*runway*Simulator Validation Report

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MITRE

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Background and Overview

What is MITRE?

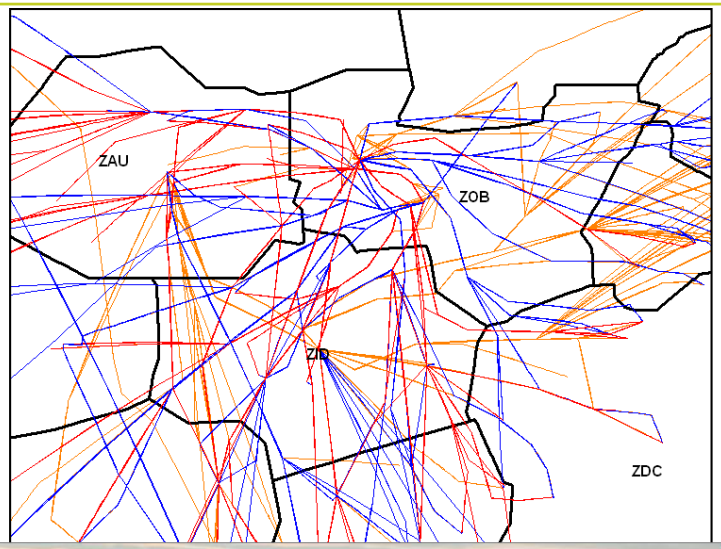
- **MITRE is a private, independent, not-for-profit organization, chartered to work in the public interest**
- **Founded in 1958 to provide engineering and technical services to the U.S. Air Force**
- **Currently manages six Federally Funded Research and Development Centers – for DoD/Intelligence, FAA, IRS/VA, DHS, Federal Judiciary, and HHS, and has been selected to run a seventh for NIST**
- **Supports a broad and diverse set of sponsors within the U.S. government as well as internationally**

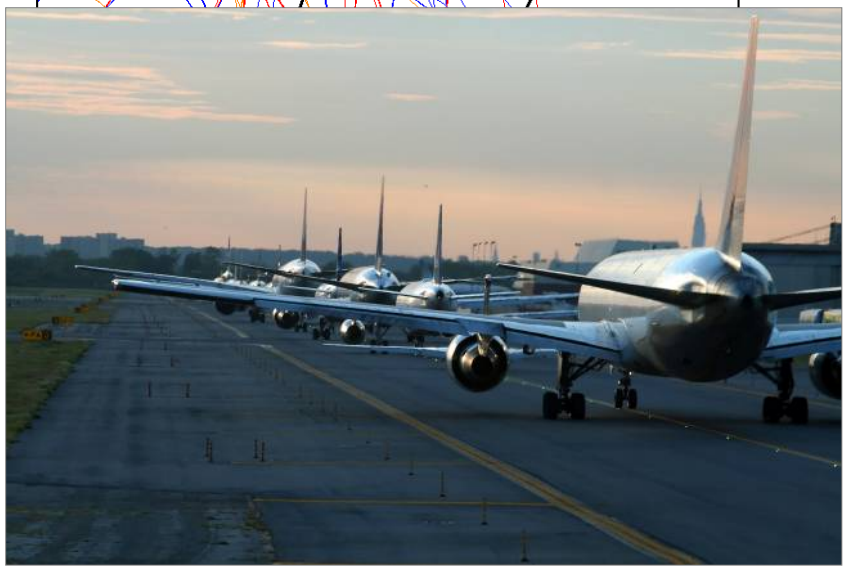
What is the Center for Advanced Aviation System Development (CAASD)?

Mission

To serve the public interest by advancing the safety, security, effectiveness, and efficiency of aviation in the United States and around the world by conducting a continuing program of research, development, and engineering in collaboration with the aviation community

CAASD was officially created in 1990, but MITRE has been supporting the FAA since 1959





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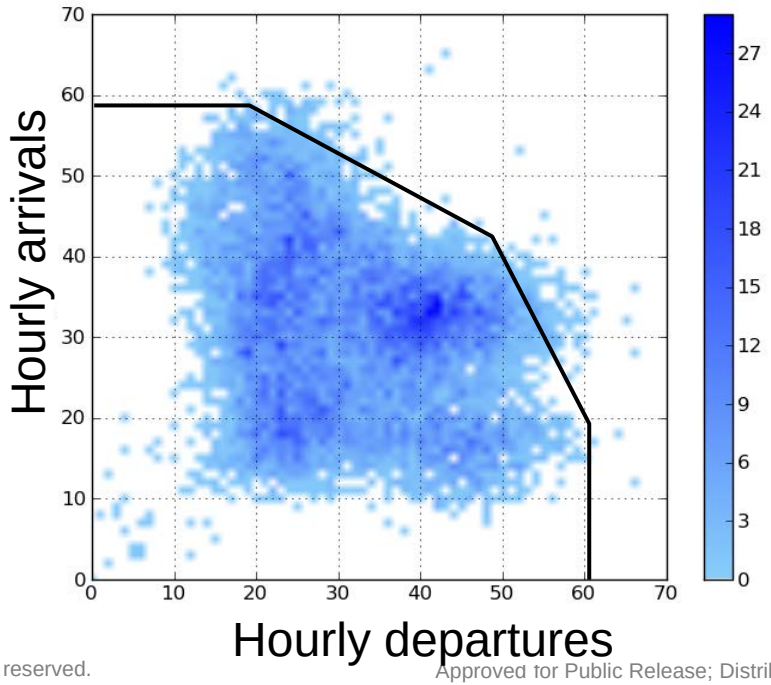
What is Airport Capacity?

- **Capacity is the hourly throughput a runway system is able to sustain during periods of high demand**
  - Expressed as hourly arrival-departure rates
  - Assuming upstream/downstream resources not constraining
  - Typically expressed as a Pareto frontier with tradeoffs between arrivals and departures



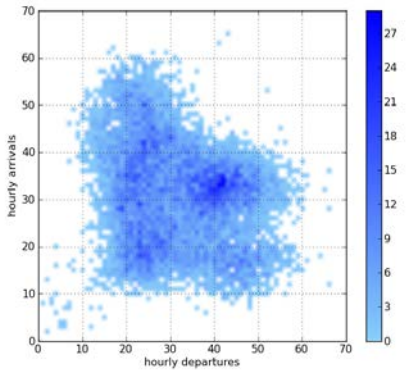
How often throughput observed (count of hours)

What is *runway*Simulator?

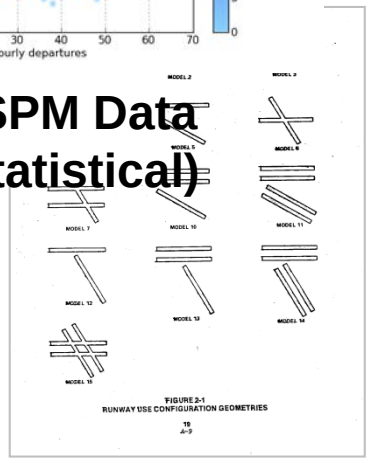
- ***runway*Simulator is a MITRE-developed Monte Carlo simulation designed to estimate airport capacity given any set of inputs**
  - Combines a trajectory model, airport and fleet characteristics, and separation rules to estimate capacity
  - Can easily handle complex interactions that analytic models struggle with
    - NextGen improvements (e.g. 7110.308, ADWs)
    - Interactions between more than 2 runways
    - More than 4 aircraft classes (e.g., for RECAT Phase I)
    - Efficient Sequencing (rather than random)
- **Final output is a capacity curve showing the modeled capacity with constant pressure on the runways**
  - Expressed in operations per hour
  - Optional output includes an animation file of the output, as well as detailed trajectory and separations information

Why use *runway*Simulator? (1/2)

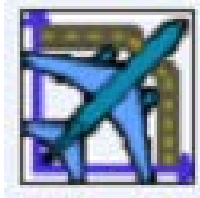
Meant to fill a niche between quick but less flexible tools like ACM, and robust but time-consuming tools like TAAM or SIMMOD



ASPM Data (Statistical)

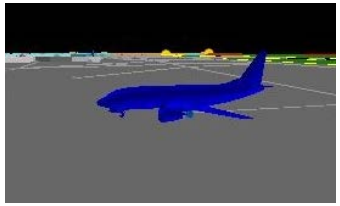


Airfield Capacity Model (Analytical)

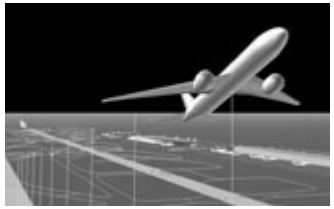


***runway*Simulator**

ADSIM/RDSIM



SIMMOD



(Simulation) TAAM

Greater fidelity
More time and expense

Why use *runway*Simulator? (2/2)

- **Capture the capacity effects of changes in factors we model**
  - Improvements, fleet mix, runway usage, etc.
  - List of model components on next slide
- **Provide capacity inputs to system-wide models or delay models**
  - MITRE's *systemwide*Modeler, FAA's System-Wide Analysis Capability (SWAC), etc.
- **Give insight into what constrains capacity**
  - Arrival/departure tradeoffs, effects of weather and various modeling assumptions

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What goes into *runway*Simulator?

- **Eight components of any *runway*Simulator simulation:**

Component	Example
Airport Layout	Runway Geometry at EWR
Arrival and Departure Procedures	ILS approach to Runway 29
Flight Attributes and Filters	Which aircraft are considered Heavy
Fleet Mix	12% E145; 4% B772; etc
Aircraft Performance Parameters	Landing Speed for B737 is 133 kts
Procedure Eligibility	No Heavies arrive on Runway 29
Separation Rules	Non-simultaneous runway occupancy
Scenario Execution Parameters	Visual Meteorological Conditions

- **Default inputs are provided for most components, but all can be tailored depending on the fidelity and depth of the modeling desired**
- **Component-based design allows efficient re-use for additional simulations**

Validation of Capacity Results

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Overview of Validations

- **Capacity curves generated by the CAASD Airport Capacity Estimation (CACE) effort conducted for the FAA NextGen office (ANG)**
  - Inputs from 2011 are used
    - Runway Layouts, Procedures, Fleet Mixes, and Separation Rules
  - Most common configuration(s) in the given meteorological conditions are used
    - Airport configuration denoted as “Arrival Runways | Departure Runways”
- **Comparison graphics are capacity curves output from *runway*Simulator overlaid on actual throughput and called rates from ASPM**
  - Called rates are a simple answer to “what is the capacity?”
  - *runway*Simulator provides both a more comprehensive answer and insight into the tradeoff between arrivals and departures
    - Called rates can provide an additional data point to assess the validity of the model results

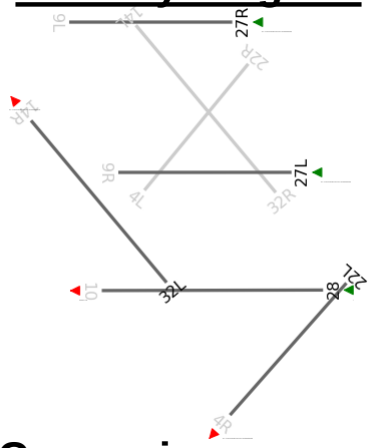
Airport Selection

- **The top six most-delayed airports in 2013 were chosen for validation. They are**
  - Chicago O'Hare International Airport (ORD)
  - Newark Liberty International Airport (EWR)
  - LaGuardia Airport (LGA)
  - San Francisco International Airport (SFO)
  - Philadelphia International Airport (PHL)
  - John F Kennedy International Airport (JFK)
- **Delay data was obtained from The Operations Network (OPSNET) data**
- **Validations were conducted in Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC).**
  - VMC graphs have many data points to compare the capacity curves to
  - IMC graphs generally have fewer data points, not only because IMC is rarer but also because of the variety of configurations used in poorer weather
    - The ASPM weather data used is binned hourly, so some data points may include higher-capacity non-IMC operations

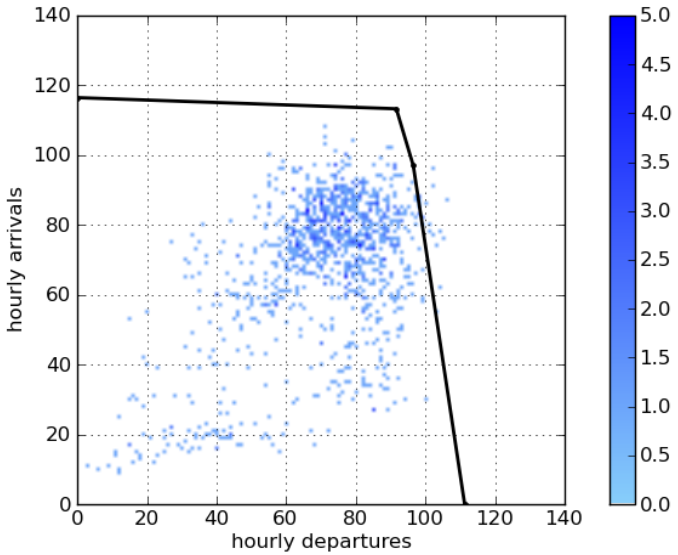
Validation at ORD in VMC Configuration: 27L,27R,28 | 22L,28,32L

- **Operations occur right up to the capacity curve modeled in *runway*Simulator**
  - The model demonstrates good adherence with actual throughputs
  - Runway crossings are modeled on some runways

