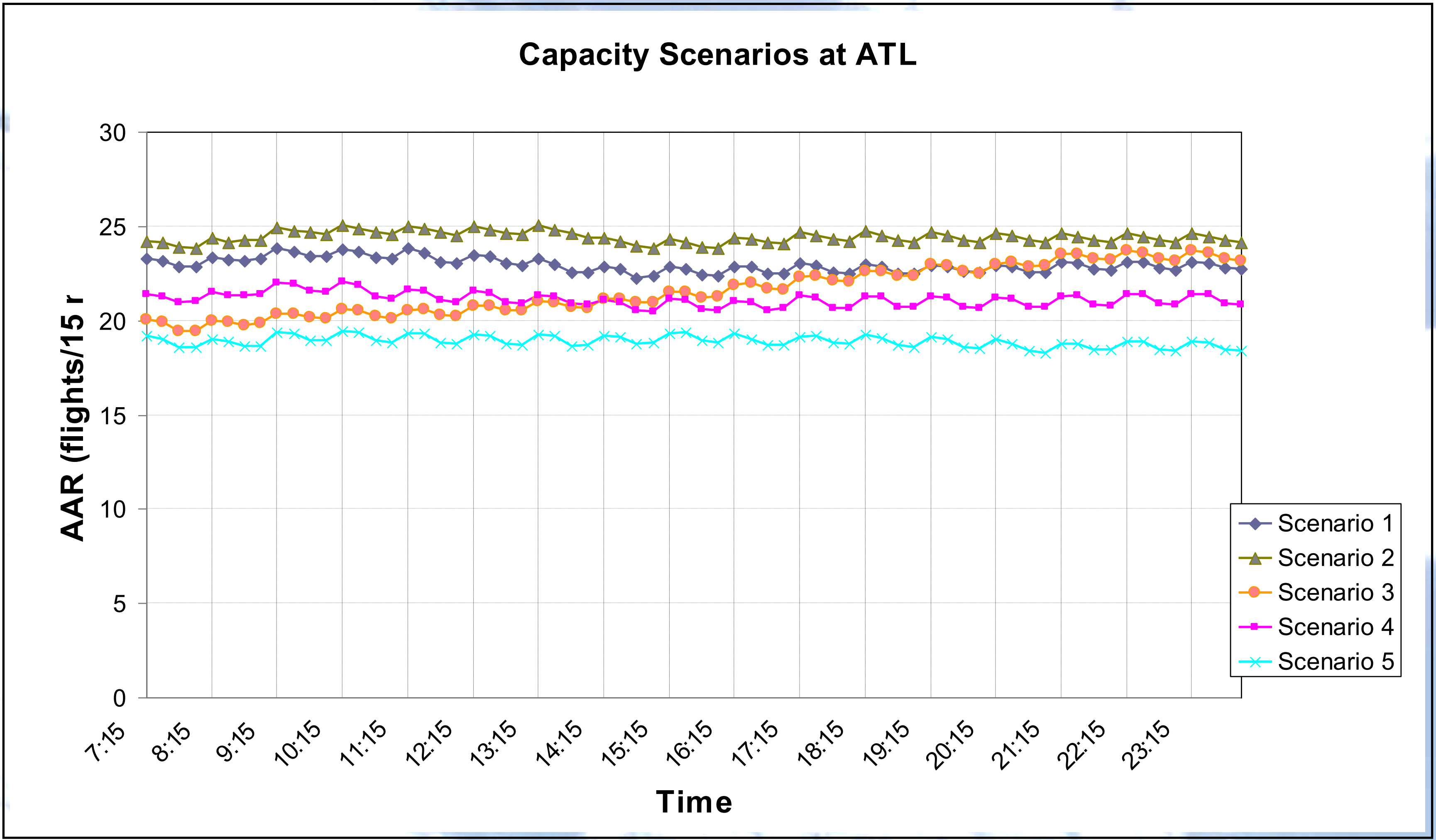
