Airfield Design Specifications

Objective:

To outline briefly the fundamental ideas behind the design specifications of airfields

Topics:

- Principal sources
- ICAO and FAA reference codes
- Airport/aircraft compatibility issues

Reference: Chapter 9

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The two most-commonly used sources of geometric specifications for airfield design are:
- ICAO Annex 14 (“Aerodromes”) and associated supplements and manuals
- FAA Advisory Circular 150/5300-13 (“Airport Design”)

FAA updates of specifications are usually developed earlier than updates to ICAO Annex 14 (e.g., Group VI standards)

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Classification (FAA)

<table>
<thead>
<tr>
<th>Aircraft Approach Category</th>
<th>Airplane Design Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: Speed &lt; 91 knots</td>
<td>I: Wing &lt; 49 ft (15 m)</td>
</tr>
<tr>
<td>B: [91 - 121) knots</td>
<td>II: [49 - 79) ft (15-24 m)</td>
</tr>
<tr>
<td>C: [121 - 141) knots</td>
<td>III: [79 - 118) ft (24-36)</td>
</tr>
<tr>
<td>D: [141 - 166) knots</td>
<td>IV: [118 - 171) ft (36-52)</td>
</tr>
<tr>
<td>E: Speed 166+ knots</td>
<td>V: [171 - 214) ft (52-65)</td>
</tr>
<tr>
<td></td>
<td>VI: [214 - 262) ft (65-80)</td>
</tr>
</tbody>
</table>
### Airport Reference Codes (ICAO)

<table>
<thead>
<tr>
<th>Code #</th>
<th>Field length</th>
<th>Code letter</th>
<th>Wing span</th>
<th>Main gear wheel span</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Up to 800 m</td>
<td>A</td>
<td>Up to 15 m</td>
<td>Up to 4.5 m</td>
</tr>
<tr>
<td>2</td>
<td>800-1200 m</td>
<td>B</td>
<td>15 – 24 m</td>
<td>4.5 – 6 m</td>
</tr>
<tr>
<td>3</td>
<td>1200-1800 m</td>
<td>C</td>
<td>24 – 36 m</td>
<td>6 – 9 m</td>
</tr>
<tr>
<td>4</td>
<td>1800 m +</td>
<td>D</td>
<td>36 – 52 m</td>
<td>9 – 14 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E</td>
<td>52 – 65 m</td>
<td>9 – 14 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F</td>
<td>65 – 80 m</td>
<td>14 – 16 m</td>
</tr>
</tbody>
</table>

### Remarks re ICAO and FAA Airport Reference Codes

- Essentially all major commercial airports are in ICAO Code #4
- Main gear wheel span (ICAO) is “dominated” by wing span
- ICAO Code Letters A-F wing spans correspond exactly to FAA Airplane Design Groups I-VI wing spans
- Most geometric specifications for airports are determined by the wing span of the most demanding (or “critical”) aircraft (>500 operations per year)

### Airport/Aircraft Compatibility

- **Problems with the 747-400**
  - Civilian aircraft with 64.9 meter wingspan
  - Outside Group V and Code 4E when introduced
  - Changes in Group V, Code 4E definitions were made as a result
- **Problems with new, larger aircraft**
  - When specifications are not met, airport may be unable to accommodate aircraft or special procedures may be required (possibly resulting in congestion or under-utilization)
### A380 vs. B747-400

Airbus A380 vs. Boeing 747

- **Airbus A380**
  - Length: 72.2m
  - Wing span: 79.8m
  - Height: 24.1m
  - Weight: 560 tons
  - Passengers: 555

- **Boeing 747**
  - Length: 70.7m
  - Wing span: 64.9m
  - Height: 19.4m
  - Weight: 396 tons
  - Passengers: 416

### Runway Separations for Aircraft Approach Cat. C-D

<table>
<thead>
<tr>
<th>Runway Centerline To...</th>
<th>AIRPLANE DESIGN GROUP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>Massive Instrument and Visual</td>
<td></td>
</tr>
<tr>
<td>Hold Line</td>
<td>250 ft</td>
</tr>
<tr>
<td></td>
<td>75 m</td>
</tr>
<tr>
<td>Massive Precision and Visual</td>
<td></td>
</tr>
<tr>
<td>Hold Line</td>
<td>250 ft</td>
</tr>
<tr>
<td></td>
<td>75 m</td>
</tr>
<tr>
<td>Taxiway Centerline</td>
<td>300 ft</td>
</tr>
<tr>
<td></td>
<td>90 m</td>
</tr>
<tr>
<td>Taxiway Centerline</td>
<td>400 ft</td>
</tr>
<tr>
<td></td>
<td>120 m</td>
</tr>
<tr>
<td>Taxiway Centerline</td>
<td>500 ft</td>
</tr>
<tr>
<td></td>
<td>150 m</td>
</tr>
</tbody>
</table>

