Analysis of Air Transportation Systems

The Aircraft and the System

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Material Presented in this Section

- The aircraft and the airport
- Aircraft classifications
- Aircraft characteristics and their relation to airport planning
- New large capacity aircraft (NLA) impacts

Purpose of the Discussion

- Introduces the reader to various types of aircraft and their classifications
- Importance of aircraft classifications in airport engineering design
- Discussion on possible impacts of Very Large Capacity Aircraft (VLCA, NLA, etc.)
- Preliminary issues on geometric design (apron standards) and terminal design

Relevance of Aircraft Characteristics

- Aircraft classifications are useful in airport engineering work (including terminal gate sizing, apron and taxiway planning, etc.)
- Most of the airport design standards are intimately related to aircraft size (i.e., wingspan, aircraft length, aircraft wheelbase, aircraft seating capacity, etc.)
- Airport fleet compositions vary over time and thus is imperative that we learn how to forecast expected vehicle sizes over long periods of time

Aircraft Classifications

Aircraft are generally classified according to three important criteria in airport engineering:

- Geometric design characteristics (Aerodrome code in ICAO parlance)
- Air Traffic Control operational characteristics (approach speed criteria)
- Wake vortex generation characteristics

Other relevant classifications are related to the type of operation (short, medium, long-haul; wide, narrow-body, and commuter, etc.)

Geometric Design Classification (ICAO)

ICAO Aerodrome Reference Code Used in Airport Geometric Design.

Design Group	Wingspan (m)	Outer Main Landing Gear Width (m)	Example Aircraft
A	< 15	< 4.5	All single engine aircraft, Some business jets
B	15 to < 24	4.5 to < 6	Commuter aircraft, large business jets (EMB-120, Saab 2000, Saab 340, etc.)
C	24 to < 36	6 to < 9	Medium-range transports (B727, B737, MD-80, A320)
D	36 to < 52	9 to < 14	Heavy transports (B757, B767, A300)
E	52 to < 65	9 to < 14	Heavy transport aircraft (Boeing 747, L-1011, MD-11, DC-10)

Geometric Design Classification (FAA in US)

FAA Aircraft Design Group Classification Used in Airport Geometric Design.

Design Group	Wingspan (ft)	Example Aircraft
I	< 49	Cessna 152-210, Beechcraft A36
II	49 - 78	Saab 2000, EMB-120, Saab 340, Canadair RJ-100
III	79 - 117	Boeing 737, MD-80, Airbus A-320
IV	118 - 170	Boeing 757, Boeing 767, Airbus A-300
V	171 - 213	Boeing 747, Boeing 777, MD-11, Airbus A-340
VI	214 - 262	A3XX-200 or VLCA (planned)

ATC Operational Classification (US)

Airport Terminal Area Procedures Aircraft Classification (FAA Scheme).

Group	Approach Speed (knots)[a]	Example Aircraft
A	< 91	All single engine aircraft, Beechcraft Baron 58,
B	91-120	Business jets and commuter aircraft (Beech 1900, Saab 2000, Saab 340, Embraer 120, Canadair RJ, etc.)
C	121-140	Medium and Short Range Transports (Boeing 727, B737, MD-80, A320, F100, B757, etc.)
D	141-165	Heavy transports (Boeing 747, L-1011, MD-11, DC-10, A340, A300)
E	> 166	BAC Concorde and military aircraft

a. At maximum takeoff gross mass.

Wake Vortex Aircraft Classification

Final Approach Aircraft Wake Vortex Classification.

Group	Takeoff Gross Weight (lb)	Example Aircraft
Small	< 41,000	All single engine aircraft, light twins, most business jets and commuter aircraft
Large	41,000-255,000	Large turboprop commuters, short and medium range transport aircraft (MD-80, B737, B727, A320, F100, etc.)
Heavy	> 255,000	Boeing 757[a], Boeing 747, Douglas DC-10, MD-11, Airbus A-300, Airbus A-340, Lockheed L-1011

a. For purposes of terminal airspace separation procedures, the Boeing 757 is now classified by FAA in a category by itself. However, when considering the Boeing 757 separation criteria (close to the Heavy category) and considering the percent of Boeing 757 in the U.S. fleet, the use of three categories does provide very similar results for most airport capacity analyes.

IATA Aircraft Classification

IATA Aircraft Size Classification Scheme.

Category	Number of Seats	Example Aircraft
0	< 50	Embraer 120, Saab 340
1	50-124	Fokker 100, Boeing 717
2	125-179	Boeing B727-200, Airbus A321
3	180-249	Boeing 767-200, Airbus A300-600
4	250-349	Airbus A340-300, Boeing 777-200
5	350-499	Boeing 747-400
6	> 500	Boeing 747-400 high density seating

Used in the forecast of aircraft movements at an airport based on the IATA forecast methodology.

Aircraft Classification According to their Intended Use

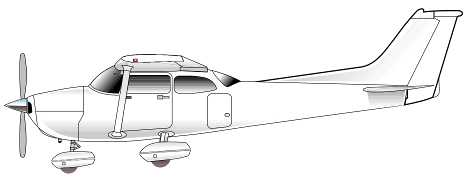
A more general aircraft classification based on the aircraft use

- General aviation aircraft (GA)
- Corporate aircraft (CA)
- Commuter aircraft (COM)
- Transport aircraft (TA)
  - Short-range
  - Medium-range
  - Long-range

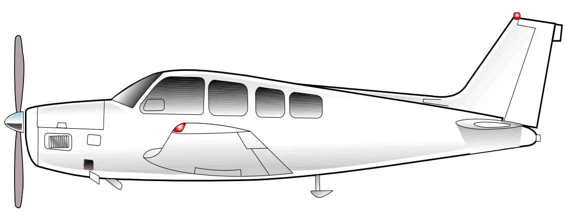
General Aviation (GA)

Typically these aircraft can have one (single engine) or two engines (twin engine). Their maximum gross weight usually is always below 14,000 lb.

Single-Engine GA

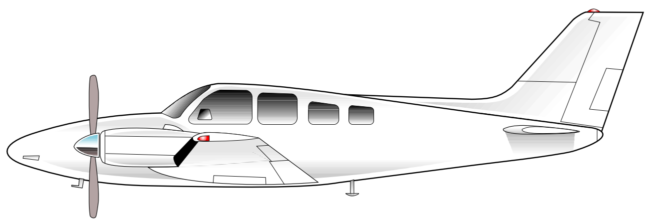


Cessna 172 (Skyhawk)

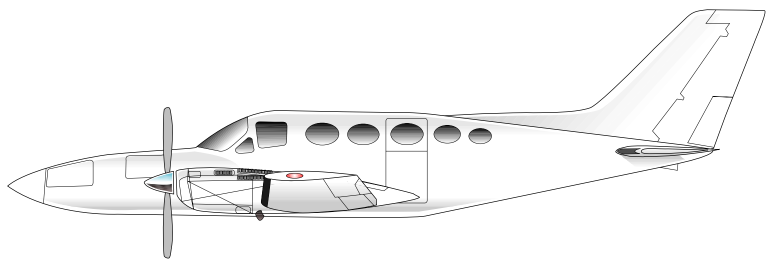


Beechcraft A36 (Bonanza)

Twin-Engine GA



Beechcraft 58TC (Baron)

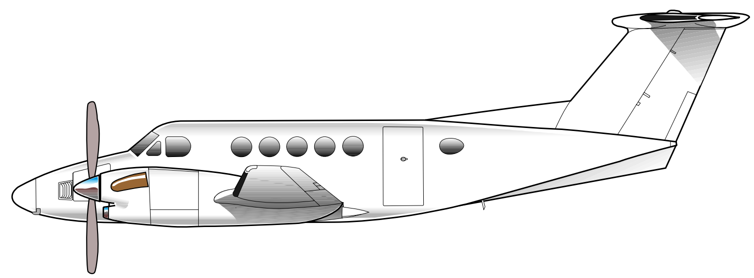


Cessna 421C (Golden Eagle)

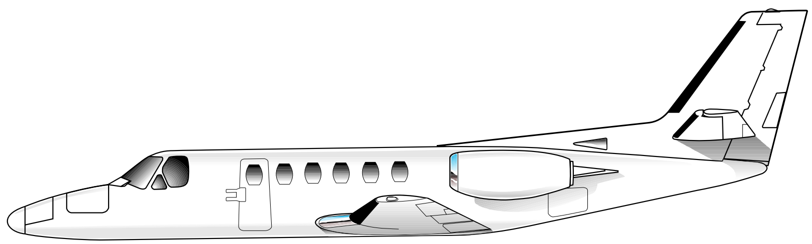
Corporate Aircraft (CA)

Typically these aircraft can have one or two turboprop driven or jet engines (sometimes three). Maximum gross mass is up to 40,910 kg (90,000 lb)

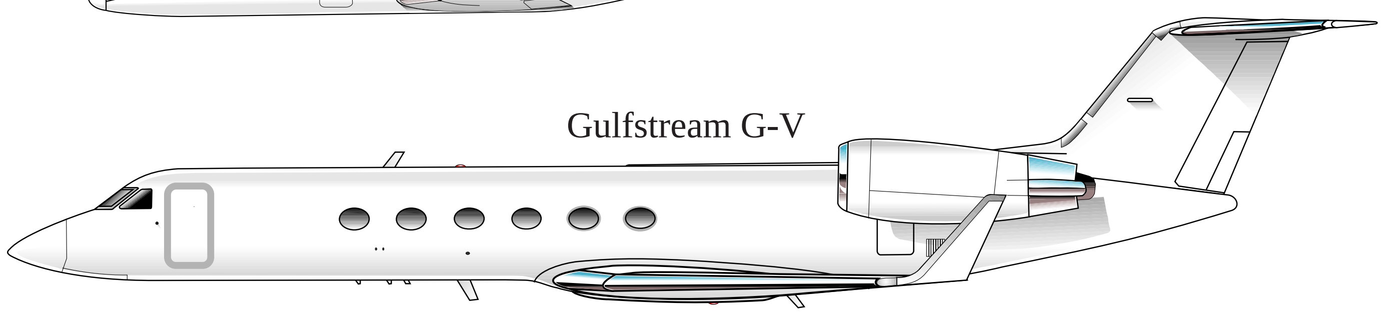
Raytheon-Beechcraft
King Air B300



Cessna Citation II



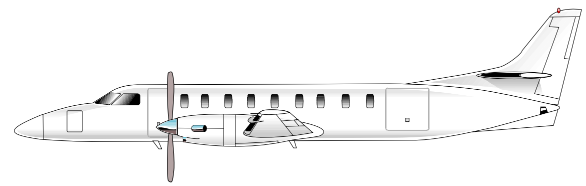
Gulfstream G-V

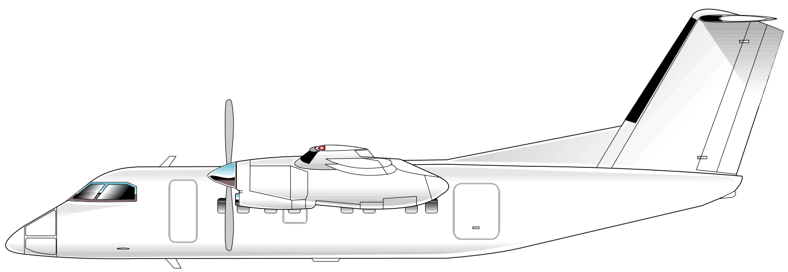


Commuter Aircraft (COM)

Usually twin engine aircraft with a few exceptions such as the DeHavilland DHC-7 which has four engines. Their maximum gross mass is below 31,818 kg (70,000 lb)