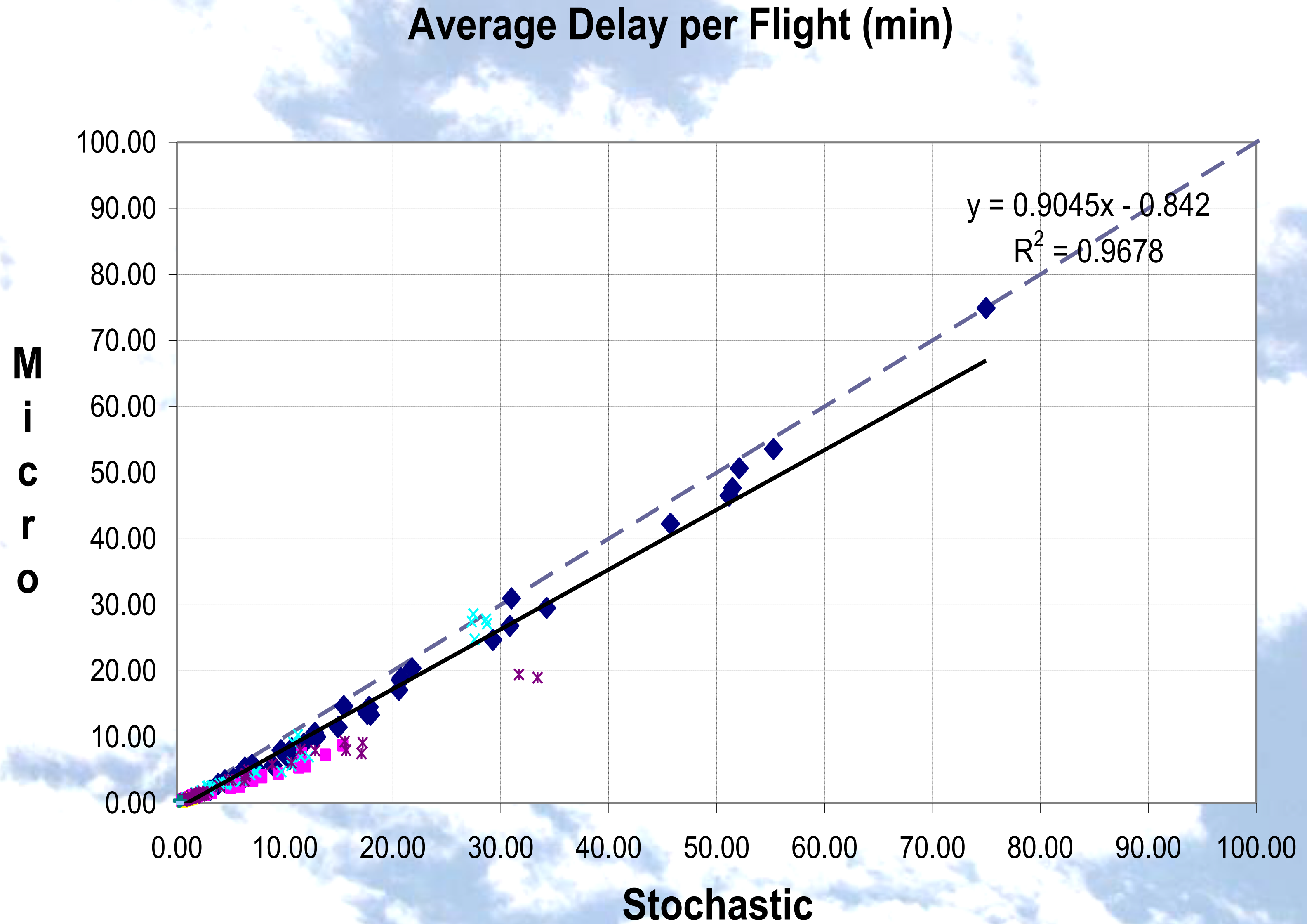
ATL Capacity Profiles



