Airspace System Efficiencies Enabled by PNT

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Motivation (1)

- Air transportation is a critical component of the "backbone" of the global economy
  - Strong correlation with gross domestic product
  - Air cargo is a leading indicator of economic activity
  - Significant number of direct, indirect, and induced jobs
  - Air transportation provides a basis for economic activity in regions with poor surface and water access
- Future economic growth will require significant efficiency improvements and/or capacity increases

Motivation (2)

- Development of air traffic control in the six decades since WWII has been driven by…
  - Technologies (e.g. Radar, VOR, ILS, RNAV) that brought new or significantly improved operational capabilities
  - Accidents precipitated mandates for technologies that were "on the shelf" (e.g. TCAS) but "could not buy their way into the system"
- Air transportation system still prone to frequent disruption and delays (mostly weather-based) despite over 50 year of all-weather operations

Motivation (3)

- Recent shift towards higher precision navigation and timing
  - Cockpit-focused Area Navigation (RNAV) with Required Navigation Performance (RNP)
  - GPS-based Automatic Dependent Surveillance - Broadcast (ADS-B)
- What can we do with PNT to improve efficiency?
  - Metering of Arrival Flows
  - Regulation of Departure Flows

Metering of Arrival Flows

Motivated by Near-Term Benefits

Optimized Profile Descent

MIA
- 50 Gallons Fuel Saved*
- 1,000 Pounds Emissions Reduced*

ATL
- 38 Gallons Fuel Saved*
- 800 Pounds Emissions Reduced*

LAX
- 26% Reduction of Average Level Flight (ALF) Time
- 5.2% Reduction of Fuel Use

*Per Flight in May 2008

2018 ESTIMATES

Reduce Delays
21%

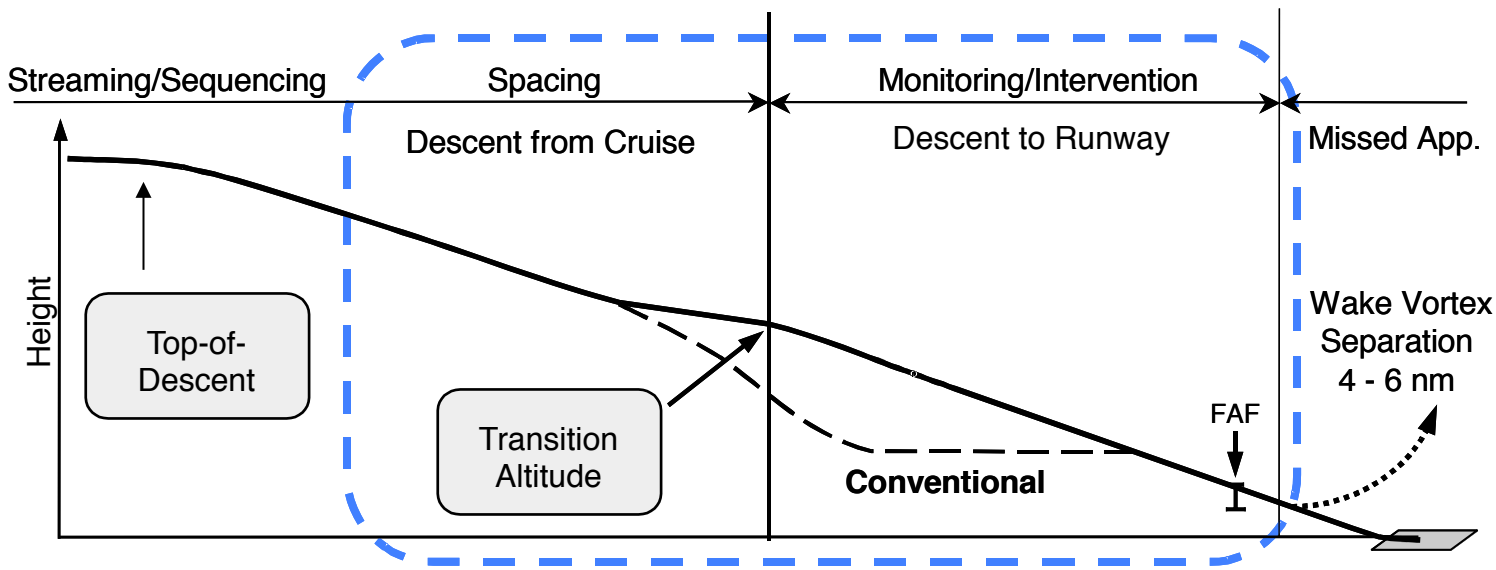
Reduce CO_2 Emissions
14M Tons Cumulative

Reduce Fuel Use
1.4B Gallons Cumulative

$22B in benefits

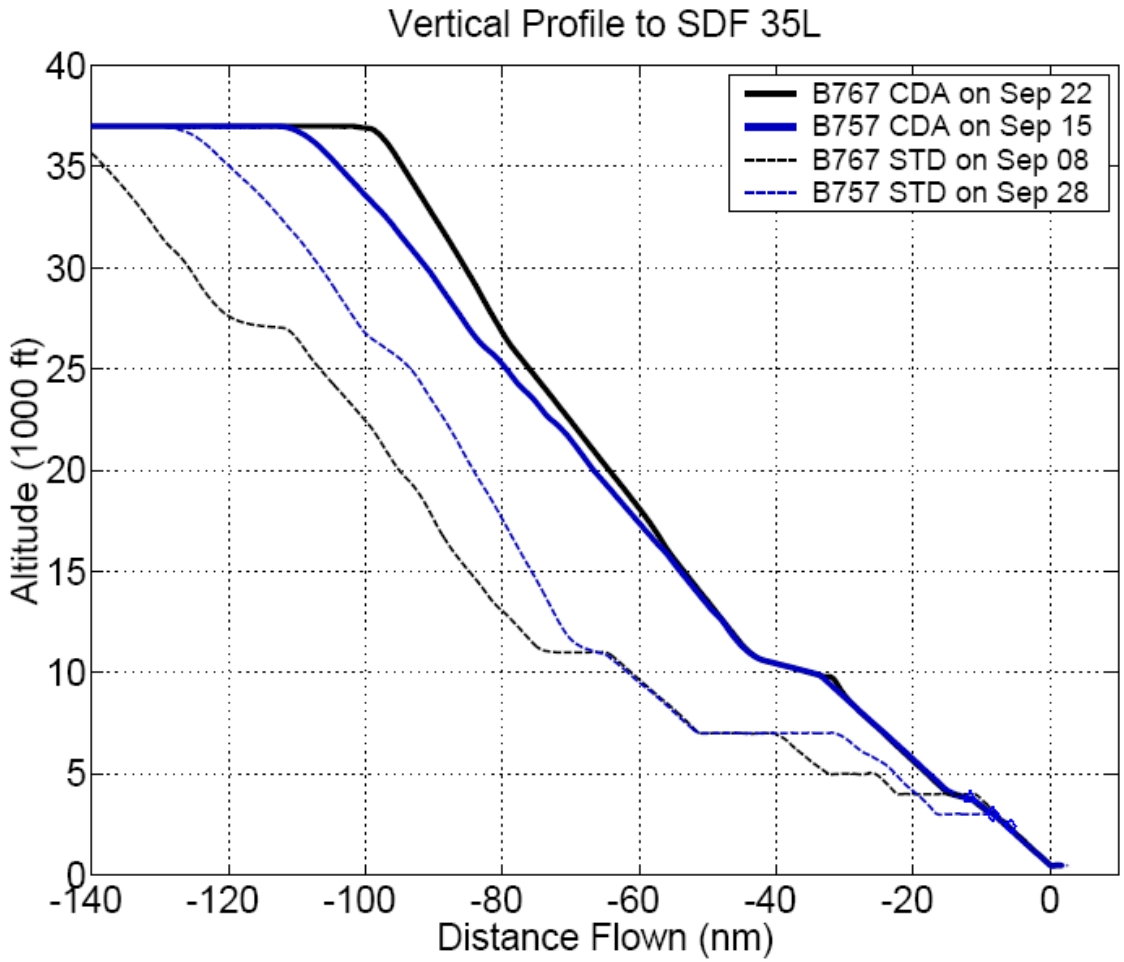
Optimized Profile Descent (OPD)*

- Aircraft actively controlled during descent from cruise (top-of-descent) to transition altitude
- Minimal intervention below transition altitude



* OPT = Continuous Descent Arrival (CDA)

OPD Trajectories (2004 Flight Trial)



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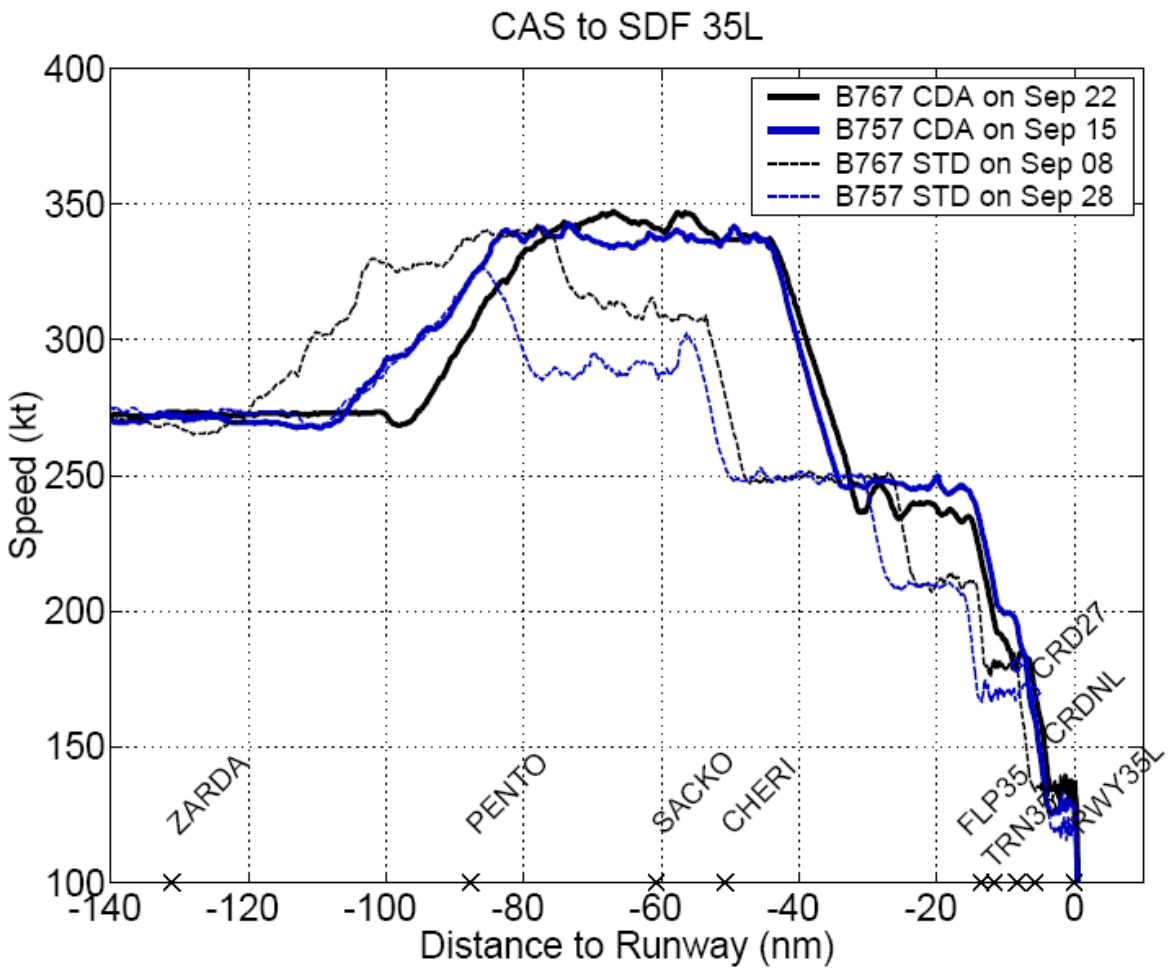

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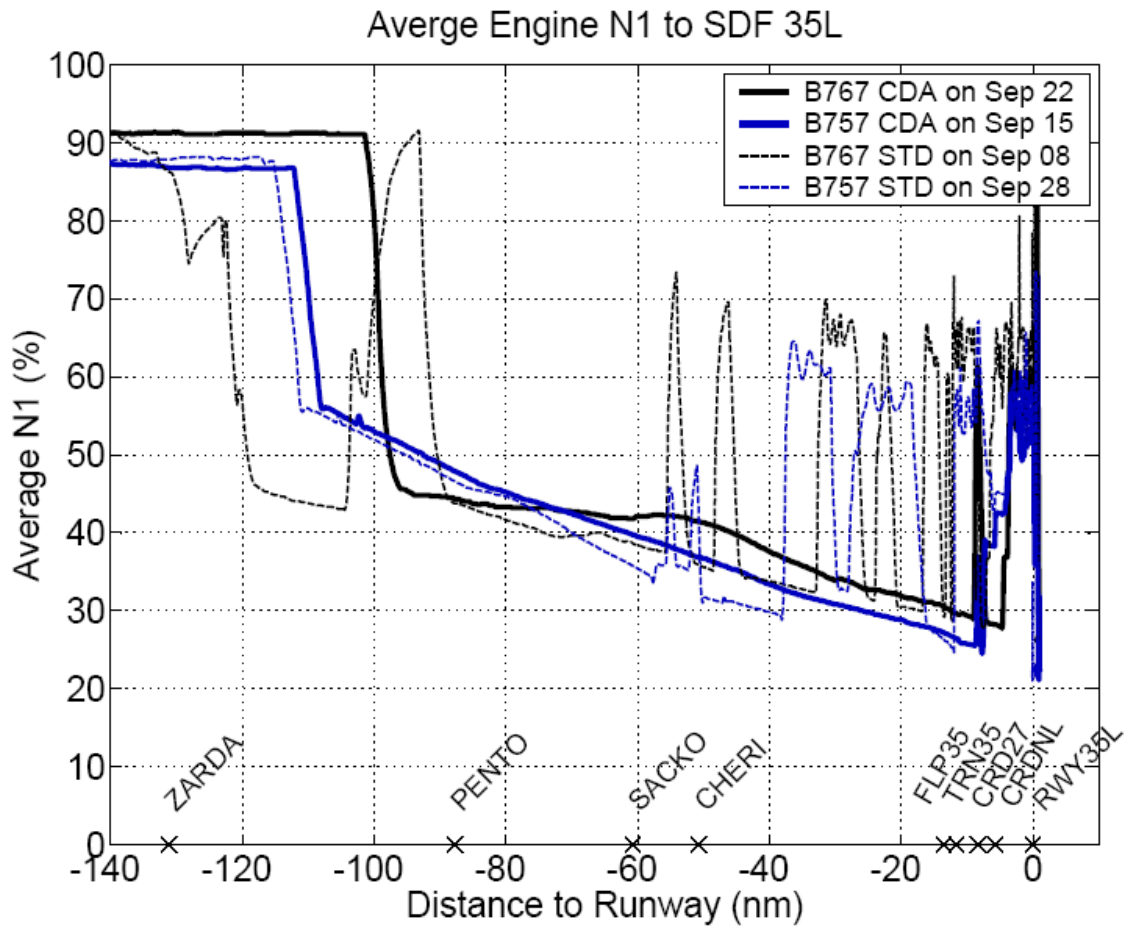
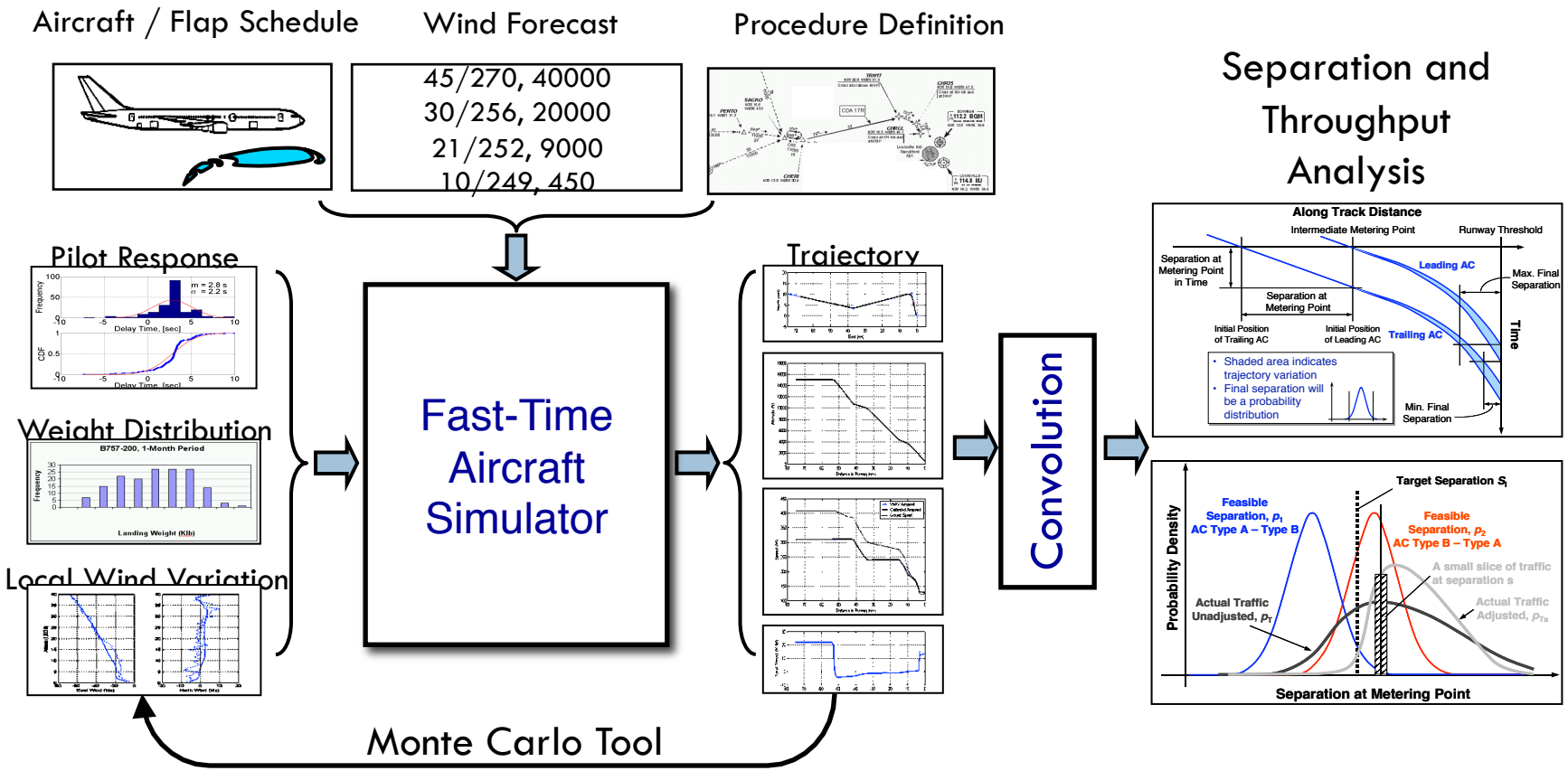


