30  18000 23000
           40  26000 31000
           50  33000 38000
           60  38000 43000
           70  41000 46000
           80  42000 48000
           90  42500 49000
```

```
        100 43000 49500];

    TLCa = table2(TLC,EQA,3);

  % To estimate only the public ticket lobby area subtract from
  % TL&Ca the counter area

    TICKETLOBBYa = TLCa - ATCOUNTERa;

% Central Waiting Lobby (Departures) in SF

  % Since all departure gate lounges have seating, the central waiting
  % lobby may be sized to seat only 20% of TPHP plus visitors. The
  % remainder pax in concessions and so on. Also, assumed visitor/pax
  % ratio of two. Then, develop central waiting lobby area vector CWL in
  % SF as a function of seats required.

    vispaxr = 2;
    visitors = vispaxr * TPHP;
    SEATSreq = 0.2 * (TPHP + visitors);

    CWL   = [ 100   3257
              200   5114
              300   6971
              400   8829
              500  10686
              600  12543
              800  16257
             1000  19971
             1200  23686
             1400  27400
             1600  31114
             1800  34829
             2000  38543
             2200  42254
             2400  45968
             2600  49682
             2800  53396
             3000  57110
             3200  60824
             3400  64538
             3600  68252
             3800  71966
             4000  75680
             4200  79394
             4400  83108
             4600  86822
             4800  90536
             5000  94250];

  CWLa = table1(CWL,SEATSreq);
```

```
% Bag Claim Lobby in SF

  % Assume two greeters per pax plus one pax (3), avg waiting time of 30
  % min.,space requirements of 16 SF/pax, and 50% of flow arriving.

    BCLidr = 1.2;
    BCLa = 3 * 16 * 0.5 * 0.5 * TPHP * BCLidr;

% Food & Beverage Services

 % Develop food & beverage services area matrix, FBS, in SF as a
 % funct of annual pax enplanements and usage factors (40%, 50%, & 60%)

   FBS = [       1    40    50    60
          1000000 14000 16000 18000
          2000000 22500 26000 31000
          3000000 31000 36000 40000
          4000000 37200 42320 46840
          5000000 34200 47400 52550
          6000000 46800 52480 58260
          7000000 51600 57560 63970
          8000000 56400 62640 69680
          9000000 61200 67720 75390
         10000000 66000 72800 81100];

   FBSa = table2(FBS,aenpl,60);

% Concessions and Building Services in SF

  % Develop concessionaire and building services area matrix, CBS, in SF
  % as a function of annual pax enplanements.

  CBS = [1000000 14000
         2000000 27000
         3000000 40000
         4000000 51000
         5000000 60000
         6000000 67000
         7000000 73000
         8000000 80000
         9000000 85000
        10000000 90000
        11000000 92000
        12000000 95000];

  CBSa = table1(CBS,aenpl);
```

```
% Other Rental Areas in SF

  % Space required is 50% of CBSa

    ORENTALidr = 1.1;
    ORENTALa = 0.5 * CBSa * ORENTALidr;

% Other Circulation Areas in SF

  % Space required is 70% of the gross total space approximated for all
  % previous terminal functions

  GTS1a = ATCOUNTERa+ATOSSa+OBFa+BAGGAGECLAIMa+AOSa+TDEPLOUNGEa+OASPACEa
  OCidr = 1.2;
  OCa = 0.7 * GTS1a * OCidr;

% Building Mechanical Systems (HVAC) in SF

  % Space required is 15% of the gross total space approximated for all
  % previous terminal functions

    GTS2a = GTS1a+TICKETLOBBYa+CWLa+BCLa+FBSa+CBSa+ORENTALa+OCa;
    HVACa = 0.15 * GTS2a;

% Building Structure in SF

  % Space allowance for columns and walls is 5% of the total gross area
  % approximated for all previous functions

    GTS3a = GTS2a + HVACa;
    BSa = 0.05 * GTS3a;

% Domestic Terminal Building Space

  DTBSa = GTS3a + BSa
  areademr = DTBSa/TPHP
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%              FAA AIRPORT TERMINAL SPACE DESIGN STANDARDS

% DOMESTIC TERMINAL SPACE DESIGN STANDARDS

% Space required per 100 TPHP (SF)

  TPHP100 = TPHP / 100;

  TLa = 1000 * TPHP / 100;        % Ticket lobby area
  AOa = 4800 * TPHP / 100;        % Airline Operational area
  BCa = 1000 * TPHP / 100;        % Baggage claim area
  WRa = 1800 * TPHP / 100;        % Waiting rooms area
  EFa = 1600 * TPHP / 100;        % Eating facilities area
  KSa = 1600 * TPHP / 100;        % Kitchen and storage area
```

```
  OCa =   500 * TPHP / 100;         % Other concessions area
  Ta  =   300 * TPHP / 100;         % Toilets area
  CMMWa = 11600 * TPHP / 100        % Circulation, mech., mainten., walls
  domtera = 24200 * TPHP / 100;     % Domestic terminal area
%%______________________________________________________________________%%
% INTERNATIONAL TERMINAL SPACE DESIGN STANDARDS

% Add the following components:

  % FEDERAL INSPECTION SERVICES (FIS) SPACE AND FACILITY REQUIREMENTS
  % AT INTERNATIONAL AIRPORTS

  INMa = 1000 * TPHP / 100;              % Immigration area
  CUSTOMSa = 3300 * TPHP / 100;          % Customs area
  PHa = 1500 * TPHP / 100;               % Public health area
  AGRICa = 200 * TPHP / 100;             % Agriculture area
  VWRa = 1500 * TPHP / 100;              % Visitor waiting rooms area
  FISa = 7500 * TPHP / 100;
  ITBSa = 7500 * TPHP / 100;      % Circul.,baggage assembly, util.,walls