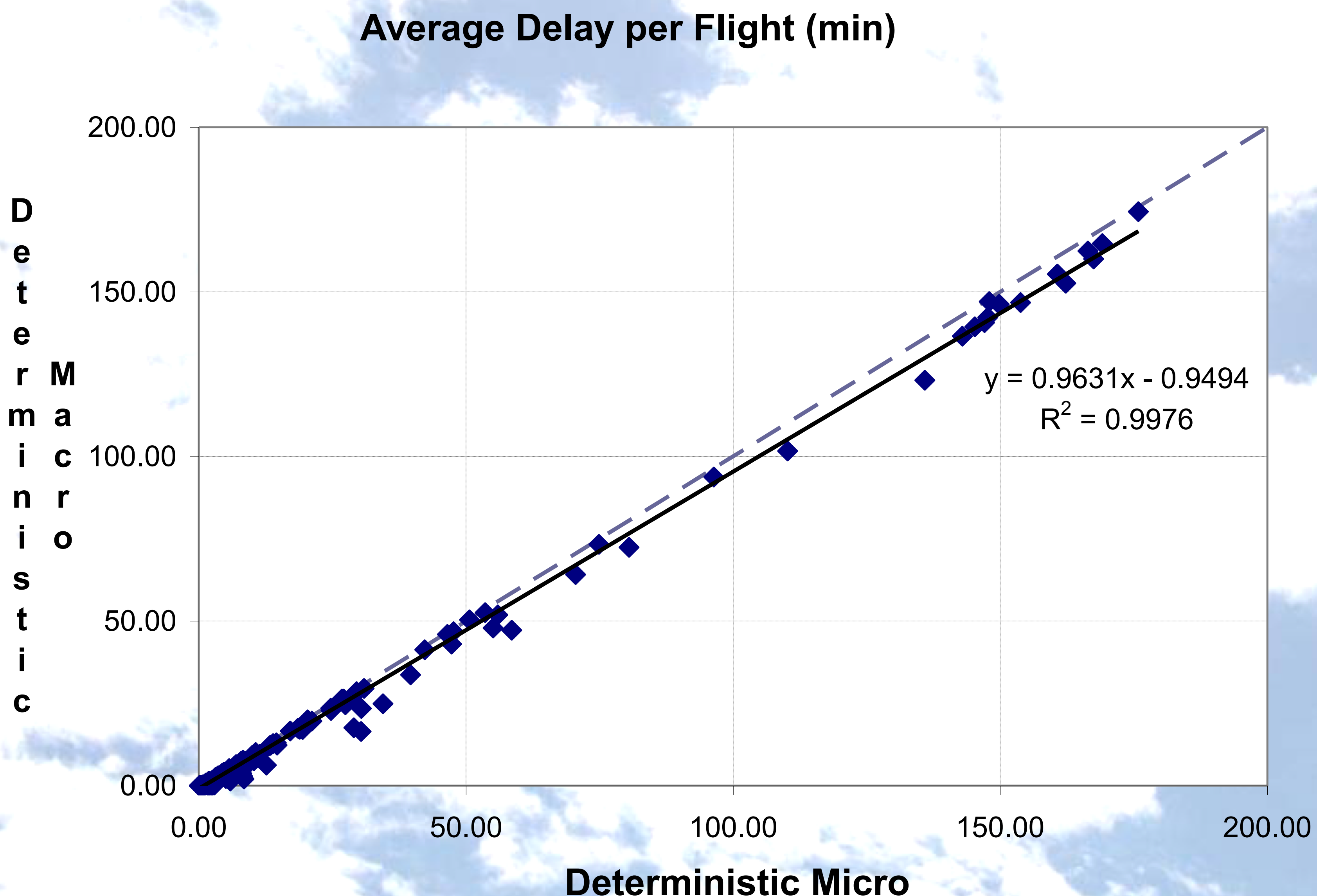
Overview

- Background and Motivation
- Queueing Models
- Approach
- Experiments
- **Results**
- On-going Research

