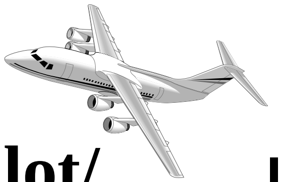

Integration of Simulation Models: Modeling Pilot/ Ground Controller Interactions

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Virginia Polytechnic Institute and State University

Sponsors: FAA and ATAC Corporation

NEXTOR Research Symposium

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Motivation for Research

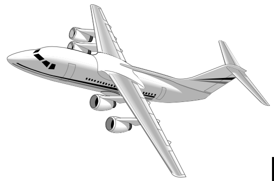
There is a need to model airport ground networks accurately

+ Consideration of ATC-pilot interactions is seldom addressed
+ Aircraft kinematics are seldom considered
+ Future ground air traffic management paradigms could render existing models obsolete
+ Some anecdotal evidence that current models have perceived simulation fidelity drawbacks

Current ground simulation models are difficult to extend or modify

+ Complexity
+ Model architecture in some cases is quite old and requires heavy maintenance to incorporate changes

Project Objectives



- To gain an understanding of model integration capabilities
- To investigate possible alternatives to integrate existing National Airspace System models as a suite of decision making tools
- To connect new algorithms with existing NAS airspace and airport simulation models (e.g., SIMMOD, RAMS, etc.)
  - + Focus on a single model to illustrate how some NARIM tools could interact with NEXTOR developed algorithms
  - + Develop a proof-of-concept model using a ground network simulator to be connected with other NARIM models (such as SIMMOD and RAMS)

Status of the Project

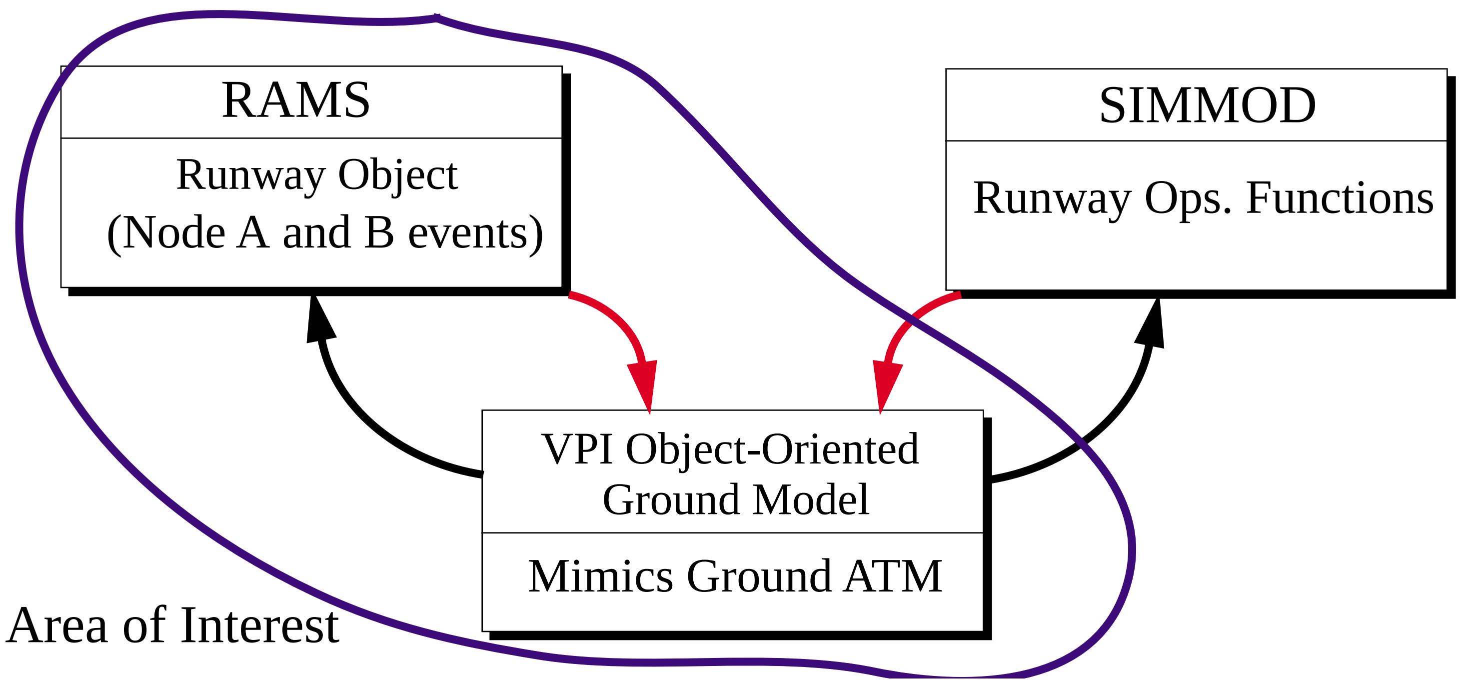
- An object-oriented programming mechanism to connect to the architecture of both models with external processes is under way
  - + Synchronization of model algorithms
  - + Data structures
  - + Message passing routines
- An Object-Oriented Modeling (OOM) framework to execute ground simulation has been developed
- Ties with RAMS and SIMMOD will follow to demonstrate the applicability of the concept
- Partial funding for this project has been received from NEXTOR's ATM research grant (Dr. R. Stevens at FAA) and ATAC Corporation (matching funds)