### Airfield Capacity

**Objective**

- To summarize fundamental concepts re. airfield capacity

**Topics**

- Definitions of capacity
- Factors affecting capacity
- Separation requirements
- A simple model for a single runway
- Capacity envelopes and capacity coverage chart

**Reference:** Chapter 10
Capacity Measures

- **Maximum-Throughput Rate**
  - Average number of demands a server can process per unit of time when always busy
  - \( \mu = \text{maximum throughput rate} \)
  - \( E(t) = \text{expected service time} \)
  - \( \mu = \frac{1}{E(t)} \)

- **Level of Service (LOS) related capacity**
  - Number of demands processed per unit of time while meeting some pre-specified LOS standards (must know \( \mu \) to compute)

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Definitions: Runway Capacity*

- **Maximum Throughput (or Saturation) Capacity**
  The expected ("average") number of runway operations (takeoffs and landings) that can be performed in one hour without violating ATC rules, assuming continuous aircraft demand.

- **Declared Capacity**
  The capacity per hour used in specifying the number of slots available for schedule coordination purposes; used extensively outside US; no standard method for its determination; no generally accepted LOS; typically set to about 85-90% of saturation capacity; may be affected by apron capacity and terminal capacity
  * These definitions can be applied to a single runway or to the entire complex of runways at an airport.

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Less Common LOS-Related Capacity Definitions

- **Practical Hourly Capacity**
  The average number of operations that can be performed in one hour on a runway (or, more generally, a system of active runways) with an average delay per operation of 4 minutes.

- **Sustained Capacity**
  The average number of operations per hour that can be "sustained" for periods of several hours; vaguely-defined, typically workload-related.

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Factors Affecting Capacity

- Number and layout of active runways
- Separation requirements (longitudinal, lateral)
- Weather (ceiling, visibility)
- Wind (direction, strength)
- Mix of aircraft
- Mix and sequencing of operations (landings, takeoffs, mixed)
- Quality and performance of ATM system (including human factor -- pilots and controllers)
- Runway exit locations
- Noise considerations
Role of ATC Separation Requirements

- Runway (and airfield) capacities are constrained by ATC separation requirements
- Typically aircraft are separated into a small number (3 or 4) of classes
- Example: FAA classification
  - Heavy (H): 255000 lbs < MTOW
  - Large (L): 41000 lbs < MTOW < 255000 lbs
  - Small (S): MTOW < 41000 lbs
- Required separations (in time or in distance) are then specified for every possible pair of aircraft classes and operation types (landing or takeoff)
- Example: “arrival of H followed by arrival of S”

IFR Separation Requirements: Single Runway (USA)

**Arrival-Arrival:**

1. Airborne separations on final approach (nmi):

<table>
<thead>
<tr>
<th></th>
<th>H</th>
<th>L or B757</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>4</td>
<td>5</td>
<td>5/6*</td>
</tr>
<tr>
<td>B757</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>L</td>
<td>2.5 (or 3)</td>
<td>2.5 (or 3)</td>
<td>3/4*</td>
</tr>
<tr>
<td>S</td>
<td>2.5 (or 3)</td>
<td>2.5 (or 3)</td>
<td>2.5 (or 3)</td>
</tr>
</tbody>
</table>

* Applies when leading aircraft is at threshold of runway

2. Leading aircraft must be clear of the runway before trailing aircraft touches down

IFR Separation Requirements: Single Runway (USA) [2]

**Departure-Departure** (approximate, in seconds)

<table>
<thead>
<tr>
<th>Leading aircraft</th>
<th>Trailing aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>90</td>
</tr>
<tr>
<td>B757</td>
<td>90</td>
</tr>
<tr>
<td>L</td>
<td>60</td>
</tr>
<tr>
<td>S</td>
<td>45</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trailing aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
</tr>
<tr>
<td>H</td>
</tr>
<tr>
<td>B757</td>
</tr>
<tr>
<td>L</td>
</tr>
<tr>
<td>S</td>
</tr>
</tbody>
</table>

