A New Paradigm to Model Aircraft Operations at Airports: The Virginia Tech Airport SIMulation Model (VTASIM)

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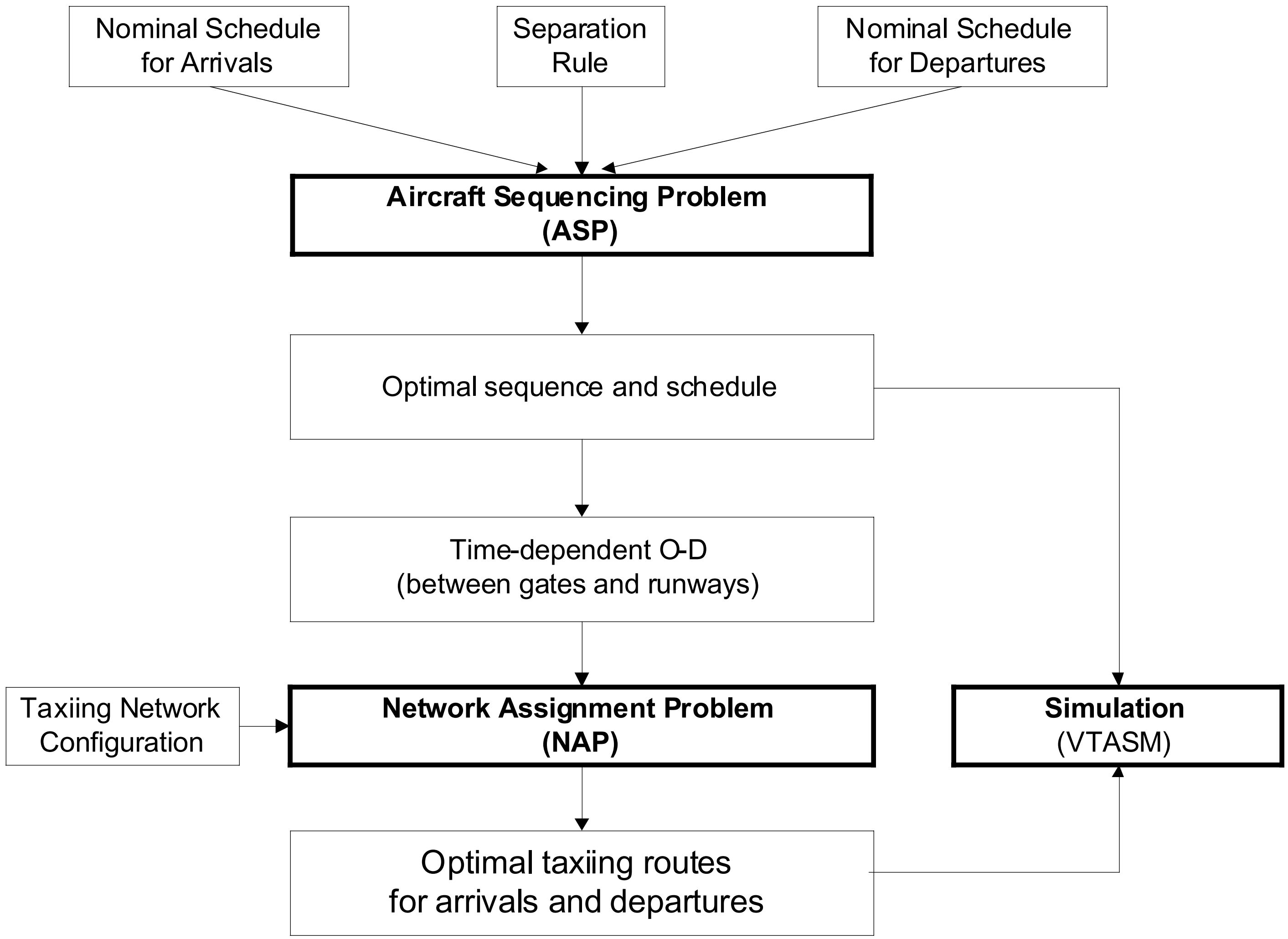
Outline of this Presentation

- Virginia Tech efforts in airport simulation and modeling future NAS operations
- Components of VTASIM
  - Algorithms
  - Sample results
- Dynamic Construction Visualizer
  - Model description
  - Visualization post-processor
- Final Remarks

The Virginia Tech Airport Simulation Model

- Hybrid simulation model
- Microscopic in nature (second-by-second output if required)
- Models aircraft operations around the airport terminal area (includes sequencing)
- Models ATC-pilot interactions explicitly (voice and datalink)
- Dynamic taxiing plans (true dynamic traffic assignment)
- Developed under the auspices of the FAA NEXTOR basic research funding (ATM agenda)

Framework for VTASIM



Development of a Simulation Model: VTASIM

- Existing microscopic simulation models for airport studies:
  - SIMMOD, TAAM (airfield and airspace analyses)
  - Airport Machine (airfield analysis)
  - RAMS (airspace analysis)
- These models are:
  - discrete-event simulation models,
  - less accurate in describing the aircraft movement,
  - do not describe communication process (ATC-pilot).

VTASIM is a Hybrid-type Simulation Model

- A discrete-event simulation model
  - Represents a system by changing the system status at the moments when an event occurs
- A discrete-time simulation model
  - Represents a system checking and changing the system status at every step size (dt).
- VTASIM is a hybrid-type simulation model
  - Movement: represented by discrete-time simulation model
  - Communication: represented by discrete-event simulation model

Entities and State Variables in VTASIM

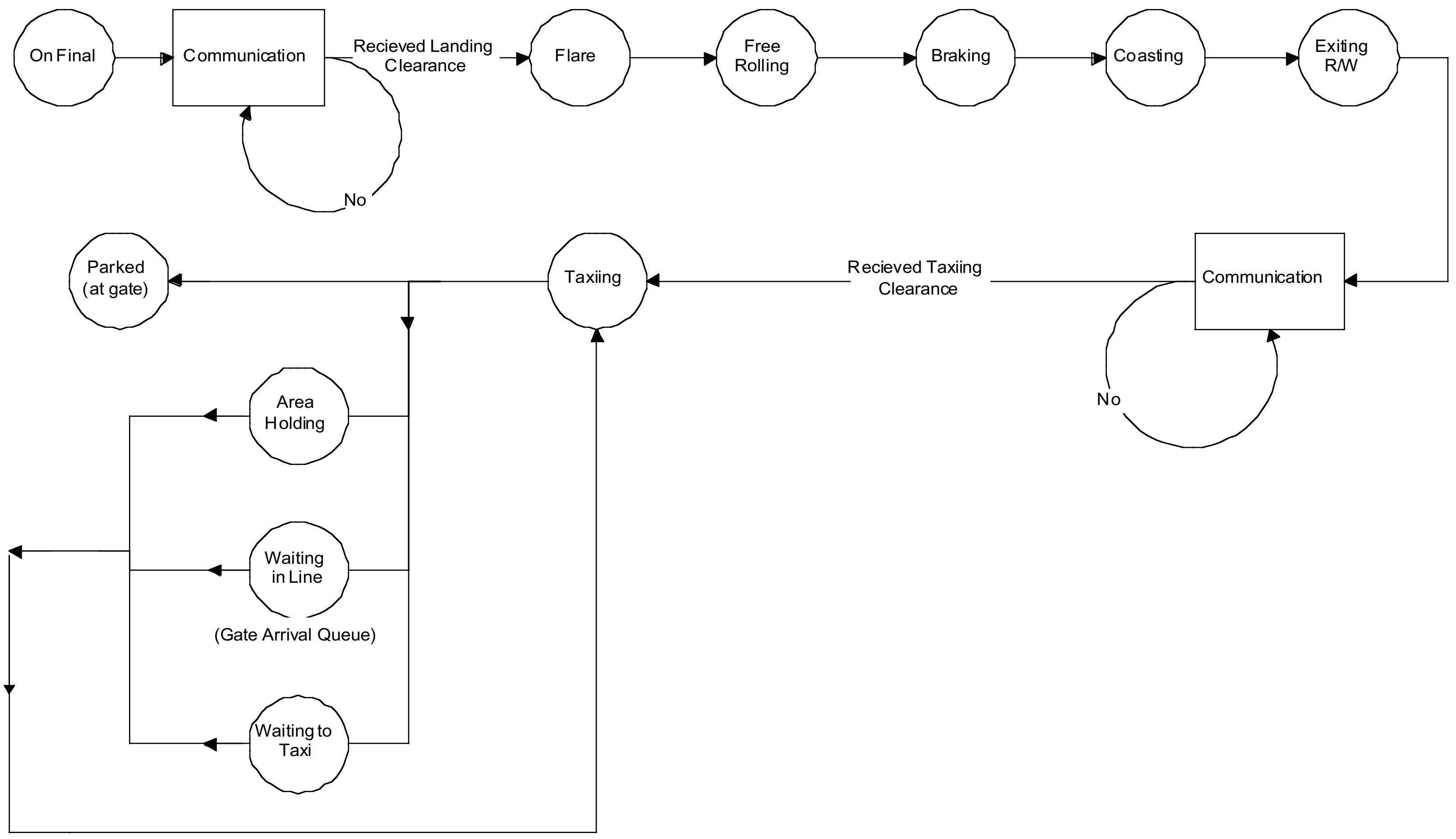
Entities:

- Two types of controllers (i.e., local and ground controllers),
- Two types of flights (i.e., departing and arriving flights), and
- Facilities including gates, taxiways, runways, etc.