Integration of Airspace/Airfield Models to External Processes

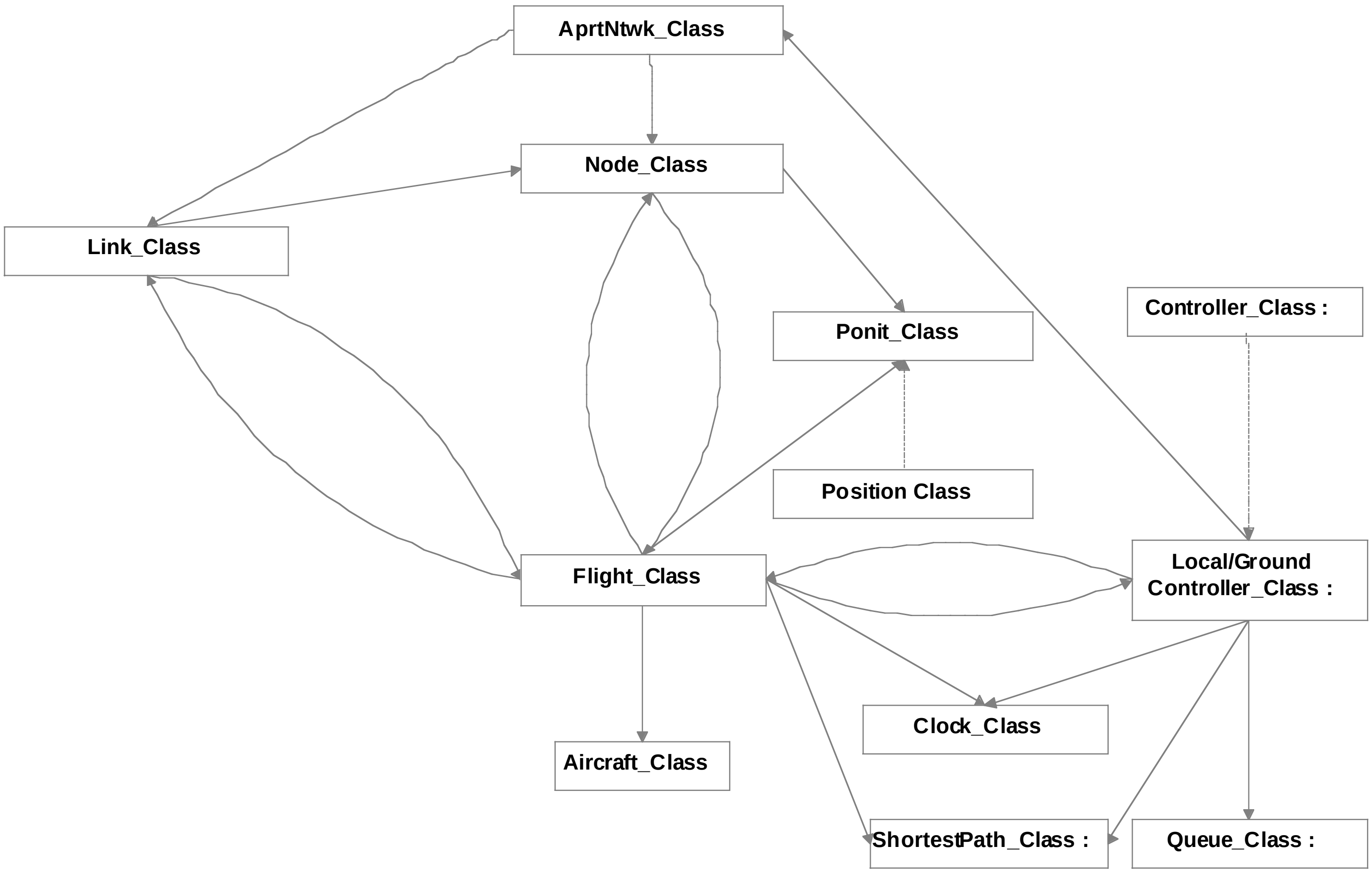
- To demonstrate the integration process RAMS and SIMMOD are being used as testcases
  - \+ RAMS - The Reorganized Airspace Mathematical Simulator
  - \+ Airspace operational model developed by Eurocontrol to simulate advanced airspace concepts
  - \+ SIMMOD - the FAA airfield and airspace model
- Curiously, none of these models was designed with a plug-in architecture in mind (SIMMOD designed in the 1970s and RAMS in the 1980s)
- Both are considered as part of the NARIM tool set
- RAMS lacks explicit ground simulation capabilities (the model was never conceived to simulate the airport ground component)

Integration Approach

- Develop an integration procedure to link dynamic events into RAMS and SIMMOD
- Ground simulation component is the common element for the integration procedure (RAMS has little ground logic)



Ground Simulation Model Design Relationships



General Model Features

- Hybrid micro-simulation model (continuous and discrete events)
- The total aircraft delay due to network congestion can be analyzed
- Implements an "aircraft-following" model
    - + The dynamic behavior of moving aircraft can be captured in more detail using this method
- Communication delays and frequency congestion is incorporated
- Discrete updating the shortest path solutions (Quasi-Dynamic)
    - + More realistic results in reasonable computation time
- All source code has been developed in ANSI C++ for portability
- Three types of data structures (Array, Linked-list, Mixed) depending on the data types

Justification of Hybrid Simulation

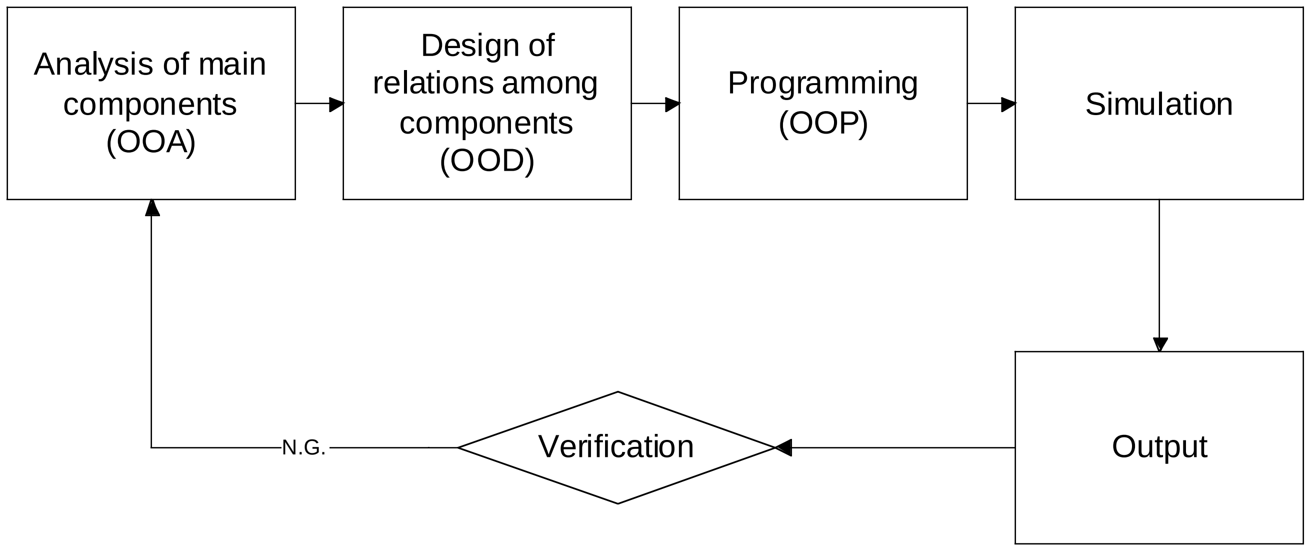
- Discrete simulation model is fast
- Continuous simulation model makes it possible to obtain more accurate results in many respects (just two examples below)
    + Second-order feedback control system can be applied in the aircraft-following model
    + Accurate airport resource information can be obtained by applying feedback control system information (i.e., runway occupancy times, controller workloads, etc.)
- In this model, the flight's movement is not considered unless it has a permission to move. But once a flight is allowed to move, the model traces its behavior in very short intervals Δt