% International Airport Terminal Space Area to Support VLCA Opeations

  APORTterma = DTBSa + ITBSa + FISa

% Airport Terminal Area to Peak-Hour Pax Demand Ratio

  areademr = APORTterma / TPHP

% NEW TERMINAL DESIGN GUIDELINES

% Possible increment in passenger flows inside terminals when
% introducing VLCA
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                     AIRPORT LANDSIDE CAPACITY MODULE
%                          LANDSIDE SIMULATIONS
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Airport Access Systems

  % Roadway Network Capacity
  % Mass Transit Systems

% Airport Public Parking Facilities to Support VLCA Operations

  % Develop airport public auto parking spaces matrix, PARK, in units of
  % parking spaces (for long and short term) as a function of
  % originating annual passengers, origpax

  origpax = 0.5 * tenpl;


  SLPARK = [1000000 1800
            1400000 2400
            1800000 2800
            2000000 3000
            2400000 3300
            2800000 3700
            3200000 4000
            3600000 4200
            4000000 4400];

  SLPARKs = table1(SLPARK,origpax);

  % Develop airport short term parking demand, SPARK, in units of
  % parking spaces as a function of peak hour originating passengers

  phorigpax = 0.5 * TPHP;

  SPARK = [   0     10
            500  182.5
           1000  355.0
           1500  527.5
           2000  700.0
           2500  872.5
           3000 1045.0
           3500 1217.5
           4000 1390.0
           4500 1562.5
           5000 1735.0];

  SPARKs = table1(SPARK,phorigpax);
```

```
% Terminal Curb Frontage Capacity in Linear Feet (drop-off/pick-up)

  TERCURBf = origpax / 1000000 * 120;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% TERMINAL DESIGN STDS TO SUPPORT AIRPLANE DESIGN GROUP V OPERATIONS

% Relevant Airport Data Collection
% Collect all airport traffic activity and obtain acft mix in pk-hr as
% in the following tabulation:
% Acft    Acft    Seat Range    Equivalent
% Type     No.                  Acft Factor
%   A      15     up to 80          0.6
%   B      16      81-110           1.0
%   C      15     111-160           1.4
%   D       4     161-210           1.9
%   E       5     211-280           2.4
%   F       3     281-420           3.5
%   G       2     421-500           4.6
%   V       0       630             6.3     (VLCA)

%          A  B   C  D  E  F  G  V         Acft type
noac5 = [15 16 15  4  5  3  2  0];        % Departures per design pk-hr

eaf5 =   [0.6                              % Equivalent acft factor
          1.0
          1.4
          1.9
          2.4
          3.5
          4.6
          6.3];

EQA5 = noac5 * eaf5;                       % Equivalent acft

% Passenger Demand Flows

  aenpl5 = 6000000;                        % Basic annual pax enplanements
  tapax5 = 12000000;                       % Basic annual passengers

% Determination of design peak hour demand (in pax per peak-hour)

  TPHP5 = TPHP5 / 100 * tapax5

%%______________________________________________________________________%%
% GROSS TERMINAL BUILDING AREA ESTIMATES

  GTBar = 250;           % Gross terminal building area rule of thumb for
                         % rough estimation in SF per design peak-hour pax
                         % (international operations)

  GTBa5 = TPHP5 * GTBar     % Overall gross terminal building area in SF
```

```
%%_______________________________________________________________________%
% COMPUTATION OF TERMINAL INDIVIDUAL AREAS

% Airline Ticket Counters:

  % Develop terminal counter frontage matrix, TCF, in feet as a function
  % of equivalent aircraft, EQA (first column), and other
  % characteristics such as:
  % 5 = Orig.>80% of annual enplan. & gate util. w/ high perc. of depart
  % 4 = Orig. > 80% & gate utilization with equal arrivals and depart
  % 3 = Orig. < 80% & gate util. w/ high perc. of departures
  % 2 = Orig. < 80% & gate utilization with equal arrivals and depart

  TCF = [ 1    2   3   4   5
         20  180 200 220 240
         30  240 270 300 330
         40  300 330 370 420
         50  330 390 430 480
         60  370 440 500 540
         70  400 500 550 600
         80  450 540 600 640
         90  480 580 550 680
        100  510 610 670 720];

  ATCOUNTERf5 = table2(TCF,EQA5,5)       % Linear ft of counter frontage
  ATCOUNTERd5 = 15;                      % Depth of counter area in ft.
  ATCOUNTERa5=ATCOUNTERf5*ATCOUNTERd5    % Airline ticket counter area SF

% Airline Ticket Offices and Support Spaces:

  % Develop ATO/SUPPORT SPACE area matrix, ATOSS, in SF as a function
  % of EQA and above characteristics

  ATOSS =    [ 1     2     3     4     5
              20  4400  4800  5200  5800
              30  5500  6300  7000  7700
              40  6500  7500  8200  9200
              50  7200  8300  9400 10300
              60  7900  9000 10200 11200
              70  8400  9800 11000 12000
              80  9000 10600 11800 12800
              90  9800 11400 13300 13700
             100 10300 12000 13200 14500];

  ATOSSa5 = table2(ATOSS,EQA5,5);

% Outbound Baggage Facilities:

  % Develop outbound baggage room area matrix, OBR, in SF as a funct of
  % EQA and the above charact., also based on the basis of an average of
  % 1.3 bags checked per passenger.
```

```
  OBR = [ 1      2      3      4      5
         20   7500   8500      0  11000
         30  10000  13000  14000  15500
         40  14000  17000  18000  20500
         50  18000  21000  22000  25500
         60  22000  25000  26000  30500
         70  26000  29000  30000  35500
         80  30000  33000  34000  40500
         90  34000  37000  38000  45500
        100  38000  41000  42000  50500];

