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Applying Flight-deck Interval Management based Continuous Descent Operation for Arrival Air Traffic to Tokyo International Airport

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Background and purposes

- Continuous Descent Operation (CDO) to Tokyo International Airport
- Flight-deck Interval Management (FIM)

Continuous Descent Operation (CDO)

- Arrival aircraft continuously descend from cruise to an airport at near-idle thrust
- Environmental-friendly, energy saving arrivals
- Currently doable in low-density traffic
- Applying CDO in high-density operation is the next challenge

Tokyo International Airport (1/2)

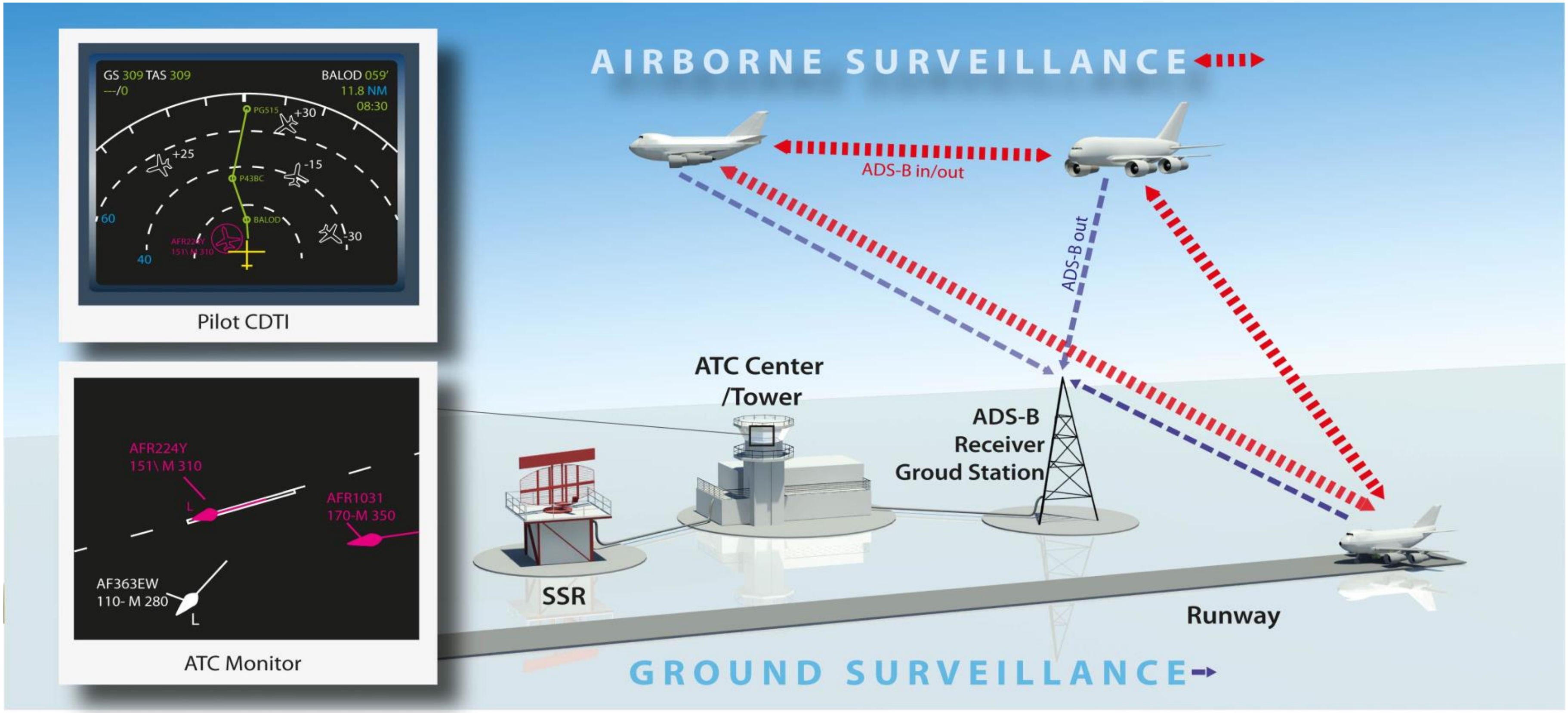
Tokyo International Airport (2/2)

- Open 24 hours
- 410,000 movements per year
- 4 runways
- Arrival aircraft land every two mins.

➔ Focus on domestic flights from west and south Japan arriving RW 34 L, which is most frequently used in the winter season.

Flight-deck Interval Management (FIM) (1/2)

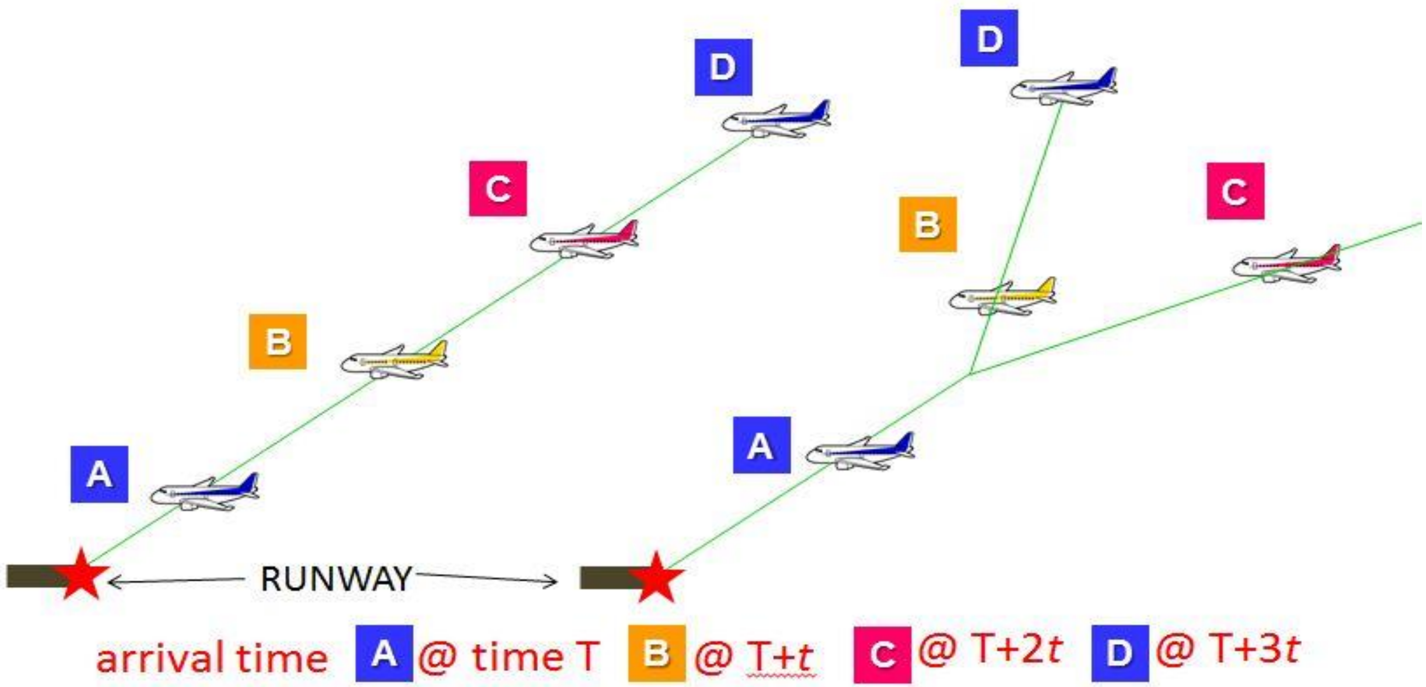
- One of the applications of Aircraft Surveillance Applications System (ASAS)



ASAS overview

Flight-deck Interval Management (FIM) (2/2)

- Airborne time-spacing by speed control



FIM application

ATCo decides a sequence of arrivals and time interval t at the runway threshold. Airspeed is controlled in the air following ATCo's instruction.