Ground Control Model Features

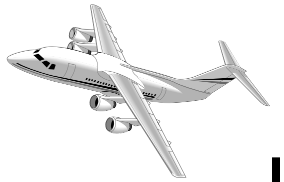
- Communication interactions between ATC controllers/data link and each aircraft is explicitly modeled
- Delay analysis. There are two types of delay:
  - + Traffic delay due to the traffic congestion on taxiway/runway
  - + Communication delay due to the controller/data link communications
- Dynamic behavior of moving aircraft by adopting aircraft-following logic
- Static and dynamic route guidance for taxing
- By applying dynamic guidance logic, more realistic and efficient routing is possible

Model Development Procedures

Follows standard Object-Oriented Modeling and Programming practices



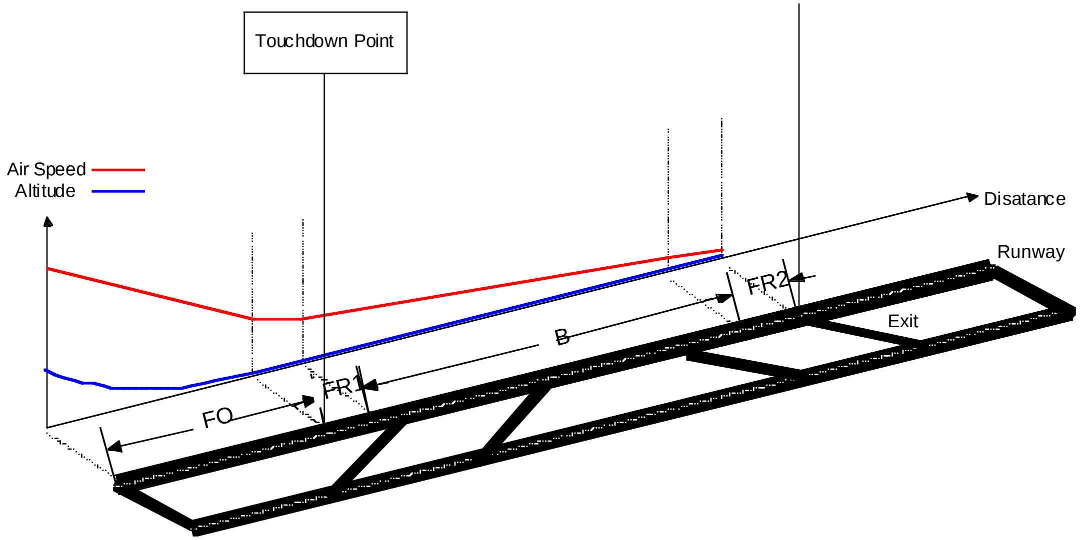
Analysis of Model Components : Class



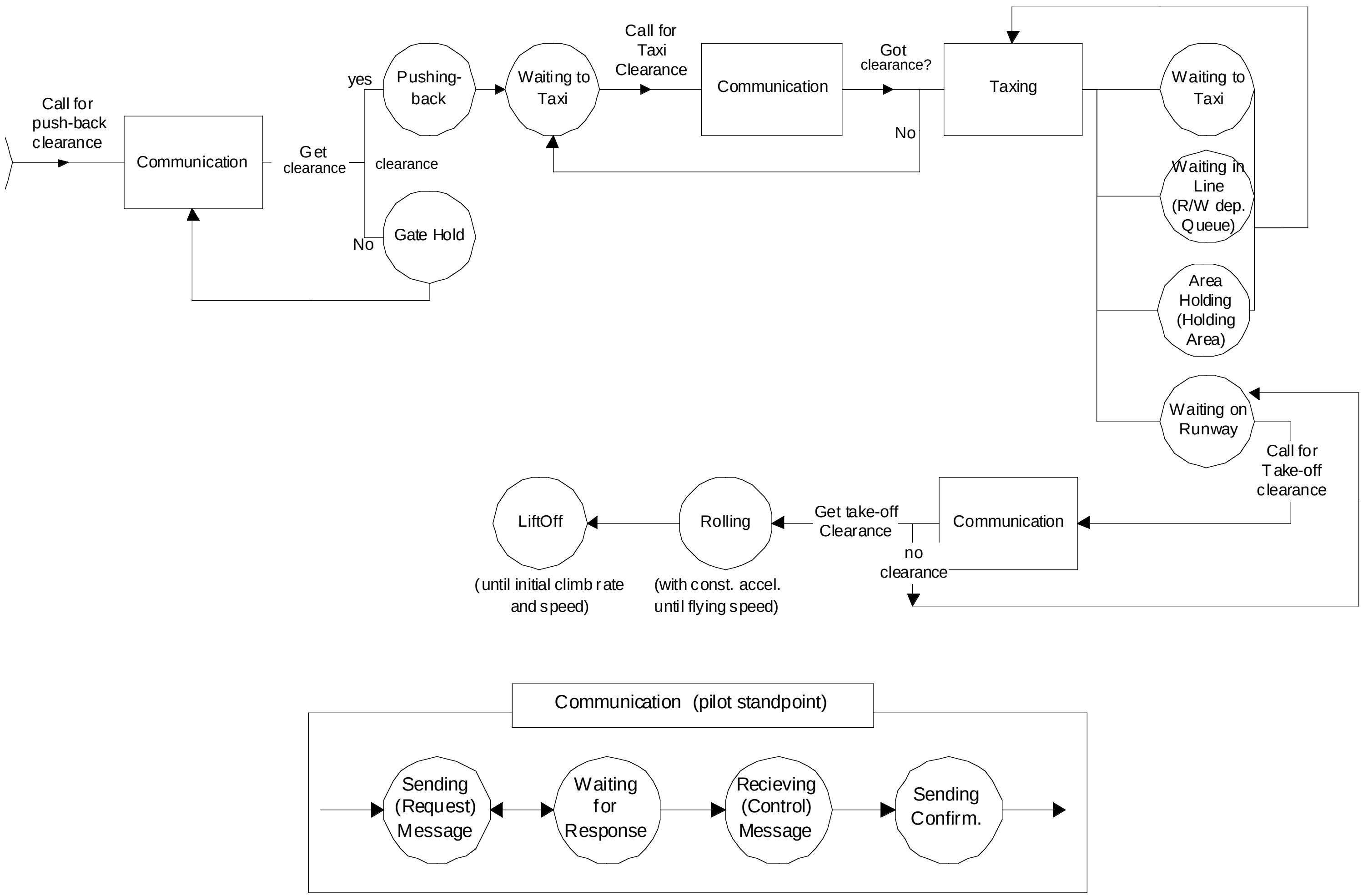
- Aircraft model has:
  + Dimensions: length, wheel base, wing area, MSTW, MLW, etc
  + Performance constants
  + Stall speed, approach speed, deceleration rate (for touchdown)
  + Coefficients for acceleration (for takeoff)
  + Maximum acceleration/deceleration rate (for taxing), etc.
- Runway/Taxiway has nodes, links
- A flight has flight information like schedule, gate, runway, etc.
- A controller (local controller or ground controller) requires finite time intervals to finish jobs (communication phase)