  OBFa5 = table2(OBR,EQA5,5);

% Baggage Claim Facilities

  % First, compute equivalent acft arrivals to approximate deplaning pax
  % in a 20 min.peak period, assuming an average of 1.3 bags per
  % deplaning pax., EQAA20.Second, identify percent of arriving pax
  % terminating locally, terpax. Third, develop inbound baggage claim
  % frontage matrix in ft., IBCF, as a function of EQAA20 (first column)
  % and terpax (first row). Compute the claiming frontage req's in ft

  arrpax = 0.50;               % Arrival passengers
  arrpax20 = 0.5;              % Percentage of arrival pax in peak 20 min

  EQAA205 = EQA5 * arrpax * arrpax20;
  terpax = 80;

  IBCF = [ 1    50    60    70    80    90   100
           5    50   100   150   200   250   300
          10   200   250   300   350   400   450
          15   360   410   460   520   575   630
          20   520   575   625   675   735   780
          25   675   740   780   845   900   950
          30   840   900   950  1000  1060  1110
          35  1000  1060  1120  1170  1220  1280
          40  1170  1230  1280  1340  1380  1440];

  BAGGAGECLAIMf5= table2(IBCF,EQAA205,terpax);

  % Then, select one of the following devices:

  % 7 = Round sloping bed/remote feed or flat bed/direct feed
  % 6 = Flat bed/direct feed (tee & U-shape alternating at 75 ft.)
  % 5 = Oval flat bed/direct feed or oval sloping bed/remote feed
  % 4 = Flat bed/direct feed (Tee & U-shape alternating at 60 ft.)
  % 3 = U-shape flat bed/direct feed
  % 2 = Fixed shelf
```

```
  % Finally, develop baggage claim area matrix, BC, in SF as a funct of
  % BAGGAGECLAIMf5 (first column) and the above mechanical claim devices

  BC = [   1     2      3      4      5      6      7
         100 2777      0   2980      0   3360   3640
         200 5554   5560   5960   6280   6720   7280
         300    0   8331   8940   9420  10080  10920
         400    0  11108  11920  12562  13440  14560
         500    0  13885  14900  15700  16800  18200
         600    0  16680  17880  18840  20160  21840
         700    0  19460  20860  21980  23520  25480
         800    0  22240  23840  25120  26880  29120
         900    0  25020  26820  28260  30240  32760
        1000    0  27800  29800  31400  33600  36400];

  BAGGAGECLAIMa5 = table2(BC,BAGGAGECLAIMf5,7);

% Airline Operations and Support Areas

  AOSa5 = 2 * ATOSSa5;

% Departure Lounges

  % First, develop departure lounge space requirements matrix,DLSR, in
  % SF on the basis of acft seating capacity and load factors (75-85%).
  % Then, compute total area for all departure lounges,TDEPLOUNGEa, as a
  % function of DLSR and no. of gates (nogates).

  DLSR = [ 675     % A
          1110     % B
          1500     % C
          2000     % D
          2500     % E
          3800     % F
          5000     % G
          6300];   % V

  nogates5 = noac5;

  TDEPLOUNGEa5 = nogates5 * DLSR;

  % VLCA Departure Lounge Space Area:
    % Two levels required
    % Double Level Loading Bridges
    % Sizing

% Other Airline Space in SF

  OASPACEa5 = 0.2 * AOSa5;
```

```
% Ticketing Lobby in SF

  % Develop ticket lobby and counter area matrix, TL&C, in SF as a funct
  % of EQA and the following characteristics:
  % 2 = For transfer stations &/or high no. of gates per airline
  % 3 = For originating/terminating stations or low no. of gates

  TLC = [ 1      2      3
         10      0   8000
         20  13000  15000
         30  18000  23000
         40  26000  31000
         50  33000  38000
         60  38000  43000
         70  41000  46000
         80  42000  48000
         90  42500  49000
        100  43000  49500];

  TLCa5 = table2(TLC,EQA5,3);

  % To estimate only the public ticket lobby area subtract from
  % TL&Ca the counter area

    TICKETLOBBYa5 = TLCa5 - ATCOUNTERa5;

% Central Waiting Lobby (Departures) in SF

  % Since all departure gate lounges have seating, the central waiting
  % lobby may be sized to seat only 20% of TPHP plus visitors. The
  % remainder pax in concessions and so on. Also, assumed visitor/pax
  % ratio of two. Then, develop central waiting lobby area vector CWL in
  % SF as a function of seats required.

  vispaxr = 2;
  visitors5 = vispaxr * TPHP5;
  SEATSreq5 = 0.2 * (TPHP5 + visitors5);

  CWL   = [ 100   3257
            200   5114
            300   6971
            400   8829
            500  10686
            600  12543
            800  16257
           1000  19971
           1200  23686
           1400  27400
           1600  31114
           1800  34829
           2000  38543
```

```
        2200 42254
        2400 45968
        2600 49682
        2800 53396
        3000 57110
        3200 60824
        3400 64538
        3600 68252
        3800 71966
        4000 75680
        4200 79394
        4400 83108
        4600 86822
        4800 90536
        5000 94250];

  CWLa5 = table1(CWL,SEATSreq5);

% Bag Claim Lobby in SF

  % Assume two greeters per pax plus one pax (3 people), average waiting
  % time of 30 min., space requirements of 16 SF/pax, and 50% of flow
  % arriving.