Deterministic / stochastic model comparisons



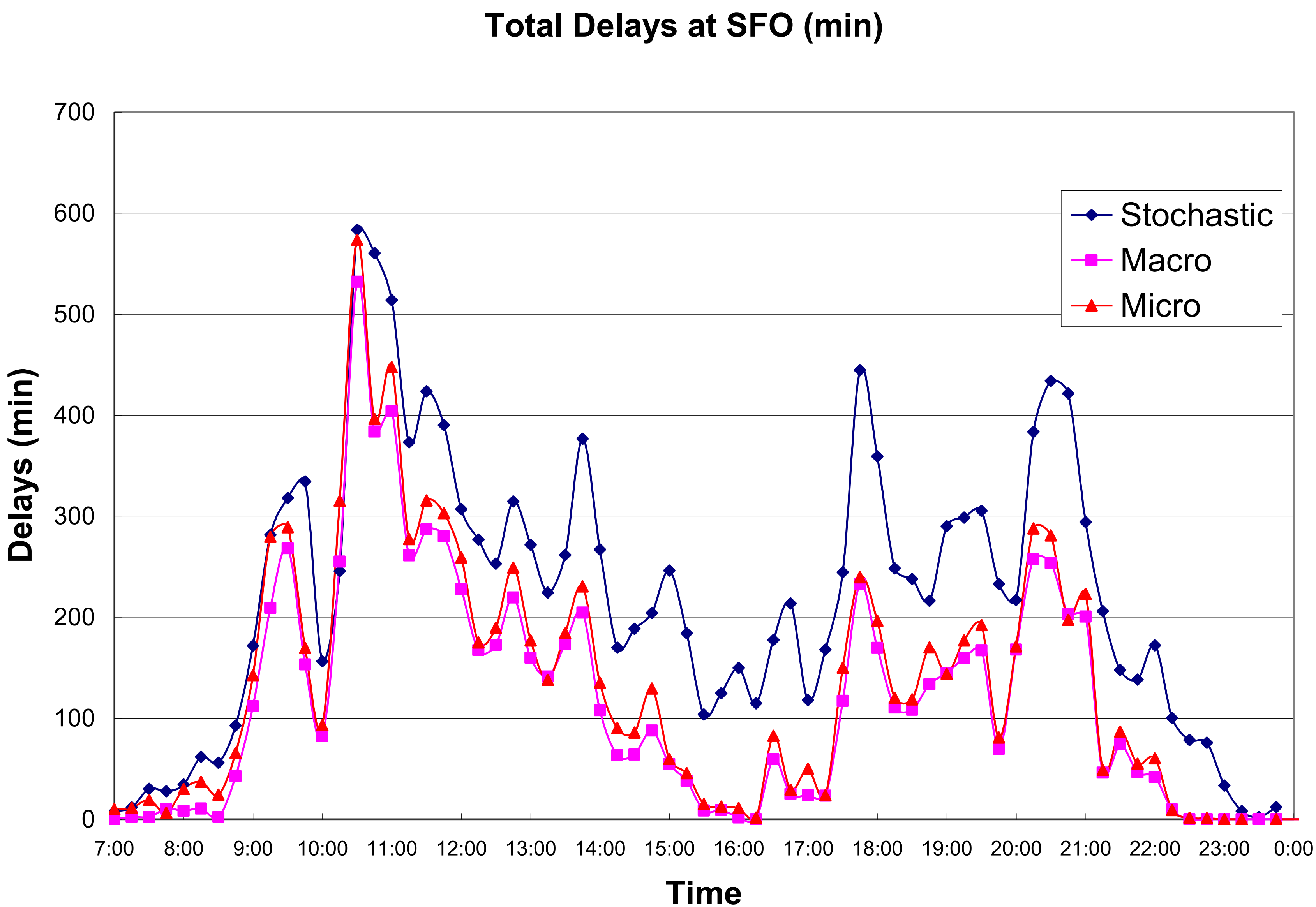
Deterministic / stochastic model comparisons