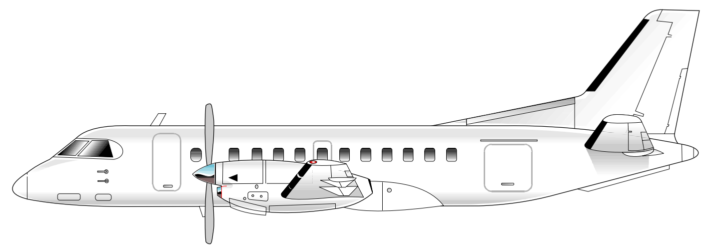
Fairchild Swearinger Metro 23

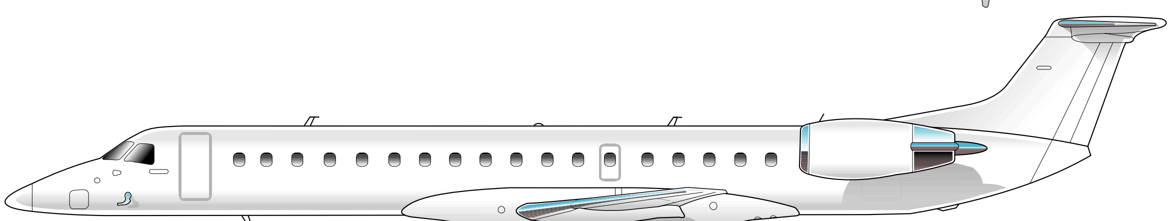




Bombardier DHC-8

Saab 340B

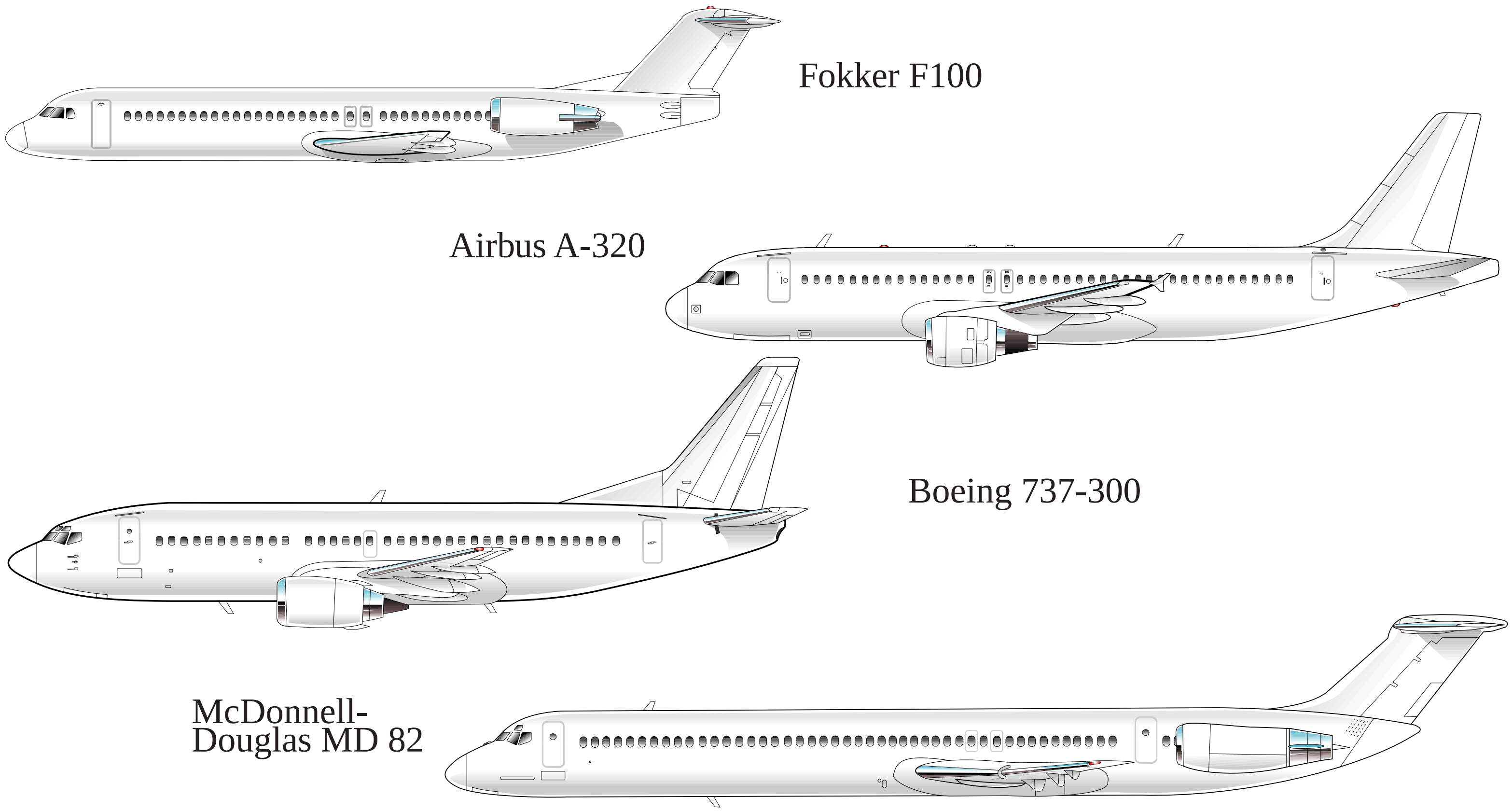




Embraer 145

Short-Range Transports (SR-TA)

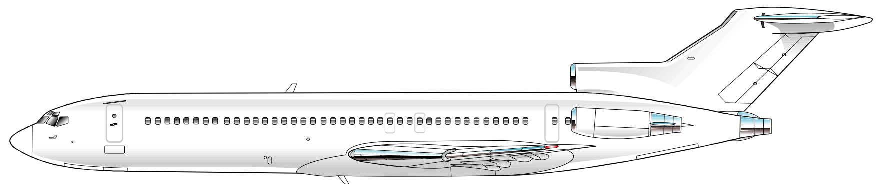
Certified under FAR/JAR 25. Their maximum gross mass usually is below 68,182 kg (150,000 lb).

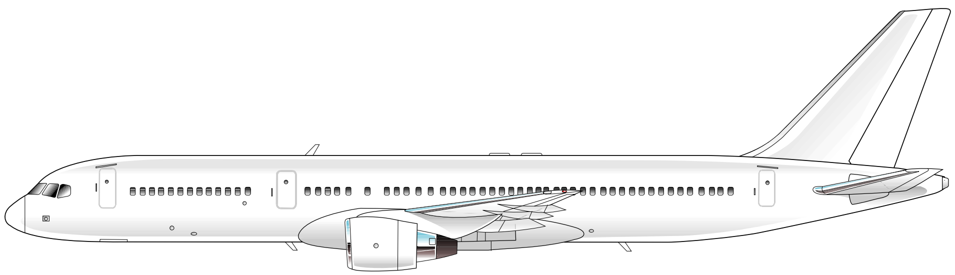


Medium-Range Transports (MR-TA)

These are transport aircraft employed to fly routes of less than 3,000 nm (typical).Their maximum gross mass usually is usually below 159,090 kg (350,000 lb)

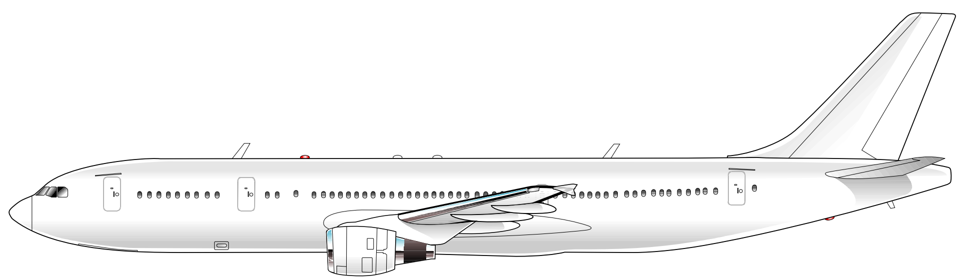
Boeing B727-200





Boeing 757-200

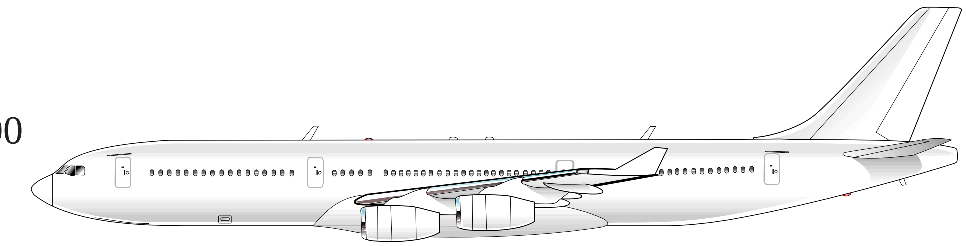
Airbus A300-600R

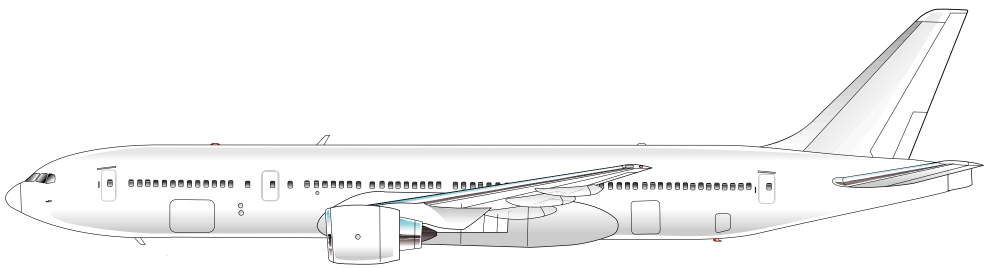


Long-Range Transports (LR-TA)

These are transport aircraft employed to fly routes of less than 3,000 nm (typical).Their maximum gross mass usually is above 159,090 kg (350,000 lb)

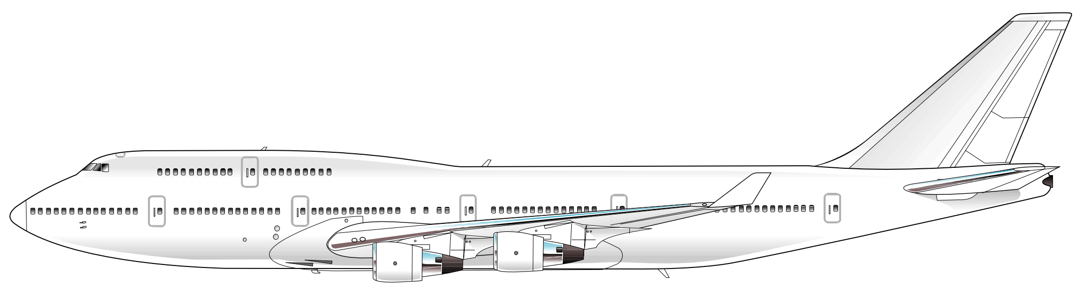
Airbus A340-200





Boeing 777-200

Boeing 747-400



Future Aircraft Issues

The fleet composition at many airports is changing rapidly and airport terminals will have to adapt

- Surge of commuter aircraft use for point-to-point services
- Possible introduction of Very Large Capacity Aircraft (VLCA)

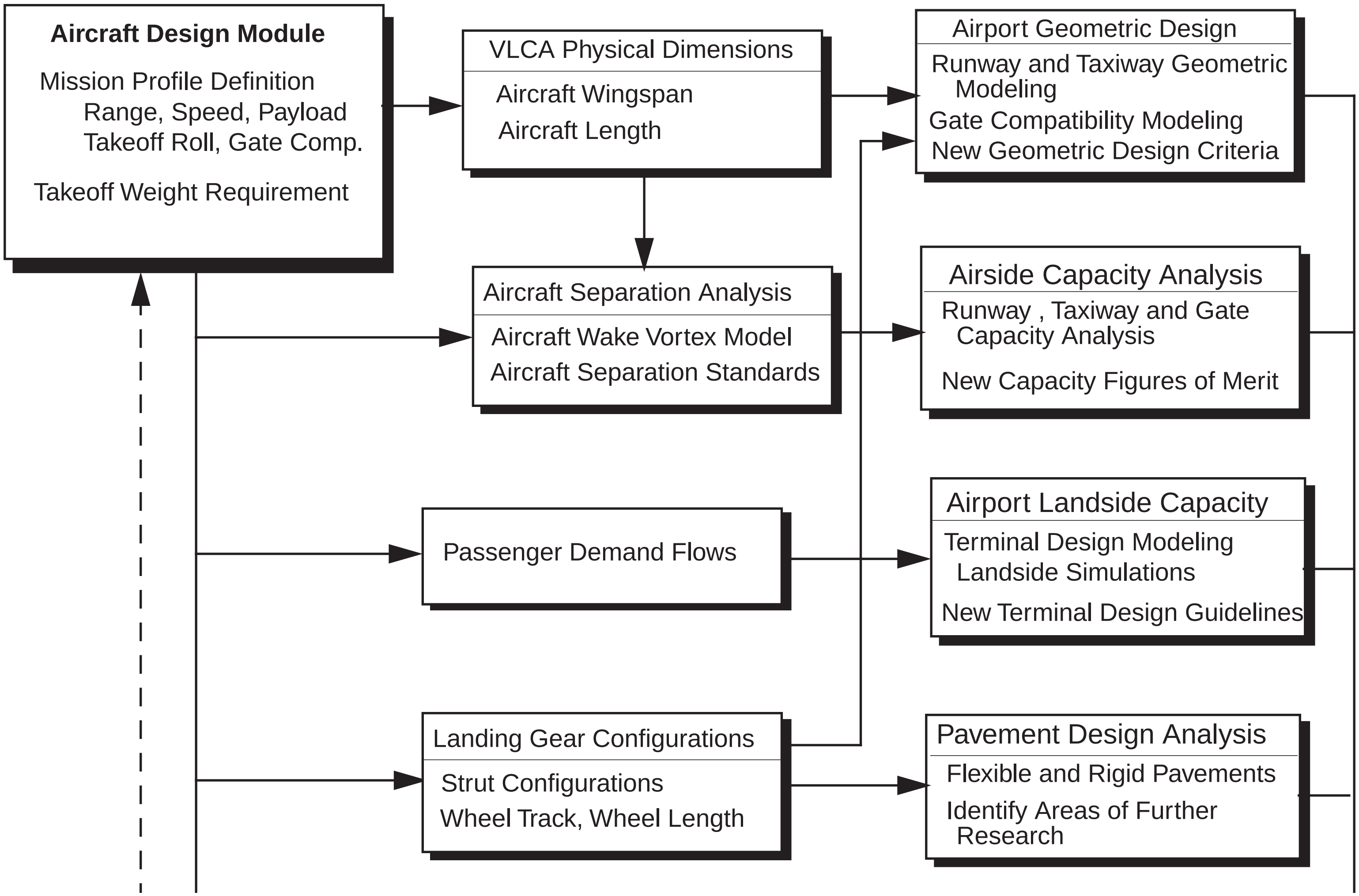
VLCA Aircraft Discussion

- Large capacity aircraft requirements
- Discussion of future high-capacity airport requirements
- Airside infrastructure impacts
- Airside capacity impacts
- Landside impacts
- Pavement design considerations
- Noise considerations
- Systems approach