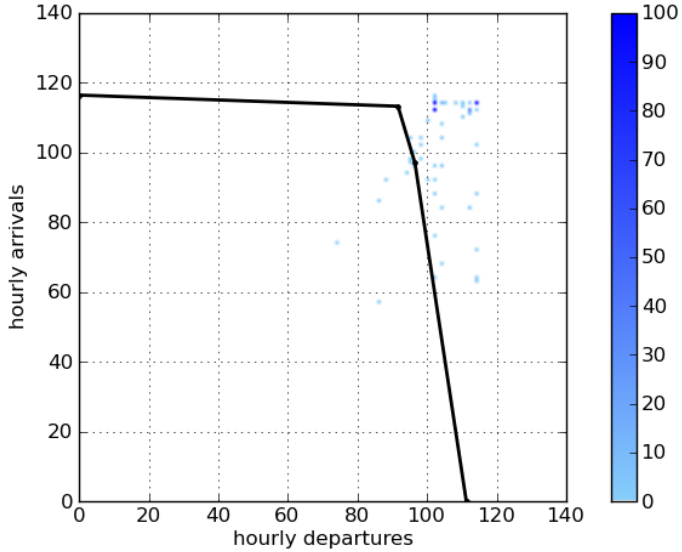
Runway Diagram



Actual Throughput Comparison



Called Rates Comparison



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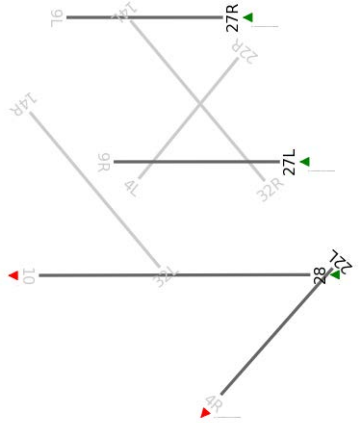
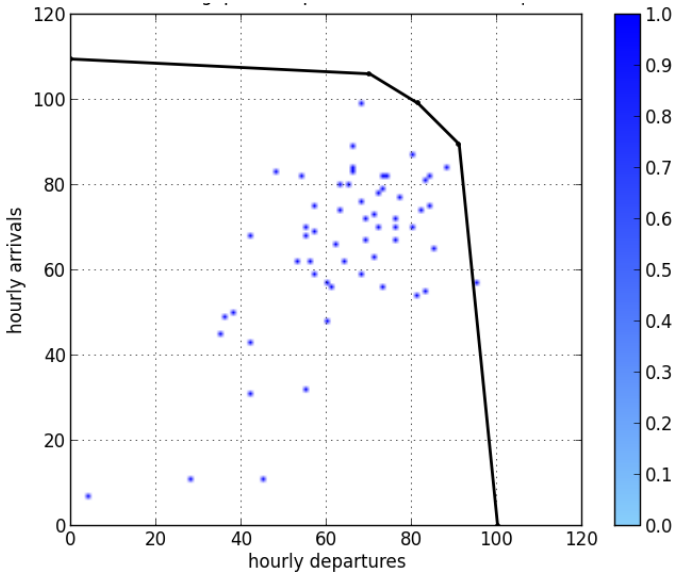
Validation at ORD in IMC Configuration: 27L,27R,28 | 22L,28

- **Operations occur right up to the capacity curve modeled in *runway*Simulator**
  - There are fewer data points in IMC for this configuration, but *runway*Simulator results match up well with actual throughputs

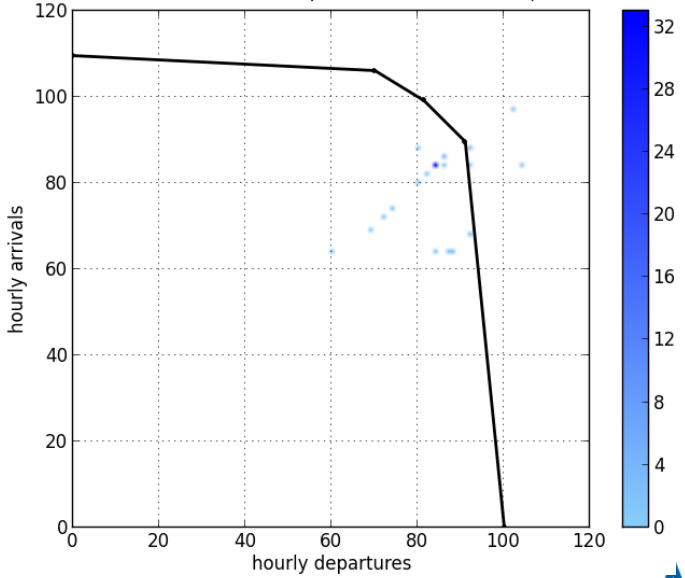
Runway Diagram



Actual Throughput Comparison



Called Rates Comparison



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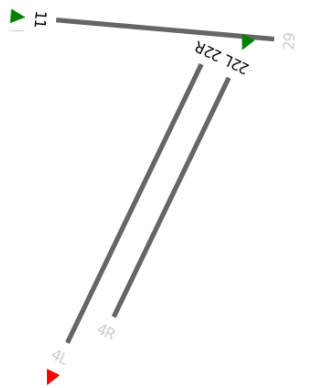
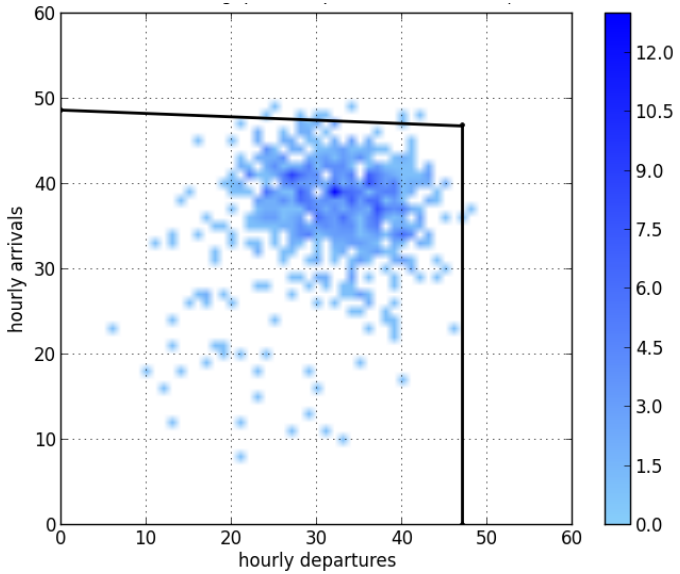
Validation at EWR in VMC Configuration: 11,22L | 22R

- **Operations occur right up to the capacity curve modeled in *runway*Simulator**
  - The simulated arrival capacity is a better upper-bound than the called Arrival rate

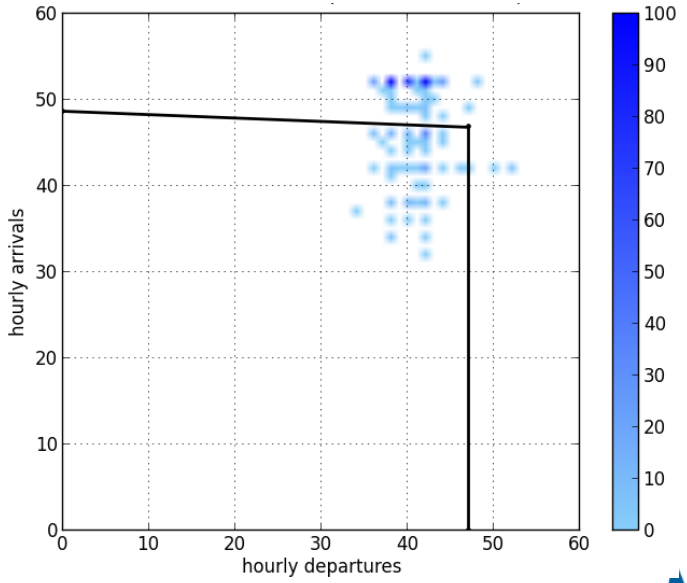
Runway Diagram



Actual Throughput Comparison



Called Rates Comparison



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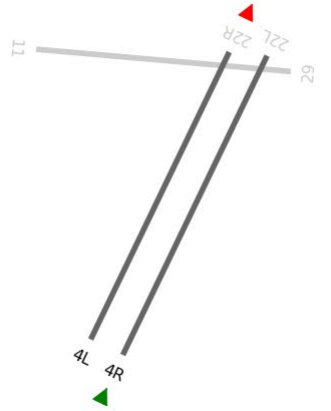
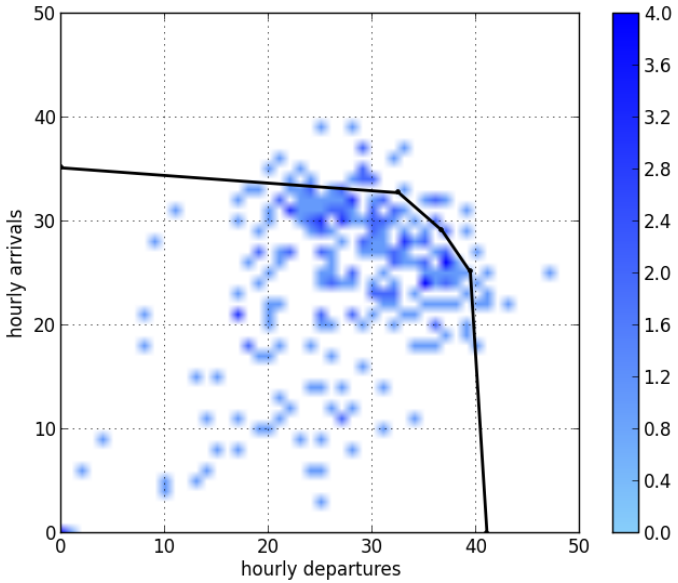
Validation at EWR in IMC Configuration: 04R | 04L

- **Some hours' operations are in excess of the capacity curve modeled in *runway*Simulator**
  - Some hours may be affected by non-instrument operations

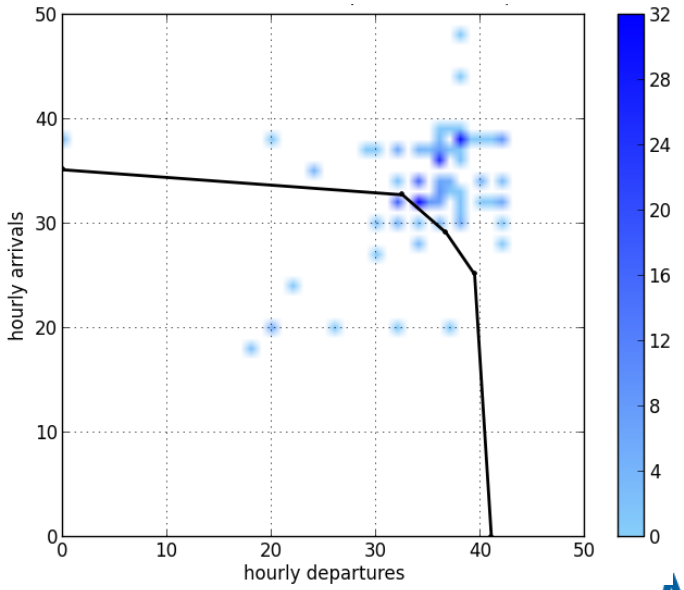
Runway Diagram



Actual Throughput Comparison



Called Rates Comparison



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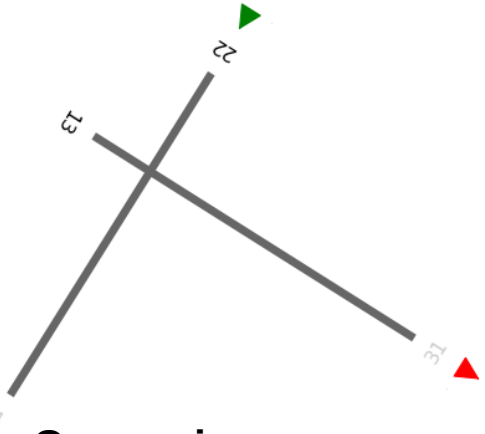
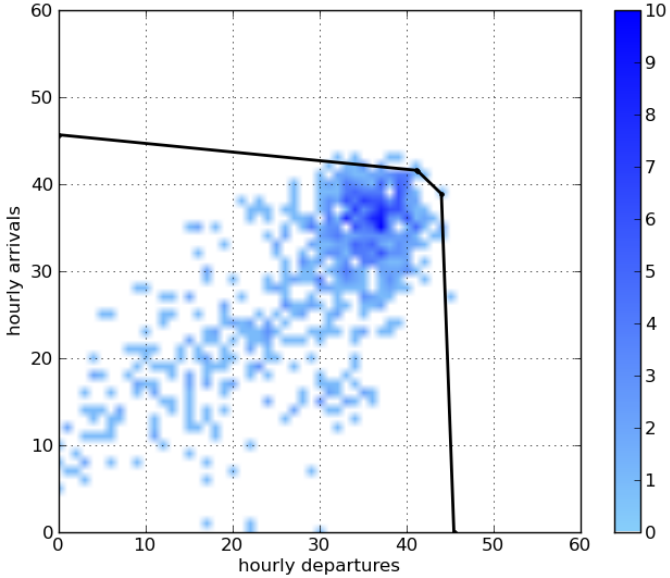
Validation at LGA in VMC Configuration: 22 | 13

- **Operations occur right up to the capacity curve modeled in *runway*Simulator**
  - The model demonstrates good adherence with actual throughputs

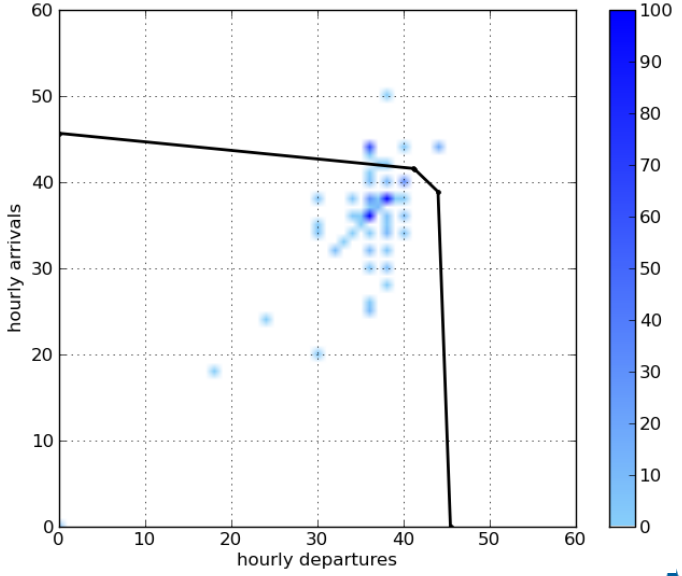
Runway Diagram



Actual Throughput Comparison



Called Rates Comparison



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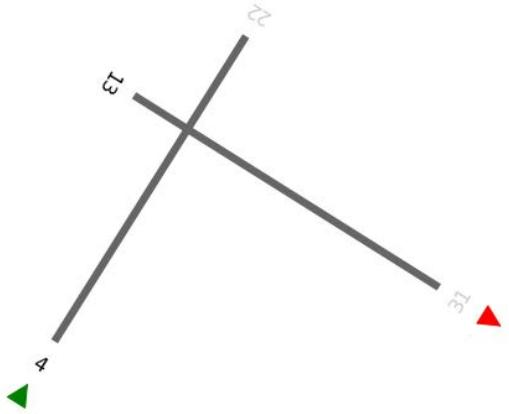
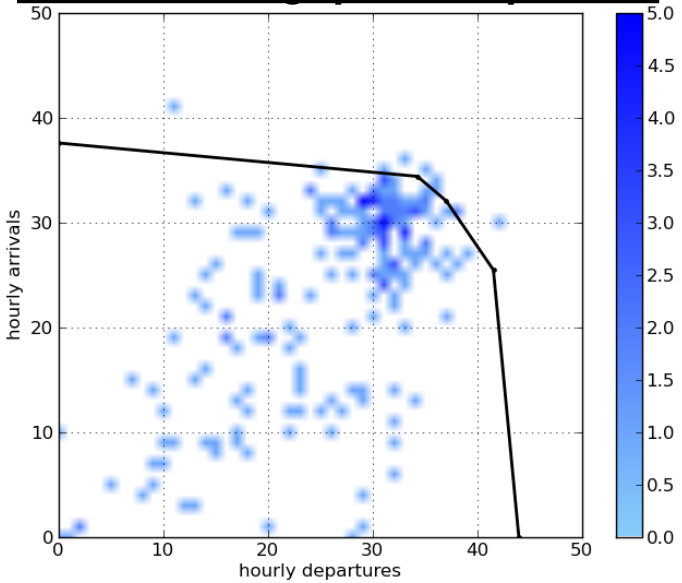
Validation at LGA in IMC Configuration: 04 | 13