State Variables:

- Controllers: controlling state, next communication time,
- Flights: communication state, next communication time, movement state, next movement time, speed, acceleration, position, etc.,
- Gates, taxiways, runways: current flight(s).

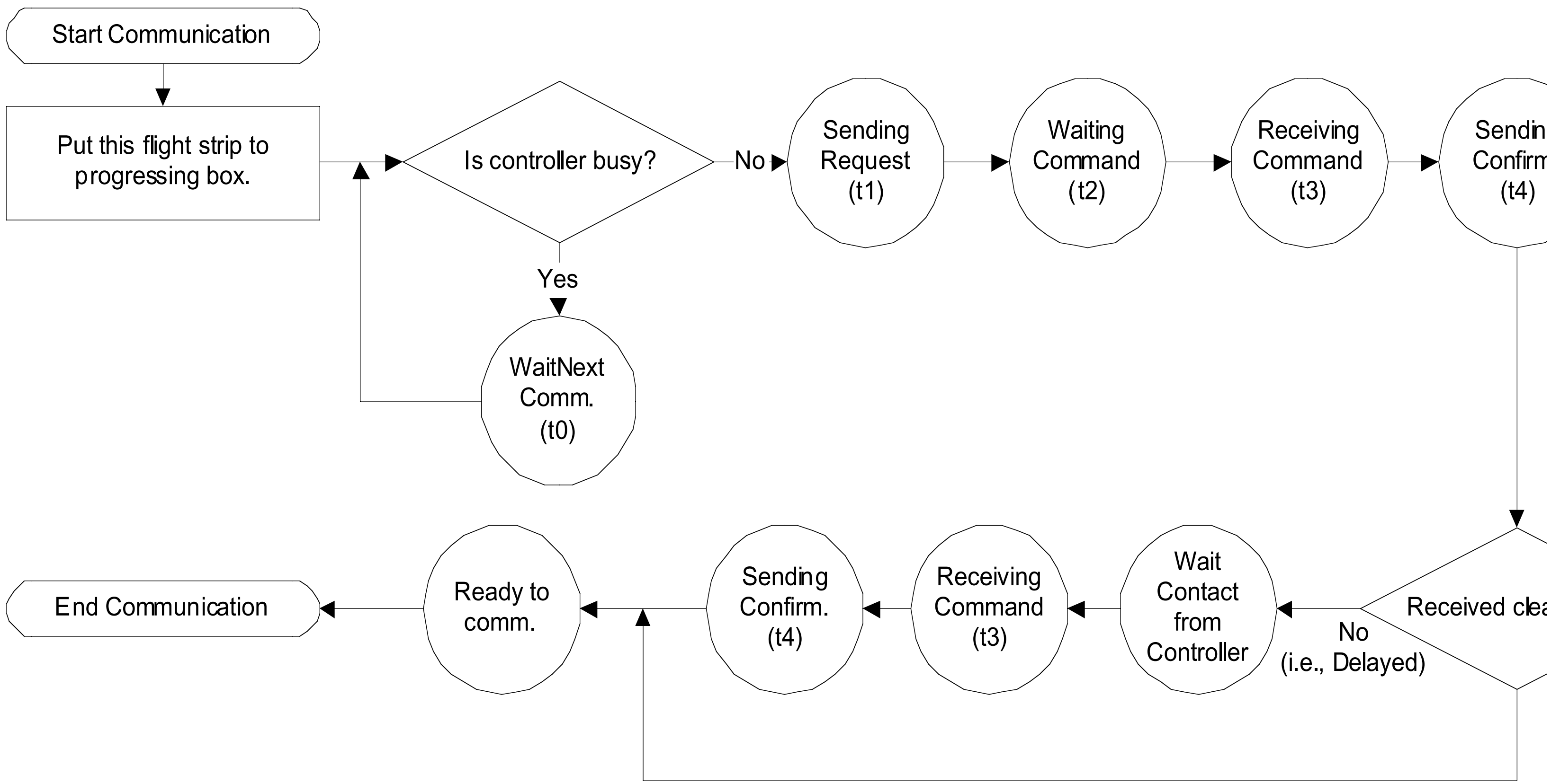
State Diagram for Arriving Aircraft Movement



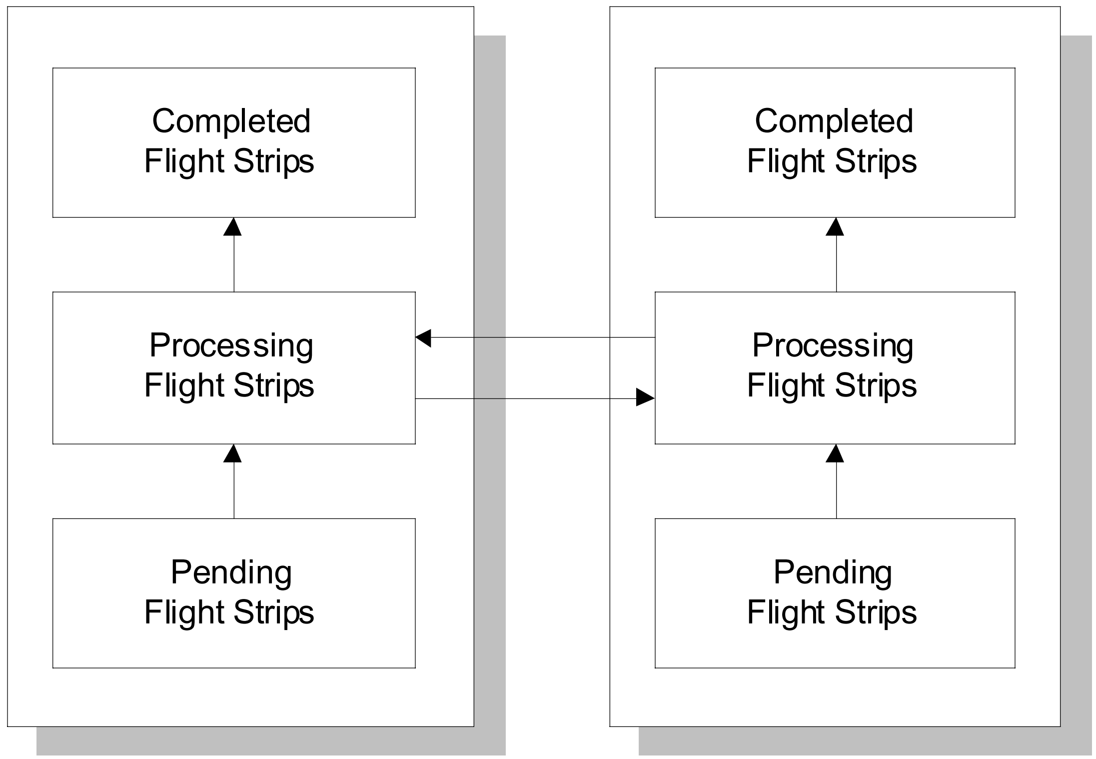
Ground Control Model Features

- 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 aircraft-following logic
- Static and dynamic route guidance for taxing
- By applying dynamic guidance logic, more realistic and efficient routing is possible.