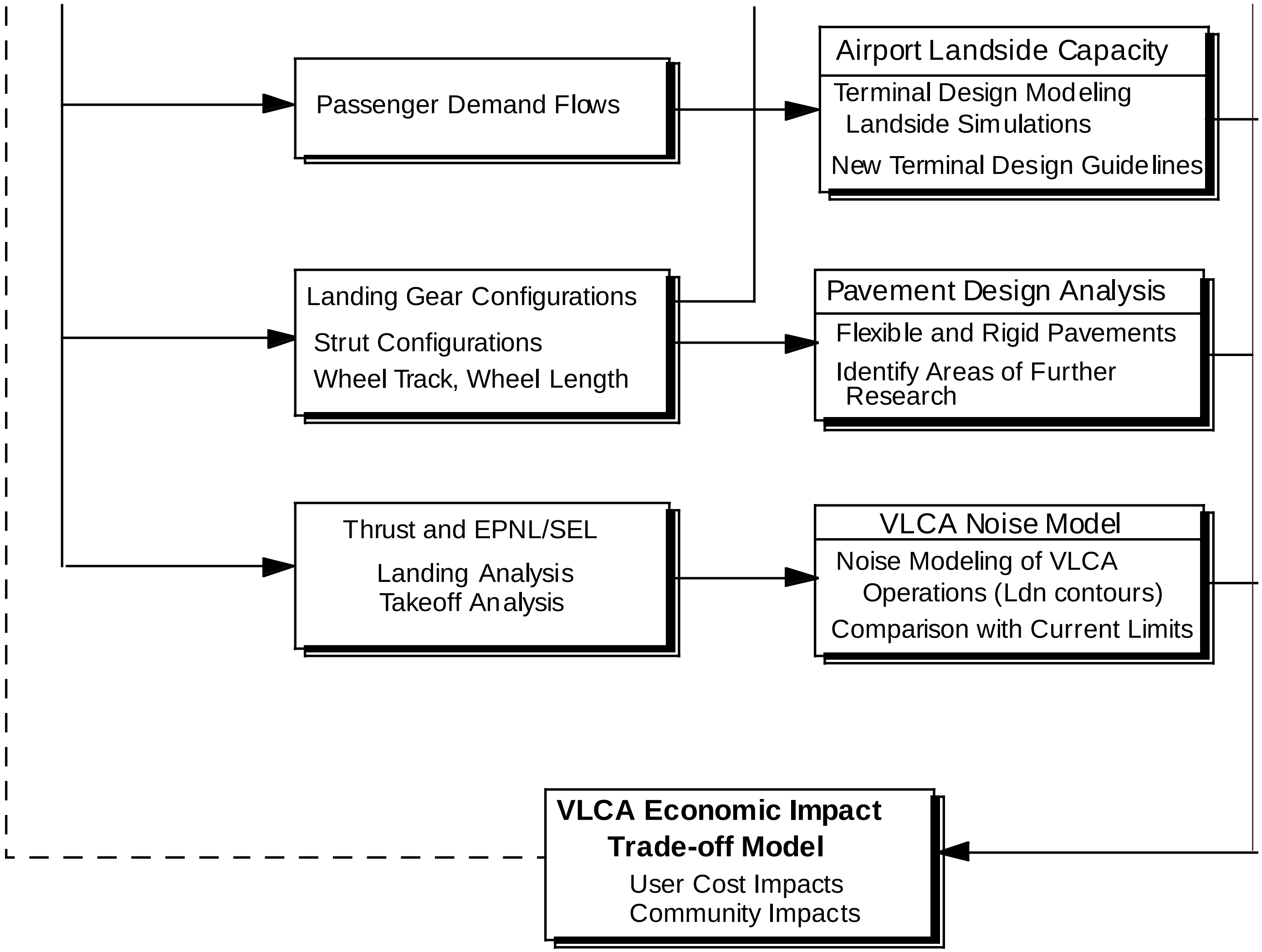
VLCA Design Trade-off Methodology

- Aircraft designed purely on aerodynamic principles would be costly to the airport operator yet have low DOC
- Aircraft heavily constrained by current airport design standards might not be very efficient to operate
- Adaptations of aircraft to fit airports can be costly
    - Some impact on aerodynamic performance
    - Weight considerations (i.e., landing gear design)
- A balance should be achieved

VLCA Impact Framework (I)



VLCA Impact Methodology (II)

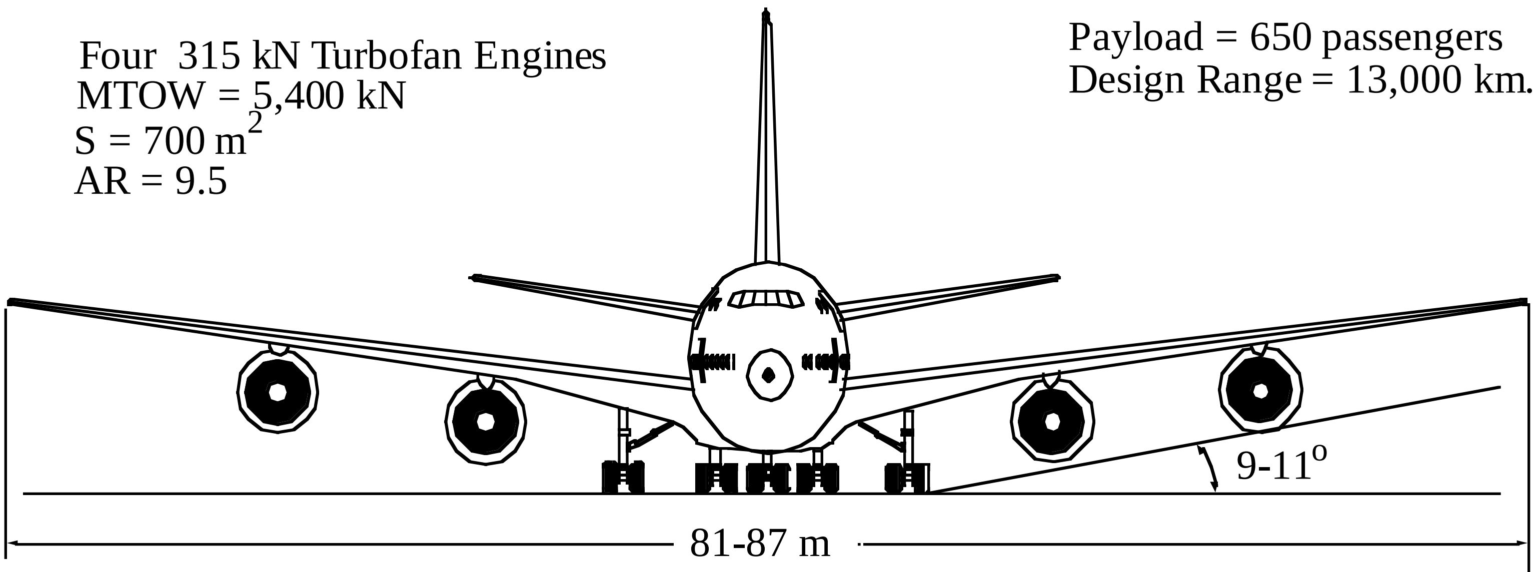


VLCA Specifications (Typical)

Parameter	Boeing 747-500X	VLCA (A380)
Range (km)	13,000	13,000
Runway Length (m)	3,000	3,000
Payload (kN)	800	1,200
Passengers	500	630-650
Max.TOW (kN)	4,200	5,400
Wingspan (m)	75	80-85
Length (m)	74-76	76-85

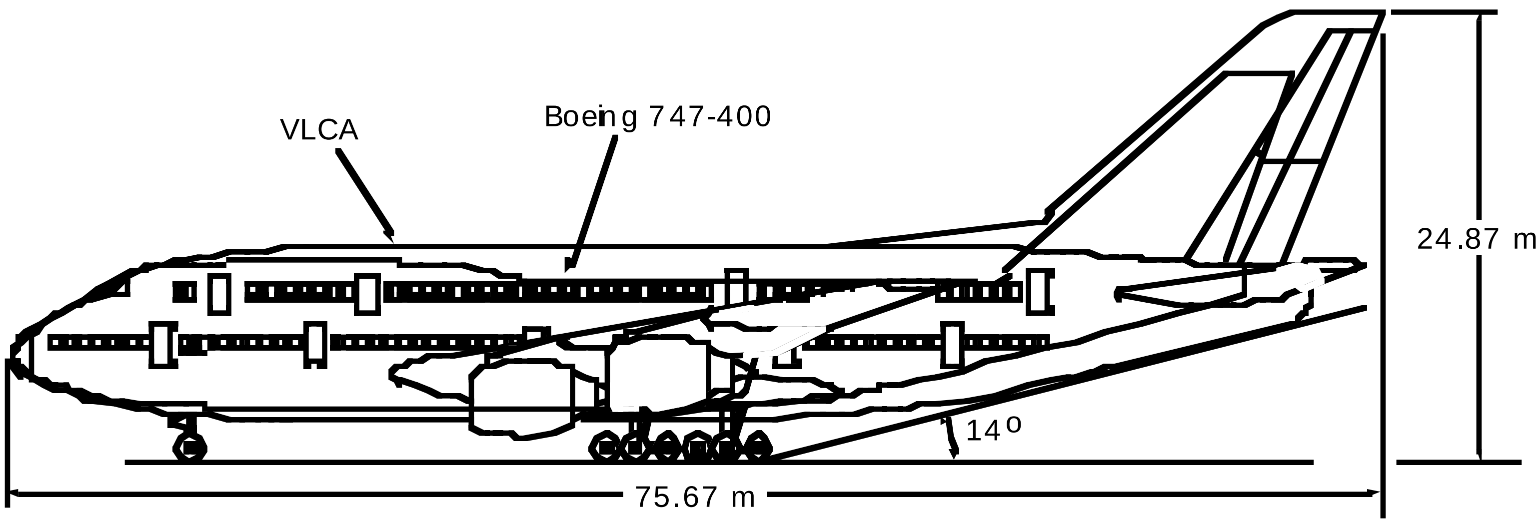
VLCA Schematic

- VLCA aircraft will have wingspans around 15-25% larger than current transports

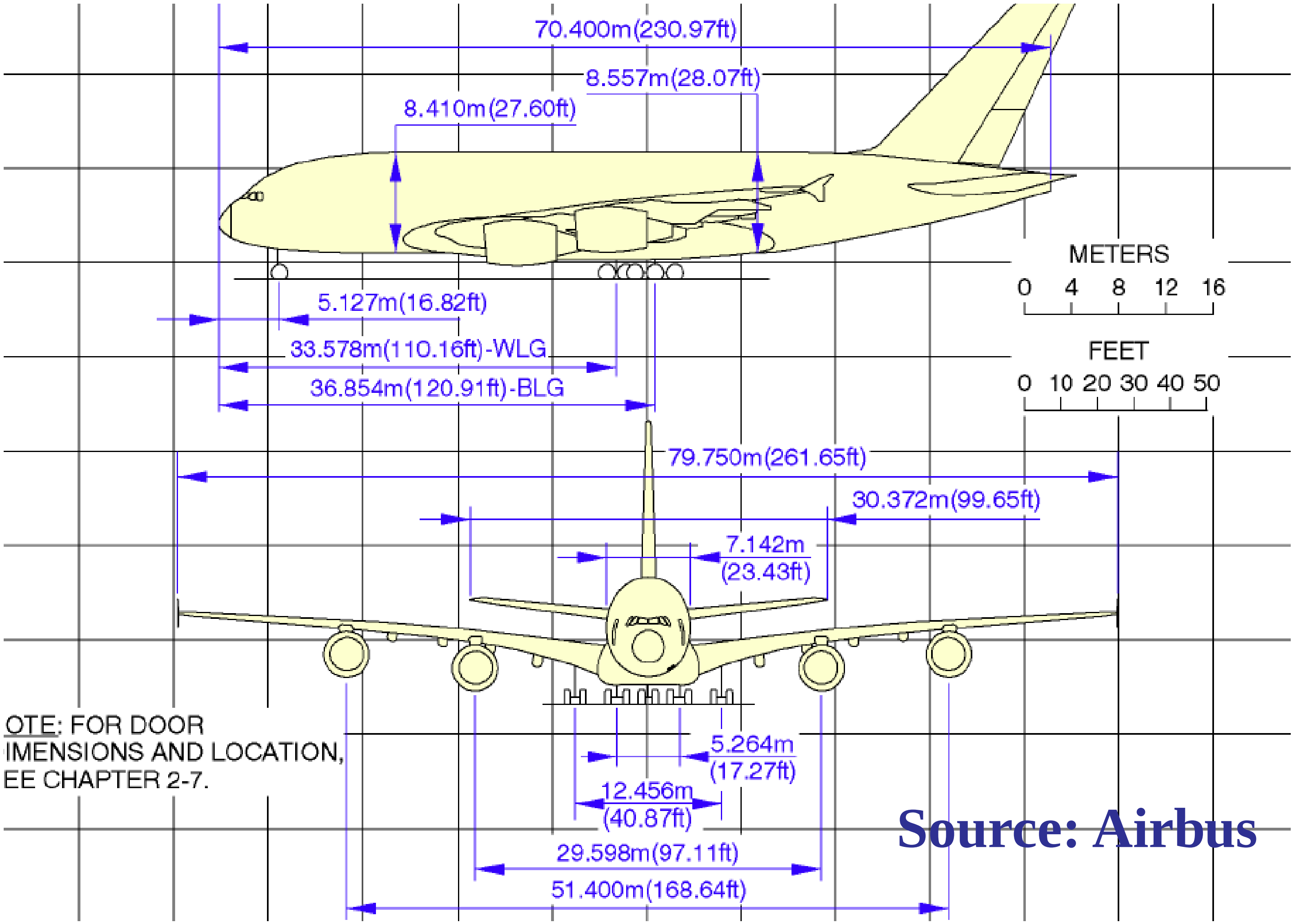


VLCA Schematic (II)

- Structural weight penalties of folding wings are likely to be unacceptable to most airlines
- The empennage height could be a problem for existing hangars at some airport facilities