Purposes

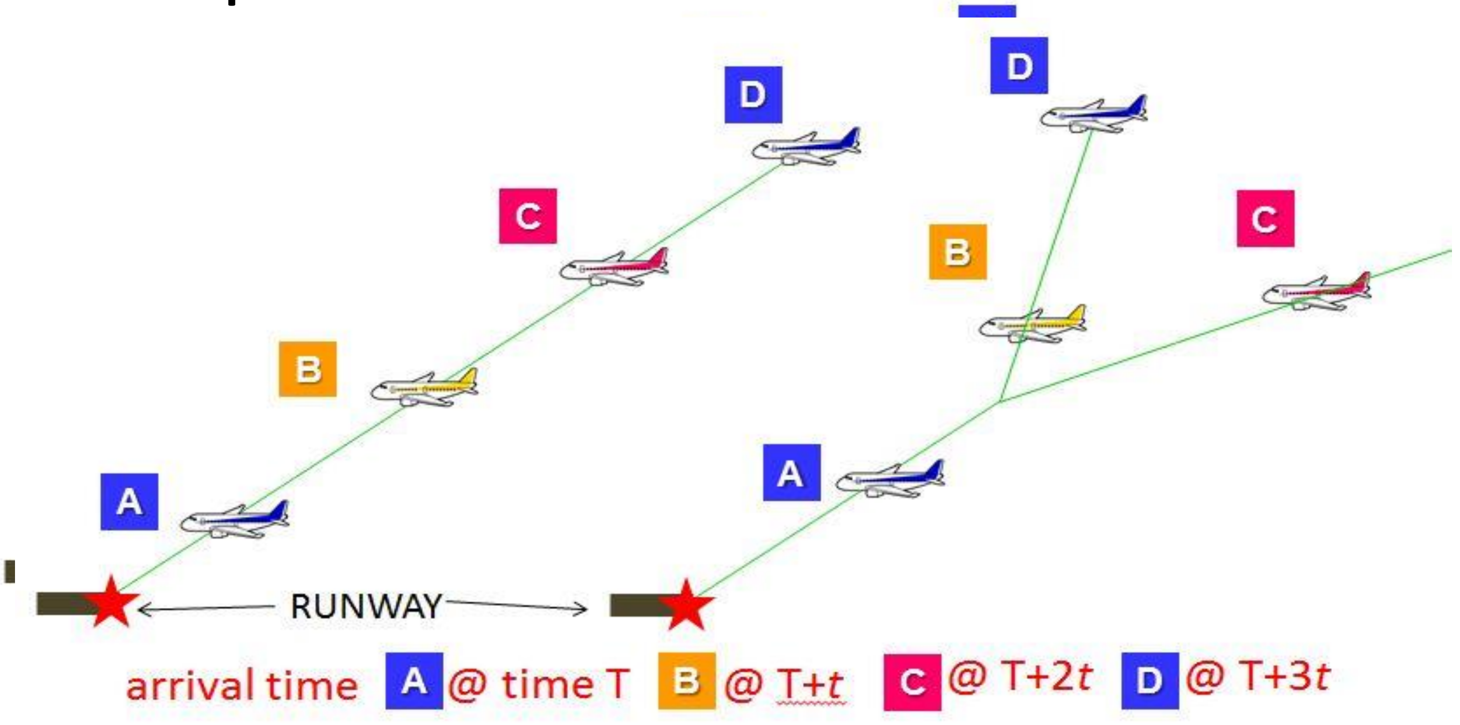
- Evaluate the performance of time-spacing and fuel consumption when the FIM-based CDO is applied to the Tokyo International Airport
- Build a fast-time simulation environment for FIM-based CDO for arrivals to Tokyo International Airport : "***SPICA software***"

FIM-based CDO

- Air route design for arrivals to Tokyo International Airport
- Operational goals
- Simulation assumptions

FIM speed control by ASTAR (1/2)

- Combination of trajectory prediction and aircraft speed control



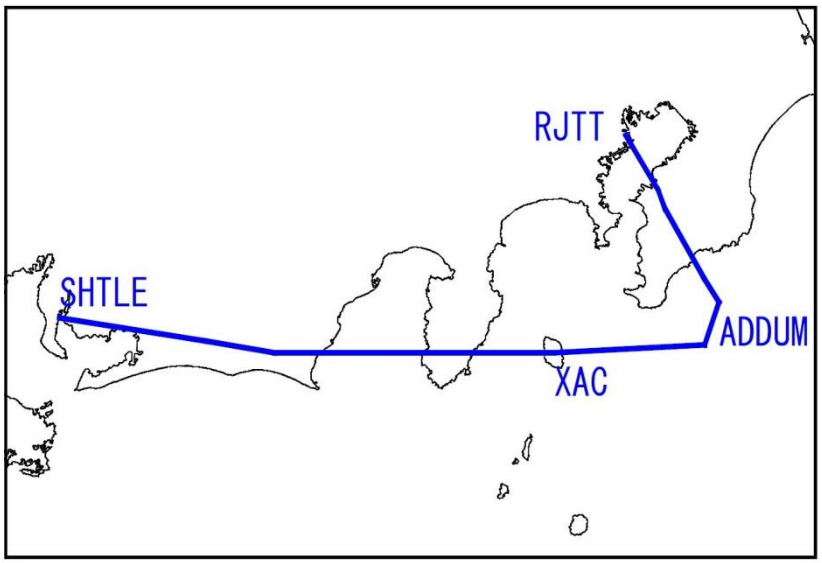
FIM speed control

FIM speed control by ASTAR (2/2)

