AVIATION NOISE 101
Gregory Maxwell – Casper Airport Solutions

UC Davis Aviation Noise & Emissions Symposium: February 25, 2017 – Long Beach, CA
<table>
<thead>
<tr>
<th>TOPIC</th>
<th>PRESENTER</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction/Ice Breaker</td>
<td>Steve &amp; Greg</td>
<td>12:00</td>
</tr>
<tr>
<td>Evolution of Aviation Noise</td>
<td>Steve</td>
<td>12:15</td>
</tr>
<tr>
<td>Break</td>
<td>------------------</td>
<td>13:00</td>
</tr>
<tr>
<td>Science of Aviation Noise</td>
<td>Gregory</td>
<td>13:15</td>
</tr>
<tr>
<td>Quantifying Aviation Noise</td>
<td>Steve</td>
<td>13:45</td>
</tr>
<tr>
<td>Break</td>
<td>------------------</td>
<td>14:15</td>
</tr>
<tr>
<td>Regulating Aviation Noise</td>
<td>Steve</td>
<td>14:30</td>
</tr>
<tr>
<td>Mitigating Aviation Noise</td>
<td>Steve</td>
<td>15:00</td>
</tr>
<tr>
<td>Break</td>
<td>------------------</td>
<td>15:30</td>
</tr>
<tr>
<td>Aircraft Performance and Noise</td>
<td>Greg</td>
<td>15:45</td>
</tr>
<tr>
<td>Performance Based Navigation</td>
<td>Greg</td>
<td>16:15</td>
</tr>
<tr>
<td>Flight Procedure Design</td>
<td>Greg</td>
<td>16:35</td>
</tr>
</tbody>
</table>
A mechanical wave that results from the back and forth vibration of the particles of the medium through which the sound wave is moving
Sound is transmitted through the air by the vibration of air molecules.
### HOW IS SOUND ENERGY MEASURED?

<table>
<thead>
<tr>
<th>Sound Source</th>
<th>dB</th>
<th>Sound Energy</th>
<th>Perceived Loudness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock Concert</td>
<td>120</td>
<td>1,000,000</td>
<td>64x</td>
</tr>
<tr>
<td>Ambulance</td>
<td>110</td>
<td>100,000</td>
<td>32x</td>
</tr>
<tr>
<td>Fire Alarm</td>
<td>100</td>
<td>10,000</td>
<td>16x</td>
</tr>
<tr>
<td>Subway Train</td>
<td>90</td>
<td>1,000</td>
<td>8x</td>
</tr>
<tr>
<td>Urban Street</td>
<td>80</td>
<td>100</td>
<td>4x</td>
</tr>
<tr>
<td>Department Store</td>
<td>70</td>
<td>10</td>
<td>2x</td>
</tr>
<tr>
<td>Typical Conversation</td>
<td>60</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Suburban Area</td>
<td>50</td>
<td>0.1</td>
<td>1/2x</td>
</tr>
<tr>
<td>Rural Area</td>
<td>40</td>
<td>0.01</td>
<td>1/4x</td>
</tr>
<tr>
<td>Whisper</td>
<td>30</td>
<td>0.001</td>
<td>1/8x</td>
</tr>
<tr>
<td>Wilderness</td>
<td>20</td>
<td>0.0001</td>
<td>1/16x</td>
</tr>
<tr>
<td>Breathing</td>
<td>10</td>
<td>0.00001</td>
<td>1/32x</td>
</tr>
<tr>
<td>Threshold of Hearing</td>
<td>0</td>
<td>0.000001</td>
<td>1/64x</td>
</tr>
</tbody>
</table>
WEATHER’S EFFECT ON SOUND TRANSMISSION

Calm and Sunny

Calm and Cloudy

Windy

Nighttime
WHAT IS NOISE?

Noise – a sound, especially one that is loud or unpleasant or that causes disturbance. (unwanted sound)
AIRPORT NOISE SOURCES

Aircraft Departures

Aircraft Arrivals

Engine Run-Ups

Reverse Thrust

Running APU

Aircraft Idling / Taxiing
AIRCRAFT NOISE SOURCES

- Engine Nacelle
- Thrust Reversers
- Slats
- Flaps
- Speed Brakes
- Fuselage
- APU
- Fan Blades
- Turbine / Fan Core
- Jet / Fan Exhaust
- Wingtip Vortices
- Landing Gear

Photo - Victor J. Pody
WHO REGULATES AIRPLANE NOISE IN THE UNITED STATES?