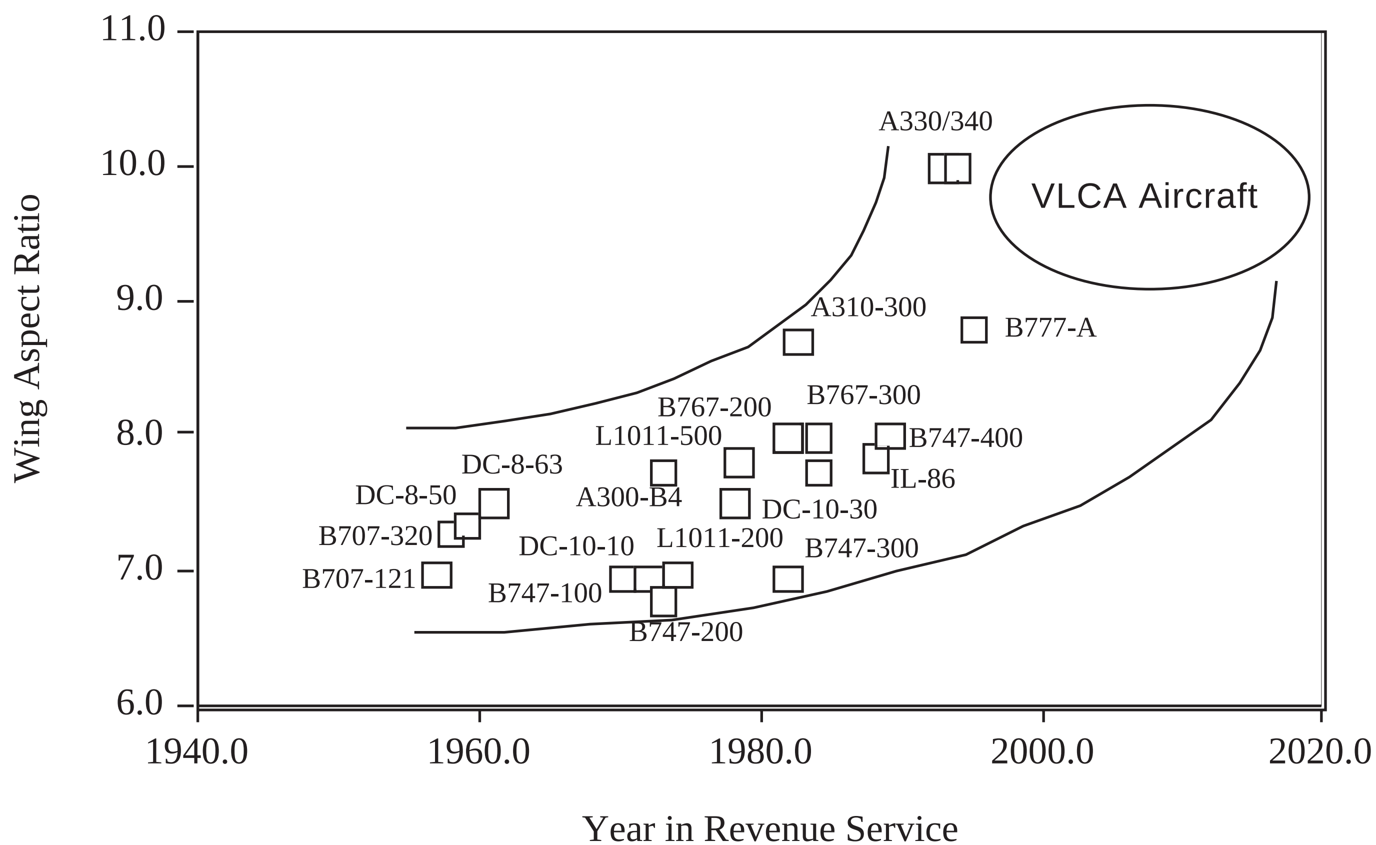
Airbus A380 - First in a Family of VLCA



Source: Airbus

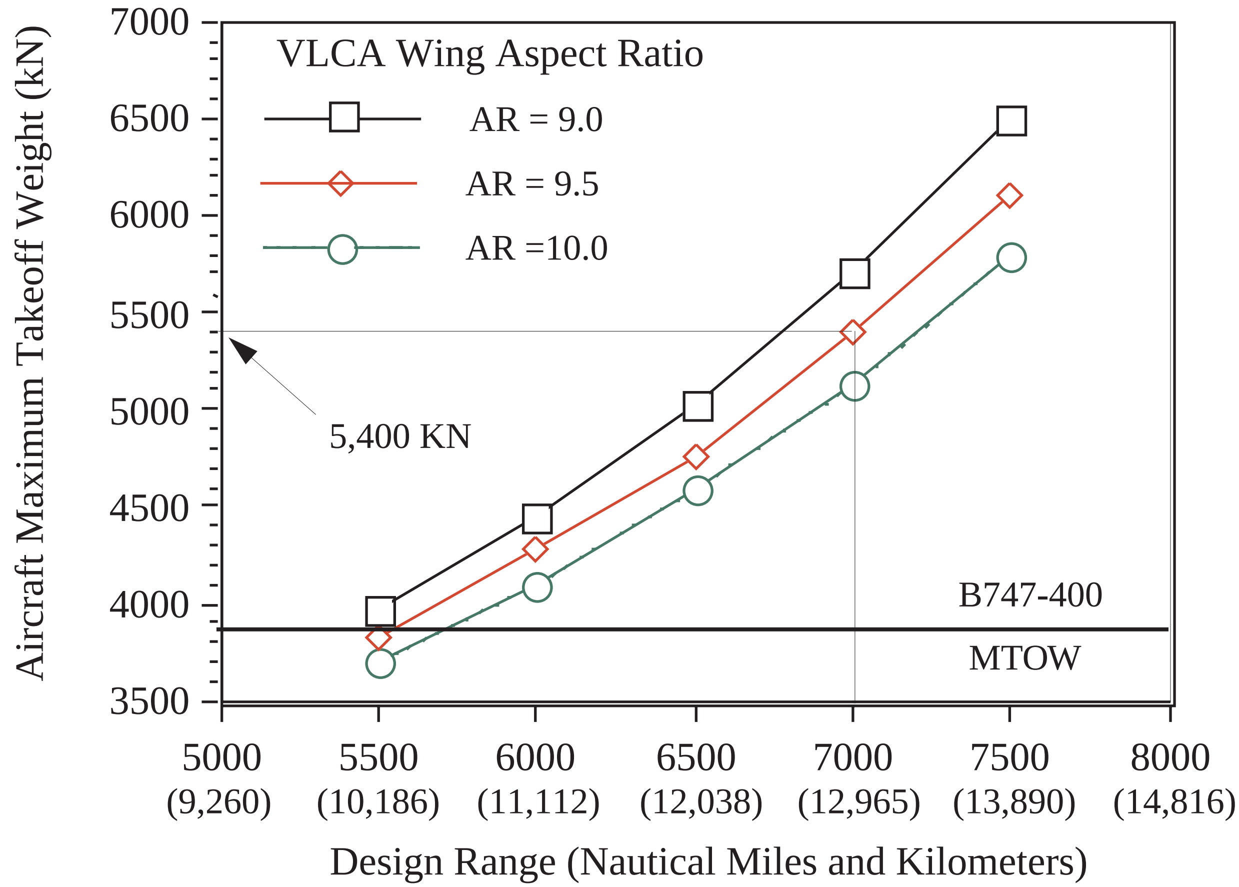
Development of Subsonic Transport Wings

The graphic below offers some idea on the development of transport wings over three decades



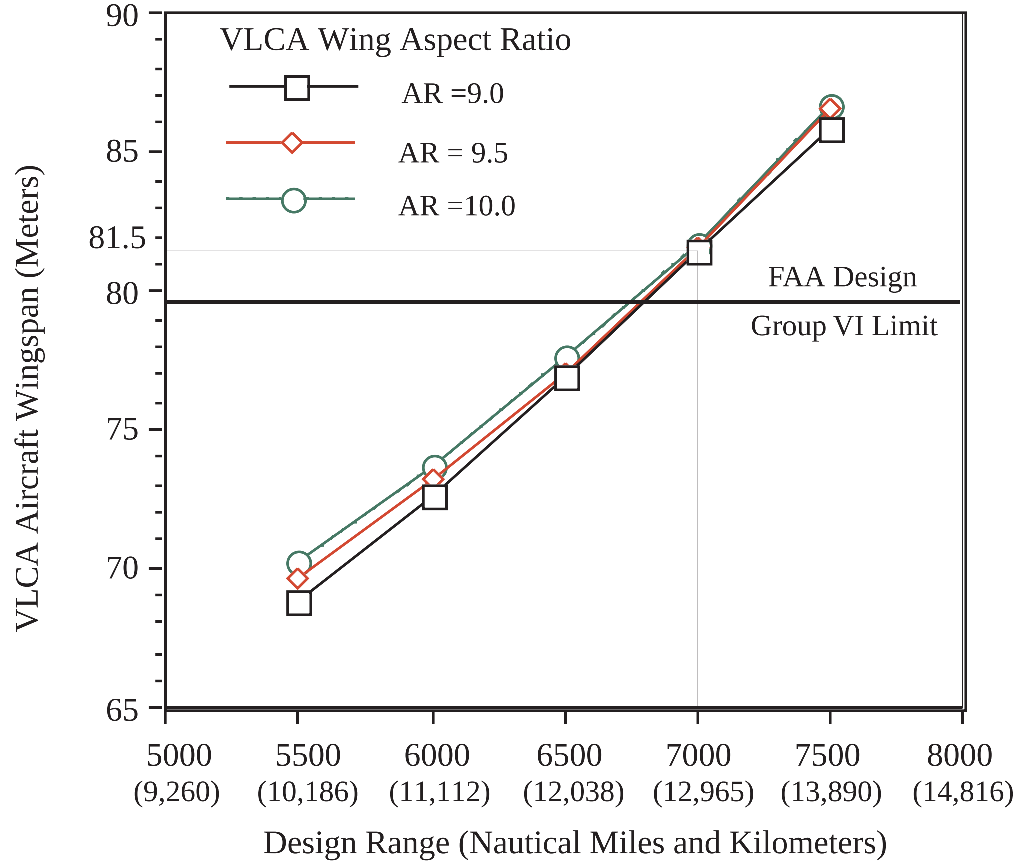
VLCA Design Trade-off Studies

Future VLCA would weight 5,400 kN for a 13,000 km design range mission



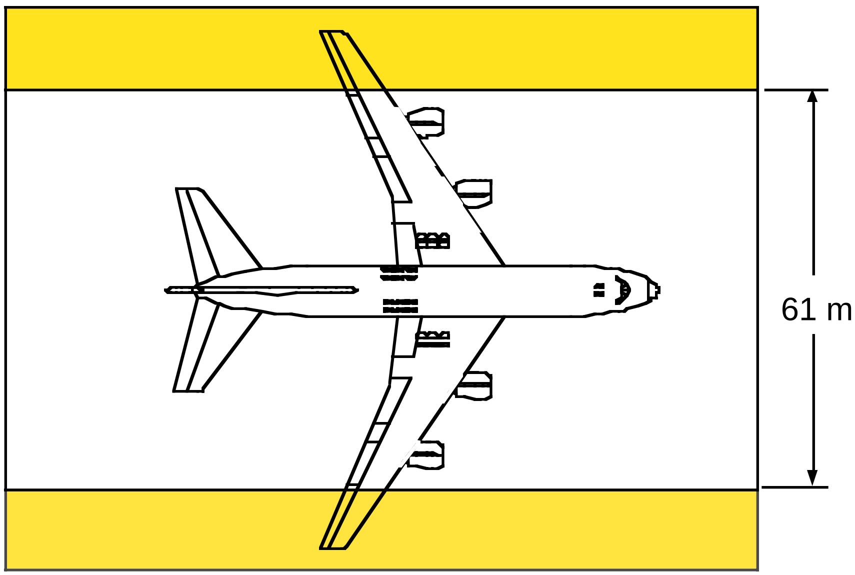
VLCA Design Trade-off Studies (II)

- It is possible that aircraft designers in the near future will exceed the FAA design group VI limits

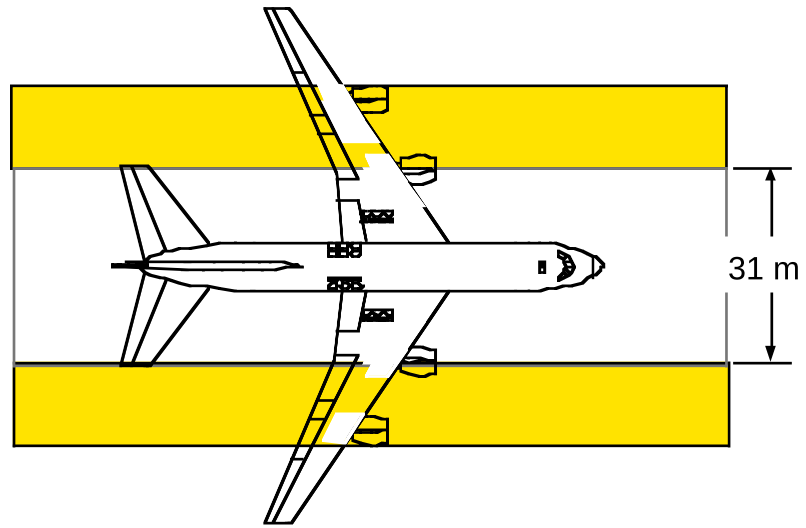


VLCA Impacts on Airside Infrastructure

- Increase taxiway dimensional standards for design group VI to avoid possible foreign object damage to VLCA engines (increase taxiway and shoulder widths to 35 m and 15 m, respectively)