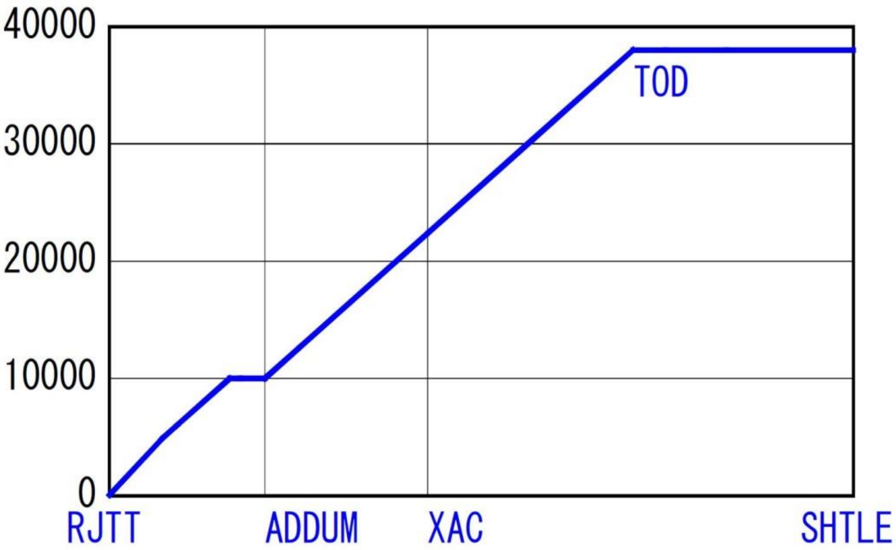
- Air route design
  - Air route is designed as a sequences of waypoints to the runway threshold defined by latitude, longitude, crossing altitude/glide path angle, crossing airspeed, ratio of airspeed, and wind data
- Trajectory generator
  - 4D trajectory is generated to estimate distance/time to the runway threshold (Distance/Time To Go (DTG/TTG))
- Speed controller
  - By using DTG/TTG of the leading/own aircraft, airspeed is controlled to achieve the assigned time-spacing at the runway threshold
  - VNAV/PATH mode, +-10% speed change from the profile

Air route design (1/2)

- Current air route to Tokyo International Airport



Current RNAV route to RW 34L



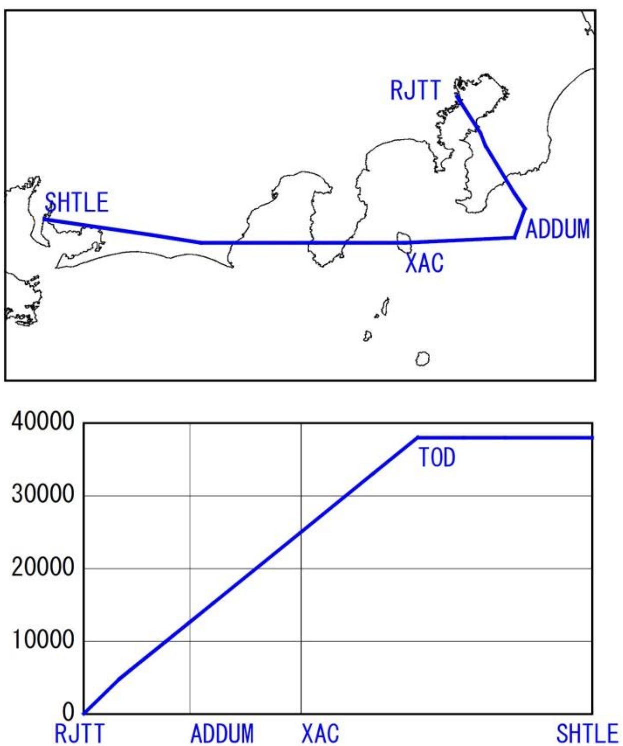
2.5 degrees path to capturing ILS

Altitude restriction 10,000 ft at a terminal gate ADDUM

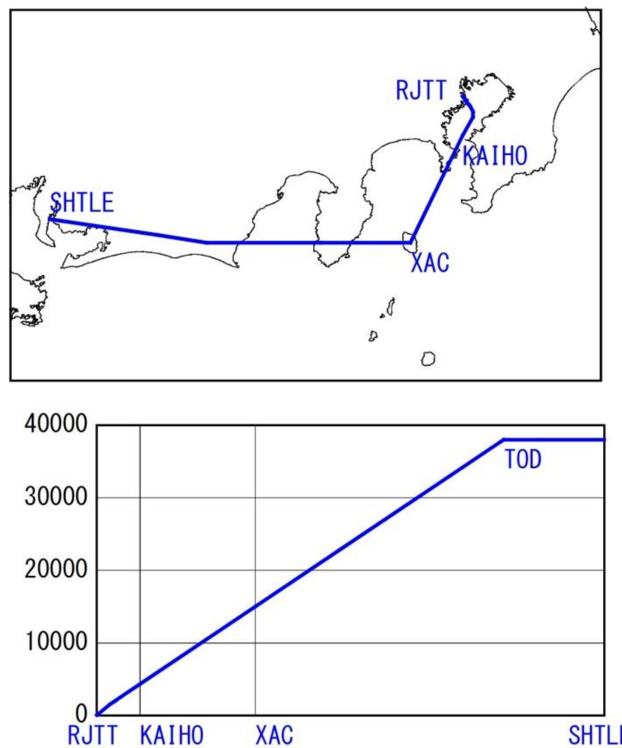
Air route design (2/2)

- Designed air routes

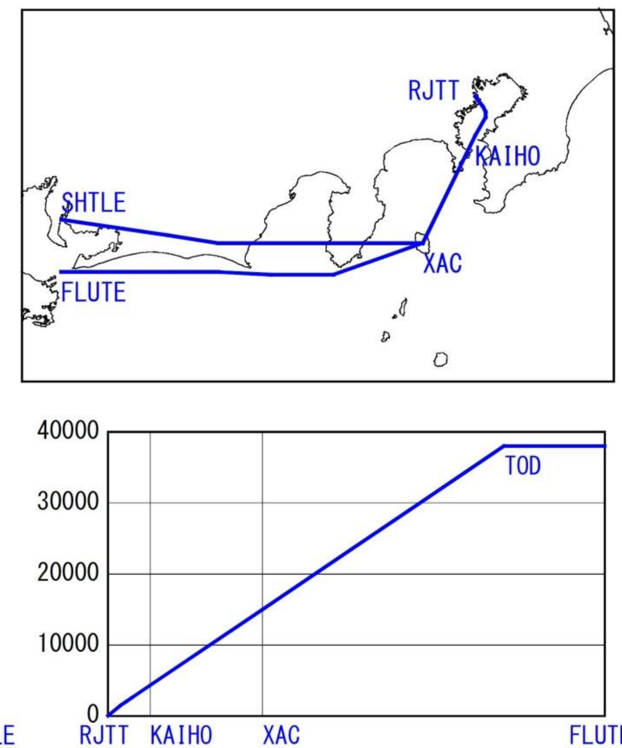
Route A: No altitude restriction at ADDUM



Route K/S: Shortcut crossing Tokyo bay



Route K/F: Shortcut merging at OSHIMA(XAC)



Operational Assumptions (1/2)

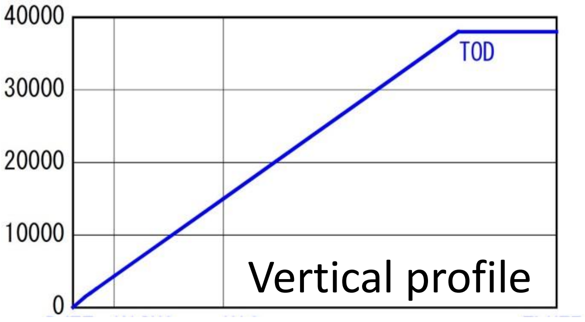
- FIM execution procedures
  - Initiation