State Diagram for Communication (Voice Channel)



State Diagram for Controller’s Flight Data Strips



Ground controller’s
flight strip organization

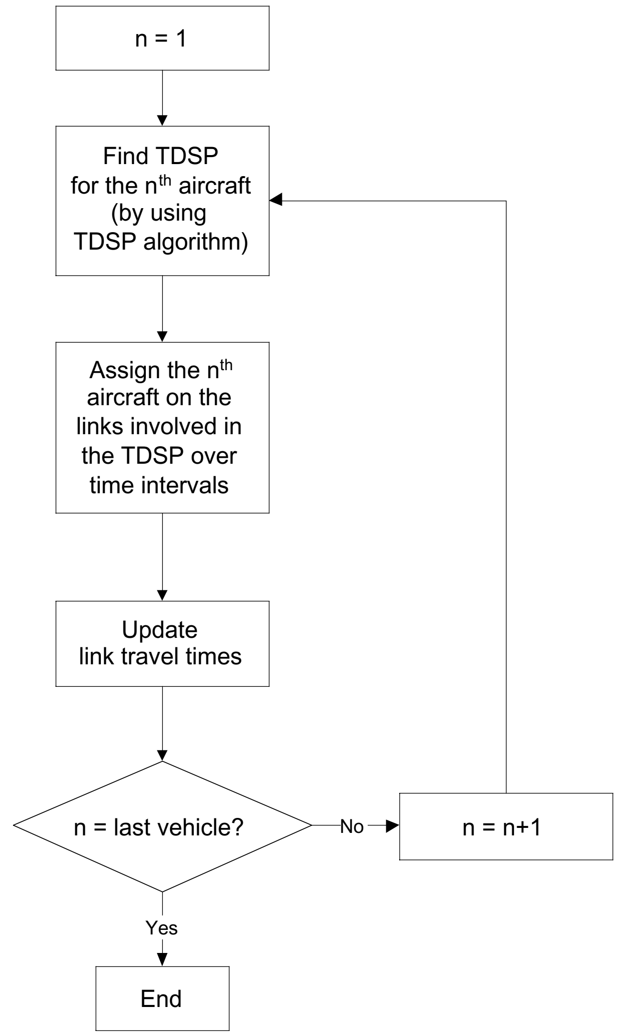
Local controller’s
flight strip organization

Algorithm: Dynamic Taxiing Route Plan

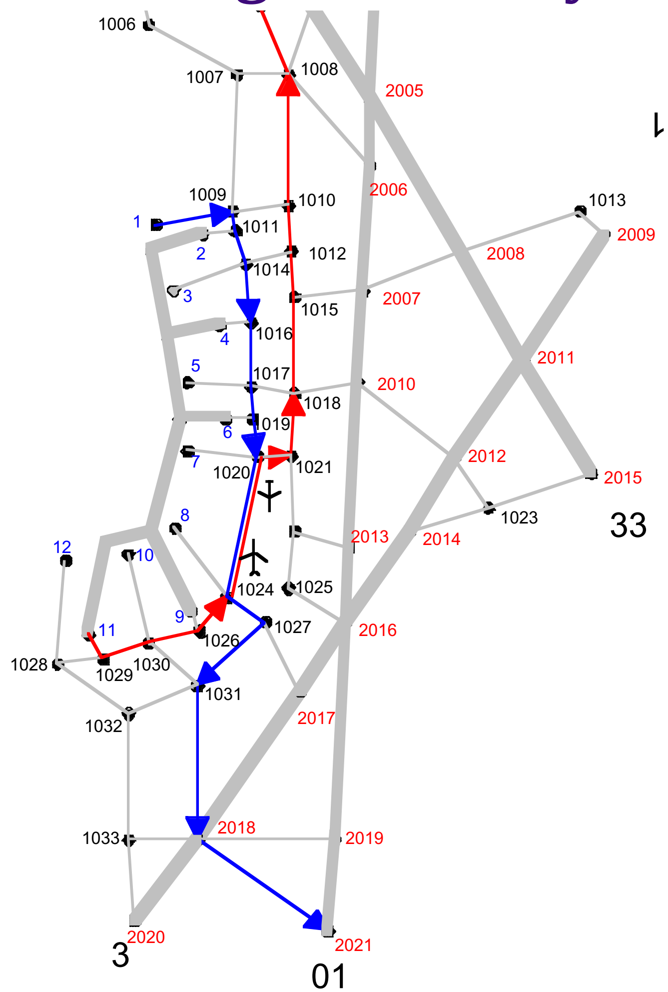
Considers time-dependent network loading

Employs an incremental time-dependent network assignment strategy

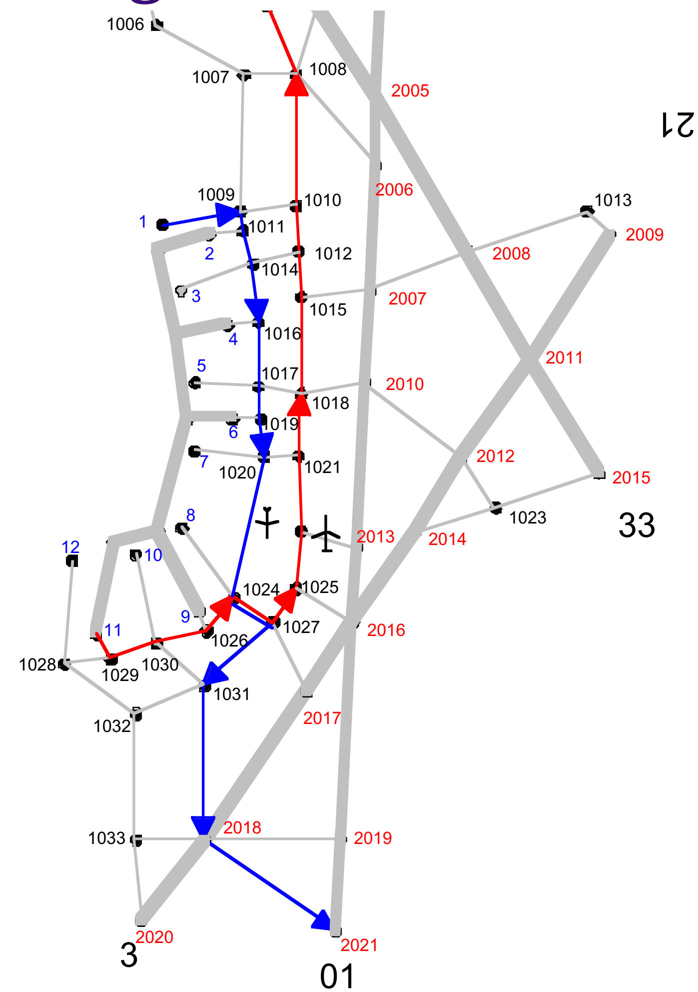
Based on time-dependent shortest path algorithm