Challenge

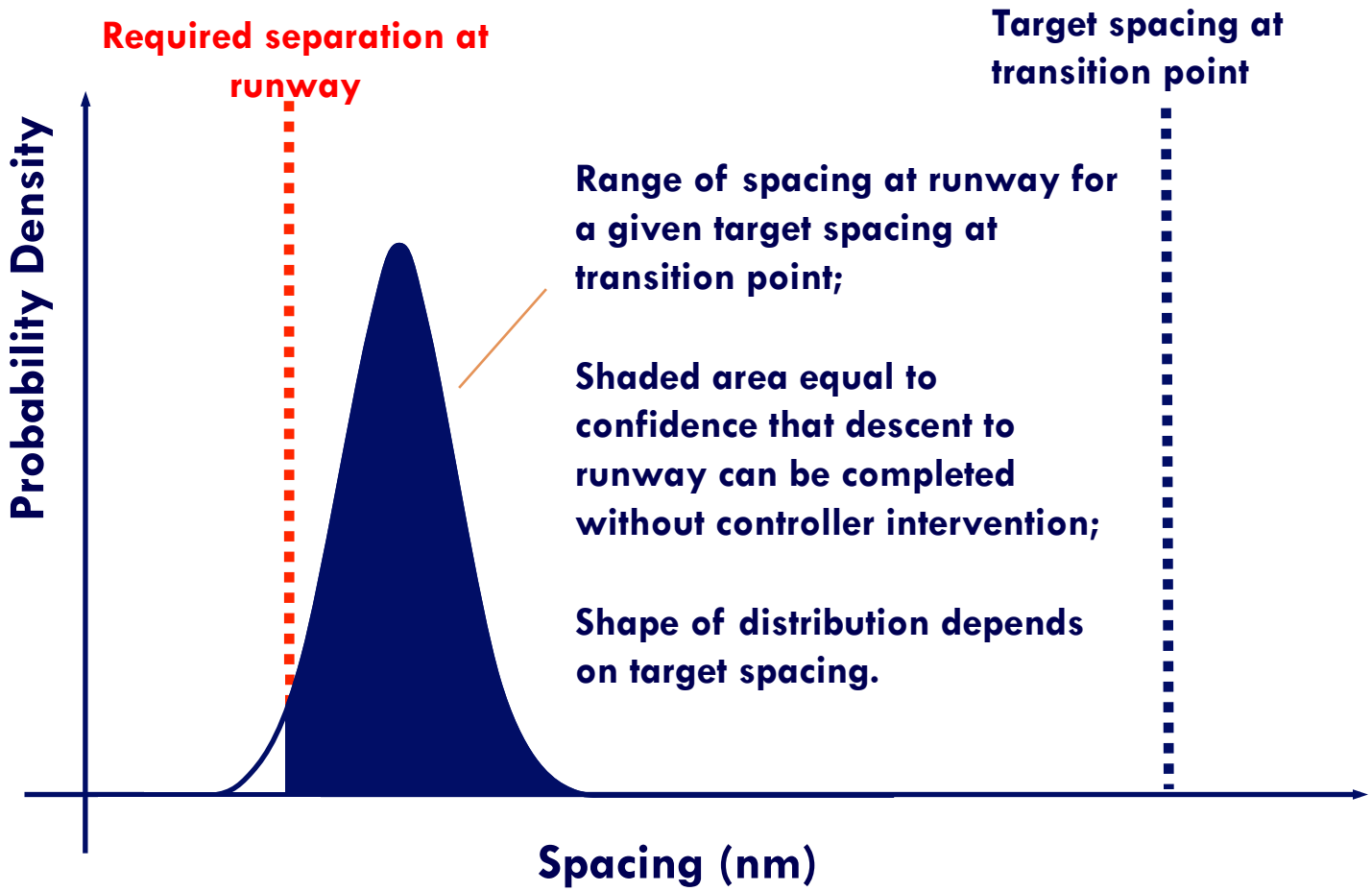
- Ability to achieve these benefits without sacrificing throughput is primarily a function of the accuracy with which aircraft can be metered
  - Intervention required if aircraft are too closely spaced
  - Throughout lost if aircraft are too widely spaced

TASAT*



* TASAT = Tool for Analysis of Separation and Throughput

Variability in Threshold Spacing



Observation

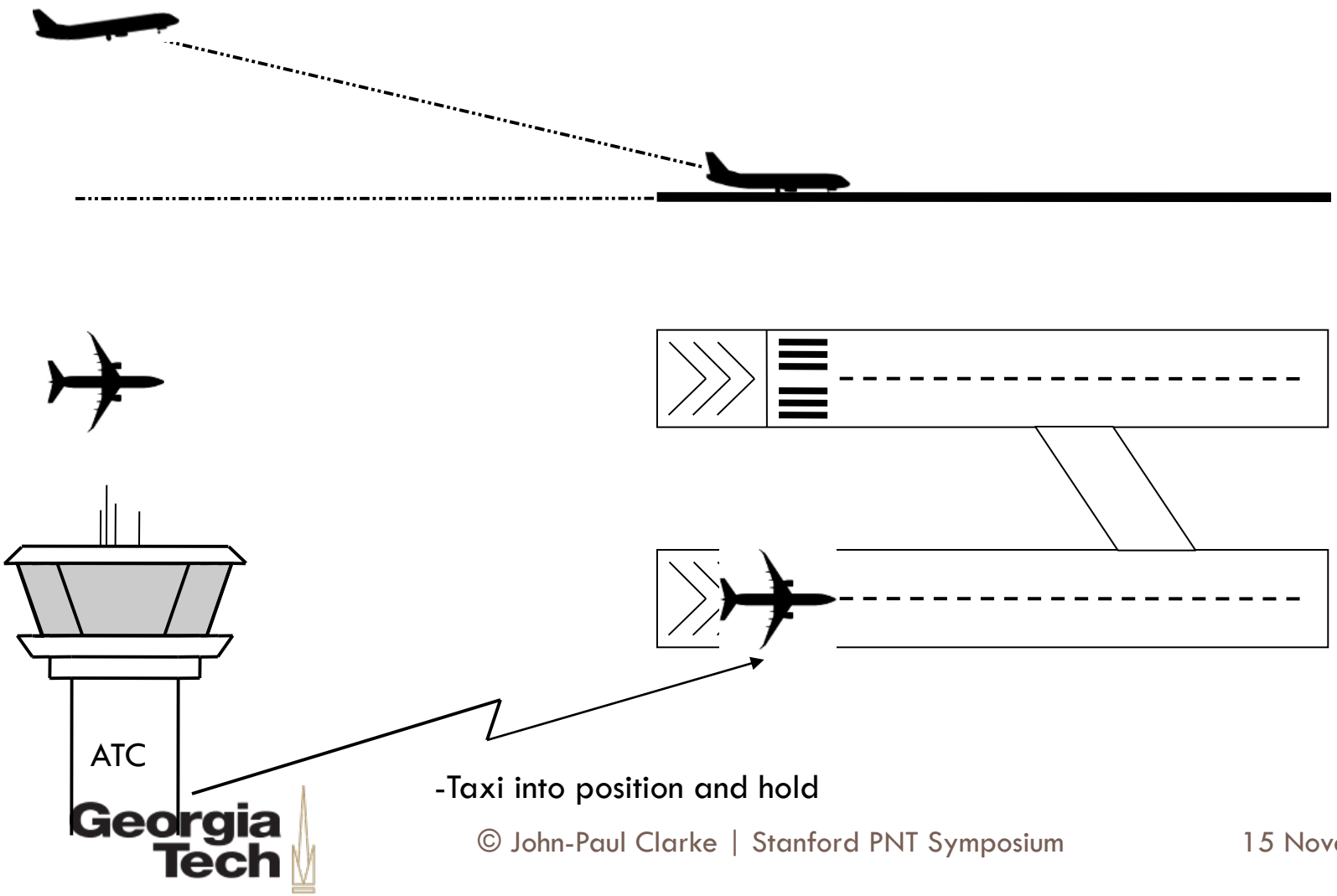
- TASAT nominally provides conditional probability density function (PDF) for the spacing between aircraft when the lead aircraft is over the threshold
  - PDF conditional on the metering being perfect
- Actual probability density function will depend on metering accuracy
  - Actual PDF will be a convolution of the conditional PDF and the PDF for the metering accuracy
- PNT is thus the key to optimizing arrival operations

Regulation of Departure Flows

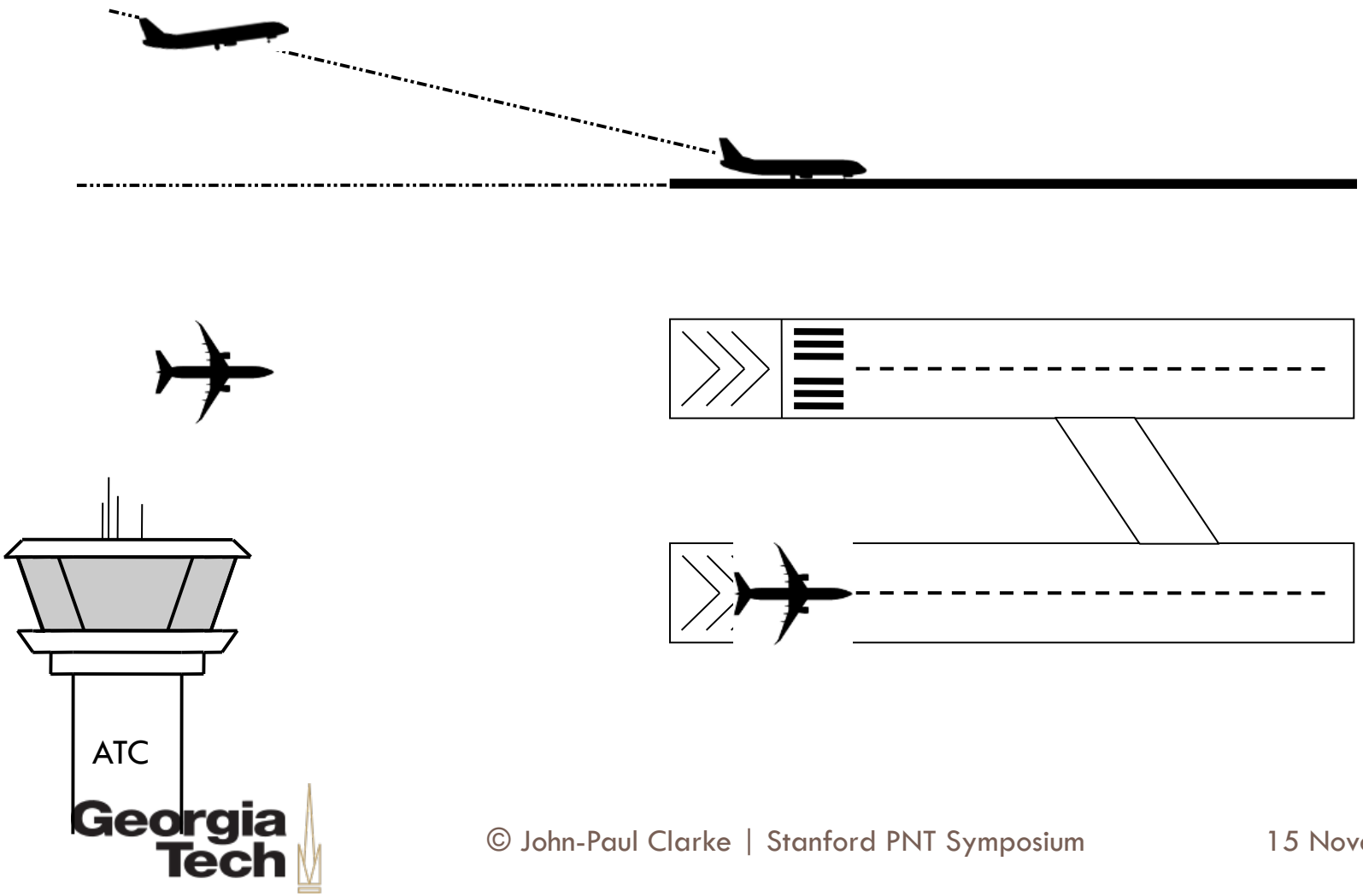
Background

- Most OEP airports have closely spaced parallel runways (CSPRs)
  - 20 out of 35 OEP airports have CSPRs
  - 27 sets of CSPRs in total at these airports (i.e. some airports have multiple sets of CSPRs)
- Departures typically wait for arrivals to "cross the threshold" or "touchdown" before commencing their takeoff roll

Nominal Departure Process (1)



Nominal Departure Process (2)



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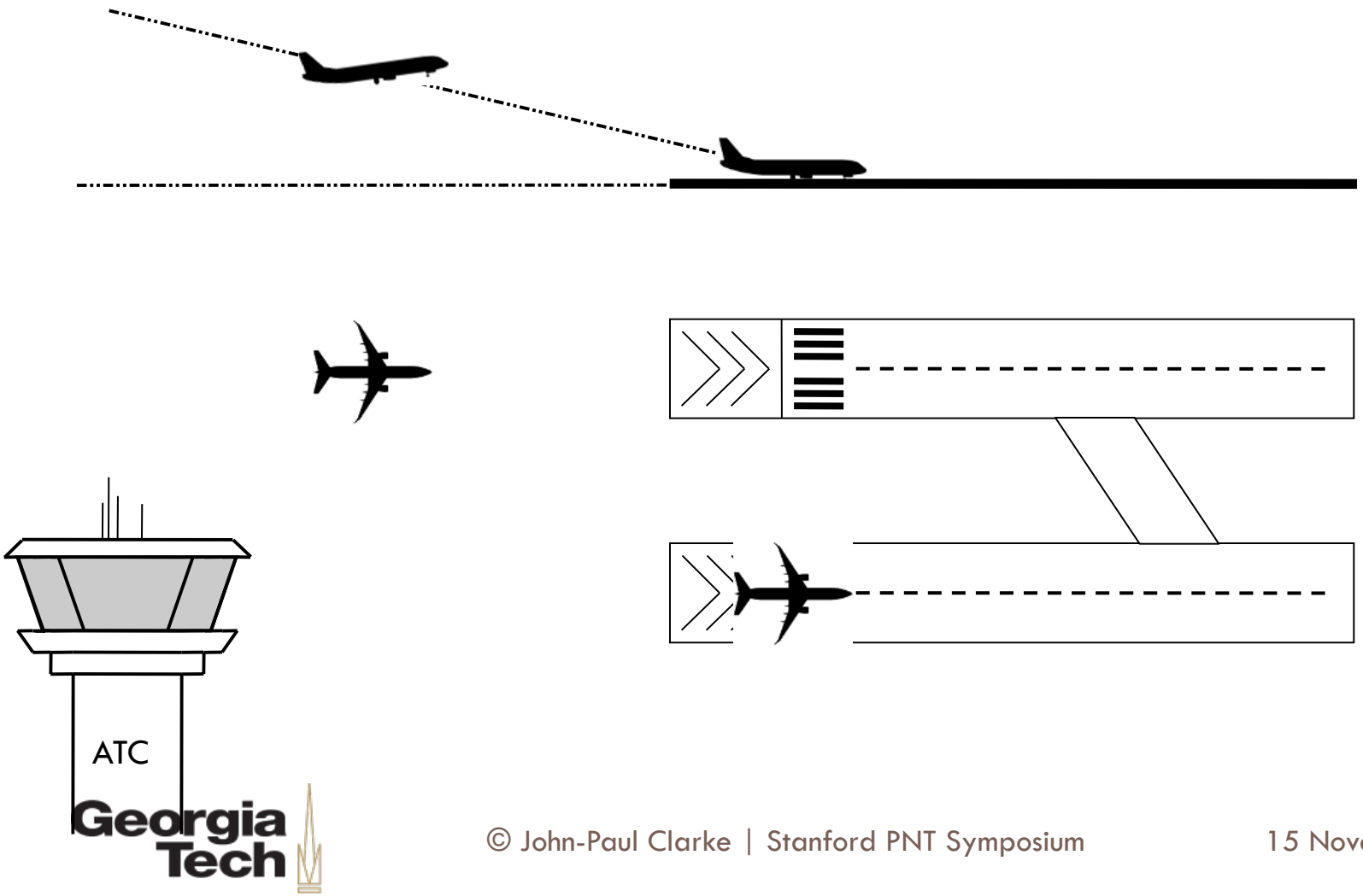