- **Operations occur right up to the capacity curve modeled in *runway*Simulator**
  - The model demonstrates good adherence with actual throughputs

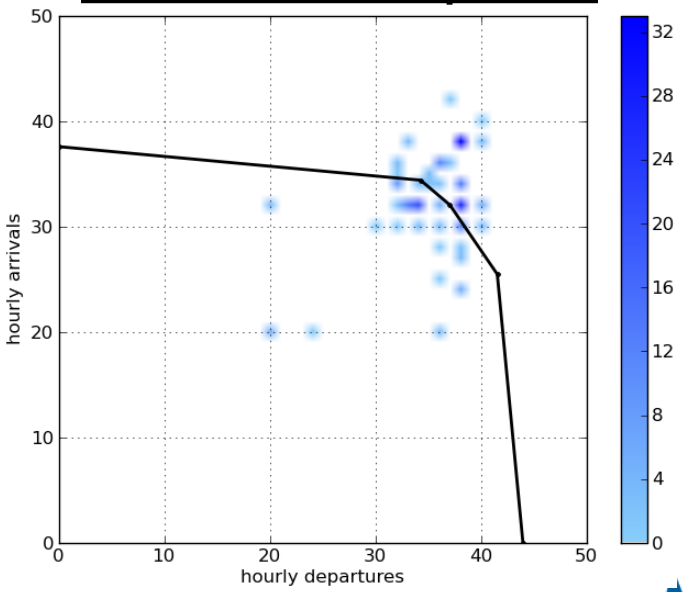
Runway Diagram



Actual Throughput Comparison



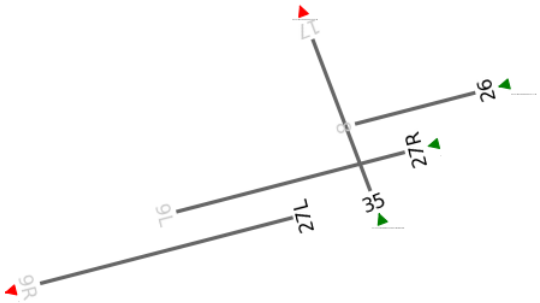
Called Rates Comparison



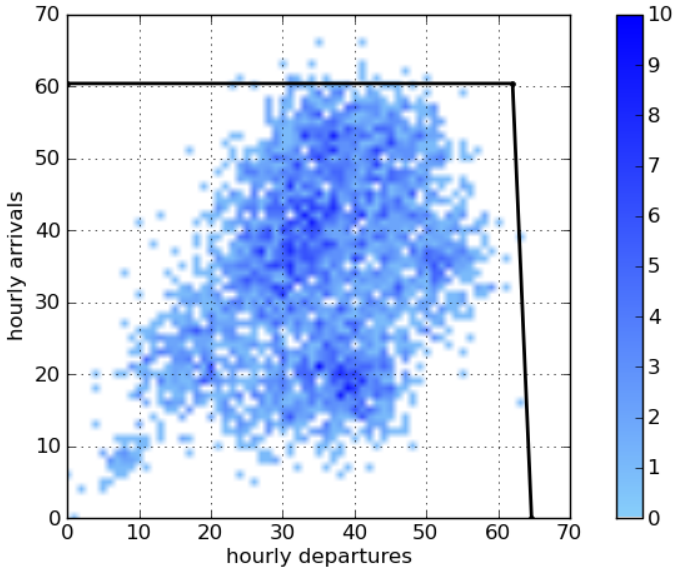
Validation at PHL in VMC Configuration: 26,27R,35 | 27L,35

- **Operations occur right up to the capacity curve modeled in *runway*Simulator**
  - The model demonstrates good adherence with actual throughputs

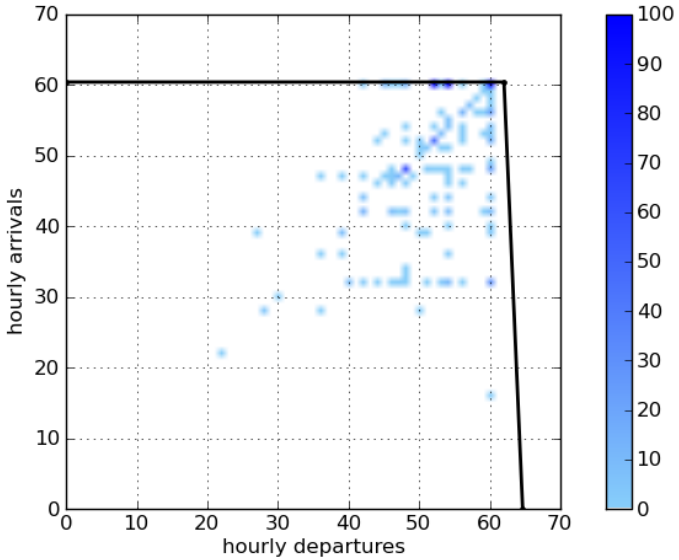
Runway Diagram



Actual Throughput Comparison



Called Rates Comparison



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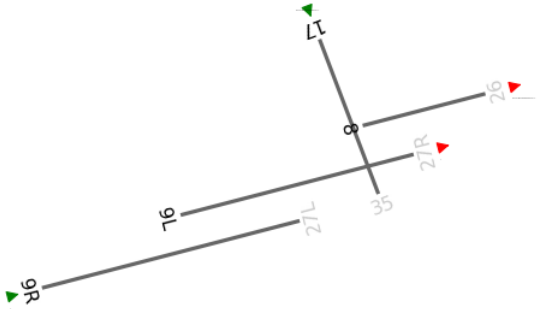
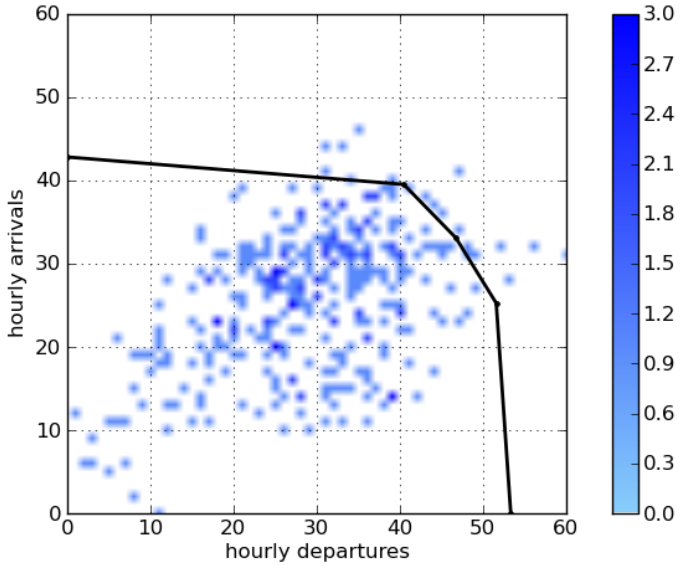
Validation at PHL in IMC Configuration: 09R,17 | 08,09L

- **Operations occur right up to the capacity curve modeled in *runway*Simulator**
  - The model demonstrates good adherence with actual throughputs

Runway Diagram



Actual Throughput Comparison



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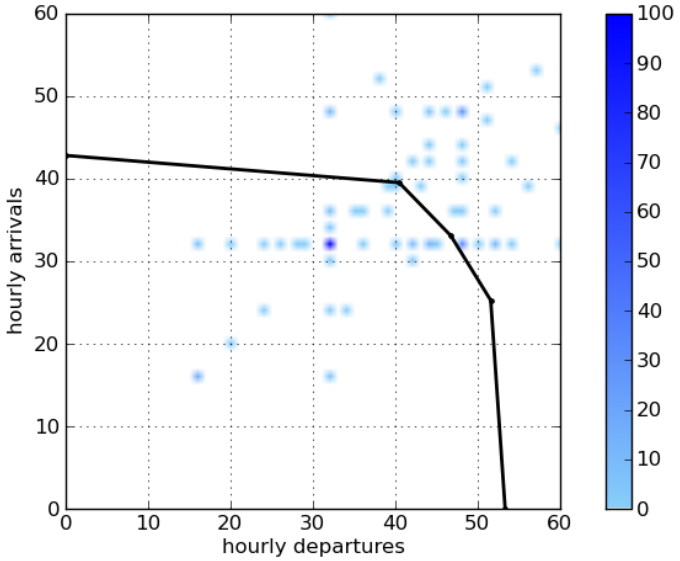

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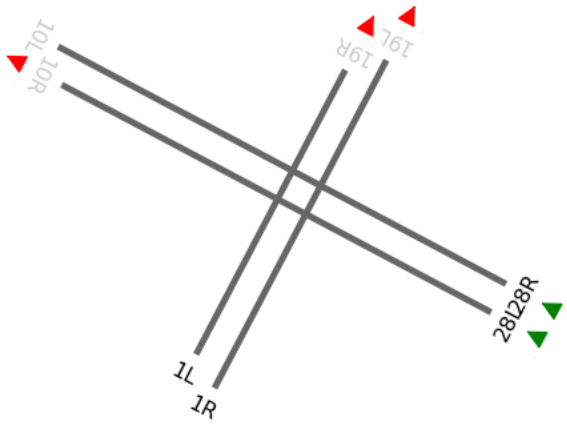
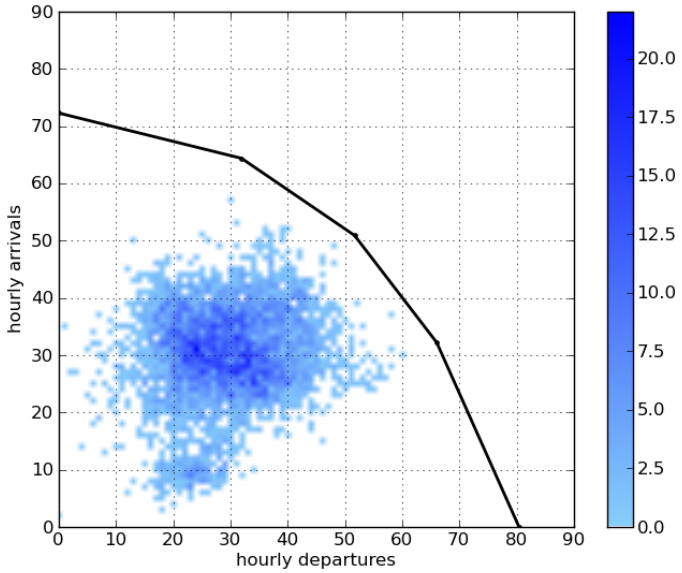
Validation at SFO in VMC Configuration: 28L,28R | 01R,01L,28L

- ***runway*Simulator's capacity estimate is higher than actual operations at SFO**
  - Significant arrival/departure tradeoff between operations
  - Due to substantial capacity decrease in poor weather, SFO doesn't fully schedule against VMC capacity. Marginal Meteorological Conditions (MMC) curve provided in backup as secondary validation

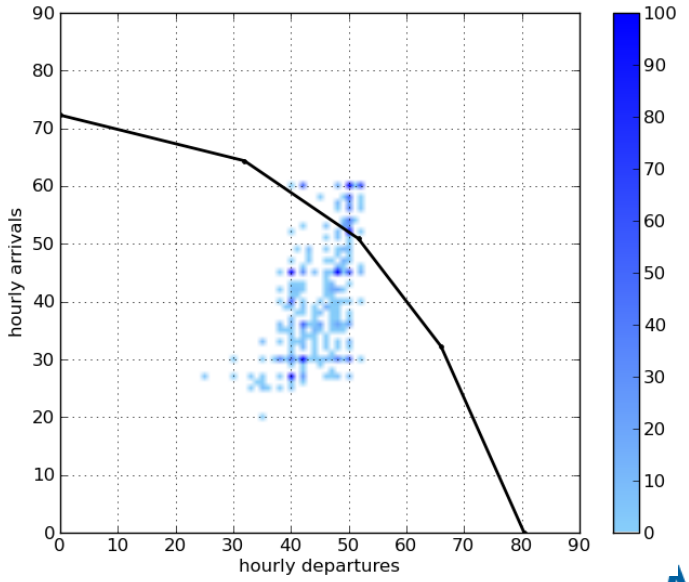
Runway Diagram



Actual Throughput Comparison



Called Rates Comparison



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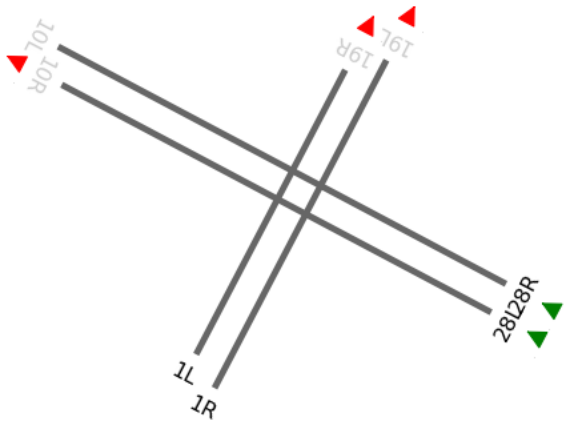
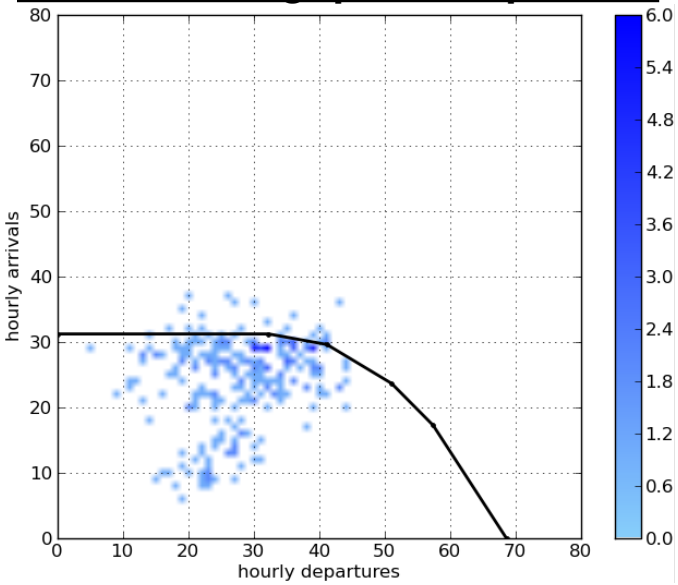
Validation at SFO in IMC Configuration: 28L,28R | 01R,01L,28L