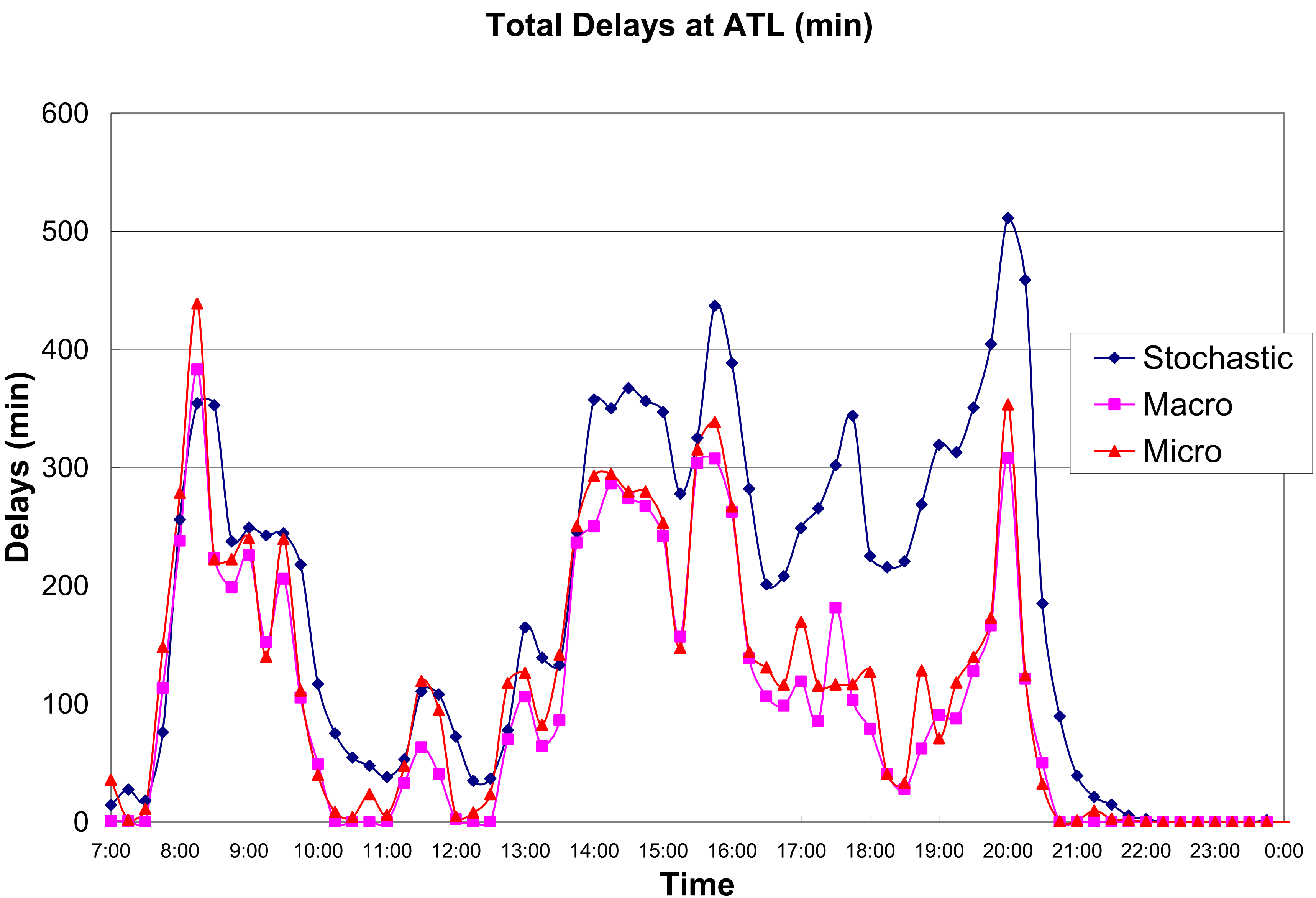
Interpretation

- Shift from highly stochastic to fully deterministic system reduces delay by 10% plus 1 minute per flight
- Evening schedule to have even inter-arrival times within each 15-minute interval reduces delay by an additional 4% plus 1 minute per flight

