Icing Encounter Flight Simulator

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SMART ICING SYSTEMS
Research Organization

Core Technologies

- Aerodynamics and Propulsion
- Flight Mechanics
- Control and Sensor Integration
- Human Factors
- Aircraft Icing Technology

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IMS Functions

- Characterize Icing Effects
- Operate and Monitor IPS
- Envelope Protection
- Adaptive Control

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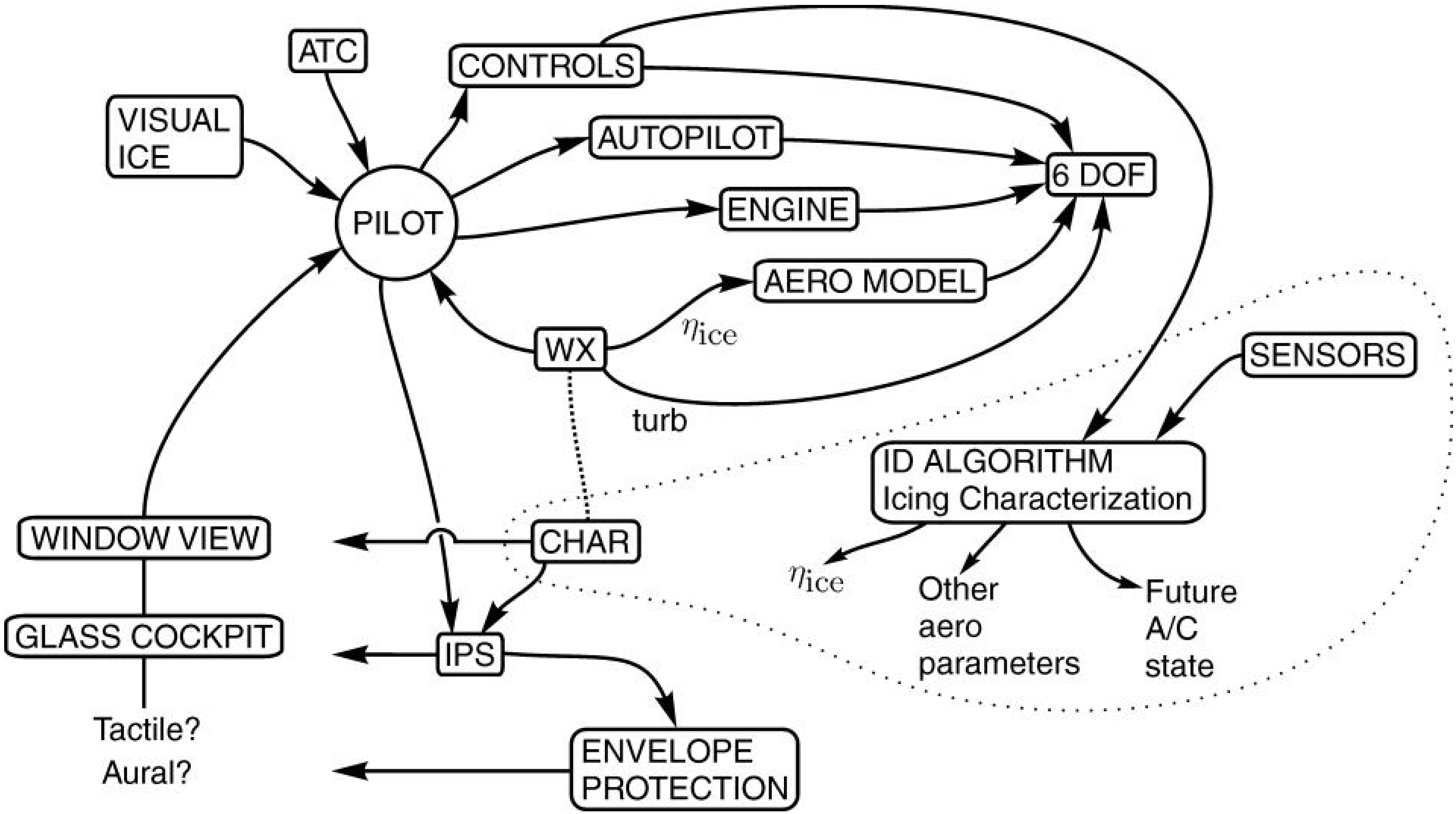
System Integration