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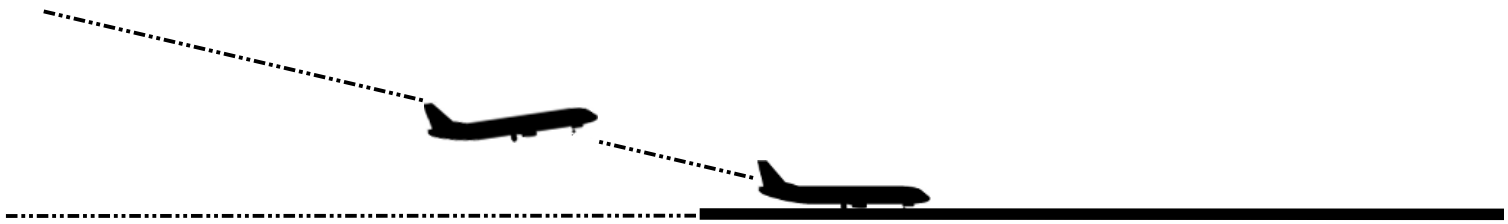

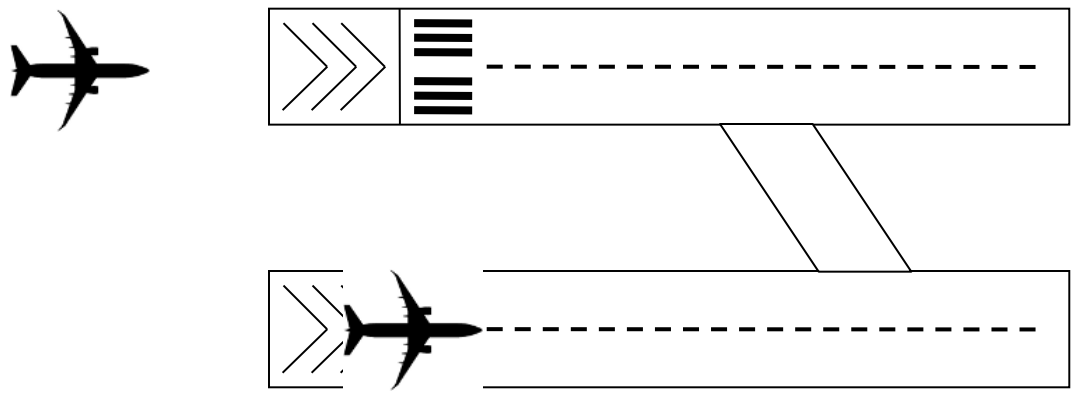

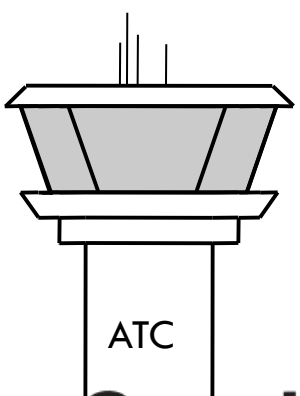

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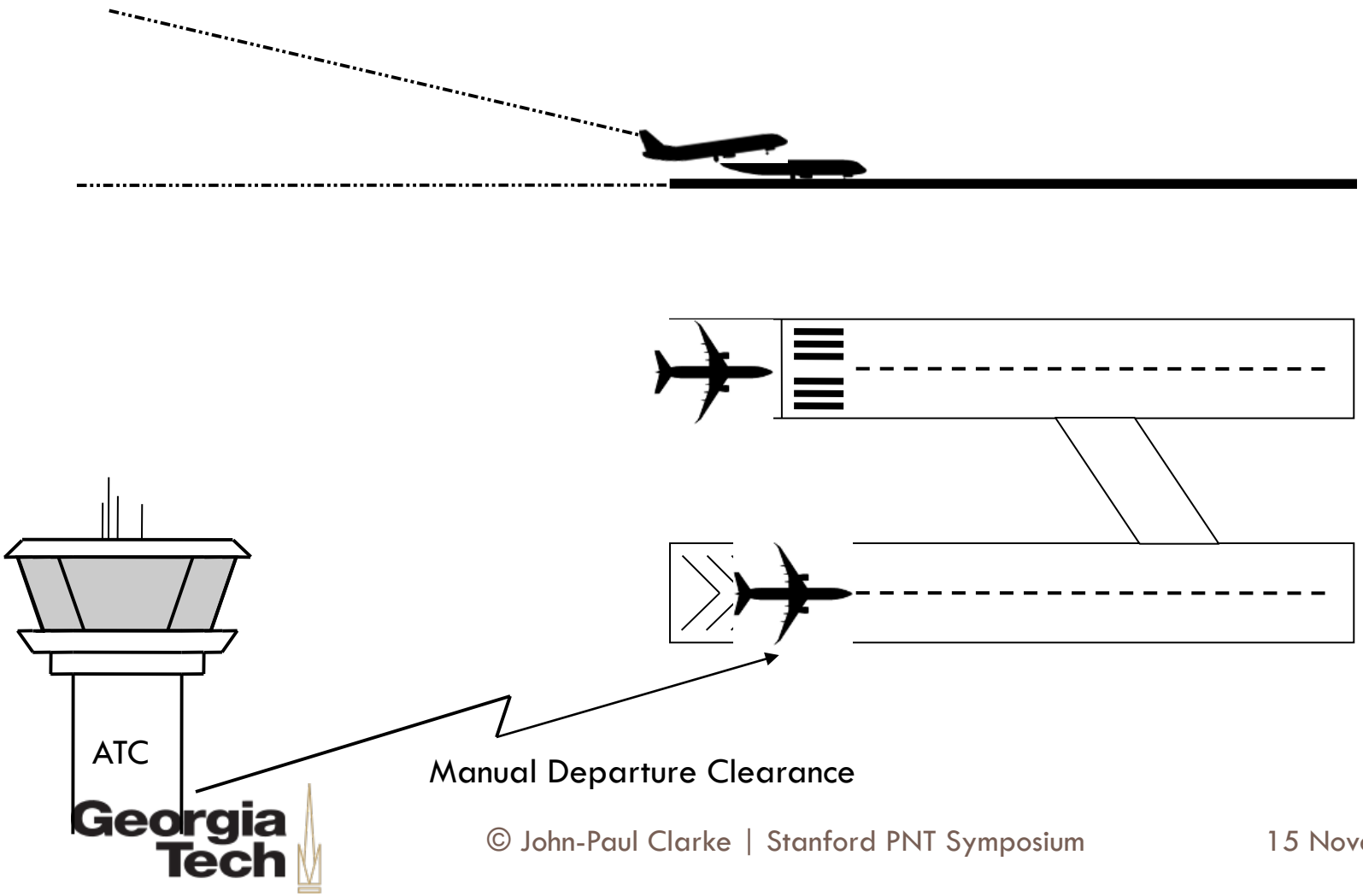

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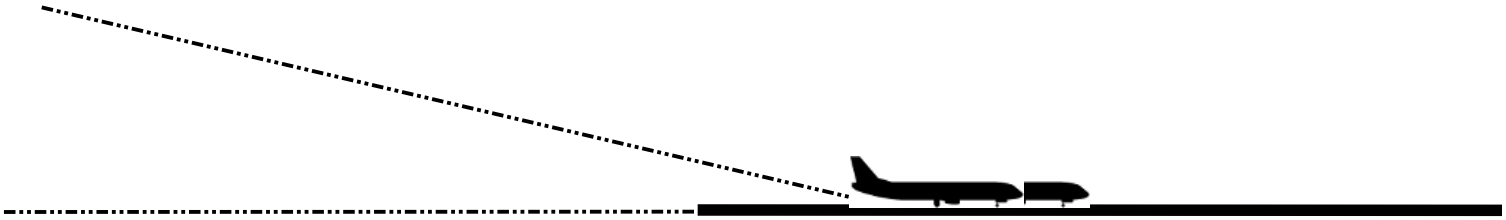

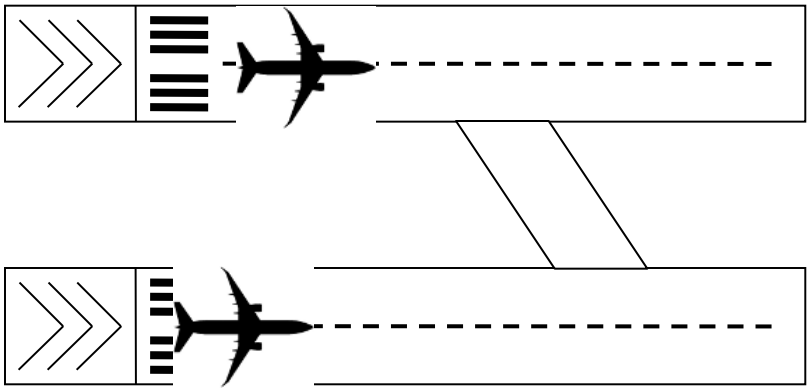

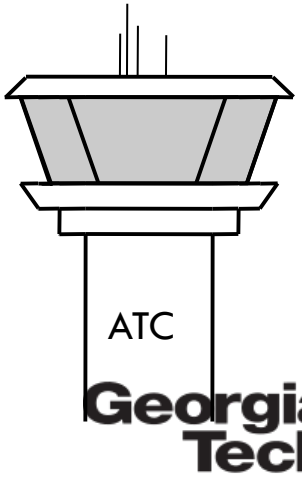

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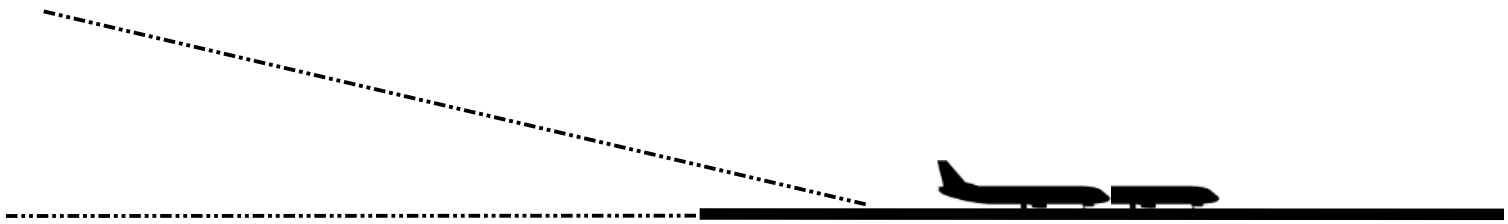

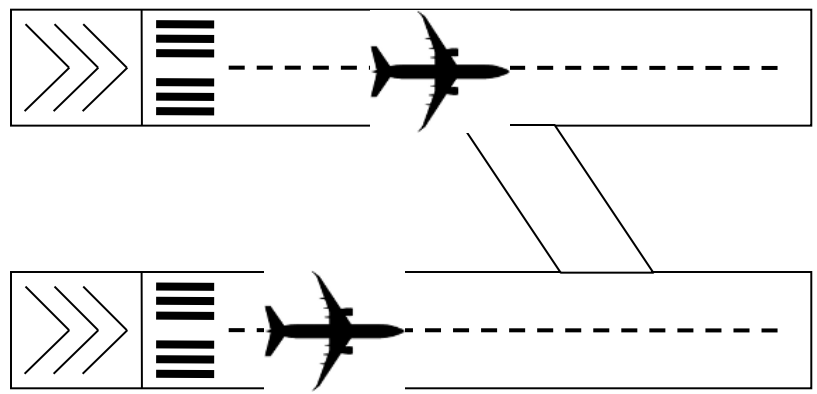

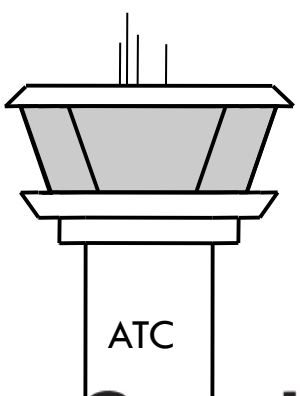

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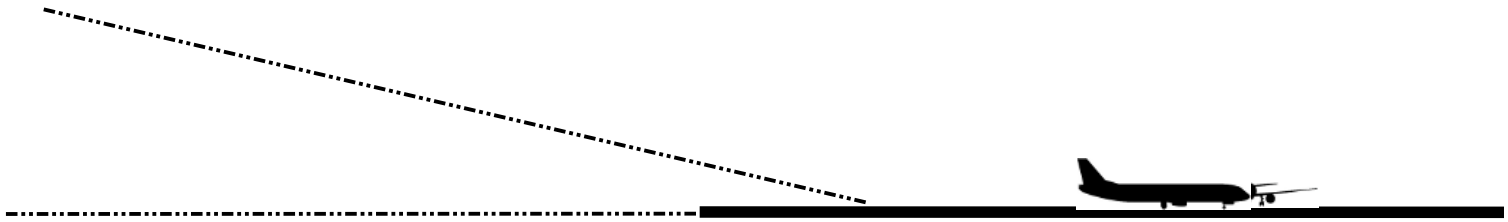

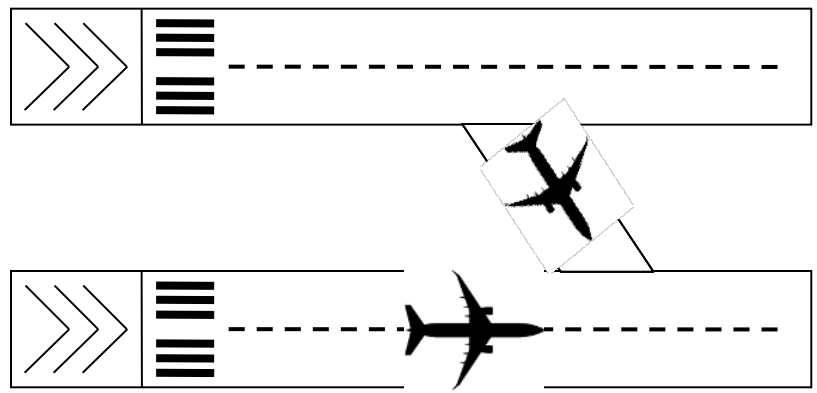

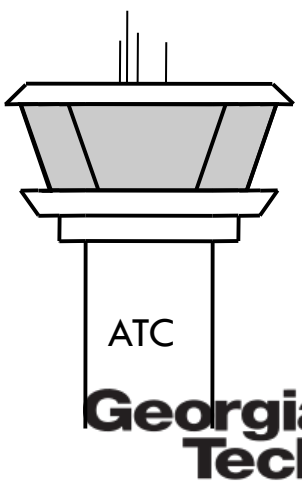

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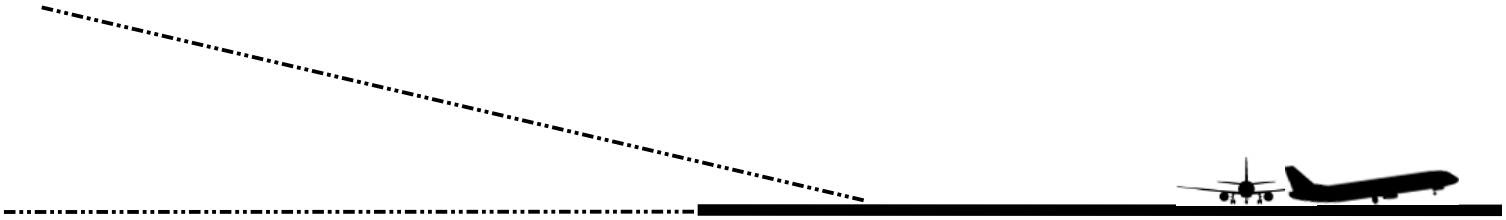

