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Air Transportation

A System Level Study of Runway Throughput Components and New Wake Vortex Separation Concepts

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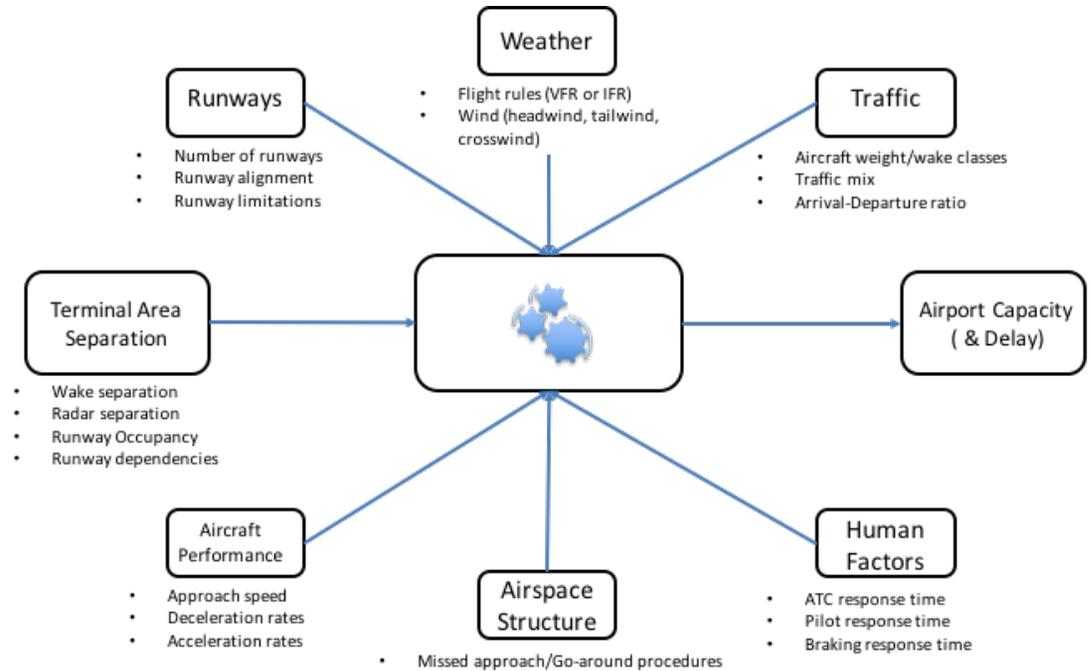
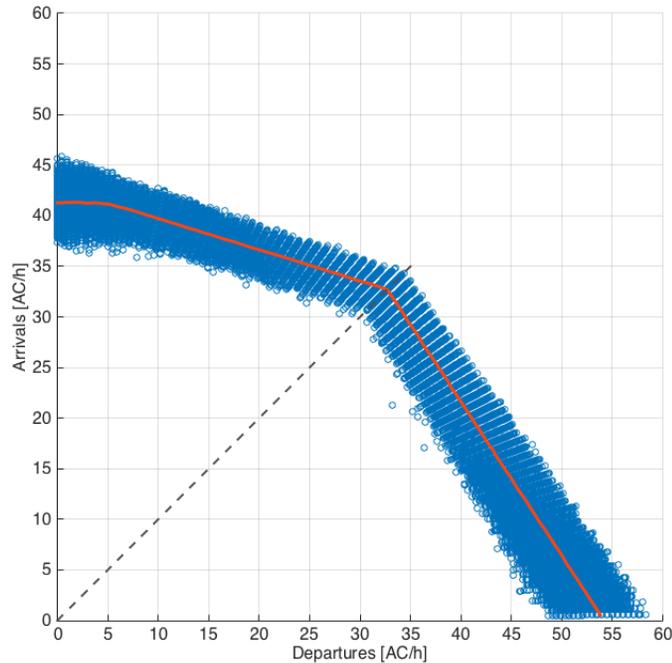
- Demand for air travel is projected to grow over next 20 years
- Current U.S. aviation network has limited capacity
 - “27 of the top 35 busiest airports have reached or are nearing their limit on capacity” – FAA, Fact3: Airport Capacity Needs in the National Airspace System
- Airport capacity is most tightly constrained by runway capacity

Identify the various factors affecting runway capacity, analyze the interactions and multidimensional tradeoffs between them, and quantify their impact.

Evaluate new wake vortex separation concepts that can increase runway capacity above what can be achieved today

Runway Capacity and Influencing Factors

- Runway capacity: expected number of movements that can be performed per unit of time, under continuous demand
- Represented by piece-wise linear operational throughput envelopes



Simulation Modeling

Monte-Carlo Based Runway Throughput Simulator

<p>INDEPENDENT VARIABLES</p>	<ul style="list-style-type: none"> • Runway Configuration • Fleet Mix • Final Approach Length • Separation Buffer • Wind • Wake Separation Rule 	<ul style="list-style-type: none"> • Single, Intersecting, CSPR • Number of Categories • Fixed Length, e.g. 6 NM • Fixed Distance, e.g. 0.25 NM • Headwind, e.g. 5 knots • Current, RECAT, TBS, etc.
<p>FIXED VARIABLES</p>	<ul style="list-style-type: none"> • Runway Occupancy Time • Touchdown Distance • Departure Aircraft Acceleration • Arrival Aircraft Deceleration • Approach Speed • Runway Exit Speed • ATC Communication Delay 	<ul style="list-style-type: none"> • Normal Distribution (sec) • Normal Distribution (ft) • Uniform Distribution (ft/s²) • Uniform Distribution (ft/s²) • Constant (knots) • Constant (ft/s) • Constant (sec)
<p>MONTE-CARLO SIMULATION</p>	<ul style="list-style-type: none"> • Fleet Mix Sampling • Aircraft Sequencing 	<ul style="list-style-type: none"> • Number of Categories
<p>DEPENDENT VARIABLE</p>	<ul style="list-style-type: none"> • Runway Throughput 	<ul style="list-style-type: none"> • Distribution (Arr-Dep/Hour)

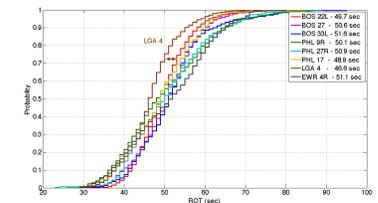
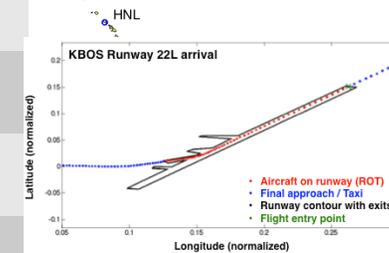
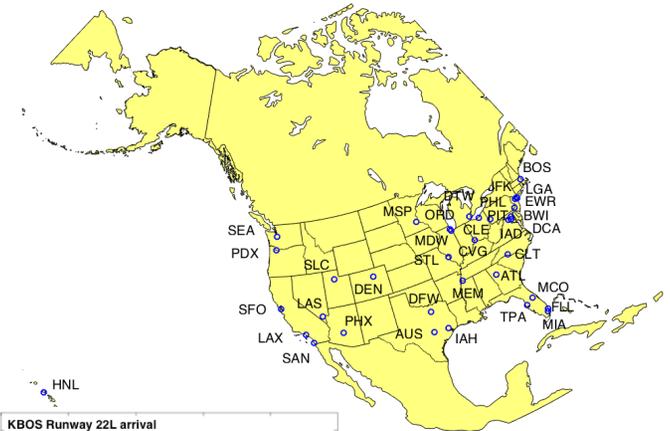
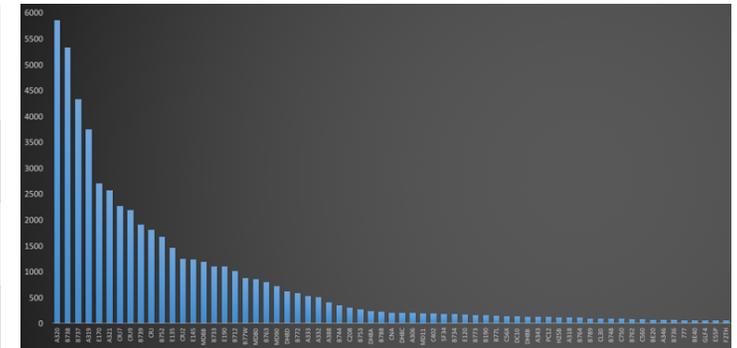
Baseline Assumptions

A



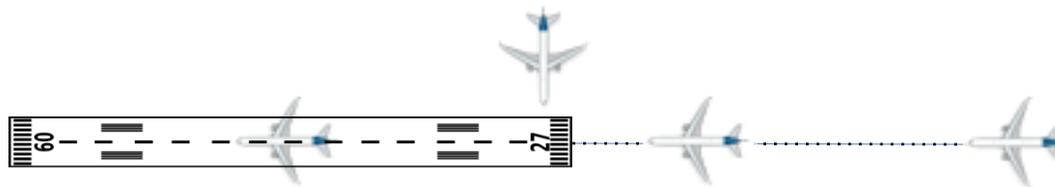
	Fleet Mix (%)	Avg. ROT (sec)	V_{Appr} (kt)
SMALL	5.3	48	110
LARGE	84.3	48	130
B757	3.5	55	140
HEAVY	6.7	65	145
SUPER	0.2	75	140

Separation Buffer	0.25 NM
Final Approach	6.0 NM
Wake Sep. Rule	Current FAA
Head Wind	0 kt
ATC Delay	15 sec
Touchdown Dist.	1200 ft
DEP Acceleration	$5.5 - 7.5 \text{ ft/s}^2$
ARR Deceleration	$4 - 6 \text{ ft/s}^2$



Baseline Assumptions Wake Separation Rules

Single Runway (SRWY) Wake Separation Rules A



$$T_{ij} = \max \left[\frac{r+s_{ij}}{v_j} - \frac{r}{v_i}, ROT_i \right] \text{ when } v_i > v_j \text{ "opening case"}$$

