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

- Nominal Schedule for Arrivals
- Separation Rule
- Nominal Schedule for Departures

Aircraft Sequencing Problem (ASP)

Optimal sequence and schedule

Time-dependent O-D (between gates and runways)

Network Assignment Problem (NAP)

Optimal taxiing routes for arrivals and departures

Simulation (VTASM)

Taxiing Network Configuration
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

1. On Final
2. Communication
3. Received Landing Clearance
4. Flare
5. Free Rolling
6. Braking
7. Coasting
8. Exiting R/W

- No

9. Parked (at gate)
10. Taxing
11. Received Taxiing Clearance

- No

12. Area Holding
13. Waiting in Line (Gate Arrival Queue)
14. Waiting to Taxi
15. Communication
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)

Start Communication
- Put this flight strip to progressing box.

Is controller busy?
- Yes: Wait Next Comm. (t0)
- No: Sending Request (t1) → Sending Confirm. (t4)

Sending Confirm. (t4) → Receiving Command (t3) → Wait Contact from Controller
- No (i.e., Delayed)
  - Received clear

Receiving Command (t3) → Ready to comm.

End Communication
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

\[ v_{t+\Delta t}^d = v^f \left( 1 - \frac{H_j}{H_t} \right) \]  

Speed equation of motion

\[ a_{n+1}^{t+\Delta t} = \frac{(v_{t+1}^d - v_t)}{\Delta t} \]  

Acceleration equation of motion
Conflict Detection and Resolution Model

Legend:
- **the current operation direction**
- **Expected arrival time to the common intersection (ET)**

- **F1**: First flight on this link (Need to check the potential collision)
- **F2**: Conflicting flights coming toward the common intersection
- **F3**: Second or later flights on this link (do follow the leading flight by car-following logic)

- **Current position of flight**
- **Start point of intersection**
- **Expected arrival time to the common intersection (ET)**

**Diagram Notes**:
- **15.6 (sec)**
- **20.8 (sec)**
- **30.7 (sec)**
Four Phases of the Landing Procedure

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

Touchdown Point
Exit point

Air Speed
Altitude

Distance
Runway
Exit

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)
readyToCommunicate
clearToTakeOff    rolling
228.557 5.65931 2006 -> 2005
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

Aircraft ID and Position
Acft. COMM State
Acft. Permission
Acft. speed, accel. and link information
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

![Graph showing departure profiles with labels for ROT, Minimum Separation, and Takeoff Distance.](image)

- Time (seconds) on the x-axis ranging from 0 to 600.
- Distance (ft) on the y-axis ranging from 0 to 12000.
- Key points labeled: ROT, Minimum Separation, Takeoff Distance.
Local Controller “Workload” Metric

Time (seconds)

Aircraft Under Control

0 200 400 600 800 1000 1200 1400 1600 1800

0 1 2 3 4 5 6 7 8 9 10

Utilization factor = 0.607
Delay Curves for Mixed Runway Operations

![Graph showing delay curves for mixed runway operations. The x-axis represents aircraft operations per hour, and the y-axis represents average aircraft delay (seconds). The graph includes data points for simulation and average delay, with error bars indicating variability.](image-url)
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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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.