Federal Aviation Regulations Part 36 – Noise Standards: Aircraft Type and Airworthiness Certification
Subpart B – Transport Category Large Airplanes and Jet Airplanes
FAR 36.101 – Noise Measurement and Evaluation
FAR 36.103 – Noise Limits
Aircraft Noise is measured in A weighted decibels (dBA)

Aircraft Noise Certification Points:
Approach, Sideline, Takeoff
FAR 36.103 – Noise Limits: A sliding scale based on aircraft weight (Stage IV)

Boeing 747-8I, Max Takeoff Weight = 987,000 lb.

<table>
<thead>
<tr>
<th>Certification Level</th>
<th>Sideline</th>
<th>Approach</th>
<th>Takeoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise Level (EPNdB)</td>
<td>94.0</td>
<td>100.9</td>
<td>94.5</td>
</tr>
<tr>
<td>Noise Limit (EPNdB)</td>
<td>103.0</td>
<td>105.0</td>
<td>106.0</td>
</tr>
<tr>
<td>Margin Below Stage IV</td>
<td>9.0</td>
<td>4.1</td>
<td>11.5</td>
</tr>
</tbody>
</table>

Boeing 787-8, Max Takeoff Weight = 502,500 lb.

<table>
<thead>
<tr>
<th>Certification Level</th>
<th>Sideline</th>
<th>Approach</th>
<th>Takeoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise Level (EPNdB)</td>
<td>91.6</td>
<td>94.2</td>
<td>86.6</td>
</tr>
<tr>
<td>Noise Limit (EPNdB)</td>
<td>100.9</td>
<td>104.3</td>
<td>98.0</td>
</tr>
<tr>
<td>Margin Below Stage IV</td>
<td>9.3</td>
<td>10.1</td>
<td>11.4</td>
</tr>
</tbody>
</table>

Boeing 737-8 MAX, Max Takeoff Weight = 181,200 lb.

<table>
<thead>
<tr>
<th>Certification Level</th>
<th>Sideline</th>
<th>Approach</th>
<th>Takeoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise Level (EPNdB)</td>
<td>88.5</td>
<td>94.2</td>
<td>82.6</td>
</tr>
<tr>
<td>Noise Limit (EPNdB)</td>
<td>97.2</td>
<td>100.9</td>
<td>92.1</td>
</tr>
<tr>
<td>Margin Below Stage IV</td>
<td>8.7</td>
<td>6.7</td>
<td>9.5</td>
</tr>
</tbody>
</table>
WHAT DOES A 10 DECIBEL INCREASE IN NOISE EQUATE TO?

10 dB increase = 10x sound energy but is only perceived to be 2x louder
HOW DOES THE FAA QUANTIFY AIRPLANE NOISE?

**DNL** – Day-night average sound level over a 24-hour period
Aircraft operations between the hours of 10 pm and 7 am have a 10 dB penalty added to them to account for the lower ambient noise levels in communities, which increases the likelihood of these events causing annoyance and sleep disturbance.

<table>
<thead>
<tr>
<th>DAYTIME AIRCRAFT NOISE</th>
<th>NIGHTTIME AIRCRAFT NOISE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Event = 1 Event</td>
<td>1 Event = 10 Events</td>
</tr>
</tbody>
</table>
WHY WAS 65 DNL CHOSEN AS THE THRESHOLD?