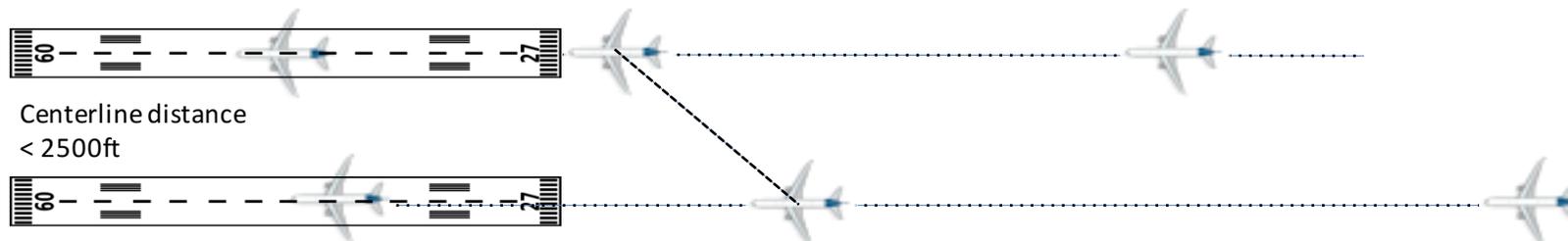
$$T_{ij} = \max \left[\frac{s_{ij}}{v_j}, ROT_i \right] \text{ when } v_i \leq v_j \text{ "closing case"}$$

Lead\Follow	Super	Heavy	B757	Large	Small
Super	MRS	6	7	7	8
Heavy	MRS	4	5	5	6
B757	MRS	4	4	4	5
Large	MRS	MRS	MRS	MRS	4
Small	MRS	MRS	MRS	MRS	MRS

Lead\Follow	Super	Heavy	B757	Large	Small
Super	180	180	180	180	180
Heavy	120	120	120	120	120
B757	120	120	120	120	120
Large	60	60	60	60	60
Small	60	60	60	60	60

Closely Spaced Parallel Runways (CSPR) Wake Separation Rules A

- Order 7110.308, ".308 rule": 1.5 NM diagonal separation when Small or Large lead
- Wake Turbulence Mitigation for Arrivals (WTMA) rule: Heavy and B757 can also lead diagonal pair

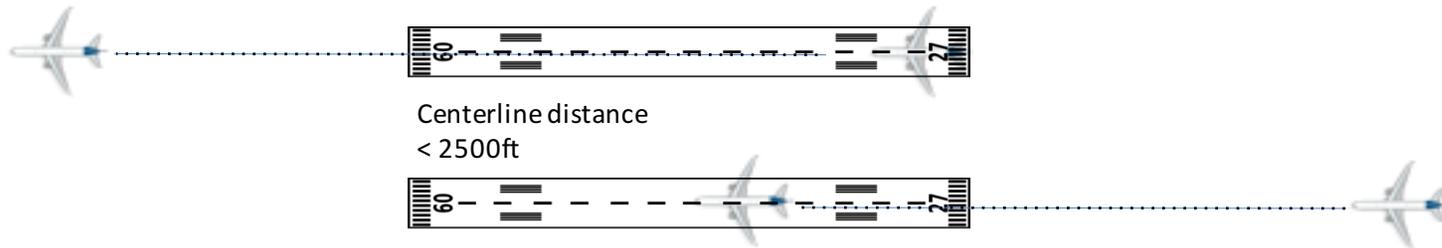


Baseline Assumptions

Wake Separation Rules

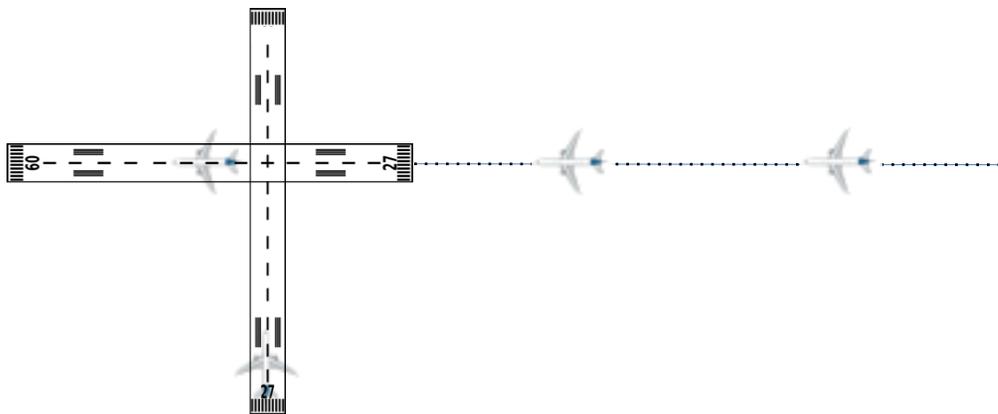
Closely Spaced Parallel Runways (CSPR) Wake Separation Rules A

“DEP aircraft to be released as long as ARR aircraft is no closer than 2 miles from runway at the time the DEP aircraft commences takeoff roll” – FAA JO 7110.65, 5-8-4



Intersecting Runways (XING) Wake Separation Rules A

“...arriving aircraft does not cross the landing threshold until ... Preceding aircraft has departed and passed the intersection/flight path or is airborne...” - FAA JO 7110.65, 3-10-4

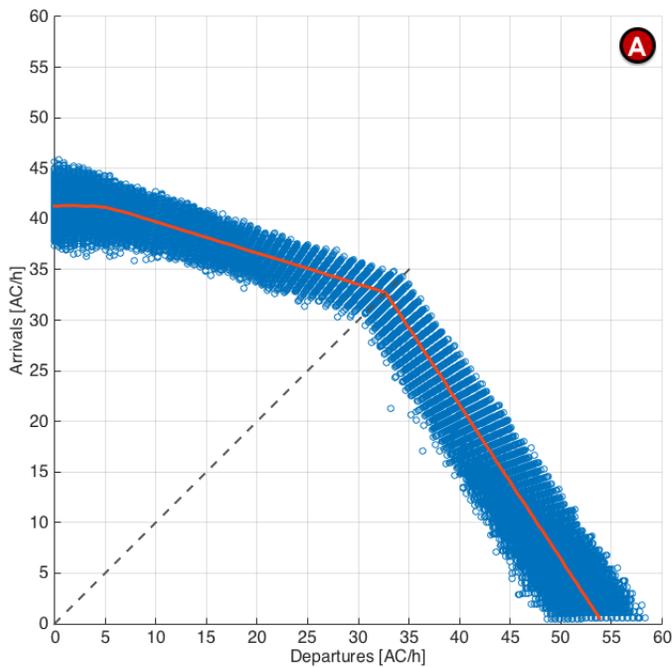
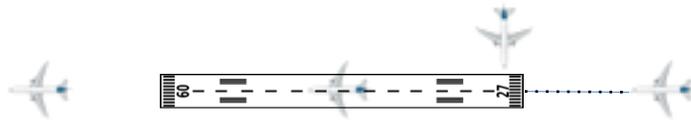


“...aircraft landing behind departing Heavy/B757 on crossing runway if ARR will fly through airborne path of DEP – 2 minutes” - FAA JO 7110.65, 3-10-4

Runway Configuration Single – Intersecting - CSPR

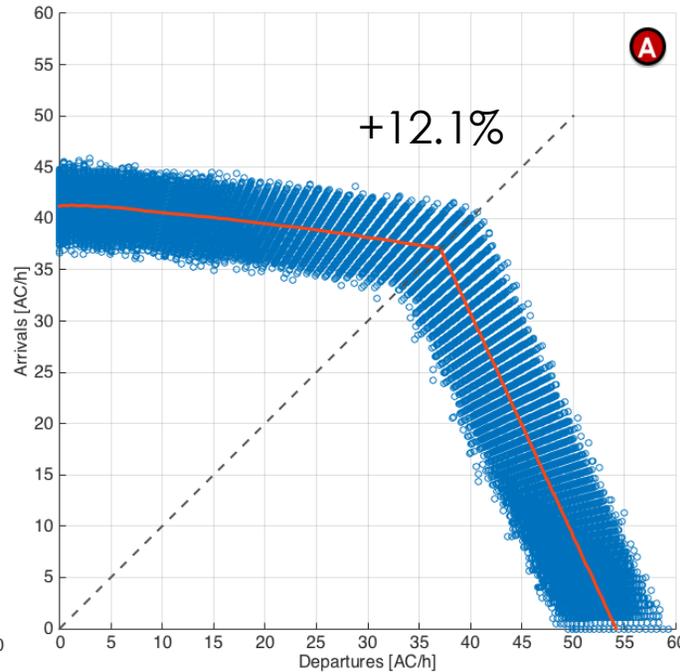
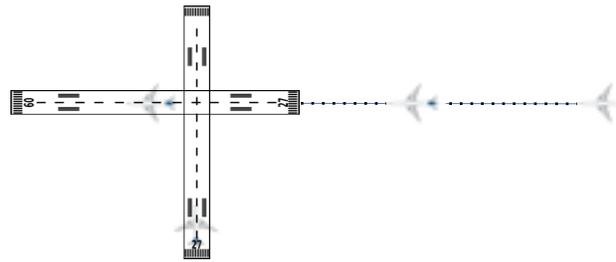
Single Runway Mixed Mode Operations

DEP aircraft needs to wait for ARR aircraft full ROT before clearance



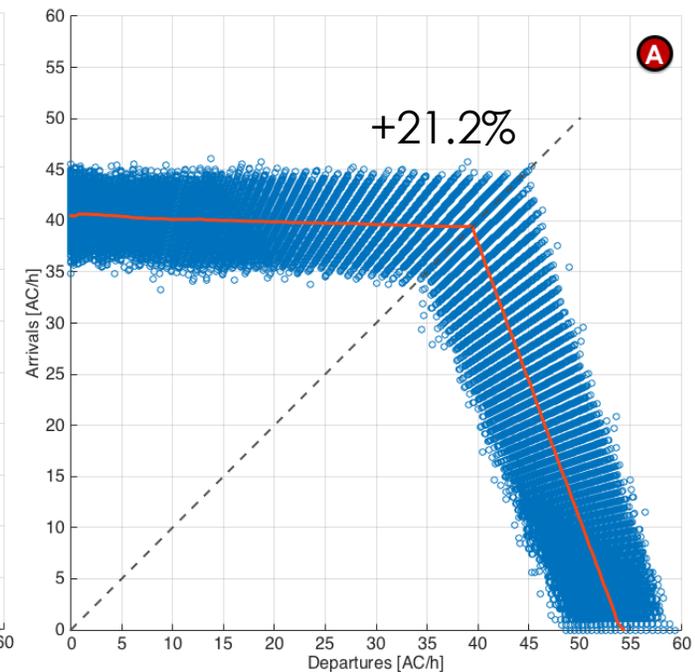
Intersecting Runways (5000ft – 5000ft to intersection)