Analysis of Model Components : Methods

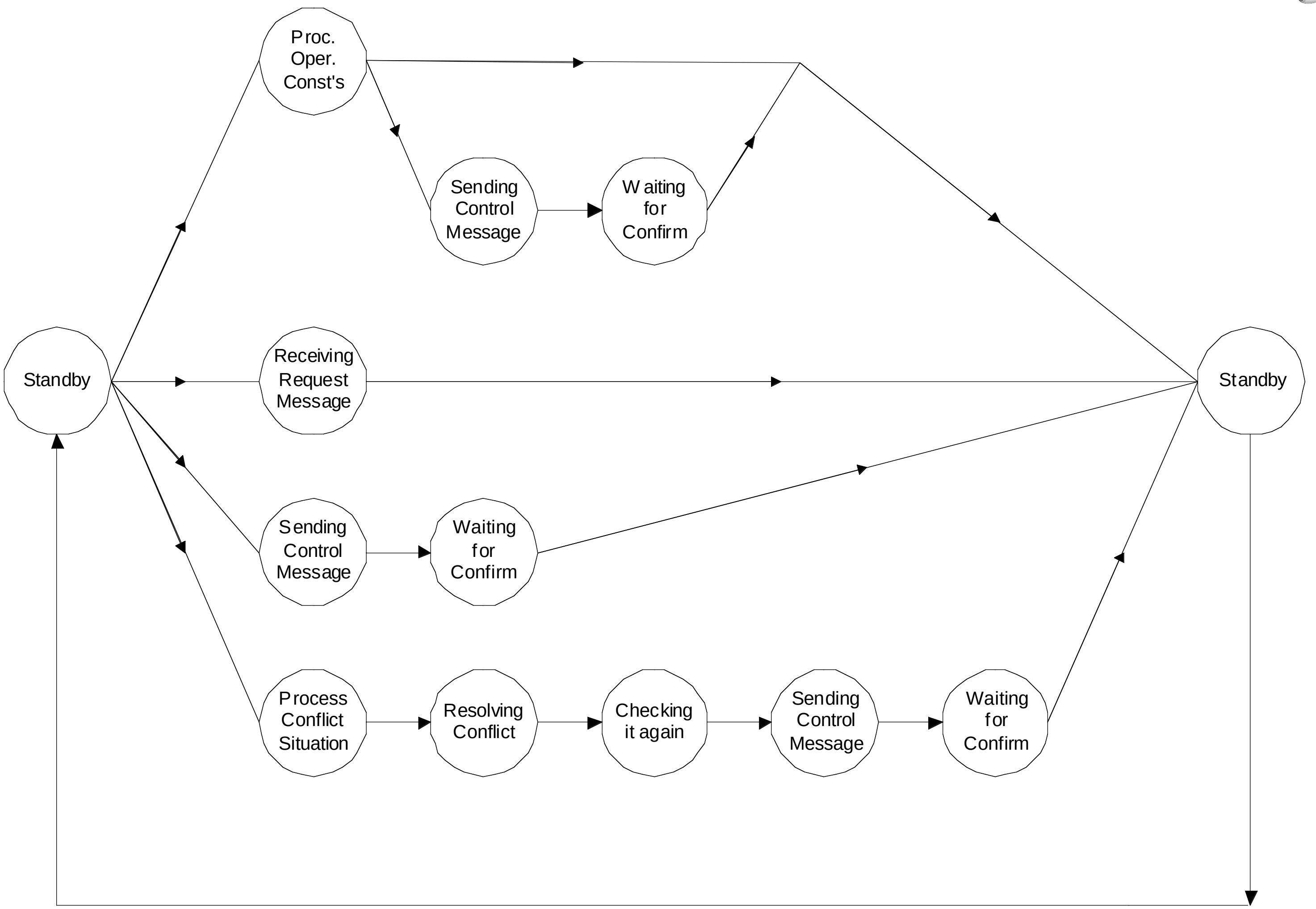
- Flight method
  - + Communicates with both L/C and G/C controllers
  - + Moves aircraft on taxiway from gate to runway or vice versa
  - + Detects and resolves conflicts during taxiing
  - + Executes a take-off (continuous simulation with 2 phases) or landing (continuous simulation with 4 phases)



Sample Departure State Transition Diagram



Sample Transition Diagram (Controller State)



Aircraft-Following Logic (Second-Order Model)

- Captures the dynamics of aircraft motion on the ground
- Incorporates realistic aircraft kinematic constraints

Distance control logic

$$\ddot{x}_{n+1}^{t+\Delta t} = k[(x_n^t - x_{n+1}^t) - D], \text{ where } k = \text{design parameter}, D = \text{safety distance}$$

$$\text{If } \ddot{x}_{n+1}^{t+\Delta t} > \ddot{x}_{\max}, \text{ then } \ddot{x}_{n+1}^{t+\Delta t} = \ddot{x}_{\max}$$