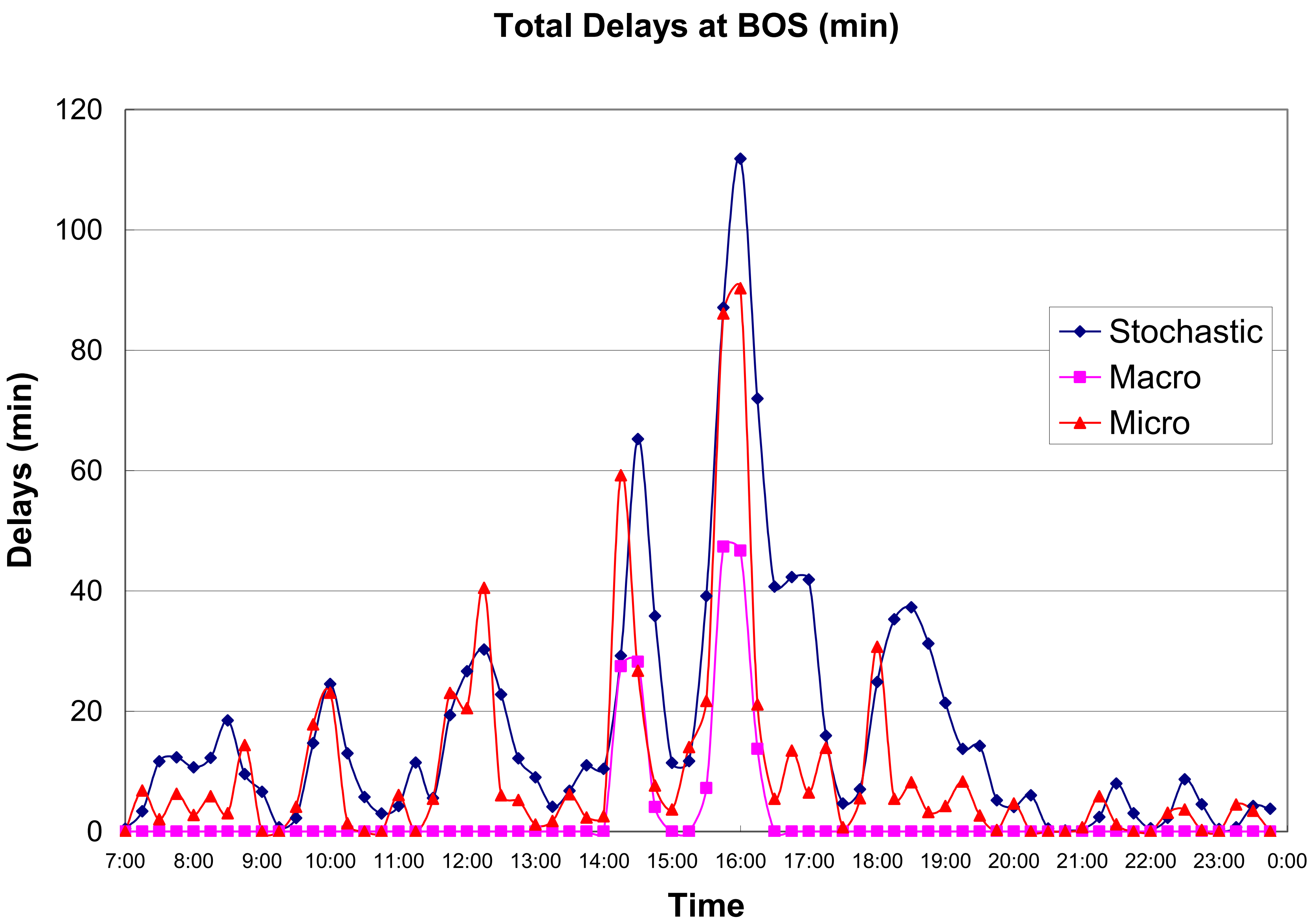
Comparison of Delay Profiles (SFO)



Comparison of Delay Profiles (ATL)



Comparison of Delay Profiles (BOS)



Conjecture

- Largest differences between stochastic and deterministic cases arise when
  - multiple congested periods exist
  - the system has time to recover between these periods in the deterministic case, but is not able to do so in the stochastic case

Conclusions

- Highly deterministic system enabled by 4D trajectory precision would reduce delay 10-14% plus 1-2 min per flight (*all else equal*)
- Result holds over a wide range of congestion levels
- Improvement may be greater under certain congestion profiles
- Queueing models are a useful complement to simulation models in examining these matters

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Intermediate Levels of Trajectory Precision