DEP aircraft needs to wait for ARR aircraft to cross before clearance



Closely Spaced Parallels

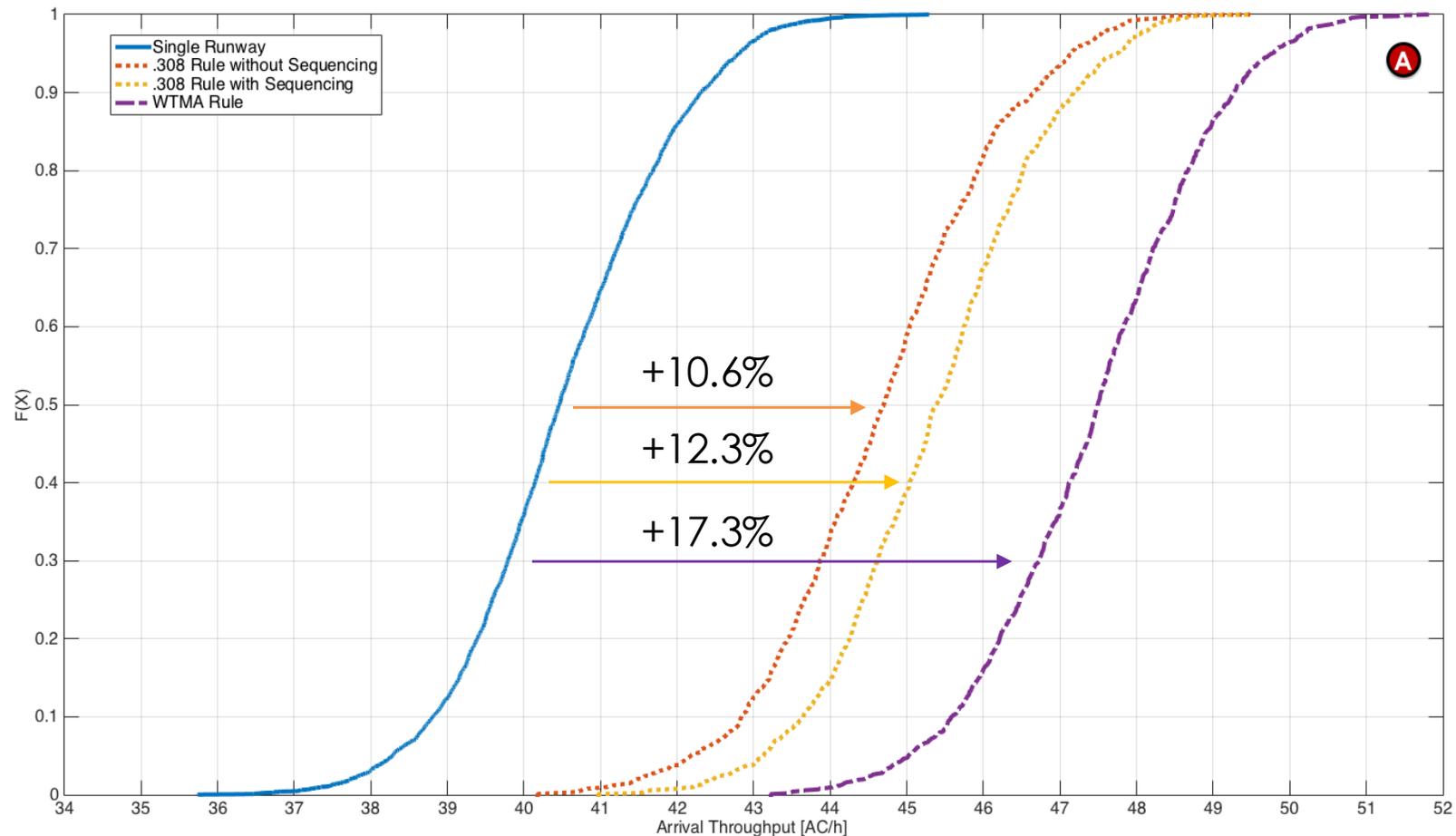
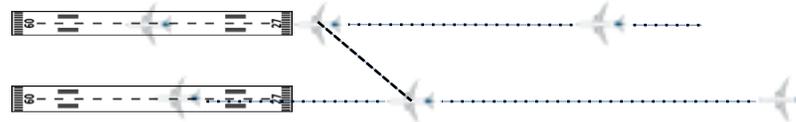
DEP aircraft needs to wait for ARR to cross landing threshold before clearance



Runway Configuration

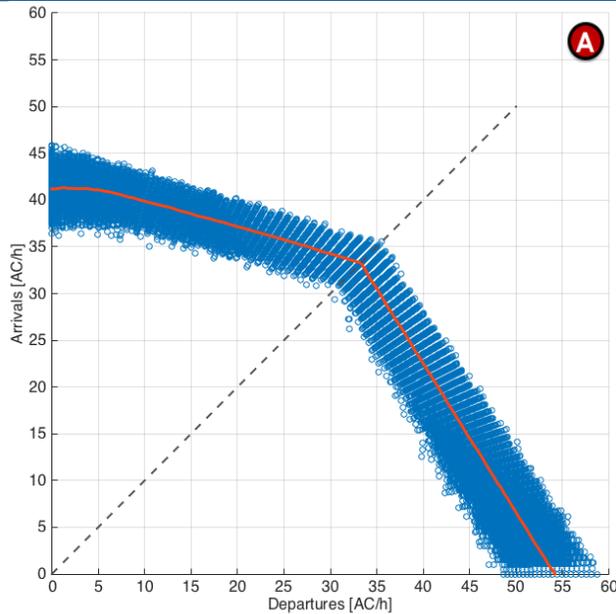
Single Runway and Closely Spaced Arrivals

- .308 rule without sequencing: random arrival sequence
- .308 rule with sequencing: for simultaneous arrivals, Small or Large takes lead to maximize number of diagonal pairs

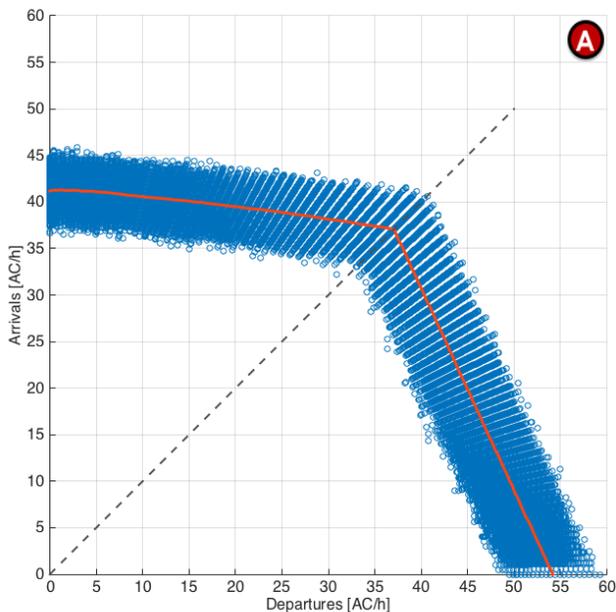
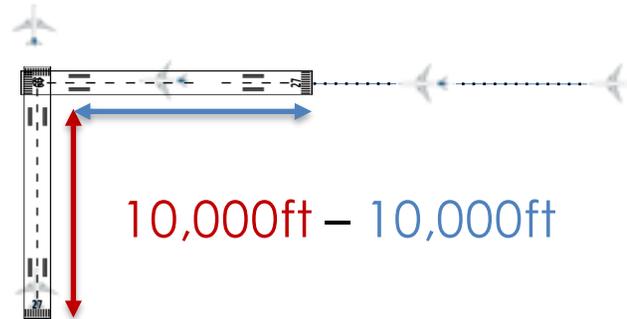


Runway Configuration

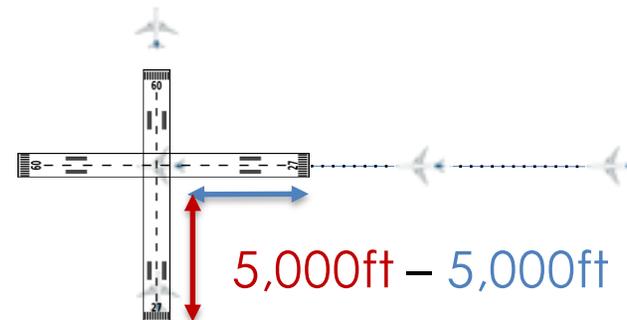
Intersecting Runways Geometry



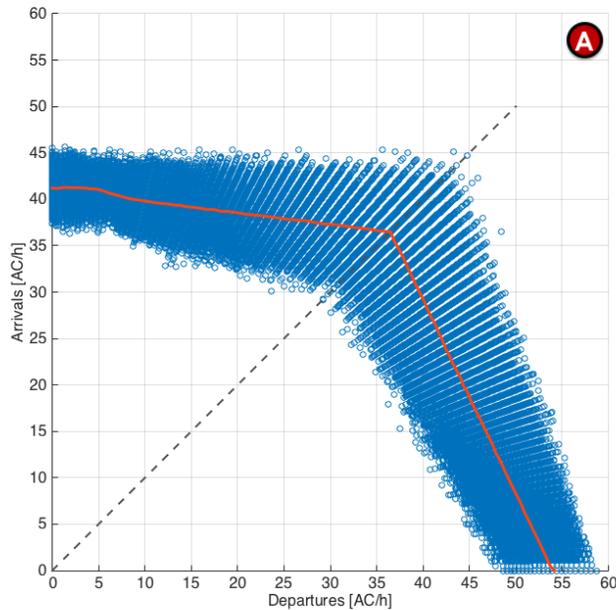
- Lowest runway throughput geometry
- Departures hold until Arrivals clear runway (ROT)
- Matches single runway capacity envelope