Speed control logic

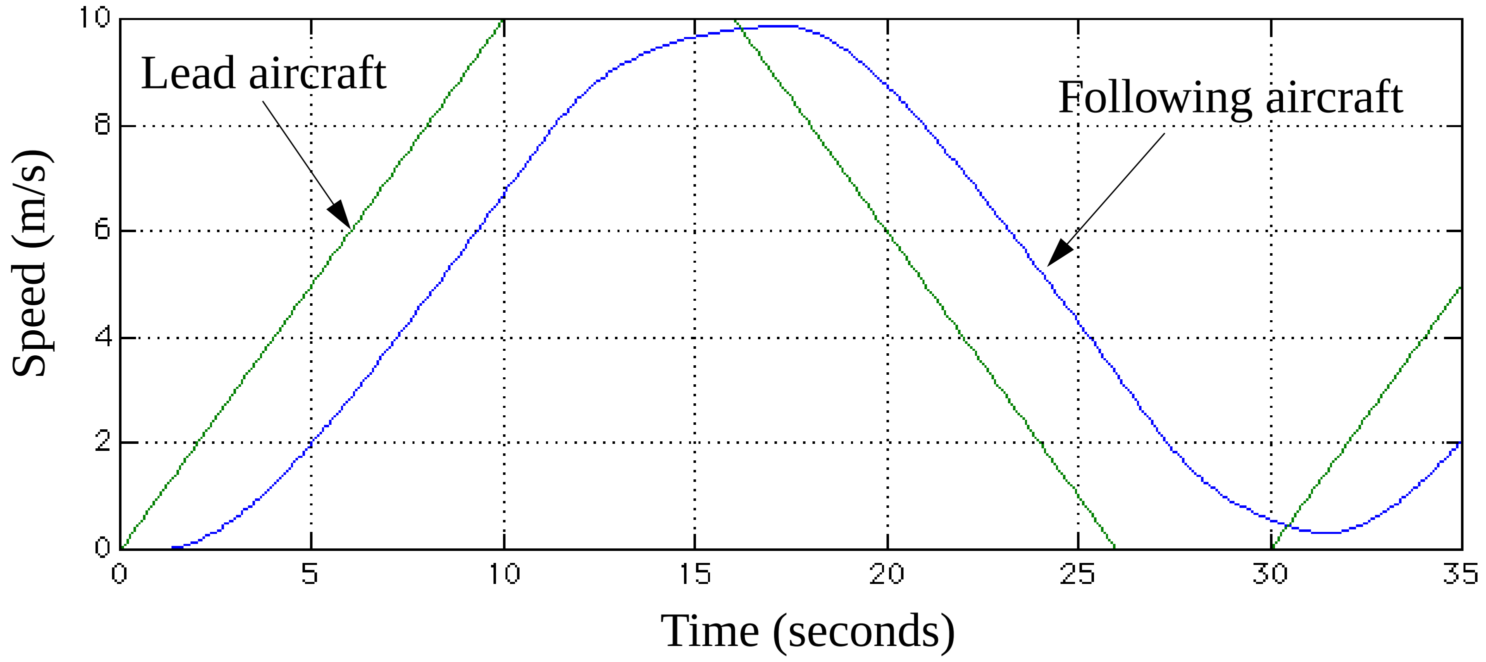
$$\ddot{x}_{n+1}^{t+\Delta t} = k(\dot{x}_n^t - \dot{x}_{n+1}^t) \quad \text{if } \ddot{x}_{n+1}^{t+\Delta t} > \ddot{x}_{\max}, \text{ then } \ddot{x}_{n+1}^{t+\Delta t} = \ddot{x}_{\max}$$

Distance-speed control logic

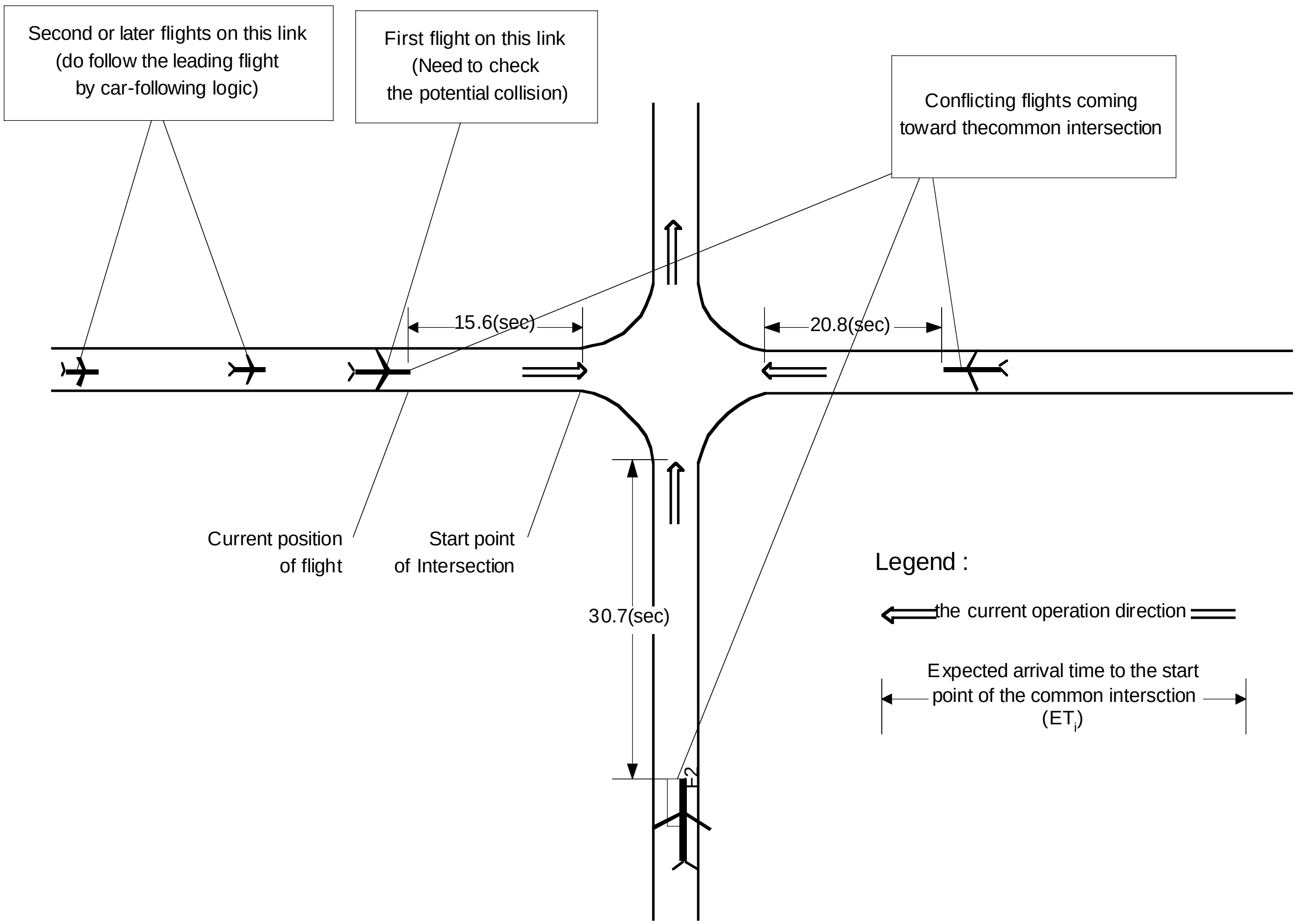
$$\ddot{x}_{n+1}^{t+\Delta t} = \alpha[\dot{x}_n^t - \dot{x}_{n+1}^t] \quad \text{where, } \alpha = C \frac{(\dot{x}_{n+1}^{t+\Delta t})^m}{[x_n^t - x_{n+1}^t]^l}$$