- **Operations occur right up to the capacity curve modeled in *runway*Simulator, with some points above the curve**
  - Some points from ASPM may have non-instrument operations (as evidenced by significantly higher called rates)

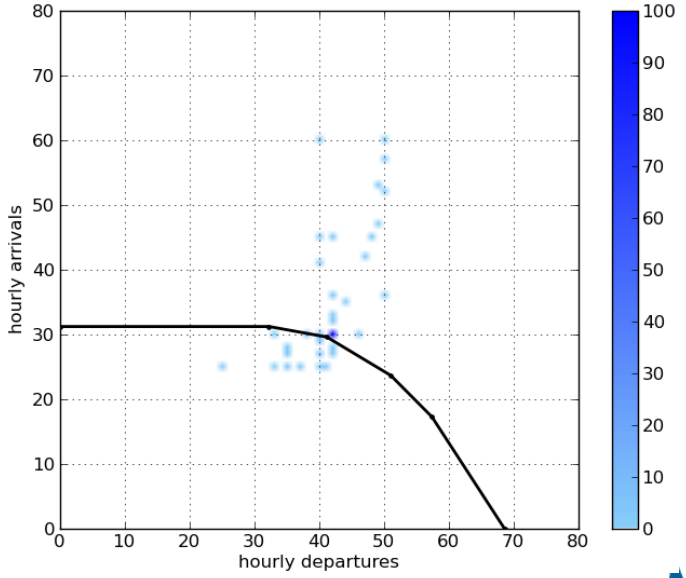
Runway Diagram



Actual Throughput Comparison



Called Rates Comparison



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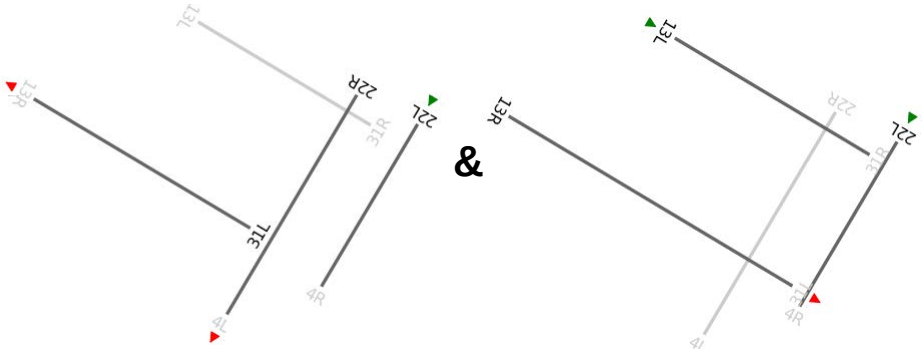
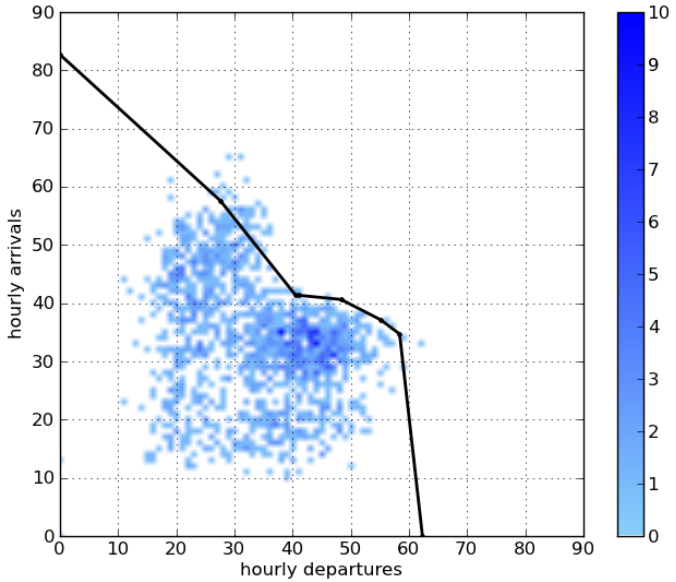
Validation at JFK in VMC
Configurations: 22L | 22R,31L and 13L,22L | 13R

- **Operations occur right up to the capacity curve modeled in *runway*Simulator**
  - Oddly shaped curve is because the two configuration's curves are blended together
  - The model demonstrates good adherence with actual throughput
  - Far more accurate than many called rates

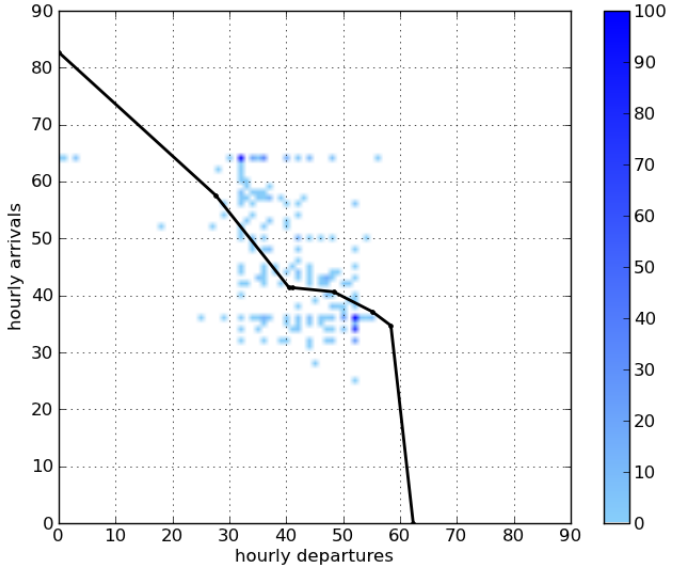
Runway Diagrams



Actual Throughput Comparison



Called Rates Comparison



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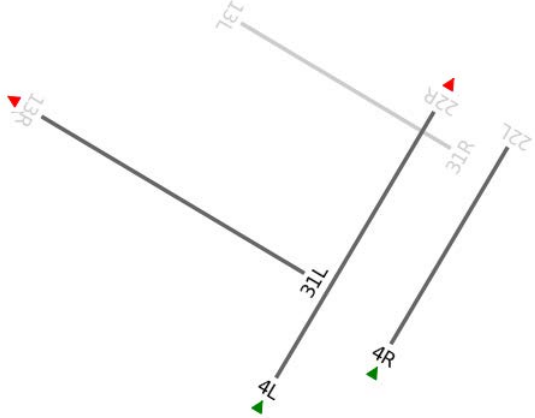
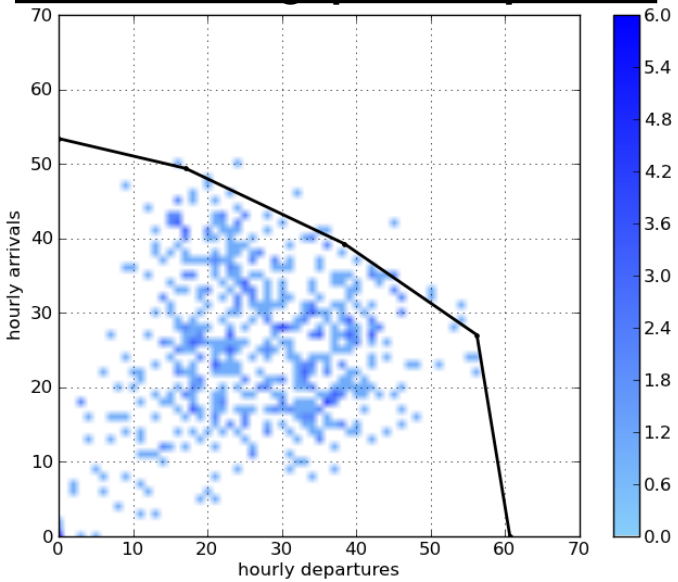
Validation at JFK in IMC Configuration: 04L,04R | 04L,31L

- **Operations occur right up to the capacity curve modeled in *runway*Simulator**
  - The model demonstrates good adherence with actual throughput
  - As with VMC, *runway*Simulator output can be far more accurate than called rates

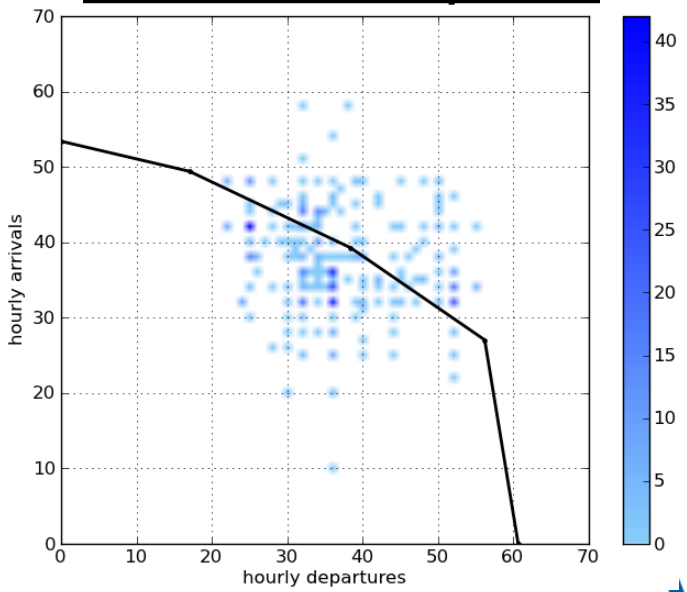
Runway Diagram



Actual Throughput Comparison



Called Rates Comparison



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Summary and Conclusions

- ***runway*Simulator is a MITRE-developed tool to calculate airport capacity**
  - Meant to fill a niche between easy-to-use but less-flexible tools like ACM, and robust but more effort-intensive tools like TAAM or SIMMOD
  - Component-based design allows easy re-use for multiple simulations
- **Results achieved with *runway*Simulator match up well with actual arrivals and departures at busy airports**
  - *runway*Simulator provides both a more accurate answer and insight into the tradeoff between arrivals and departures than simple called rates in both visual and instrument conditions
- **Additional validation analyses have been conducted by external organizations. For further details and comparisons to other models, please consult**
  - A. Kim and M. Hansen, “Validation of Runway Capacity Models,” ATM2009
  - ACRP 03-79, “Evaluating Airport Capacity”, Transportation Research Board

Backup

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Additional Simulation Comparisons to Throughput

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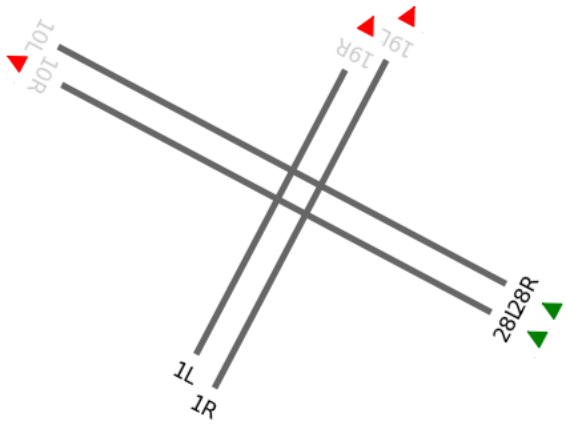
Additional Airport Validations

- **Four additional airport configurations were chosen to give additional insight into *runway*Simulator. They are**
  - SFO in Marginal Meteorological Conditions (MMC)
  - Washington Dulles International Airport (IAD) in VMC
  - Orlando International Airport (MCO) in Instrument Meteorological Conditions (IMC)
  - San Antonio International Airport (SAT) in MMC
- **MCO and SAT do not operate close to their maximum runway system capacity, and therefore cannot be validated in the same way**
  - Nevertheless, *runway*Simulator gives insight into the tradeoff between arrival and departure capacity, and can still estimate the capacity benefits of new procedures and technology at the airports
  - While in other cases, the *runway*Simulator capacity curves are higher fidelity than the called rates, in these cases the called rates can be used to verify that the *runway*Simulator capacity curves are reasonable

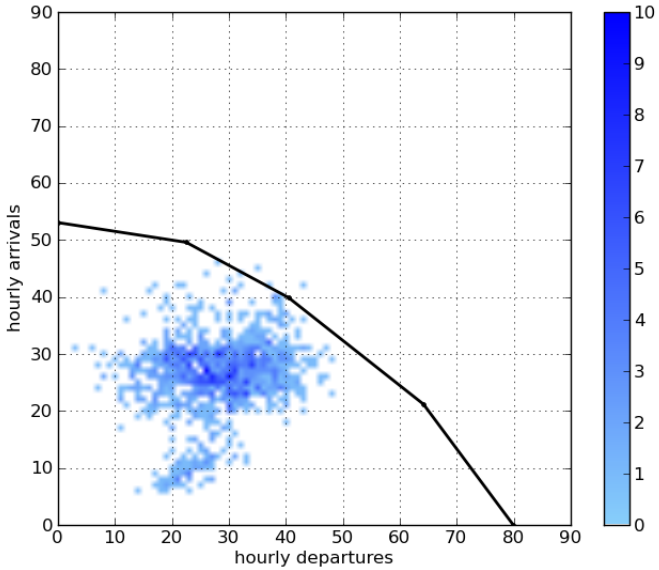
Validation at SFO in MMC Configuration: 28L,28R | 01R,01L,28L

- **Operations occur right up to the capacity curve modeled in *runway*Simulator**
  - The model demonstrates good adherence with reality

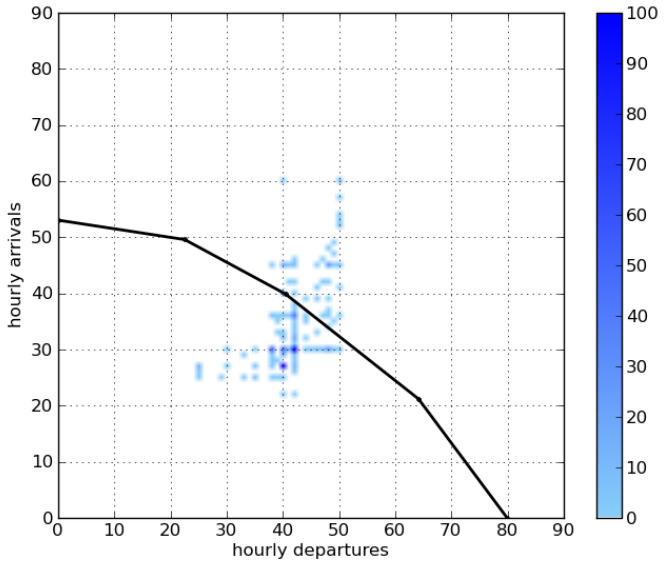
Runway Diagram



Actual Throughput Comparison



Called Rates Comparison



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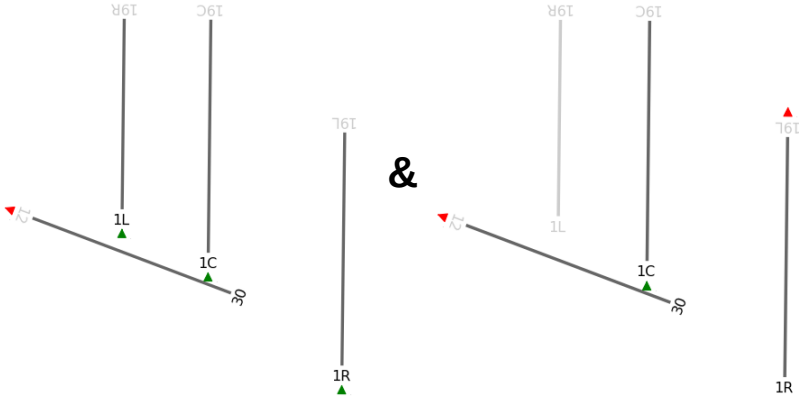
Validation at IAD in VMC

