Runway Occupancy Time Estimation and SIMMOD

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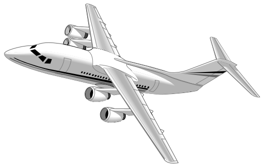
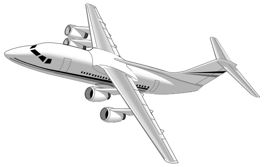


Outline of this Presentation

- Review of past Runway Occupancy Time (ROT) research
  - Modeling approaches
  - Airport data collection
  - Flight simulation work
- Past ROT SIMMOD modeling activities at VPI
  - SIMMOD ROT pre-processor module development
  - SIMMOD engine runway module development
- Future steps

Definitions of ROT



- Landing ROT

  - Time spent on a runway from threshold crossing point until aircraft clears imaginary plane of the runway

  - NOTE: Our definition of ROT includes the turnoff time

- Departure ROT

  - Time spent on a runway from the clearance of imaginary runway plane until threshold crossing point (opposite end of the runway)

  -

Importance of Runway Occupancy Time

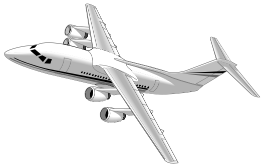
- Interarrival separation criteria dominates arrival service times (tendency to neglect ROT)
  - Some runways exhibit quite large variations in ROT
  - Large σ ROT (in seconds) is undesirable
- In mixed runway operations ROT matters as it affects the time to release departures (short ROT values are desirable)
- For VMC operations at large airports (say Atlanta) inter-arrival seperations and ROT values are not very far (some go-arounds are possible in a day)

Typical ROT Values vs. Runway Exit Types

Scenario Number	Scenario	Runway Exits Description Exit Location (m.) Exit Type						Weighted Average ROT (s.)
		Exit # 1	Exit # 2	Exit # 3	Exit # 4	Exit # 5	Exit # 6	
1	Baseline	390 90 deg.	1154 90 deg.	1614 90deg.	2159 90 deg.	2713 90 deg.	3042 90 deg.	54.50
2	Wide Throat	390 90 deg.	950 WT	1225 WT	1425 WT	1900 WT	3042 90 deg.	51.20
3	30 Degree Standard FAA	390 30 deg.	950 30 deg.	1200 30 deg.	1400 30 deg.	1925 30 deg.	3042 90 deg.	44.63
4	30 Degree FAA Modified Exit[a]	390 90 deg.	900 30 deg. modified	1150 30 deg. modified	1350 30 deg. modified	1875 30 deg. modified	3042 90 deg.	43.00
5	REDIM 3030[b]	390 90 deg.	875 RE 3020	1125 RE 3020	1325 RE 3020	1825 RE 3020	3042 90 deg.	40.80
6	REDIM 3530[c]	390 30 deg.	825 RE 3520	1050 RE 3520	1250 RE 3520	1650 RE 3520	3024 90 deg.	36.80

a.The FAA modified 30 degree, acute angle geometry includes a 457 m. (1400 ft.) transition spiral.
b.The designation RE 3030 implies a high-speed exit designed for 30 m/s entry speed and a 30 degree exit angle.
c.The designation RE 3530 implies a high-speed exit designed for 35 m/s entry speed and a 30 degree exit angle.

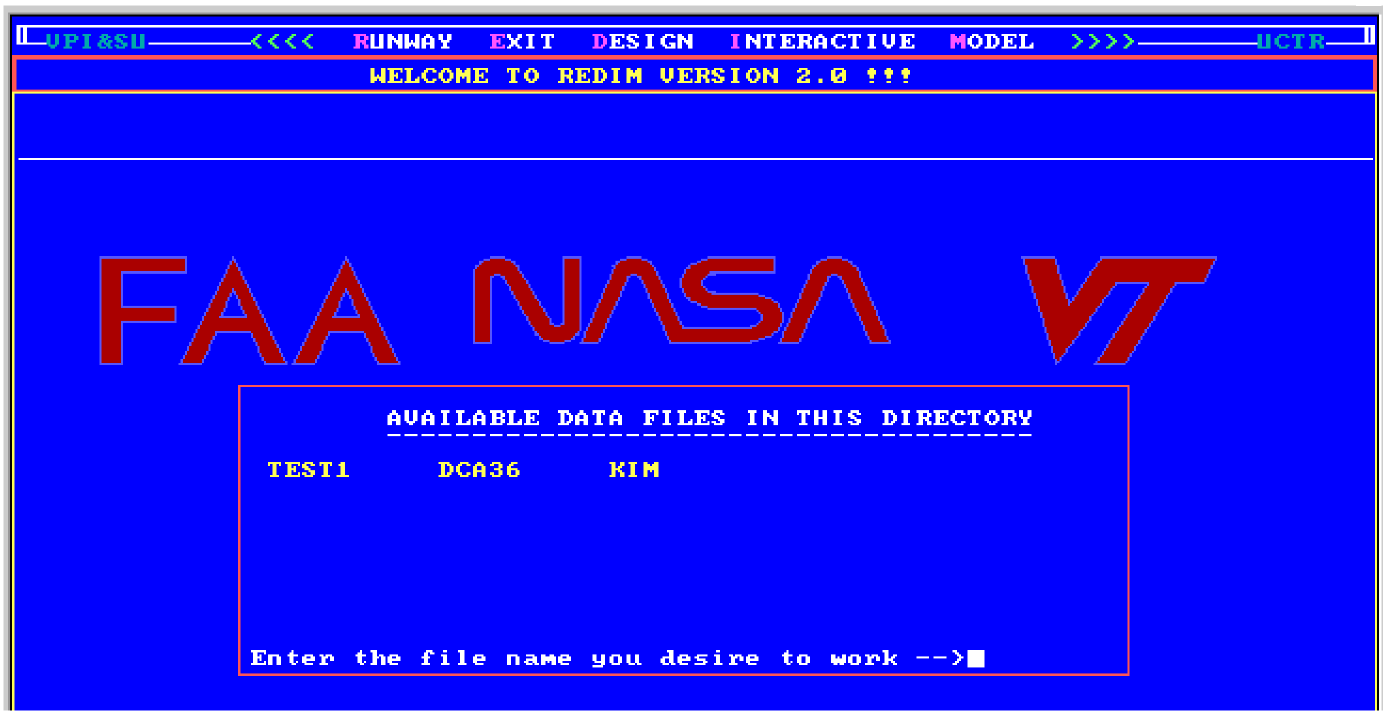
Previous Research in ROT at VPI



- Development of the Runway Exit Design Interactive Model (REDIM) - 1990-1993
  - Report site: http://www.ce.vt.edu/faa/redim.html
- Calibration of REDIM with field observations - 1993-1994
- Investigation of high-speed runway exits using an FAA Boeing 727 aircraft simulator (6-DOF simulator) - 1995
  - Report site: http://www.ce.vt.edu/faa/fltsim.html
- Implementation of SIMMOD engine changes (at VPI) using UNIX MOTIF GUI standards - 1996
  - Report site: http://www.ce.vt.edu/faa/simmod.html

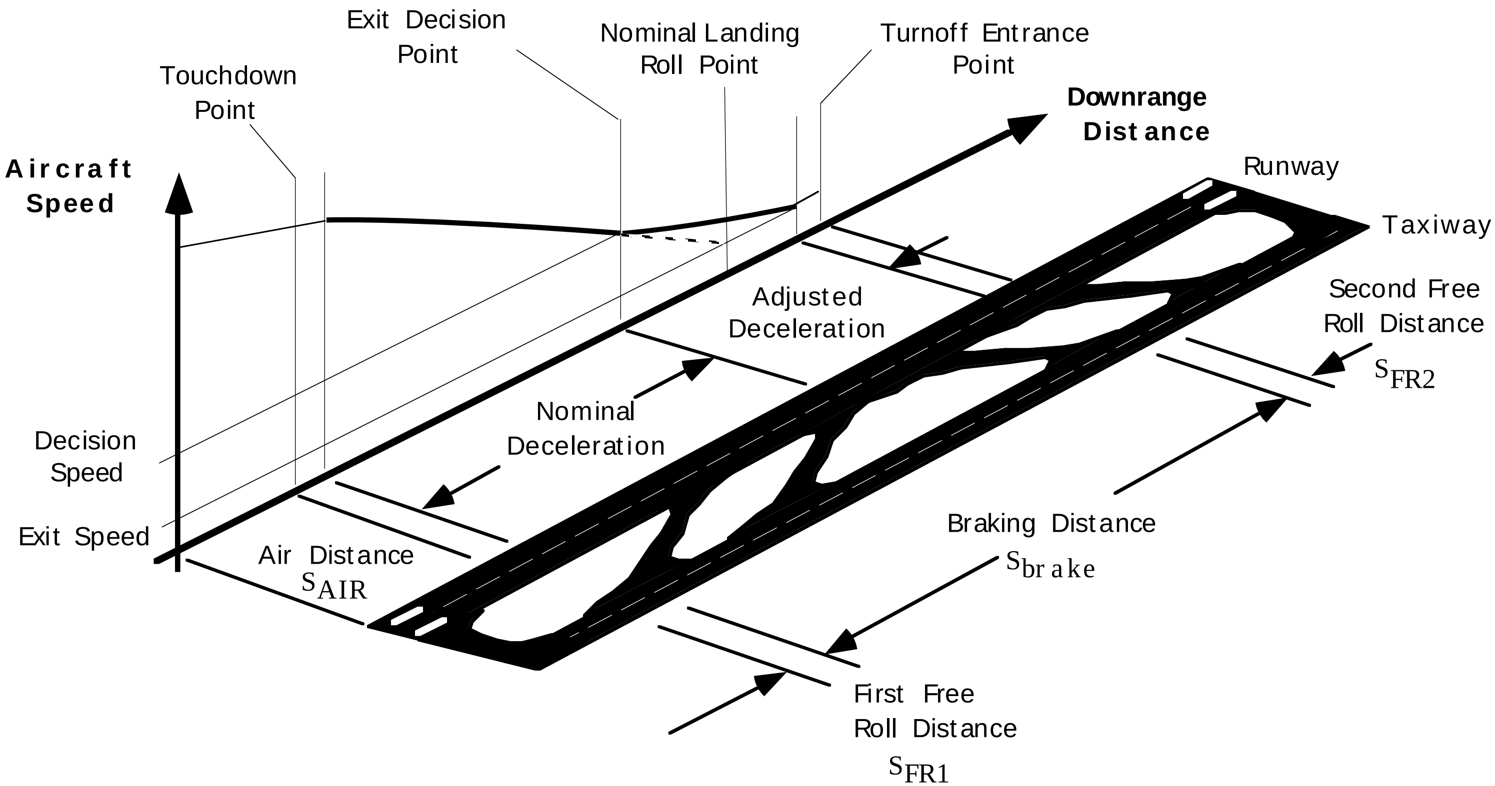
REDIM Model

- Provides an estimation of ROT values for a single runway and a user-defined aircraft mix (FAA/NASA sponsors)
- Provides guidance on optimal runway exit locations

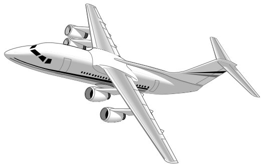


Aircraft Landing Roll Analysis

- Characterization of aircraft landing roll profiles



Aircraft Mix Selection Menu



VPI&SU ———— <<<< RUNWAY EXIT DESIGN INTERACTIVE MODEL >>>> ———— UCTR

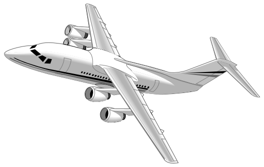
INPUT the percentages of aircraft: Press <Tab> key after editing.

Peak Period Operation Mix

TERPS-A		TERPS-B		TERPS-C		TERPS-D		TERPS-E	
BE-F33A	:10	BE-58	:0	Avro_RJ85	:0	A330-300	:0	F-4	:0
CE-172	:0	BE-300	:0.7	A300-600	:0	A340-200	:0		
CE-182	:0	BE-400	:0.4	A310-300	:2.6	B-747-200B	:0		
CE-208	:0	CE-402	:0.7	A320-200	:0.7	B-747-400	:0		
CE-210P	:0	CE-421	:0	B717-200	:0	B767-300	:0		
PA-28-161	:0	CE-550	:0.4	B727-200	:0	B777-200	:0		
PA-28-236	:0	CE-650	:0	B737-200	:28.4	C-5A	:0		
PA-32-301	:0	CRJ-200	:0	B737-300	:0	DC-8-73	:0		
PA-38-112	:0.4	DA-200	:0	B737-800	:4	DC-10-30	:0		
PA-46-310P	:0	DHC-7	:0.7	B757-200	:9.5	MD-11	:0		
		DHC-8	:0	Bae-146-20	:0	L1011-500	:0		
		Do-328	:0	CL-601-3A	:20.3				
		Do-728	:0.4	DC-9-32	:0				
		EMB-120	:0	Fokker-100	:12.2				
		EMB145	:1.9	Gulfstream	:0				
		Lear-31	:0	IAI-1124	:0.4				
		PA42-1000	:1	Lear55	:0				
		Saab-340	:2.6	MD-83	:0				
		SA227	:0	MD-87	:0				
		Shorts-330	:0.4						

NO. of Aircraft = 20
TOTAL Percentage = 97.7

Typical REDIM Results



- Sample ROT table for various aircraft

VPI&SU <<<< RUNWAY EXIT DESIGN INTERACTIVE MODEL >>>> UCTI

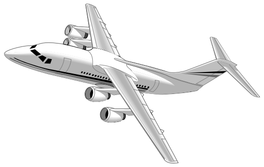
Edit Analysis Output Print Newfile Quit

ROT/ASSIGNMENT TABLE
(This is for Evaluating an Existing Runway)