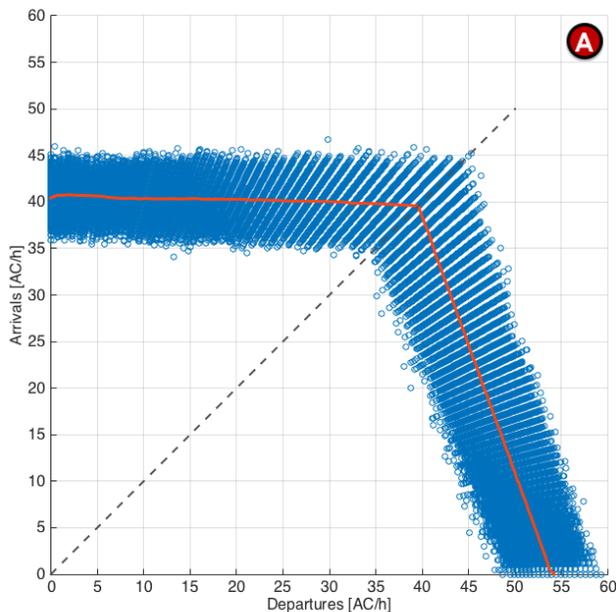
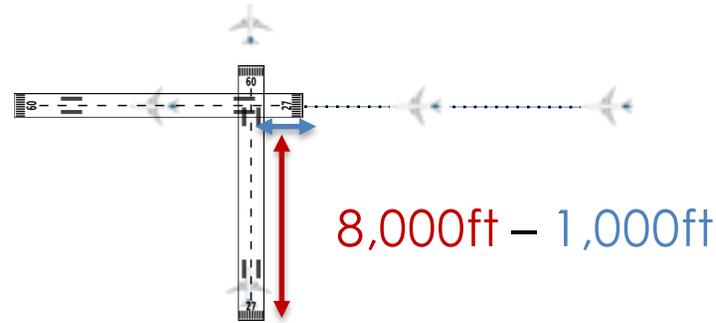
- Arrivals have touched down before intersection
- Departures hold until Arrivals pass intersection < ROT
- Slightly more than single runway capacity



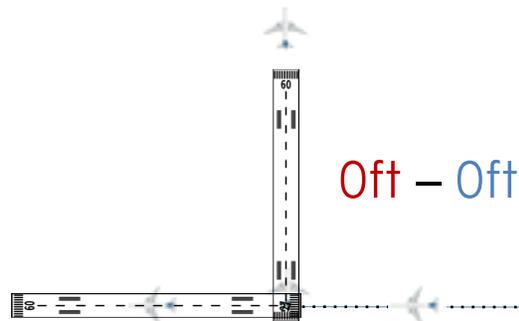
Runway Configuration Intersecting Runways Geometry



- Arrivals are airborne at intersection
- Departures are also airborne at intersection
- 2 min rule activated for some pairs



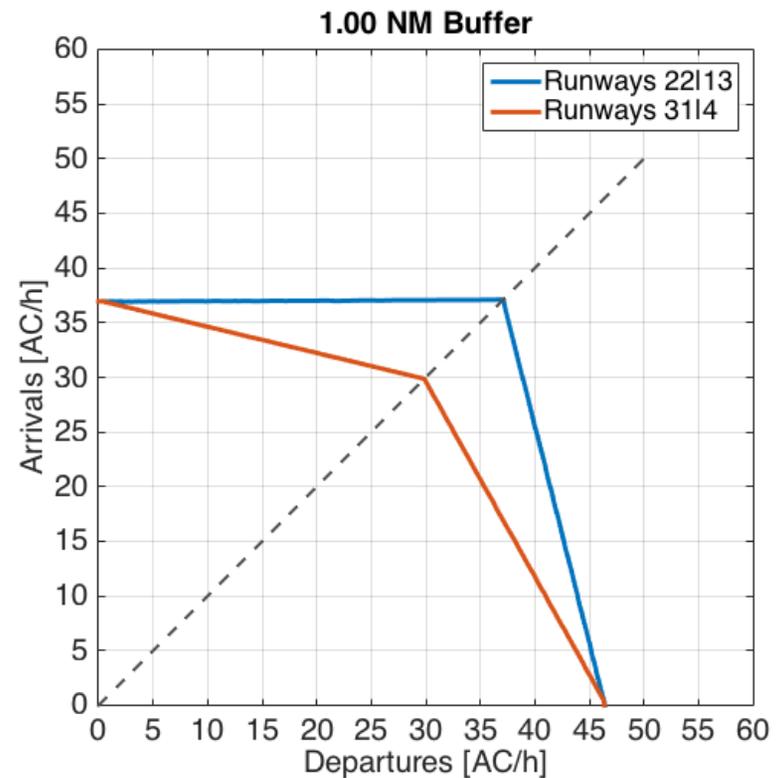
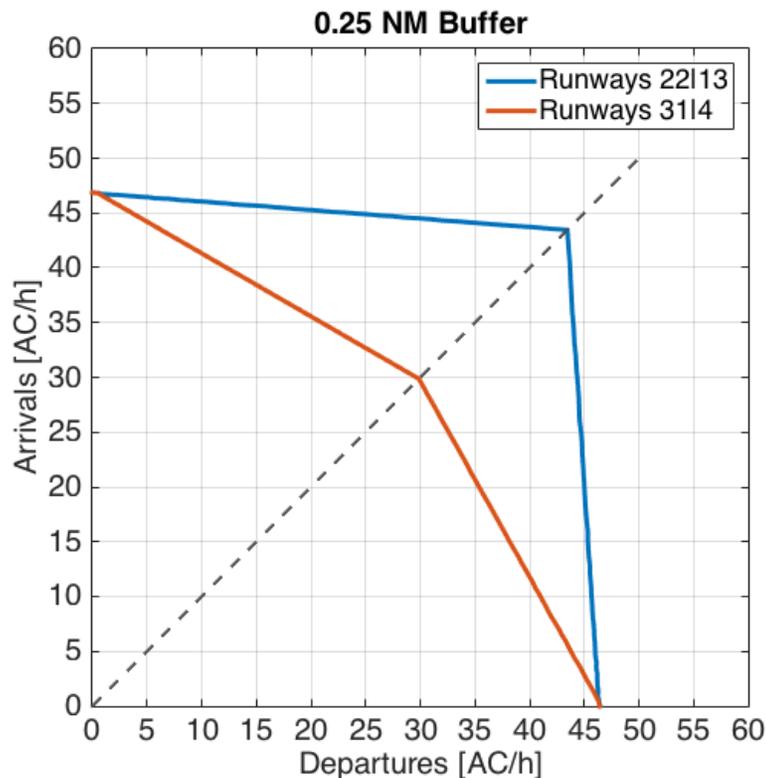
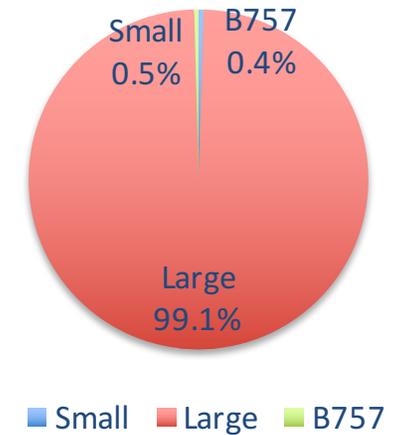
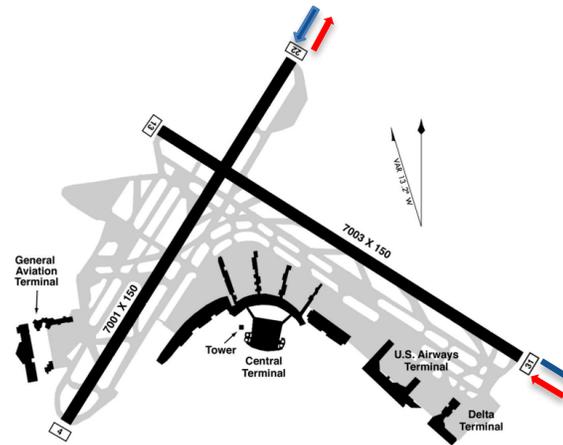
- Highest runway throughput geometry
- Departures cleared as soon as arrivals cross threshold



Runway Configuration

Intersecting Runways Geometry - LGA

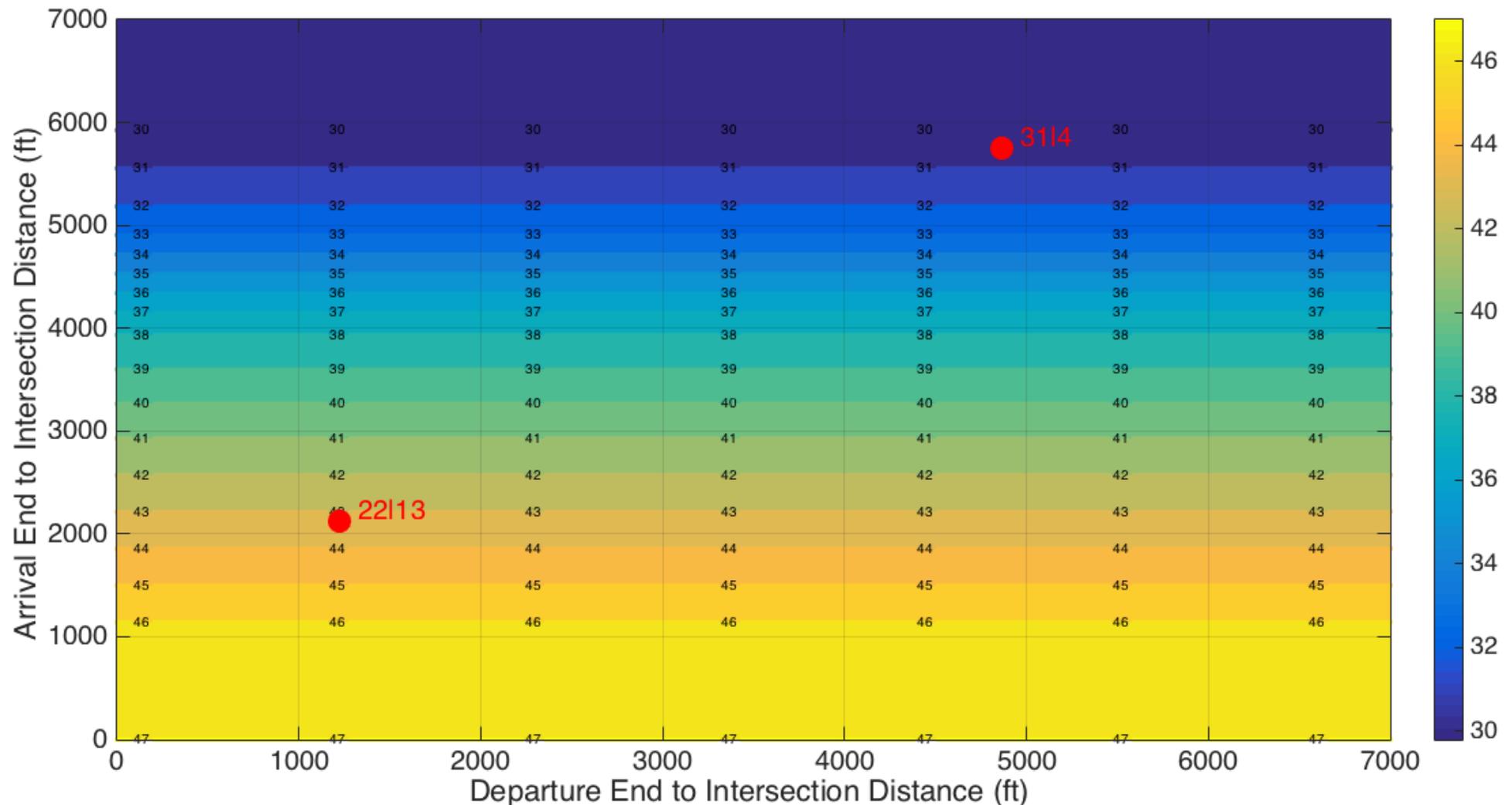
- LaGuardia Airport, NY (LGA)
- Two 7,000ft intersecting runways
- Most common runway configurations: 31 | 4 and 22 | 13