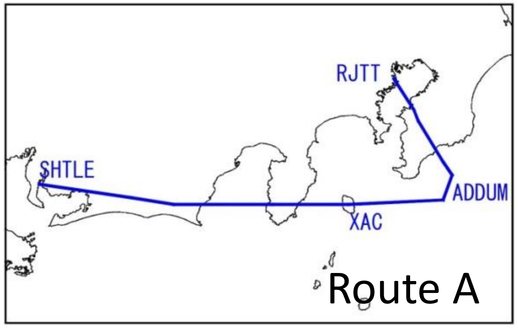
    *ATCo instructs the arrival sequence and time-spacing intervals 10–15 minutes before FIM execution point, SHTLE/FLUTE.
  - Execution

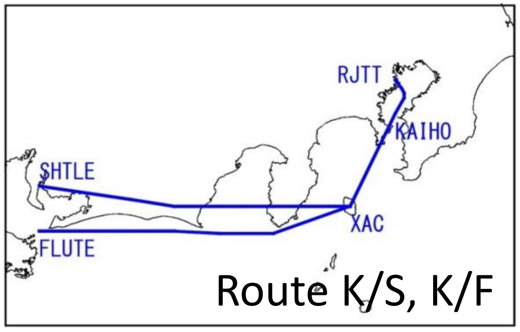
    *Pilot executes FIM to comply with the ATCo instructions.

    *FIM commands are input to FMS
  - Termination

    *FIM is terminated when the leading aircraft arrives at the threshold of RW34L.



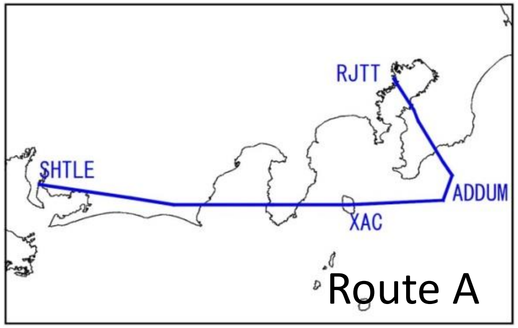


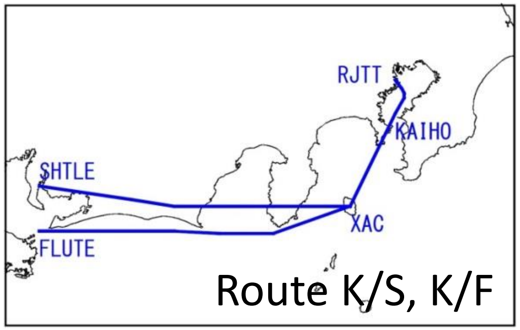


Operational Assumptions (2/2)

- Aircraft types and flight scenarios
  - Medium fidelity aircraft model of B777-200 and B737-800 including VNAV/LNAV, engine system, and flight control systems
  - Three pairs of aircraft trailing, a total of four aircraft, in a string according to ATCo comments

Case	Aircraft type (Route name)			
	1st aircraft	2nd aircraft	3rd aircraft	4th aircraft
A	B777-200 (Route A)	B777-200 (Route A)	B777-200 (Route A)	B777-200 (Route A)
B	B777-200 (Route A)	B737-800 (Route A)	B737-800 (Route A)	B777-200 (Route A)
C	B777-200 (Route K/S)	B777-200 (Route K/S)	B777-200 (Route K/S)	B777-200 (Route K/S)
D	B777-200 (Route K/S)	B777-200 (Route K/F)	B777-200 (Route K/S)	B777-200 (Route K/F)
E	B777-200 (Route K/S)	B737-800 (Route K/F)	B737-800 (Route K/S)	B777-200 (Route K/F)





Assumptions on MC simulation

- Wind
  - typical winter seasonal west wind of 100 knots at 40,000 ft decreasing linearly with altitude to 20 knots at RW34L.
- Wind estimation errors
  - wind estimation error is assumed to be 10 knots: actual velocity of the west wind is 10 knots stronger than the estimate.
- Initial time-spacing intervals
  - $\pm$ 15 second deviation from a standard two-minute landing interval: $t_{min} = 105\ sec$, $t_{max} = 135$ sec, given by uniform density

Simulation results

- Time-spacing performance
- Fuel consumption

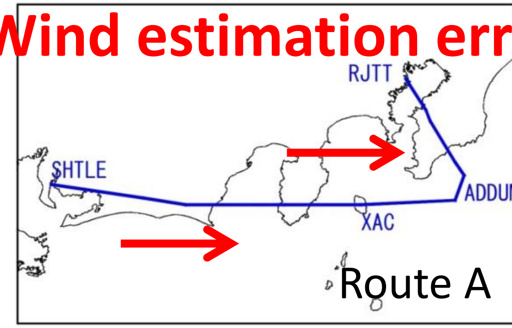
Time-spacing performance(1/7)

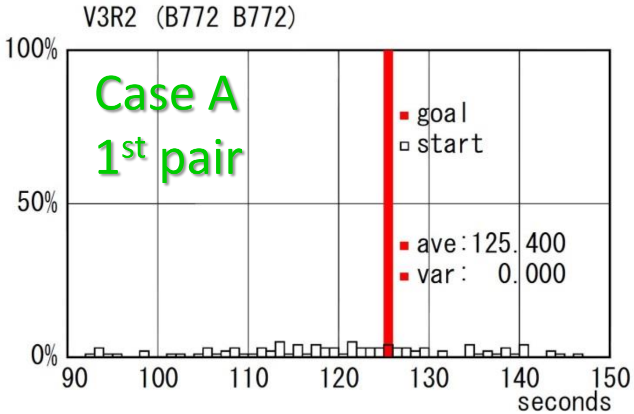
- Does FIM achieve good performance in time-spacing?
- Dose the time-spacing performance depend on aircraft types/route design?
- Is FIM feasible under the wind effects and wind estimation errors?

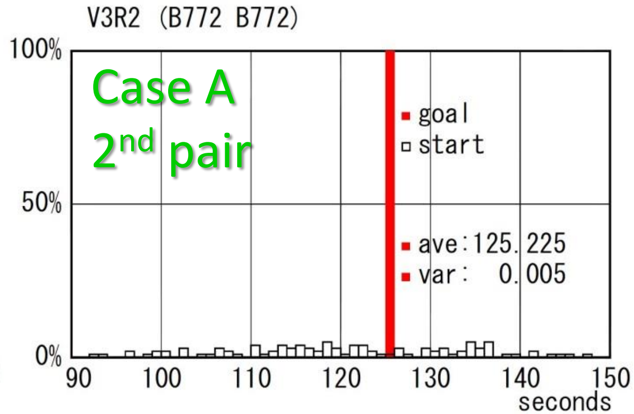
Time-spacing performance(2/7)

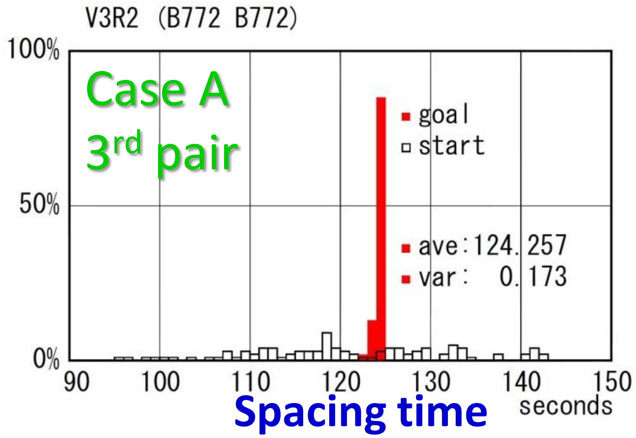
- Route A:

Case A (B777-B777-B777-B777)



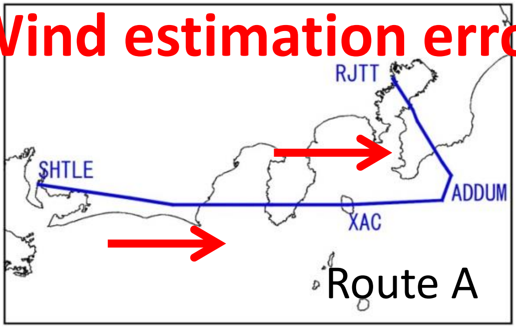


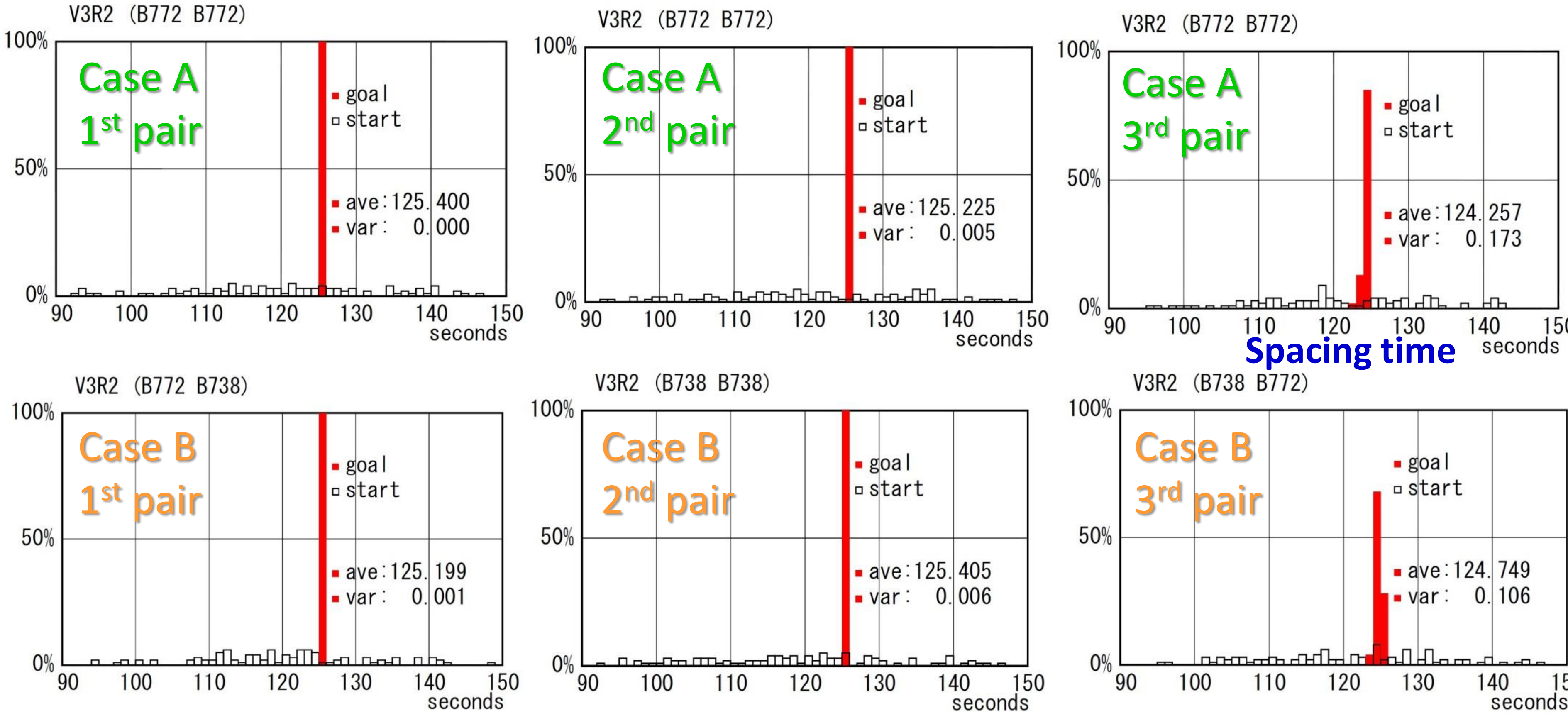




Time-spacing performance(3/7)

- Route A:
  - Case A (B777-B777-B777-B777)
  - Case B (B777-B737-B737-B777)

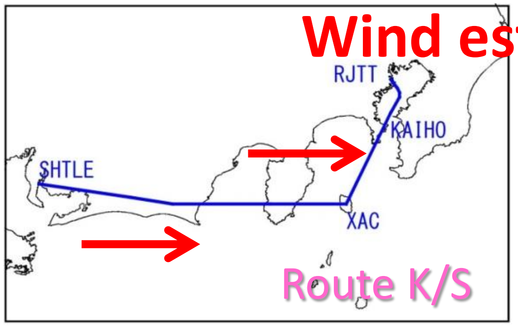


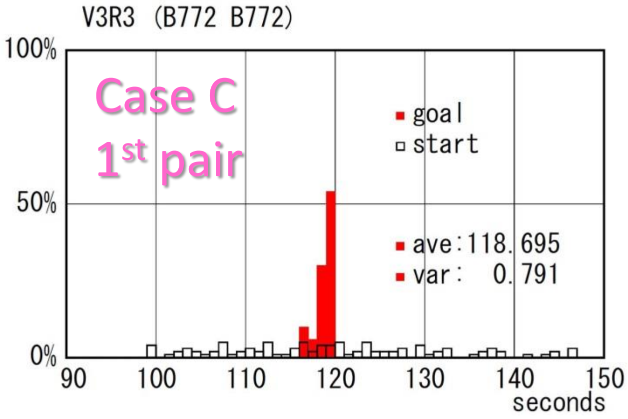


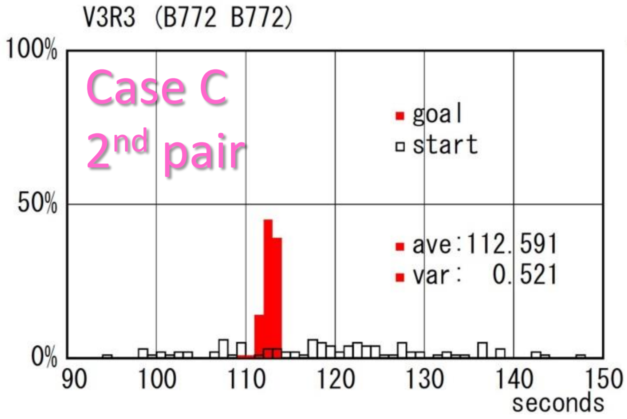
Time-spacing performance(4/7)