Exit #	1	2	3	4	5	6
Location (m)	600.0	940.0	1008.0	1368.0	1507.0	2078.0
Open/Close	Close	Open	Open	Open	Open	Open
Exit Type	U-Def	90-Deg	U-Def	U-Def	U-Def	90-Deg
B737-800						
DRY (4.1%) ROT				47.78 96.0%	51.15 4.0%	
WET (0.0%) ROT				47.99 62.0%	51.92 35.0%	67.93 3.0%
B757-200						
DRY (9.7%) ROT				48.23 100.0%		
WET (0.0%) ROT				48.31 86.0%	52.02 14.0%	
CL-601-3A						
DRY (20.8%) ROT		36.42 100.0%				
WET (0.0%) ROT		36.92 85.0%	36.22 15.0%			

ROT - Runway Occupancy Time in Secs   Weighted Average ROT = 45.72

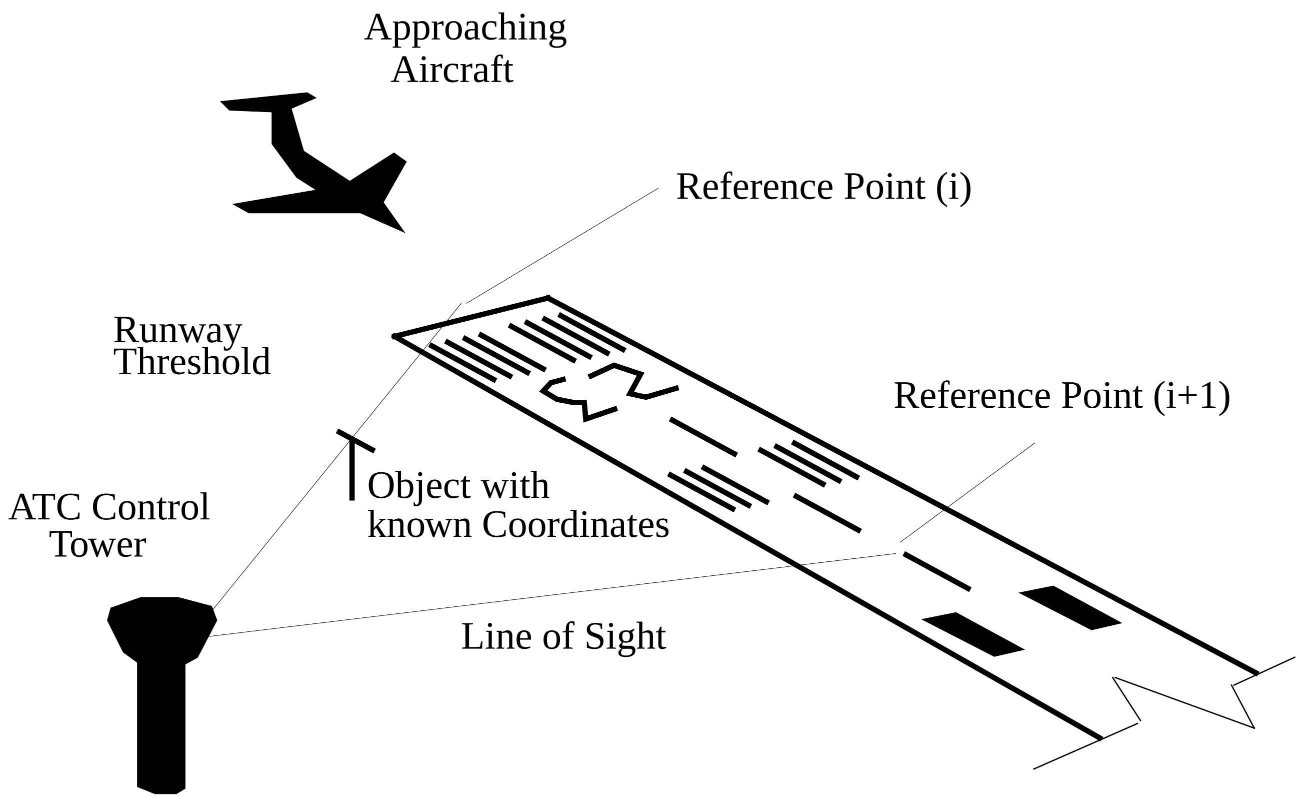
ROT Airfield Calibration Study



- Collected data at five airports in the U.S. East Coast
  - RDU, DCA, IAD, CLT and ATL
  - 2,400 landings under dry and wet pavement conditions
  - Use of video equipment to study aircraft time-space motion
- Developed a simplified ROT runway model (that can be programmed in a spreadsheet or numerical package see page 18 of this presentation)
- Incorporated heuristic rules into REDIM

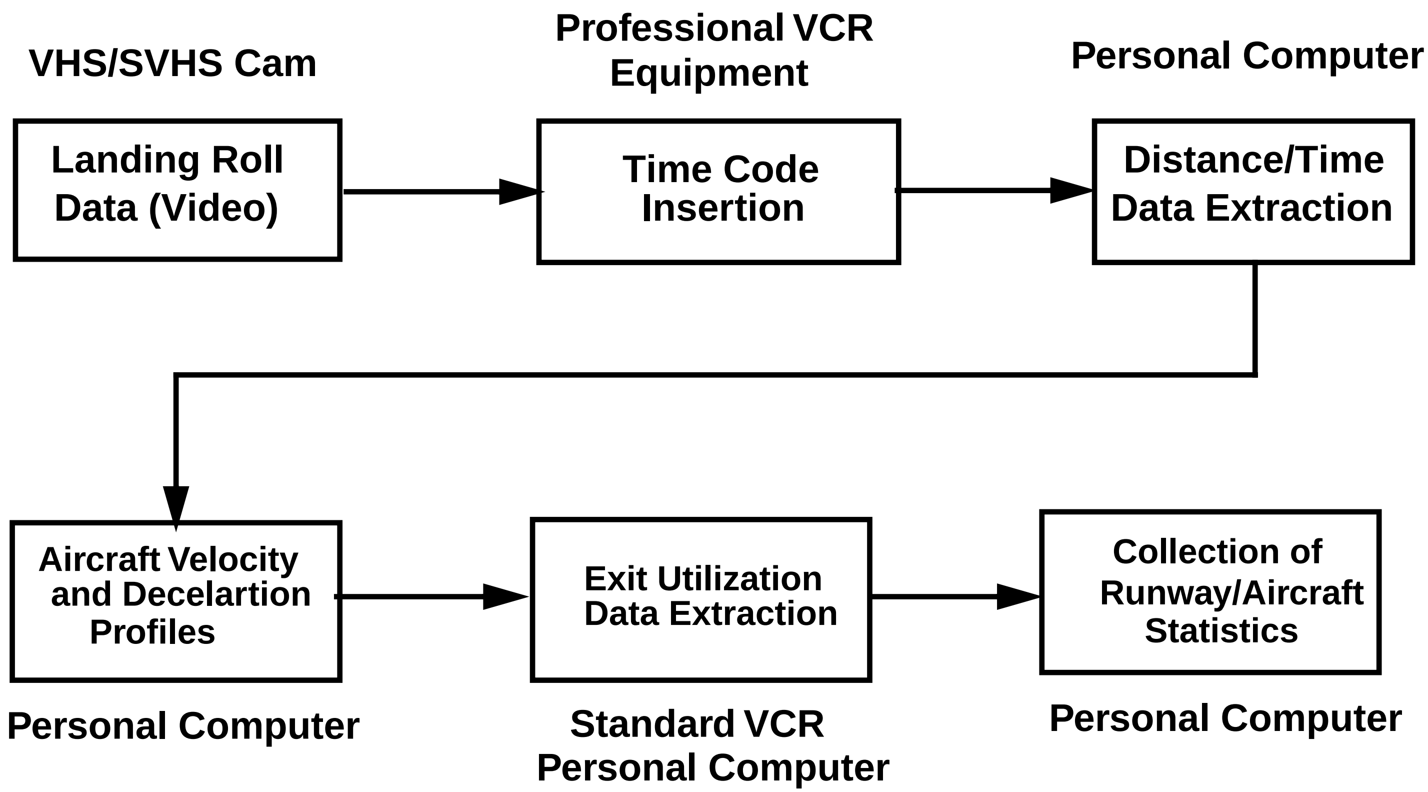
Data Collection Method

Use of video cameras located at the ATC control tower to assess ROT with precision



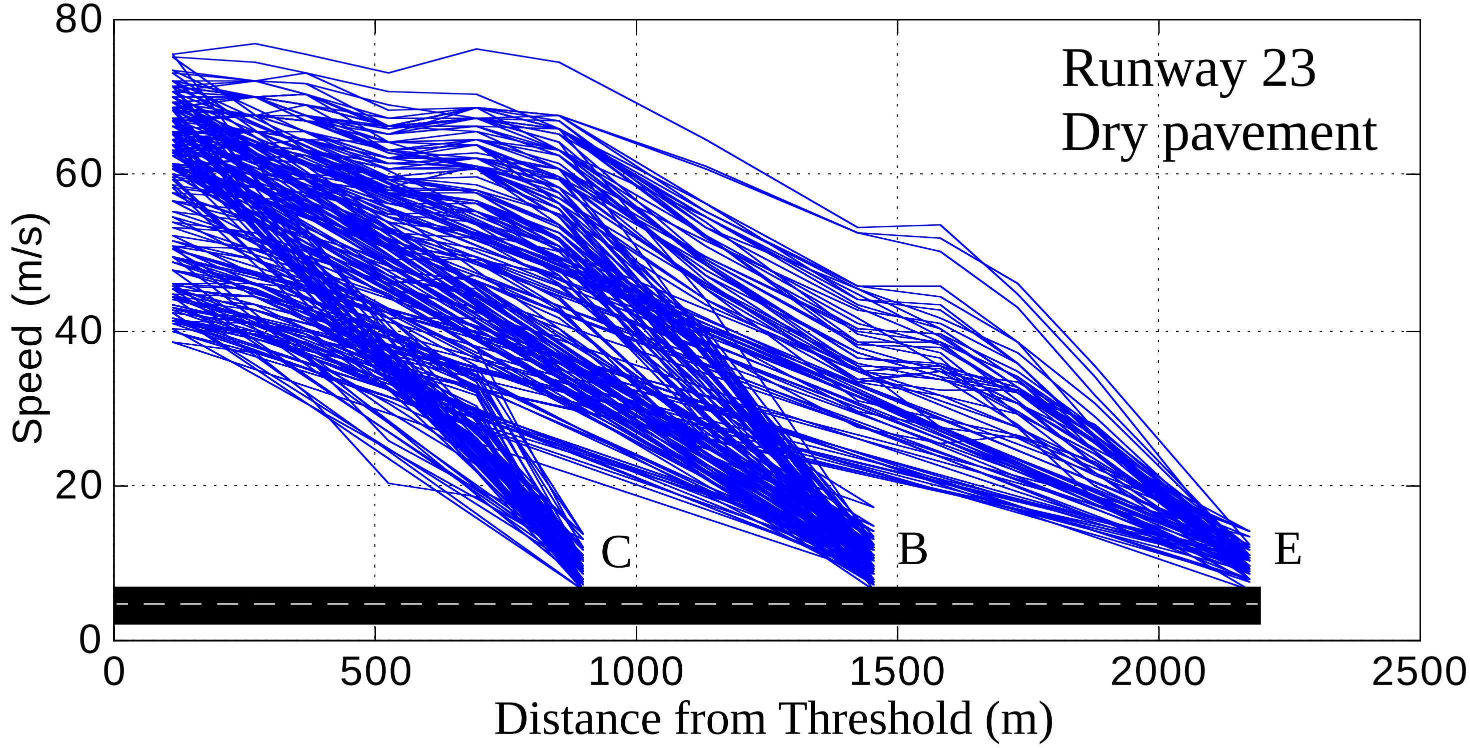
Data Analysis Techniques

Use of computers and video editing hardware to extract ROT

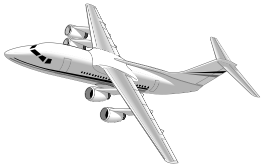


Sample Runway Velocity Profiles

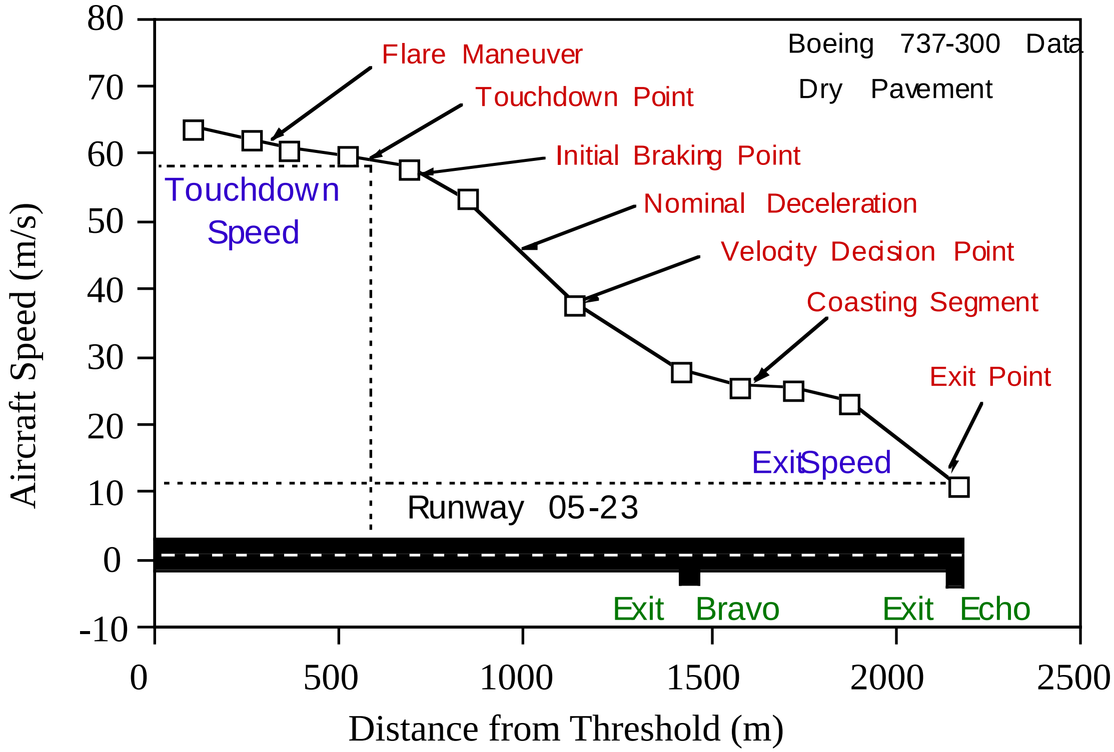
- Aircraft display large differences in landing roll behavior at real airports (shown data for CLT)