Federal Interagency Committee on Urban Noise (FICUN)

Guidelines for Considering Noise in Land Use Planning and Control (1980)


This report established the Federal government’s DNL 65 dB standard and related guidelines for land use compatibility.
According to the FAA, noise levels of DNL 65 dB or above are generally considered incompatible with residential land uses and people living within the DNL 65 dB or higher contour are considered to be significantly impacted by aircraft noise.
EQUIVALENT DNL NOISE LEVELS

1 Event/Day SEL 114.4 dBA = 65 DNL

10 Events/Day SEL 104.4 dBA = 65 DNL

100 Events/Day SEL 94.4 dBA = 65 DNL
HOW DOES NOISE GET INTO MY HOME?
AERODYNAMIC FORCES ACTING ON AN AIRPLANE

- Drag
- Lift
- Thrust
- Weight
THE EVOLUTION OF THE COMMERCIAL JET ENGINE

1958
Pratt & Whitney JT3C-6
Turbojet
Bypass Ratio = 0:0
Fan Diameter = 38.8 in
Max Thrust = 11,200 lbf
Sideline Noise = 115 dB

1964
Pratt & Whitney JT8D-7
Low Bypass Turbofan
Bypass Ratio = 1:1
Fan Diameter = 42.5 in
Max Thrust = 14,000 lbf
Sideline Noise = 105 dB

1970
Pratt & Whitney JT9D-3A
High Bypass Turbofan
Bypass Ratio = 5:1
Fan Diameter = 95.6 in
Max Thrust = 44,250 lbf
Sideline Noise = 98 dB

2011
Rolls Royce Trent 1000-A
Ultra High Bypass Turbofan
Bypass Ratio = 10:1
Fan Diameter = 112.0 in
Max Thrust = 69,294 lbf
Sideline Noise = 87 dB

1995
GE90-94B
High Bypass Turbofan
Bypass Ratio = 9:1
Fan Diameter = 123.0 in
Max Thrust = 94,700 lbf
Sideline Noise = 93 dB
AERODYNAMIC EVOLUTION OF THE BOEING 737 FAMILY

Boeing 737 Aerodynamic Efficiency Improvement

- 737-600W
  - Wingspan 117.4 ft.
- 737-600
  - Wingspan 112.6 ft.
- 737-200 Adv
  - Wingspan 93.0 ft.
- 737-500
- Source: Boeing
EVOLUTION OF THE NARROWBODY COMMERCIAL JET

Narrowbody Jet Sideline Noise Certification Measurements

-28 dB
FACTORS THAT EFFECT AIRCRAFT TAKEOFF PERFORMANCE

- Aircraft Weight
- Weather Conditions
- Airport Elevation
- Runway Length

- Plane
- Payload
- Fuel
- Hotter Reduced Thrust
- Engine Thrust
- Colder Increased Thrust
- Higher Less Dense Air
- Lift Produced
- Lower More Dense Air
- Longer Higher Weight
- Payload Uplift
- Shorter Lower Weight
Los Angeles (LAX) to Sydney (SYD)
Aircraft Assigned: Boeing 747-438 (VH-OJS)
Flight Plan Distance: 7,560 miles

Los Angeles (LAX) to New York (JFK)
Aircraft Assigned: Boeing 747-438 (VH-OJT)
Flight Plan Distance: 2,536 miles

EXPLAINING THE VARIABILITY IN DEPARTURE PROFILES
### BOEING 747-400 (4x RB211-524H) WEIGHTS

<table>
<thead>
<tr>
<th>Weight Category</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Empty Weight</td>
<td>394,088 lb. / 178,755 kg.</td>
</tr>
<tr>
<td>Max Structural Payload</td>
<td>148,412 lb. / 67,319 kg.</td>
</tr>
<tr>
<td>Max Zero Fuel Weight</td>
<td>542,500 lb. / 246,074 kg.</td>
</tr>
<tr>
<td>Max Useable Fuel</td>
<td>382,336 lb. / 173,425 kg.</td>
</tr>
<tr>
<td>Max Taxi Weight</td>
<td>877,000 lb. / 397,801 kg.</td>
</tr>
<tr>
<td>Max Takeoff Weight</td>
<td>875,000 lb. / 396,893 kg.</td>
</tr>
<tr>
<td>Max Landing Weight</td>
<td>630,000 lb. / 285,763 kg.</td>
</tr>
</tbody>
</table>
HOW MUCH FUEL DO WE NEED FOR OUR TRIP?

Boeing 747-400 Fuel Capacity

Capacity = 386,000 lb. 175,087 kg.
Useable = 382,336 lb. 173,425 kg.
Unusable = 3,664 lb. 1,662 kg.
**FUEL LOAD PLANNING**

QFA11 LAX-JFK = 2,536 miles  
Flight Time = 4 hr 39 min  
Empty Weight = 394,088 lb.  
Fuel = 120,557 lb.  