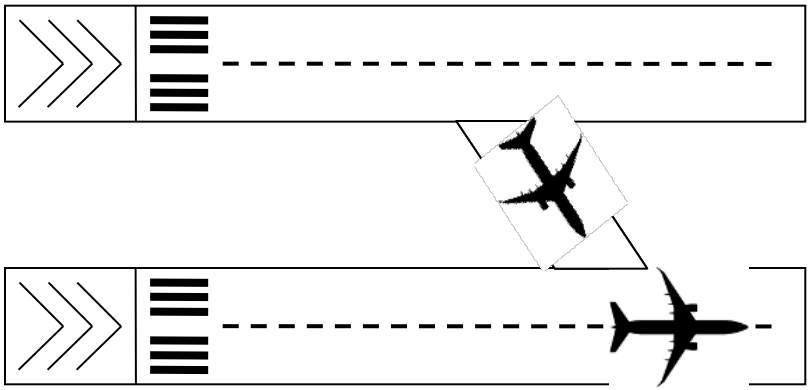

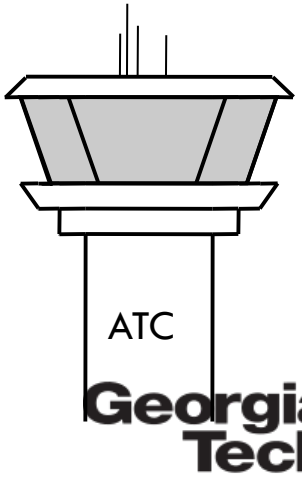

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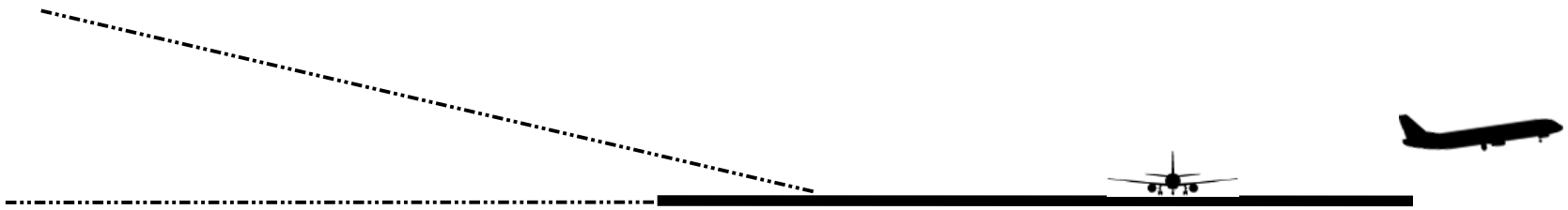
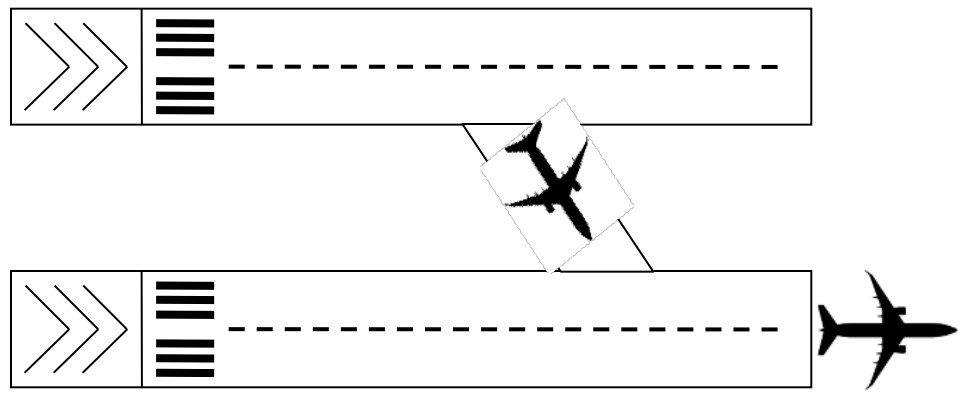
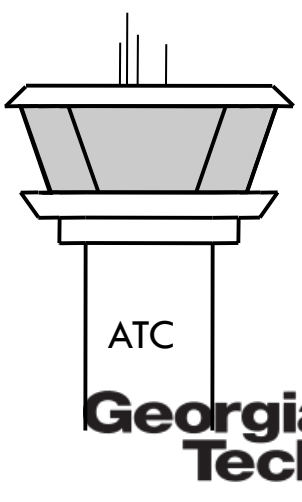
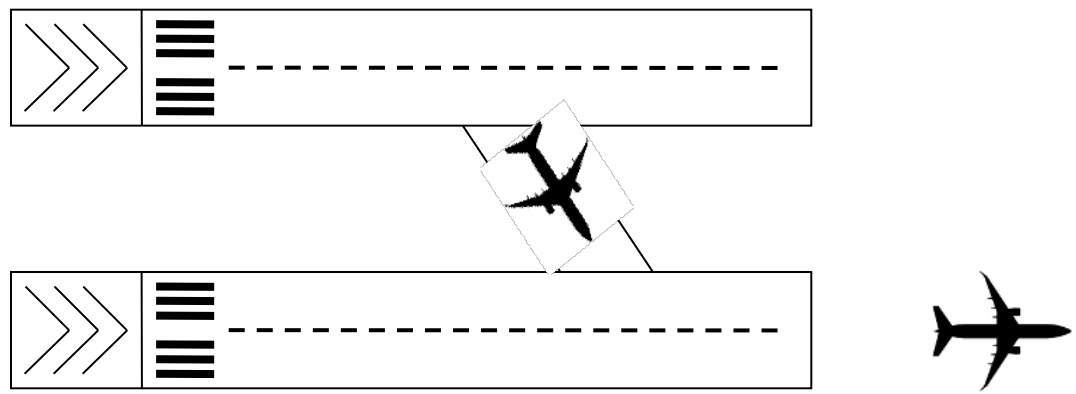






Nominal Departure Process (11)



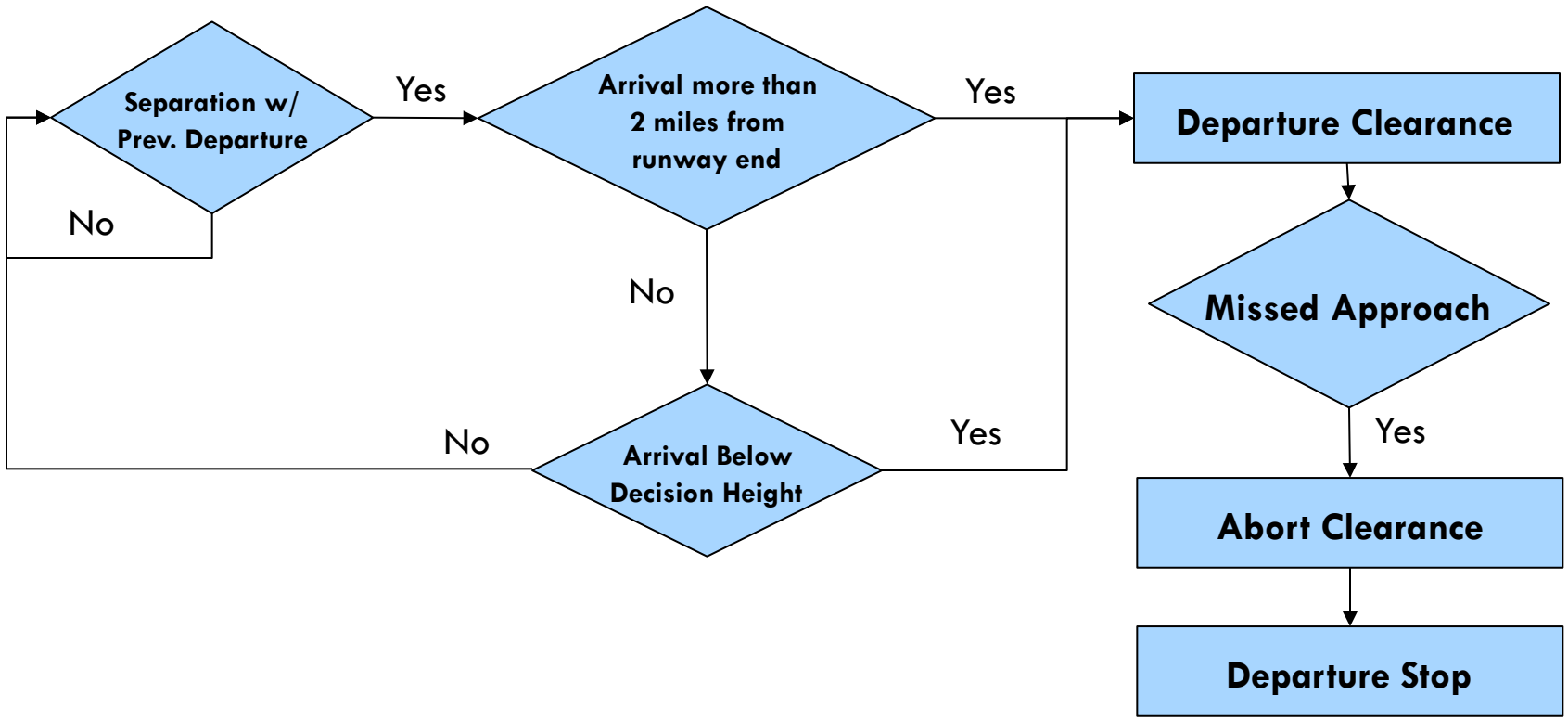
Runway Regulator – Objective

- For each set of
  - Closely spaced parallel runways
- Decide
  - When to issue automated takeoff clearance/advisory
- Given
  - Position of arrival (e.g. from ADS-B)
  - Potential future trajectories of all aircraft
  - Probabilities that landing will be completed
  - Probability successful response to missed approach

Runway Regulator – Logic Flow

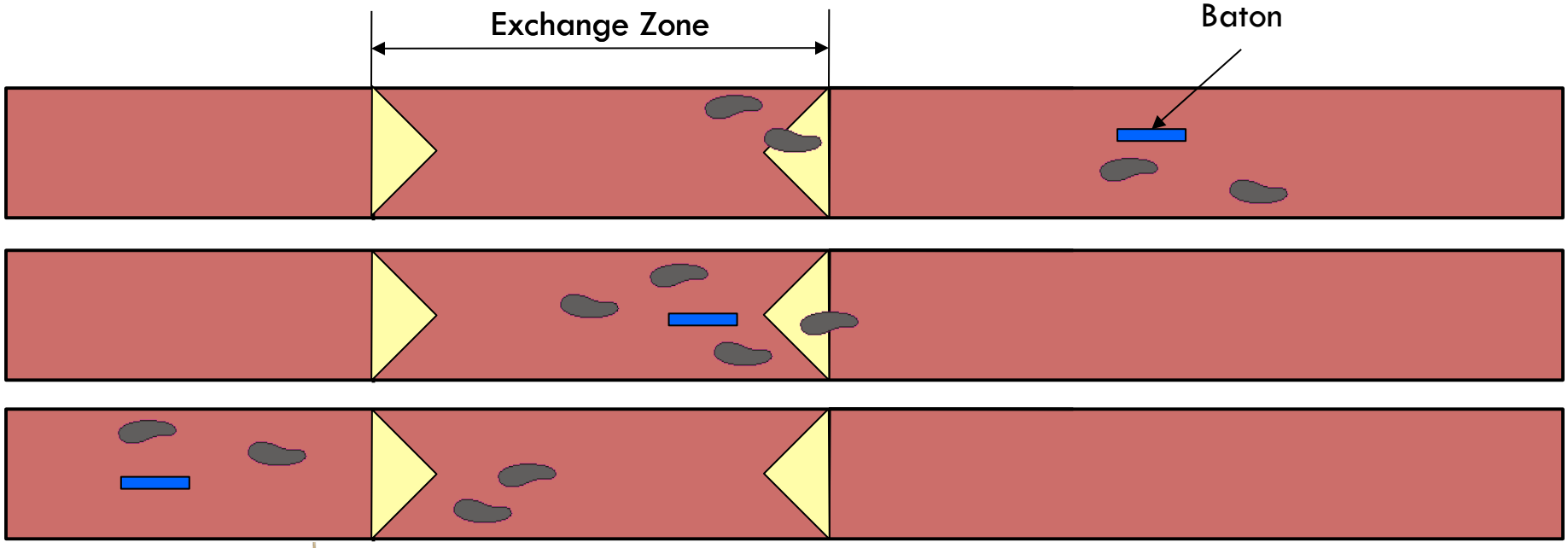
- Departure aircraft given clearance by ATC to:
  - taxi into position and hold
  - await automated departure clearance
- Automated departure clearance/advisory issued when:
  - Next arrival descends below decision height
  - There is sufficient separation between previous departure
- Automated abort clearance/advisory issued if:
  - Arrival executes a missed-approach

Departure Regulator – Logic Flow



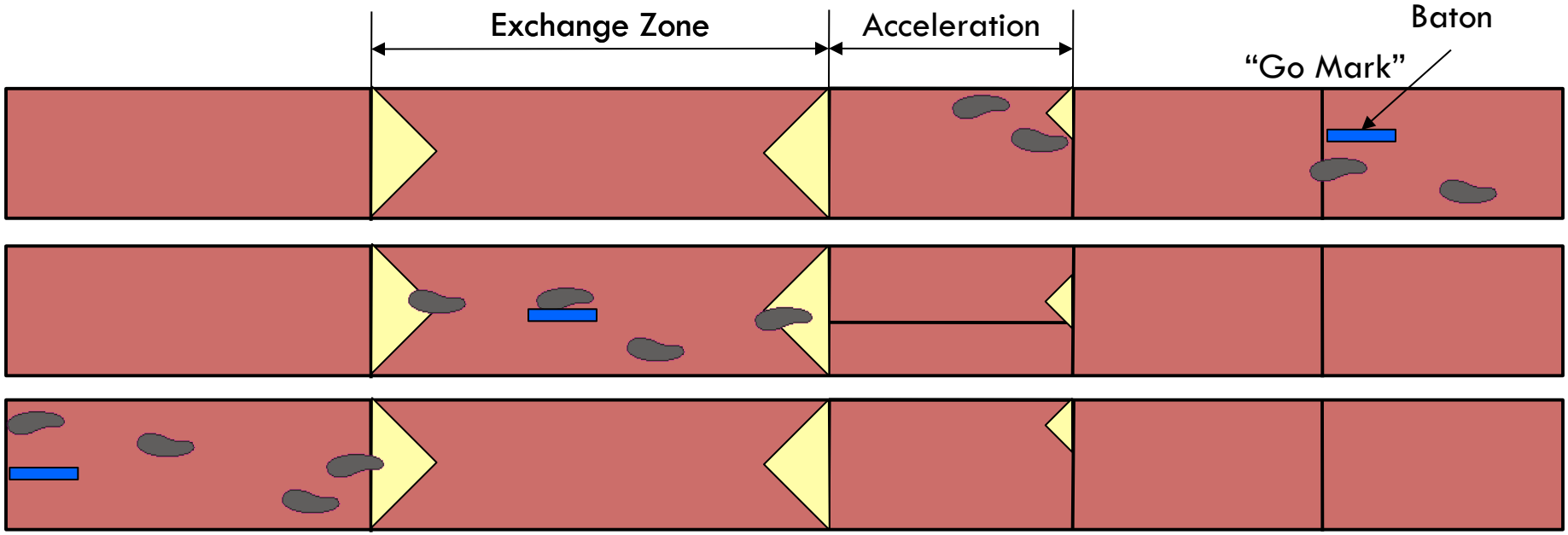
Track and Field Analogy (1)

- The 4x400m
  - Handoff occurs at low speed
  - Relay time approximately equal to sum of individual times