  BCLidr = 1.2;
  BCLa5 = 3 * 16 * 0.5 * 0.5 * TPHP5 * BCLidr;

% Food & Beverage Services

  % Develop food & beverage services area matrix, FBS, in SF as a funct
  % of annual pax enplanements and usage factors (40%, 50%, & 60%)

  FBS = [1          40    50    60
         1000000 14000 16000 18000
         2000000 22500 26000 31000
         3000000 31000 36000 40000
         4000000 37200 42320 46840
         5000000 34200 47400 52550
         6000000 46800 52480 58260
         7000000 51600 57560 63970
         8000000 56400 62640 69680
         9000000 61200 67720 75390
        10000000 66000 72800 81100];

  FBSa5 = table2(FBS,aenpl5,60)

% Concessions and Building Services in SF

  % Develop concessionaire and building services area matrix, CBS, in SF
  % as a function of annual pax enplanements.
```

```
  CBS = [1000000 14000
          2000000 27000
          3000000 40000
          4000000 51000
          5000000 60000
          6000000 67000
          7000000 73000
          8000000 80000
          9000000 85000
         10000000 90000
         11000000 92000
         12000000 95000];

  CBSa5 = table1(CBS,aenpl5);

% Other Rental Areas in SF

  % Space required is 50% of CBSa

  ORENTALidr = 1.1;
  ORENTALa5 = 0.5 * CBSa5 * ORENTALidr;

% Other Circulation Areas in SF

  % Space required is 70% of the gross total space approximated for all
  % previous terminal functions

  GTS1a5=
ATCOUNTERa5+ATOSSa5+OBFa5+BAGGAGECLAIMa5+AOSa5+TDEPLOUNGEa5+OASPACEa5
  OCidr = 1.2;
  OCa5 = 0.7 * GTS1a5 * OCidr;

% Building Mechanical Systems (HVAC) in SF

  % Space required is 15% of the gross total space approximated for all
  % previous terminal functions

  GTS2a5 = GTS1a5+TICKETLOBBYa5+CWLa5+BCLa5+FBSa5+CBSa5+ORENTALa5+OCa5;
  HVACa5 = 0.15 * GTS2a5;

% Building Structure in SF

  % Space allowance for columns and walls is 5% of the total gross area
  % approximated for all previous functions

  GTS3a5 = GTS2a5 + HVACa5;
  BSa5 = 0.05 * GTS3a5;

% Domestic Terminal Building Space
  DTBSa5 = GTS3a5 + BSa5
  areademr5 = DTBSa5 / TPHP5
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%             FAA AIRPORT TERMINAL SPACE DESIGN STANDARDS

% INTERNATIONAL TERMINAL SPACE DESIGN STANDARDS

% Add the following components:

  % FEDERAL INSPECTION SERVICES (FIS) SPACE AND FACILITY REQUIREMENTS
  % AT INTERNATIONAL AIRPORTS

  INMa5 = 1000 * TPHP5 / 100;             % Immigration area
  CUSTOMSa5 = 3300 * TPHP5 / 100;         % Customs area
  PHa5 = 1500 * TPHP5 / 100;              % Public health area
  AGRICa5 = 200 * TPHP5 / 100;            % Agriculture area
  VWRa5 = 1500 * TPHP5 / 100;             % Visitor waiting rooms area
  FISa5 = 7500 * TPHP5 / 100;
  ITBSa5 = 7500 * TPHP5 / 100;   % Circul.,baggage assembly, util.,walls

% International Airport Terminal Space Area to Support VLCA Opeations

  APORTterma5 = DTBSa5 + ITBSa5 + FISa5

% Airport Terminal Area to Peak-Hour Pax Demand Ratio

  areademr5 = APORTterma5 / TPHP5

% NEW TERMINAL DESIGN GUIDELINES

% Possible increment in passenger flows inside terminals when
% introducing VLCA
pause


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                           OTHER AIRPORT ISSUES MODULE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Emergency Response Equipment
  % Rescue and fire fighting complications
% Expansion of Airport into Environmentally Sensitive Areas
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                    AIRPORT LANDSIDE CAPACITY MODULE
%                         LANDSIDE SIMULATIONS
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Airport Public Parking Facilities to Support Airplane Design Group V

  % Develop airport public auto parking spaces matrix, PARK, in units of
  % parking spaces (for long and short term) as a funct of originating
  % annual passengers, origpax (annual pax enplanements).

  origpax5 = 0.5 * aenpl5;

  SLPARK = [1000000 1800
            1400000 2400
            1800000 2800
            2000000 3000
            2400000 3300
            2800000 3700
            3200000 4000
            3600000 4200
            4000000 4400];

  SLPARKs5 = table1(SLPARK,origpax5);

  % Develop airport short term parking demand, SPARK, in units of
  % parking spaces as a function of peak hour originating passengers

  phorigpax5 = 0.5 * TPHP5;

  SPARK = [   0     10
            500  182.5
           1000  355.0
           1500  527.5
           2000  700.0
           2500  872.5
           3000 1045.0
           3500 1217.5
           4000 1390.0
           4500 1562.5
           5000 1735.0];

  SPARKs5 = table1(SPARK,phorigpax5);

% Terminal Curb Frontage Capacity in Linear Feet (drop-off/pick-up)
% to Support Airplane Design Group Five Operations

  TERCURBf5 = origpax5 / 1000000 * 120;
pause
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                           NOISE MODULE
%          Noise Modeling of VLCA Operations (Ldn Contours)
%              Comparison with Current Limits (MD11GE)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                 THRUST AND "SEL" TAKEOFF ANALYSIS

% From an Integrated Noise Modeling (INM) noise curve data, enter the
% Sound Exposure Level (SEL) matrix for one of the most powerful
% existing engines, GE 2CF68D. This engine (3) serves MD-11's with an
% MTOW of 580,000 pounds.