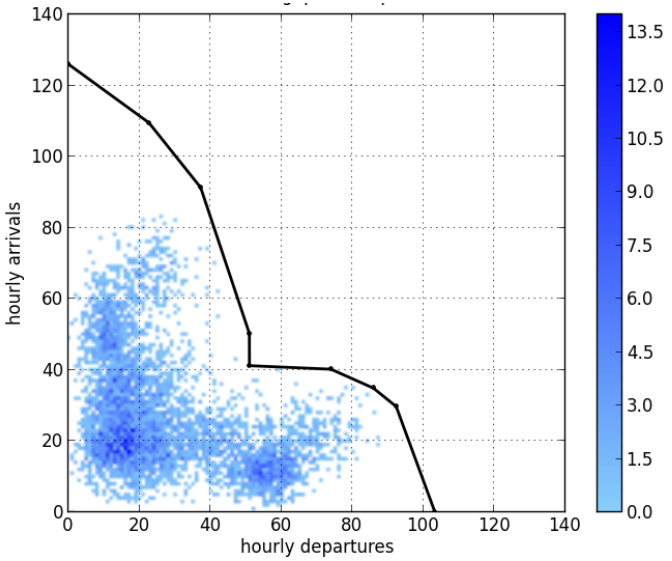
Configurations: 01L,01C,01R | 30 and 01C | 01R,30

- **IAD operates with heavy arrival and departure pushes, so two curves were blended to describe the airport behavior**
  - Actuals arrivals and departures are within the simulated curve
  - The departure-heavy configuration (01C|01R,30) is rarely reflected in called rates but is used frequently

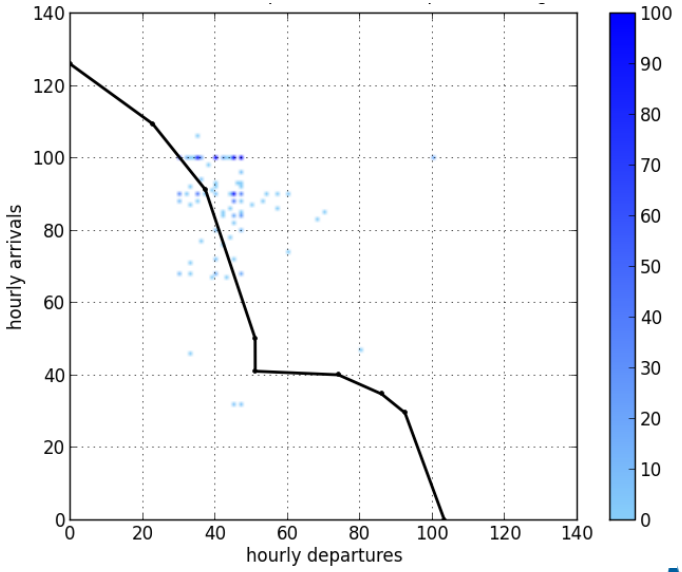
Runway Diagrams



Actual Throughput Comparison



Called Rates Comparison



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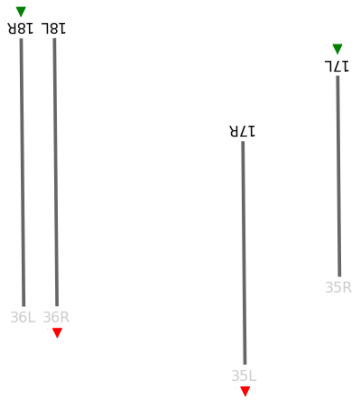
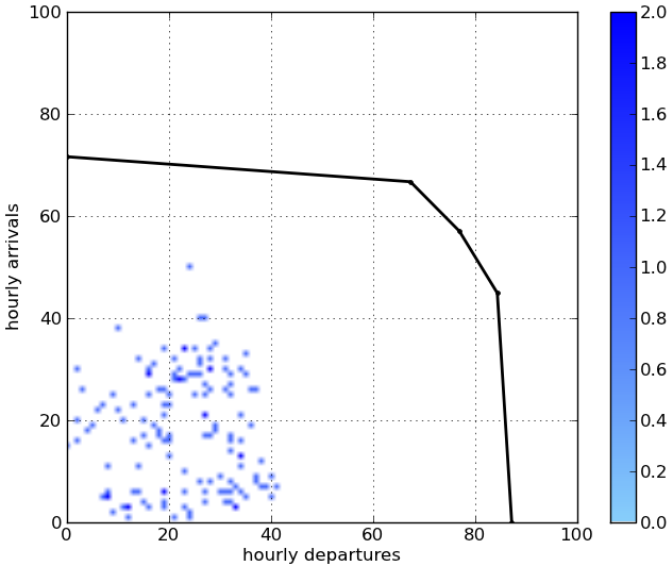
Validation at MCO in IMC Configuration: 17L,18R | 17R,18L

- **MCO has lots of additional spare capacity in IMC**
  - It is difficult to validate a capacity curve when no hourly arrival or departure counts are close to it

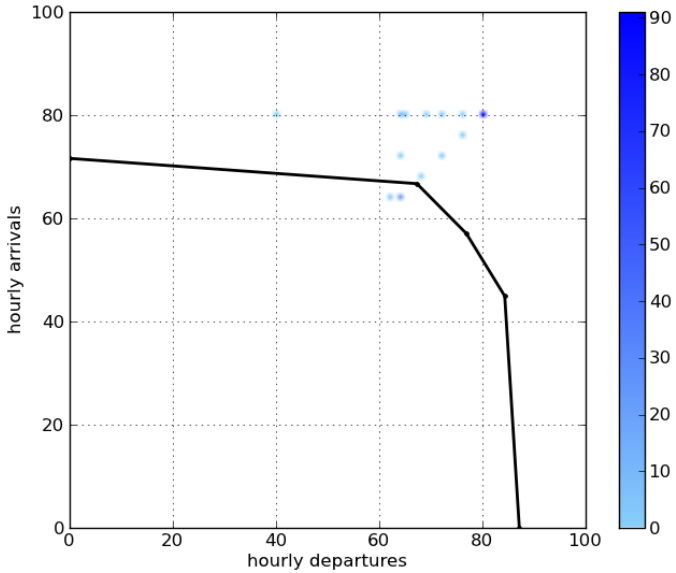
Runway Diagram



Actual Throughput Comparison



Called Rates Comparison



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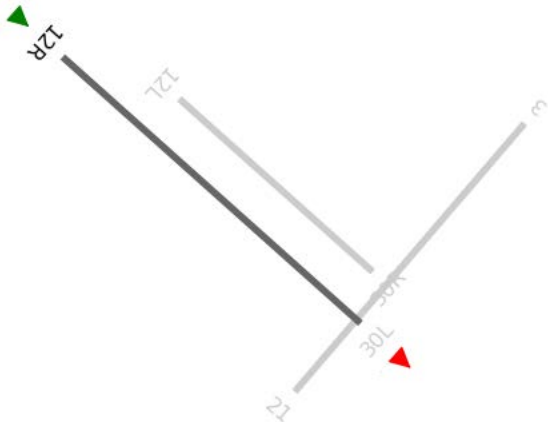
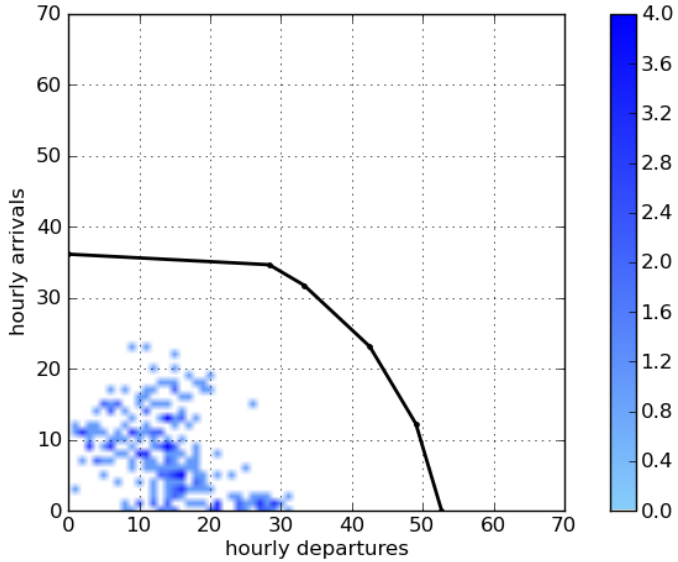
Validation at SAT in MMC Configuration: 12R | 12R

- **SAT has lots of additional spare capacity in MMC**
  - It is difficult to validate a capacity curve when no hourly arrival or departure counts are close to it
  - *runway*Simulator gives insight into the tradeoff between arrivals and departures

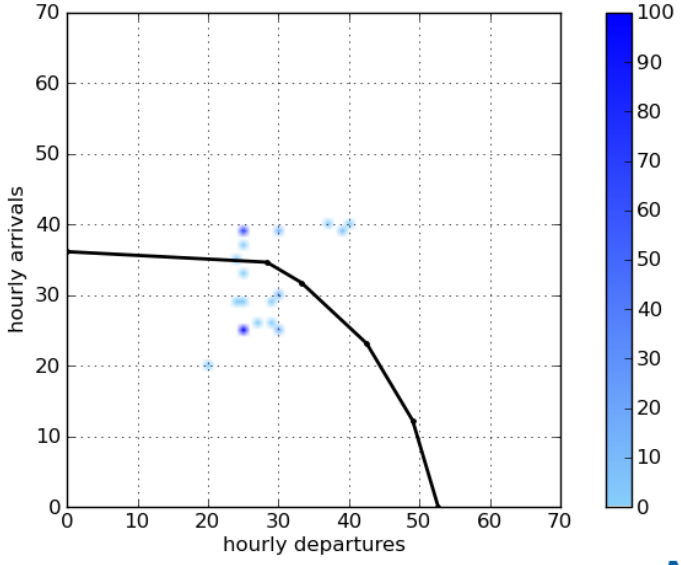
Runway Diagram



Actual Throughput Comparison



Called Rates Comparison



Separations Validation

Approved for Public Release; Distribution Unlimited. Case Number 14-3186

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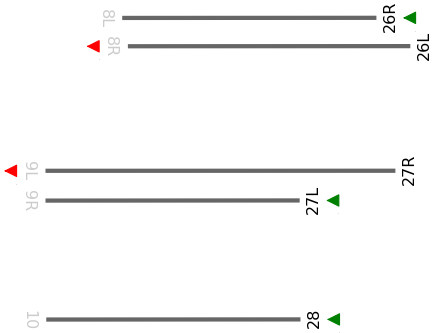
Separation Validation Description

- **Atlanta Hartsfield Jackson International Airport (ATL) was modeled in VMC, using 2013 data and assumptions**
  - This was after the implementation of the Equivalent Lateral Spacing Operation (ELSO) procedure was enabled, allowing for additional departure headings contingent on equipage

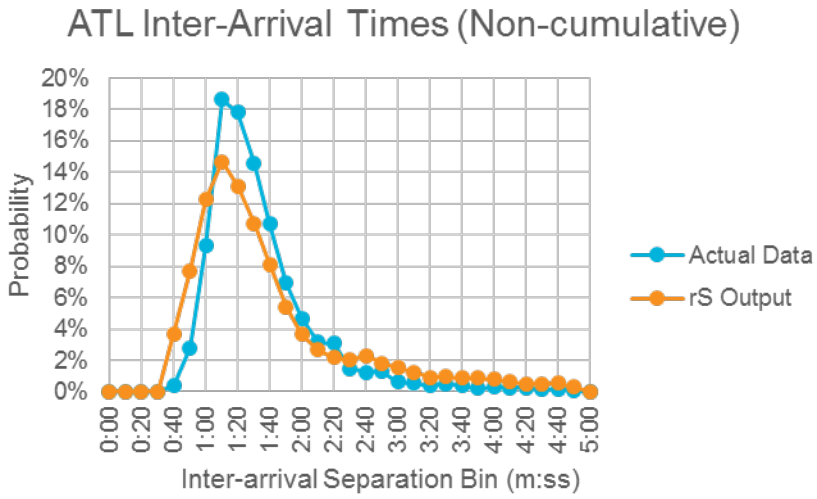
Runway Diagram

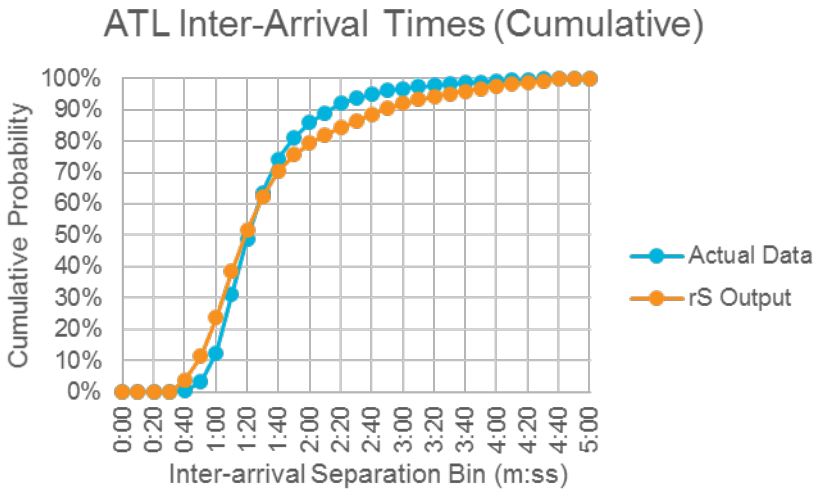


- **For validation, FAA surveillance data was used to measure separation across the arrival threshold, as well as inter-departure times (as measured from rotation/wheels-up)**
  - Data was taken from peak hours in May 2014, prior to the implementation of Wake Recategorization (RECAT) Phase I
    - Arrival peaks were 8:00-8:59 am and 7:00-7:59 pm
    - Departure peak was 10:00-10:59 am
  - All same-runway pairs separated by less than five minutes were included in the analysis