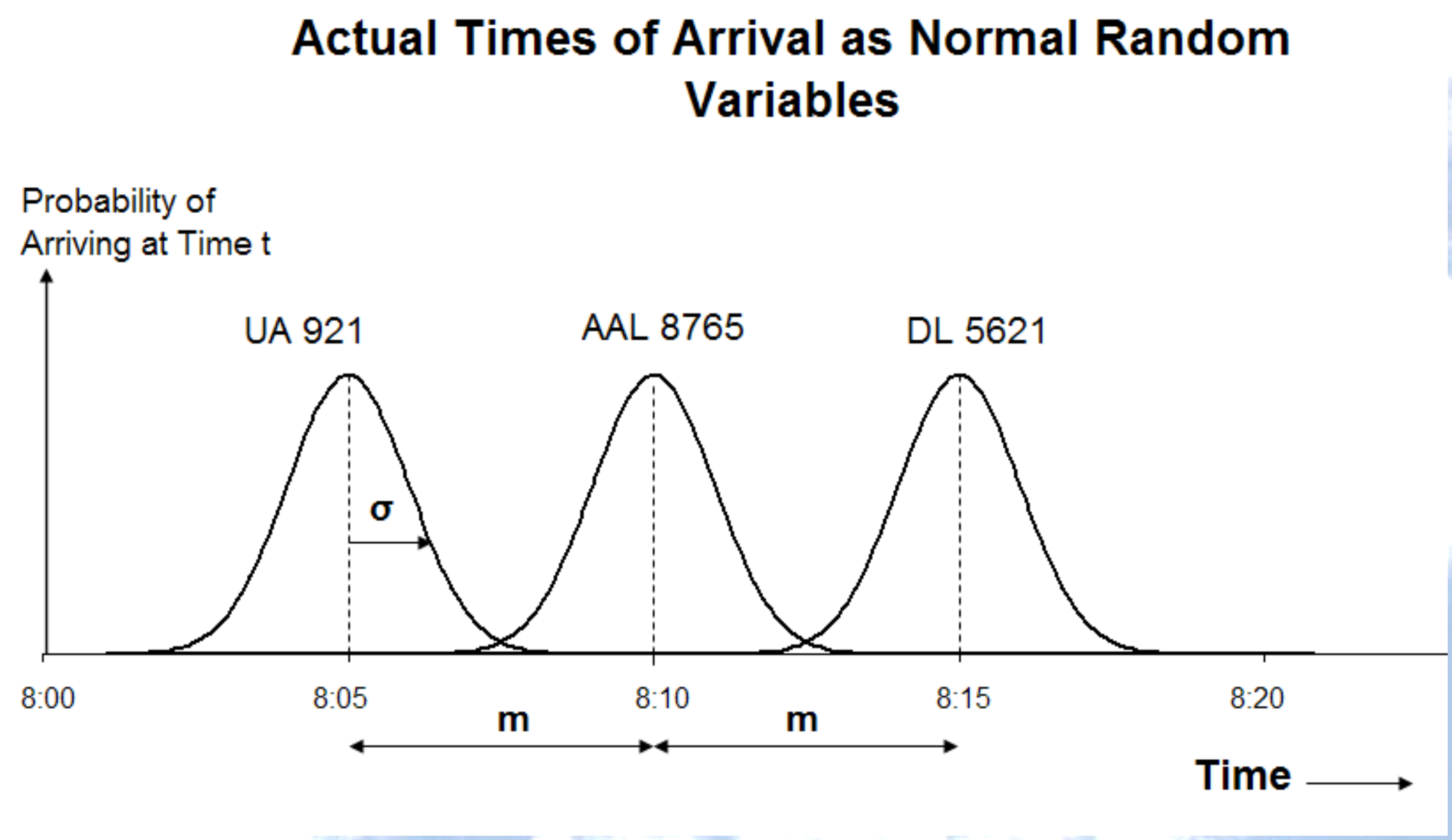
Two approaches:

1. Extend the Deterministic Queueing Model by Assigning Lateness Errors to Flights
2. Think of Queue Length as a mass, and model its diffusion over time

Metered Time Adherence Error Model

- Each flight is assigned a **Scheduled Time of Arrival**, which it meets with some **imprecision error**
- Inputs: *Metered schedule of arrivals*; *safety separation headways, level of adherence error*
- Approach: Model time of arrivals as normal random variables (*with standard deviation representing adherence error*)
- Outputs: *Expected delay of all flights; average number of flights in queue; average waiting time per flight, etc.*