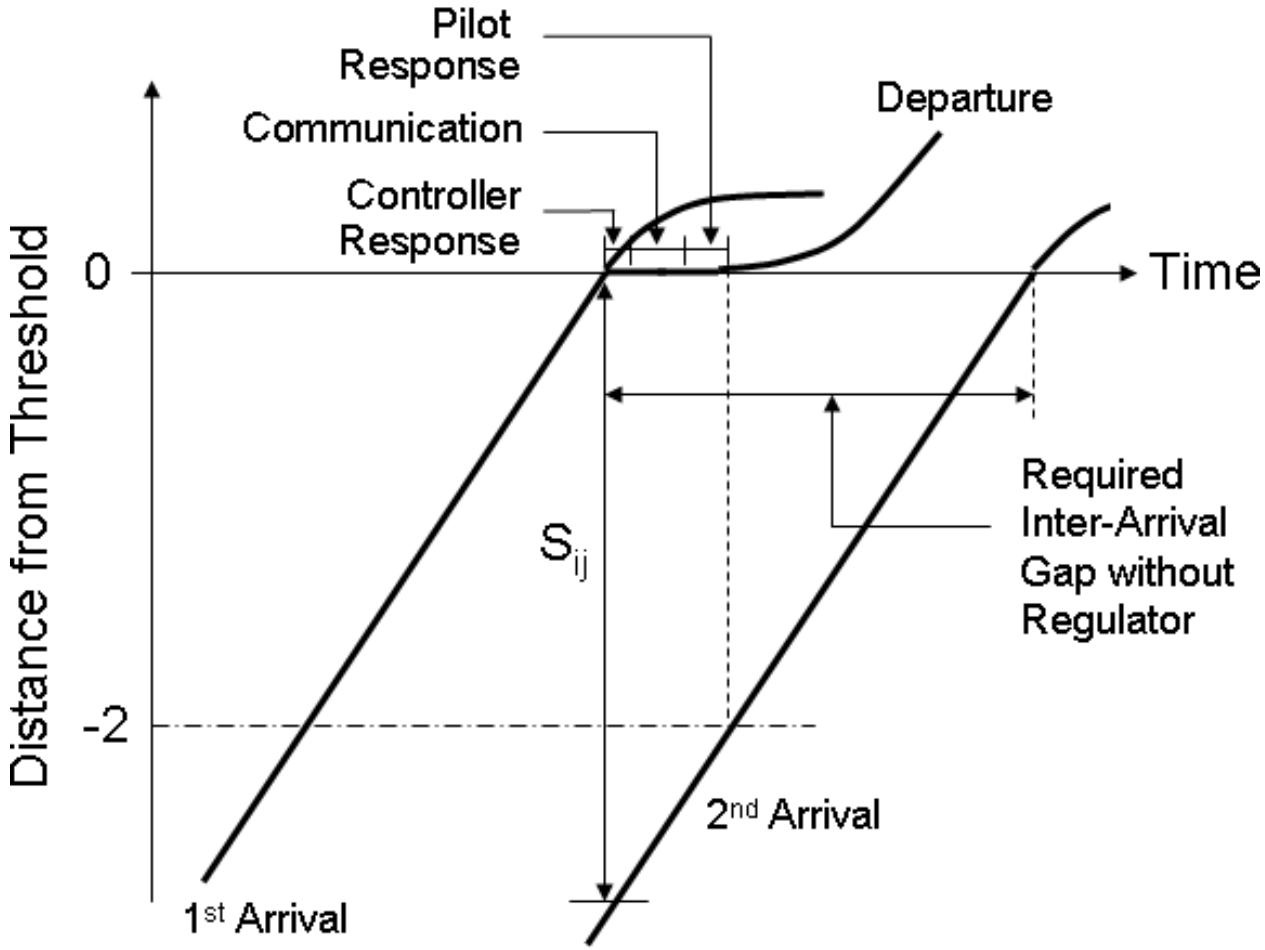


Track and Field Analogy (2)

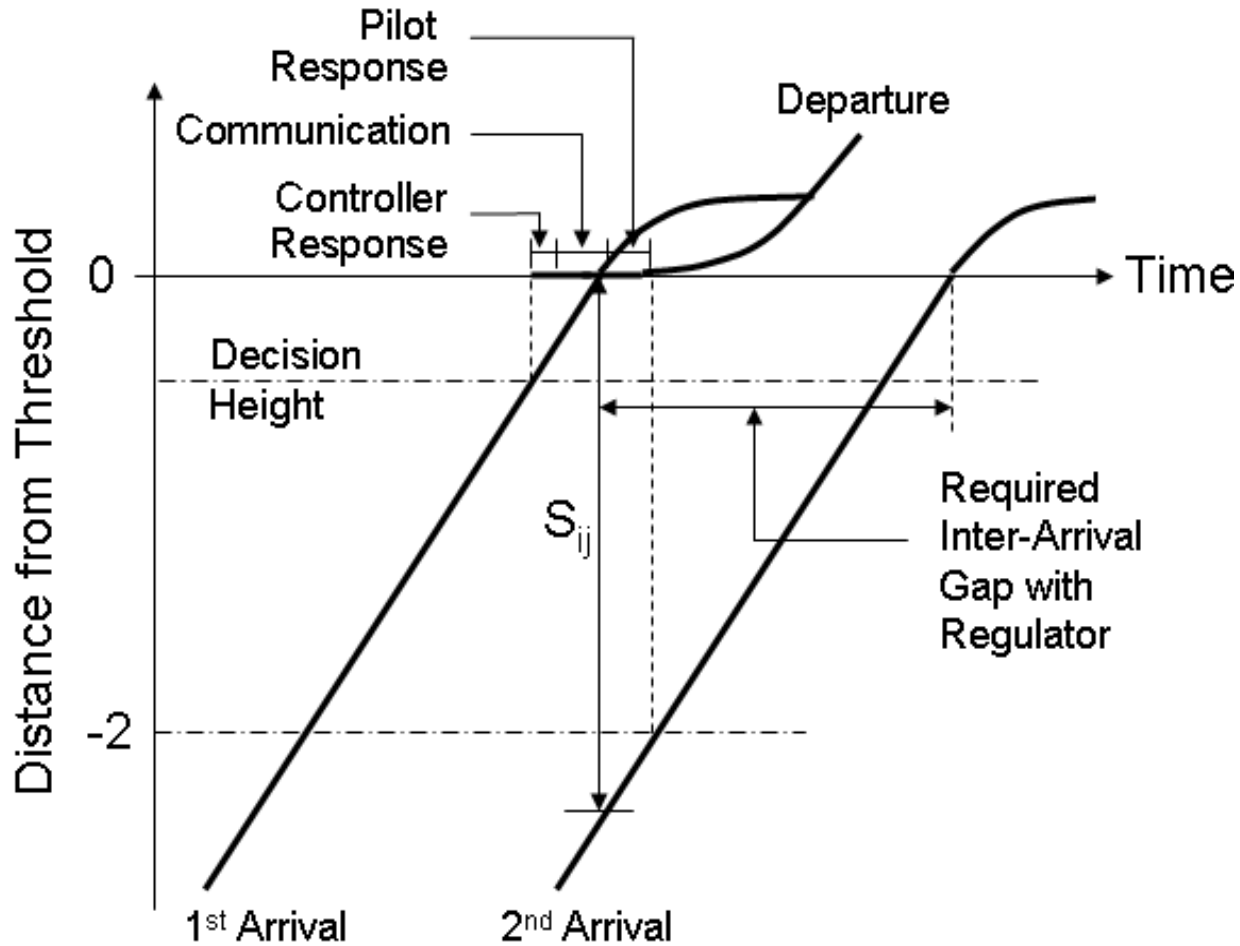
- The 4x100m
  - Handoff occurs at high speed
  - Relay time less than sum of individual times



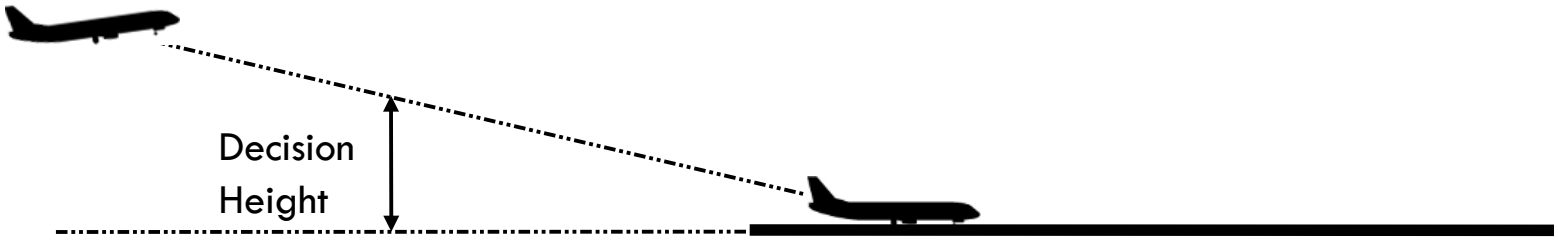
Nominal Departure Process

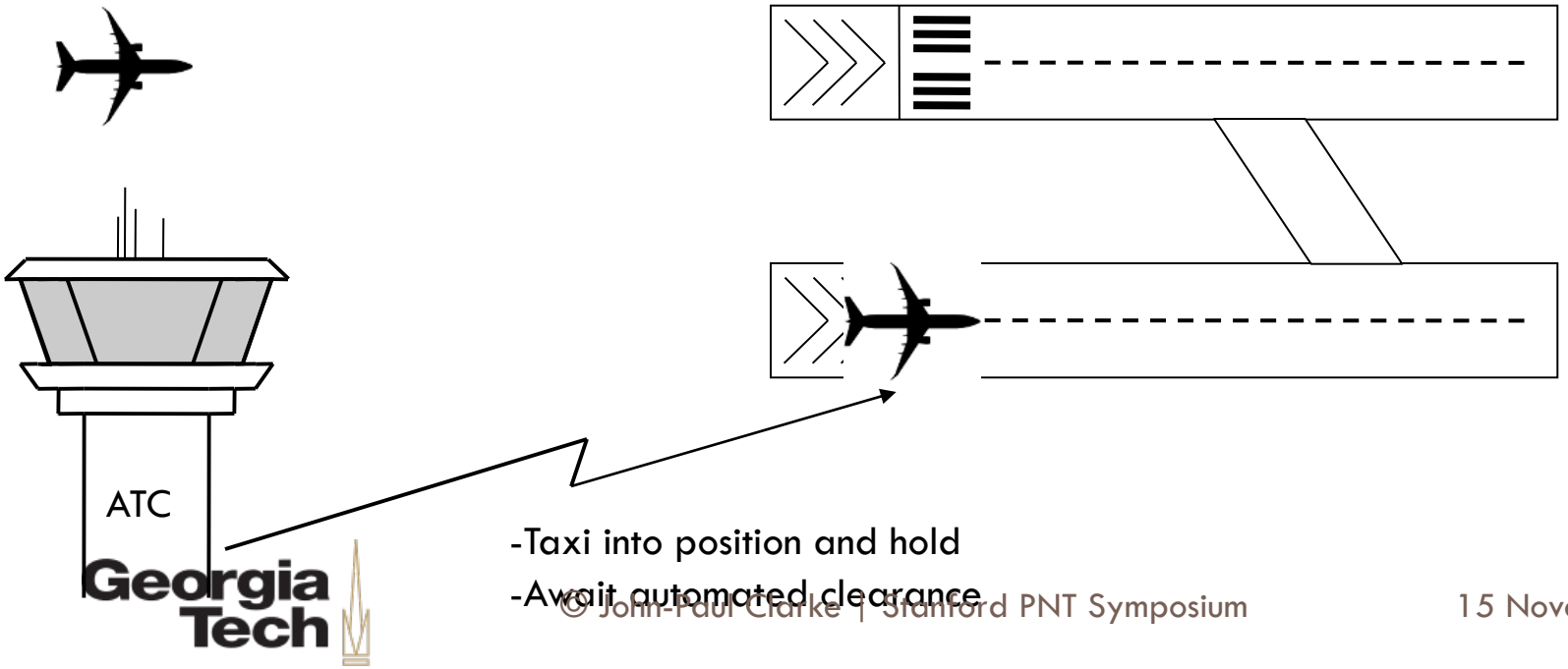


Regulated Departure Process



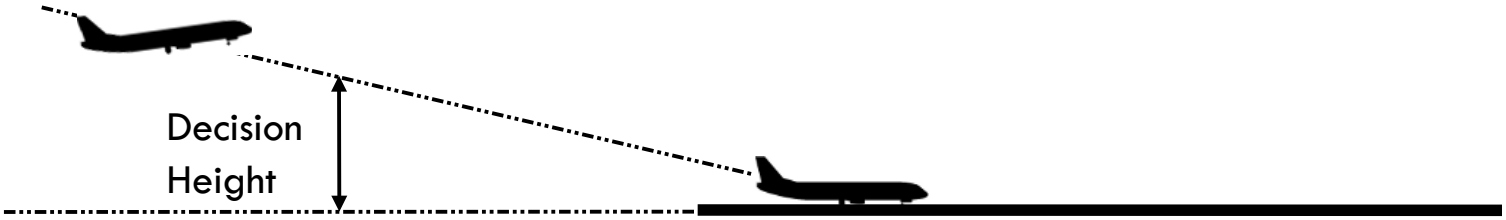
Regulated Departure Process (1)