Aircraft Velocity Profile Phases



- A sample distance-velocity profile showing all aircraft landing phases modeled



Statistical Analysis

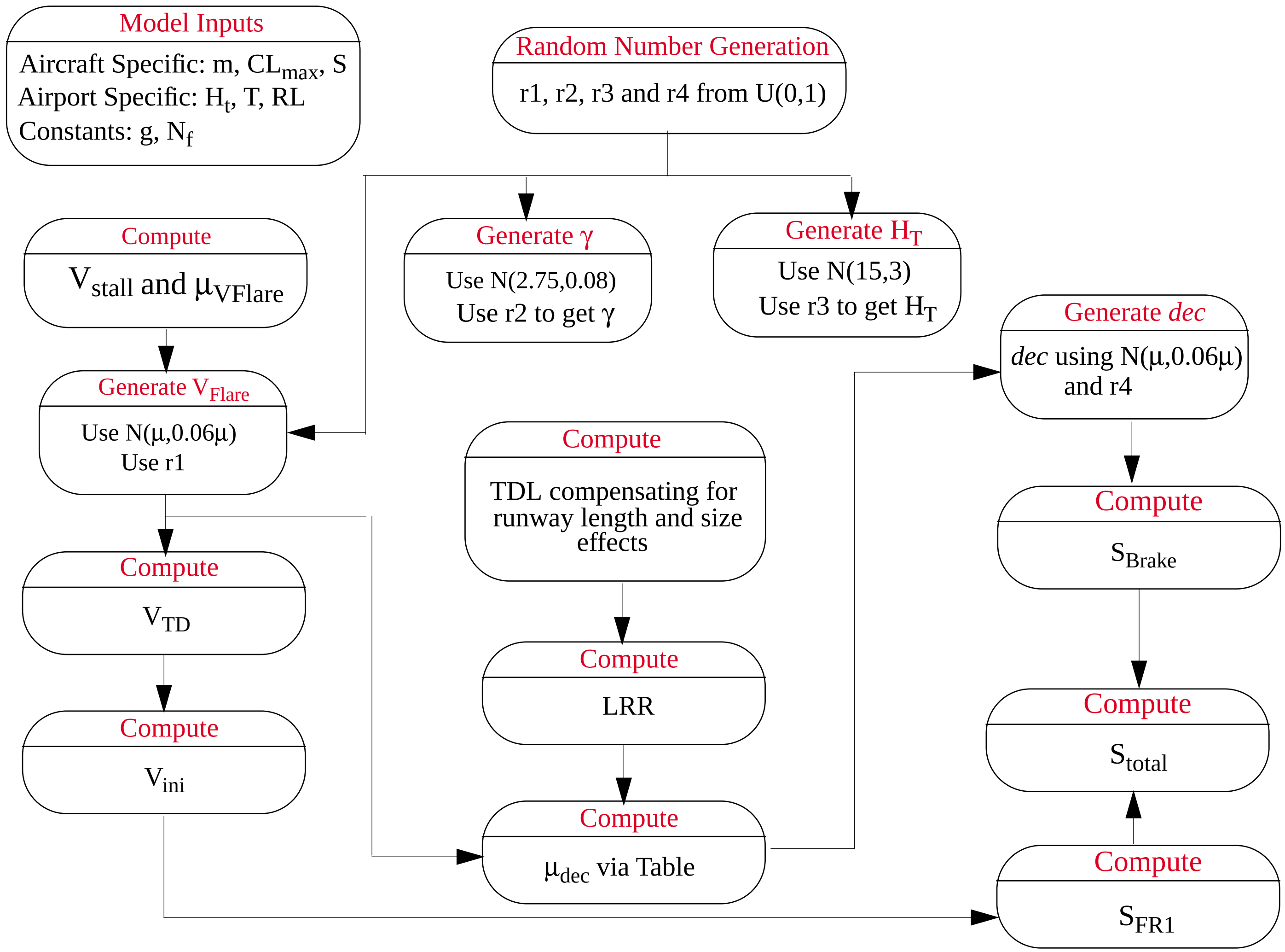
- Parameter statistical correlation (2-way ANOVA)

Variable	Factor	F-statistics	F-criteria[a]	p-value	Conclusion[b]
Flare Speed (m/s)	A/C Type	5.44	2.37	0.0003	H_1
	Airport	8.59	3.00	0.0002	H_1
	Interaction	2.00	1.94	0.0461	Marginal
T. D. Location (m)	A/C Type	3.95	2.37	0.0038	H_1
	Airport	69.09	3.00	0.0001	H_1
	Interaction	2.36	1.94	0.0173	H_1
Braking Dec. (m/s^2)	A/C Type	3.64	2.37	0.0064	H_1
	Airport	11.36	3.00	0.0001	H_1
	Interaction	1.10	1.94	0.3617	H_0

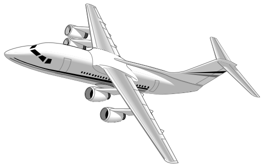
a.F-criteria is set for 5% significance level

b.H_0: the factor does not affect the variable in question (H_1: not H_0)

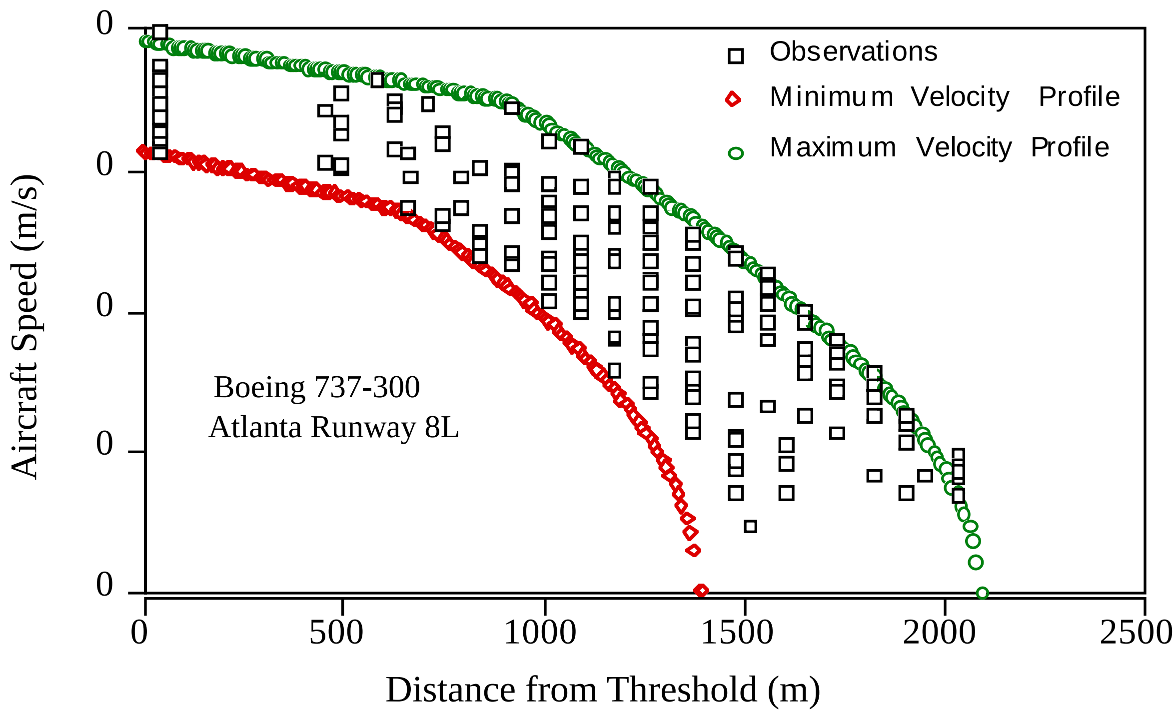
Simple Model Computational Procedure



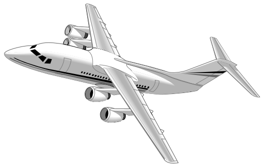
Mathematical Model vs. Observations



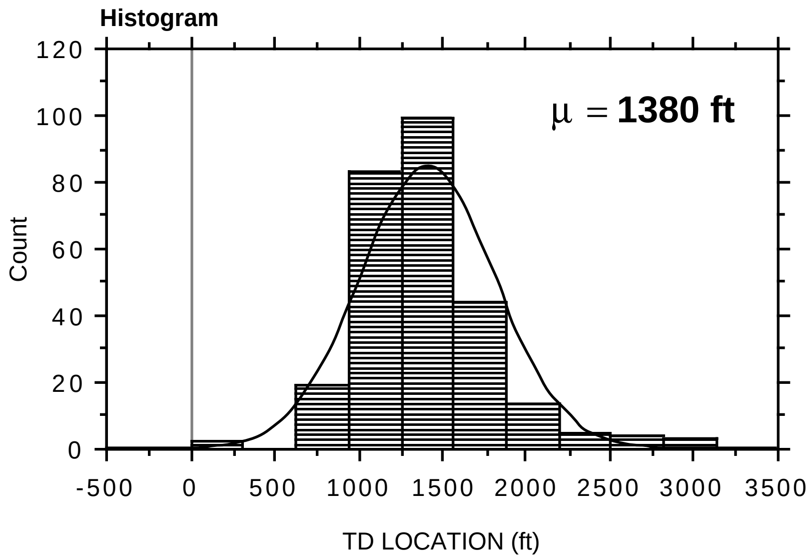
- Model comparison with actual aircraft landing roll observations (Boeing 737-300 landings at Atlanta 8L)



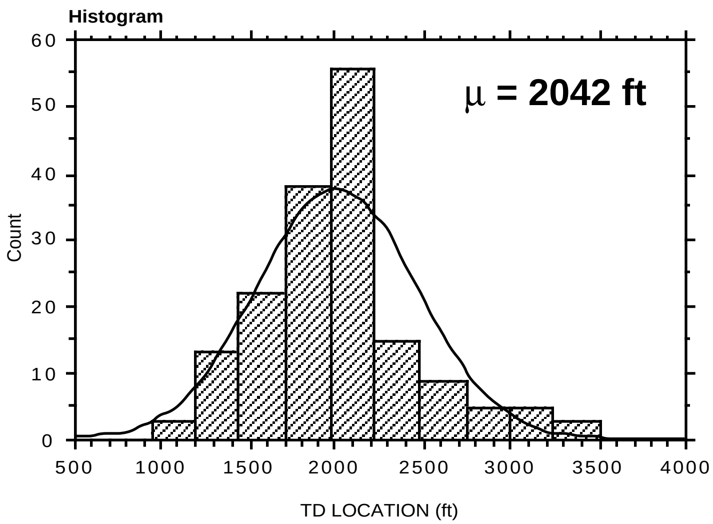
Sample Results of the Runway Module



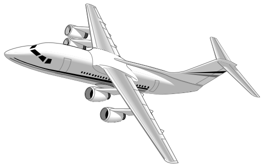
Model adaptation to various runway length conditions



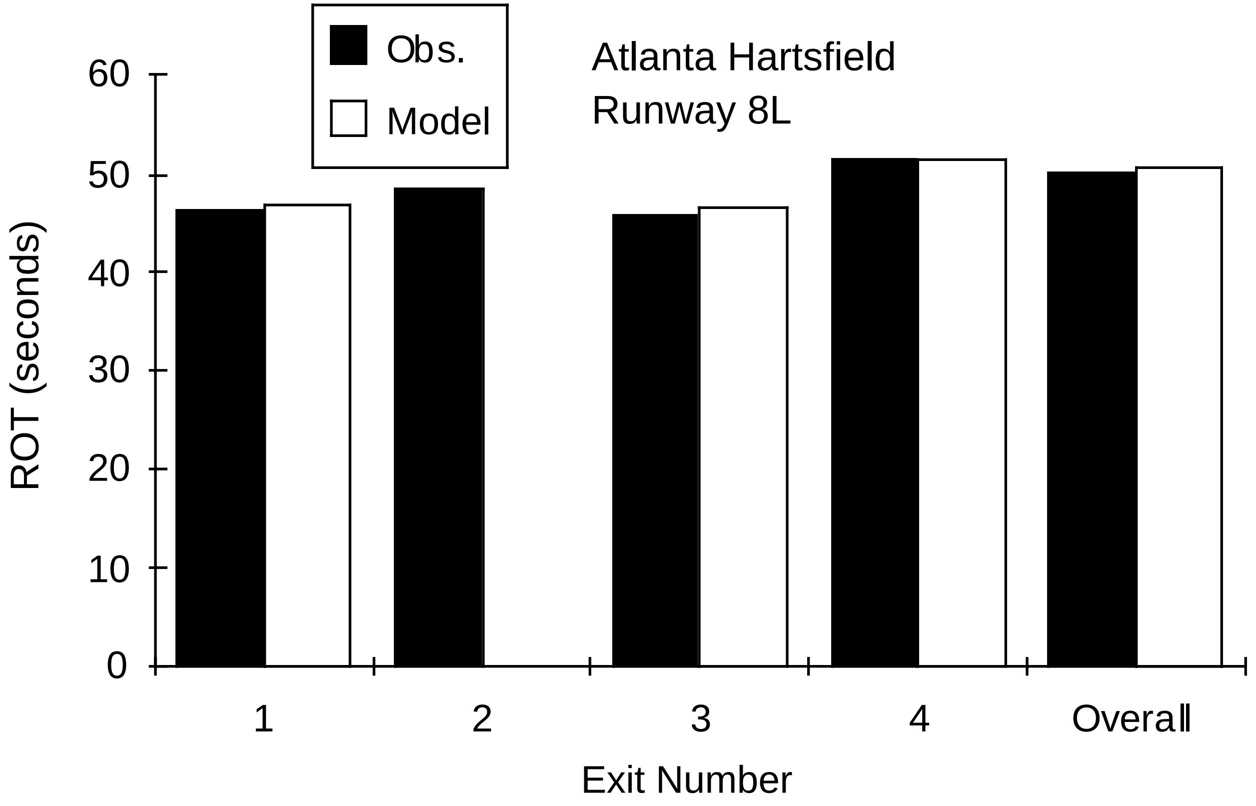
National Runway 36 (6700 ft)