Algorithm: Dynamic Taxiing Route Plan

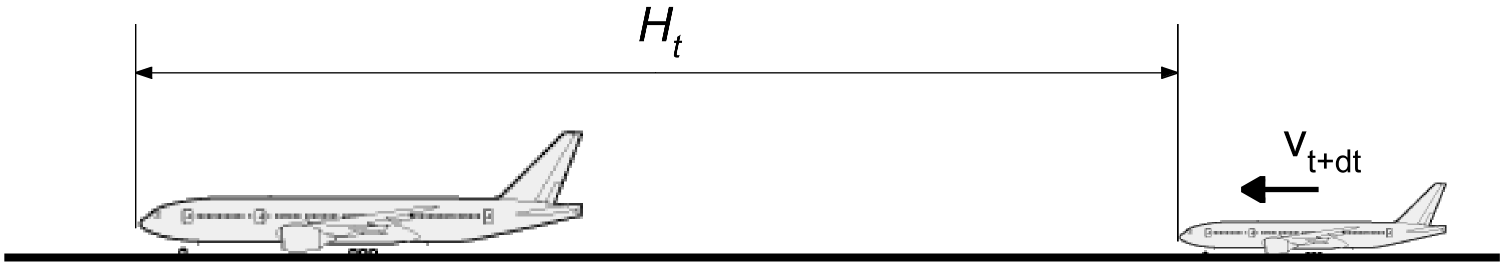


Statically assigned path



Time-dependent assigned path

Aircraft Following Model

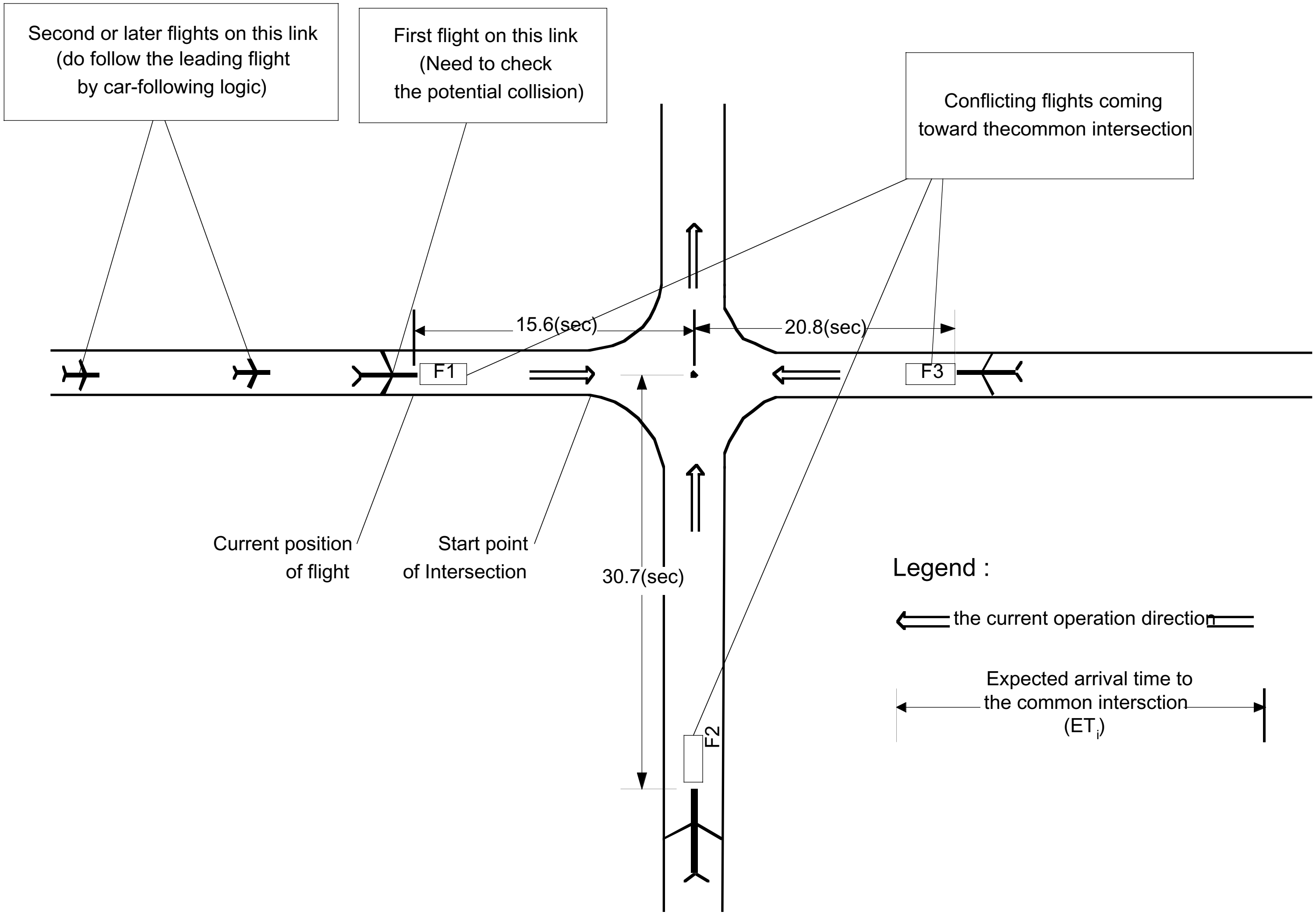


Basic equations of motion to characterize the aircraft taxiing following model

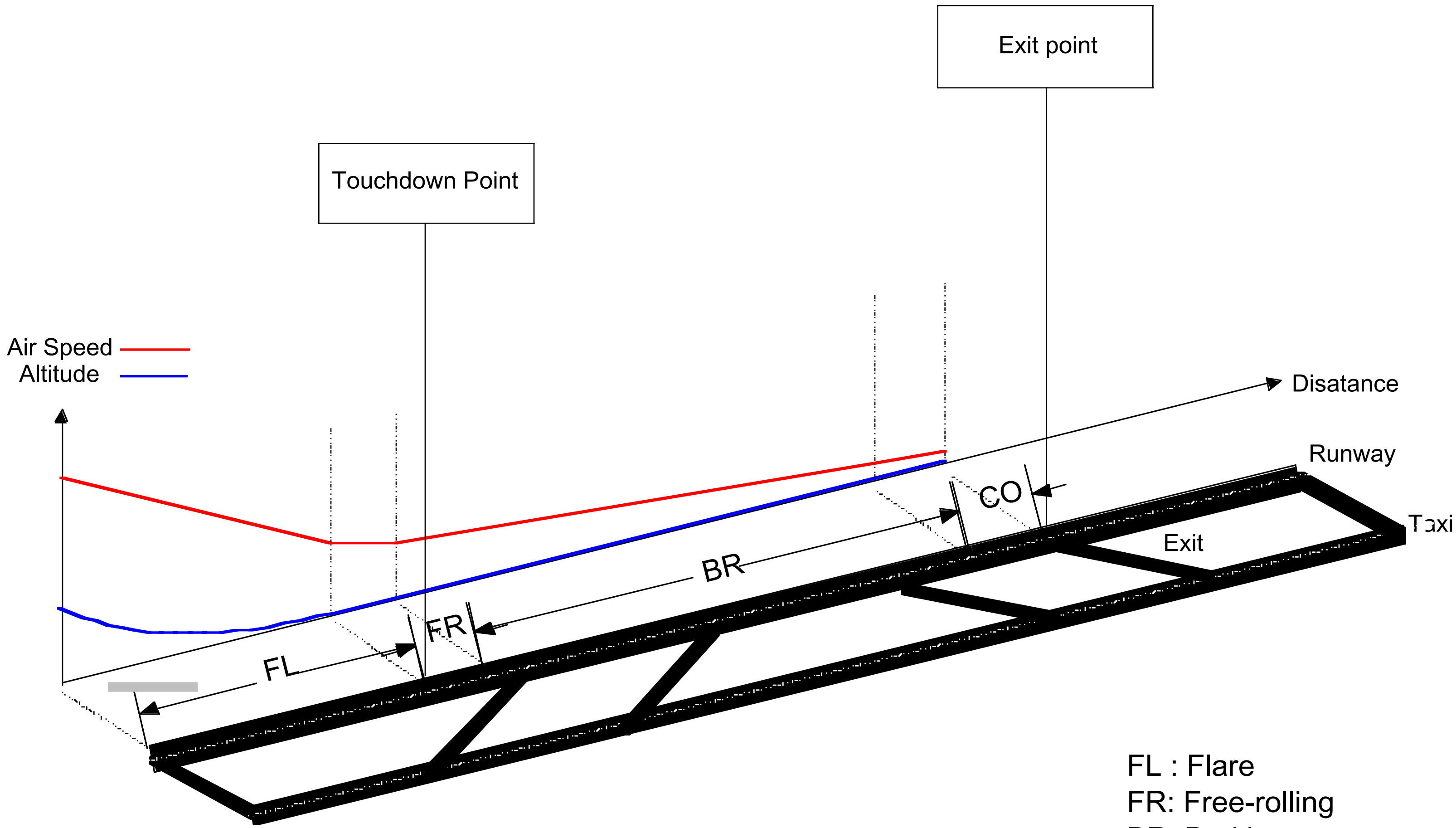
$$v^d_{t+\Delta t} = v^f (1 - \frac{H_j}{H_t})$$ Speed equation of motion

$$a^{t+\Delta t}_{n+1} = (v^d_{t+1} - v_t) / \Delta t$$ Acceleration equation of motion

Conflict Detection and Resolution Model



Four Phases of the Landing Procedure



FL : Flare
FR: Free-rolling
BR: Braking
CO: Coasting

Example of Output File (1): Log File

Second-by-second statistics can be obtained in VTASIM

Time = 320.000

DEP_1 (4.27860, 7.23847) ← Aircraft ID and Position
readyToCommunicate ← Acft. COMM State
clearToTakeOff rolling ← Acft. Permission
228.557 5.65931 2006 -> 2005 ← Acft. speed, accel. and link information
347.582 322.875 8907.85

DEP_2 (3.44770, 3.71363)
readyToCommunicate
clearToTaxi taxiingToDepQue
27.3409 0.000000 1031 -> 2018
782.058 727.237 3832.22

Example of Output File (2): Summary File

------------------------------ SUMMARY ------------------------------

Flight (Departure DEP_1, B727-100, Gate 1, Runway 36)

Enters into the simulation at : 1 sec.