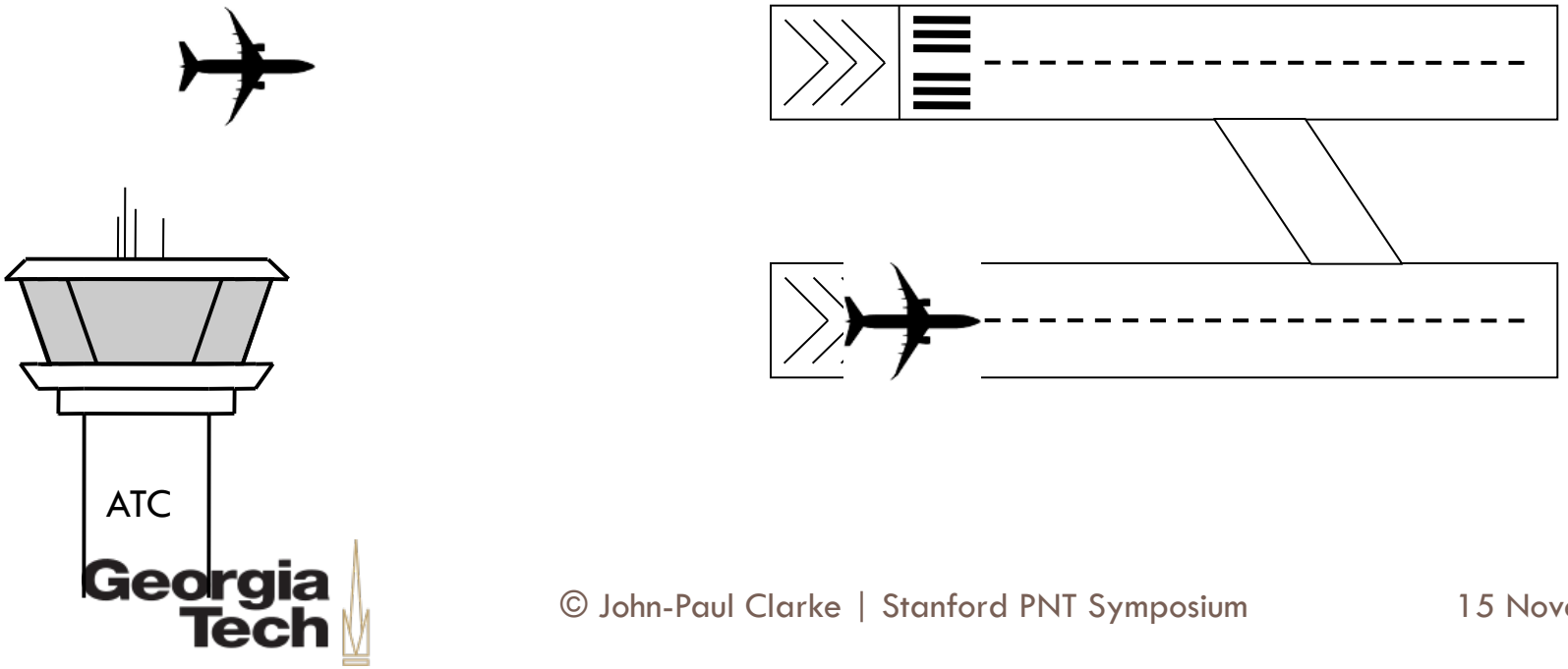




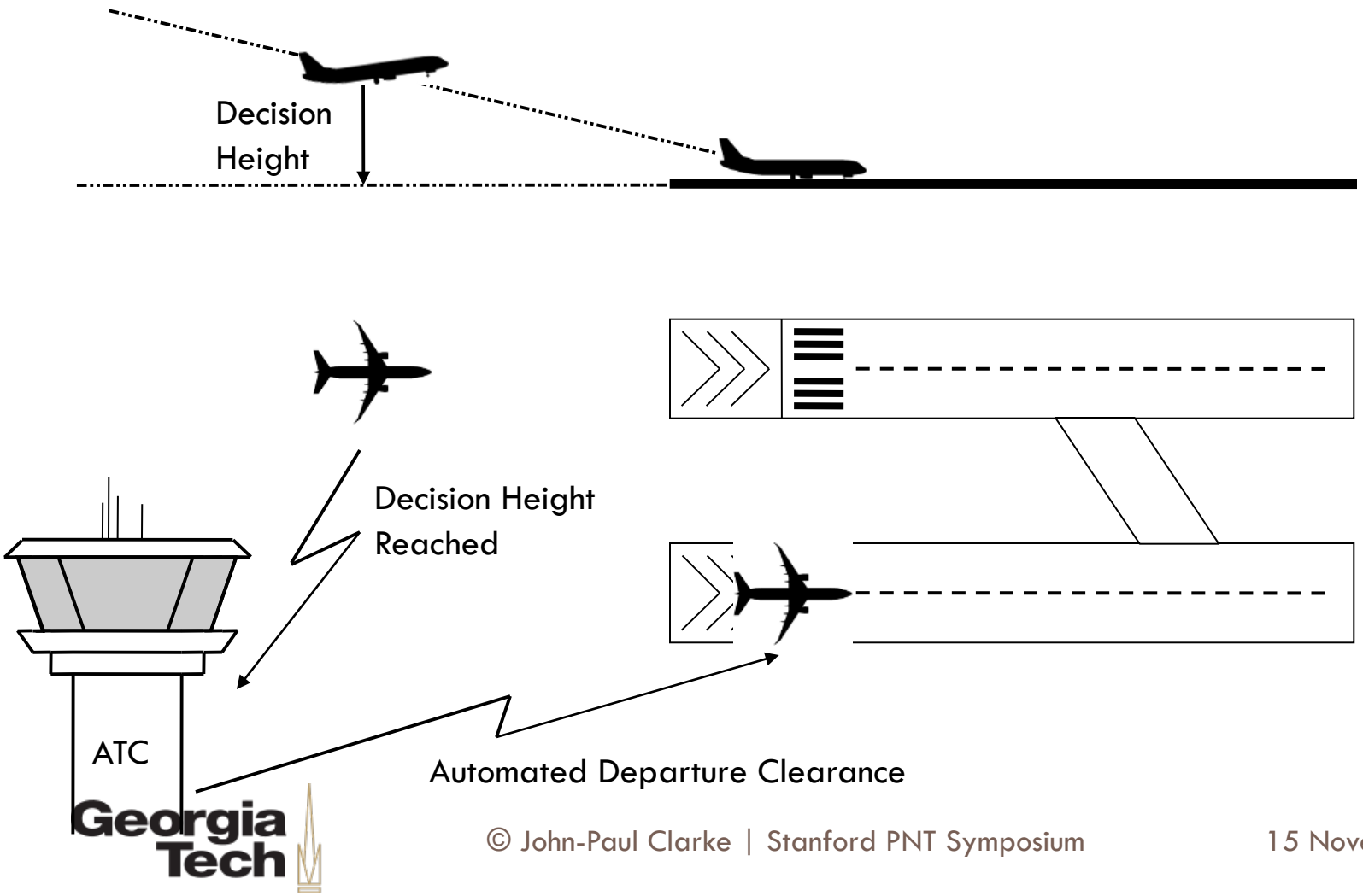
-Taxi into position and hold
-Await automated clearance

Regulated Departure Process (2)





Regulated Departure Process (3)



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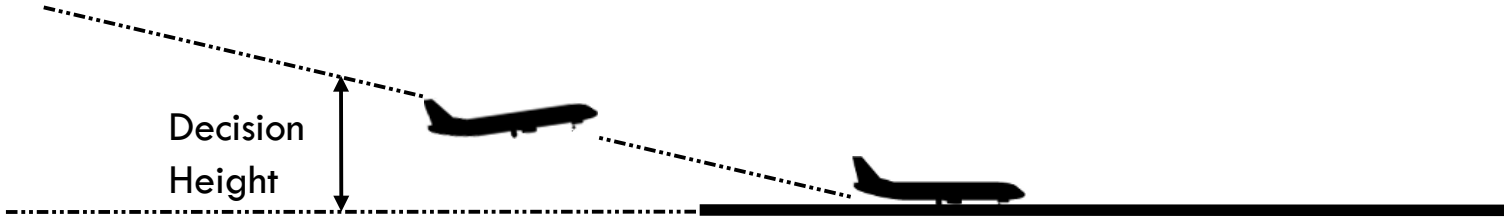
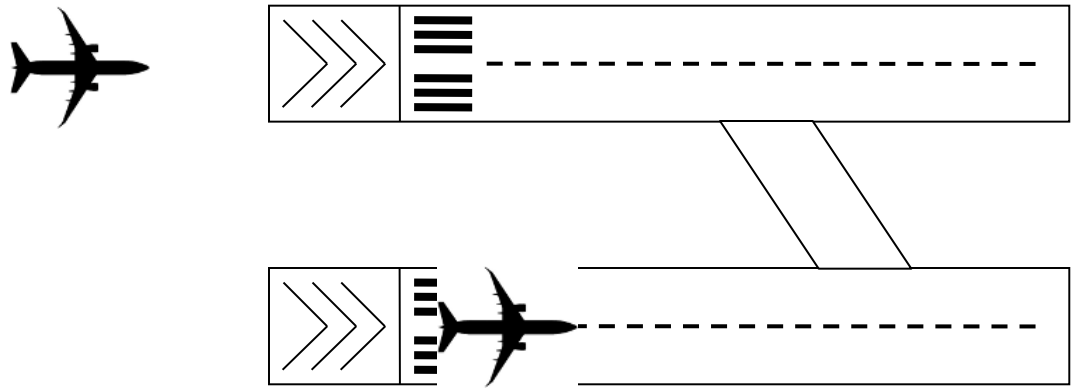
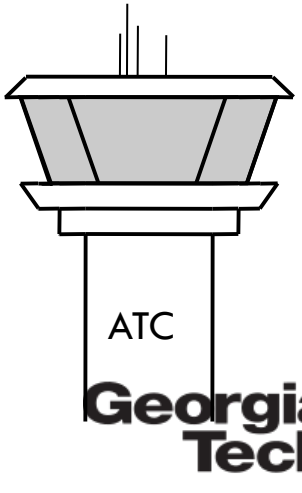
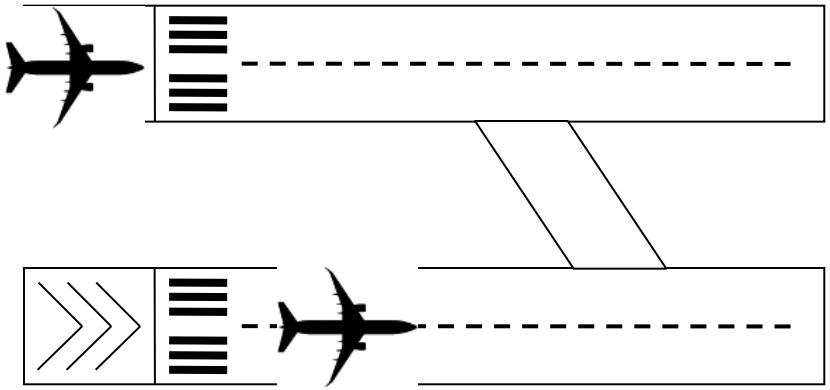
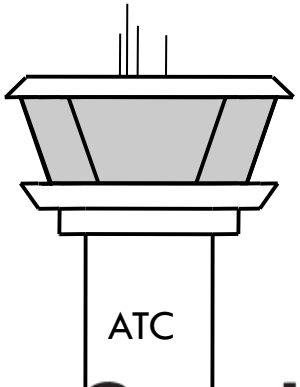






Regulated Departure Process (5)





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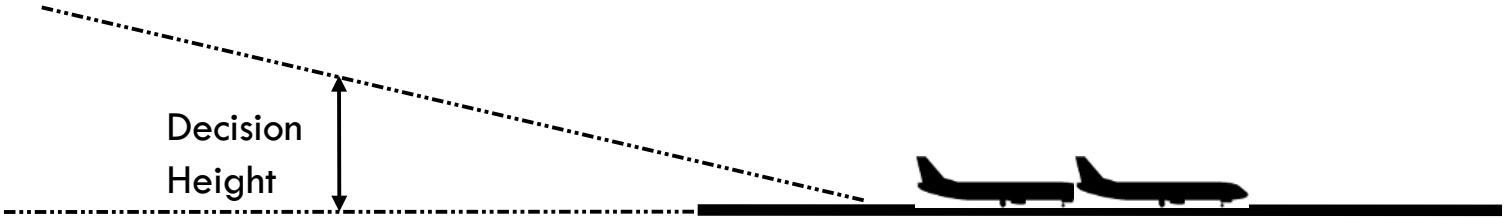

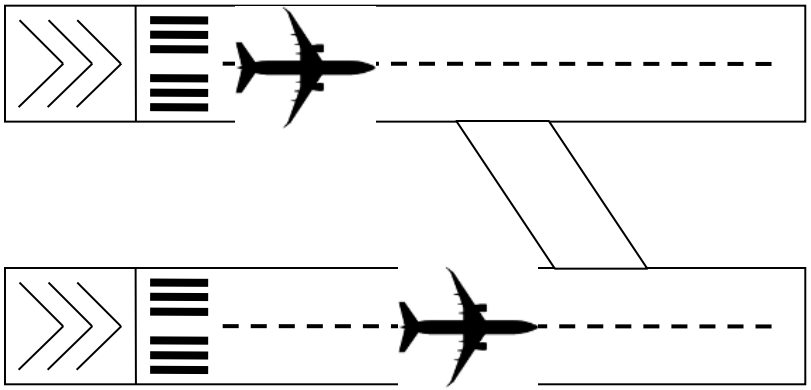

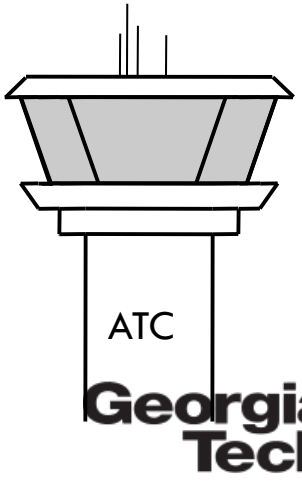

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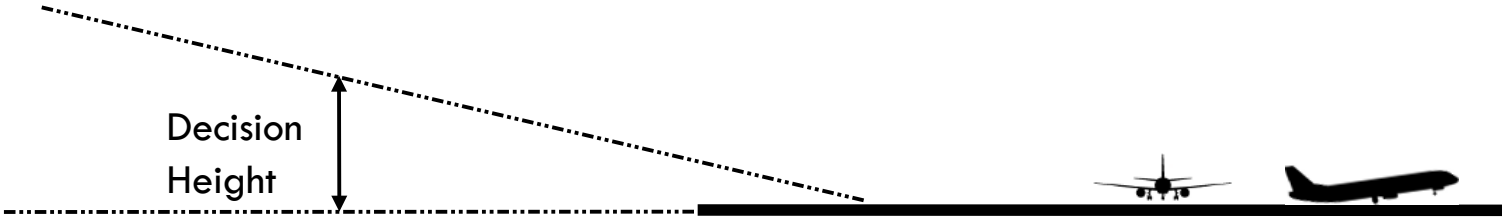

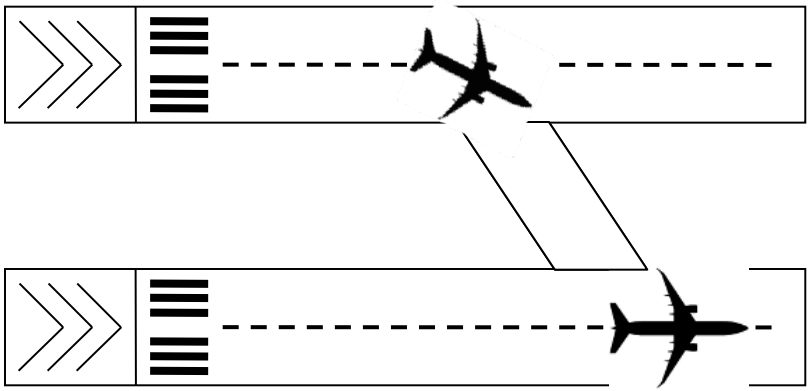

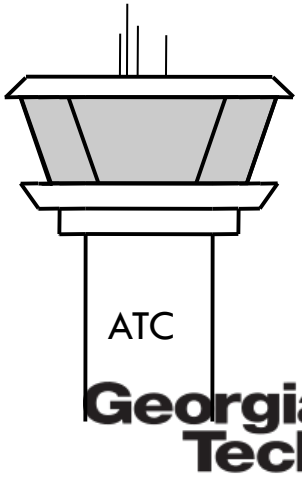

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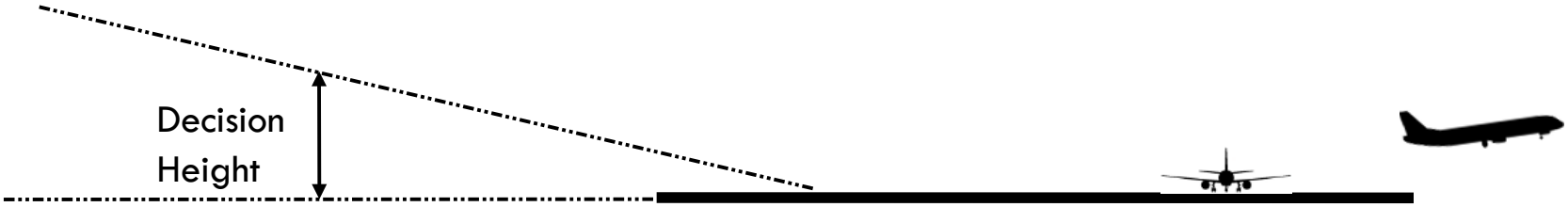
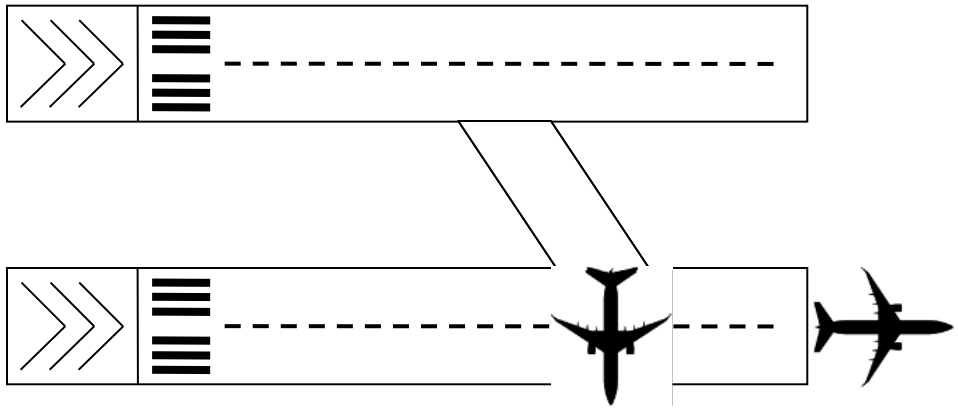
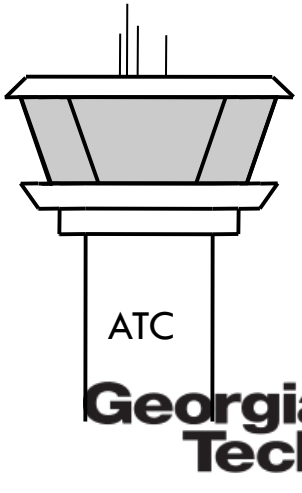
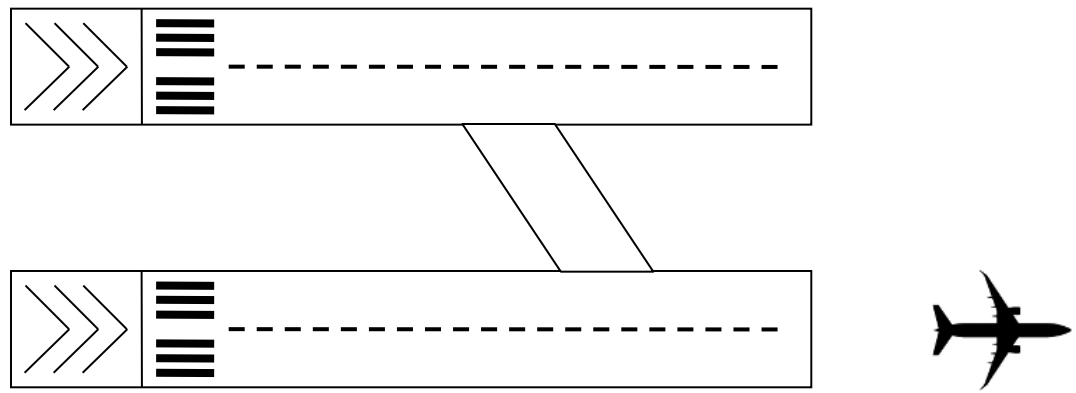






Regulated Departure Process (9)