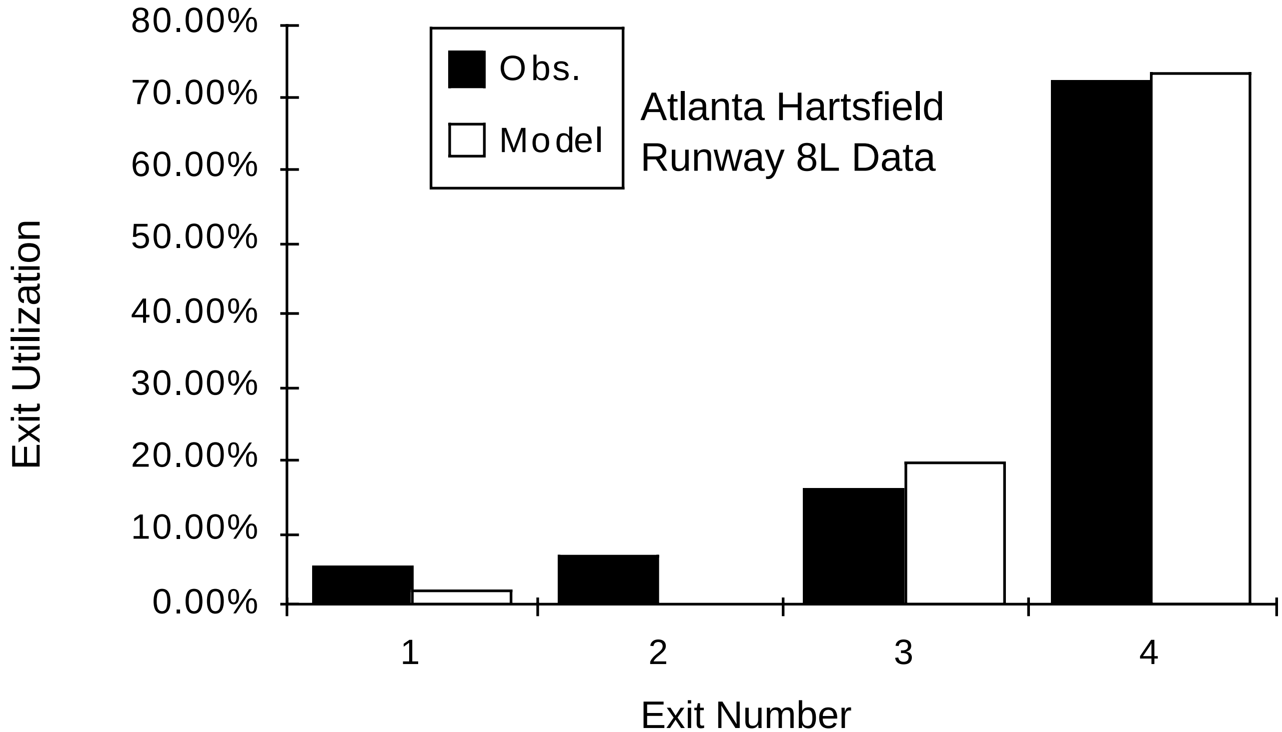
Atlanta Runway 8L (10,000 ft runway)



Runway Occupancy Time Predictive Capabilities

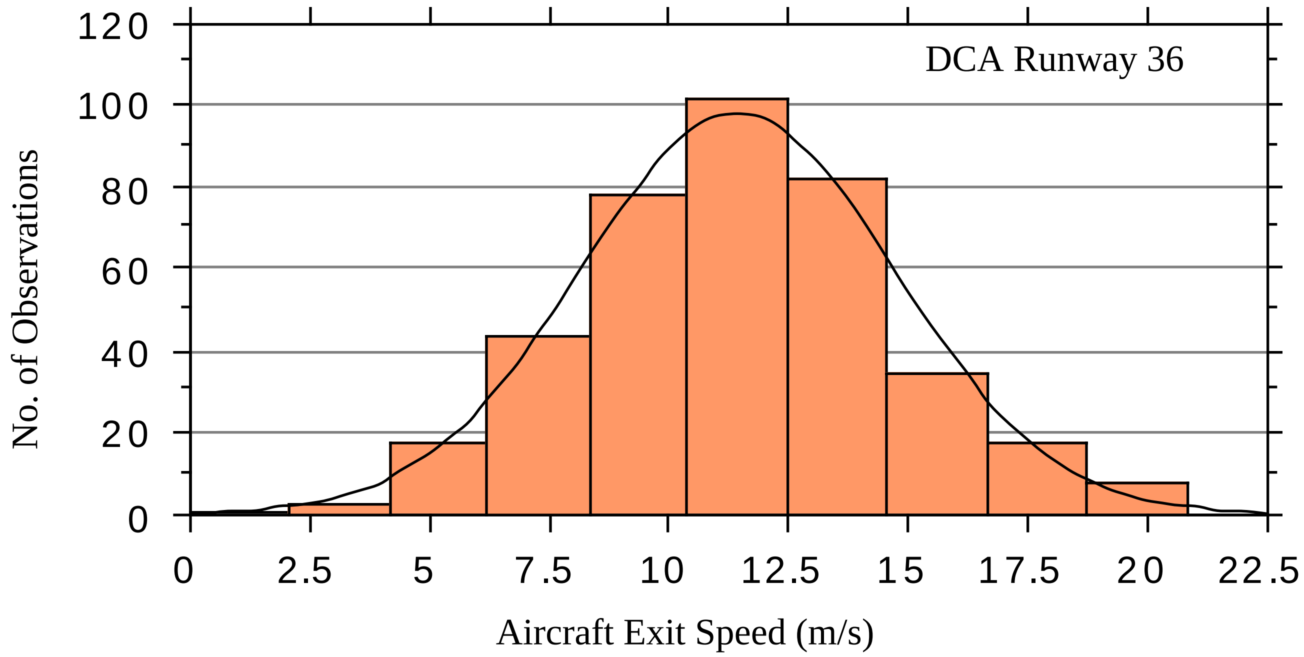


Runway Exit Utilization Results

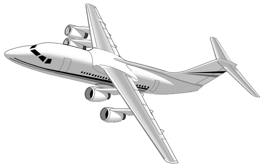


Runway Exit Data Collection

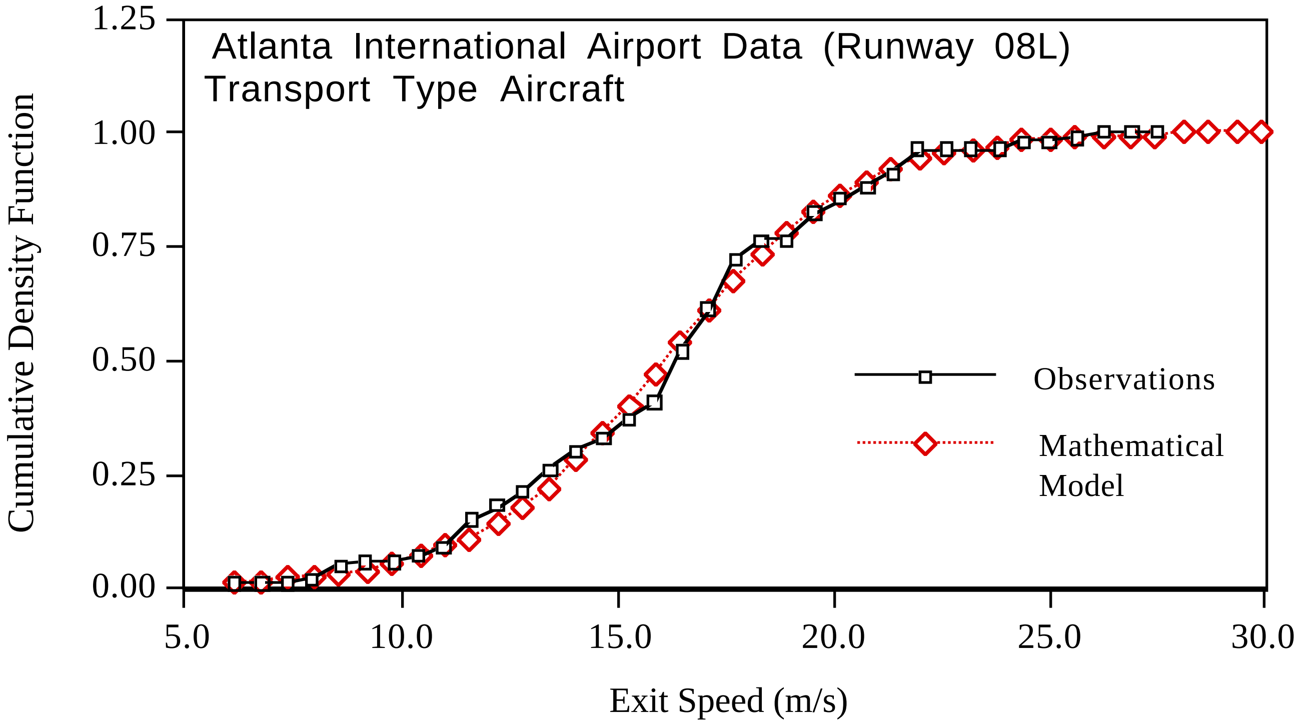
- Runway exit data has also been modeled mathematically



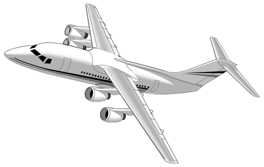
Runway Exit Mathematical Modeling



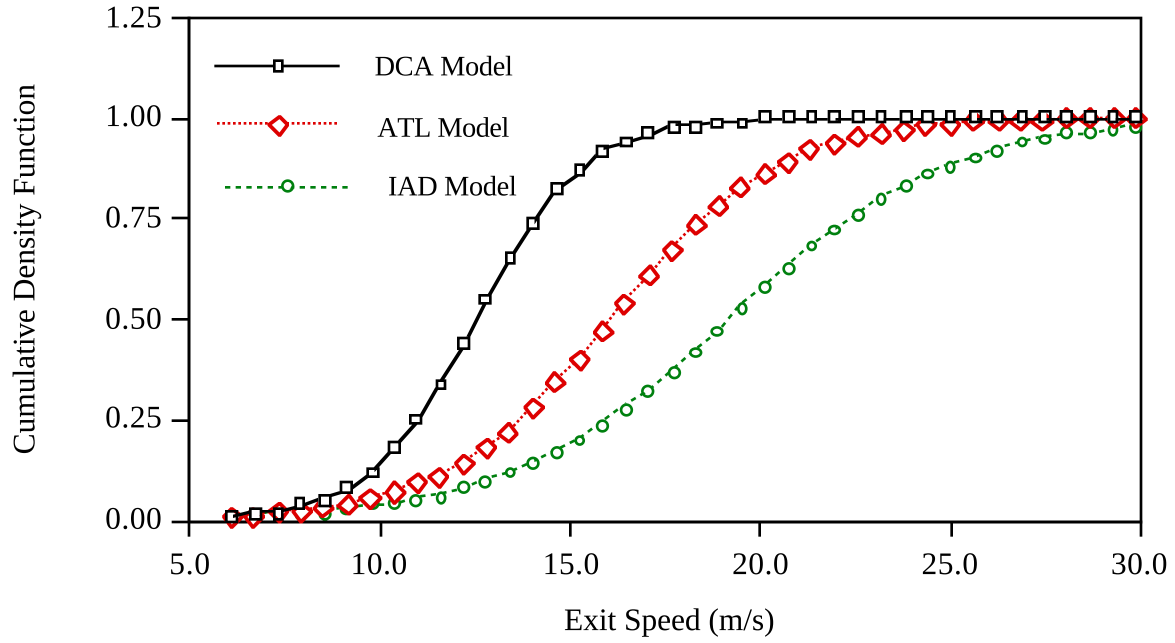
- In many instances the runway exit data was observed to follow normal distribution trends