SELge=[    0    61   122   192   305  610 1220 1921 3050 4878 7622 15122 30183
       10020  99.5  95.1  91.4  88.3 82.5 76.3 71.9 66.6 61.3 56.3  31.9  10.3
       23190 105.1 100.6  97.1  93.7 87.0 80.1 75.1 69.5 64.0 58.4  32.5  10.1
       25940 103.7  98.7  95.4  92.2 87.0 80.7 76.0 70.2 64.0 55.2  29.4   8.3
       39180 106.0 101.7  98.7  96.2 91.2 85.2 80.2 75.0 68.7 60.2  34.2  11.0
       51530 110.2 106.2 103.4 100.7 99.2 90.7 86.2 81.2 75.2 67.2  40.1  14.6
       55500 113.2 109.2 106.4 103.7 98.2 94.2 89.7 85.2 79.2 72.0  45.8  18.5];

% Now, develop SELv metric matrix produced by one VLCA engine by
% defining the Sound Exposure Level (SEL) curve matrix in terms of
% horizontal distance, r, (first row) in n.m. and power thrust,t, (first
% column) in pounds. The SELv matrix is based on SELge matrix SELv el's
% are derived as follows.

% For existing thrust levels the sound elements will increase by three
percent
% if MD11ge power and VLCA power differ by about 20,000 pounds.

  deltaSEL = 3.0

  for i=2:1:7
    for j=2:1:13
  SELv(i,j) = SELge(i,j);
    end
  end

% This loop defines elements of the first row (same slant distances)

  for j=1:1:13
    SELv(1,j) = SELge(1,j);
  end

% This loop defines elements of the first column (same thrust levels)

  for i=1:1:7
    SELv(i,1) = SELge(i,1);
end
```

```
% This loop defines elements of the last row (sound elements for new
% VLCA power thrust level)

for j=2:1:13
 SELv(8,j) = SELge(7,j) + SELge(7,j)*deltaSEL/100;
end

SELv(8,1) = 75702

SELV = SELv                          % VLCA sound exposure level matrix
pause

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                         NOISE MITIGATION AREA

% Estimate surface area impacted by noise pollution produced
% by MD-11GE and VLCA takeoff operations around an airfield.
% Then, estimate the difference of noise impacted area that
% requires mitigation.
%%_________________________________________________________________%%
% MD-11GE NOISE IMPACTED AREA

% Define Ldn Noise Contours in Terms of SELm matrix

% Define MD-11GE takeoff and climb profile
% in terms of x,y, and z coordinates.
% Assume: x is along runway centerline,
%         y does not change (always runway heading), and
%         z is altitude in meters.

% Define the takeoff & climb trajectory data, (x,z) points
% at maximum thrust (from INM takeoff profile data).

xzm = [0.000 0.00
        2692 0.00
        5127  305
        6407  404
        6712  433
        8567  610
       11734  915
   17902 1314
   34529 3049];

% Define the thrust (t) produced per engine for each position x
% (from INM takeoff profile data).

xtm = [0.000 51110
        2692 43720
        5127 44731
        6407 44289
        6712 34154
```

```
        8567 35222
       11734 36806
       17902 36913
       34529 33000];

% Define night and day operations

  Nn = 1.0;
  Nd = 1.0;

% Define increments and number of iterations

  dx = 500;                                           % Increments in the x
  dy = 100;                                           % Increments in the y

  stepx = 20;                                         % Iteration no. in x
  stepy = 20;                                         % Iteration no. in y

% Start big computational loop

sumcontouraream = 0.0;
for i=1:1:stepx
  for j=1:1:stepy

xm(i) = i * dx;                          % Set distance equivalents
ym(j) = j * dy;                          % Set distance equivalents

zm(i) = table1(xzm,xm(i));               % Find altitude in meters
Tm(i) = table1(xtm,xm(i));               % Find thrust in pounds

rm = sqrt(xm(i)^2+ym(j)^2+zm(i)^2);      % Compute distance to origin

SELm(i) = table2(SELge,Tm(i),rm);        % Compute SEL noise metric

LDNm(i,j) = SELm(i)+10*log10(Nd+10*Nn)-49.4;  % Compute LDN metric
Lm(i,j) = 10 * log10(3 * 10^[LDNm(i,j)/10]);  % Add 3 engine sounds
if Lm(i,j) > 55                          % Area inside 55 Ldn contour
  sumcontouraream = sumcontouraream + (dx * dy);
end
  end
  end

  mesh(xm,ym,Lm)
  pause

% Compute the first quarter contour area for 55 LDN metric

  MCONTOURarea1q = sumcontouraream / 1000000
```

```
% Compute the first half contour area for 55 LDN metric
% (ahead from runway threshold)

  K1 = 2;                              % Twice the first quarter area
  MCONTOURarea1h = MCONTOURarea1q * K1;

% Compute the second half contour area for 55 LDN metric
% (behind from runway threshold)

  K2 = 0.23;                           % Percentage from first half
area
  MCONTOURarea2h = K2 * MCONTOURarea1h;

% Compute the total noise contour area for 55 LDN metric
% impacted by MD-11GE operations around airfield

  MCONTOURareatot = MCONTOURarea1h + MCONTOURarea2h

%%_____________________________________________________________________%%
% VLCA NOISE IMPACTED AREA

% Define Ldn Noise Contours in terms of SELv matrix

% Define VLCA takeoff and climb profile in terms of
% x,y, and z coordinates.
% Assume: x is along runway centerline,
%         y does not change (always runway heading), and
%         z is altitude in meters.