Taxiing Duration : 73 - 217

Taxiing Delay : 2.22827

Nominal Takeoff Time (= NTOT) : 186

Sequenced Takeoff Time (= STOT) : 268

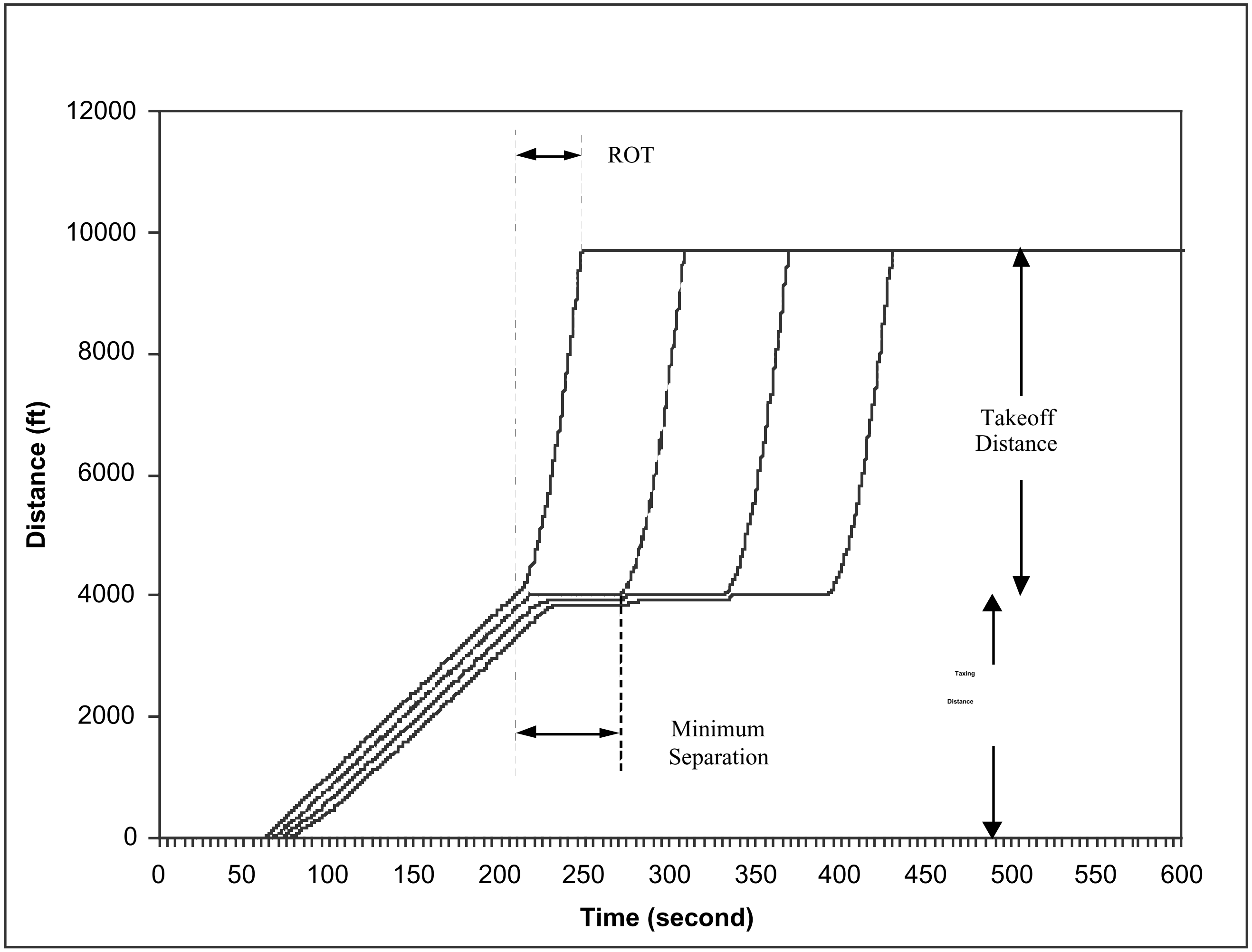
Actual Takeoff Time (= ATOT) : 289

Runway Occupancy Time (= ROT) : 289 - 328

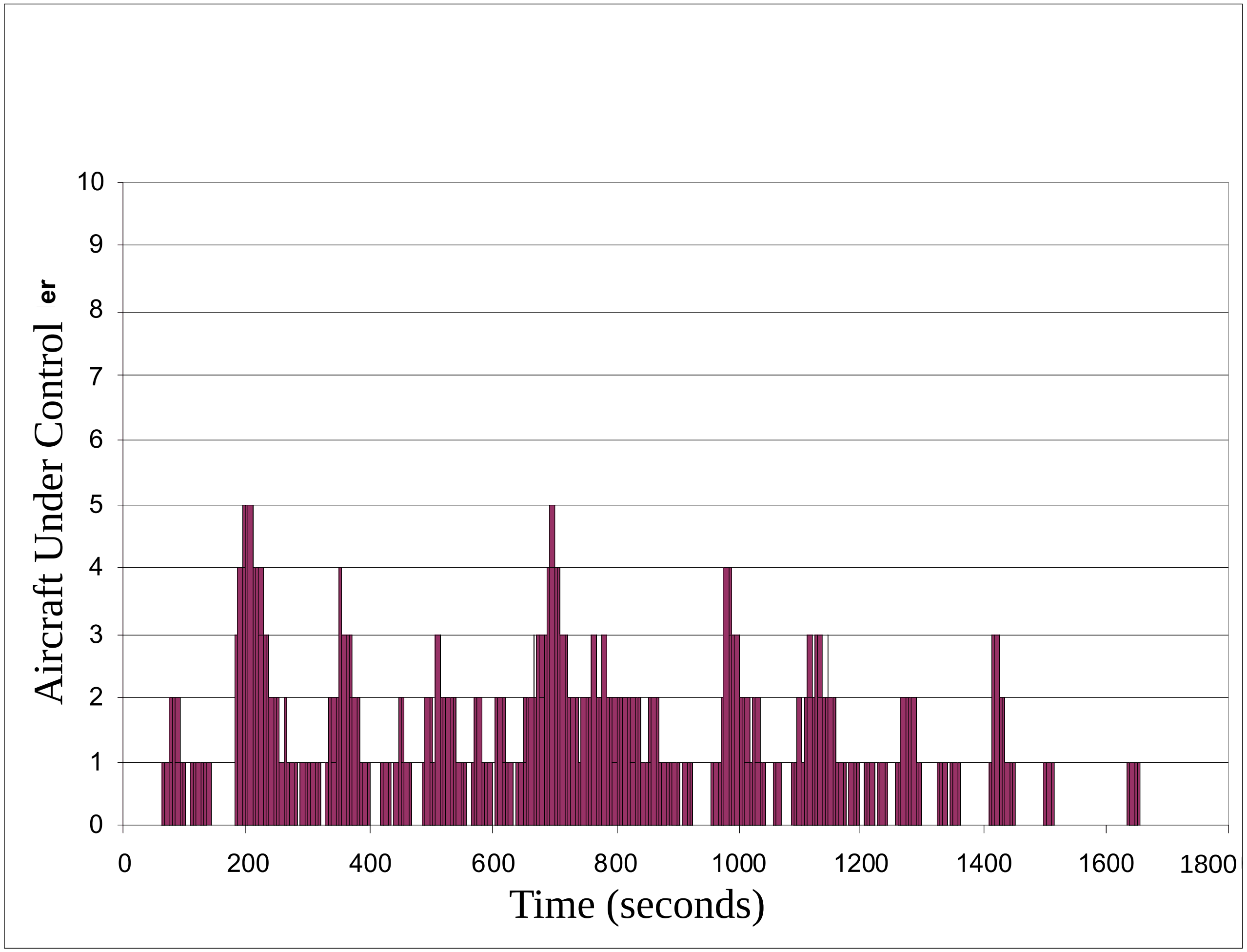
Sequenced Delay (= ATOT - STOT) : 21

Runway Delay (= ATOT - NTOT) : 103