Runway Exit Speed Models

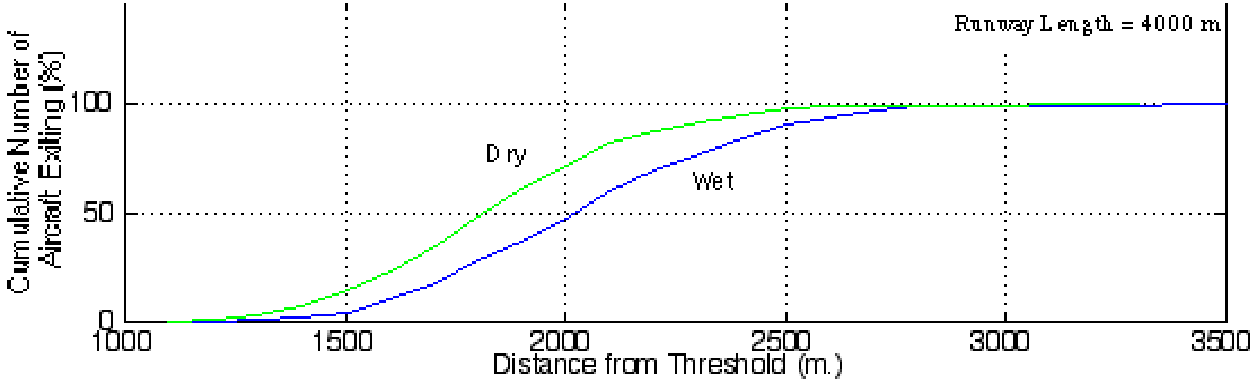


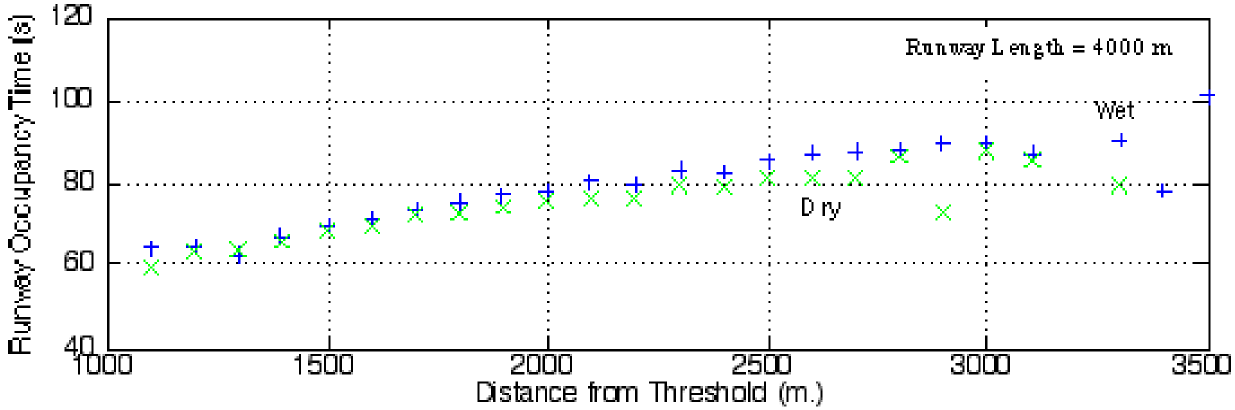
As expected, runway exit speeds vary drastically with the geometric features of the turnoff and the available lateral distances



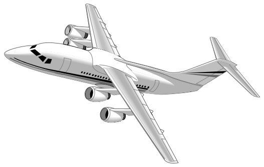
ROT and Exit Assignment Plots

- Runway Exit Assignment (Group D and 90 deg. turnoff)





Conclusions from Airfield ROT Data



- Individual aircraft show dissimilar landing roll characteristics at various airports
  - flare speed
  - touchdown location
  - runway deceleration, etc.

The individual aircraft modeling scheme adopted in REDIM and later in the SIMMOD engine seems justified

SIMMOD Runway Module Development

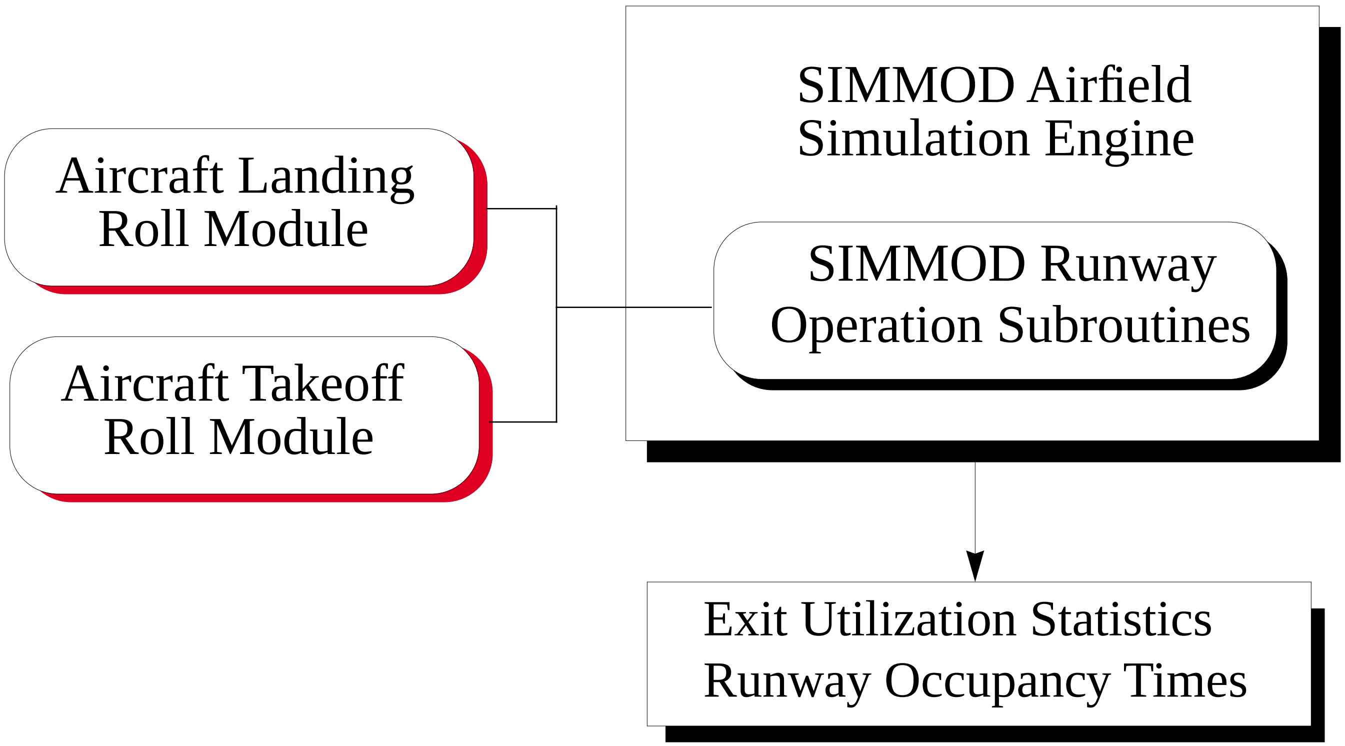
Sponsored by FAA (Steve Bradford - technical monitor)

Main goals of this project:

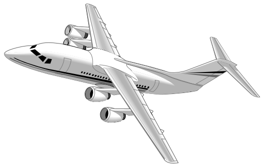
- Development a more realistic runway operations model (based in algorithms developed for REDIM) and its incorporating into the SIMMOD engine
- Develop a pre-processor to execute all tasks available in REDIM (i.e., runway evaluation, runway enhancement and optimization of ROT parameters)

Model Applications (Runway Operations)

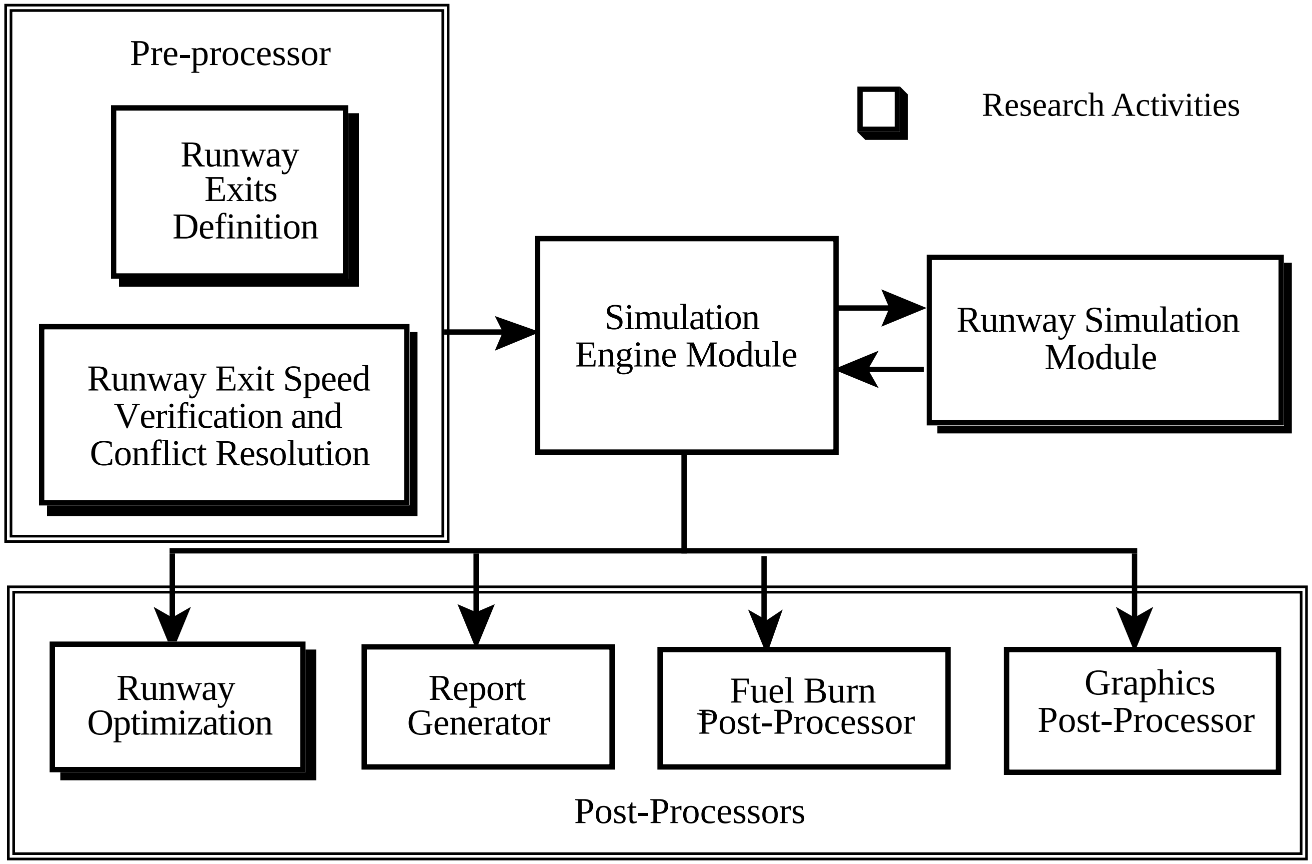
- SIMMOD runway operation model implementation



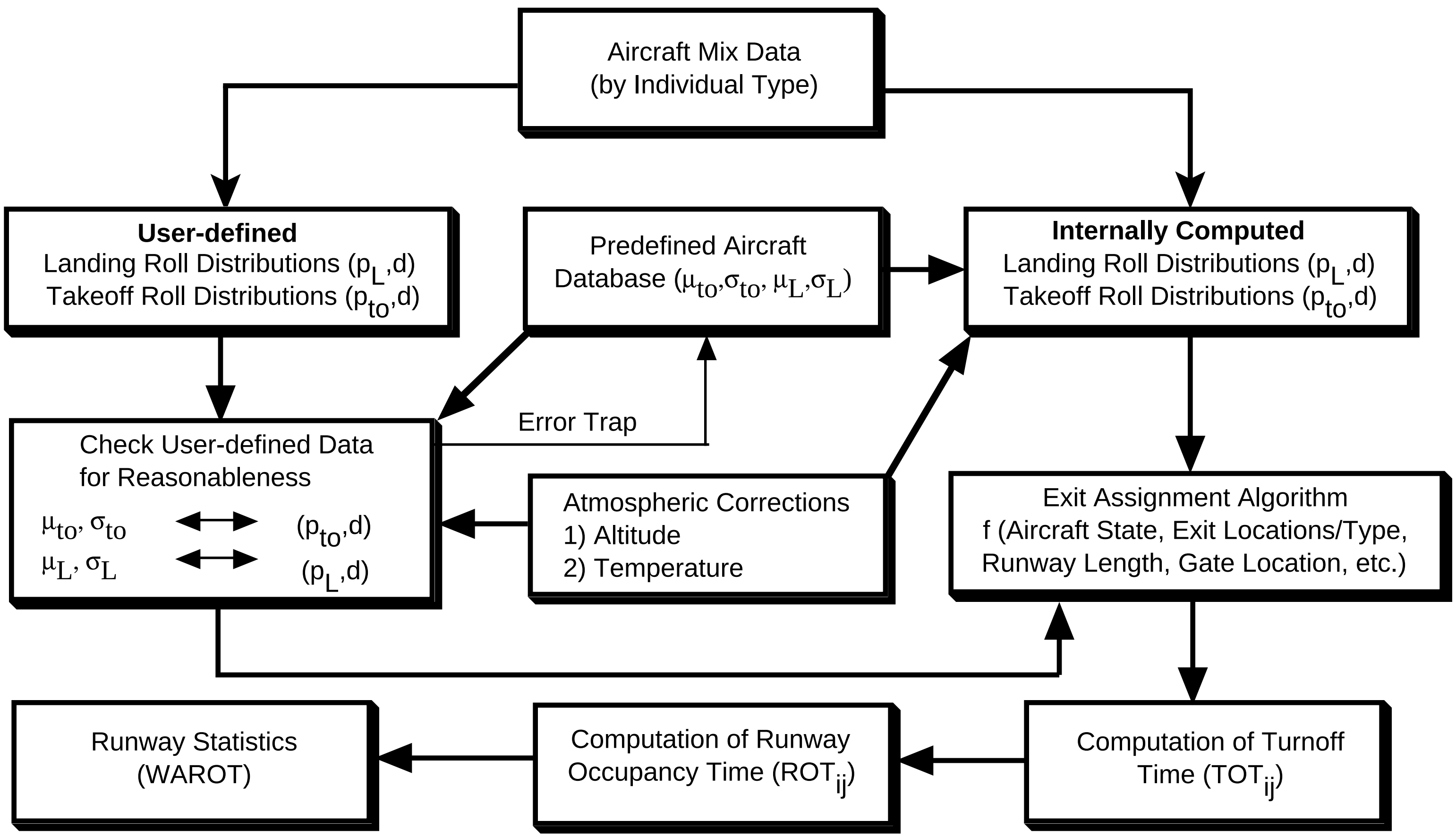
Implementation Issues



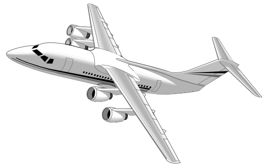
- Research Activities to Enhance SIMMOD (for ROT Estimation)