Aircraft-Following Logic Sample Results

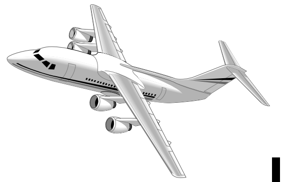
- A simple speed-based aircraft following time delay model is shown below (τ = 1.5 s)

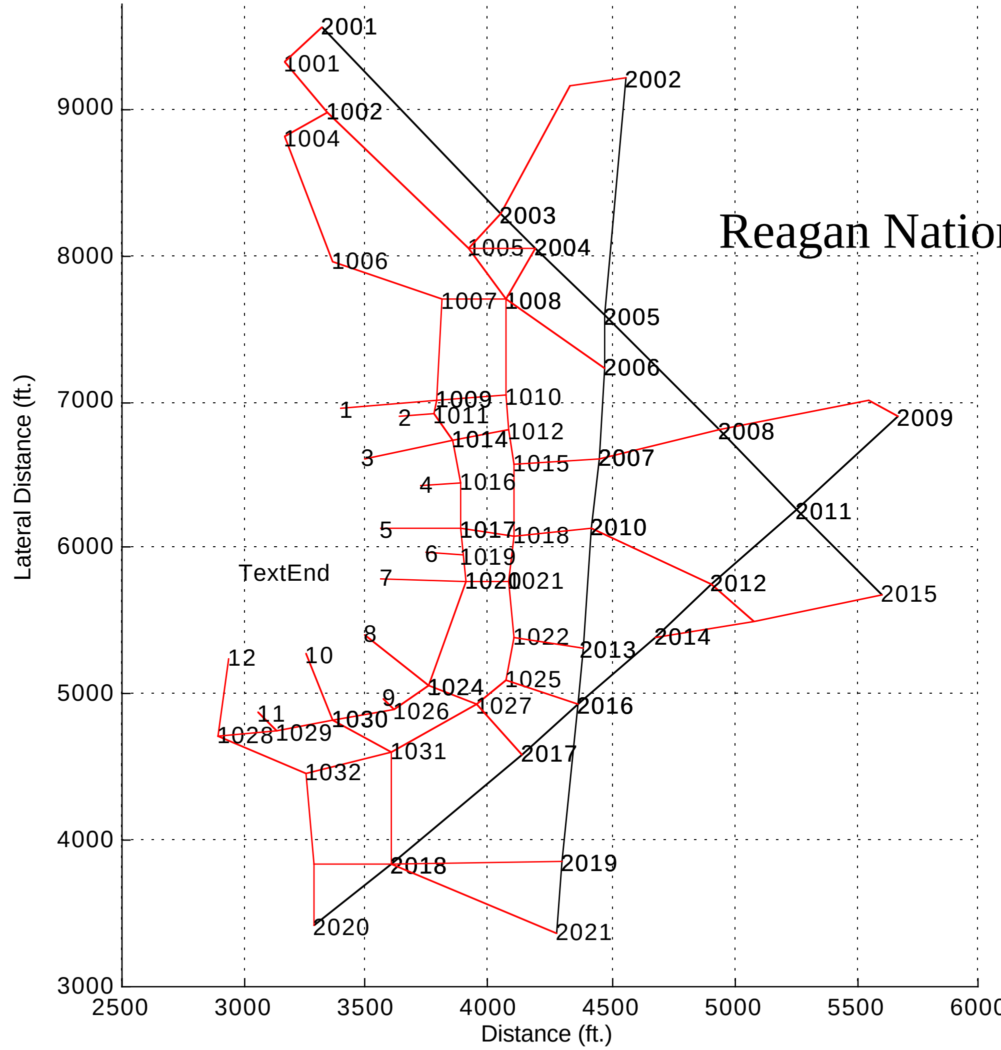


Collision Detection Submodel



Networks (Model Testing)





Reagan National Airport

Sample Input Data Files

File 1: Node Data

1. NodeId
2. NodeType (Gate/Taxiway/Runway)
3. TT
4. Restriction

File 2: Link Data

1. FromNode
2. ToNode
3. LinkType
4. LinkId
5. Restriction
6. Direction

File 3: Aircraft Model

1. Model_Id
2. Wingspan
3. Length_f
4. MaxAccel
5. Etc.

File 4: Flight Plan

1. Flt No.
2. Acft_Type
3. Flt_Type
4. S_Time: Start time
5. O_Node: Origin Node
6. D_Node: Destination node
7. etc

File 5: MinPath Matrix

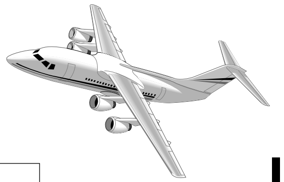
from\to	0	1	2	3	4	5
0	0	1	1	3	3	3
1	-9999	0	2	-9999	4	4
2	-9999	-9999	0	-9999	-9999	5
3	-9999	-9999	-9999	0	4	4
4	-9999	-9999	-9999	-9999	0	5
5	-9999	-9999	-9999	-9999	-9999	0