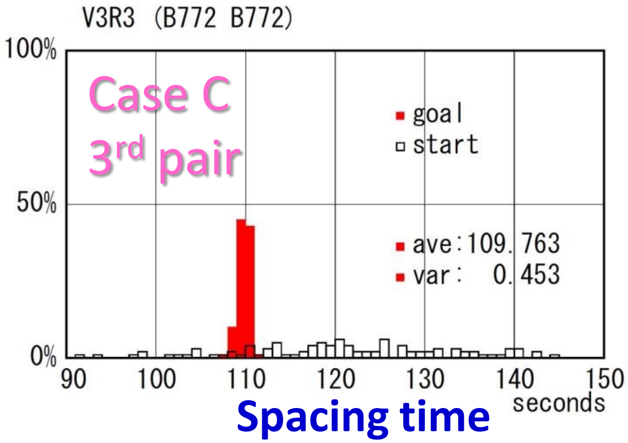
- Route K/S:

Case C (B777-B777-B777-B777)









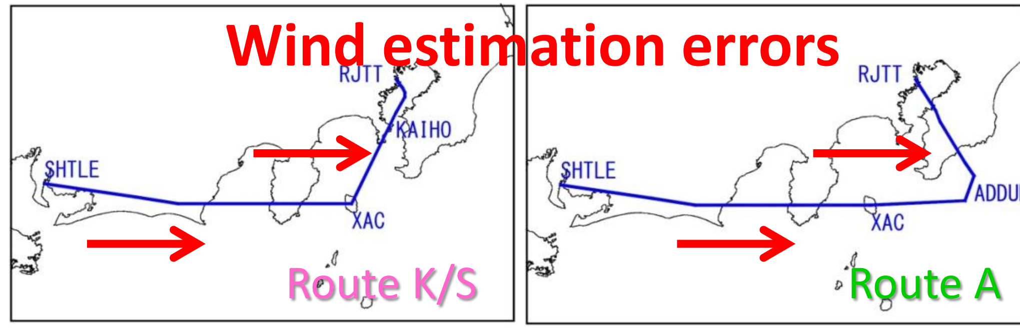
Time-spacing performance(5/7)

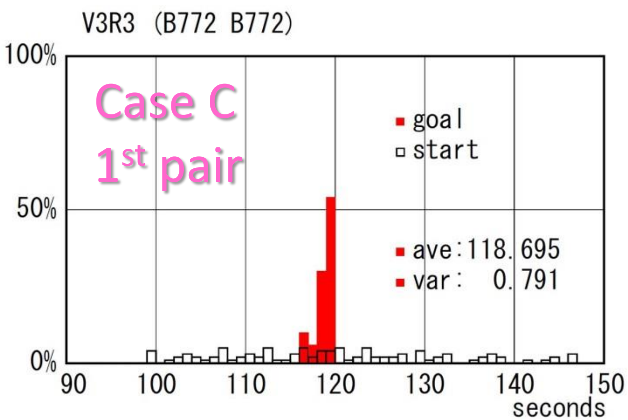
- Route K/S:

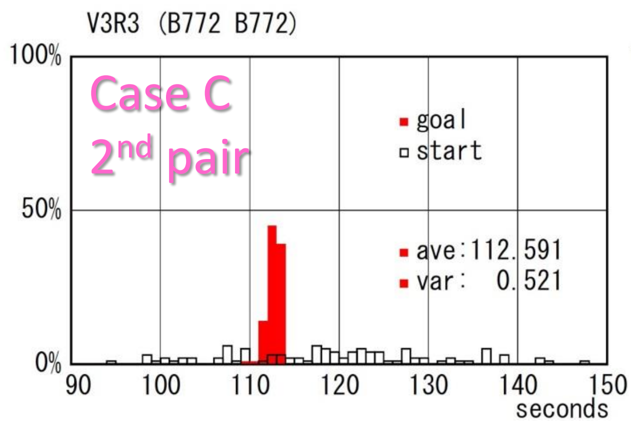
Case C (B777-B777-B777-B777)

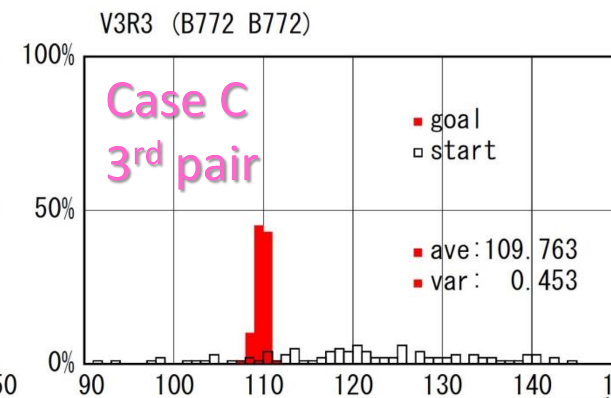
- Route A

Case A (B777-B777-B777-B777)