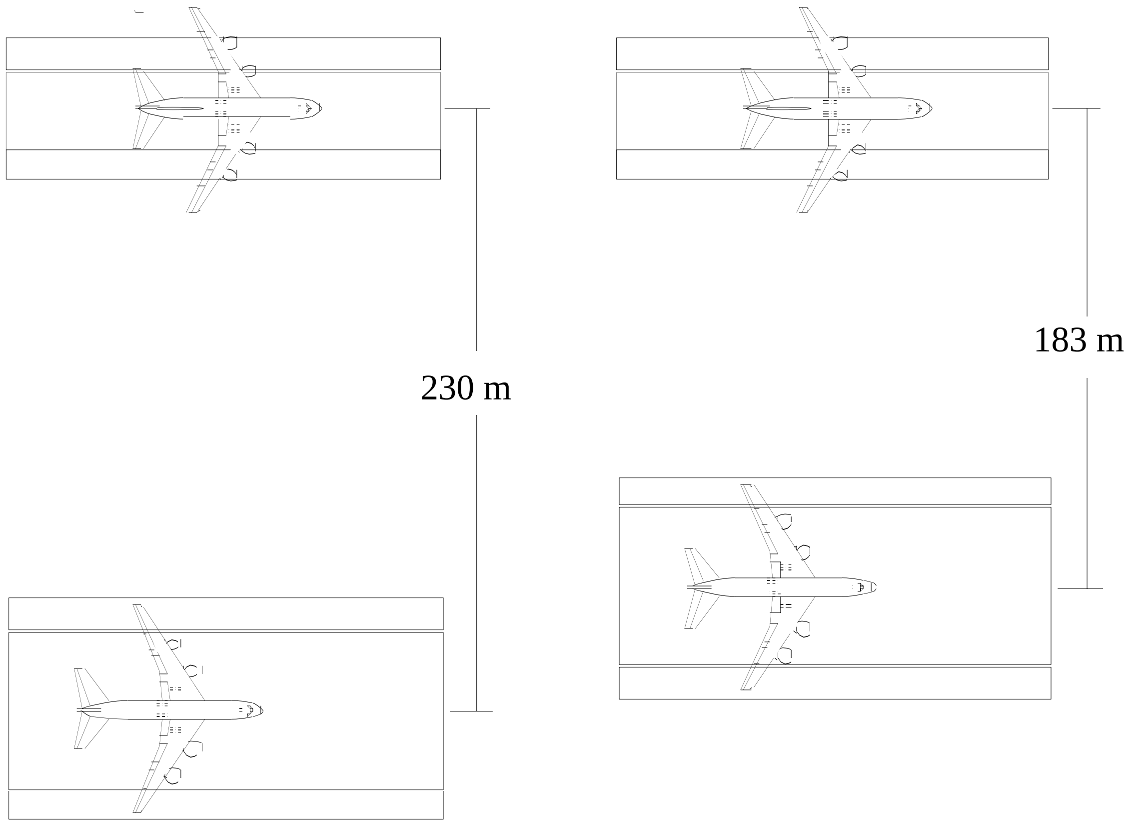
VLCA on DG VI Runway



VLCA on DG VI Taxiway

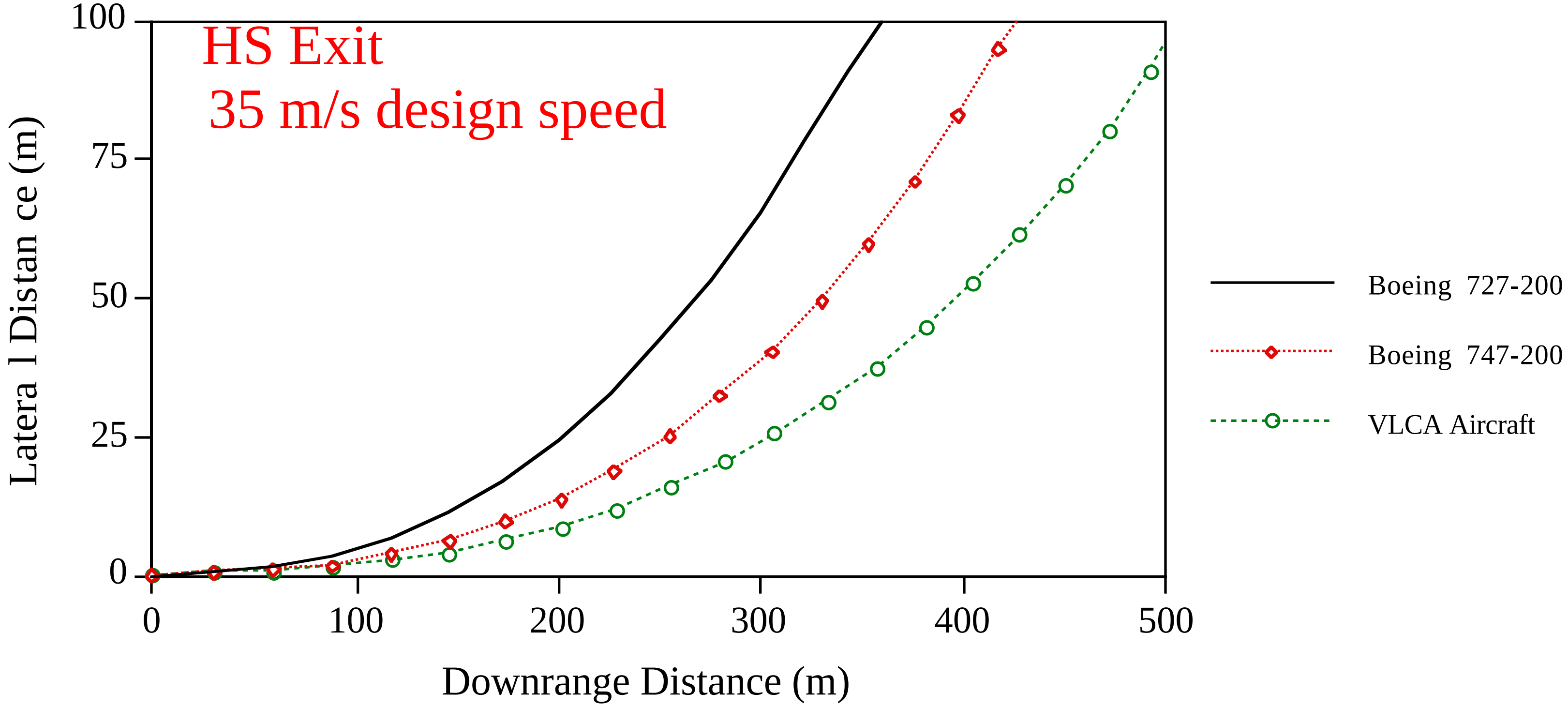
Runway-Taxiway Separation Criteria

- Increase the minimum runway to taxiway separation criteria to 228 m (750 ft.). This should increase the use of high-speed exits



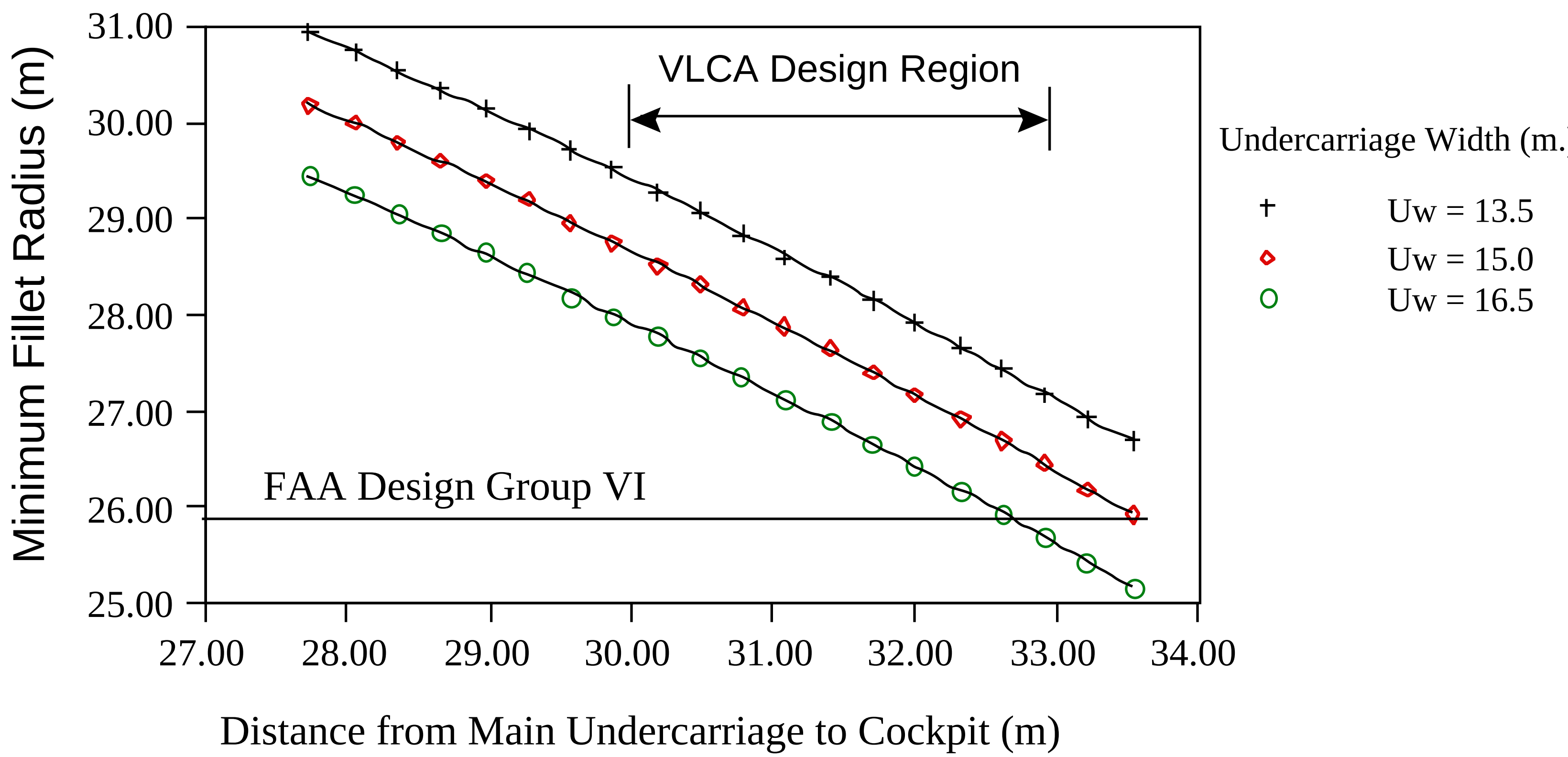
HS Runway Exits for VLCA

- Larger transition radii (due to large aircraft yaw inertia)
- Linear taper turnoff width from 61 m to 40 m (metric stations 250 to 650)



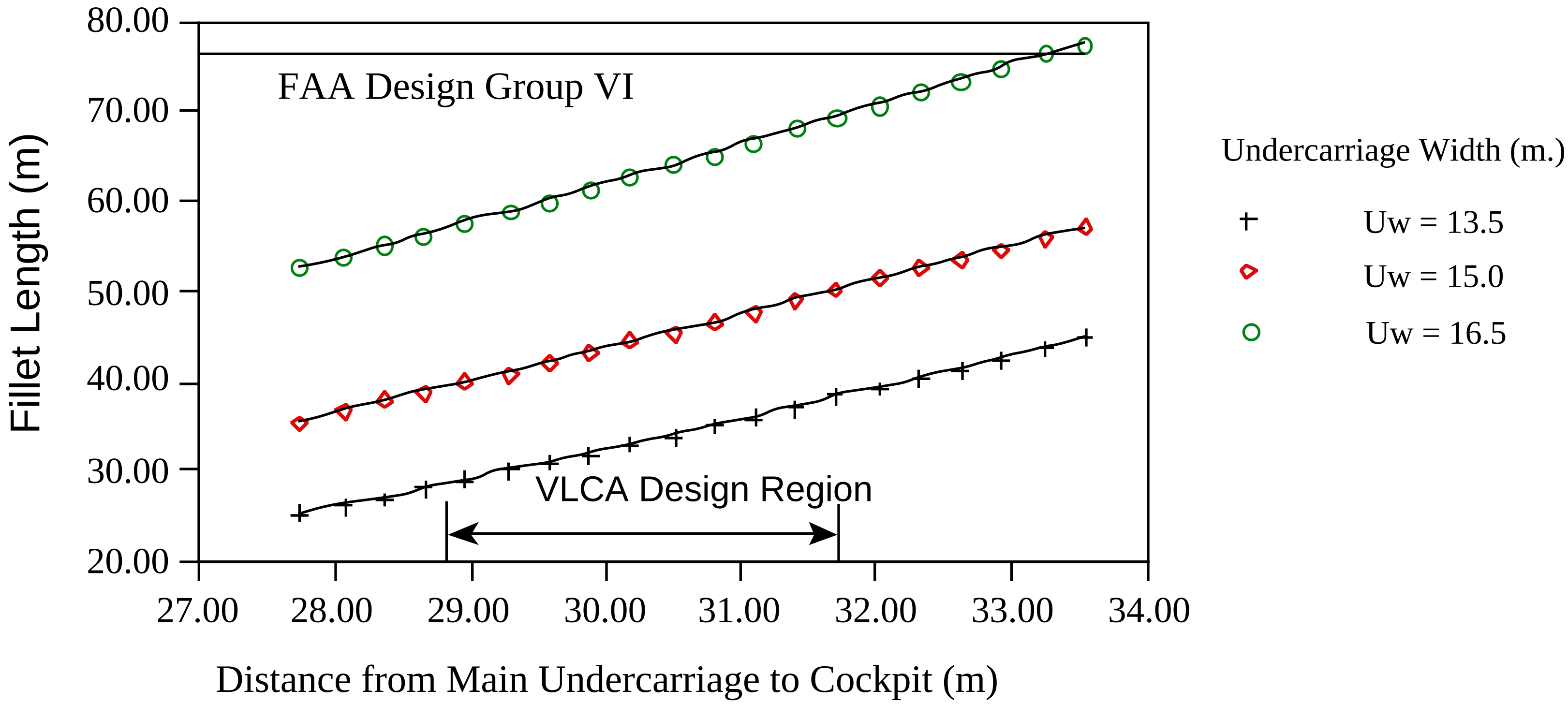
VLCA Taxiway Fillet Radius Requirements

- The fillet radius design standards for design group VI should suffice for VLCA aircraft



Taxiway Length of Fillet Requirements

- VLCA length of fillet requirements will probably be satisfied using current geometric design criteria



Impacts to Aircraft Separation

- Critical to estimate safe aircraft separation criteria
  - Induced rolling acceleration principle (p quotient)
  - Tangential speed matching method
- Derived formulation (using p quotient principle)