Takeoff Weight = **394,088 lb.**

QFA18 LAX-SYD = 7,560 miles  
Flight Time = 14 hr 5 min  
Empty Weight = 394,088 lb.  
Fuel = 373,703 lb.  

Takeoff Weight = **373,703 lb.**

Takeoff Weight Difference  
253046 lb.
HOW ARE PASSENGER AND CARGO WEIGHTS CALCULATED?

<table>
<thead>
<tr>
<th>FAA Average Summer Weights (Estimates)</th>
<th>Palletized and Containerized Cargo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult: 190 lb. 86 kg</td>
<td>Weighed prior to loading</td>
</tr>
<tr>
<td>Child (2-13 years): 82 lb. 37 kg.</td>
<td></td>
</tr>
<tr>
<td>Checked: 29 lb. 13 kg.</td>
<td></td>
</tr>
<tr>
<td>Carry-On: 15 lb. 7 kg.</td>
<td></td>
</tr>
<tr>
<td>Overweight: 59 lb. 27 kg.</td>
<td></td>
</tr>
</tbody>
</table>

FAA Average Summer Weights (Estimates)
CARGO LOAD PLANNING

QFA11 LAX-JFK = 2,536 miles
Flight Time = 4 hr 39 min
Empty Weight = 394,088 lb.
Fuel = 120,557 lb.
Bags/Cargo = 24,888 lb.

Takeoff Weight = **539,535 lb.**

QFA18 LAX-SYD = 7,560 miles
Flight Time = 14 hr 5 min
Empty Weight = 394,088 lb.
Fuel = 373,703 lb.
Bags/Cargo = 33,735 lb.

Takeoff Weight = **867,326 lb.**

Takeoff Weight Difference
263,998 lb.
QFA11 LAX-JFK = 2,536 miles
Flight Time = 4 hr 39 min
Empty Weight = 394,088 lb.
Fuel = 120,557 lb.
Bags/Cargo = 24,888 lb.
Passengers = 187 (32,435 lb.)
Takeoff Weight = **589,988 lb.**

QFA18 LAX-SYD = 7,560 miles
Flight Time = 14 hr 5 min
Empty Weight = 394,088 lb.
Fuel = 373,703 lb.
Bags/Cargo = 33,735 lb.
Passengers = 416 (71,992 lb.)
Takeoff Weight = **870,518 lb.**

Takeoff Weight Difference
261,998 lb.
HOW MUCH RUNWAY DO WE NEED TO TAKEOFF?
CALCULATING TAKEOFF DISTANCE

**QFA11 LAX-JFK**

Density Altitude = 251 ft. / 77 m.
Takeoff Weight = 568,968 lb. / 258,079 kg.
Flap Setting: 20°
Power Setting: 1.76 EPR (0% Derate)
Takeoff Runway = 25R (12,091 ft. / 3,685 m. available)
Takeoff Distance = 6,050 ft. / 1,844 m.

**QFA18 LAX-SYD**

Density Altitude = 251 ft. / 77 m.
Takeoff Weight = 870,518 lb. / 394,860 kg.
Flap Setting: 20°
Power Setting: 1.76 EPR (0% Derate)
Takeoff Runway = 25R (12,091 ft. / 3,685 m. available)
Takeoff Distance = 10,323 ft. / 3,146 m.
The volume of air ingested into a jet engine is fixed, but the density of that same air is not.

**Temperature has an inverse correlation with Air Density**

Hot air is less dense than cold air and thus the warmer the temperature the less net thrust a jet engine produces. Warmer temperatures also decrease lift, which increases the length of runway needed for takeoff, reduces climb performance and lessens the payload weight that can be lifted.
TEMPERATURE’S EFFECT ON TAKEOFF PERFORMANCE

Current Automatic Terminal Information Service (ATIS): Los Angeles Int’l Airport (LAX)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Dew Point</th>
<th>Winds</th>
<th>Altimeter Setting</th>
<th>Field Elevation</th>
<th>Departing</th>
</tr>
</thead>
<tbody>
<tr>
<td>99°F / 36°C</td>
<td>36°F / 2°C</td>
<td>Calm</td>
<td>29.92 in / 1030 mb.</td>
<td>128 ft. / 39 m.</td>
<td>Runway 25R</td>
</tr>
</tbody>
</table>

QFA11 LAX-JFK
Density Altitude = 2521 ft. / 768 m.
Takeoff Weight = 568,968 lb. / 258,079 kg.
Flap Setting: 20°
Power Setting: **1.76 EPR (0% Derate)**
Takeoff Runway = 25R (12,091 ft. / 3,685 m. available)
Takeoff Distance = 6,050 ft. / 1,844 m.
Takeoff Length Difference = 0 ft. / 0 m.