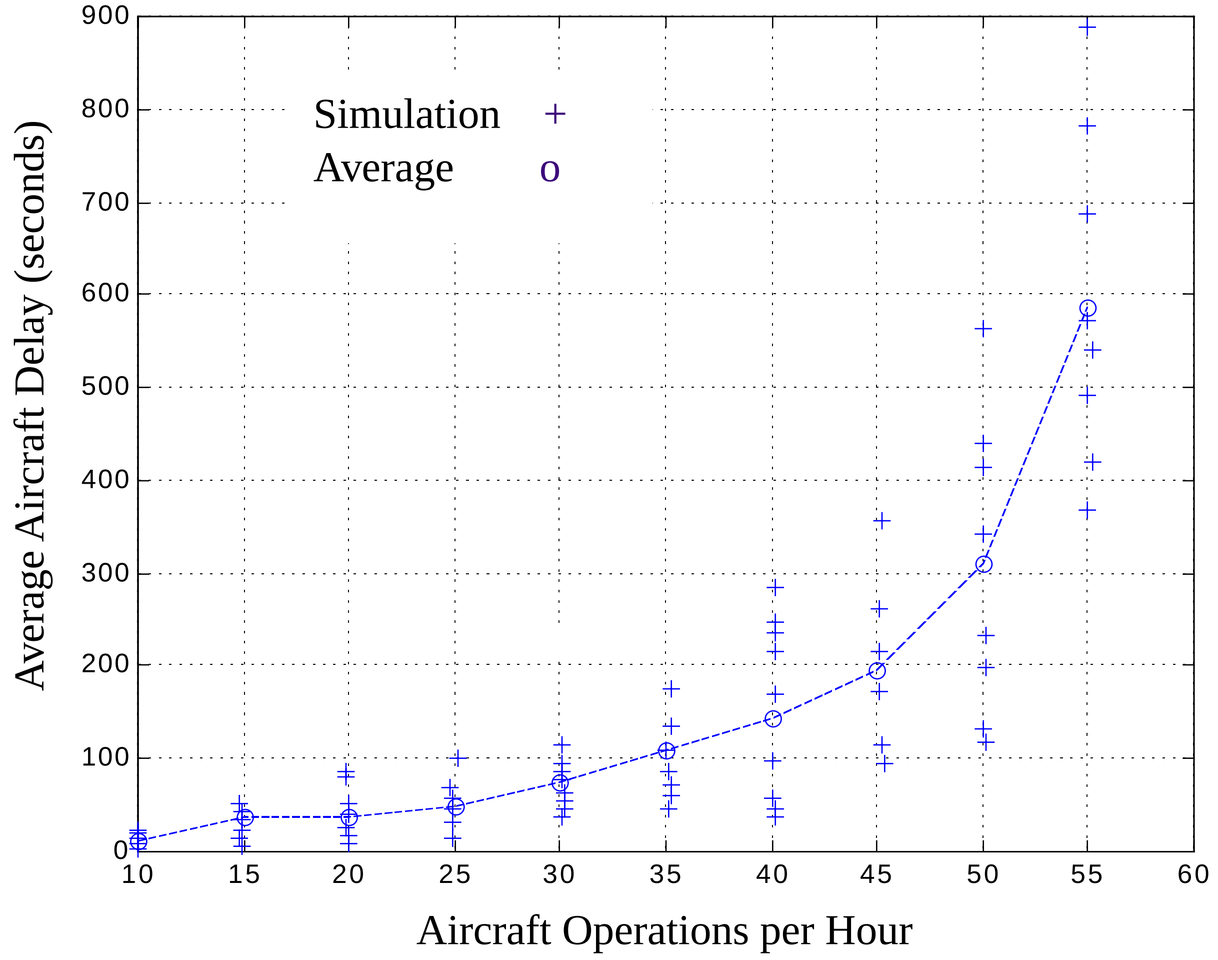
Example of Output: Departure Profiles



Local Controller "Workload" Metric

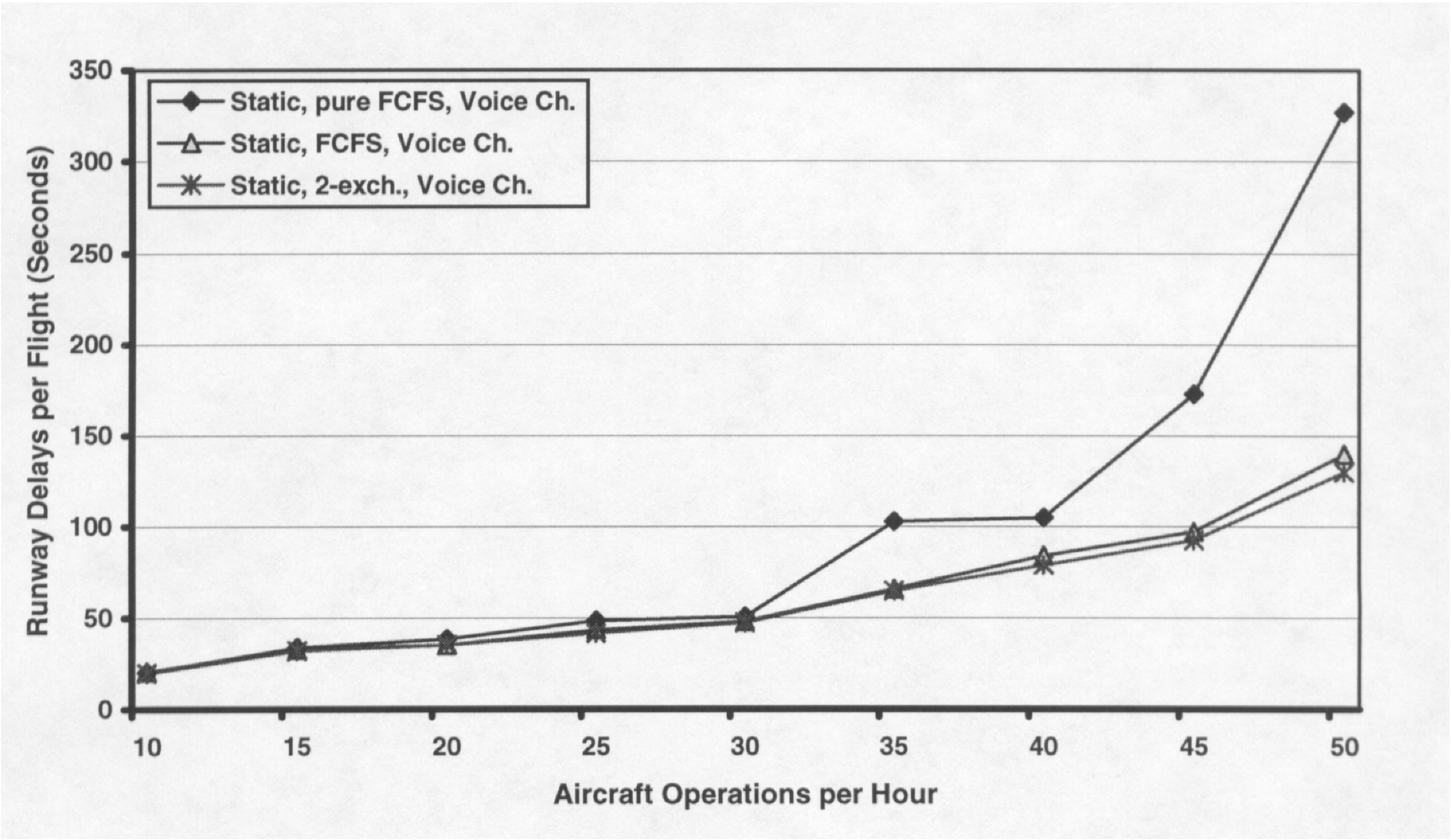


Delay Curves for Mixed Runway Operations



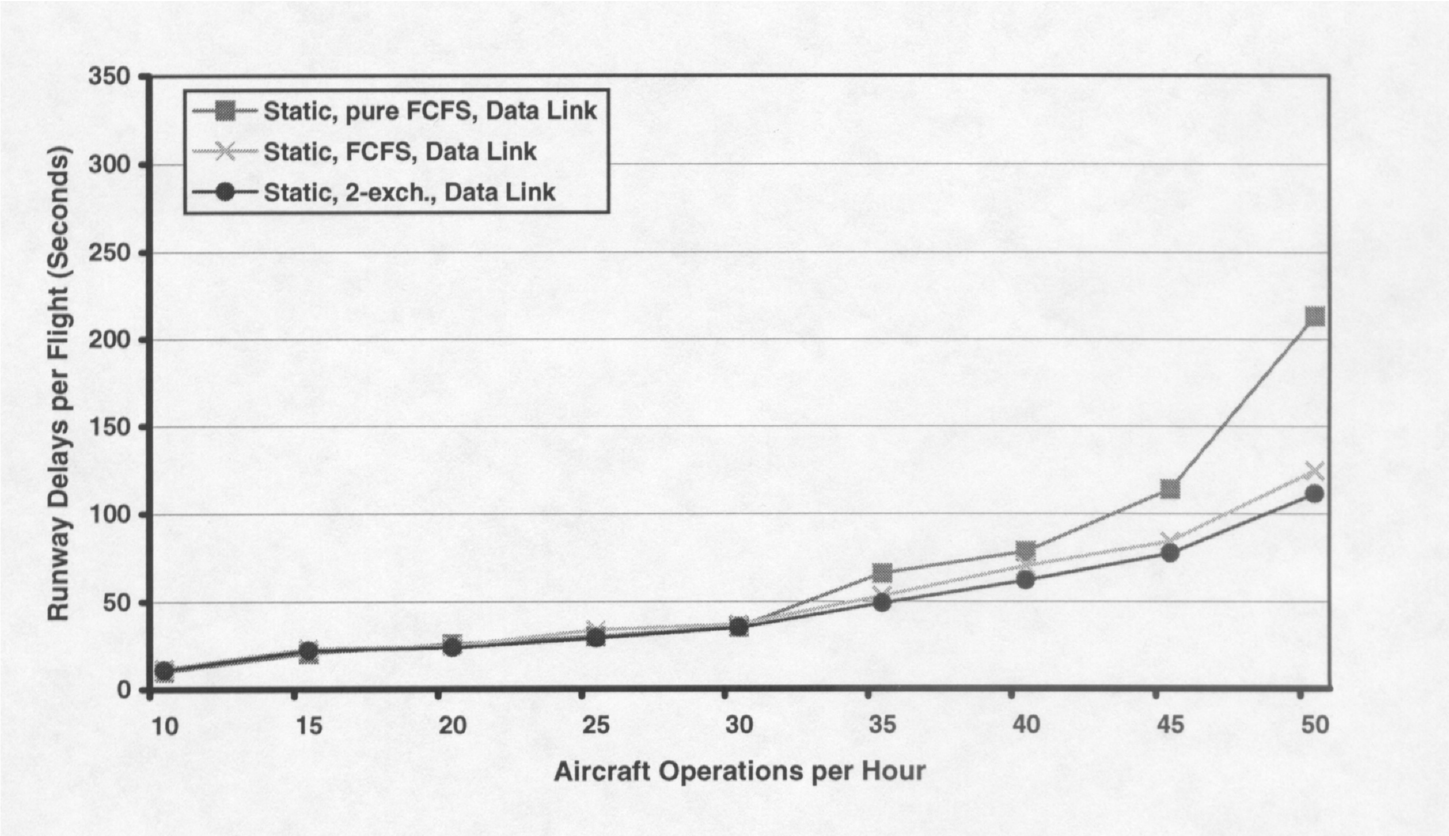
Sample Aircraft Delays Curves

Voice channel - three assignment techniques studied



Sample Delay Curves (datalink analysis)