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

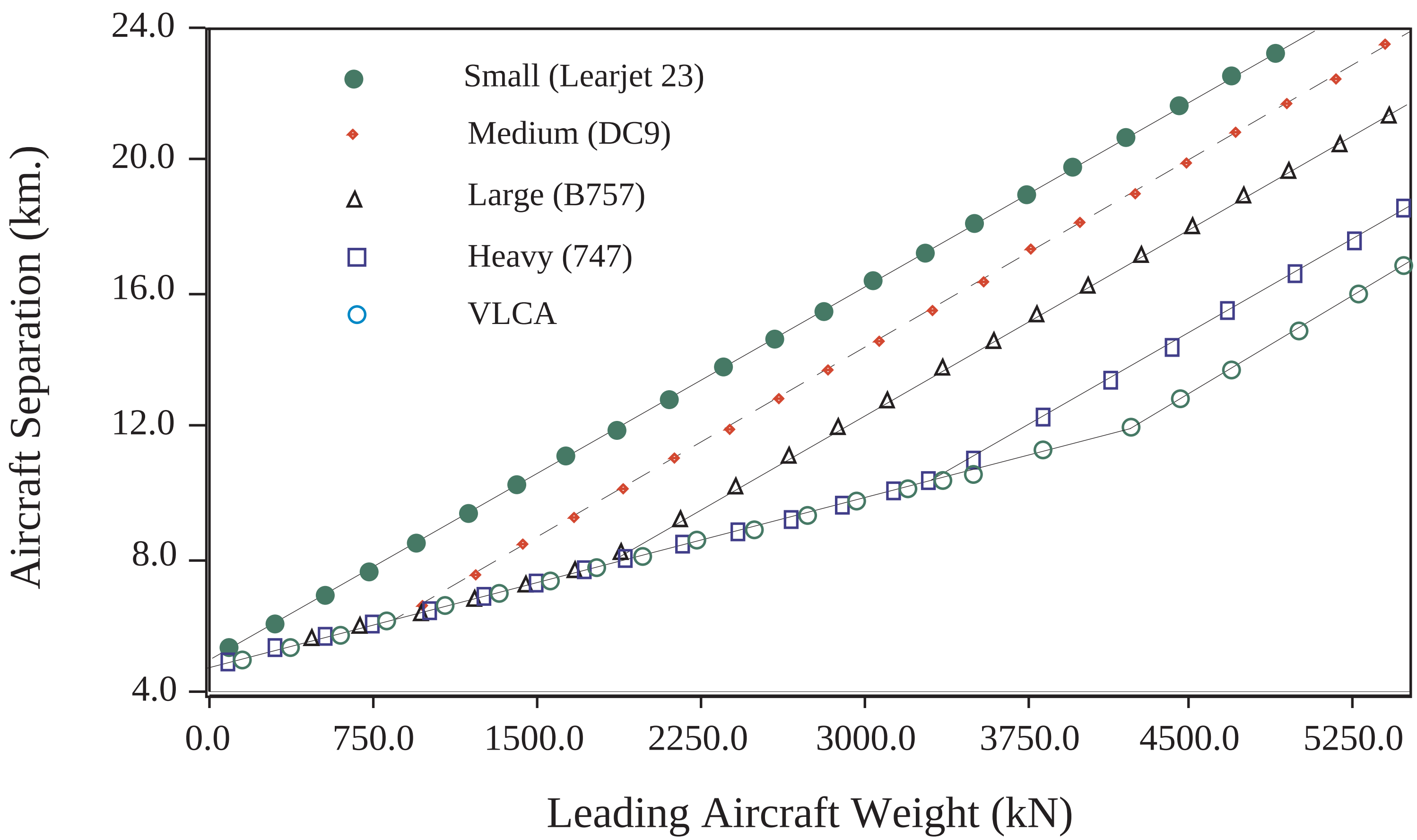
δ_{ij} is the separation distance between aircraft i and j in km

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

L_1 and L_2 are 4.7000 and 0.00172 and have been derived using empirical roll control flight simulation data

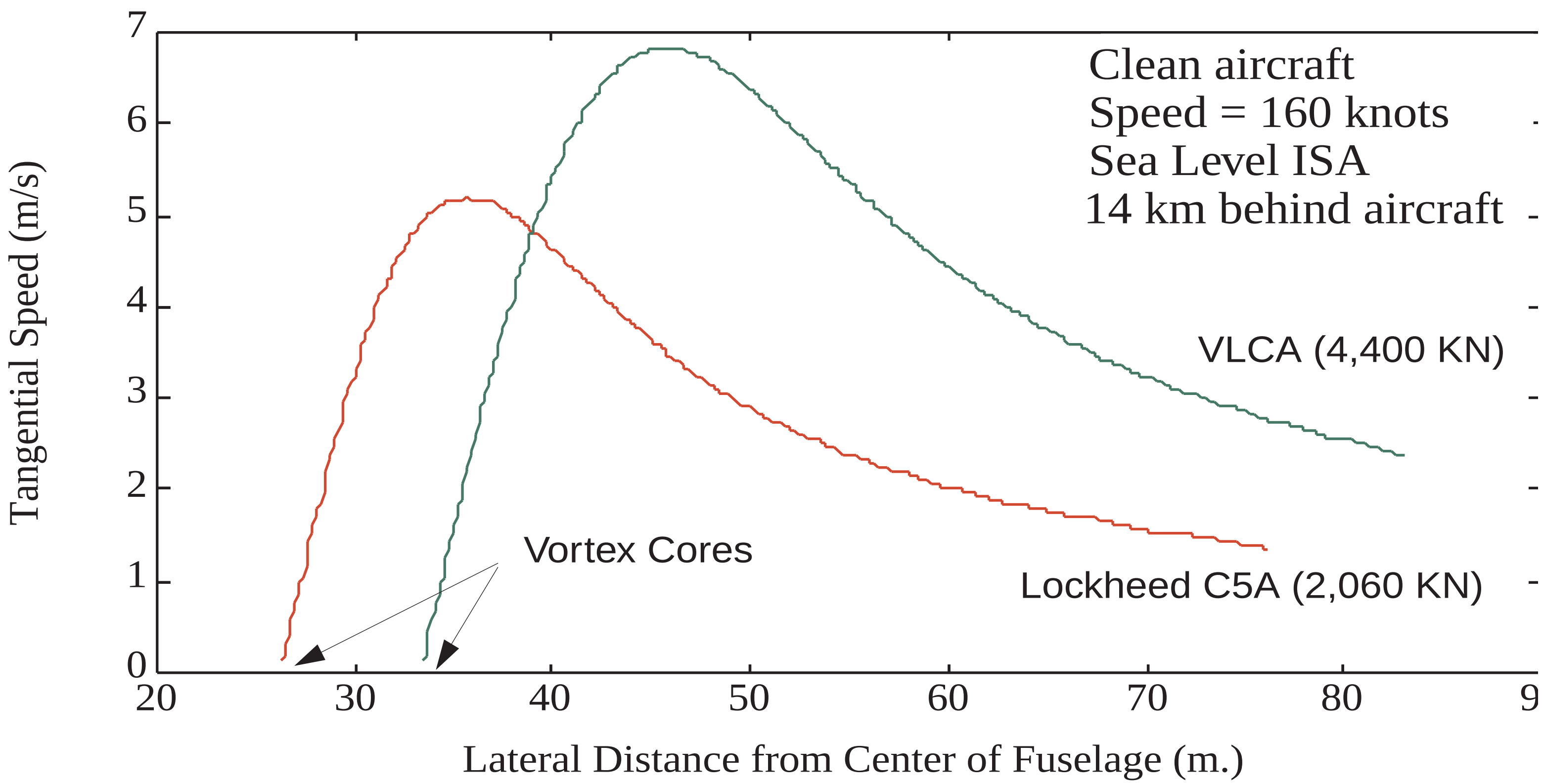
Aircraft Separation Analysis

- Recommended in-trail separation criteria for approaching aircraft using the P quotient criteria



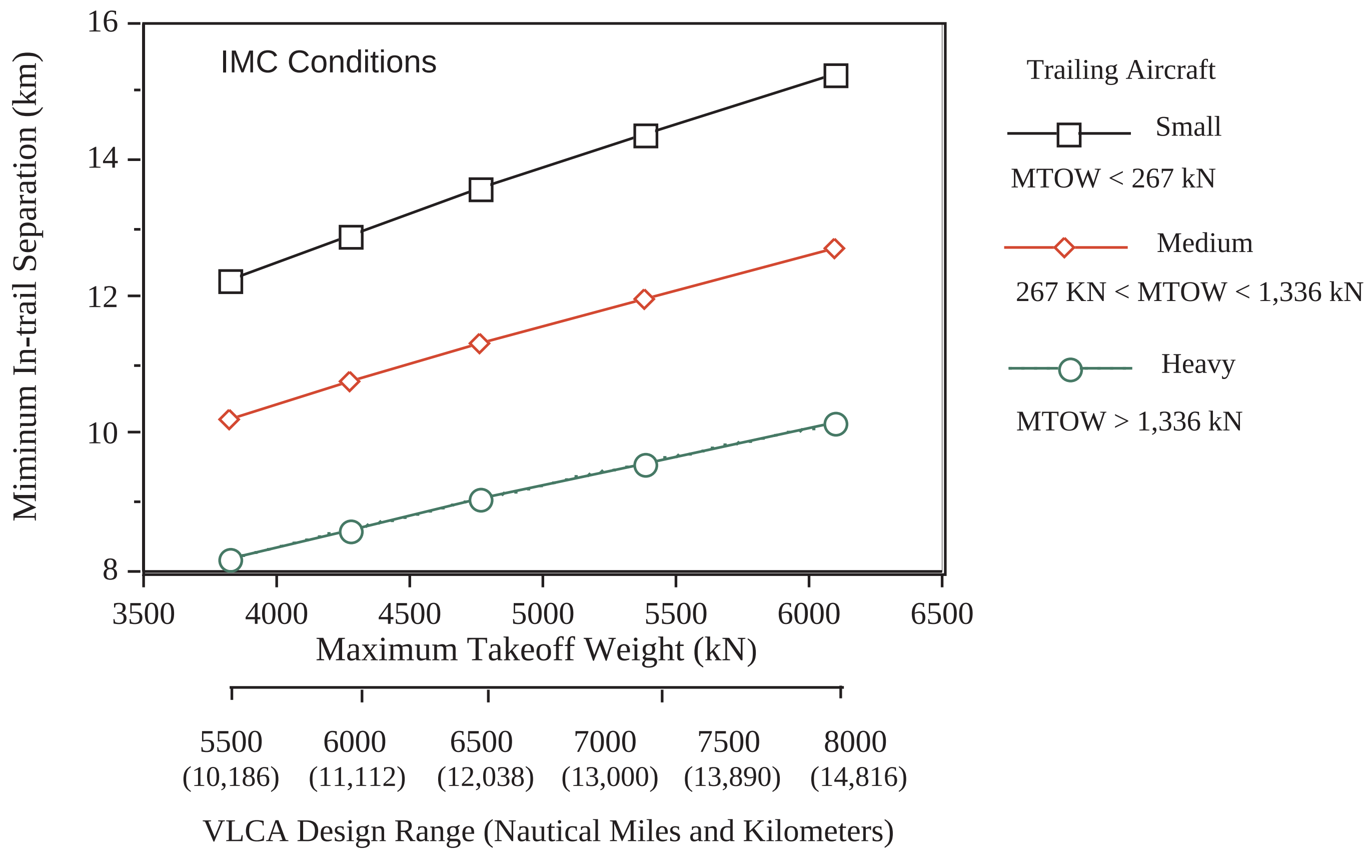
Wake Vortex Tangential Speed Estimation

- Predicted tangential speeds of wake vortex using Robinson and Larson semi-empirical vortex model



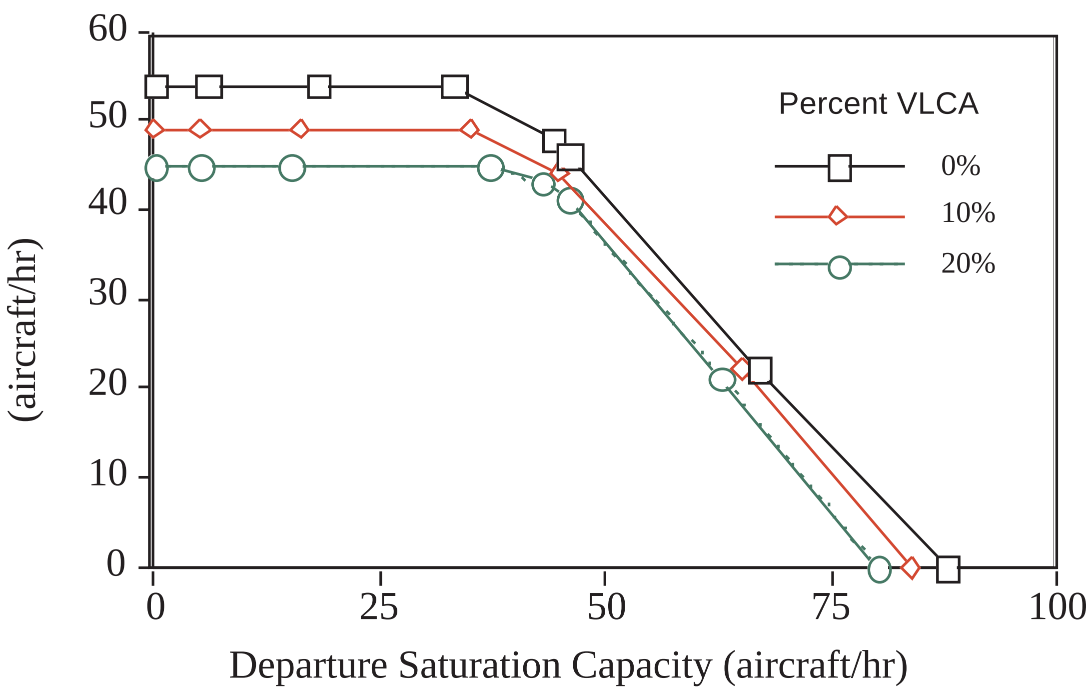
Aircraft Separation Analysis (cont.)