Runway Configuration

Intersecting Runways Geometry Sensitivity - LGA

- Runway throughput values indicate 50-50 arrival-departure point
- 0.25 NM separation buffer
- Throughput is only impacted by arrival runway geometry

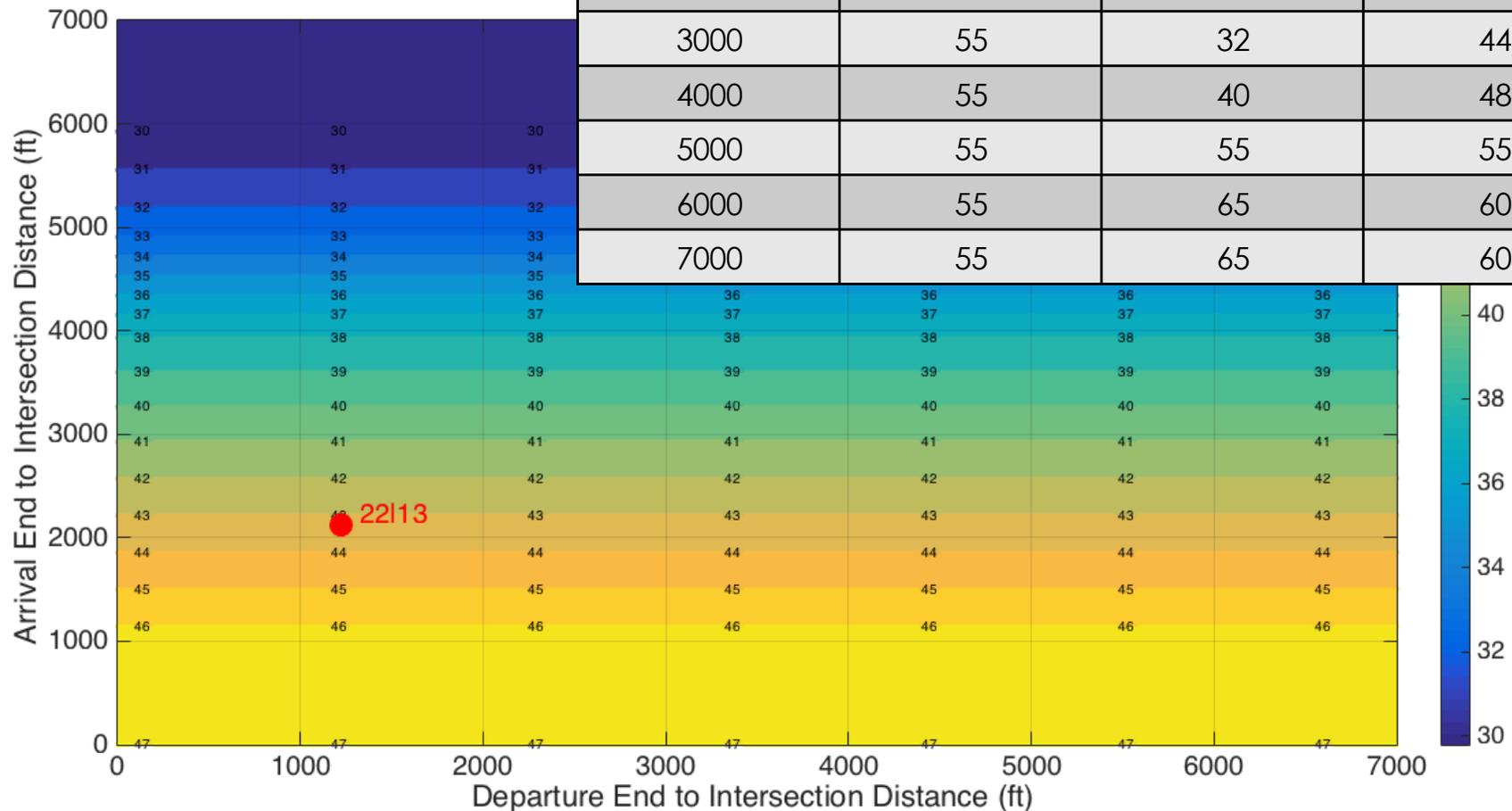


Runway Configuration

Intersecting Runways Geometry Sensitivity - LGA

- DEP-ARR separation remains unchanged due to 2 NM requirement

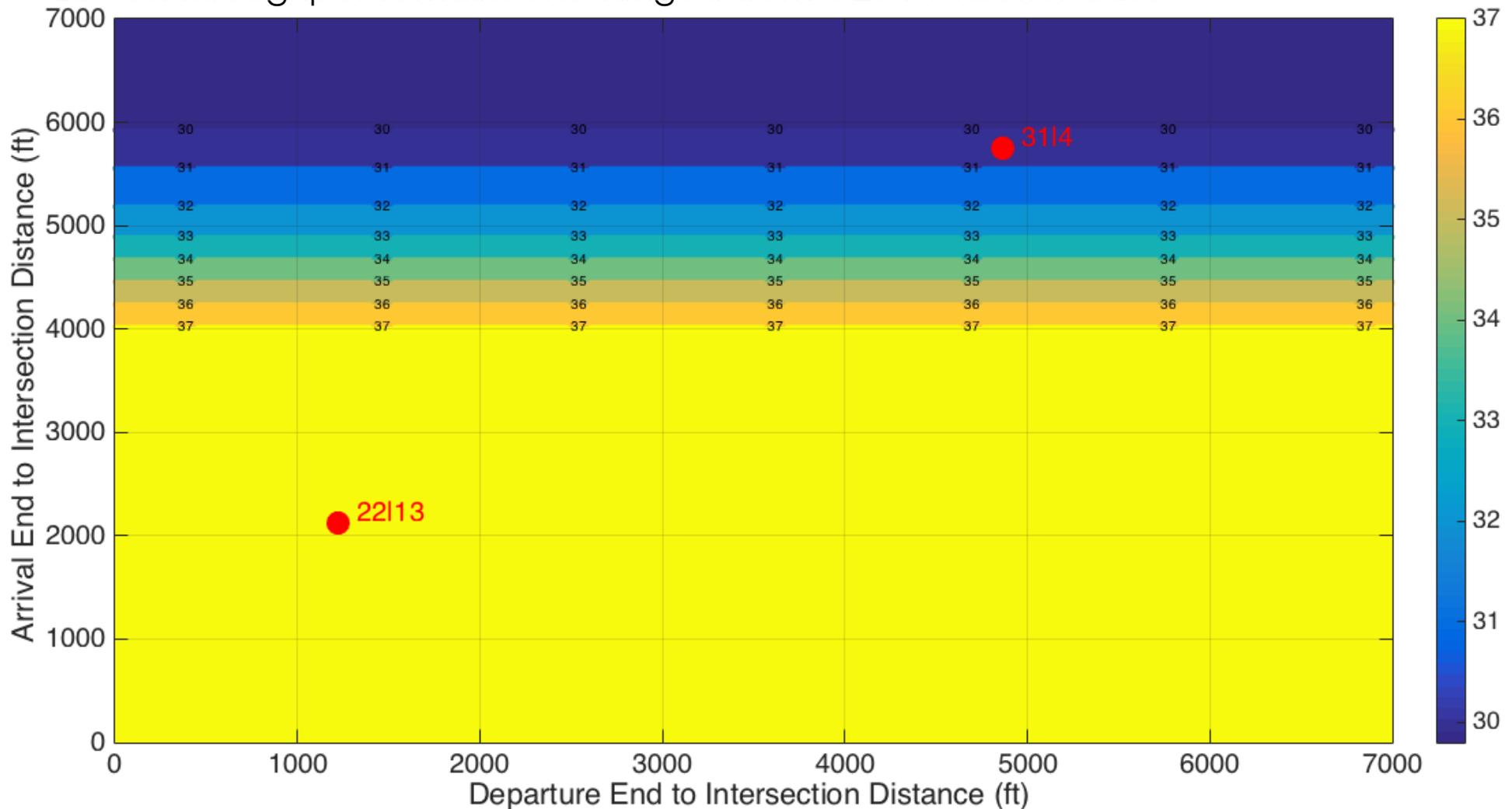
ARR Dist. To Xing	DEP-ARR Sep. (sec)	ARR-DEP Sep. (sec)	Avg. Sep. (sec)
0	55	17	36
1000	55	21	38
2000	55	26	41
3000	55	32	44
4000	55	40	48
5000	55	55	55
6000	55	65	60
7000	55	65	60