- Flight Simulation
- Flight Test

Icing Encounter Flight Simulator

- Objectives:
  - Function as a systems integrator by bringing together the various flight simulator components composed of an aircraft model, flight mechanics, aerodynamics, propulsion, controls, sensors, the ice protection system, the smart icing system, and human factors
  - Perform "virtual flight tests" to examine the effects of icing on aircraft operations under a variety of conditions
- Approach:
  - Develop an Icing Encounter Flight Simulator
  - Apply the simulator to icing scenarios and experiments

Simulation Flowchart and Models



Aerodynamics

- Nonlinear model
- No stability derivatives used with current Twin Otter
- All coefficients determined through lookup tables
- In body axis
- 3D interpolation
- Data usage follows

Aerodynamics

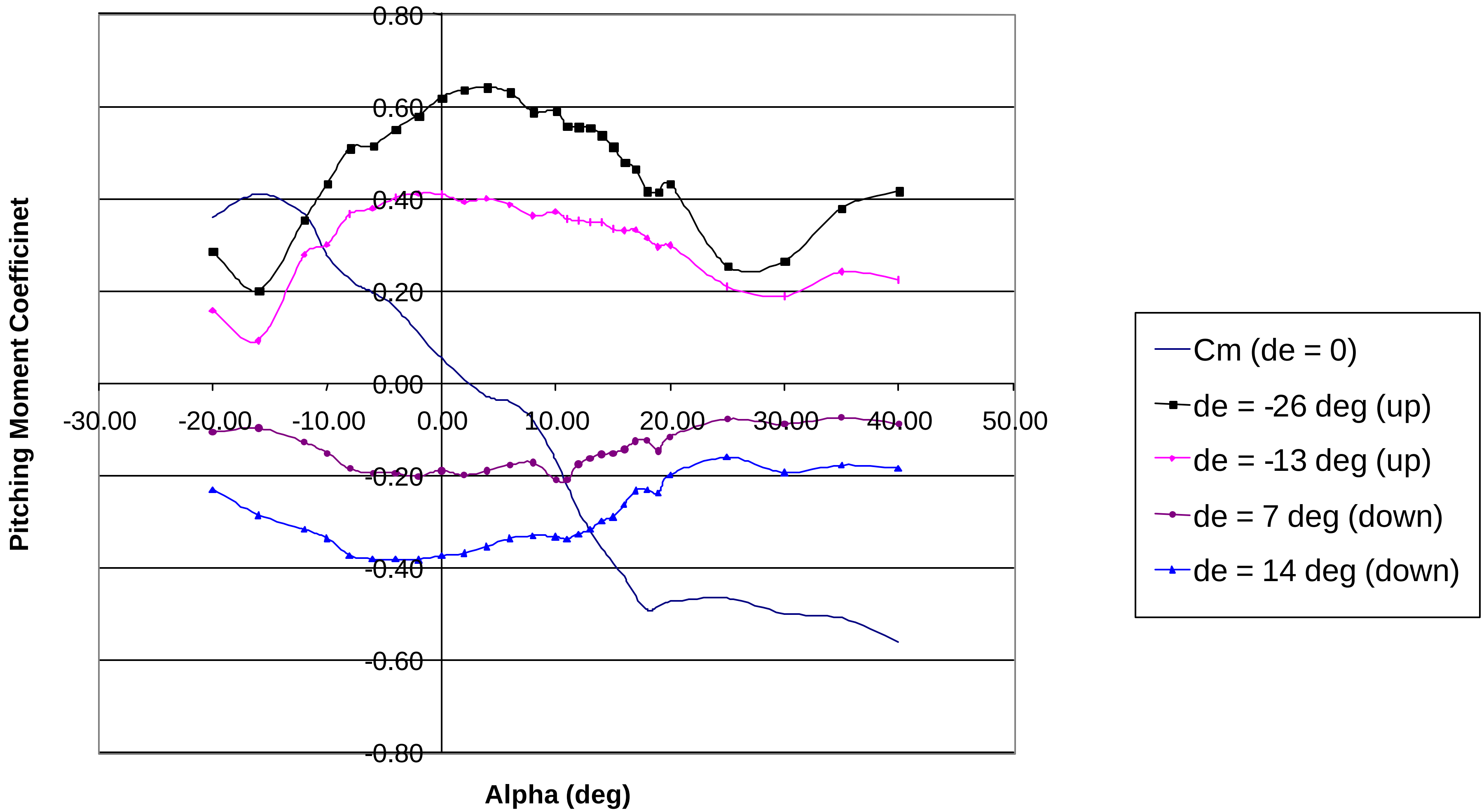
- Component build-up

$$C_Z = C_Z^*(\alpha,\beta) + \Delta C_Z^*(\alpha,\delta_e) + \Delta C_Z^*(\alpha,q)$$
$$C_X = C_X^*(\alpha,\beta) + \Delta C_X^*(\alpha,\delta_e) + \Delta C_X^*(\alpha,q)$$
$$C_m = C_m^*(\alpha,\beta) + \Delta C_m^*(\alpha,\delta_e) + \Delta C_m^*(\alpha,q)$$
$$C_Y = C_Y^*(\alpha,\beta) + \Delta C_Y^*(\alpha,\delta_a) + \Delta C_Y^*(\alpha,p) + \Delta C_Y(\alpha,\delta_r) + \Delta C_Y^*(\alpha,r)$$
$$C_l = C_l^*(\alpha,\beta) + \Delta C_l^*(\alpha,\delta_a) + \Delta C_l^*(\alpha,p) + \Delta C_l^*(\alpha,r)$$
$$C_n = C_n^*(\alpha,\beta) + \Delta C_n^*(\alpha,\delta_r) + \Delta C_n^*(\alpha,p) + \Delta C_n^*(\alpha,r)$$

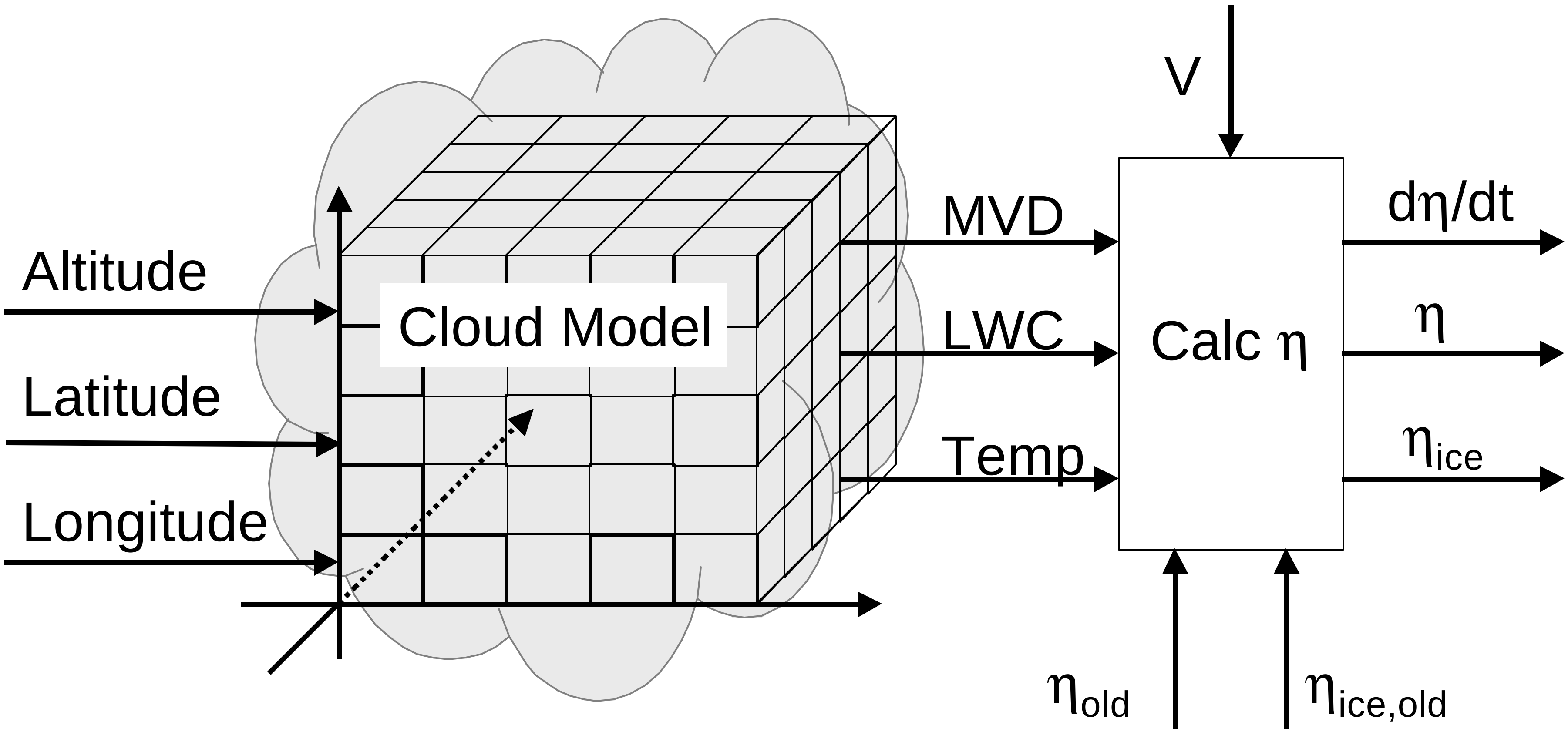
* denotes functions of flap (typically 0, 20, 40 deg)