SIMMOD Runway Operations Module



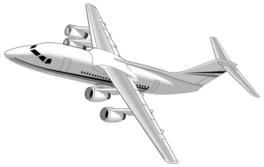
SIMMOD Modules Affected



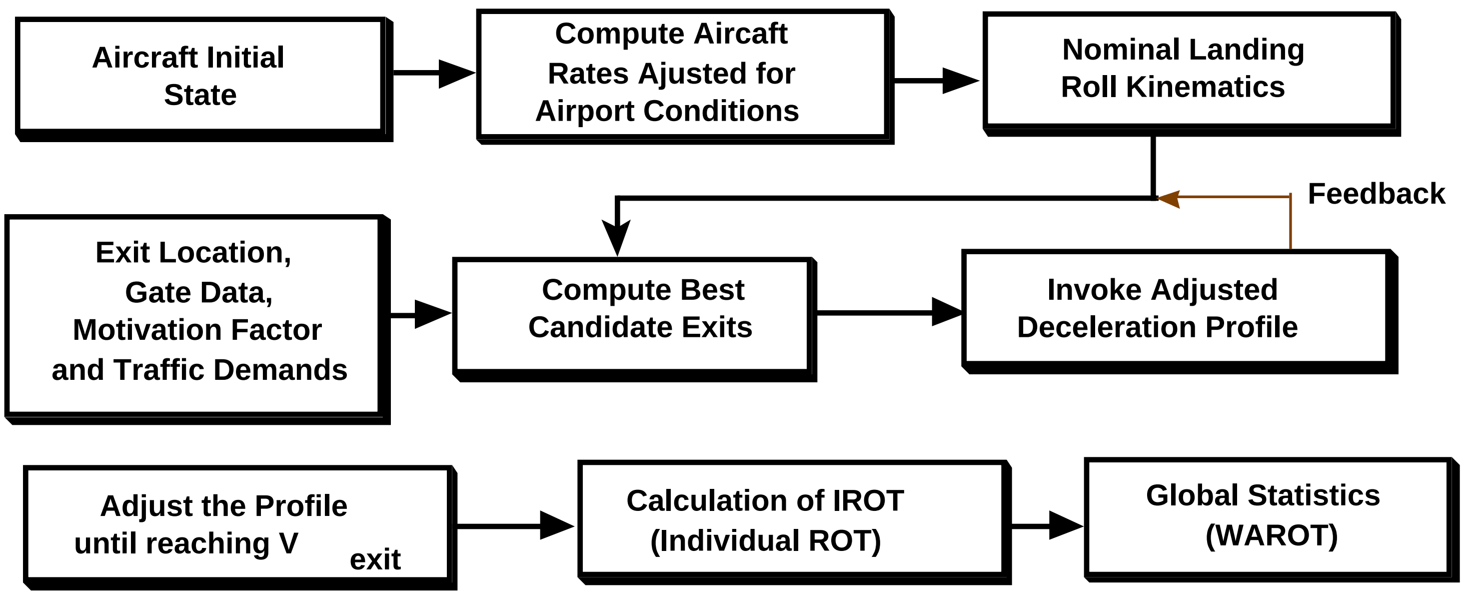
Various modifications were made to the following SIMMOD modules:

- Preamble
- ROUTINE ARR.TAXIWAY.PLANNING
- PROCESS QUE.ARRIVAL
- DISCOVER.RWY.EXIT
- ROLL.TIME

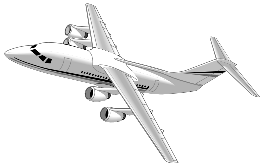
Pilot Decision Making Module



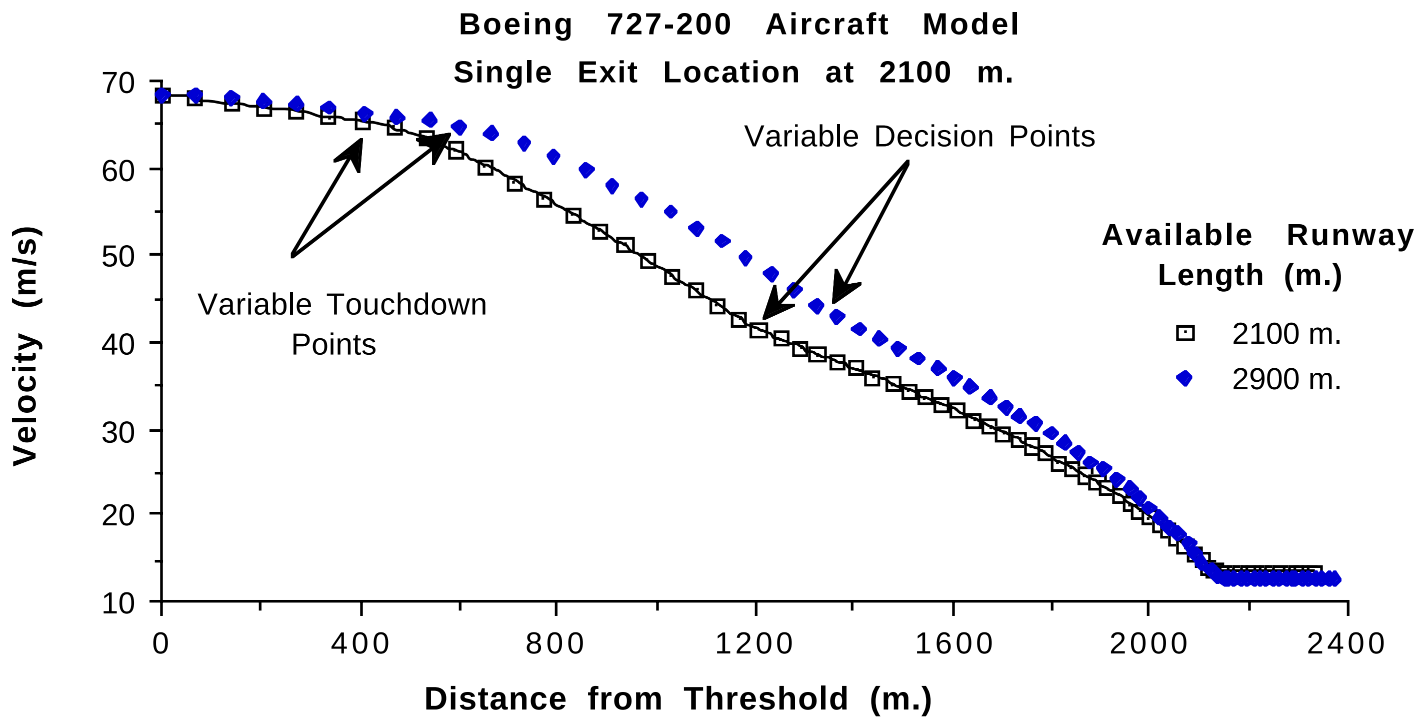
Several exit choice models were developed for SIMMOD considering aircraft performance, airline motivational practices, exit location proximity and ground traffic state conditions



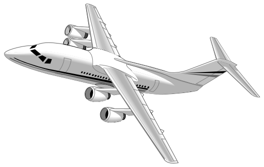
Use of a 2nd Order Feedback Model



A simple pilot-vehicle model adjusts the aircraft kinematics to model the behavior on the runway



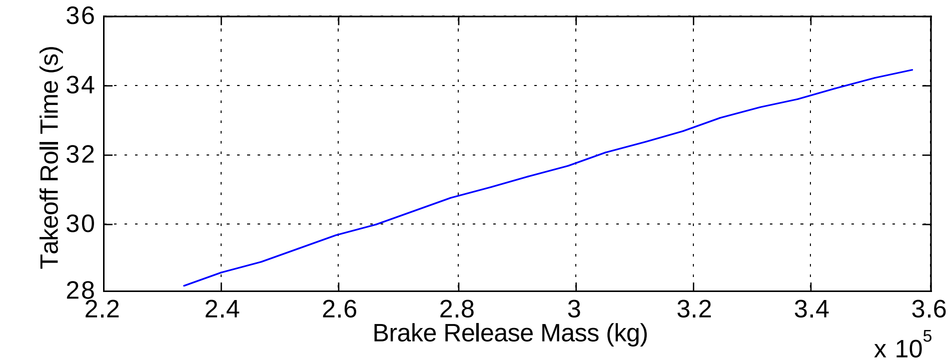
Takeoff Roll Time Estimation

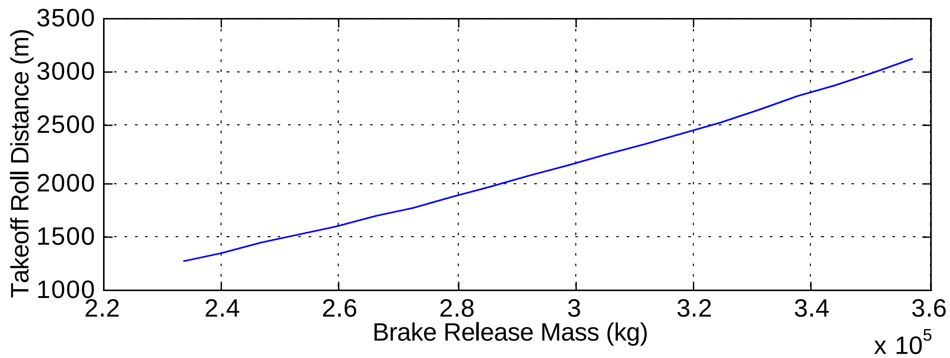


- Use a dynamic takeoff roll model derived from the static SAE 1847 takeoff roll procedure employed in INM
- Use numerical integration of simplified aerodynamic coefficients along the runway
- Procedure is accurate yet simple enough to be introduced into a fast-time simulation model like SIMMOD

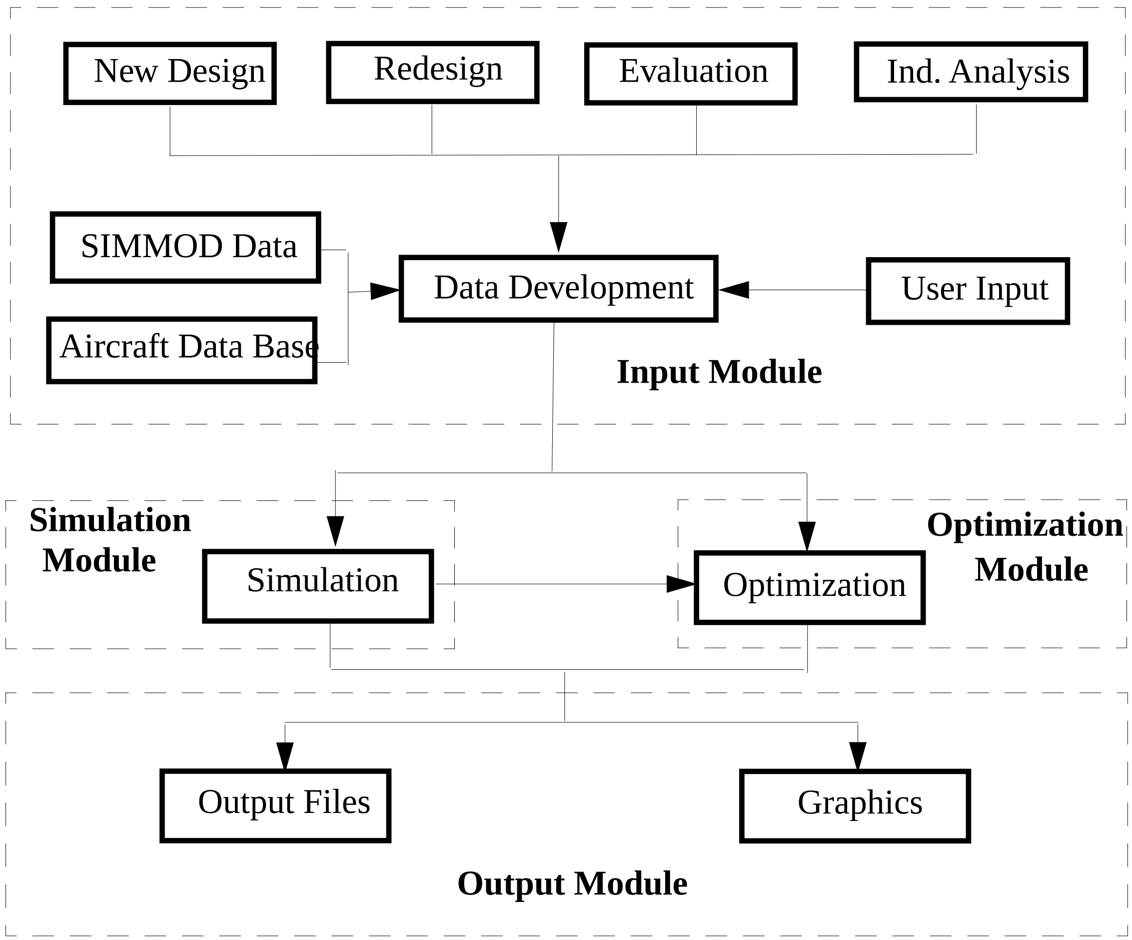
Sample Takeoff Roll Times and Distances

The example illustrates TO roll time and distance for a Boeing 747-200 aircraft





SIMMOD Runway Analysis Module



SIMMOD ROT Pre-Processor Structure

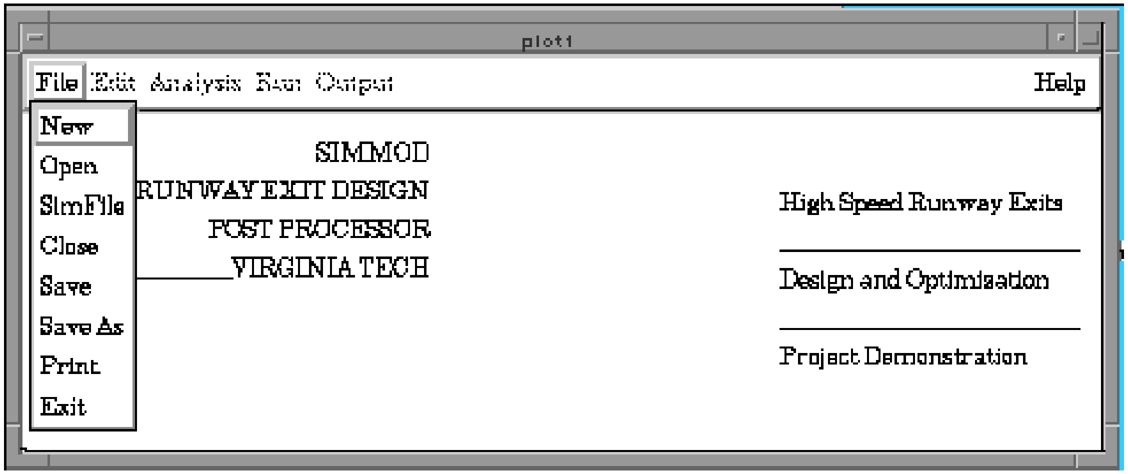
File | **Edit** | **Analysis** | **Run** | **Output** | **Help**