Runway Configuration

Intersecting Runways Geometry Sensitivity - LGA

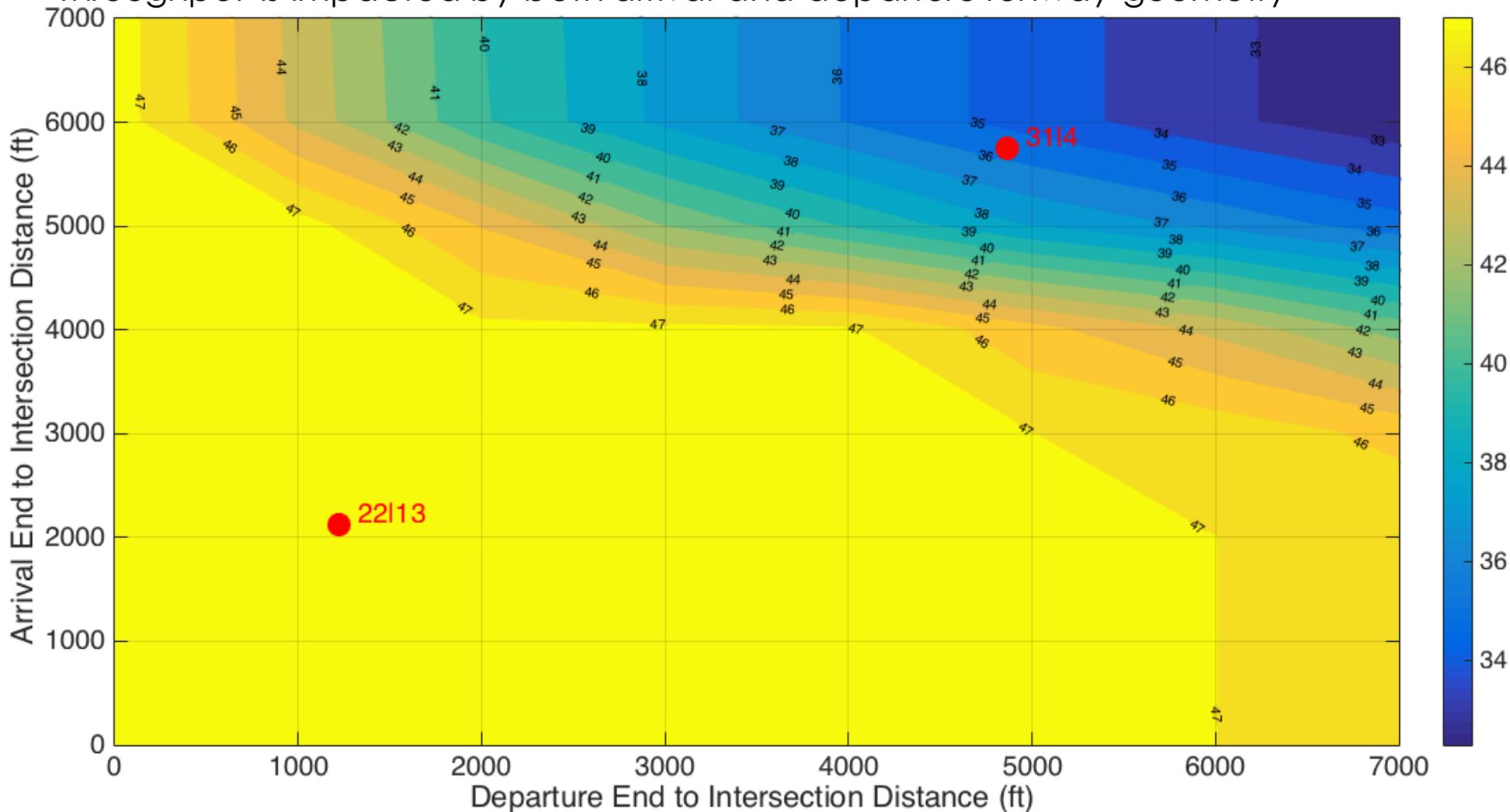
- 1.00 NM separation buffer
- Throughput is only impacted by arrival runway geometry
- Large buffer makes throughput less sensitive to runway geometry
- Lowest throughput remains unchanged from 0.25 NM buffer case



Runway Configuration

Intersecting Runways Geometry Sensitivity - LGA

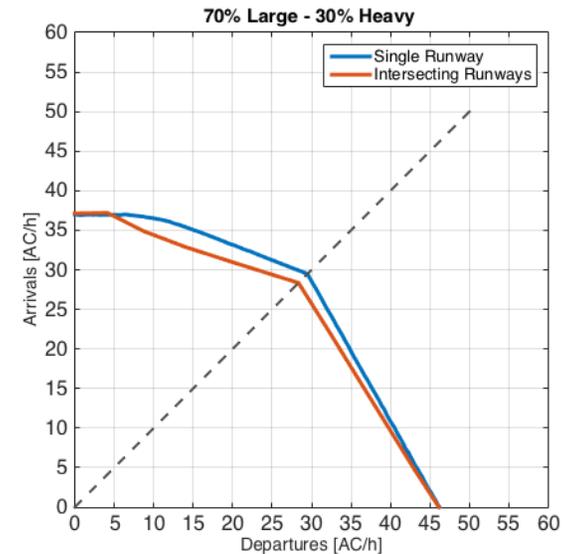
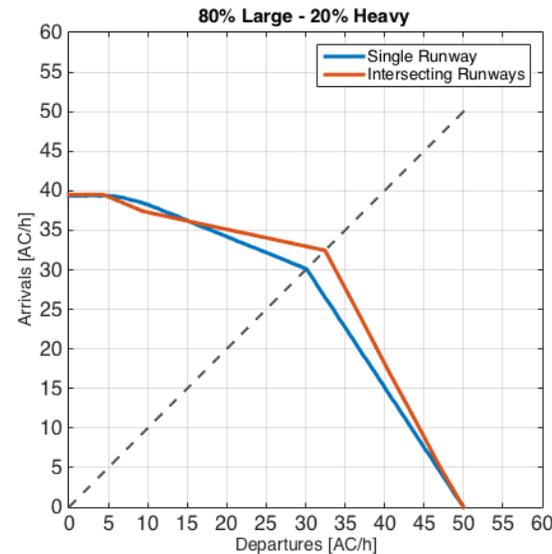
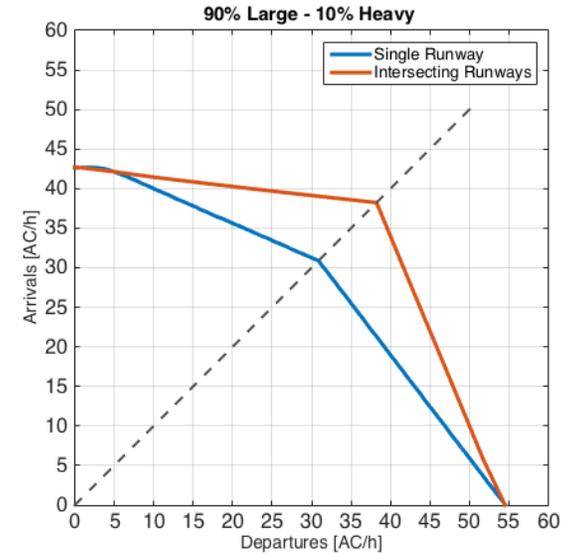
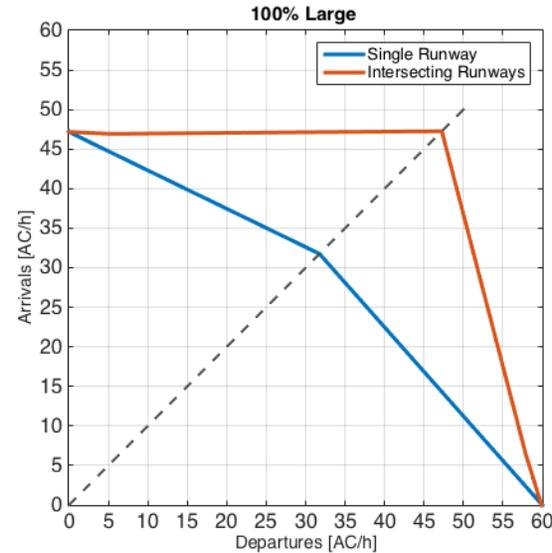
- Changed DEP-ARR separation requirement: ARR 2 NM from threshold → time of DEP clearing intersection
- 0.25 NM separation buffer remains unchanged
- Throughput is impacted by both arrival and departure runway geometry