**Arrival-Departure and Departure-Arrival**

- Leading aircraft must be clear of runway at the instant when trailing aircraft starts takeoff roll or touches down on the runway, respectively. In D-A case, trailing arrival must also be at least 2 nmi from runway when takeoff run begins.
Separation Requirements

(Italy; until recently)

<table>
<thead>
<tr>
<th>Arrival/Arrival</th>
</tr>
</thead>
<tbody>
<tr>
<td>(in nautical miles)</td>
</tr>
<tr>
<td>$H$</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

**Departure/Departure**

120 seconds between successive departures

**Departure/Arrival**

Arrival must be at least 5 n.mi. away from runway threshold

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Parallel Runways (IFR): USA

<table>
<thead>
<tr>
<th>Separation between runway centerlines</th>
<th>Arrival/arrival</th>
<th>Departure/Departure</th>
<th>Arrival/arrival</th>
<th>Departure/arrival</th>
</tr>
</thead>
<tbody>
<tr>
<td>700-2499 ft</td>
<td>As in single runway</td>
<td>As in single runway</td>
<td>Arrival touches down</td>
<td>Departure is clear of runway</td>
</tr>
<tr>
<td>2500-4300 ft</td>
<td>1.5 nmi (diagonal)</td>
<td>Independ’nt</td>
<td>Independ’nt</td>
<td>Independ’nt</td>
</tr>
<tr>
<td>4,300 ft or more</td>
<td>Independ’nt</td>
<td>Independ’nt</td>
<td>Independ’nt</td>
<td>Independ’nt</td>
</tr>
</tbody>
</table>

The diagonal separation between two aircraft approaching medium-spaced parallel runways

$S_{ij} = 1.5$ n.mi. $[2,500 \text{ ft} \leq d < 4,300 \text{ ft.}]$

Staggered parallel runways; the “near” runway is used for arrivals and the other for departures
Two high-capacity configurations in opposite directions at Boston/Logan (VMC)

A low-capacity configuration in VMC at Boston Logan

Configurations: Same Direction, Different Weather Conditions

Typical Approach for Estimating Airside Capacity

1. Compute average time interval for all possible aircraft class pairs \( i, j \)
   \[ t_{ij} = \text{average time interval between successive movements of a pair of aircraft of types } i \text{ and } j \text{ (} i \text{ followed by } j \text{) such that no ATC separation requirements are violated} \]

2. Compute probability for all \( i, j \)
   \[ p_{ij} = \text{probability of occurrence of the pair of aircraft types } i \text{ and } j \text{ (} i \text{ followed by } j \text{)} \]

3. Compute overall average service time
   \[ E(t) = \sum_i \sum_j p_{ij} t_{ij} \]
   \[ \mu = \frac{1}{E(t)} \]
## Numerical Example

<table>
<thead>
<tr>
<th>Aircraft Types</th>
<th>Type</th>
<th>Mix (%)</th>
<th>Approach Speed (kts)</th>
<th>Runway Occupancy Time (secs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heavy (1)</td>
<td>20</td>
<td>140</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Large (2)</td>
<td>50</td>
<td>120</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>Small (3)</td>
<td>30</td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>

Given: Single Runway (Arrivals Only: IFR)

\[ n = 5 \text{ N. Miles} \]

\[ \begin{bmatrix} 1 & 2 & 3 \\ 1 & 4 & 5 & 6^* \\ 2 & 3 & 3 & 4^* \\ 3 & 3 & 3 & 3 \end{bmatrix} \]

* Applies only with lead aircraft at threshold (all other separations apply throughout final approach).