- **File Menu**
  - New
  - Open
  - SimFile
  - Close
  - Print
  - Exit
- **Edit Menu**
  - Aircraft Mix
  - Weight Factors
  - Operation Data
  - Env. Data
  - Geometry
  - RWY Exit
- **Analysis Menu**
  - New Design
  - Redesign
  - Evaluation
  - Ind. Analysis
- **Run**
  - Start
  - Stop
- **Output Menu**
  - ROT Table
  - Exit Locations
  - ROT Statistics
  - Landing Roll Stat.
  - Exit Usability

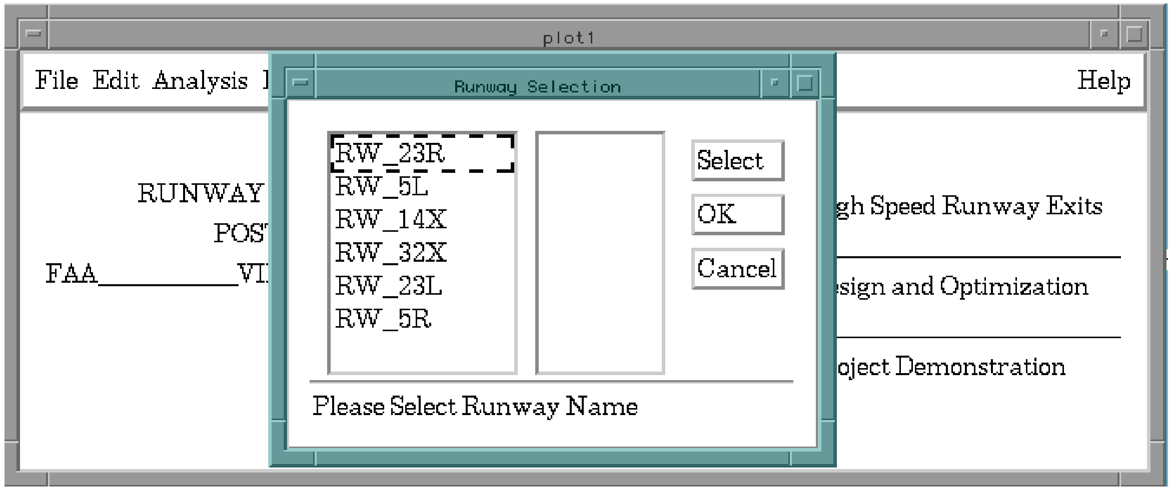
Sample GUI Screens

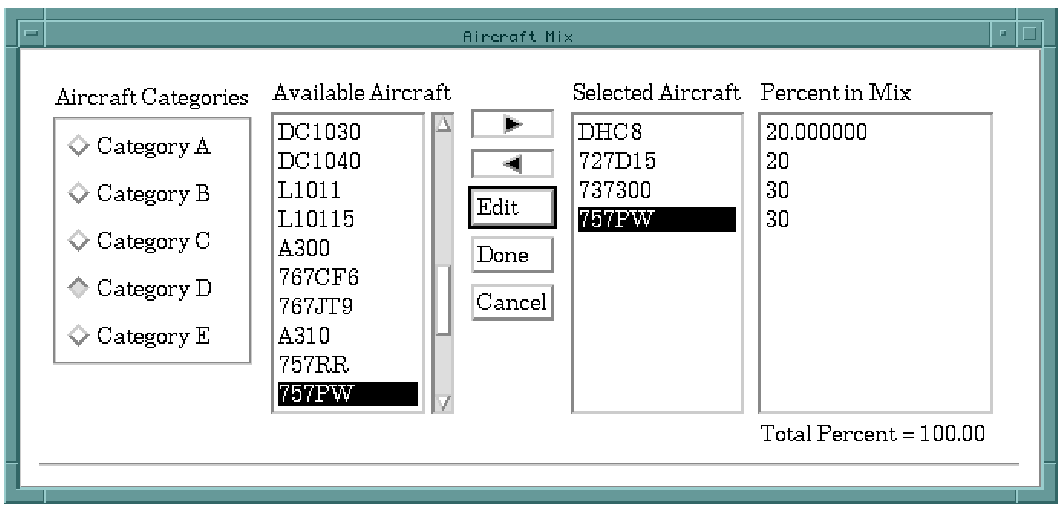
All module development done in the C language and MOTIF standards (for the GUI) - portability was an issue

Original implementation (IBM AIX 4.5) later ported to Solaris 2.5

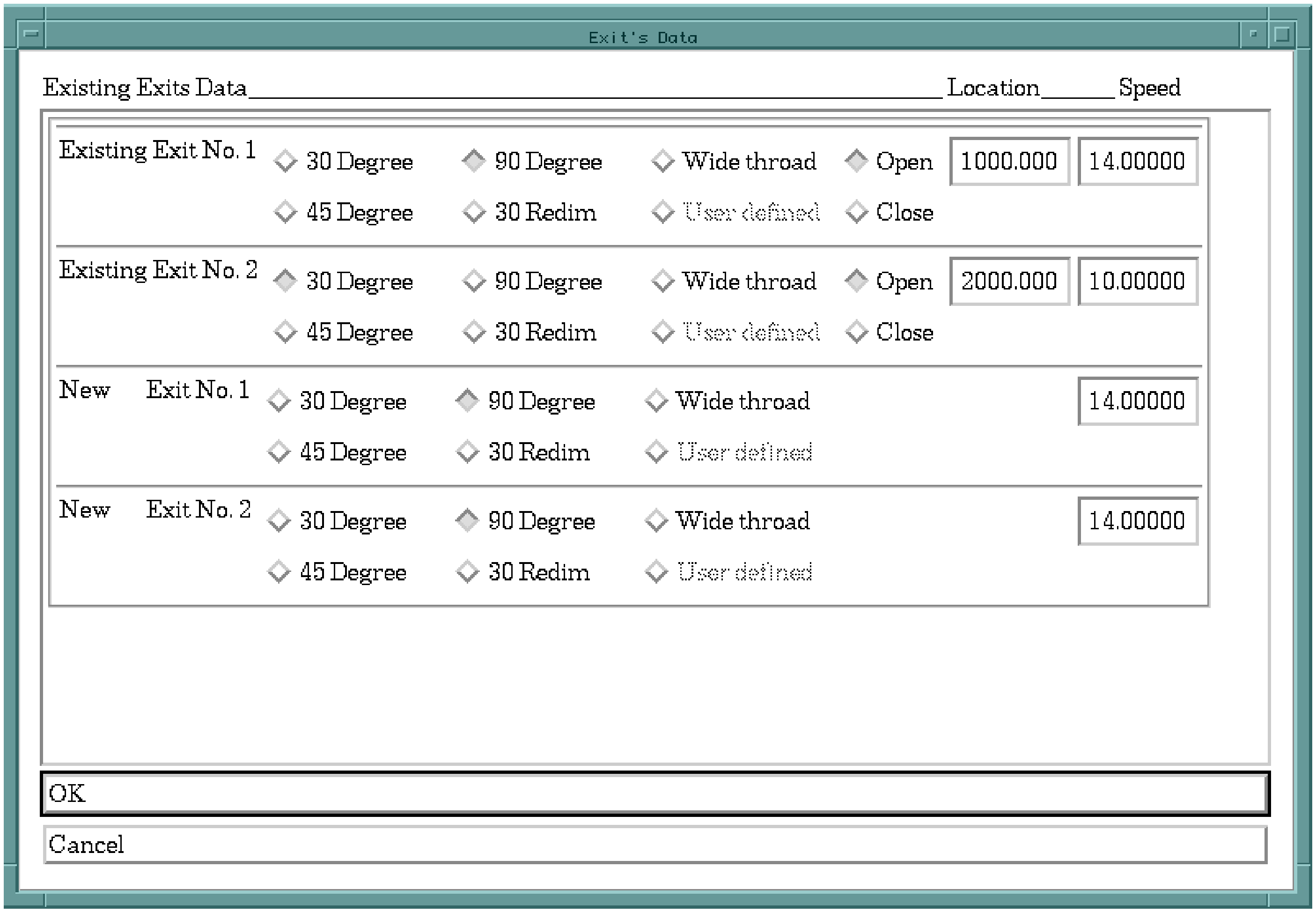


Runway and Aircraft Mix Screens

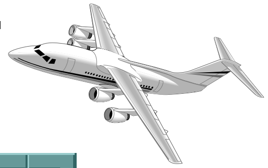




Runway Exit Data Entry Screen



ROT Table Output



Report: New Design Case

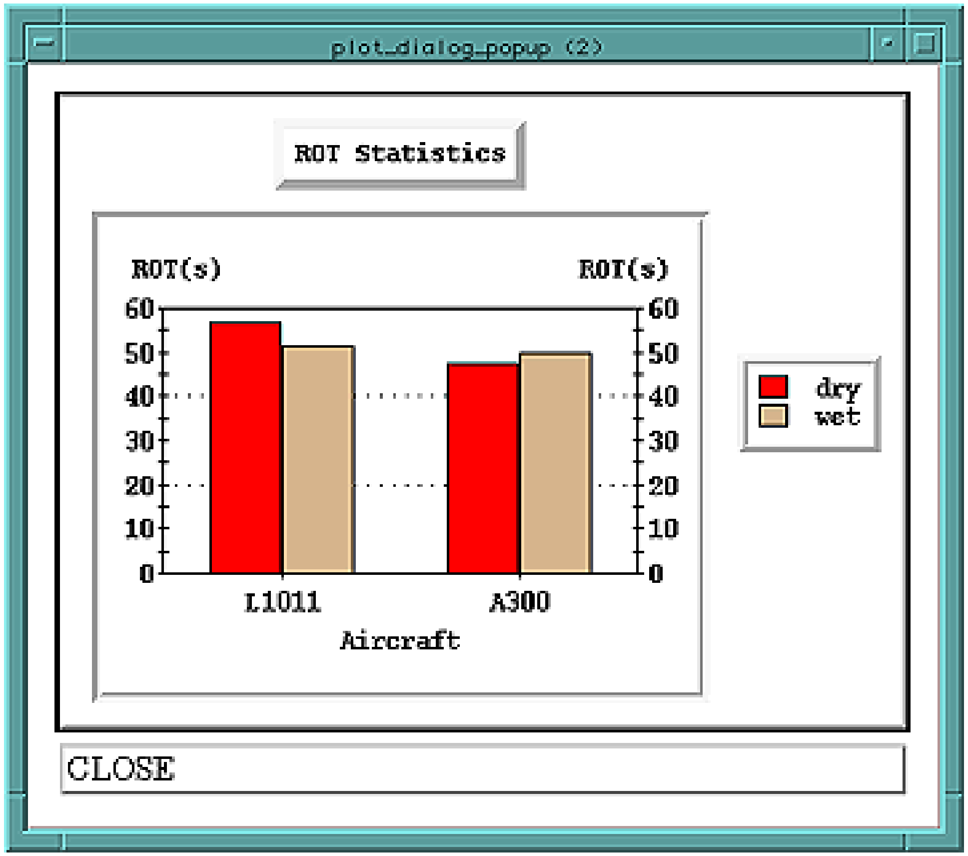
Report: Runway Occupancy Time Table

Exit #	1	2	3
Location(m)	1412.50	1912.50	3000.00
Upper Bound	1325.00	1825.00	3000.00
Lower Bound	1500.00	2000.00	3000.00
Open/Close	Open	Open	Open
Exit Type	30 Degree	30 Degree	90 Degree
DHC8	1	2	3
Dry	53.80	0.00	0.00
%	1.00	0.00	0.00
Wet	54.20	0.00	0.00
%	1.00	0.00	0.00
737300	1	2	3
Dry	48.90	57.80	0.00
%	0.84	0.16	0.00
Wet	49.70	58.80	0.00