Arrival Separations

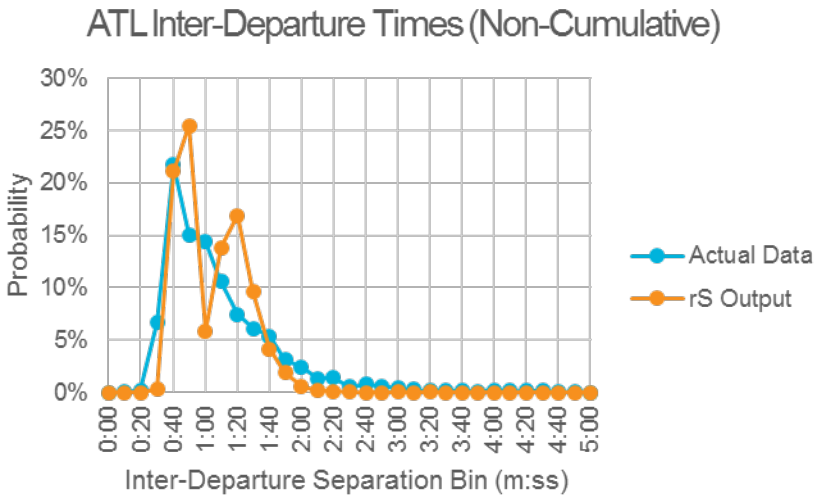
- **On average, rS output stated an average separation of 1:39, while the surveillance data showed an average separation of 1:35**
  - The rS output has a wider distribution due to the runway crossings modeled on Runway 27L
    - The number of runway crossings in reality are lower than modeled, since ATL does not use Runway 28 as often as 26R and 27L due to the significantly longer taxi

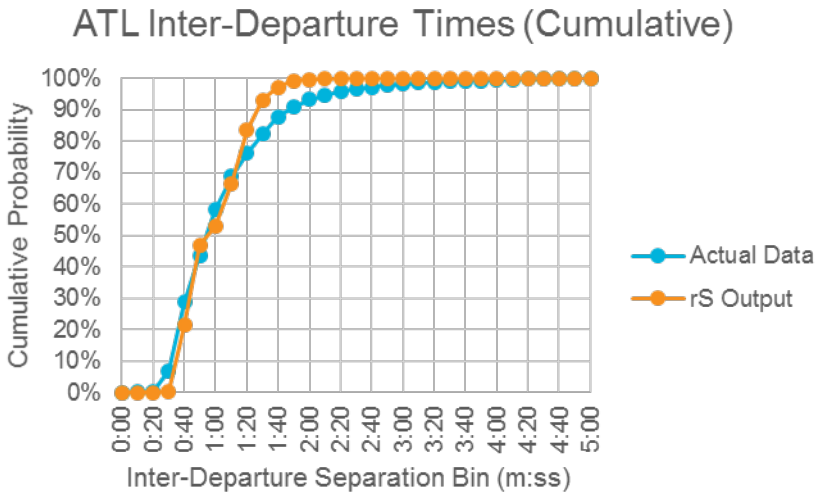




Departure Separations

- **On average, rS output stated an average separation of 1:04, while the surveillance data showed an average separation of 1:09**
  - The departure distribution has two peaks for aircraft that are, and are not, fanned departures
    - The right tail of the actual data shows a longer tail than what is modeled; could be due to factors *runway*Simulator is not modeling





Separations Validation Conclusions

- **With limited airport-specific factors modeled, simulated separations were close to actual surveillance data (averages within 5 seconds)**
  - This is true for both arrivals and departures
  - *runway*Simulator supports additional tailoring of parameters in the model, which would bring the separation values closer to the actuals; however, this would require a more detailed airport-specific analysis at an added cost
- ***runway*Simulator is simulating the runway system under continuously high demand, and with no irregular operations. While much of the radar data is thought to represent similar conditions, the matching is not exact. *runway*Simulator mimics the human responses of ATC and other stakeholders to various real but random events. Many aspects of the NAS outside the runway system are not directly modeled.**

Speed Profile Validation

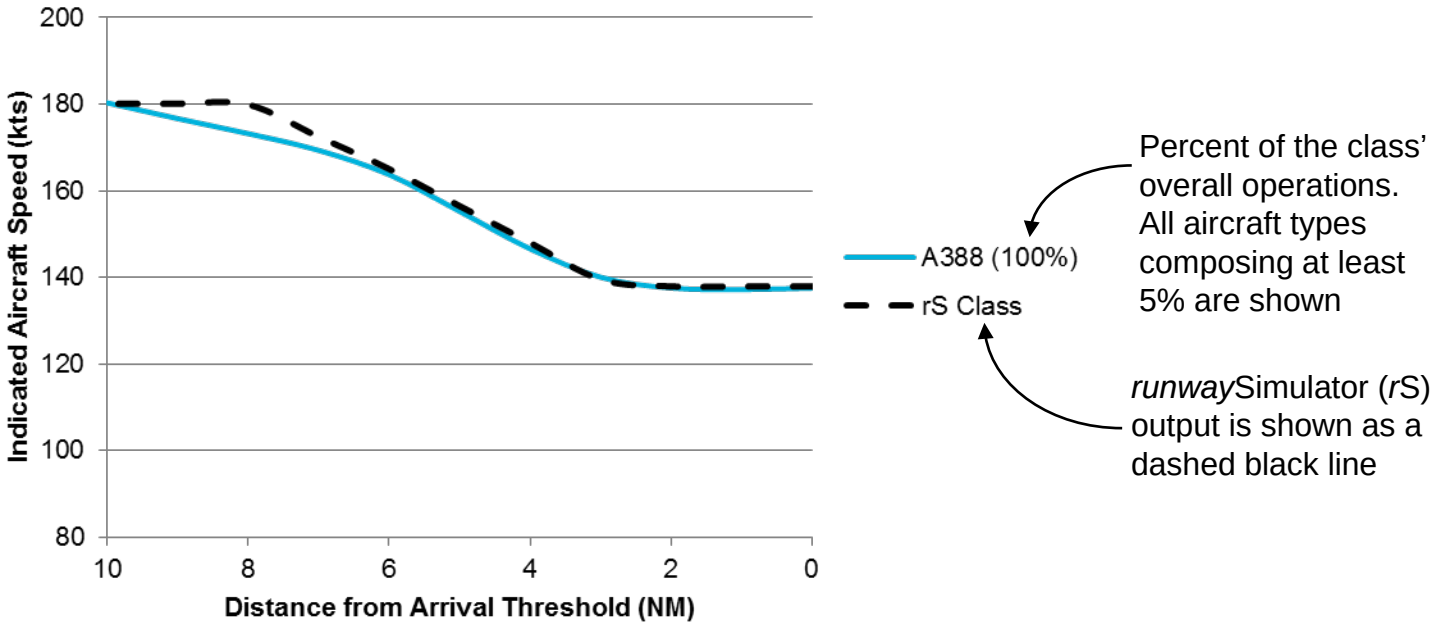
Approved for Public Release; Distribution Unlimited. Case Number 14-3186

Speed Profile Validation Description

- **FAA surveillance data was used to determine the national weighted-average arrival speed profiles for various aircraft types**
  - Weighted by operations at Core 30 airports (operations outside of Core 30 not included in this analysis)
- **By default, various aircraft types are represented by a single aircraft type in the model**
  - E.g., Small Turboprop Category III aircraft are all represented by the Embraer Brasilia (E120) aircraft type
- ***runway*Simulator supports additional tailoring of parameters in the model, which would bring the speed profiles closer to the actuals; however, this would require a more detailed airport-specific analysis at an added cost**
  - Additionally, aircraft within a class can be modeled separately if that level of fidelity is required

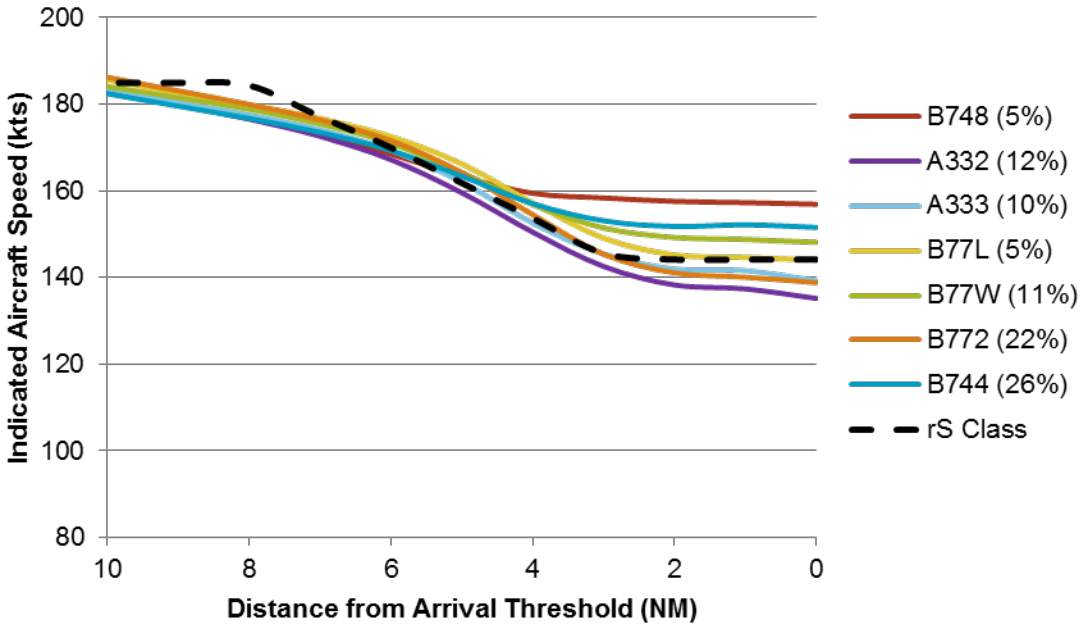
Weight Class: Super, Category A (RECAT)
Engine Type: Jet
Same Runway Separation Category: III

- **The A380 is the only aircraft type in this category with significant operations**
- **Similar to many larger jets, it has a stabilized approach point around 3 NM from the arrival threshold at which the landing speed is reached**
- **Within six miles (the default Final Approach Fix, or FAF), the time to fly is**
  - 146 seconds in *runway*Simulator
  - 152 seconds in the surveillance data



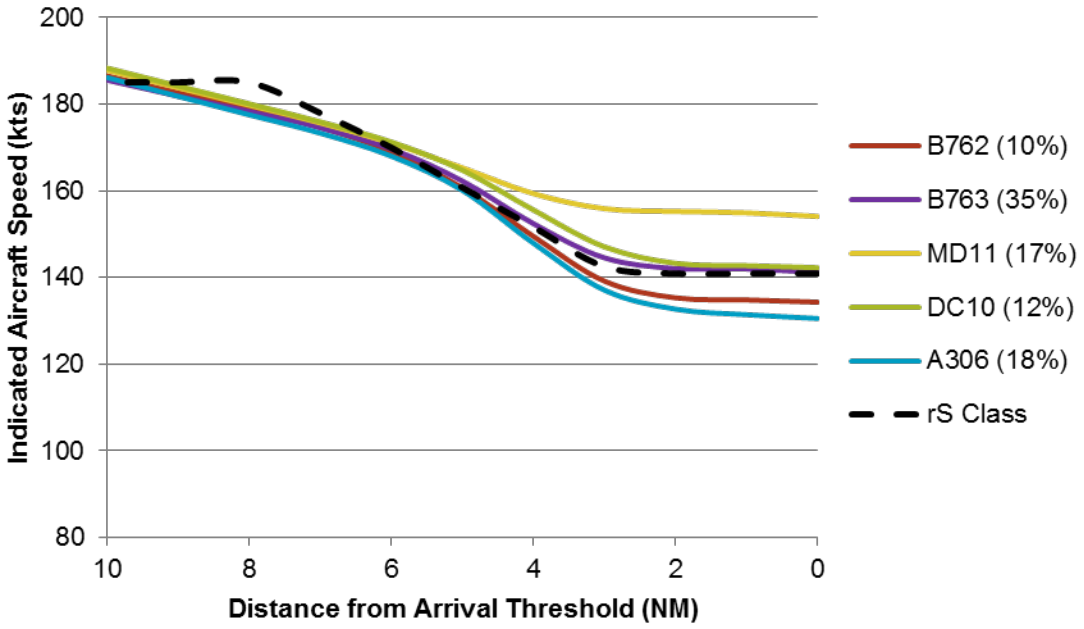
Weight Class: Heavy, Category B (RECAT)
Engine Type: Jet
Same Runway Separation Category: III

- **The B748 lands at a significantly faster speed than other Heavy aircraft**
- **The two most common in this class, B744 and B772, have landing speeds that differ by 15 knots**
- **Within six miles (the default FAF), the time to fly is**
  - 140 seconds in *runway*Simulator
  - 145 seconds in the surveillance data



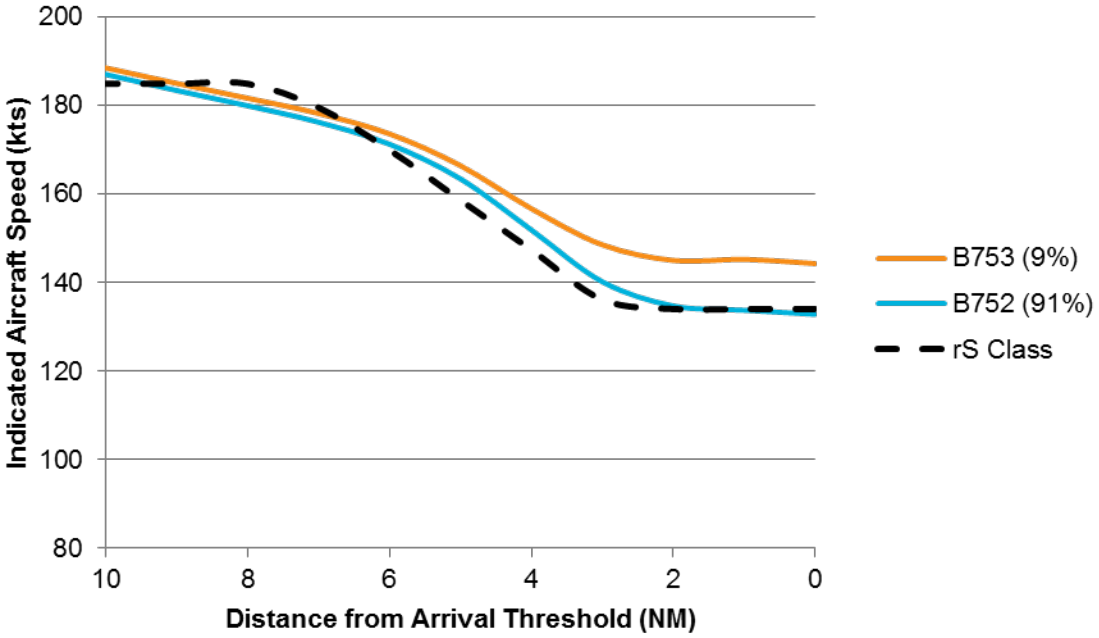
Weight Class: Heavy, Category C (RECAT)
Engine Type: Jet
Same Runway Separation Category: III