## Single Runway Model: Arrivals Only

- Consider two aircraft, i and j. Let
  - \( n \) = length of final approach (typically 5-8 n.mi.)
  - \( s_{ij} \) = separation in air between i and j
  - \( v_i, v_j \) = approach speed of i, j
  - \( o_i, o_j \) = runway occupancy time of i, j
  - \( T_{ij} \) = min. time separation between i and j at runway
- Assume \( v_i > v_j \)
  - **Opening Case:** Aircraft i precedes j
    \[ T_o = \max \left( \frac{n + s_{ij}}{v_j} - n, o_i \right) \]
  - **Closing Case:** Aircraft j precedes i
    \[ T_c = \max \left( \frac{s_{ij}}{v_j}, o_j \right) \]

## Graphical Description of the Model
Effect of Airborne Separation Requirement

**Closing Case**
- Second aircraft is faster, and must have required separation distance from first aircraft at runway threshold; separation at merge area (beginning of final approach) is greater than minimum

**Opening Case**
- Second aircraft is slower, and must meet separation requirement from first aircraft in merge area when approach is initiated; separation at runway threshold is greater than minimum

Matrix of Minimum Separations

- The number $T_{ij}$ in row $i$ and column $j$ is the minimum separation (sec) for the case of aircraft type $i$ followed by type $j$

$$T_{ij} = \begin{bmatrix} 103 & 171 & 216 \\ 77 & 90 & 144 \\ 77 & 90 & 108 \end{bmatrix}$$

- **Opening Case**
  $$T_{ij} = \max \begin{bmatrix} 10 \text{ n. mi.} & 5 \text{ n. mi.} & 60 \text{ sec} \\ 120 \text{ knots} & 140 \text{ knots} \end{bmatrix} = \max (171 \text{ sec}, 60 \text{ sec}) = 171 \text{ sec}$$

Matrix of Minimum Separations [2]

- **Closing Case**
  $$T_{ij} = \max \begin{bmatrix} 3 \text{ n. mi.} & 50 \text{ sec} \\ 140 \text{ knots} \end{bmatrix} = \max (77 \text{ sec}, 50 \text{ sec}) = 77 \text{ sec}$$

- **Stable Case**
  $$T_{ij} = \max \begin{bmatrix} 3 \text{ n. mi.} & 55 \text{ sec} \\ 120 \text{ knots} \end{bmatrix} = \max (80 \text{ sec}, 55 \text{ sec}) = 80 \text{ sec}$$

- **“Special” Case (also $T_{23}$)**
  $$T_{ij} = \max \begin{bmatrix} 6 \text{ n. mi.} & 60 \text{ sec} \\ 100 \text{ knots} \end{bmatrix} = \max (216 \text{ sec}, 60 \text{ sec}) = 216 \text{ sec}$$

Safety Buffer

- In practice, a safety buffer is added to the minimum separations between aircraft, to make up for imperfections in the ATC system
  - Allow a buffer of an additional $b = 10$ seconds between each aircraft for safety (10 seconds implies about 1/3 n. mi. longitudinal separation)
Matrix of Average Time
Separations

The $t_{ij}$ indicate the average separation (sec) between an aircraft of type $i$ and a following aircraft of type $j$.

$$t_{ij} = T_{ij} + b$$

$$t_{ij} = \begin{bmatrix} 113 & 181 & 226 \\ 87 & 100 & 154 \\ 87 & 100 & 118 \end{bmatrix}$$

Matrix of Pair Probabilities

$\rightarrow$ Let $p_{ij}$ = probability that an aircraft of type $i$ will be followed by one of type $j$

* Assume first-come, first-served (FCFS) runway service

$$p_{ij} = \begin{bmatrix} 0.04 & 0.1 & 0.06 \\ 0.1 & 0.25 & 0.15 \\ 0.06 & 0.15 & 0.09 \end{bmatrix}$$

Example

• 20% of aircraft are Type 1, 50% are Type 2

Therefore, the probability of a Type 1 followed by a Type 2 is: $p_{12} = (0.2)^*(0.5) = 0.1$

* Note: This is valid only for an FCFS system; no sequencing.

Numerical Example [2]

Matrix of average time intervals, $t_{ij}$ (in seconds), for all possible pairs of aircraft types:

$$[t_{ij}] = \begin{bmatrix} 1 & 113 & 181 & 226 \\ 2 & 87 & 100 & 154 \\ 3 & 87 & 100 & 118 \end{bmatrix}$$

Matrix of probabilities, $p_{ij}$, that a particular aircraft pair will occur:

$$[p_{ij}] = \begin{bmatrix} 1 & 0.04 & 0.1 & 0.06 \\ 2 & 0.1 & 0.25 & 0.15 \\ 3 & 0.06 & 0.15 & 0.09 \end{bmatrix}$$

Numerical Example [3]

$\rightarrow$ By multiplying the corresponding elements of the matrices $[p_{ij}]$ and $[t_{ij}]$ we can compute the average separation (in seconds) between a pair of aircraft on the runway in question.