Datalink active - three assignment techniques studied



Dynamic Construction Visualizer (DCV)

- General-purpose tool for 3D visualization of discrete-event and continuous simulation models
- Developed by **Dr. J. Martinez** and **V. Kamat** (Virginia Tech)
- Independent of simulation tools
- Processes log (trace) files to depict motion
- Uses 3D CAD models of simulation entities
- Language that merges together modeling and CAD tools to achieve dynamic visualization

The DCV Language

```
TIME 0;
CLASS Airfield Airfield.wrl;
CREATE TheAirfield Airfield;
PLACE TheAirfield AT (0,0,0);
TIME 6;
CLASS B747 B747.wrl;
CREATE NW56 B747;
PLACE NW56 ON TaxiToRunway;
```

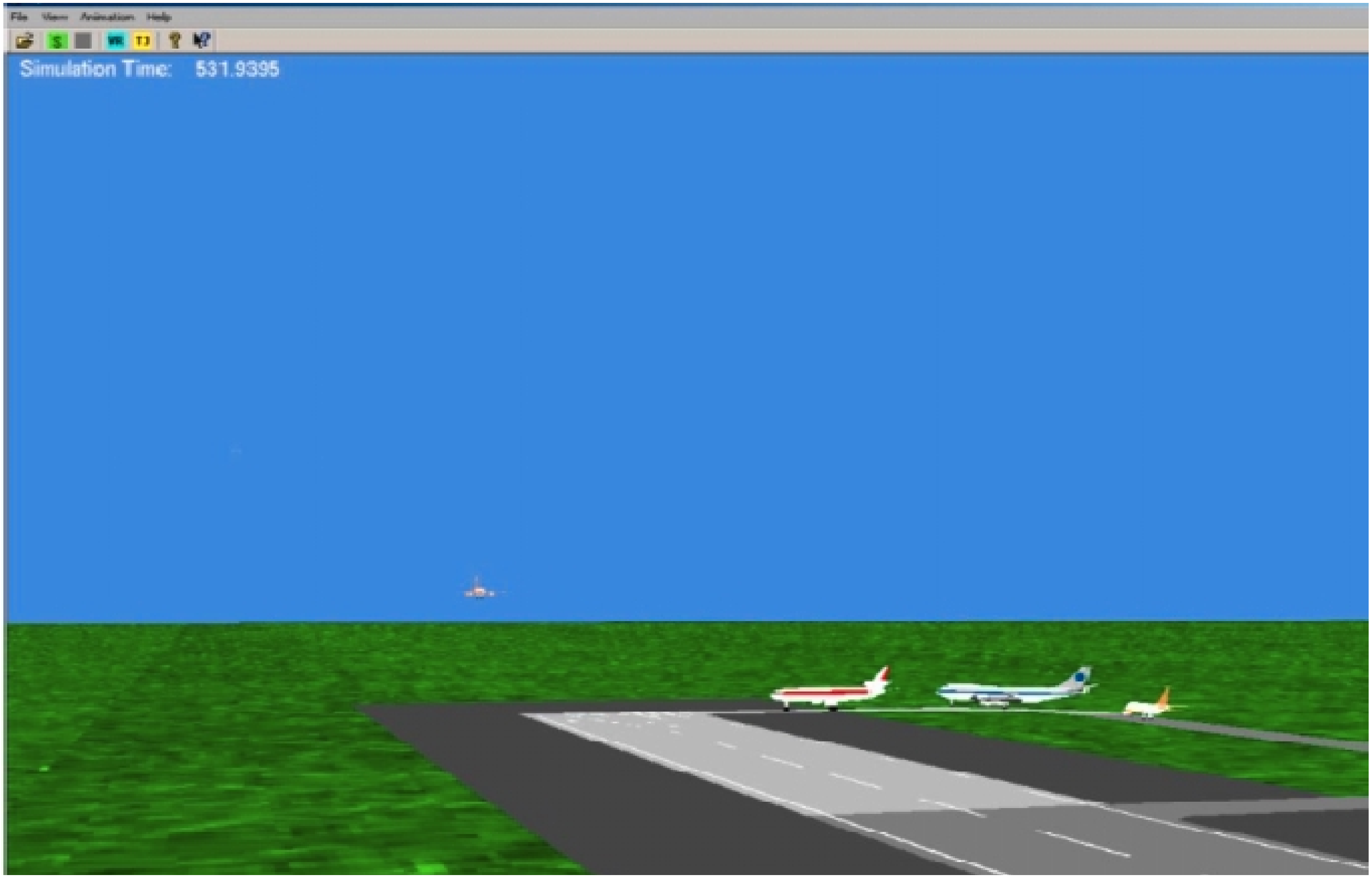
Building DCV Files

- Files for actual modeled operations can be very long
- Not meant to be typed by humans
- Meant to be generated by simulation models as they run
- Practically any simulation model can produce DCV compatible trace files
  - VTASIM
  - SIMMOD
  - TAAM
  - RAMS, etc.

Tools and Implementation

- Microsoft Windows™ (98, NT, 2000)
- Visual C++ 6.0
- SGI Computer Graphics APIs (Libraries)
  - Cosmo3D
  - OpenGL Optimizer

Sample DCV Graphic User Interface



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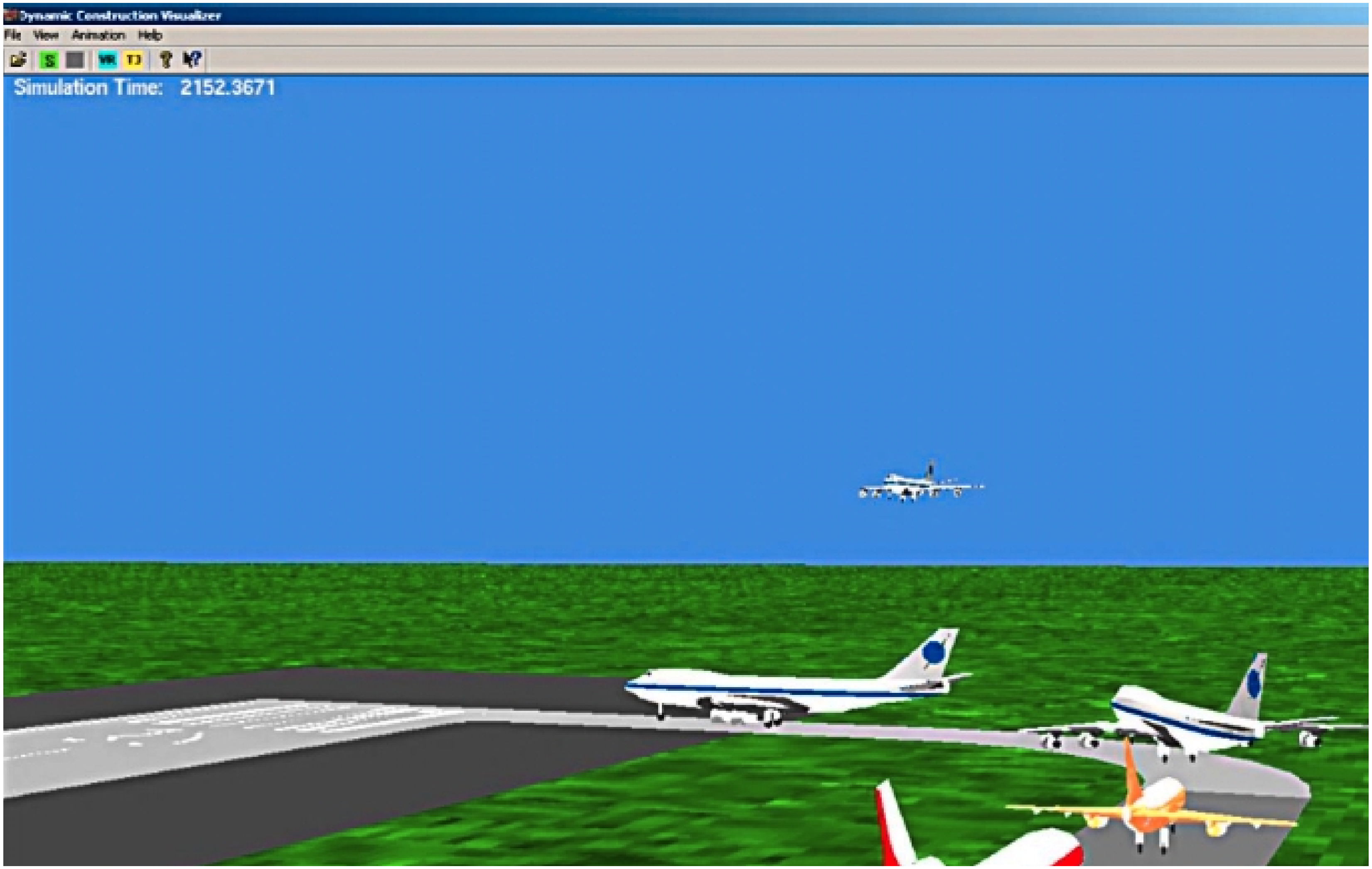