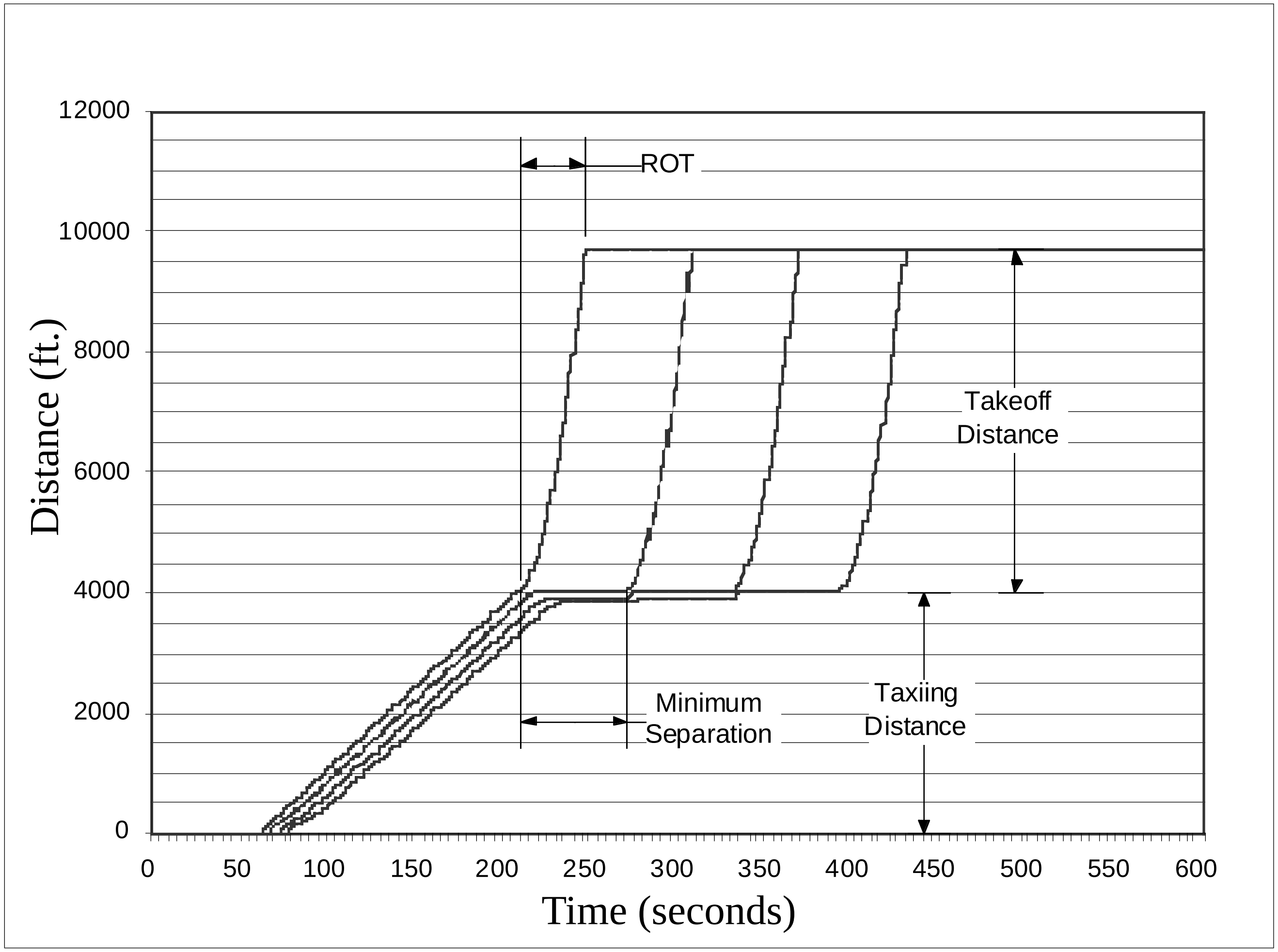
Sample Output Information (Trace File)

Sample Results (1): Sample output

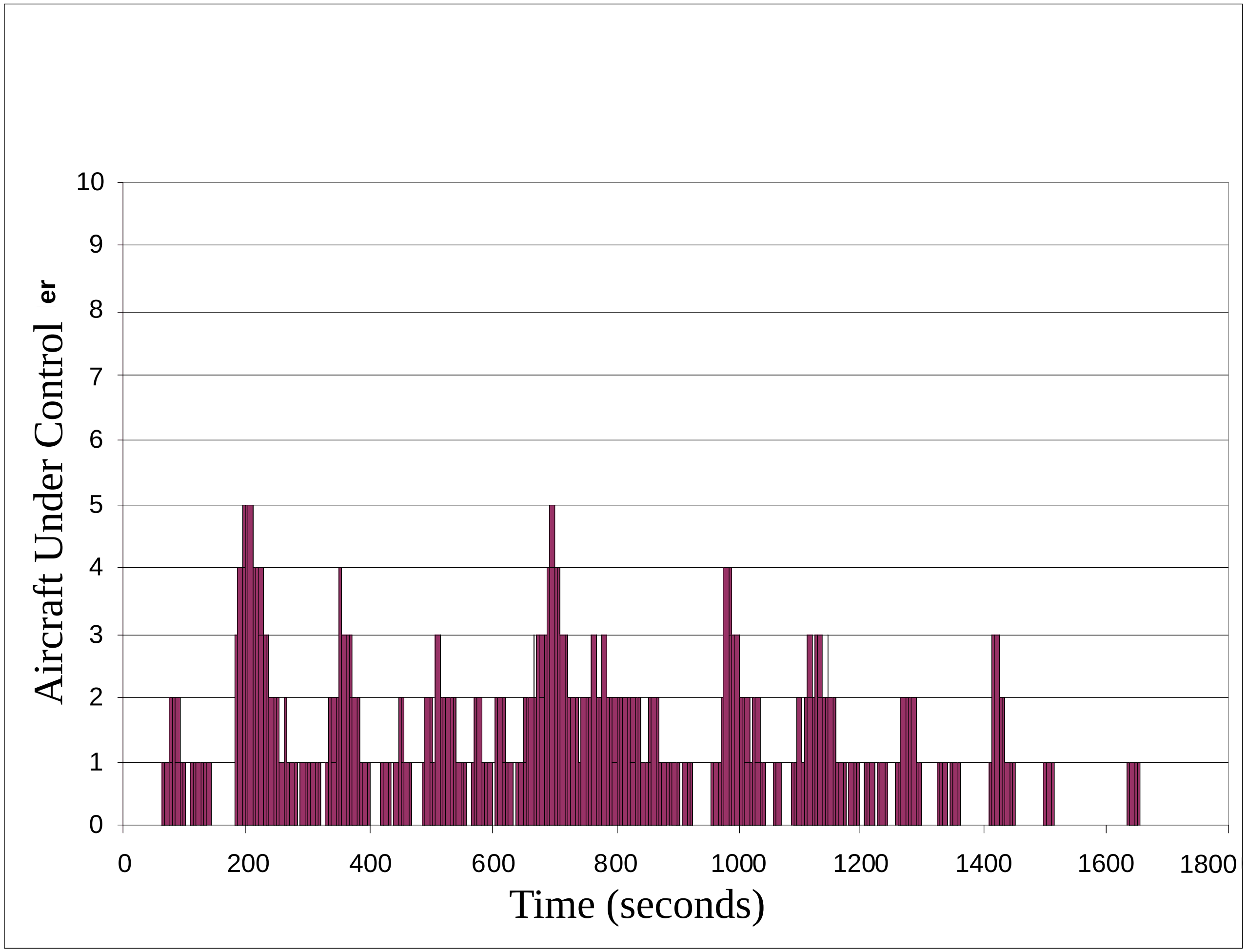
```
Time FLT #    (x, y)       currCommState    currMoveState   speed    accel  currLink linkLeng

60.5 AA378 (3.55881,6.15414) readyToCommunicate taxingToDepQue 3.20622 15.6622 4 ->
    AA789 (3.55850,6.15410) readyToCommunicate parking       0.00000  0.0000 0 -> 0      0
    AA790 (3.55850,6.15410) readyToCommunicate parking       0.00000  0.0000 0 -> 0      0
    AA791 (3.55850,6.15410) readyToCommunicate parking       0.00000  0.0000 0 -> 0      0

60.6 AA378 (3.55918,6.15418) readyToCommunicate taxingToDepQue 4.70198  14.9576 4 -
    AA789 (3.55850,6.15410) readyToCommunicate parking       0.00000   0.0000 0 -> 0      0
    AA790 (3.55850,6.15410) readyToCommunicate parking       0.00000   0.0000 0 -> 0      0
    AA791 (3.55850,6.15410) readyToCommunicate parking       0.00000   0.0000 0 -> 0      0
```