That is:

$$E(t) = \sum_{i} \sum_{j} p_{ij} \cdot t_{ij}$$

Numerically:

$$E(t) = (0.04)(113) + (0.1)(181) + (0.06)(226) + (0.1)(87) + (0.25)(100) + (0.15)(154) + (0.06)(87) + (0.15)(100) + (0.09)(118)$$

$\ast$ $E(t) = 124$ seconds

Saturation Capacity $= \frac{3600 \text{ seconds}}{124 \text{ seconds}} = 29$ aircraft
Numerical Example [4]

- The variance (a measure of variability) of the service times (intervals between successive landings in this case) can also be computed from:

\[ \sigma_t^2 = \sum_i \sum_j p_{ij} \cdot [t_{ij} - E(t)]^2 \]

- Or,

\[ (0.04)(113-124)^2 + (0.1)(181-124)^2 + \ldots + (0.09)((118-124)^2 \]

\[ = 1542 \text{ sec}^2 \]

- The standard deviation, \( \sigma_t = \sqrt{1542} = 39 \) seconds

Sensitivity of the model

- The model (and the runway’s arrival capacity) is sensitive to
  - Airborne separation requirements (regular and wake-turbulence related)
  - Runway occupancy times
  - Final approach speeds of aircraft
  - Length of final approach
  - Safety-related margins (buffers) allowed by air traffic controllers
  - Mix of traffic (homogeneity)
  - Sequencing of aircraft

A typical capacity envelope for a single runway

Capacity envelope when operating with strings of arrivals and departures
Capacity envelope for two parallel runways, one used for arrivals and the other for departures

Arrivals/hour

Departures/hour

A hypothetical capacity envelope for a multi-runway airport with mixed use of the runways

Arrivals/hour

Departures/hour

Runway Configuration Capacity Envelopes

Runway Configuration Capacity Envelopes
(Source: ETMS / Tower Records, 7-9 AM, 4-8 PM, July 1-15 1998 except Saturdays, Logan Airport)

Source: Idris (2000)

Capacity Coverage Chart

- CCC shows how much capacity is available for what percentage of time
- Assumptions:
  - airport will operate at all times with the highest capacity configuration available for prevailing weather/wind conditions
  - the capacity shown is for a 50%-50% mix of arrivals and departures

Note: Neither of these assumptions is necessarily true in practice (e.g., noise may be principal consideration in selecting configuration during periods of low demand)
Annual Capacity Coverage Chart: Boston/Logan

Runway configuration usage at Boston/Logan, January 1999 (from Logan FAA tower logs)

Capacity Coverage Chart [2]

- The CCC summarizes statistically the supply of airside capacity
- CCC requires a capacity analysis for all weather/wind conditions and runway configurations
- “Flat” CCC implies predictability and more effective utilization of airside facilities
  - Operations (takeoffs and landings) can be scheduled with reference to a stable capacity level
  - Fewer instances of under-utilization and over-utilization of facilities

Range of Airfield Capacities

- The capacity of a single runway varies greatly among airports, depending on local ATC rules, traffic mix, operations mix, local conditions and the other factors identified earlier (12 – 60+ movements per hour is possible)
- At major commercial airports, in developed countries, the range is 25 – 60 movements per hour for each runway
- Depending on the number of runways and the airport’s geometric configuration, total airfield capacity of major commercial airports ranges from 25 per hour to 200+ per hour
## Airport Capacity: US vs. Non-US

- FAA capacity benchmarks (2001): 31 busiest airports
  - 24 of 31: VMC capacity > 100/hour; range: 50 – 270
  - 16 of 31: IMC capacity > 100/hour; range: 45 – 184
  - 14 of 31: Plan a new runway by 2010 (none of the 7 most congested); capacity benefits of 17 – 50%
  - Capacity benefits due to ATM by 2010: 0 – 17% (mostly 3 – 13%)
  - [www.faa.gov/events/benchmarks/](http://www.faa.gov/events/benchmarks/)
- Airports elsewhere enjoy a significant advantage in average aircraft size and serve fewer aircraft operations for same number of annual passengers ...but this may be diluted by deregulation and by growth in regional services
- Only three non-US airports with capacity > 100/hour (!)