Metered Time Adherence Error Model

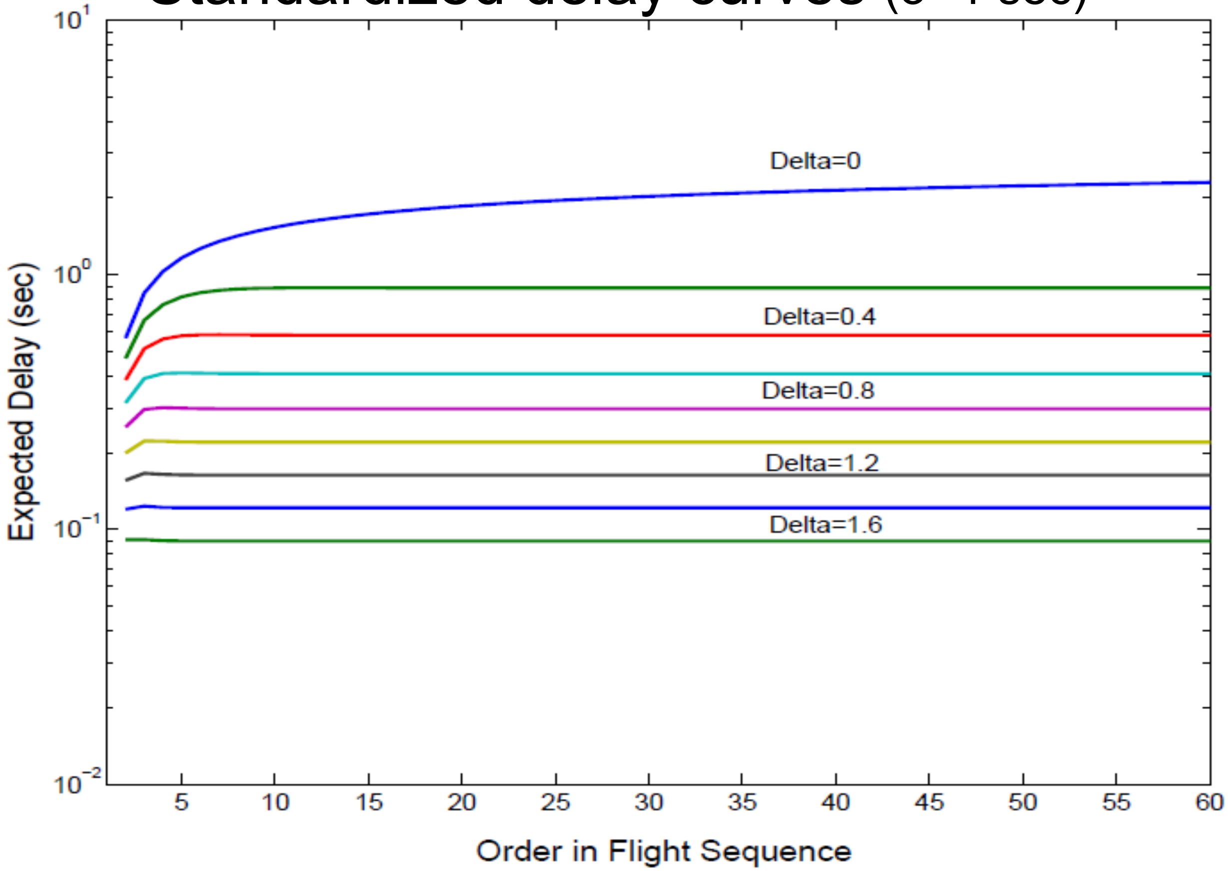


Metered Time Adherence Error Model

- Application:
  - Estimate delays due to imperfect adherence to metered arrival times
  - Inputs: *Time spacing between consecutive metered arrivals* ***m***; *minimum headway* ***h***; *level of adherence error* $\boldsymbol{\sigma}$
  - Assumption: Flights do not overtake each other (adherence errors are small)
  - Sample Application: Stream of flights for landing, runway as meter point, freeze horizon is 400 nmi

Metered Time Adherence Error Model

Standardized delay curves (σ=1 sec)



1. Compute Δ=(m-h)/σ
2. Select corresponding curve
3. Multiply values in vertical axis by σ

Metered Time Adherence Error Model – Next Steps

- Include two types of aircraft: *4DT equipped* (high precision) and *non-equipped* (low precision) aircraft
- Re-sequencing of arrivals:
  - Cases where precision errors are large enough
  - Flights don't arrive at the meter fix in the scheduled order

Diffusion Approximation

- Queue Length can be expressed on a continuum, which is approximately true when very large numbers of customers are involved
- Solve the Kolmogorov Forward Diffusion Equation:

$f_i(x;t) =$ density of length of queue i at time t