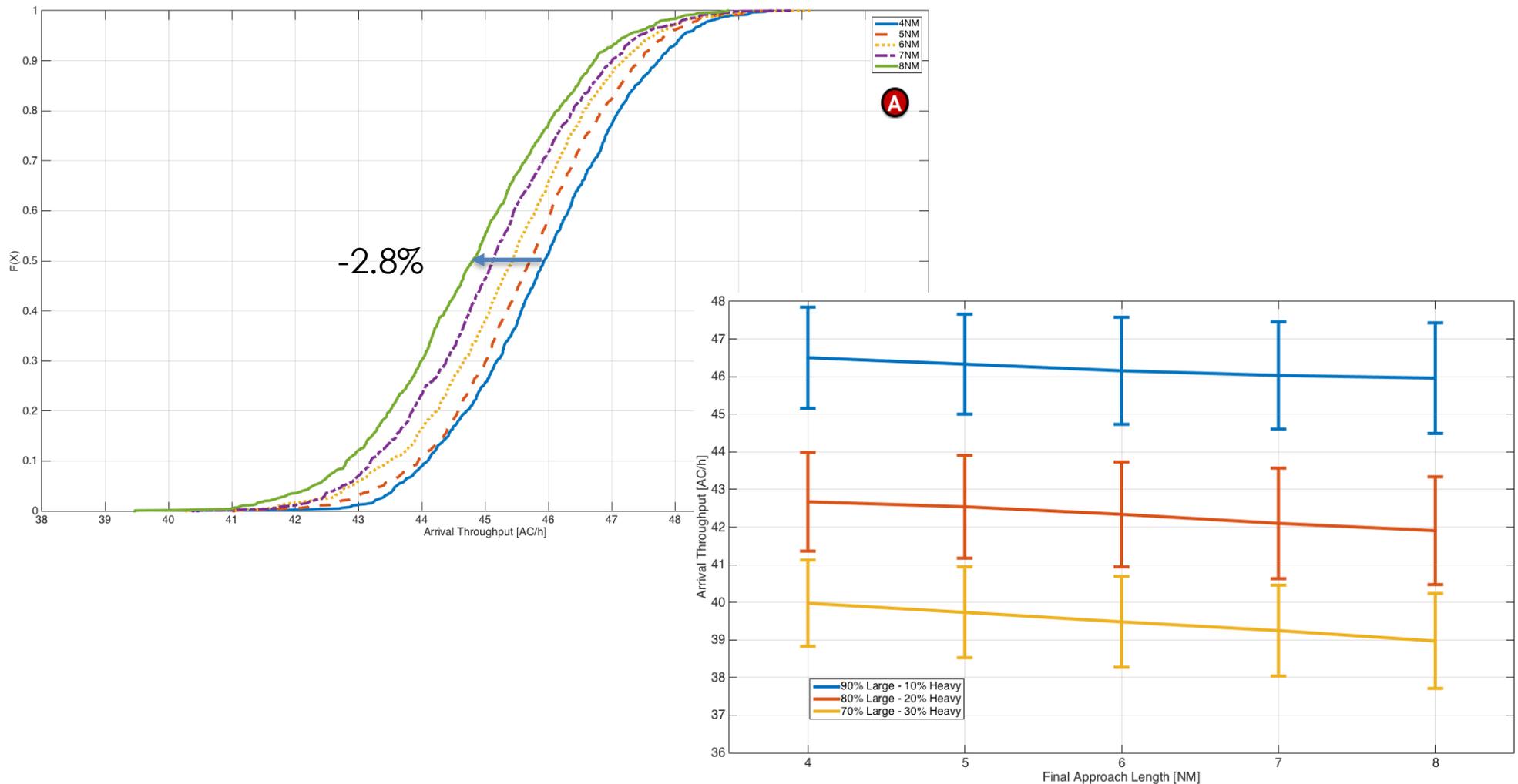
Runway Configuration

Single Runway vs. Intersecting Runways

- Intersecting runway geometry: both Arrivals and Departures are airborne at intersection (2 min wake separation behind Heavy/B757)
- 0.25 NM buffer
- At 30% Heavy fleet mix, 2min additional separation reduces throughput below single runway

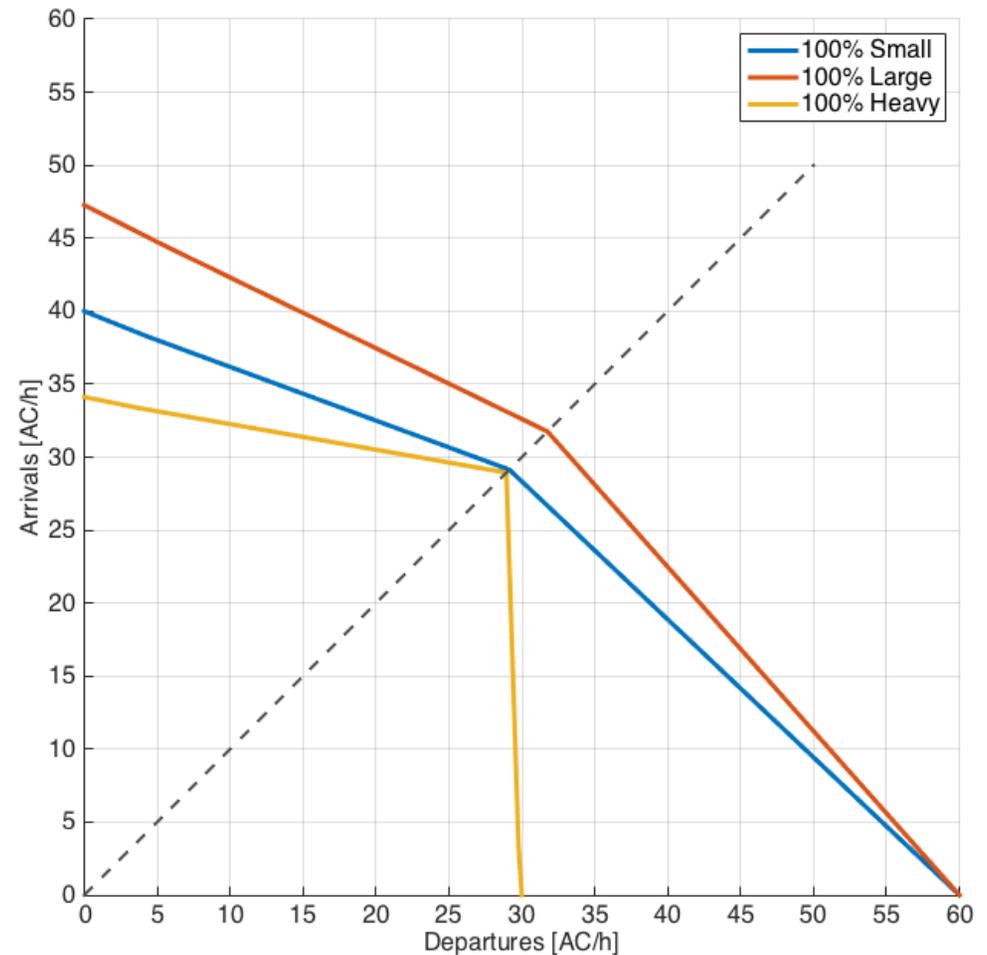


- Single runway arrivals only configuration
- As expected, throughput decreases with longer final approaches
- This is true when speed differences exist between aircraft
- Throughput does not change with FAF length if fleet mix is homogeneous



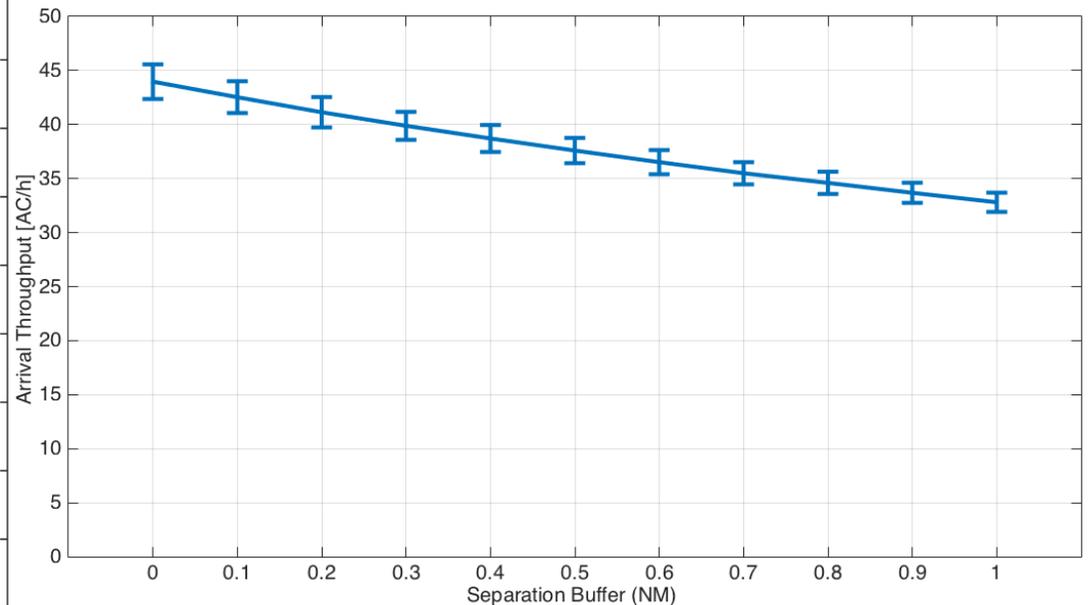
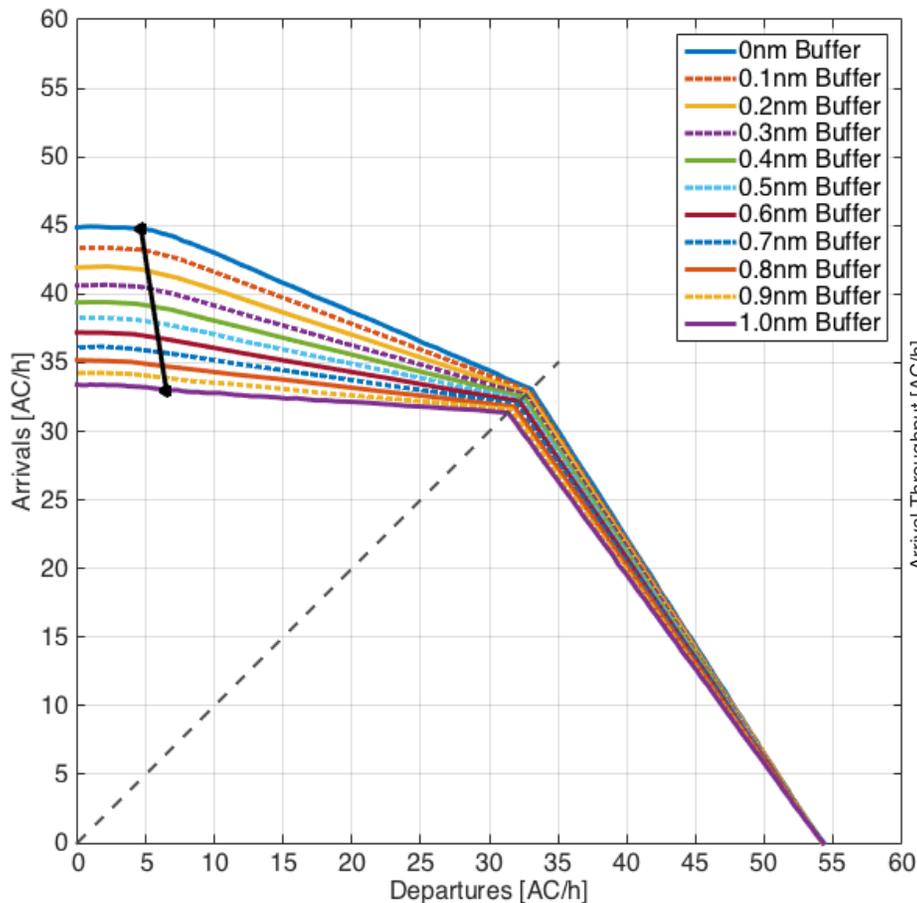
Single Runway Capacity – Homogeneous Fleet Mix