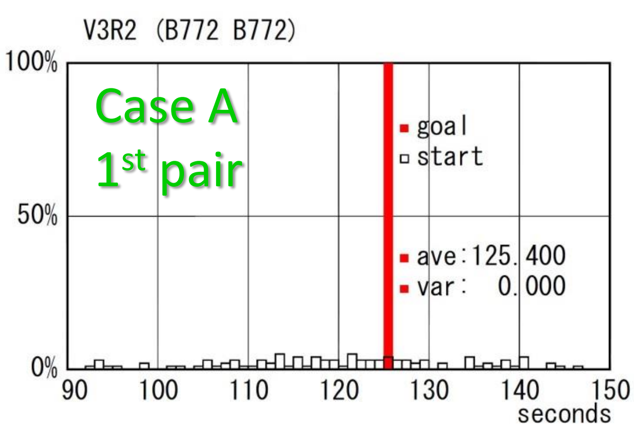


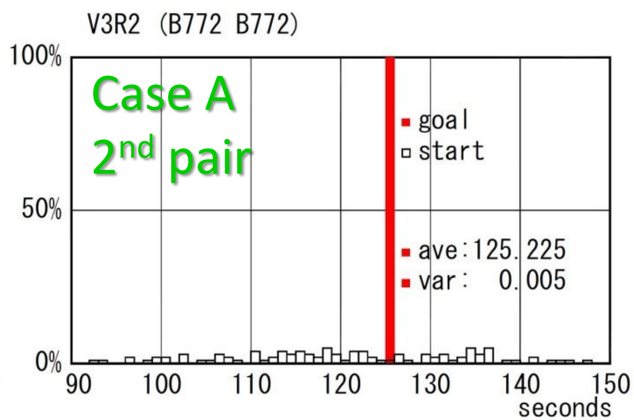


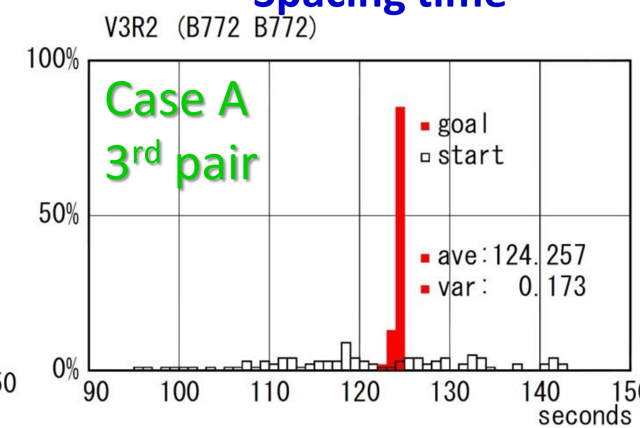




Spacing time

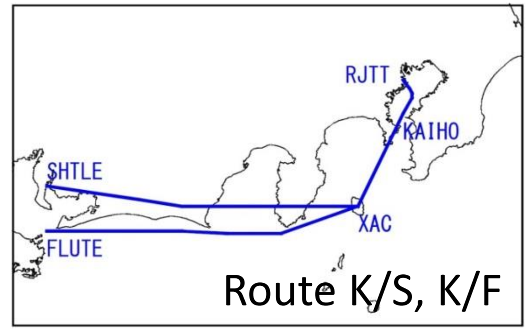


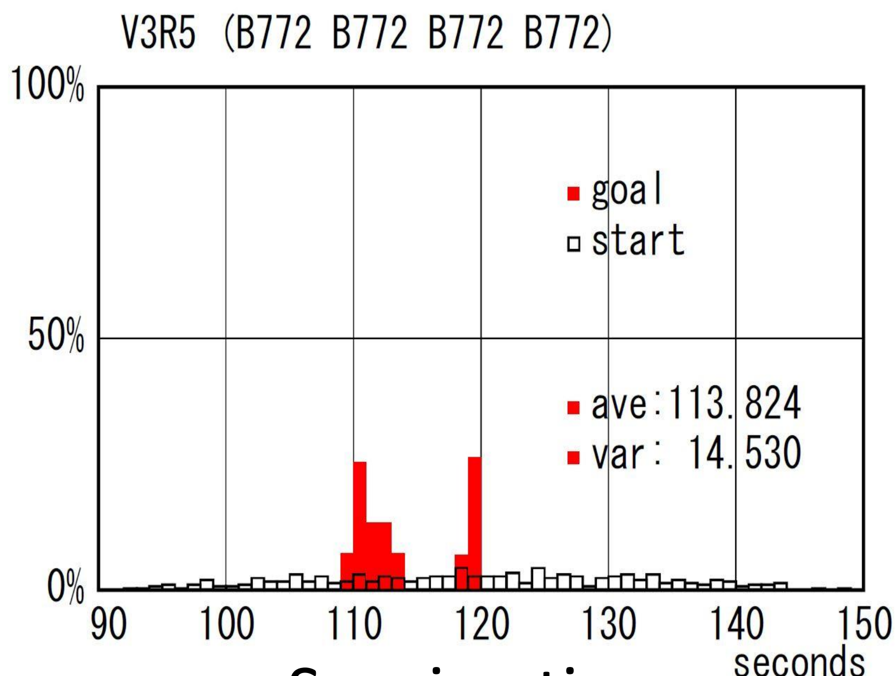




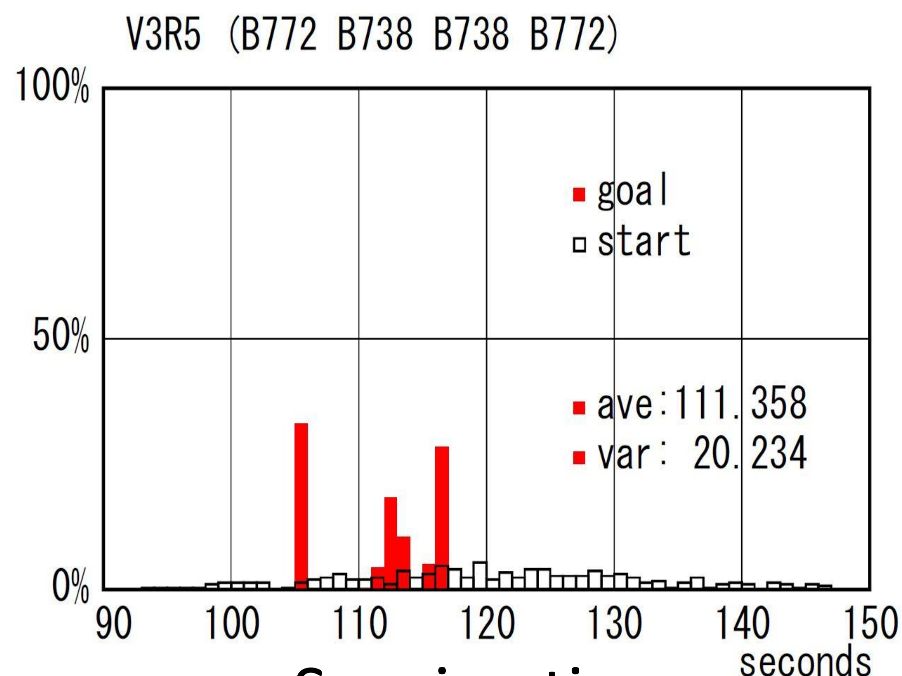
Time-spacing performance(6/7)

- Route K/S, K/F:
  - Case D (B777-B777-B777-B777)
  - Case E (B777-B737-B737-B777)