% Define the takeoff & climb trajectory data, (x,z) points
% at maximum thrust from VLCA climb performance model.

    xz = 1.0e+05 * [
    0.00000000000000   0.00000000000000
    0.02200000000000   0.00000000000000
    0.03200000000000   0.00001200000000
    0.03626991579472   0.00077573737266
    0.04303375949495   0.00199557868508
    0.04987560303228   0.00321511757312
    0.05679810439640   0.00443453186058
    0.10011005391425   0.01174635872655
    0.15413443000158   0.02024909791430
    0.20532397846113   0.02765186277694
    0.25250471858365   0.03378284601321
    0.30317186619127   0.03988198570602
    0.35737175950418   0.04596380615942
    0.40336727180863   0.05081333177110
    0.47733214569082   0.05806969903952];
```

```
% Define the thrust (t) produced per engine for each position x
% from climb performance model.

   xt =  1.0e+05 * [
    0.00000000000000   0.75702000000000
    0.02200000000000   0.64000000000000
    0.03200000000000   0.60000000000000
    0.03626991579472   0.58997371483004
    0.04303375949495   0.58607474224573
    0.04987560303228   0.57995741556960
    0.05679810439640   0.57385862737672
    0.10759755280605   0.53285974904914
    0.15413443000158   0.50552601520288
    0.19637618541202   0.47395199486049
    0.20532397846113   0.46723233245011
    0.25250471858365   0.43775376839045
    0.30317186619127   0.41471477670483
    0.34626475349829   0.39809276981839
    0.39159846204550   0.38036337154241
    0.43960453972953   0.36251224710343
    0.49025066443805   0.34608138014695];

% Define night and day operations

  Nn = 1.0;
  Nd = 1.0;

% Define increments and number of iterations

  dx = 500;                                    % Increments in the x
  dy = 100;                                    % Increments in the y

  stepx = 20;                                  % Iteration no. in x
  stepy = 20;                                  % Iteration no. in y

% Start big computational loop

sumcontourareav = 0.0;
for i=1:1:stepx
  for j=1:1:stepy

x(i) = i * dx;                    % Set distance equivalents
y(j) = j * dy;                    % Set distance equivalents

z(i) = table1(xz,x(i));           % Find altitude in meters
T(i) = table1(xt,x(i));           % Find thrust in pounds

r = sqrt(x(i)^2 + y(j)^2 + z(i)^2); % Compute distance to origin
```

```
SEL(i) = table2(SELv,T(i),r);        % Compute SEL noise metric

LDN(i,j) = SEL(i)+10*log10(Nd+10*Nn)-49.4; % Compute LDN metric
L(i,j) = 10*log10(4*10^[LDN(i,j)/10]);      % Add 4 engine sounds
if L(i,j) > 55;                      % Area inside 55 Ldn contour
  sumcontourareav = sumcontourareav + (dx*dy);
end
  end
end

mesh(x,y,L)
pause

% Compute the first quarter contour area for 65 LDN metric

  CONTOURarea1q = sumcontourareav / 1000000

% Compute the first half contour area for 65 LDN metric
% (ahead from runway threshold)

  K1 = 2;                            % Twice the first quarter area
  CONTOURarea1h = CONTOURarea1q * K1;

% Compute the second half contour area for 65 LDN metric
% (behind from runway threshold)

  K2 = 0.23;                         % Percentage from first half area
  CONTOURarea2h = K2 * CONTOURarea1h;

% Compute the total noise contour area for 65 LDN metric
% impacted by VLCA operations around airfield

  CONTOURareatot = CONTOURarea1h + CONTOURarea2h

% Finally, estimate the noise impacted area difference b/t operating
% MD-11GE or VLCA airplanes. This noise polluted area will
% require expensive mitigation.
% Based on one day and one night daily operations.

  NOISEIMPACTEDa = CONTOURareatot - MCONTOURareatot
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                        VLCA ECONOMIC IMPACT MODULE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% CASE 1:  AN OPTIMAL VLCA PERFORMANCE DESIGN AIRCRAFT THAT ECONOMICALLY
%                  IMPACTS THE AIRPORT INFRASTRUCTURE

%                  VLCA LIFE CYCLE AIRPORT COST MODEL

% Estimate life cycle airport cost to serve VLCA airplanes by knowing
% the required infrastructure difference between an airport serving only
% airplane design group V (B747-400) and the same airport serving also
% VLCA airplanes.

%%____________________________________________________________________%%
% Airfield Pavement Section Improvements

  % Current airfield flexible pavement section design standards will
  % satisfy weight impact of VLCA airplanes. The impact of VLCA aircraft
  % weight on pavement sections should be less critical than B747-400.
  % The only required pavement improvement will come from the new
  % airfield geometric design standards that need to be developed.
  % Runways/taxiways, shoulders, aprons, and taxiway fillets may require
  % additional pavement area in order to adequately service VLCA
  % airplanes.

  % Airfield Pavement Section Improvement Cost: $ 0.0

    PAVSECc = 0.0

%%___________________________________________________________________%%
% VLCA Noise Mitigation

  % VLCA Noise Signature

    Mc = 1000000;                    % Noise mitigation cost per sq. Km.
    NOISEAadd = NOISEIMPACTEDa   % Additional noise area to be mitigated
NOISEMITIGc = NOISEAadd * Mc       % Noise Mitigation Costs


%%__________________________________________________________________%%
% Airfield Geometric Infrastructure Improvements

% Runway Improvements:

  % Runway Length Improvements

  % Determine runway length difference between B747-400 and VLCA to
  % see which length is the critical and to estimate runway length
  % improvement cost
```

```
    if Stom > RL747
      RLv = Stom;
      else
      RLv = RL747;
     RLc = 0.0;                         % Runway length improvement cost
    end

  % Runway Width Improvements

    RWd = RWv - RW5;                    % Runway width difference
RAd = RWd * RLv;                        % Additional runway pavement area
RAc = RAd * 100;                        % Runway width improvement cost