QFA18 LAX-SYD
Density Altitude = 2521 ft. / 768 m.
Takeoff Weight = 870,518 lb. / 394,860 kg.
Flap Setting: 20°
Power Setting: **1.75 EPR (0% Derate)**
Takeoff Runway = 25R (12,091 ft. / 3,685 m. available)
Takeoff Distance = 6,083 ft. / 1,844 m.
Takeoff Length Difference = 0 ft. / 0 m.

Current Automatic Terminal Information Service (ATIS): Los Angeles Int’l Airport (LAX)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Dew Point</th>
<th>Winds</th>
<th>Altimeter Setting</th>
<th>Field Elevation</th>
<th>Departing</th>
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<tbody>
<tr>
<td>99°F / 36°C</td>
<td>36°F / 2°C</td>
<td>Calm</td>
<td>29.92 in / 1030 mb.</td>
<td>128 ft. / 39 m.</td>
<td>Runway 25R</td>
</tr>
</tbody>
</table>

QFA11 LAX-JFK
Density Altitude = 2521 ft. / 768 m.
Takeoff Weight = 568,968 lb. / 258,079 kg.
Flap Setting: 20°
Power Setting: **1.76 EPR (0% Derate)**
Takeoff Runway = 25R (12,091 ft. / 3,685 m. available)
Takeoff Distance = 6,050 ft. / 1,844 m.
Takeoff Length Difference = 0 ft. / 0 m.

QFA18 LAX-SYD
Density Altitude = 2521 ft. / 768 m.
Takeoff Weight = 870,518 lb. / 394,860 kg.
Flap Setting: 20°
Power Setting: **1.75 EPR (0% Derate)**
Takeoff Runway = 25R (12,091 ft. / 3,685 m. available)
Takeoff Distance = 6,083 ft. / 1,844 m.
Takeoff Length Difference = 0 ft. / 0 m.
A headwind equals airspeed over the wings which increases lift.

Airplanes takeoff and land into the wind to increase lift and reduce the amount of runway needed for takeoff and landing. An aircraft sitting at the end of the runway pointed into a 15 knot headwind has ground speed of 0 and an airspeed of 15 knots.
WIND’S EFFECT ON TAKEOFF PERFORMANCE

Current Automatic Terminal Information Service (ATIS): Los Angeles Int’l Airport (LAX)

**QFA11 LAX-JFK**

Density Altitude = 251 ft. / 77 m.
Takeoff Weight = 568,968 lb. / 258,079 kg.
Flap Setting: 20°
Power Setting: 1.76 EPR (0% Derate)
Takeoff Runway = 25R (12,091 ft. / 3,685 m. available)
Takeoff Distance = 6,060 ft. / 1,807 m.
Takeoff Length Difference = 449 ft. / 137 m.

**QFA18 LAX-SYD**

Density Altitude = 251 ft. / 77 m.
Takeoff Weight = 870,518 lb. / 394,860 kg.
Flap Setting: 20°
Power Setting: 1.76 EPR (0% Derate)
Takeoff Runway = 25R (12,091 ft. / 3,685 m. available)
Takeoff Distance = 9,638 ft. / 2,949 m.
Takeoff Length Difference = 197 m.
Altitude has an inverse correlation with air density

At higher altitudes the air is less dense, decreasing the lifting effectiveness of the wing. Altitude also effects engine performance, reducing the net thrust output from a jet engine. Both of these factors combined increase the amount of runway needed for takeoff, negatively impact aircraft climb performance and restrict the payload weight that can be lifted.