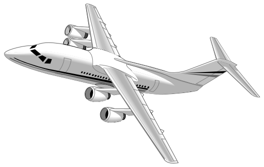
The weighted average ROT = 54.276489

Ok

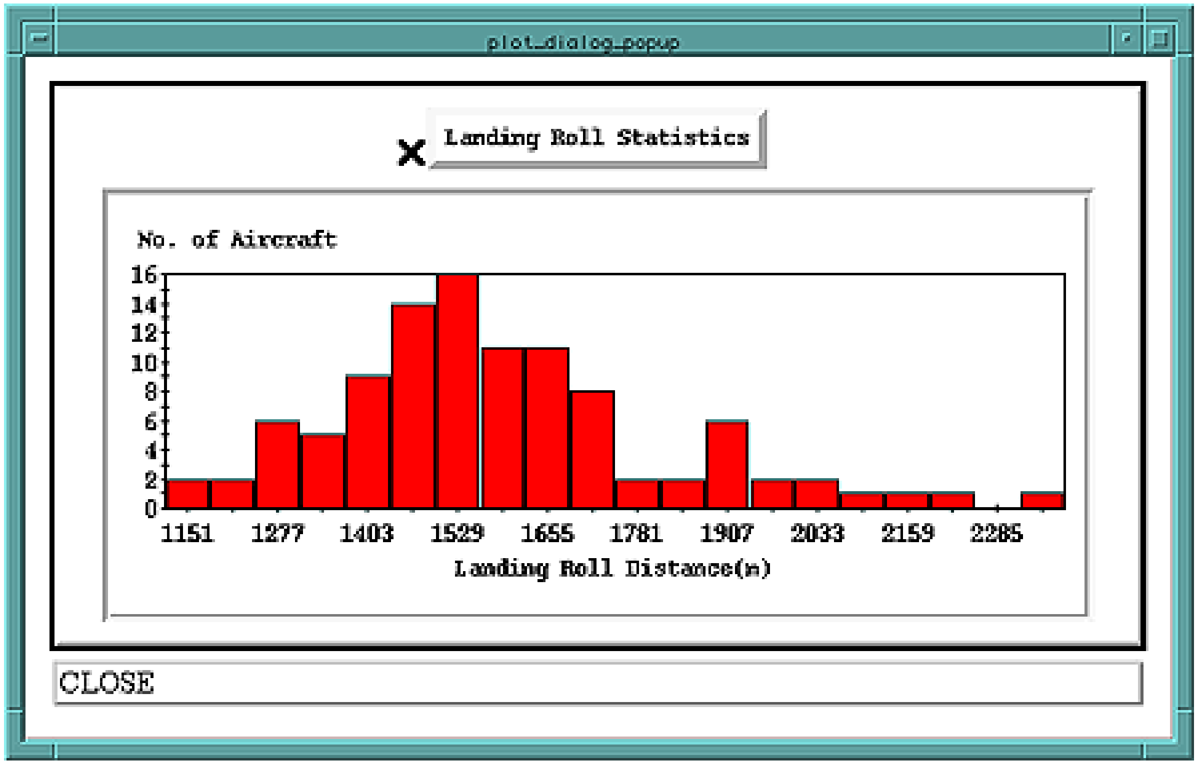
ROT Graphical Output



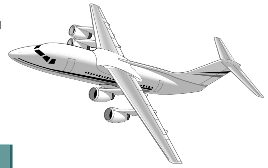
Aircraft Landing Roll Statistics

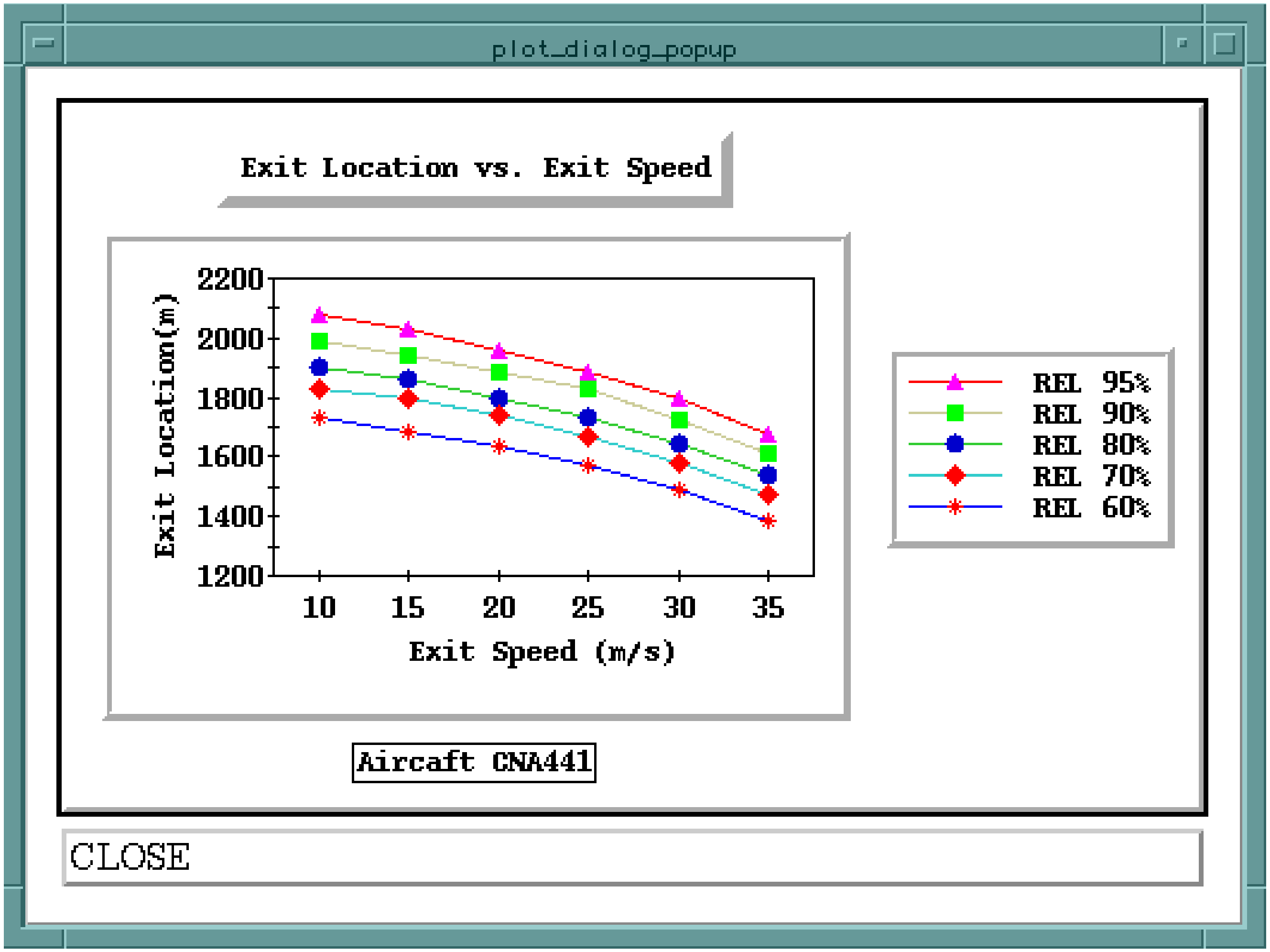


- Example of a SIMMOD runway operations pre-processor developed at VPI



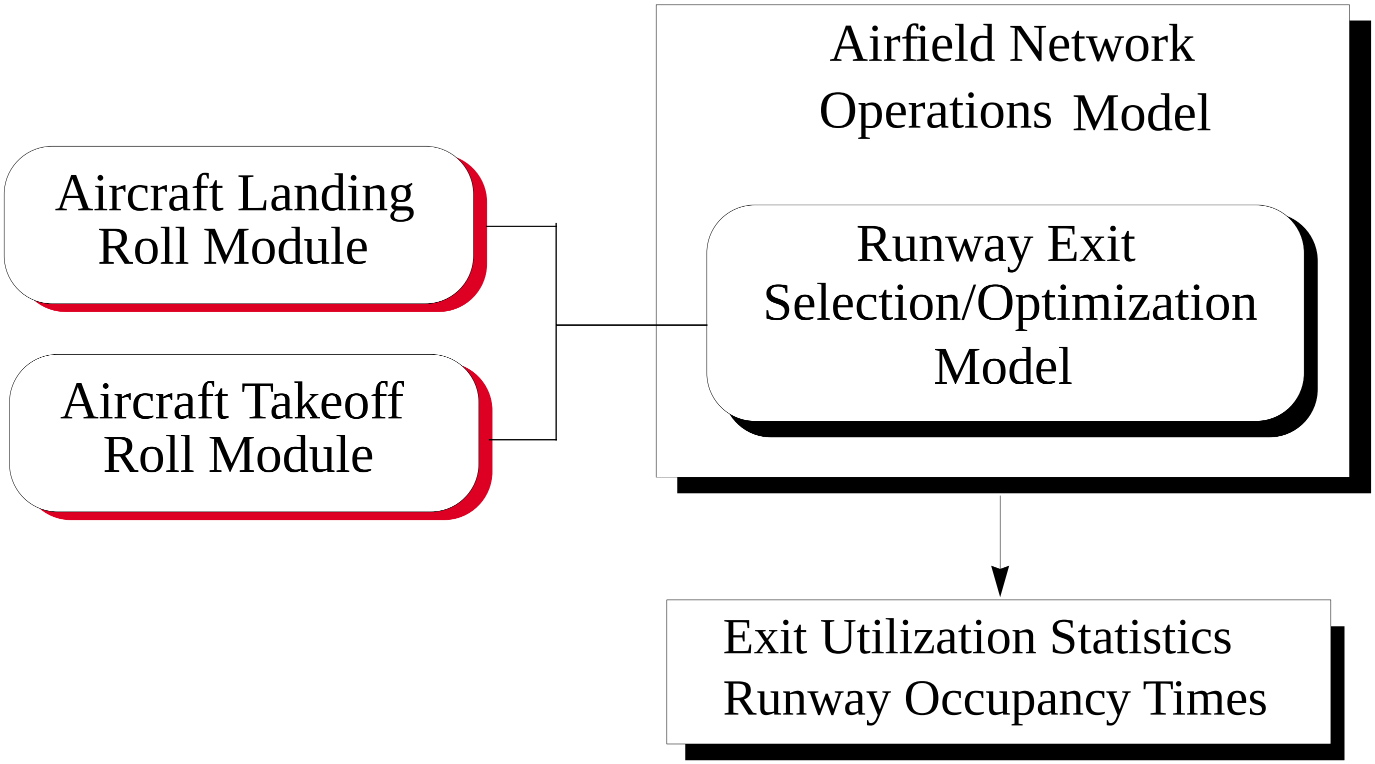
Exit Speed vs. Exit Location Trade-off Plot



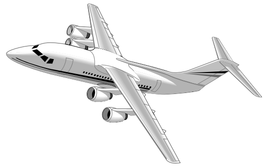


Model Extensions (Gate Location)

- An extension of the runway model accounts for pilot motivational behaviors due to gate location constraints



Model Extensions (Gate Location Constraint)



A multiobjective integer programming optimization model has been developed. Minimizing the aircraft runway occupancy time (ROT) and taxiing time (TT) are the two objectives of this model. The model can be described mathematically as follows:

$$\text{Minimize} \sum_{i=1}^{n} (ROT_{ik} + wfTT_{ik})x_i$$

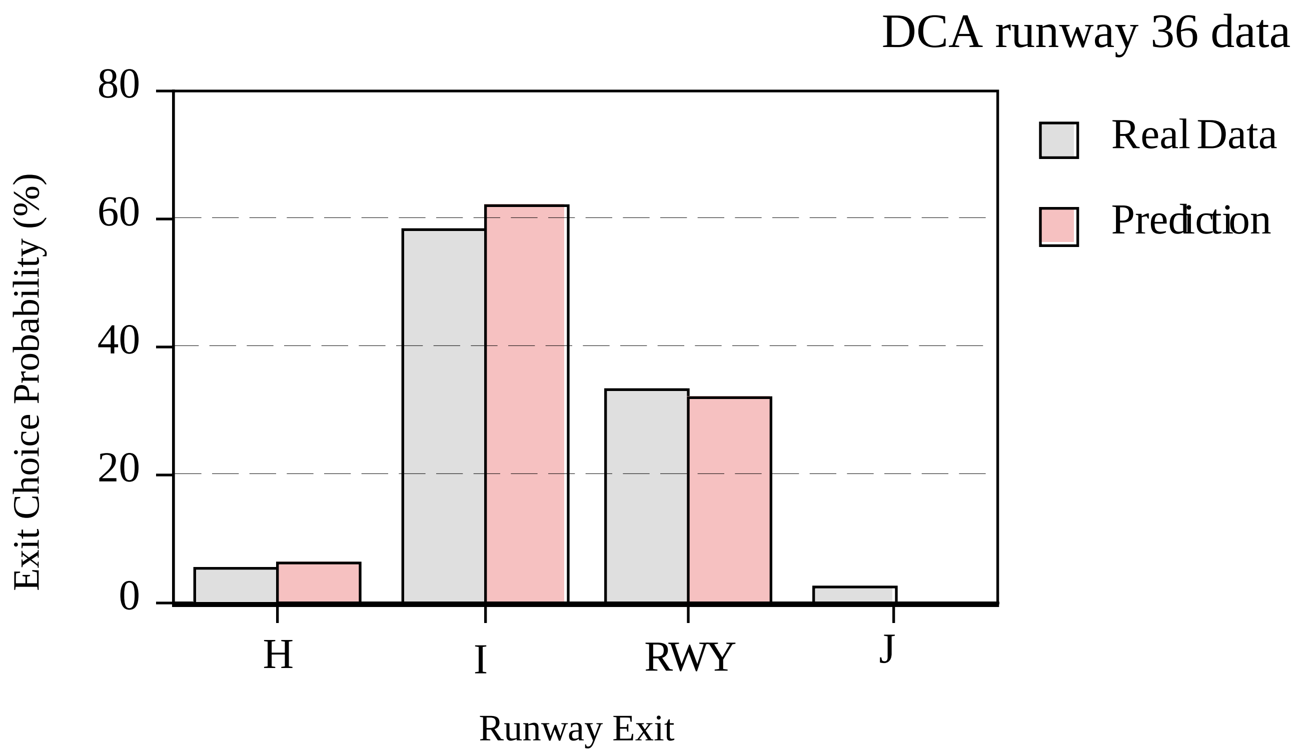
$$\text{Subject to} \sum_{i=1}^{n} x_i = 1$$

$$l_{ex}(i) \geq S_{air} + S_{fr1} + S_{fr2} + S_{br}$$

$$x_i = 0 \quad or \quad 1$$

Model Extension Results (Gate Motivation)

- Observed vs. predicted runway exits at DCA



Final Remarks

- The refined SIMMOD model realistically predicts runway service times for all possible runway/taxiway configurations (i.e., aircraft mix and runway/turnoff layouts)
- With these improvements, the new SIMMOD model airport planners could perform sensitivity analyses of various turnoff alternatives based upon delay and fuel consumption evaluations
- Long-term benefits of high-speed turnoffs could be further assessed in terms of landing and takeoff delay analysis
- The new term Dynamic Runway Occupancy Time (DROT) has renewed interest to FAA and NASA