- **MD11s are significantly faster, but B763s are the most common and very close to the *runway*Simulator profile**
- **Within six miles (the default FAF), the time to fly is**
  - 142 seconds in *runway*Simulator
  - 147 seconds in the surveillance data



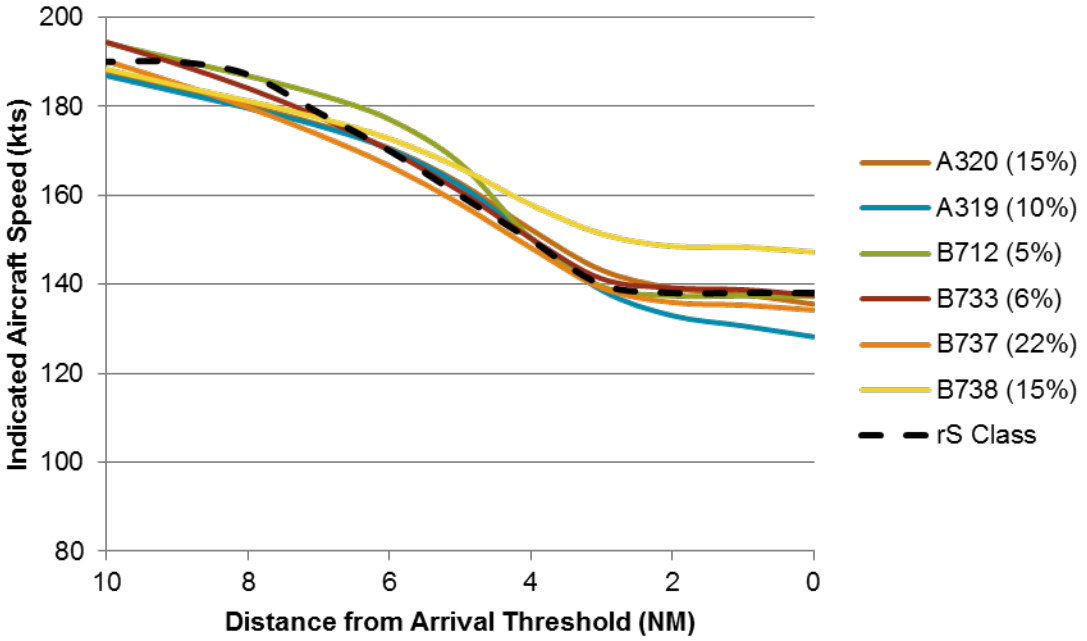
Weight Class: B757, Category D (RECAT)
Engine Type: Jet
Same Runway Separation Category: III

- **B752s are far more common than B753s**
- **Within six miles (the default FAF), the time to fly is**
  - 148 seconds in *runway*Simulator
  - 150 seconds in the surveillance data



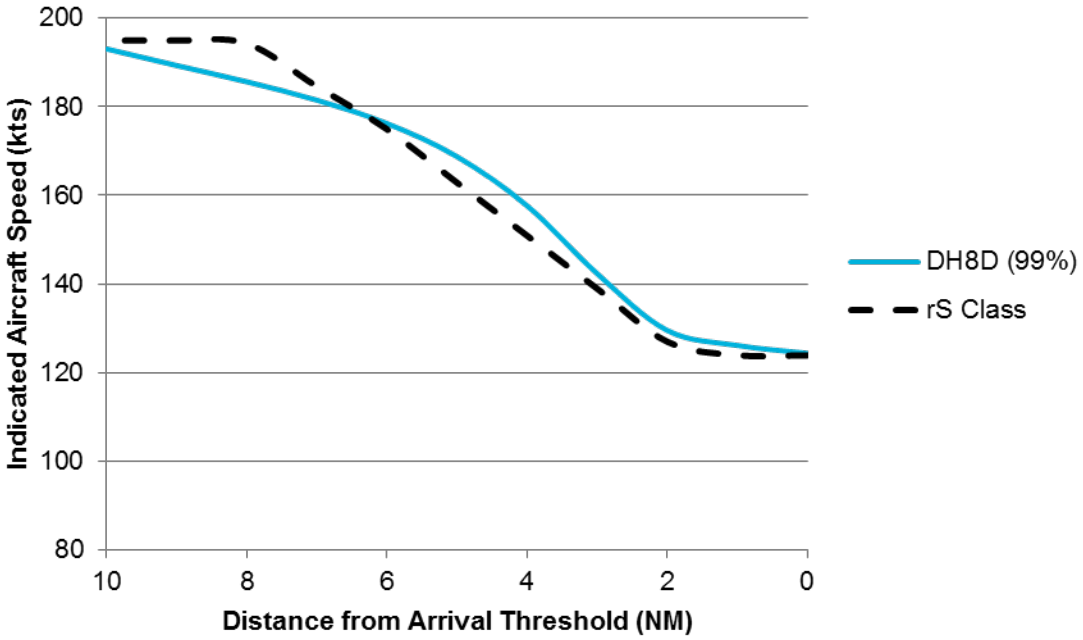
Weight Class: Large, Category D (RECAT)
Engine Type: Jet
Same Runway Separation Category: III

- **B738s land at a faster speed than the rest of the aircraft.**
- **The MD80 family (MD82, 83, 88, and 90) do not individually contain 5% but are clustered within 5 knots of the average landing speed**
- **Within six miles (the default FAF), the time to fly is**
  - 145 seconds in *runway*Simulator
  - 147 seconds in the surveillance data



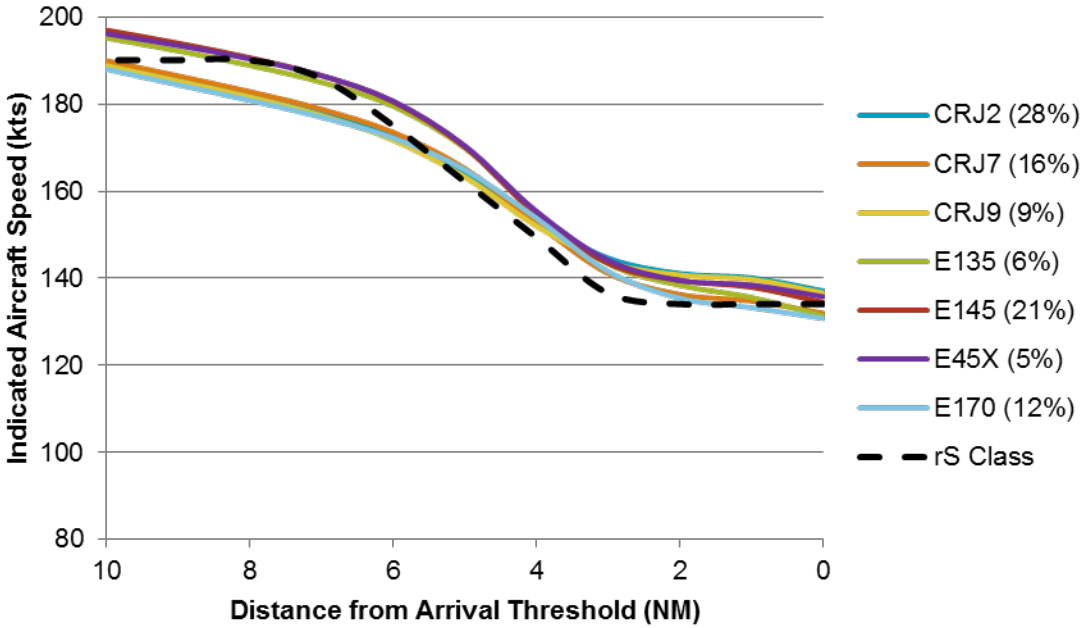
Weight Class: Large, Category D (RECAT)
Engine Type: Turboprop
Same Runway Separation Category: III

- **The DH8D by far the most prevalent aircraft type in this category**
  - Stabilized Approach Point is closer to 2 NM than 3 NM
- **Within six miles (the default FAF), the time to fly is**
  - 151 seconds in *runway*Simulator
  - 155 seconds in the surveillance data



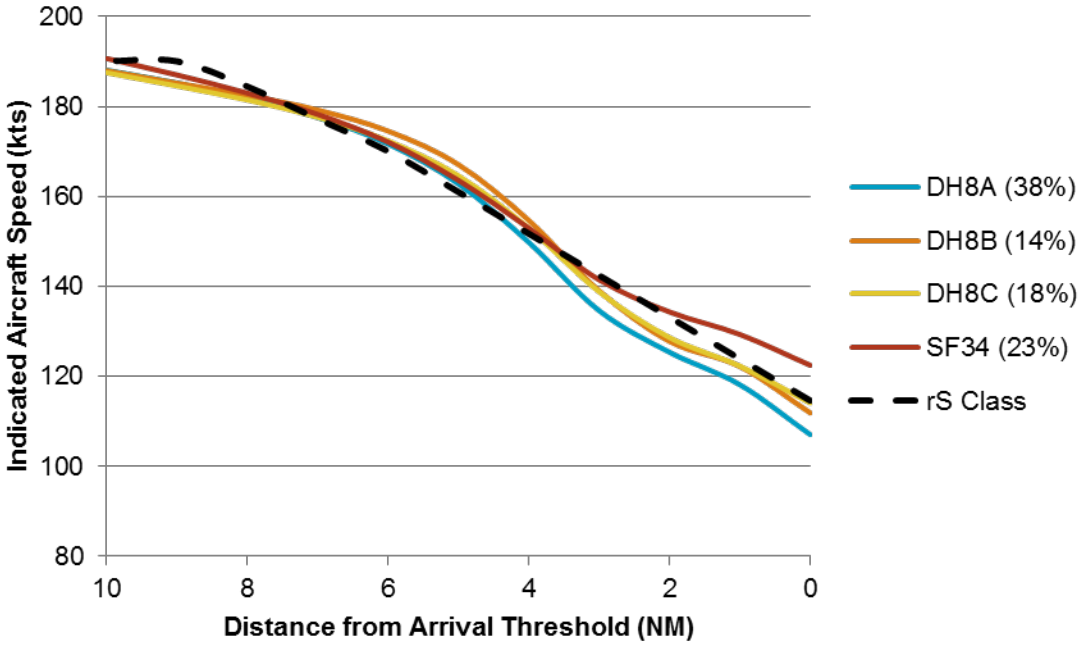
Weight Class: Large, Category E (RECAT)
Engine Type: Jet
Same Runway Separation Category: III

- **The regional jets are all very tightly clustered in their speeds**
- **Within six miles (the default FAF), the time to fly is**
  - 147 seconds in *runway*Simulator
  - 149 seconds in the surveillance data



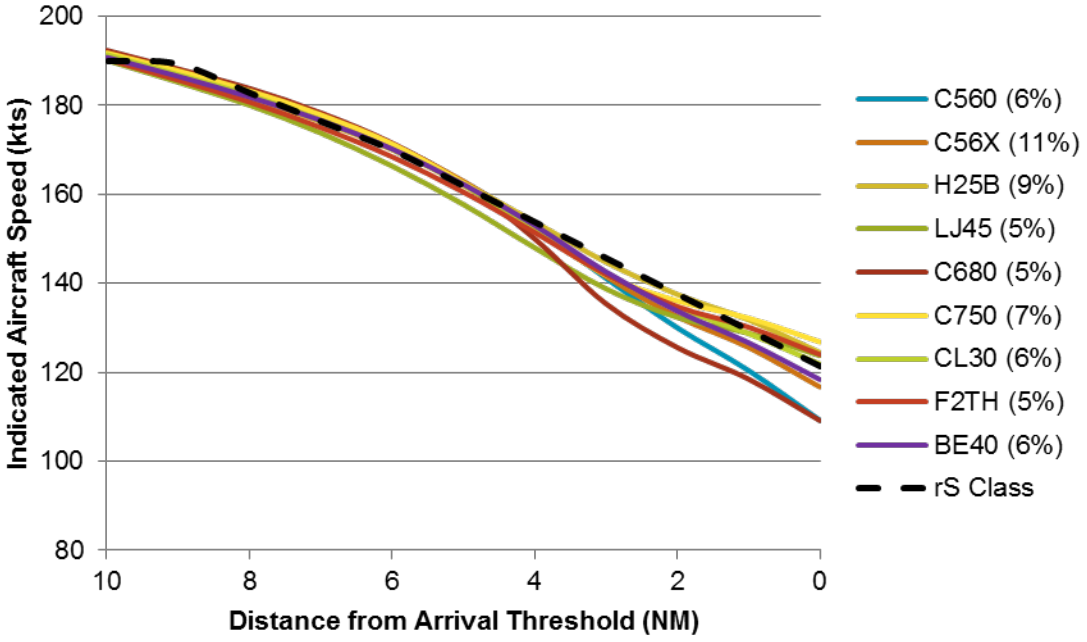
Weight Class: Large, Category E (RECAT)
Engine Type: Turboprop
Same Runway Separation Category: III

- **As aircraft's landing speeds decrease, their ability to stabilize their approach speeds prior to the threshold decreases (unlike larger aircraft, which reach their landing speed at a stabilized approach point typically 3 NM from the runway)**
  - These aircraft continue to decelerate until landing; true for all the next slides as well
- **Within six miles (the default FAF), the time to fly is**
  - 149 seconds in *runway*Simulator
  - 159 seconds in the surveillance data



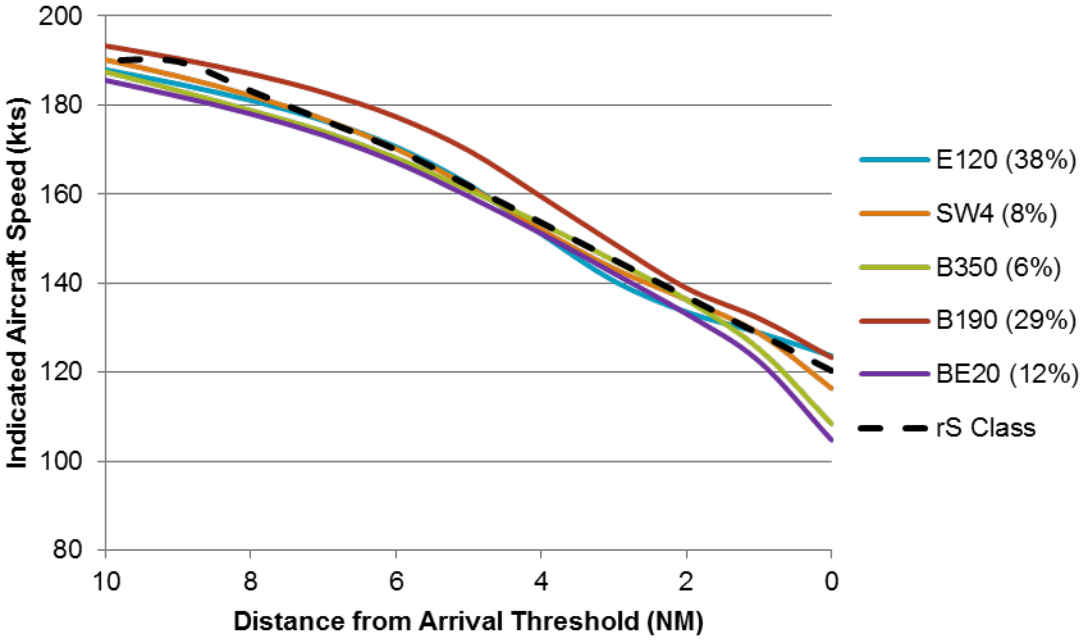
Weight Class: Small, Category F (RECAT)
Engine Type: Jet
Same Runway Separation Category: III