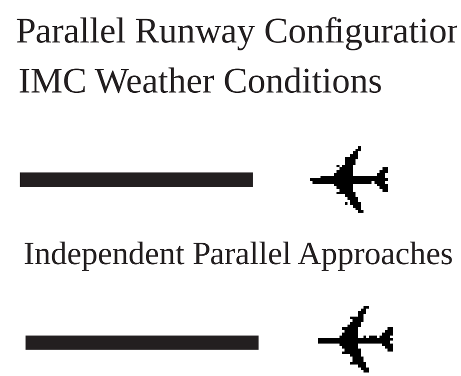
- In-trail separation criteria for approaching aircraft using the tangential speed matching method



Runway Saturation Capacity Impacts

- Small to moderate saturation capacity changes





Airport Terminal Impacts (Landside)

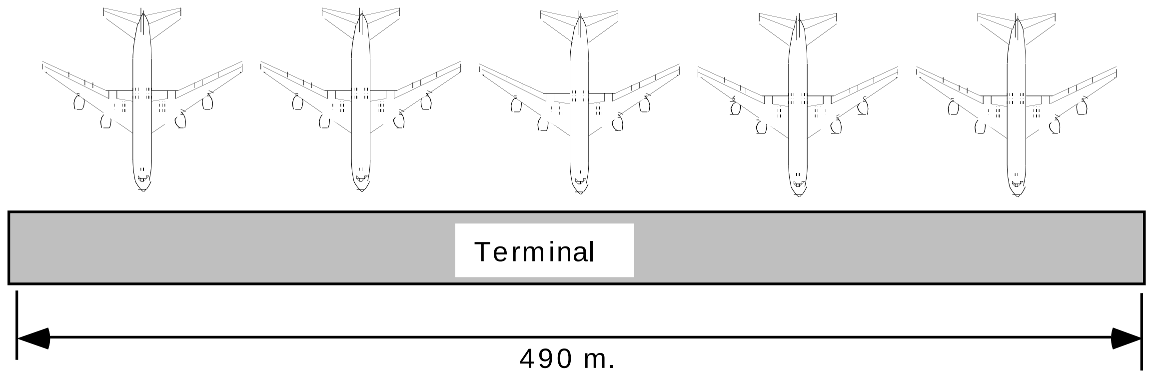
VLCA will certainly impact the way passengers are processed at the terminal in various areas:

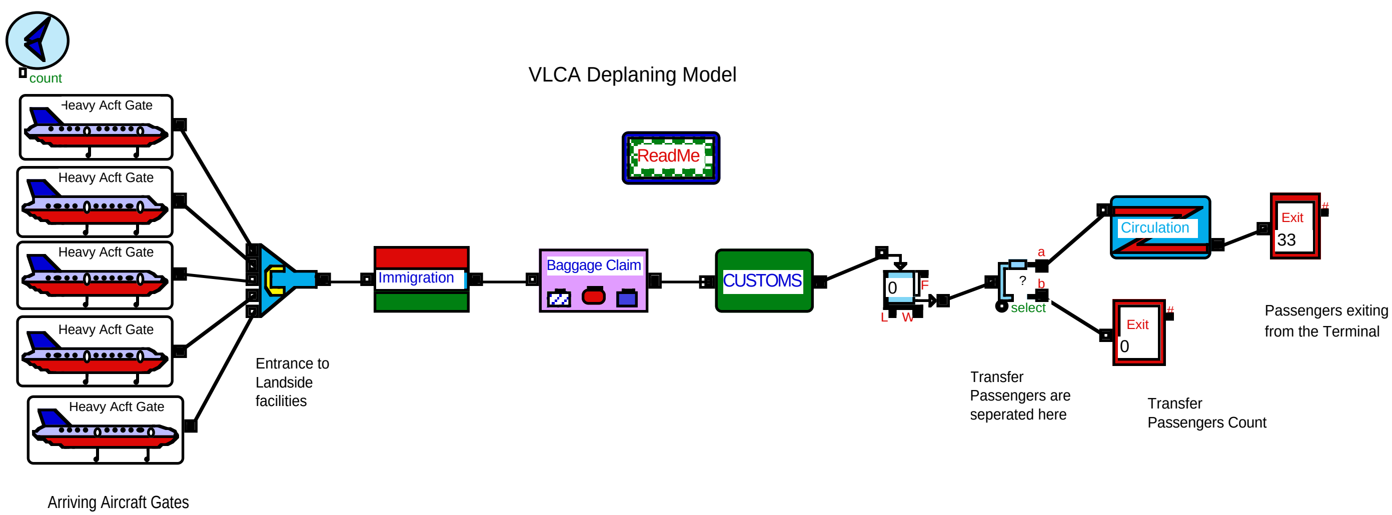
- Gate interface (dual-level boarding gates)
- Service areas (ticket counters, security counters, immigration cheking areas, corridors, etc.)
- Apron area parking requirements

Airport Landside Effects

- Use of simulation models to estimate landside LOS

5 VLCA Aircraft (or 7 Boeing 747-400)

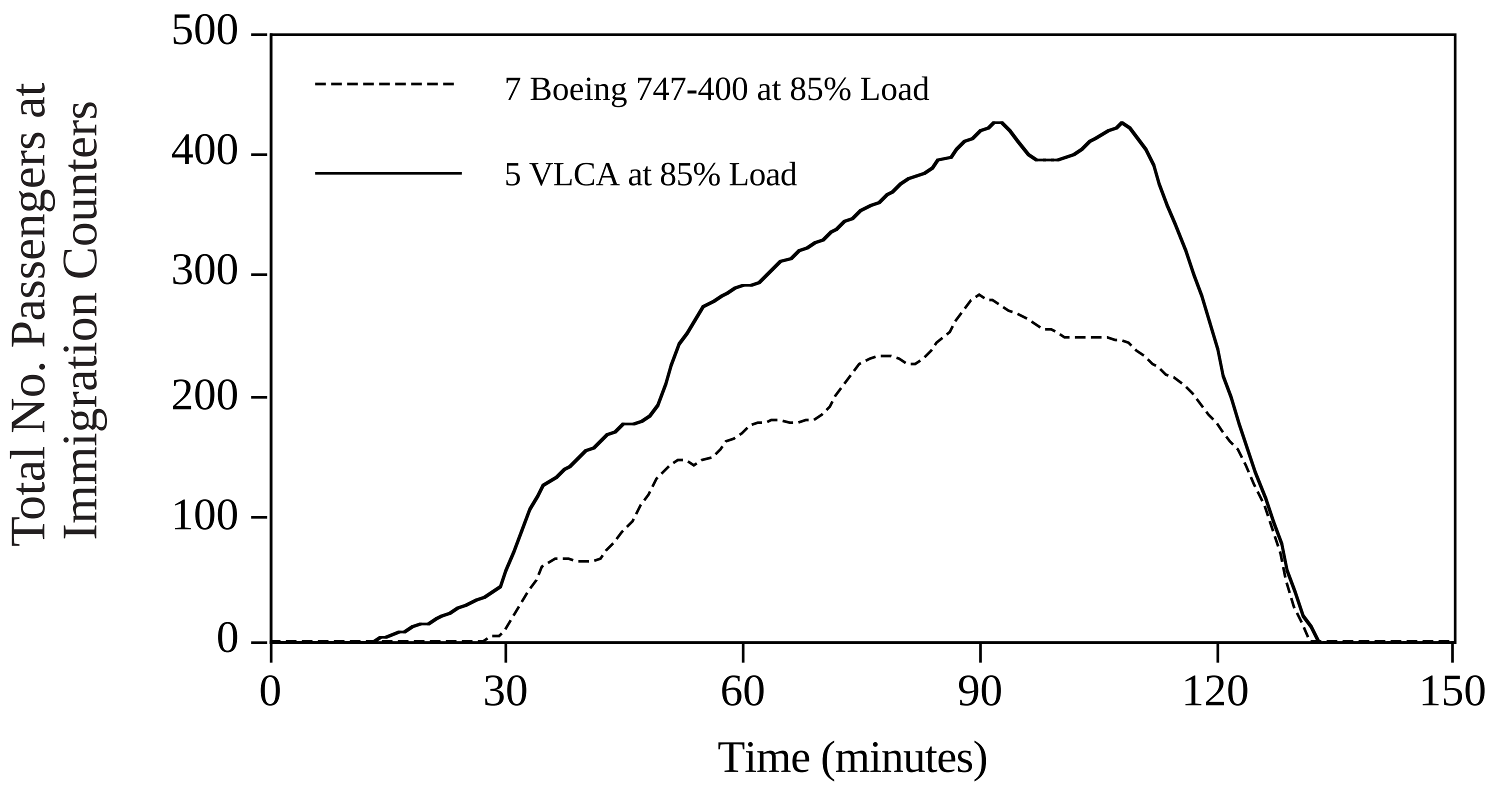




Sample Landside Simulation Results

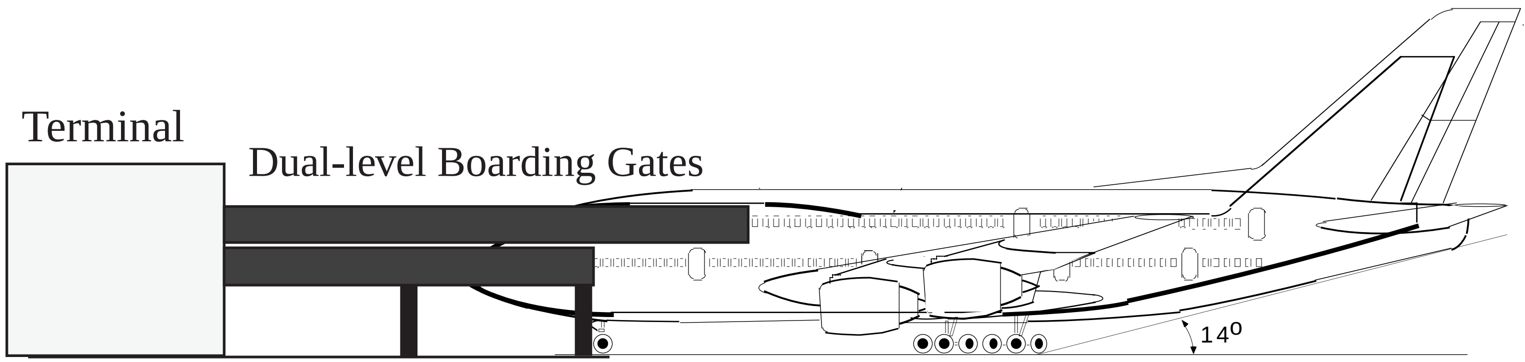
- Analysis using the Airport Terminal Simulation Model

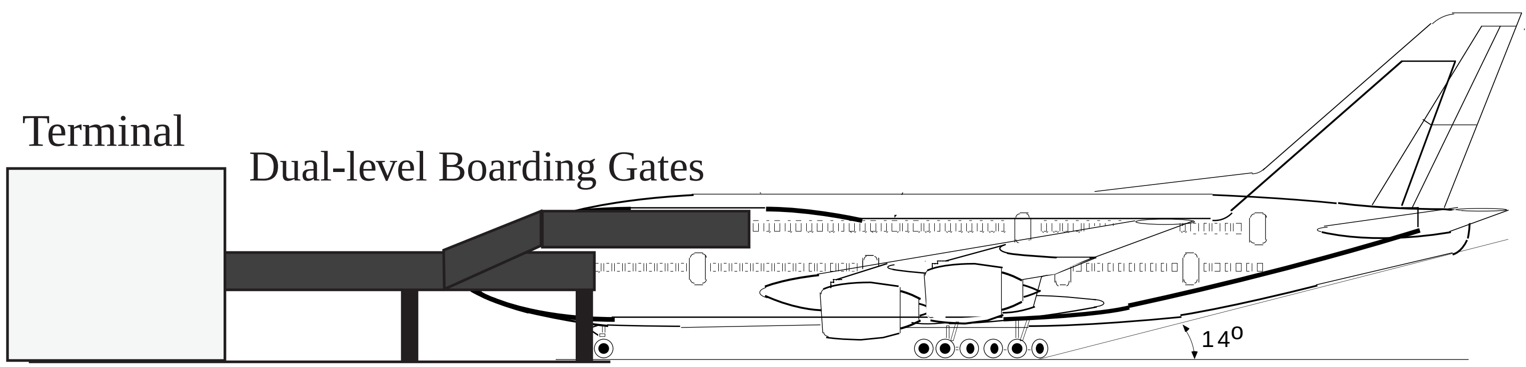
30 immigration counters
Normal service times (μ=1.0 and σ=0.25 minutes)



Airport Gate Interface Challenges

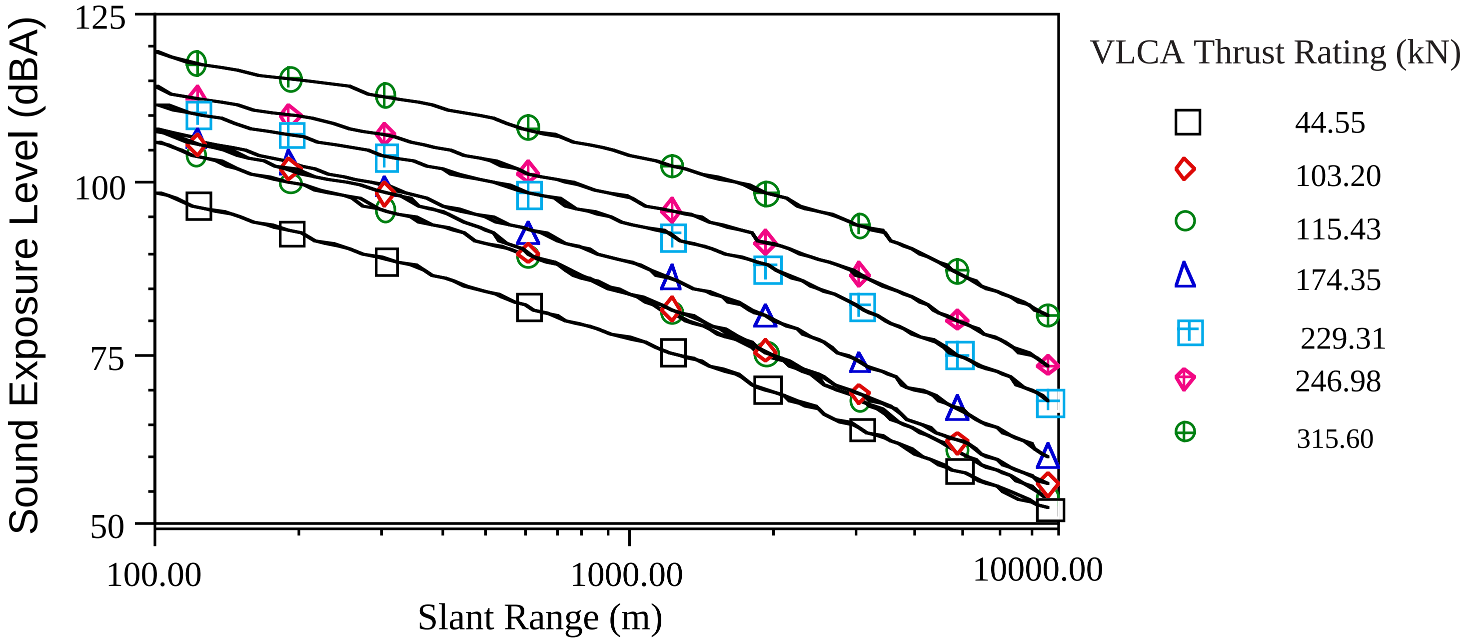
- VLCA aircraft could employ dual-level boarding gates to provide acceptable enplanement performance