Sample Output (Time-Space Diagram)

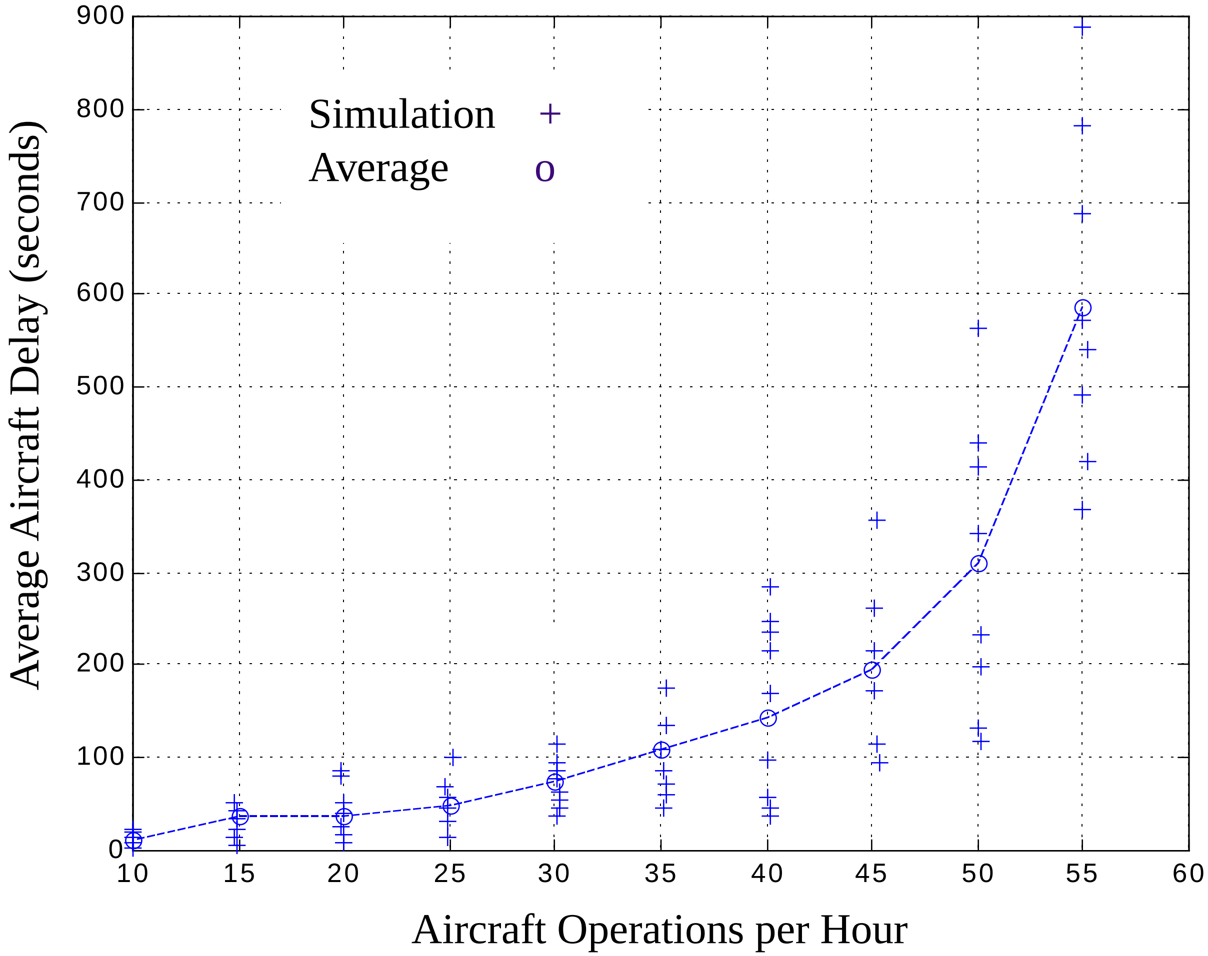




Local Controller “Workload” Metric



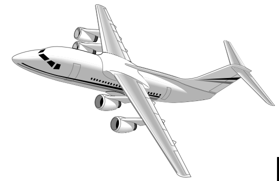
Delay Curve for Mixed Operations



Relevance of the Model

- Integration with other NARIM tools
  - + RAMS-OPGEN
  - + RAMS-VTGSM (the work described here)
- While moderate gains in airspace capacity might be possible in NAS under future concept of operations the airport capacity limits of the system remain a critical issue
- The FAA, airspace users (i.e., airlines, corporate and general aviation), and airport authorities should all benefit from simulation models that incorporate better ground simulation capabilities
- The ground simulation framework developed could also be used in conjunction with ATC decision support aids such as CTAS (to estimate ground ready times or optimal push back times)

Final Remarks



- Challenging ATC-pilot modeling requirements expected of future ATM concepts
- In the next five years it is safe to assume that existing airspace/ airfield models could maintain some value (to airport planners and research organizations) without major algorithmic changes
- Planned ATC/ATM changing strategies associated with Free-Flight and automated ground control operations at airports would require radical changes into the logic of existing NAS simulation models in the long term
- The research model presented is a low level effort in the development of a new generation of tools to understand a critical part of NAS.