Temperature = 59°F / 15°C
Dew Point = 36°F / 2°C
Altimeter = 29.92 Hg.
Winds = Calm
LAX Field Elevation = 128 ft. / 39 m.
DEN Field Elevation = 5,434 ft. / 1,656 m.
## ALTITUDE’S EFFECT ON TAKEOFF PERFORMANCE

### Current Automatic Terminal Information Service (ATIS): Los Angeles Int’l Airport (LAX)

- **QFA11 LAX-JFK**
  - Density Altitude = 5,434 ft. / 1,656 m.
  - Takeoff Weight = 568,968 lb. / 258,079 kg.
  - Flap Setting: 20°
  - Power Setting: **1.76 EPR (0% Derate)**
  - Takeoff Runway = 25R (12,091 ft. / 3,685 m. available)
  - Takeoff Distance = 6,050 ft. / 1,844 m.
  - Takeoff Length Difference = 0 ft. / 0 m.

- **QFA18 LAX-SYD**
  - Density Altitude = 5,434 ft. / 1,656 m.
  - Takeoff Weight = 870,518 lb. / 394,860 kg.
  - Flap Setting: 20°
  - Power Setting: **1.76 EPR (0% Derate)**
  - Takeoff Runway = 25R (12,091 ft. / 3,685 m. available)
  - Takeoff Distance = 10,323 ft. / 3,146 m.
  - Takeoff Length Difference = 0 ft. / 0 m.
WEIGHT RESTRICTION DUE TO RUNWAY LENGTH
AVAILBLE RUNWAY LENGTH’S EFFECT ON AIRCRAFT WEIGHT

| Current Automatic Terminal Information Service (ATIS): Los Angeles Int’l Airport (LAX) |
|---|---|---|---|---|---|
| **Temperature** | **Dew Point** | **Winds** | **Altimeter Setting** | **Field Elevation** | **Departing Runway** |
| 59°F / 15°C | 36°F / 2°C | Calm | 29.92 in / 1030 mb. | 128 ft. / 39 m. | 25R |

**QFA11 LAX-JFK**

- Density Altitude = 251 ft. / 77 m.
- Takeoff Weight = 568,968 lb. / 258,079 kg.
- Flap Setting: 20°
- Power Setting: 1.76 EPR (0% Derate)
- Takeoff Runway = 25R (1,959 ft. / 596.5 m. available)
- Takeoff Distance = 6,050 ft. / 1,844 m.
- Takeoff Weight Difference = 0 lb. / 0 kg.

**QFA18 LAX-SYD**

- Density Altitude = 251 ft. / 77 m.
- Takeoff Weight = 829,908 lb. / 373,397 kg. (0 Bags/Cargo and -74 Passengers)
- Flap Setting: 20°
- Power Setting: 1.76 EPR (0% Derate)
- Takeoff Runway = 25R (1,959 ft. / 596.5 m. available)
- Takeoff Distance = 9,165 ft. / 2,793 m.
- Takeoff Weight Difference = 0 lb. / 0 kg.
AVERAGE DEPARTURE TRACK PROFILE COMPARISON

QFA11 (LAX-JFK) 568,968 lb. / 258,079 kg.

QFA18 (LAX-SYD) 870,518 lb. / 394,860 kg.

Climb Rate 2,500 ft./min

Climb Rate 1,900 ft./min

0 ft. 2,115 ft. 3,048 ft. 3,750 ft. 4,769 ft.

0 41 82 129 179 234 280 332 373 417 472 Sec.
PERFORMANCE BASED NAVIGATION
METROPLEX

Geographic area that includes several commercial and general aviation airports in close proximity serving large metropolitan areas.

The FAA has identified 21 metroplex areas where airspace congestion and other limiting factors such as environmental constraints combine to create bottlenecks that effect system efficiency nation wide.
Optimization of Airspace & Procedures in the Metroplex

Optimization of the airspace and procedures encompassing multiple airports in a metroplex region provides for the most efficient traffic management solutions on both a regional and national basis.

By examining airspace problems on a regional scale the FAA can customize the solutions to ensure they maximize throughput of airplanes through the entire airspace in the safest and most efficient manner possible while at the same time customizing procedures to meet the unique requirements of individual airports.