- 0.25 NM buffer
- Large and Small category separations are the same, throughput benefit comes from faster approach speeds
- ROT for Large and Small are the same
- Heavy-Heavy separation is 4 NM, leads to lower throughput



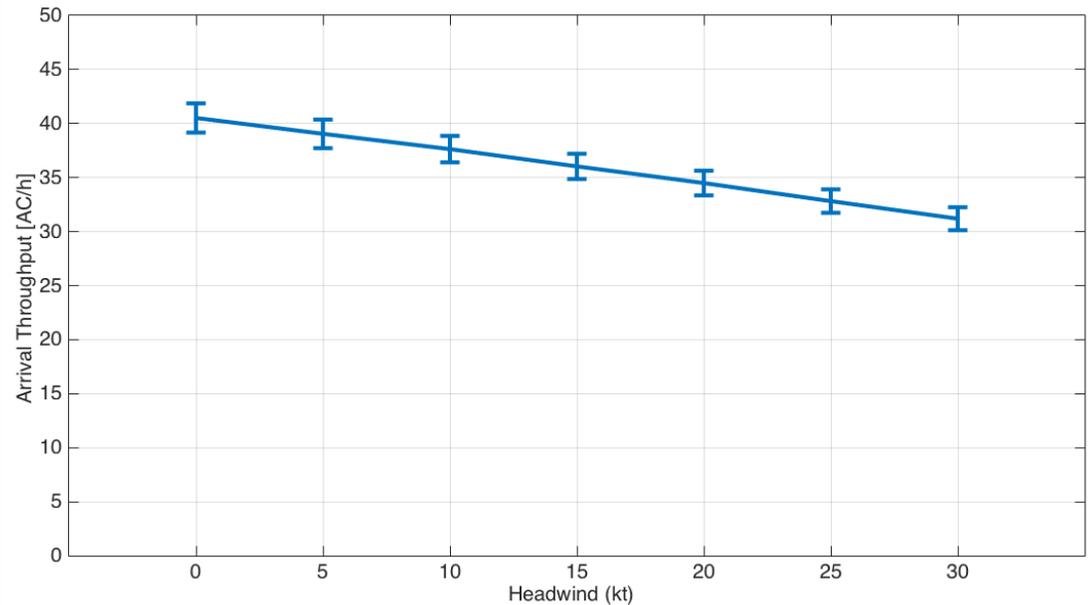
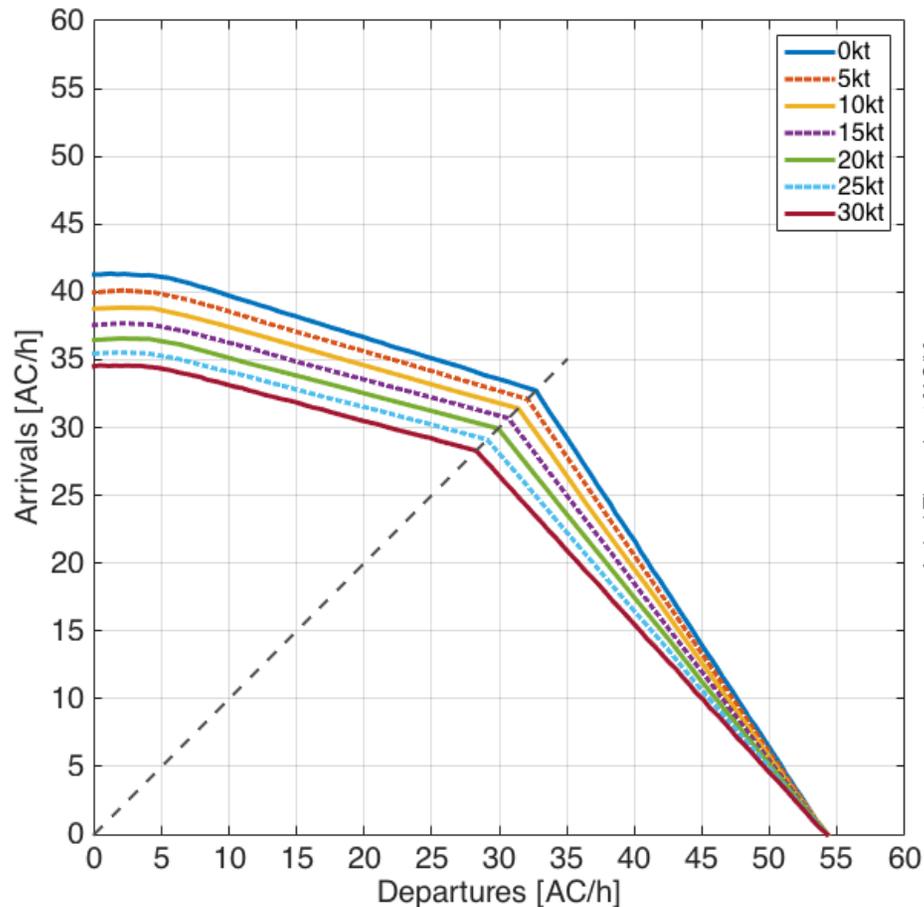
Single Runway Capacity – Sensitivity to Separation Buffer

- Separation buffer: from no buffer to 1 NM with 0.1 NM steps
- Arrival throughput decreases with increasing buffer from 44.8 ARR/hr to 33.7 ARR/hr
- “Free departures” point slightly increases from 4.8 DEP/hr to 6.7 DEP/hr
- 50-50 point decreases from 33 to 31 movements/hr



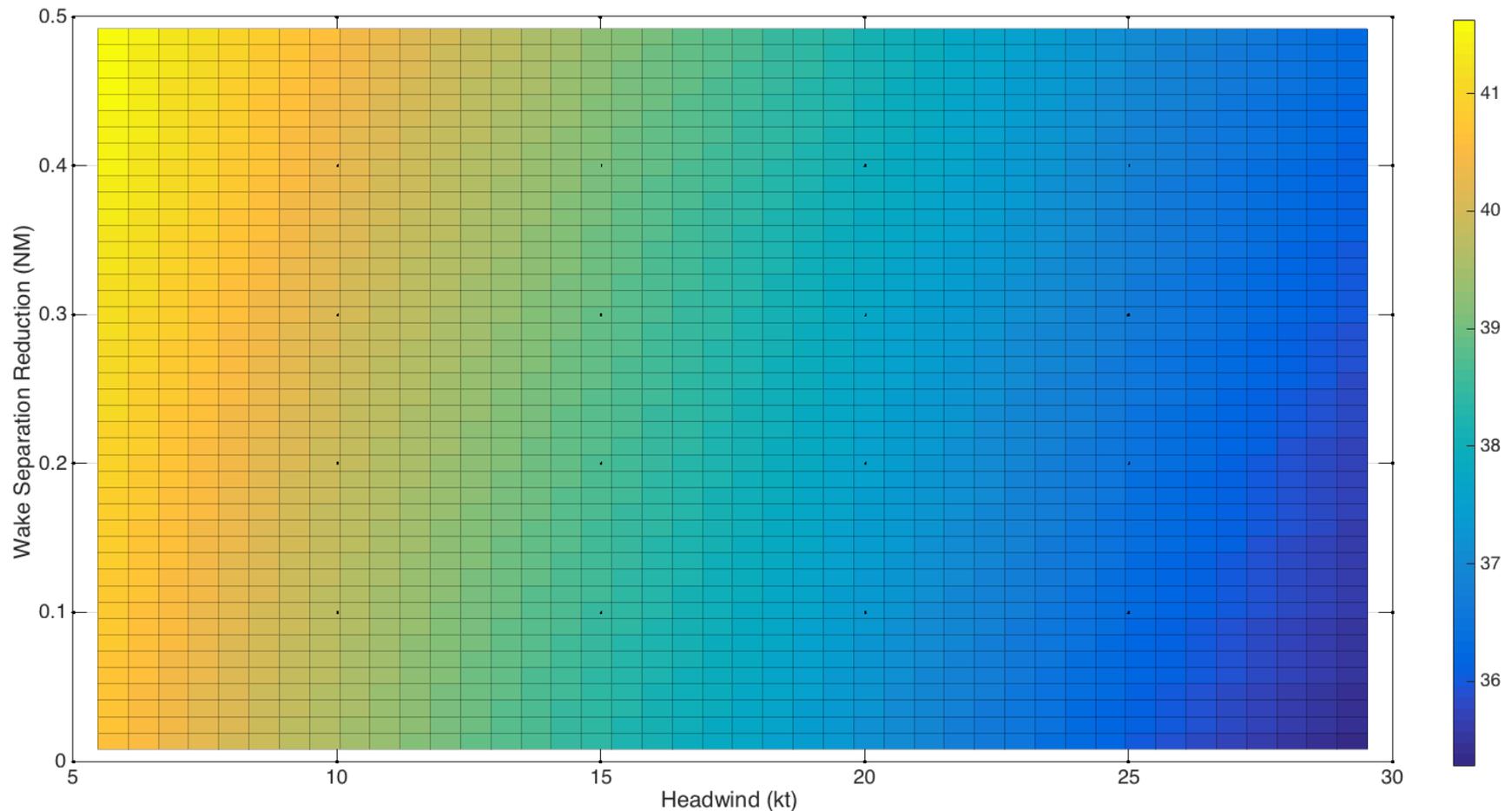
Single Runway Capacity – Sensitivity to Headwind

- Headwind: from no wind to 30 knots with 5 knot steps
- Arrival throughput decreases with increasing headwind from 41 ARR/hr to 34 ARR/hr
- “Free departures” point remains unchanged
- 50-50 point decreases from 33 to 28 movements/hr



Single Runway Capacity – Sensitivity to Headwind

- Headwind: from no wind to 30 knots with 5 knot steps
- Arrival-Arrival separation reduction is possible if headwind is strong or crosswind is present (faster vortex decay)
- Time-Based Separation concept is built on this idea



Next Steps

- Complete system-level runway capacity study
- As part 2 of the project, evaluate the impact of future wake separation concepts at selected U.S. airports
 - Most delayed airports in the NAS:
 - LGA, EWR, JFK, SFO, ORD, BOS, LAX
 - New wake separation concepts:
 - Single flow traffic: RECAT (1 & 2), TBS, CREDOS, Large-Large 2NM
 - CSPR flows: RECAT (1 & 2), WTMA-S/P, Paired-Arrivals, Paired-Departures