- **There are many different aircraft types but they are clustered close together**
- **Within six miles (the default FAF), the time to fly is**
  - 146 seconds in *runway*Simulator
  - 155 seconds in the surveillance data



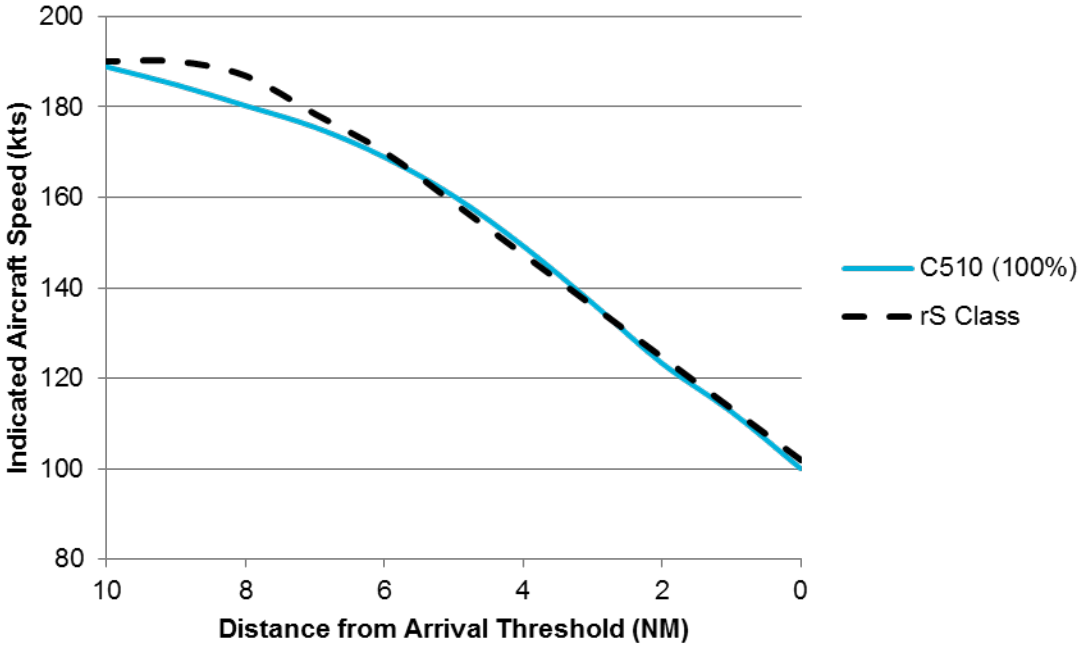
Weight Class: Small, Category F (RECAT)
Engine Type: Turboprop
Same Runway Separation Category: III

- **The E120 and B190 are by far the most prevalent aircraft in this category**
- **Within six miles (the default FAF), the time to fly is**
  - 146 seconds in *runway*Simulator
  - 148 seconds in the surveillance data



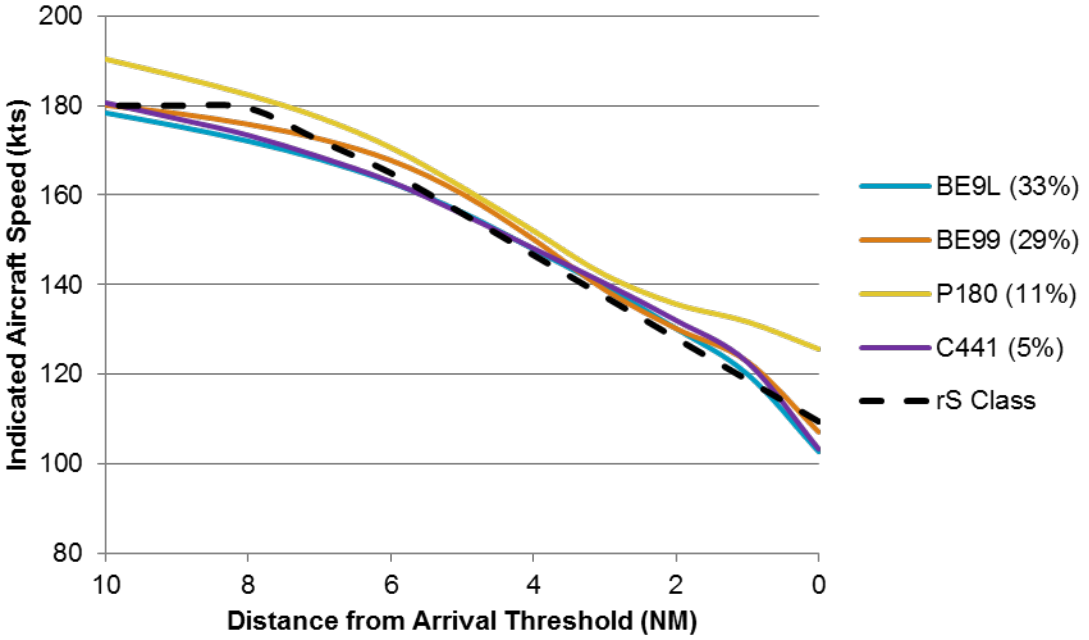
Weight Class: Small, Category F (RECAT)
Engine Type: Jet
Same Runway Separation Category: II

- **The C510 is the only aircraft in this category**
- **Within six miles (the default FAF), the time to fly is**
  - 157 seconds in *runway*Simulator
  - 165 seconds in the surveillance data



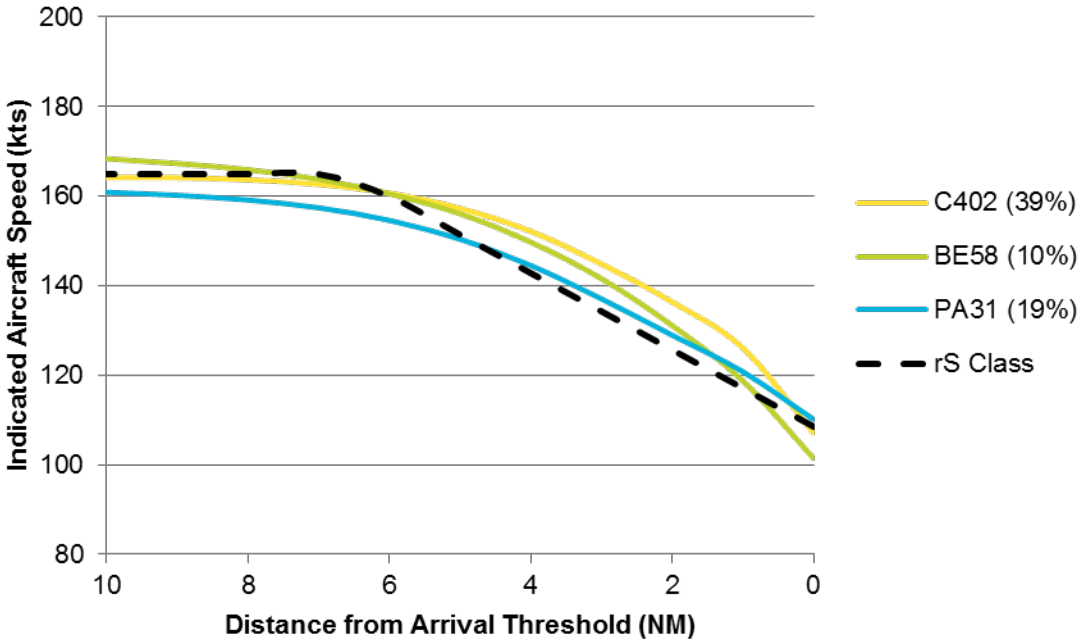
Weight Class: Small, Category F (RECAT)
Engine Type: Turboprop
Same Runway Separation Category: II

- **Smaller aircraft need to keep their speed up as long as possible when flying into busy airports such as the Core 30. Aircraft characteristics may change significantly at smaller airports.**
- **Within six miles (the default FAF), the time to fly is**
  - 155 seconds in *runway*Simulator
  - 158 seconds in the surveillance data



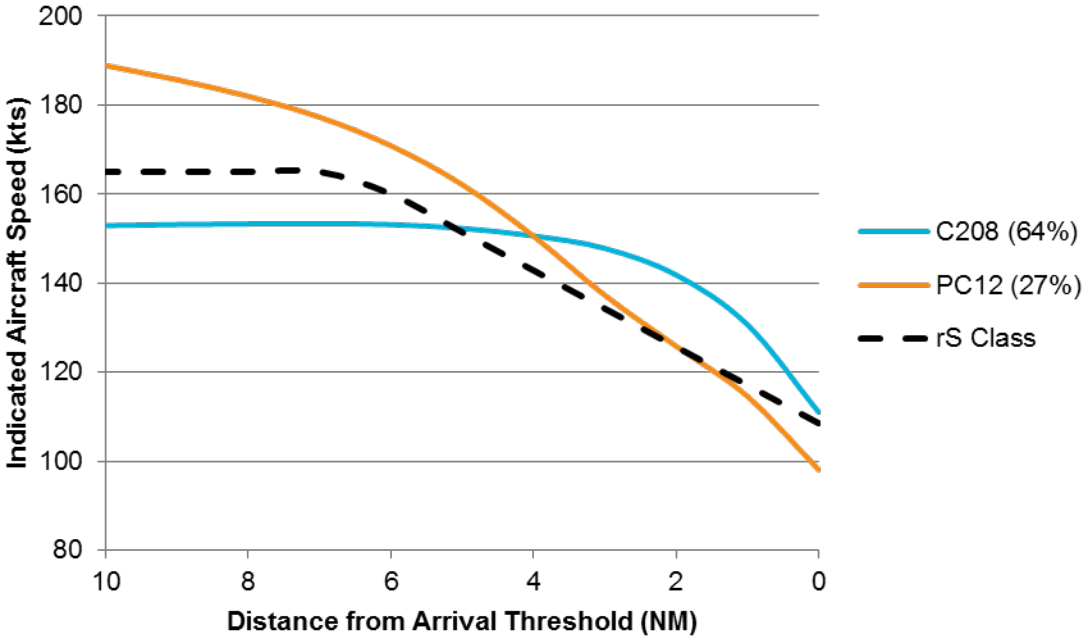
Weight Class: Small, Category F (RECAT)
Engine Type: Piston
Same Runway Separation Category: II

- **Piston aircraft have a much slower speed outside of the Final Approach Fix than larger Jet or Turboprop aircraft**
- **Within six miles (the default FAF), the time to fly is**
  - 158 seconds in *runway*Simulator
  - 160 seconds in the surveillance data



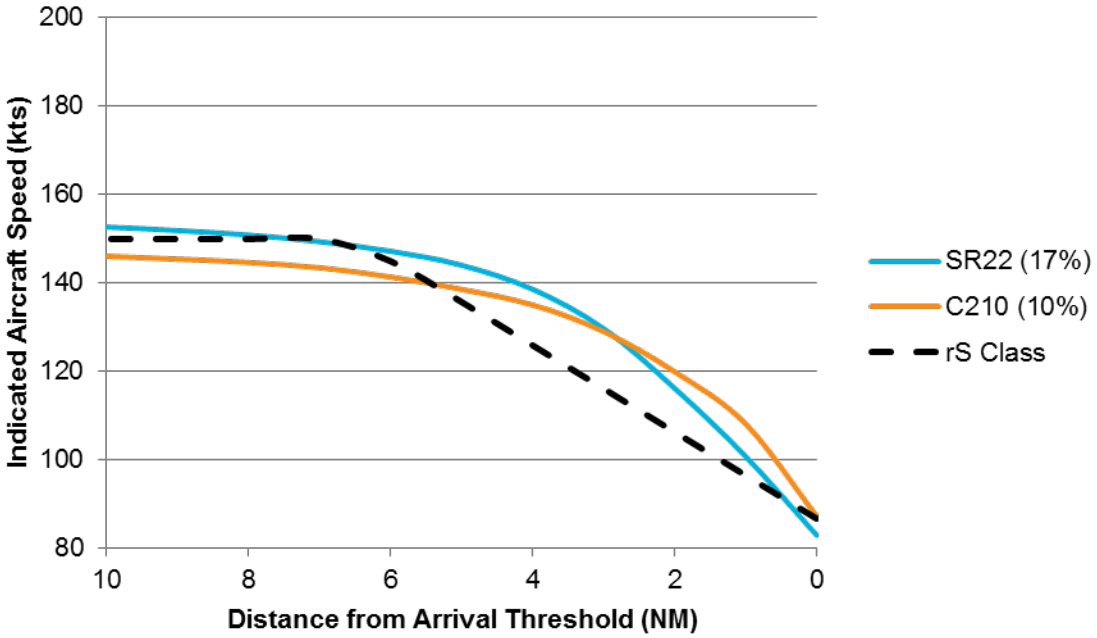
Weight Class: Small, Category F (RECAT)
Engine Type: Turboprop
Same Runway Separation Category: I

- **The two most common aircraft types in this category have very different speed profiles. *runway*Simulator uses a weighted average of the two**
- **Within six miles (the default FAF), the time to fly is**
  - 158 seconds in *runway*Simulator
  - 156 seconds in the surveillance data



Weight Class: Small, Category F (RECAT)
Engine Type: Piston
Same Runway Separation Category: I

- **Data was unavailable for many smaller aircraft types, but the two most common show similar speed profiles**
- **Within six miles (the default FAF), the time to fly is**
  - 183 seconds in *runway*Simulator
  - 181 seconds in the surveillance data



Summary and Conclusions

- **For flights into the nation's busiest airports, *runway*Simulator does a good job of approximating their approach speeds**
  - Difference in time to fly the last six miles averages around 2.5% for the various aircraft categories
- **By default, various aircraft types are represented by a single aircraft type in the model**
  - E.g., Small Turboprop Category III aircraft are all represented by the Embraer Brasilia (E120) aircraft type
- ***runway*Simulator supports additional tailoring of parameters in the model, which would bring the speed profiles closer to the actuals; however, this would require a more detailed airport-specific analysis at an added cost**
  - Additionally, aircraft within a class can be modeled separately if that level of fidelity is required

NOTICE