WHAT IS OAPM?
Performance Based Navigation

A transformational change from conventional ground-based navigation aids and procedures to satellite-based navigation aids and area navigation procedures, which are more accurate and allow for shorter, more direct routes between two given points as well as more efficient takeoffs and landings.

PBN enables aircraft to fly on any desired flight path within the coverage of ground or satellite based navigation aids using the aircraft’s capability to navigate by means of performance standards utilizing either Area Navigation (RNAV) or Required Navigation Performance (RNP).

WHAT IS PBN?

Ground Based Navigational Aid

Satellite Based Navigational Aid
Fly-By Waypoint

Much greater predictability in the flight path flown and a narrower track dispersion.

The aircraft navigation system will anticipate the turn and calculate the radius of the turn to intercept the next waypoint.

Fly-Over Waypoint

Much less flight path predictability caused by overflying the waypoint and having to turn back to recapture the track to the next waypoint.

Differences in airspeed and aircraft mass result in a wide track dispersion during the turn.
Area Navigation

Developed in the 1960s, with the first routes being published and flown in the 1970s.

This method of instrument flight rules (IFR) navigation allows an aircraft to choose any course within a network of navigation beacons, rather than navigate directly to and from the beacons.

RNAV requires an aircraft to be equipped with a GPS navigation system like a Flight Management System (FMS) which uses the GPS to triangulate the aircraft’s position to within a circle with a defined radius.

RNAV is primarily used for departure procedures and/or arrival procedures that do not require the narrow tolerances defined by RNP procedures.

What is RNAV?

RNAV 1

Within 1 nm 95% of flight time

Track Centerline

Within 1 nm 95% of flight time

RNAV 1 – implies you have a 95% probability of keeping within 1 nm of your track course.
FLYING AN RNAV DEPARTURE
Developed in the early 1990s, with the first route being published and flown in 1996 by Alaska Airlines at Juneau, Alaska.

This method of instrument flight rules (IFR) navigation is fundamentally similar to RNAV with the difference being that RNP incorporates onboard performance monitoring and alerting.

The Flight Management System (FMS) uses position data from two independent GPS receivers as well as inertial navigation data to crosscheck and monitor the position of the aircraft. The system reports to the pilots if the position accuracy falls outside the tolerances for the given procedure.

RNP is primarily used for approaches into airports surrounded by mountainous terrain and/or other obstacles.

RNP 0.1 – implies you have a 95% probability of keeping within 0.1 nm of your track course
RNP 0.2 – implies you have a 95% probability of keeping within 0.2 nm of your track course
RNP 0.3 – implies you have a 95% probability of keeping within 0.3 nm of your track course

RNP 0.1 - Alert if the probability of keeping within 0.2 nm of the course centerline is less than 99.999%
FLYING AN RNP APPROACH
Standard Instrument Departure

An IFR air traffic control departure procedure that utilizes a series of specific waypoints, headings and altitudes to organize traffic departing the airport and place aircraft on a fixed route with defined transition points exiting the airspace.

SIDs are optimized for air traffic control routing efficiency while striking a balance between terrain and obstacle avoidance, noise abatement and airspace management.

A specific SID is assigned to an IFR flight by ATC based on a combination of the aircraft’s destination, the first waypoint in the flight plan and the takeoff runway assigned.

Phoenix Sky Harbor Int’l
KPHX - YOTES.3 SID Illustrated
WHAT IS A STAR?

Standard Terminal Arrival Route

An IFR air traffic control arrival procedure that utilizes a series of specific waypoints, headings and altitudes to organize traffic arriving to the airport by placing airplanes on fixed routes with defined transition points entering the airspace.

STARS cover the portion of the flight between the top of descent and the initial approach fix to the runway.

The STAR simplifies ATC clearance procedures and allows for a smooth transition of aircraft between en-route and approach controllers. Assignment of STARS by ATC is dictated by many factors including the weather conditions, runway/approach in use as well as airport congestion.

San Francisco Int’l
KSFO - WWAVS.1 STAR Illustrated
Arrival

An arrival procedure covers the portion of the flight from the top of descent point in cruise flight down to a position just short of the initial fix on a specific approach. Arrivals don’t end at a runway end, but rather usually terminate near the initial fix for a specific approach.