  % Runway Shoulder Width Improvements

    RSWd = RSWv - RSW5;                 % Runway shoulder width diff.
    RSAd = RSWd * RLv;                  % Additional runway shoulder pav. area
    RSAc = 2 * RSAd * 50;               % Runway shoulder improvement cost

    Rc = RLc + RAc + RSAc               % Runway improvement cost

% Taxiway Improvemens:

  % Taxiway Width Improvements

    TWd = TWv - TW5;                       % Taxiway width difference
    TAv = TWd * Tlv;                       % Additional taxiway pavement area
    TAc = TAv * 100;                       % Taxiway width improv. cost

  % Taxiway Shoulder Width Improvements

    TSWd = TSWv - TSW5;              % Taxiway shoulder width diff.
    TSAv = 2 * TSWd * Tlv;           % Additional taxiway shoulder pav. area
    TSAc = TSAv * 50;                % Taxiway shoulder improv. cost

    Tc = TAc + TSAc                        % Taxiway improvement cost

% 90 Degrees Exit Improvements:

  % 90 Degrees Exit Pavement Improvements

    W90exitd = TWv - TW5;                        % 90 deg exit width diff
    L90exitd = L90exit5 - L90exitv;              % 90 deg exit length diff
    A90exitd = 2 * W90exitd * L90exitd;          % Add'l 90 deg exit pav. area
    A90exitdc = A90exitd * 100;      % 90 deg exit pav. area improv. cost

  % 90 Degrees Exit Shoulder Improvements

   SA90exitd = TSWd * 4 * L90exitd;     % Add'l 90 deg shoulder pav. area
   SA90exitc = SA90exitd * 50;          % 90 deg shoulder improv. cost
   exit90c = A90exitdc + SA90exitc      % 90 deg exit improvement cost
```

```
% Runway Blast Pad Area Improvements

  RBPW5 = 220;                        % Group V runway blast pad width
  RBPL5 = 400;                        % Group V runway blast pad length
  RBPA5 = RBPW5 * RBPL5;              % Group V runway blast pad area
  RBPWv = RWv + 2 * RSWv;             % VLCA runway blast pad width
  RBPLv = 400;                        % VLCA runway blast pad length
  RBPAv = RBPWv * RBPLv;              % VLCA runway blast pad area
  RBPAd = RBPAv - RBPA5;              % Runway blast pad surface area diff.
  RBPc = RBPAd * 50                   % RW blast pad area improv. cost

% Terminal Apron Area Improvements

  % Dual Taxilane Scenario (Between Piers)

    N = 10;                           % Nose to building distance
    TLW5 = 2 * TLOBJ5;                % Group five taxilane width
    TLWv = 2 * TLOBJv;                % VLCA taxilane width
    TAW5 = 2*N + 2*TLW5 + 2*L747;     % Group five terminal apron width
    TAWv = 2*N + 2*TLWv + 2*Lv;       % VLCA terminal apron width
    TAL5 = WS747 + 45;                % Group five terminal apron length
    TALv = WSv + 45;                  % VLCA terminal apron length
    TAA5 = TAW5 * TAL5;               % Group five terminal apron area
    TAAv = TAWv * TALv;               % VLCA terminal apron area
    TAAd = TAAv - TAA5;               % Additional terminal apron area
    TAAc = TAAd * 125;                % Terminal apron area improv. cost

% Taxiway Fillet Improvements

  TFc = 0;

% Estimate Min. Land Occupancy by a Runway-Taxiway Combination

  ROFAW5 = ROFAWv;
  TOFAW5 = TOFAWv;
  RTW5 = 0.5*ROFAW5 + RTsep5 + 0.5*TOFAW5;  % Group V RW & TW land width
  RTWv = 0.5*ROFAWv + RTsepv + 0.5*TOFAWv;  % VLCA RW & TW land width
  RTWd = RTWv - RTW5;                       % RW & TW land width diff.
  RTL = RLv + 2 * ROFALv;                   % RW & TW land length
  RTA = RTWd * RTL;                         % RW & TW land area
  RTAc = RTA * 1                            % Land acquisition cost

% Estimate Min. Land Occupancy by a Taxiway-Taxiway/Taxiland Combination

  TT5 = 1.2 * WS747 + 10;             % Gruop V TW CL to TW CL sep.
  TTW5 = TOFAW5 + TT5;                % Group V TW & TW land width
  TTWv = TOFAWv + TTv;                % VLCA TW & TW land width
  TTWd = TTWv - TTW5;                 % VLCA TW & TW land width diff.
  TTL = RLv;                          % VLCA TW & TW land length
  TTAd = TTWd * TTL;                  % VLCA TW & TW land area
  TTAc = TTAd * 1                     % Land acquisition cost.
```

```
% Airfield Geometric Infrastructure Improvement Cost

  GEOMETRICc = Rc + Tc +exit90c + RBPc + TAAc + TFc + RTAc + TTAc

%%____________________________________________________________________%%
% Landside Infrastructure Improvements

  TERCURBfd = TERCURBf - TERCURBf5    % Additional terminal curb frontage
  TCURBc = TERCURBfd * 1000           % Terminal curb frontage cost

  SLPARKsd = SLPARKs - SLPARKs5;  % Additional S & L term parking spaces
  SLPARKc = SLPARKsd * 11000      % Short & long term parking garage cost

  LANDSIDEc = TCURBc + SLPARKc         % Total landside improvement cost

%%__________________________________________________________________%%
% Terminal Infrastructure Improvements

  APORTtermad = APORTterma - APORTterma5   % Add'l airport terminal area
  IATERMc = APORTtermad*500      % Int aport term. infrast. improv. cost