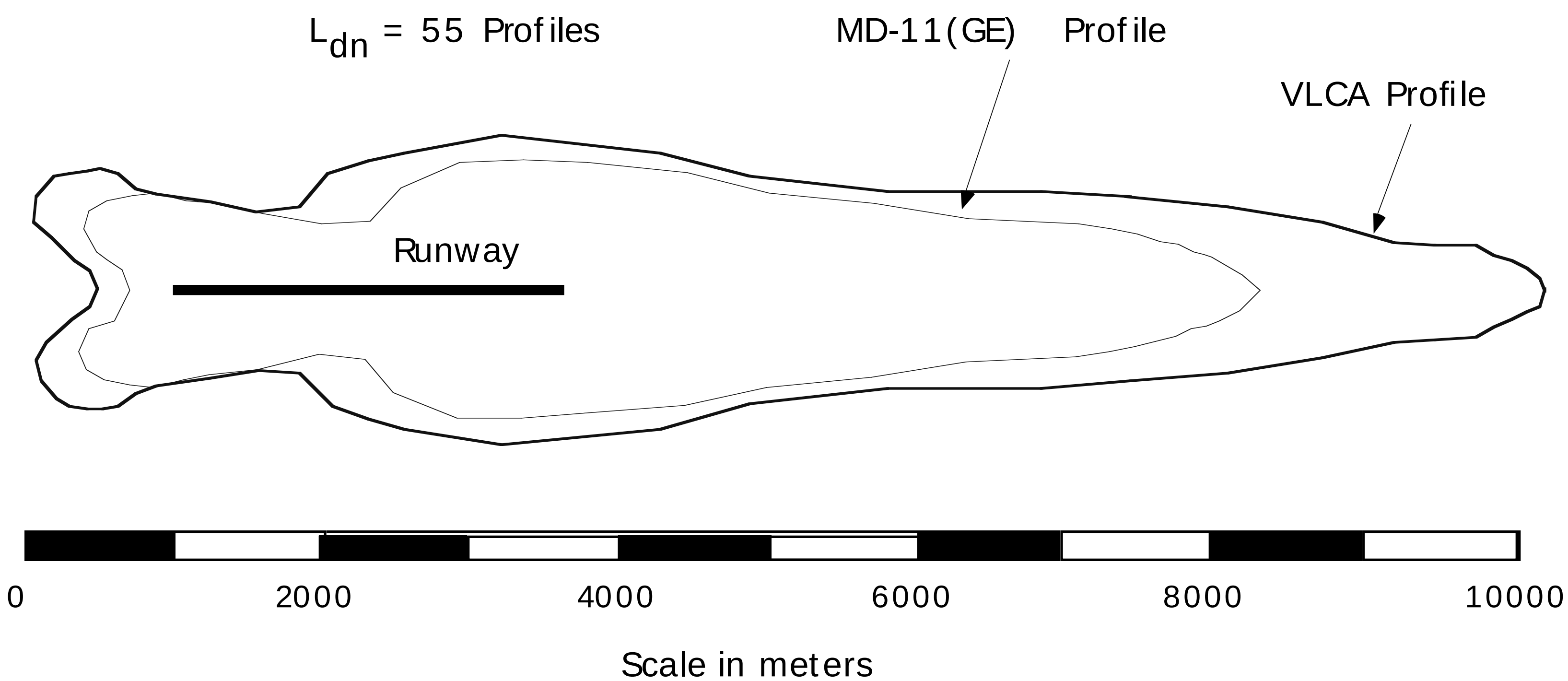
Noise Impacts

- High by-pass ratio turbofan engines with maximum takeoff thrust of 315-350 kN will be necessary to power VLCA aircraft
- The engine size will probably be determined by takeoff run and engine-out climb requirements



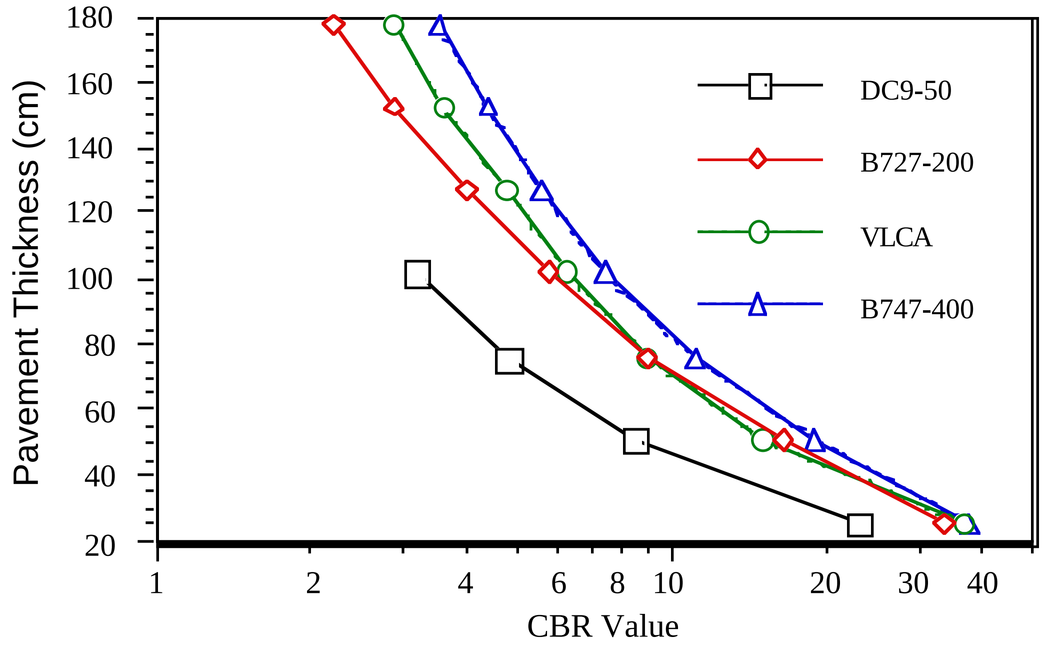
DNL Takeoff Contours

- Larger engines coupled with smaller initial climb rate capability (compared to twin and three-engine aircraft) could result in expanded noise contours at most airports

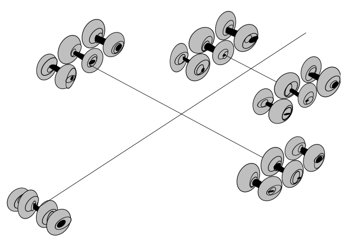


Pavement Design Impacts

- Multiple triple-in-tandem landing gear configurations are likely to be used for VLCA applications

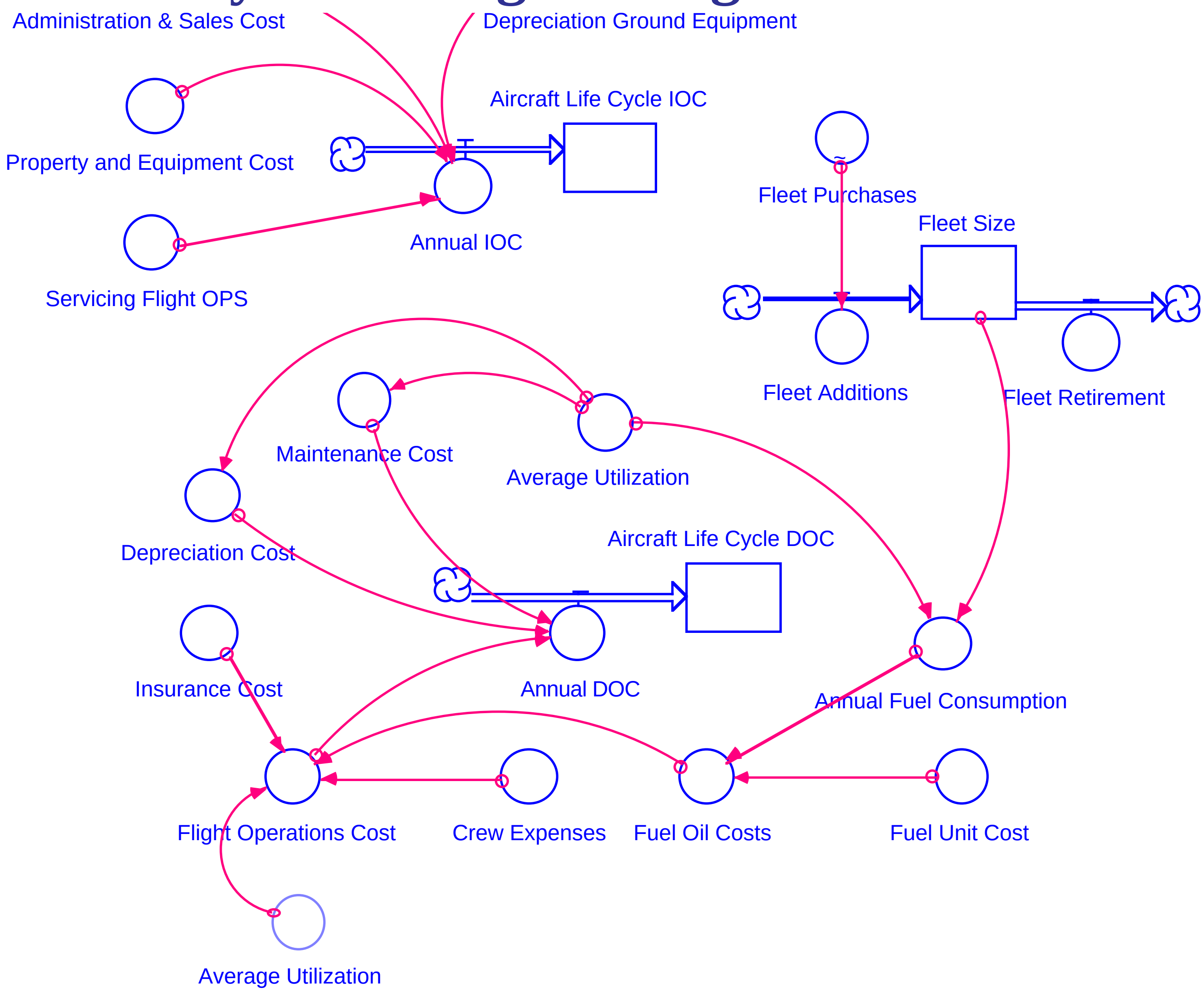


Landing Gear Configuration



Quadruple + Triple-in-Tandem

Systems Engineering Model



Sample Application of the Model

Desired Range in Km. and (n.m.) Aspect Ratio Cruise Mach Number VLCA Capacity (pass.) MTOW kN (lbs) Wingspan (m.)	10,186 (5,500) 9.5 0.85 650 3,830 (860,000) 70	12,965 (7,000) 9.5 0.85 650 5,385 (1,210,000) 82	13,890 (7,500) 9.5 0.85 650 6,100 (1,370,000) 87
Airfield Pavement Section Improvement	0	0	0
Noise Mitigation	5,000,000	7,872,000	10,000,000
Runway Improvement	19,250,000	19,250,000	24,319,277
Taxiway Improvement	13,663,234	13,663,237	15,413,237
90 Degree Exit Improv.	276,343	384,694	386,622
Runway Blast Pad Area Improvement	1,200,000	1,200,000	1,589,673
Terminal Apron Area Improve-ment	0	77,685	113,207
Land Acquisition Cost	63,869	229,328	297,101

Desired Range in Km. and (n.m.) Aspect Ratio Cruise Mach Number VLCA Capacity (pass.) MTOW kN (lbs) Wingspan (m.)	10,186 (5,500) 9.5 0.85 650 3,830 (860,000) 70	12,965 (7,000) 9.5 0.85 650 5,385 (1,210,000) 82	13,890 (7,500) 9.5 0.85 650 6,100 (1,370,000) 87
Airfield Geometric Infrastructure Improvement Cost	39,017,641	48,299,715	59,736,701
Terminal Curb Frontage Improvement Cost	45,900	45,900	45,900
Parking Garage Improvement Cost	2,653,750	2,653,750	2,653,750
Landside Improvement Cost	2,699,650	2,699,650	2,699,650
International Terminal Infrastructure Improvement Cost	77,523,165	77,523,165	77,523,165
Total Airport Infrastructure Improvement Cost	**124,240,456**	**136,394,530**	**149,959,516**

Summary

- An integrated life-cycle approach is needed to estimate the impacts of VLCA aircraft
- High-capacity aircraft operating at high-capacity airports will require some changes to current design standards
- Some of the design standards for airside infrastructure should be revised to plan ahead for strategic VLCA aircraft
- The effect of reduced airside capacity will not yield reduced passenger demand flow rates at airport terminals

- High capacity airports could benefit from lower flight frequencies resulting from VLCA operations if the passenger demand flows are the same