Approach

An approach procedure cover the portion of the flight from the initial approach fix down to the runway. ATC sequences airplanes onto an approach to a specific runway at set intervals. The approach procedure guides the aircraft down to the runway.
REAL WORLD EXAMPLE AAL530 (SEA-PHL)

Gate D9

Philadelphia, PA

Flight
AA 530

Departs
10:25pm

Arrives
6:23am EDT

Boarding in 20 minutes

AAdvantage ® Miles: 2,375 • Flight Time: 4 hr 42 min • Aircraft Type: Airbus A321T
AAL530 FLIGHT DETAILS

AIRBUS A321-231T (Transcon)
Aircraft:  N102NN
Filed:  FL330
ETE:  4 hr 42 min

Route:  KSEA SUMMA8 SUMMA J54 BKE KU87Q RAP HAYNS GIJ J146 WOOST J34 DJB EWC JST BOJID1 KPHL
Route: KSEA SUMMA8 SUMMA J54 BKE KU87Q RAP HAYNS GIJ J146 WOOST J34 DJB EWC JST BOJID1 KPHL
PHILADELPHIA INT’L (PHL) BOJID.1 RNAV ARR. STAR
FLIGHT PROCEDURE DESIGN
PRIMARY DESIGN CONSIDERATIONS

SAFETY OF FLIGHT

• Terrain Clearance
• Obstacle Clearance
• Aircraft Performance Limitations
• Traffic Separation
• Traffic Deconfliction

AIRSPACE EFFICIENCY

• Increase System Throughput
• Increase Predictability of Operations
• Reduce Required Aircraft Spacing
• Reduce Track Miles Flown
• Reduce Radio Communications
TERRAIN AND OBSTACLE CLEARANCE

Maintain Separation

- Minimum Climb Gradient
- Maximum Descent Gradient
- Altitude Crossing Limits
- Minimum Turn Radius
- Airspeed Restrictions
- Navigation Error Tolerance
- Aircraft Restrictions
Vertical Profile – Climb Gradient

Minimum climb gradients are predicated on the worst case scenario:

Losing an engine on takeoff with the aircraft at maximum takeoff weight on a very hot day.

The vertical profile must allow all aircraft to clear all obstacles safely with one engine inoperative.
Aircraft with a smaller mass flying at a lower airspeed can turn within a tighter radius.
TRAFFIC SEPARATION / DECONFLICTION

**Boeing 747-8I**
- Cruise Speed = 570 mph
- Approach Speed = 172 mph
- Max Takeoff Weight = 987,000 lb.

**Semi-Truck**
- Cruise Speed = 70 mph
- Max Weight = 80,000 lb.

**Bicycle**
- Cruise Speed = 15 mph
- Avg. Weight = 200 lb.

**Boeing 777-8**
- Cruise Speed = 559 mph
- Approach Speed = 177 mph
- Max Takeoff Weight = 302,500 lb.

**Boeing 737-8 Max**
- Cruise Speed = 522 mph
- Approach Speed = 163 mph
- Max Takeoff Weight = 181,200 lb.

**Bombardier Q400**
- Cruise Speed = 414 mph
- Approach Speed = 145 mph
- Max Takeoff Weight = 64,500 lb.

**Cessna 172**
- Cruise Speed = 140 mph
- Approach Speed = 75 mph
- Max Takeoff Weight = 2,550 lb.
TRAFFIC SEPARATION / DECONFLICTION

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community
INCREASE THROUGHPUT / PREDICTABILITY
REDUCE REQUIRED AIRCRAFT SPACING
REDUCE TRACK MILES FLOWN
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The following programs and sources were used to create this presentation.

Casper Noise
Adobe Photoshop CC 2016
AirNav.com (airnav.com)
Boeing 747-400 Airplane Characteristics for Airport Planning (boeing.com/commercial/airports/plan_manuals.page)
Esri ArcGIS ArcMap v10.3.1
Federal Aviation Administration (faa.gov)
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Microsoft PowerPoint 2016
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Plane Simple Truth – Clearing the Air on Aviation’s Environmental Impact (2008)
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Professional Flight Planner X (flightsimsoft.com/pfpx)
Take-Off and Landing Performance Calculation Tool (flightsimsoft.com/topcat)
QUESTIONS?