%%____________________________________________________________________%%
% Airport Infrastructure Improvement Cost to Support VLCA Operations
% with an Optimal VLCA Performance Aircraft

  AIcov = PAVSECc + NOISEMITIGc + GEOMETRICc + LANDSIDEc + IATERMc

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Additional Airport Income Due to VLCA Operations

  PFC = 3;                            % Passenger facility charge ($ per
pax)
  PFCincv = aVLCAenp * PFC          % Annual PFC income due to VLCA op's
($)

  LF = 0.005;                         % Landing fee (in $ per landing pound)
  LANDFEESv = OPERyr*MTOW*LF        % Annual VLCA landing fees ($)

  AINCOMEv = PFCincv+LANDFEESv      % Annual airport income due to VLCA

% Benefit Cost Ratio

  BCR = AINCOMEv / AIcov
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                      LIFE CYCLE AIRLINE (USER) COST MODEL

% Estimate total operating cost (TOC) of an airline operating optimal
% designed VLCA airplanes

  INITcv = 250000000;

%                 VLCA LIFE CYCLE DIRECT OPERATING COST (DOC)

% FLIGHT OPERATIONS COST:

% Fuel and Oil Costs

  SL = ran * 1.15;          % Stage length or mission range in s.m.
  MF = TOTfcl;              % Fuel consumed from engine start to shutdown
  MFg = MF / 6.75;          % Mission fuel consumed in gallons per trip
  galfc = 1.7;              % Fuel price in dollars per gallon
  FUELc = MFg * galfc       % Fuel cost ($ per VLCA trip)

% Crew Expenses

  HRFLYmp = 90;             % Hours of flying per month per pilot
  HROPERyv = 4000;          % Hours of operation per year per aircraft

  Vdesc = 250;              % Average descent speed in knots
  Ddesc = 100;              % Descent distance (horiz.) in n.m.

  FLIGHTt = tclhr+(ran-dclnm-Ddesc)/Vcrk+Ddesc/Vdesc     % Mission flying
                                                          %  time (hr)

  PNTRIPSm = HRFLYmp / FLIGHTt;         % Max trips per month per pilot
  PNTRIPSy = PNTRIPSm*12;               % Max trips per year per pilot
  PSALARY = 300000;                     % Annual pilot salary ($)
  PILOTcTRIP = PSALARY/PNTRIPSy;        % Pilot expense ($ per VLCA trip)
  npilots = 4;                          % Required no. of pilots per trip
  PILOTScTRIP = npilots*PILOTcTRIP      % Pilots expense ($ per trip)

  HRFLYms = 90;                         % Flying hrs per month per steward
  SNTRIPSm = HRFLYms / FLIGHTt;         % Max trips per month per steward
  SNTRIPSy = SNTRIPSm*12;               % Max.trips per year per steward
  SSALARY = 40000;                      % Annual steward salary ($)
  STEWARDcTRIP = SSALARY/SNTRIPSy;      % Steward expense ($ per trip)
  nstes = 26;                           % Required no of stewards per trip
  STEWARDScTRIP=nstes*STEWARDcTRIP;      % Stewards expense ($ per trip)

  CREWc = PILOTScTRIP+STEWARDScTRIP      % Crew expenses ($ per trip)
```

```
% Insurance Cost

  NTRIPvy = HROPERyv/FLIGHTt;          % Max. annual VLCA trips
  INSURc = (0.03*INITcv)/NTRIPvy       % Insurance cost ($ per trip)

  FOPERc = FUELc + CREWc + INSURc      % Flight operations cost

% Aircraft Depreciation Cost

  DEPRECc = (0.04 * INITcv) / NTRIPvy  % Depreciation cost ($ per trip)

% Aircraft Maintenance Cost

  MAINTENc = 0.15 * FUELc              % Maintenance cost ($ per trip)

  DOC = FOPERc + DEPRECc + MAINTENc    % VLCA DOC ($ per trip)
  ASM = ran * npax                     % Available seat miles per trip
  DOCASM = DOC / ASM                   % VLCA DOC per ASM

%            VLCA LIFE CYCLE INDIRECT OPERATING COST (IOC)

% Includes administration and sales cost, property and equipment cost,
% servicing flight operations, and depreciation ground equipment

  MMHFH = 7.0;                         % Maintenance hours per fligth hr
  MHPY = MMHFH * HROPERyv;             % Maintenance hours per year
  MCPH = 1000;                         % Maintenance cost per hour
  MCPT = MMHFH * FLIGHTt * MCPH        % Maintenance cost per trip

  ADCPT = 0.25 * MCPT                  % Administrative cost

  IOC = ADCPT + MCPT                   % VLCA IOC ($ per trip)

%            VLCA LIFE CYCLE TOTAL OPERATING COST (TOC)

  TOCv = DOC + IOC
```

Vita

Mr. Alceste Venturini was born on August 10, 1966, in Cochabamba, the second largest city of Bolivia. After graduation with honors from high school in Santa Cruz, Bolivia, he pursued studies of the Italian language and Engineering-Architecture at Turin Polytechnic University, in Turin, Italy. He obtained his Bachelor's degree in Civil Engineering from Virginia Polytechnic Institute and State University, in the state of Virginia, United States in May 1992. After working and gaining experience for 15 months in airport airfield design, he again joined Virginia Tech, in Blacksburg, Virginia to pursue his Master's degree in Civil Engineering with specialization in Transportation Engineering. During the 1993 fall semester and 1994 spring semester, he worked as a Graduate Research and Teaching Assistant with Dr. Antonio A. Trani in the field of airport design, planning and operations and in air transportation systems. He completed his Master of Science in Civil Engineering, in September 1994. He plans to become an international consultant in the air transportation, airport, and airline industries.

Alceste Venturini
September 15, 1994