Implementation Options

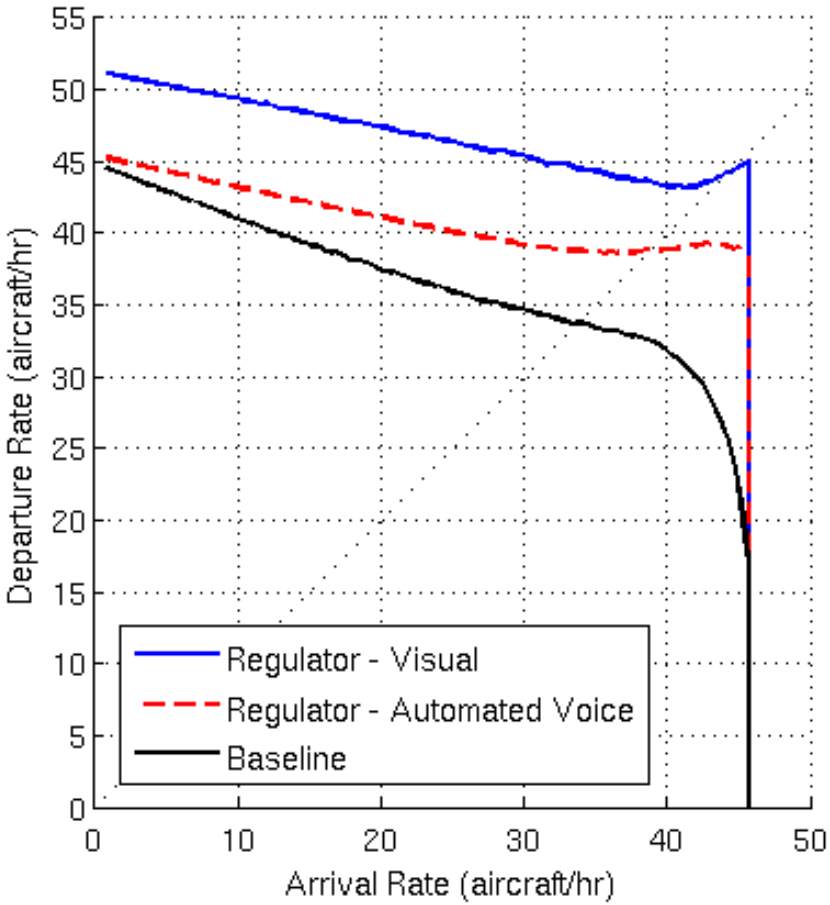
- Options for Automated Clearance:
  - Audio clearance via computer generated voice message
  - Visual clearance via lights (similar to drag racing)
- Option for Automated Advisory:
  - Audio and visual cue to controller who then issues clearance as normal

Simulation

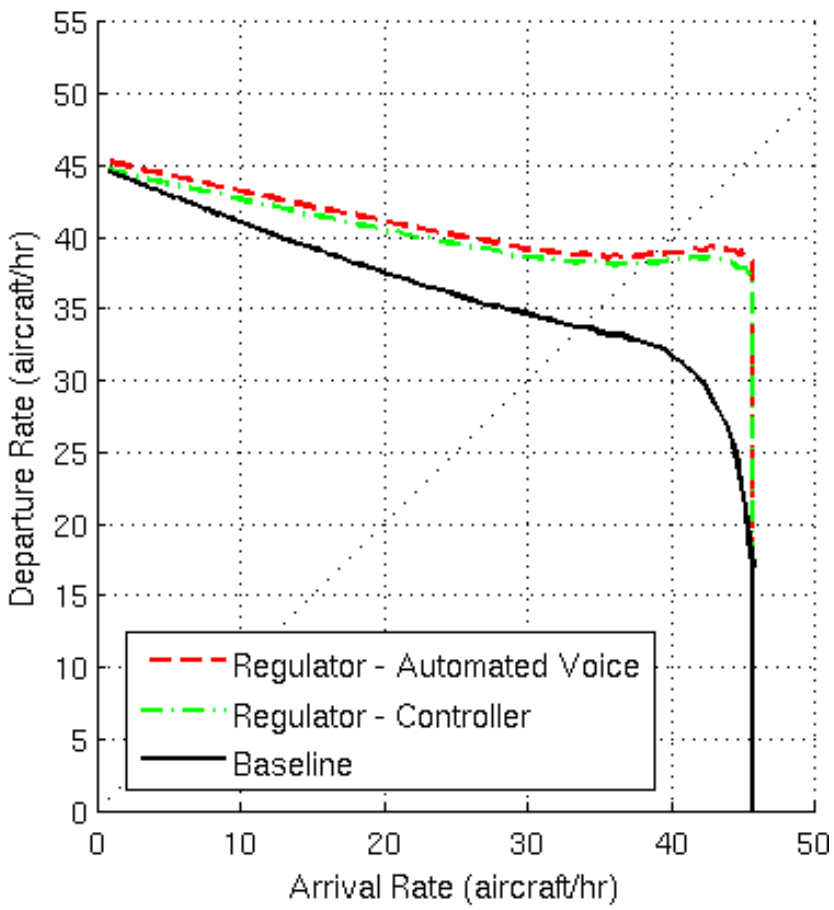
- Overview:
  - Models arrivals and departures on a set of CSPRs
  - Varies arrival rate
  - Finds maximum departure rate
- Inputs:
  - Fleet Mix
  - Flight Conditions
- Output:
  - Pareto Frontier

Simulation Results

Automated Clearances



Automated Advisories



Observations (1)

- As expected… Slope of Pareto Capacity Curve is shallower with runway regulator
  - Probability of finding a large enough gap in the arrival stream is increased so more departures are allowed

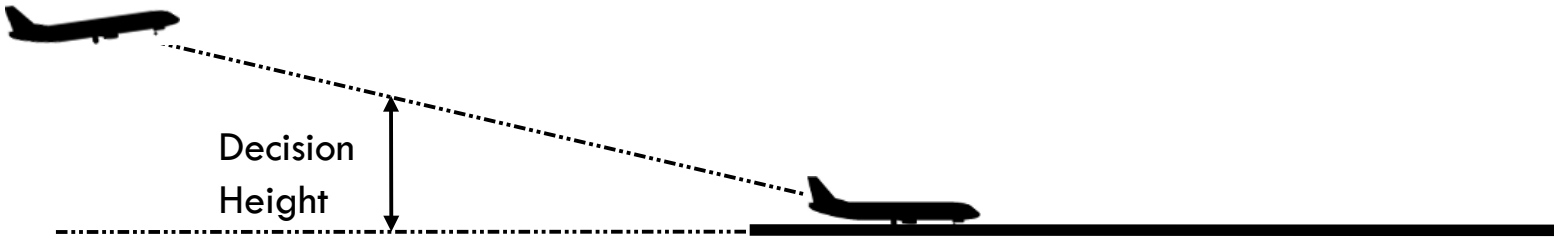
Observations (2)

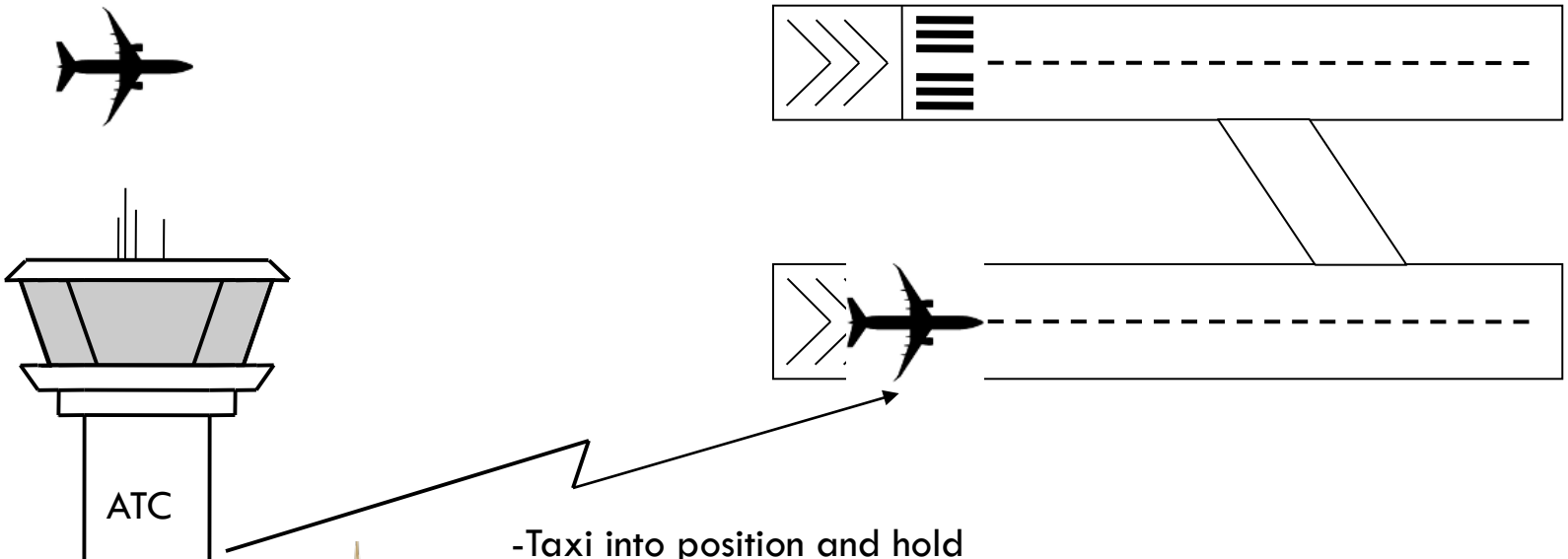
- Surprisingly… Slope of Pareto Capacity Curve reverses and starts to increase at large arrival rates
  - Counter to the nominal situation where the slope continually decreases
  - Mode of operation changes from "finding a gap in the arrival stream to fit a departure" to "finding the next arrival with which to synchronize a departure"
  - Akin to "driving system near resonance"
- Up to 34% increase in throughput possible!

Robustness Issues

- What happens when the arrival executes a missed-approach?

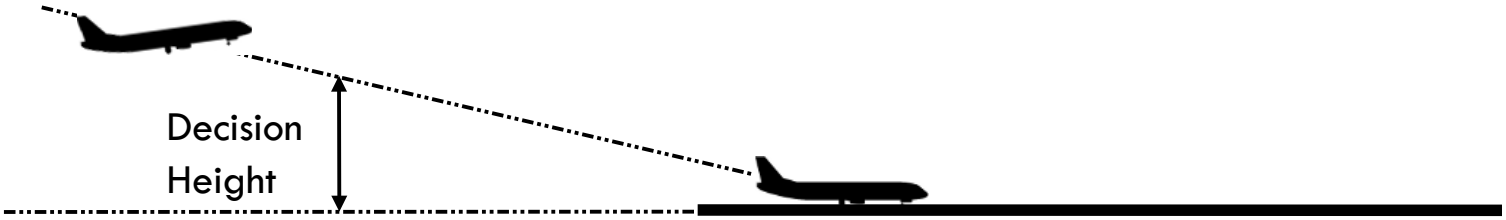
Regulated Missed-Approach (1)

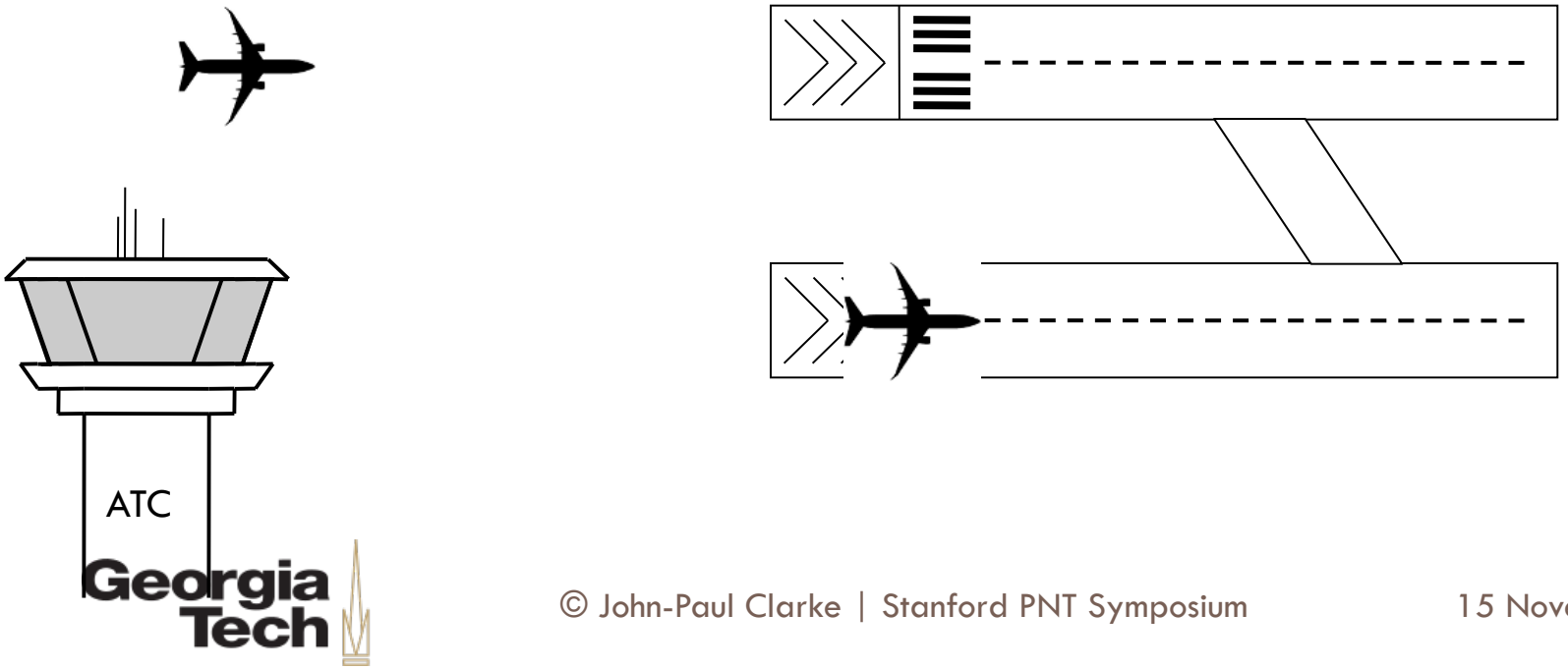




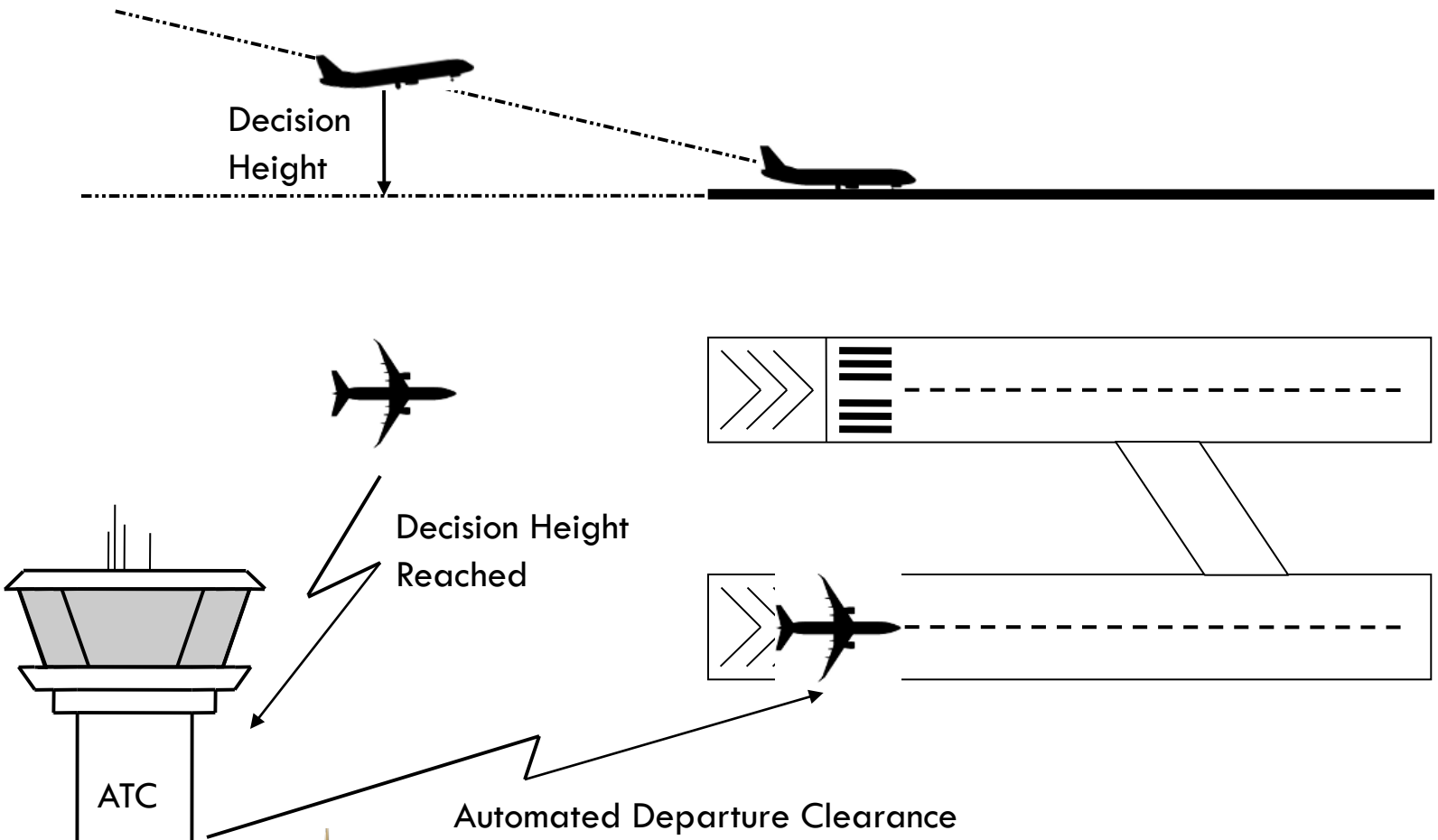
-Taxi into position and hold
-Await automated clearance