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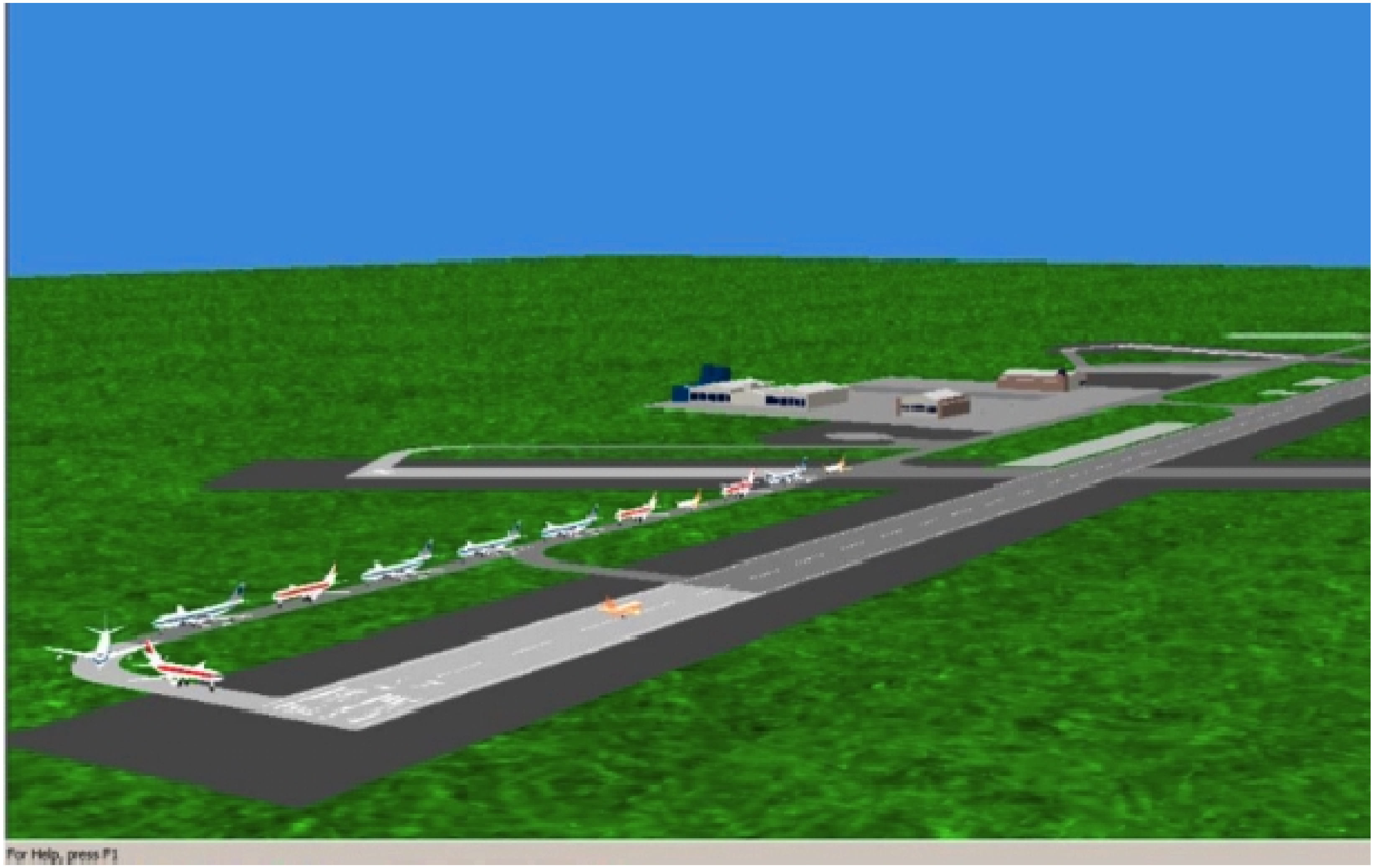

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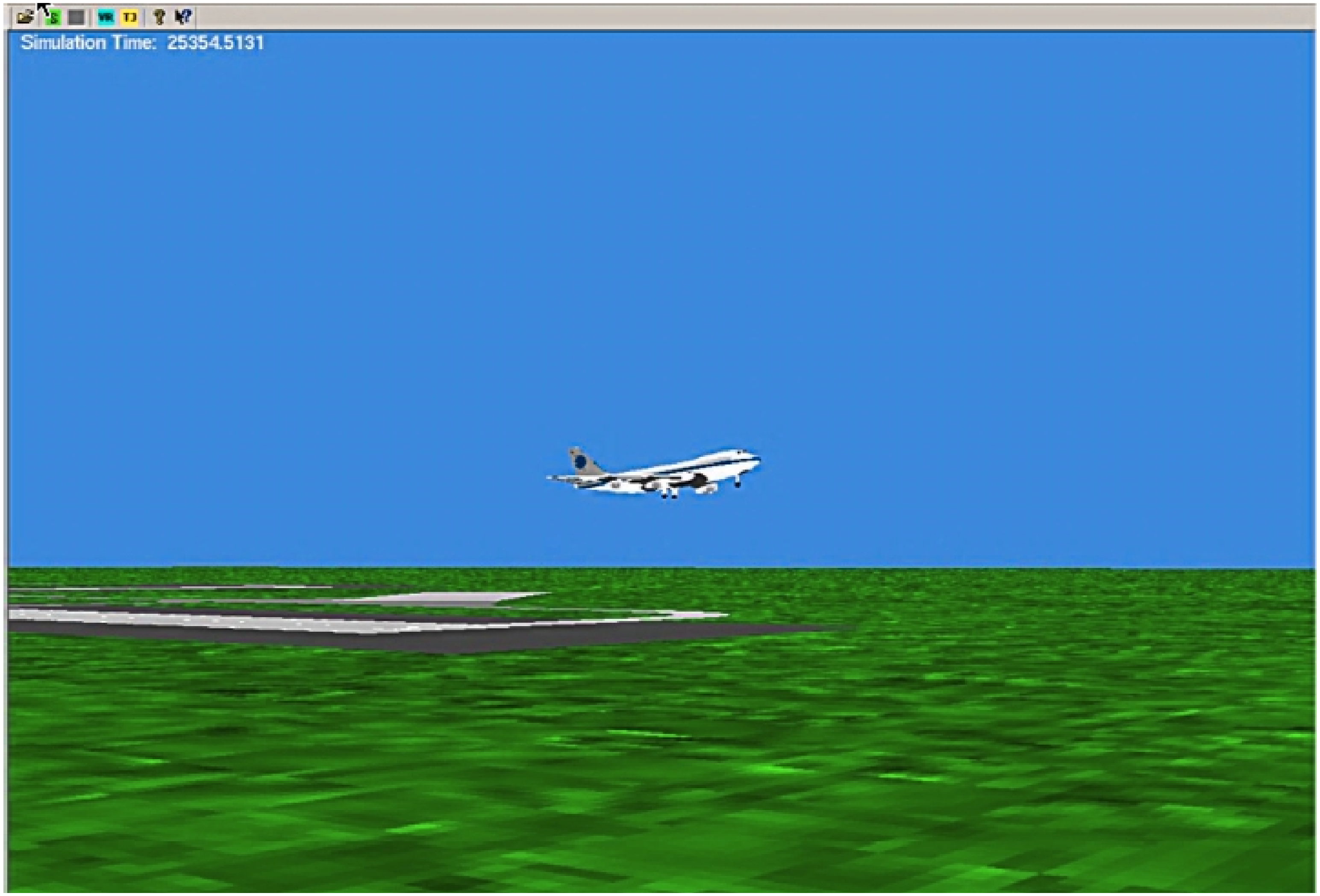

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- The support of the National Science Foundation (NSF) in the development of the Dynamic Construction Visualizer is gratefully acknowledged.

Remarks about VTASIM

- The model characterizes aircraft movement at the microscopic level
  - Provides better insight of traffic dynamics around the airport taxiway-apron network
  - Provides better interaction between aircraft operating on runway and taxiway networks
- ATC-pilot voice or datalink exchanges are modelled explicitly
- With proper adaptations and calibration VTASIM could be employed as an ATC advisory system with aircraft predictive capabilities (sequencing is explicitly modeled)

Remarks about DCV

- The model serves as a good visualization complement to any discrete-event or discrete-time simulation model
- Provides powerful visualization tool could be adapted for real-time use if desired
- Excellent 3D graphics with open standards (OPEN GL API)
  - Portable
  - Easy to use
- A good example on how small projects at NEXTOR universities provide synergy to work being sponsored by FAA and other agencies

Final Remarks

- Fast-time model requirements are changing to keep up with changes in NAS procedures and automation
- Challenging ATC-pilot modeling requirements expected of future ATM concepts
- 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 models presented is a low level effort in the development of a new generation of tools to understand a critical part of NAS.