Spacing time
Case D



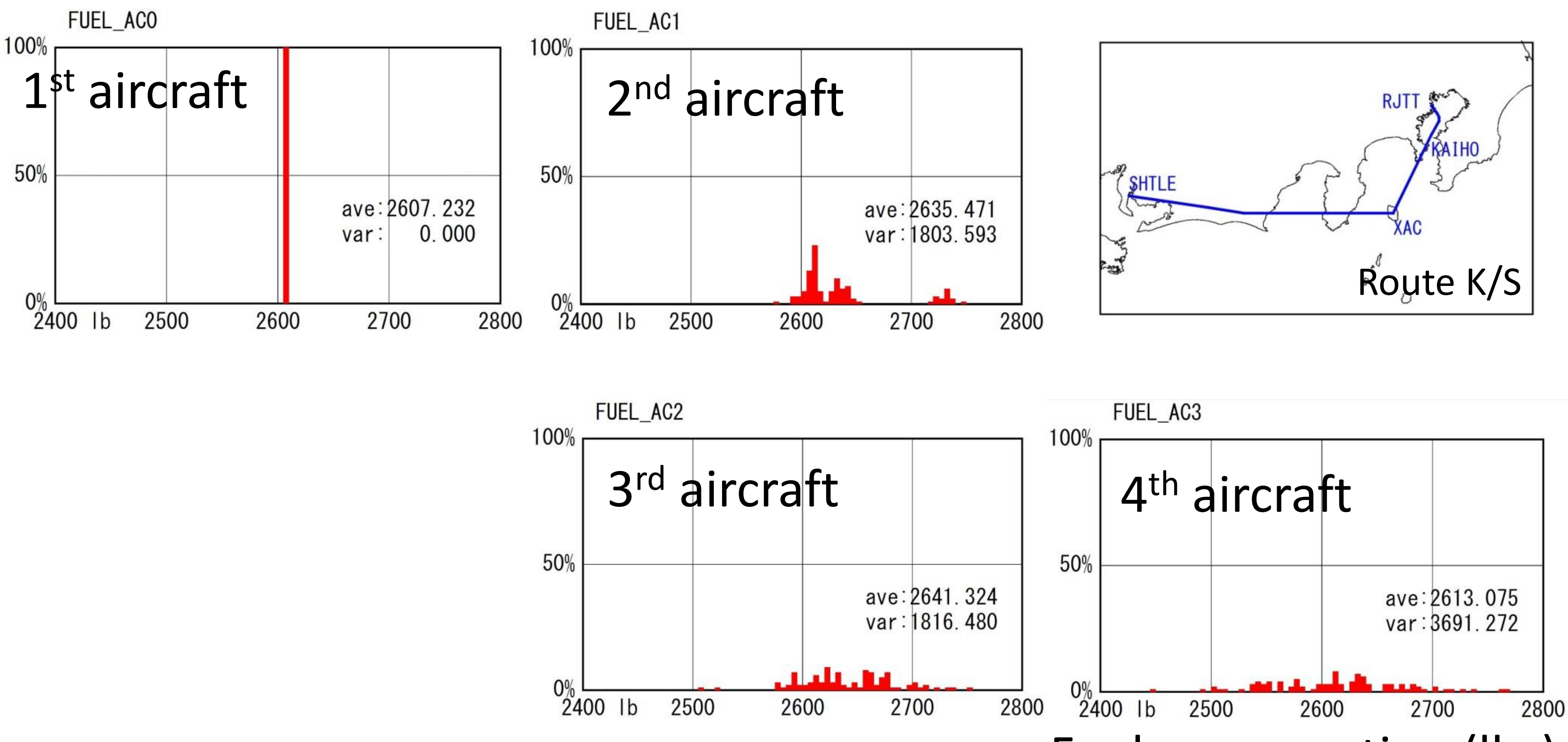
Spacing time
Case E

Time-spacing performance(7/7)

- FIM time-spacing performance depends on characteristics of the designed air route.
- Combinations of aircraft types influence on time-spacing performance depending on the air route design.
- Further simulations are required based on air routes designed for FIM-based CDO.
- The effect of the wind estimation errors is one of the potentials to deteriorate the time-spacing performance.

Fuel consumption(1/3)

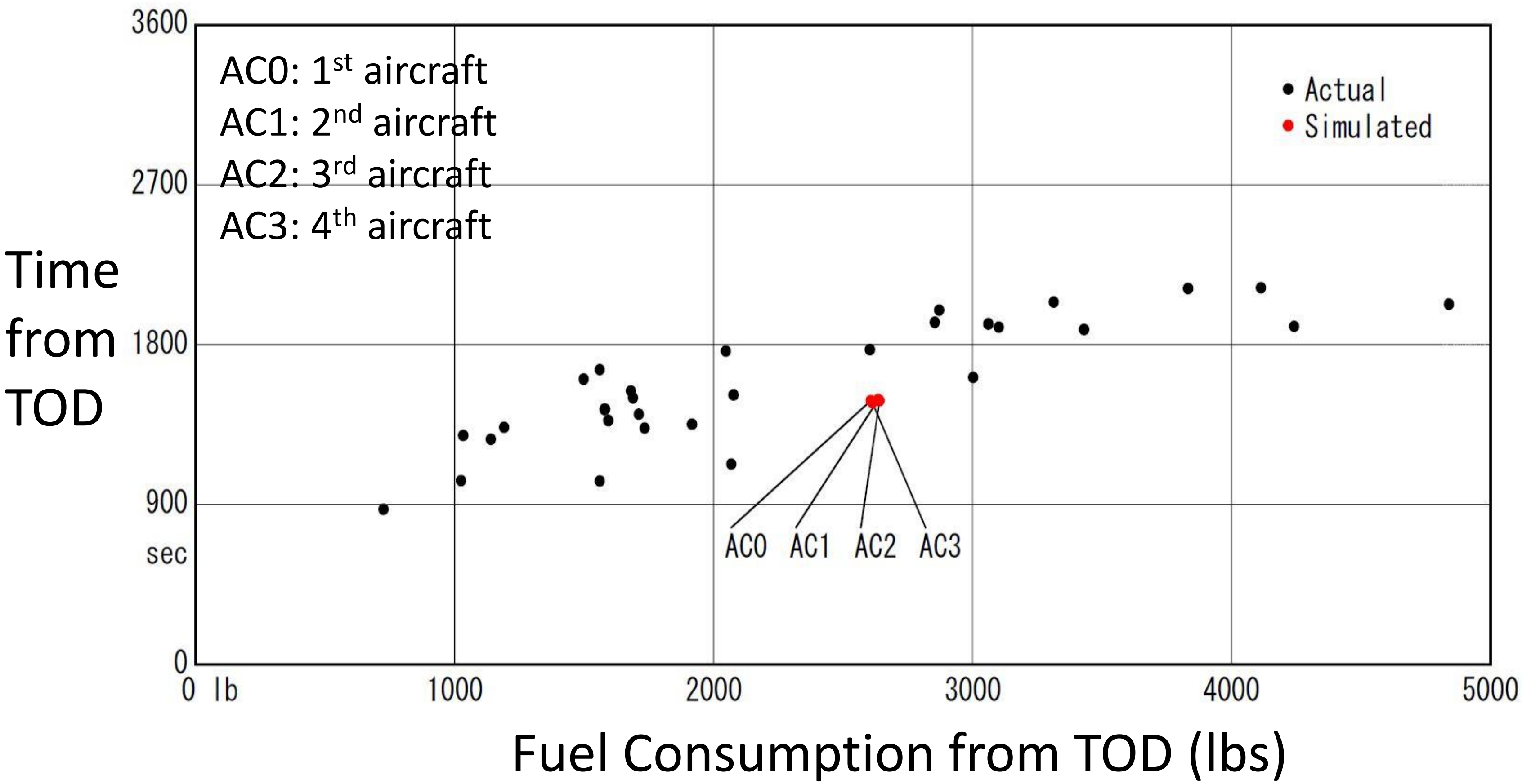
- Simulated B777-200 fuel consumption from Top Of Descent (TOD) on Route K/S



Fuel consumption (lbs)

Fuel consumption(2/3)

- Comparison of simulated B777-200 fuel consumption and time from TOD with actual data



Fuel consumption(3/3)

- FIM-based CDO realizes energy-saving arrivals.
- The variances of average fuel consumption and required time from TOD for each of the four aircraft in the simulated data are significantly smaller than the variances in actual data.
- Applying FIM-based CDO has a potential to achieve assigned time spacing while reducing fuel consumption for all traffic, not just for specific aircraft.

Concluding remarks

Conclusion

- Implemented FIM-based CDO with a medium-fidelity aircraft model including VNAV and LNAV autopilot modes, an engine system, and TECS, in a fast-time simulation via SPICA software.
- Estimated the effectiveness of the FIM-based CDO to Tokyo International Airport based on the time spacing performance and fuel consumption.

Future works

- Further simulation studies to evaluate the effect of combinations of air route design, wind effect, wind estimation errors, including more aircraft types via SPICA software
- Consider mixed equipage situation
- Analyze how to harmonize with the ground operation
- Estimate FIM off-nominal events

Thank you!

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