Regulated Missed-Approach (2)

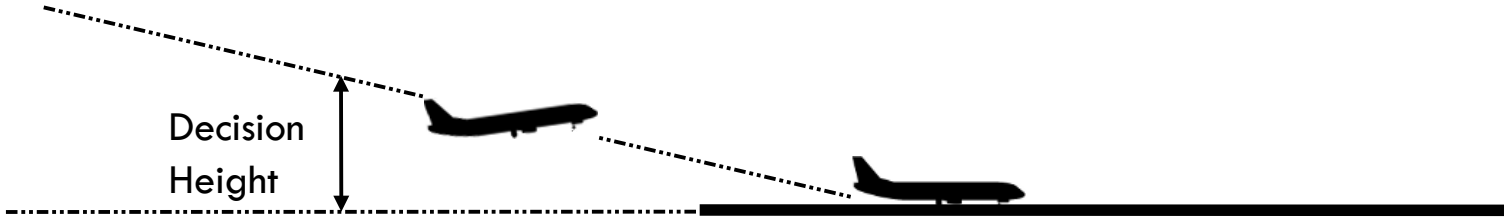


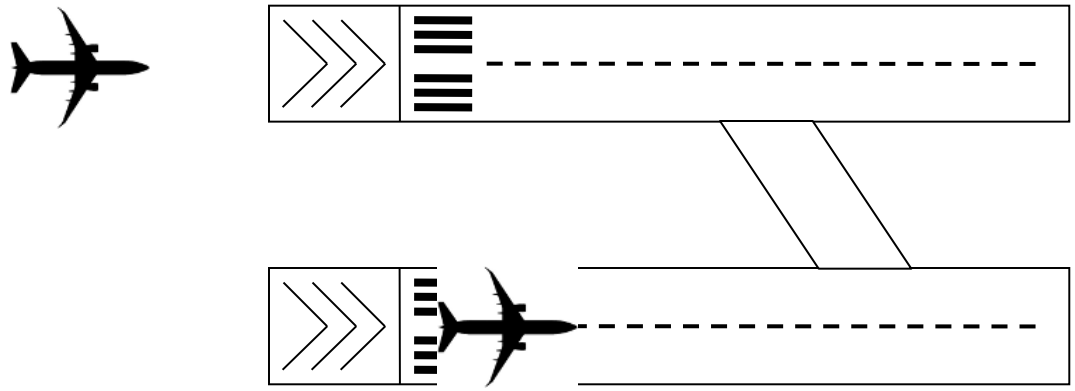


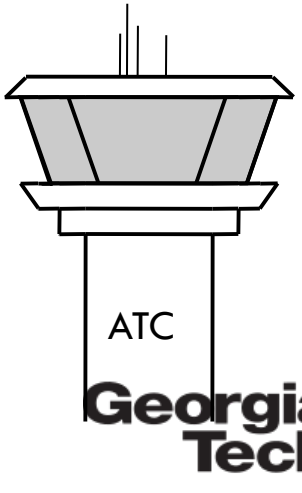
Regulated Missed-Approach (3)



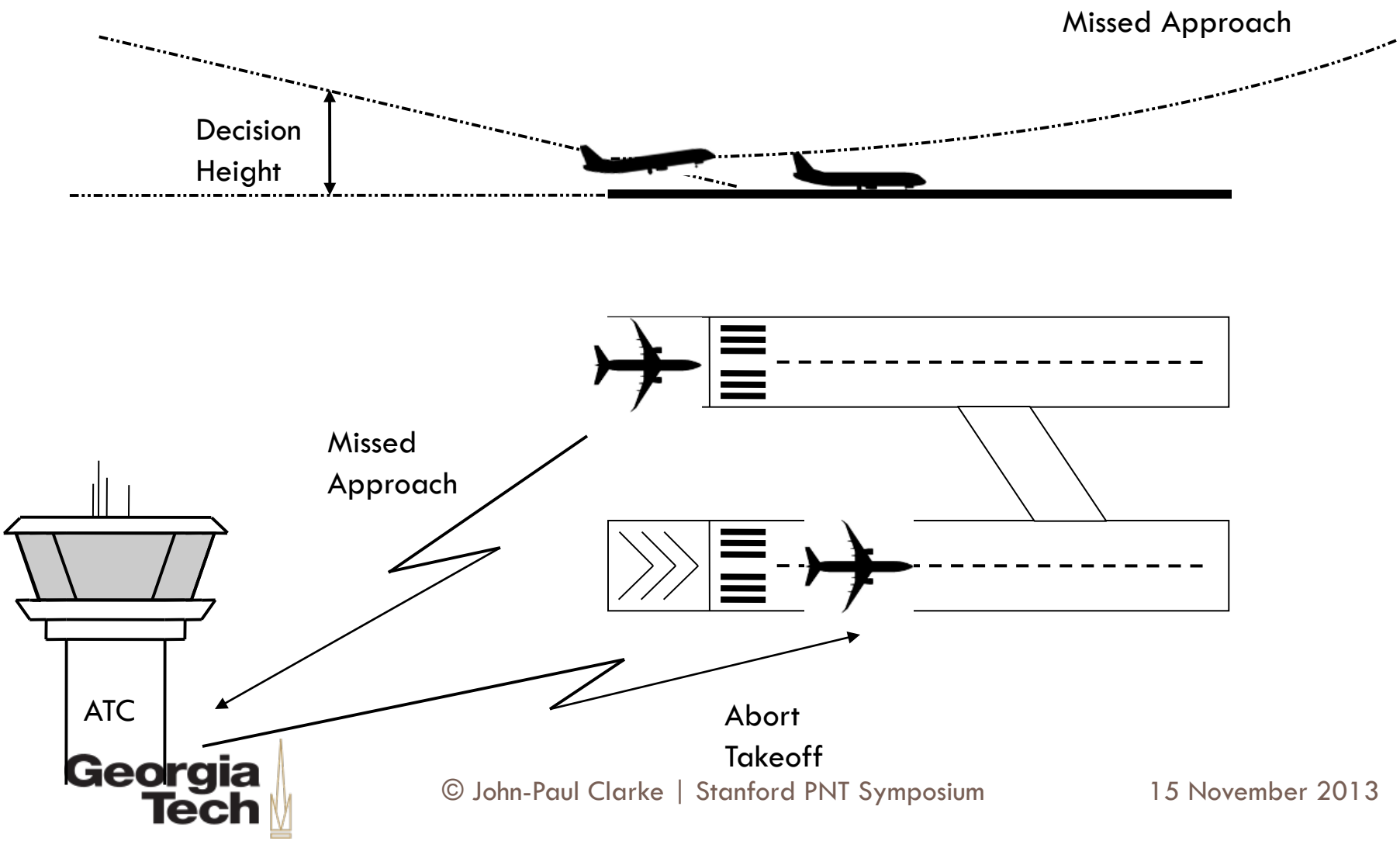
Regulated Missed-Approach (4)



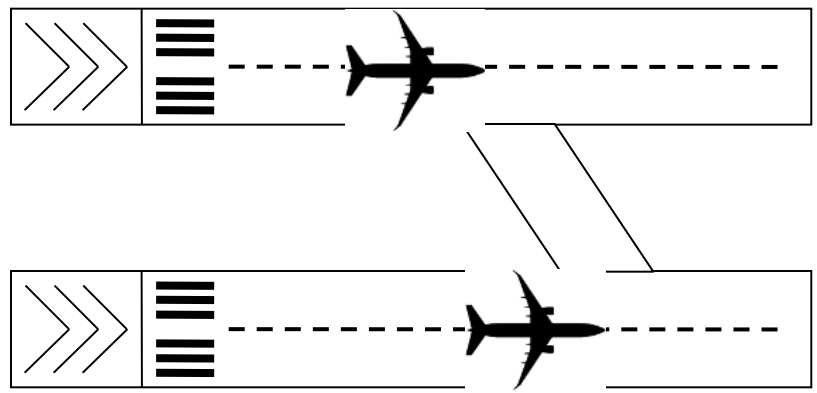


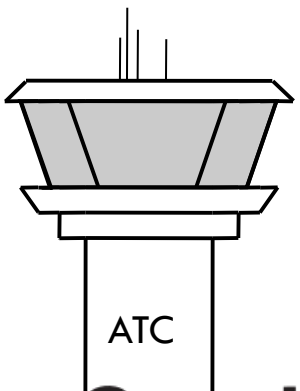


Regulated Missed-Approach (5)

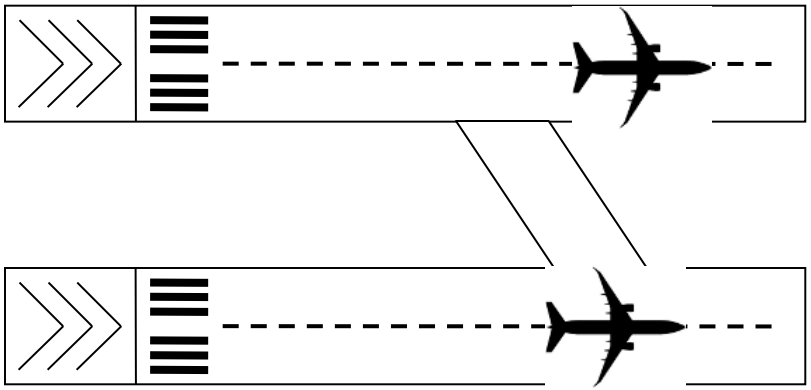


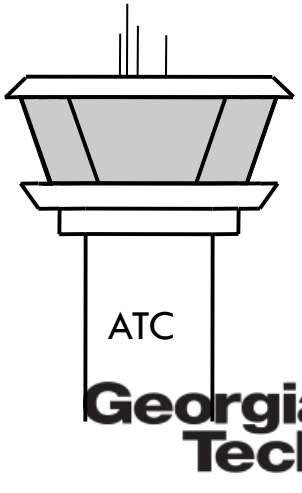
Regulated Missed-Approach (6)



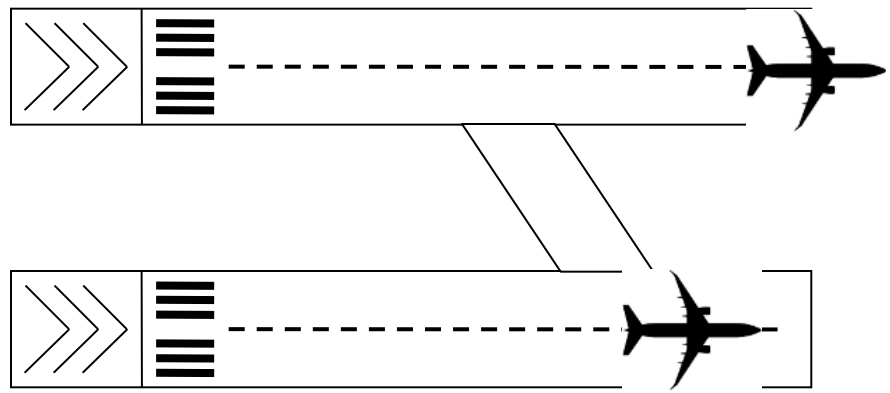


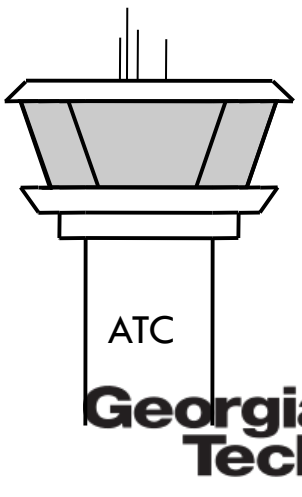
Regulated Missed-Approach (7)



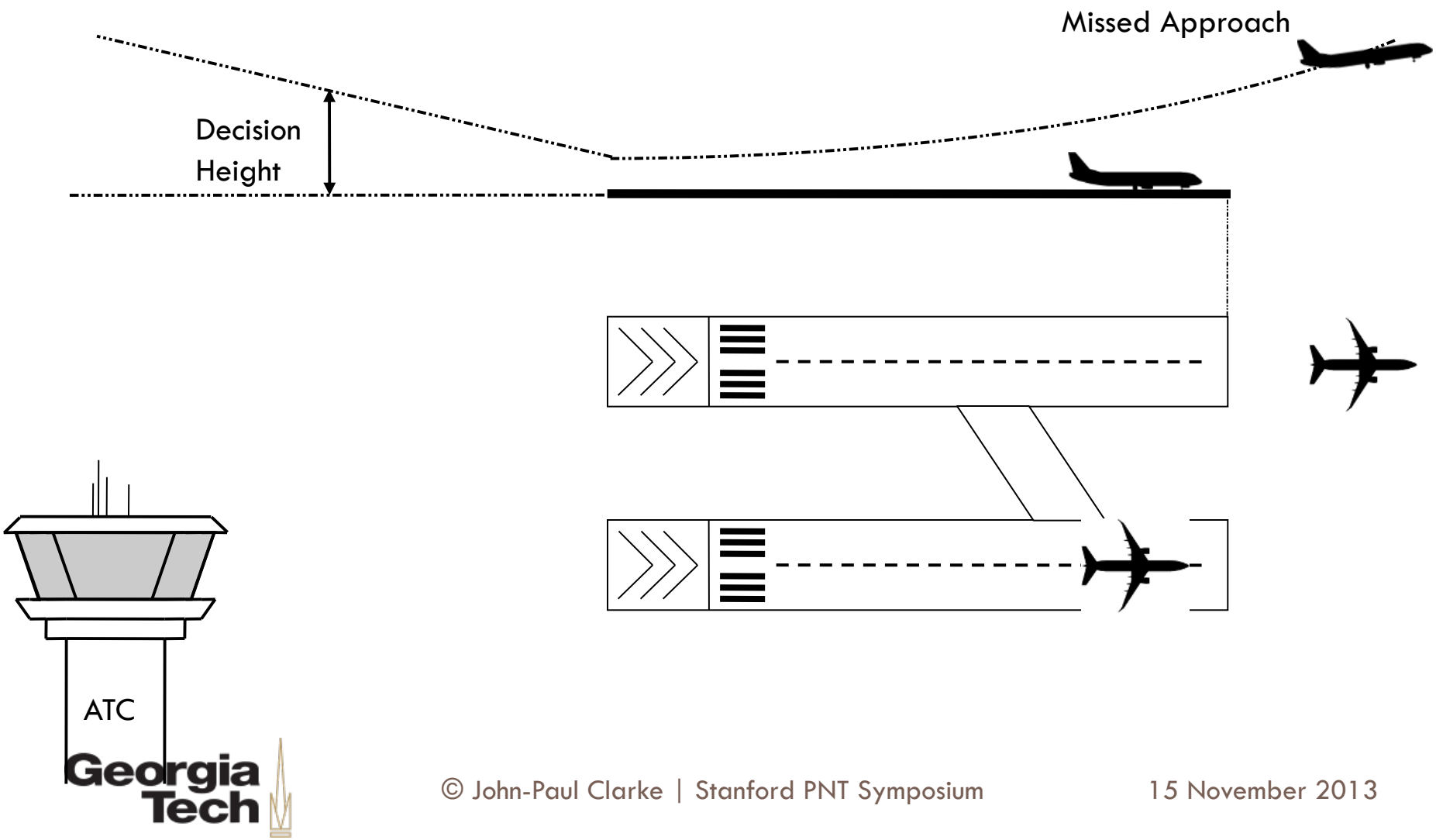


Regulated Missed-Approach (8)





Regulated Missed-Approach (9)



How could this be fielded?

- Dedicate set of CSPRs to ADS-B equipped aircraft
  - Consistent with best equipped-best served paradigm
- Phase 1: Install underlying sensing and processing systems and validate their performance
  - Address expected system operating curve issues
- Phase 2: Install automated advisory tool in tower
  - Requires the least change on the part of controllers
  - Enables controllers to build confidence in system
- Phase 3: Install automated clearance capability