- Sample nonlinear coefficient data follows

Pitching Moment Data

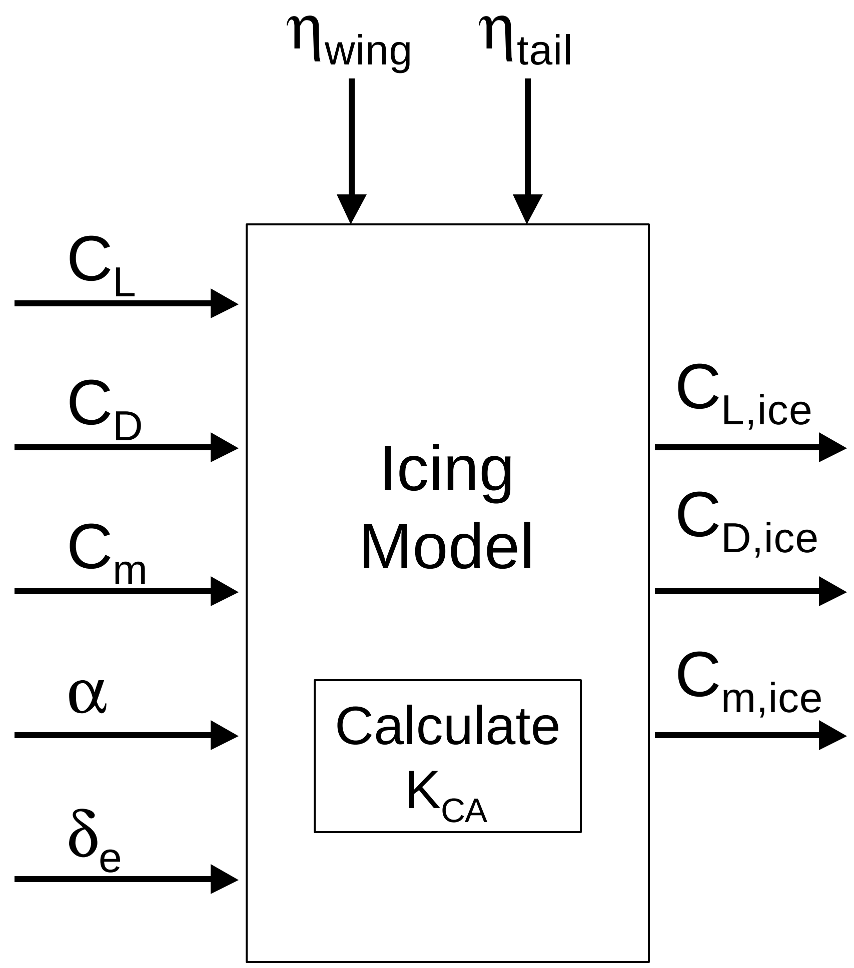


Weather



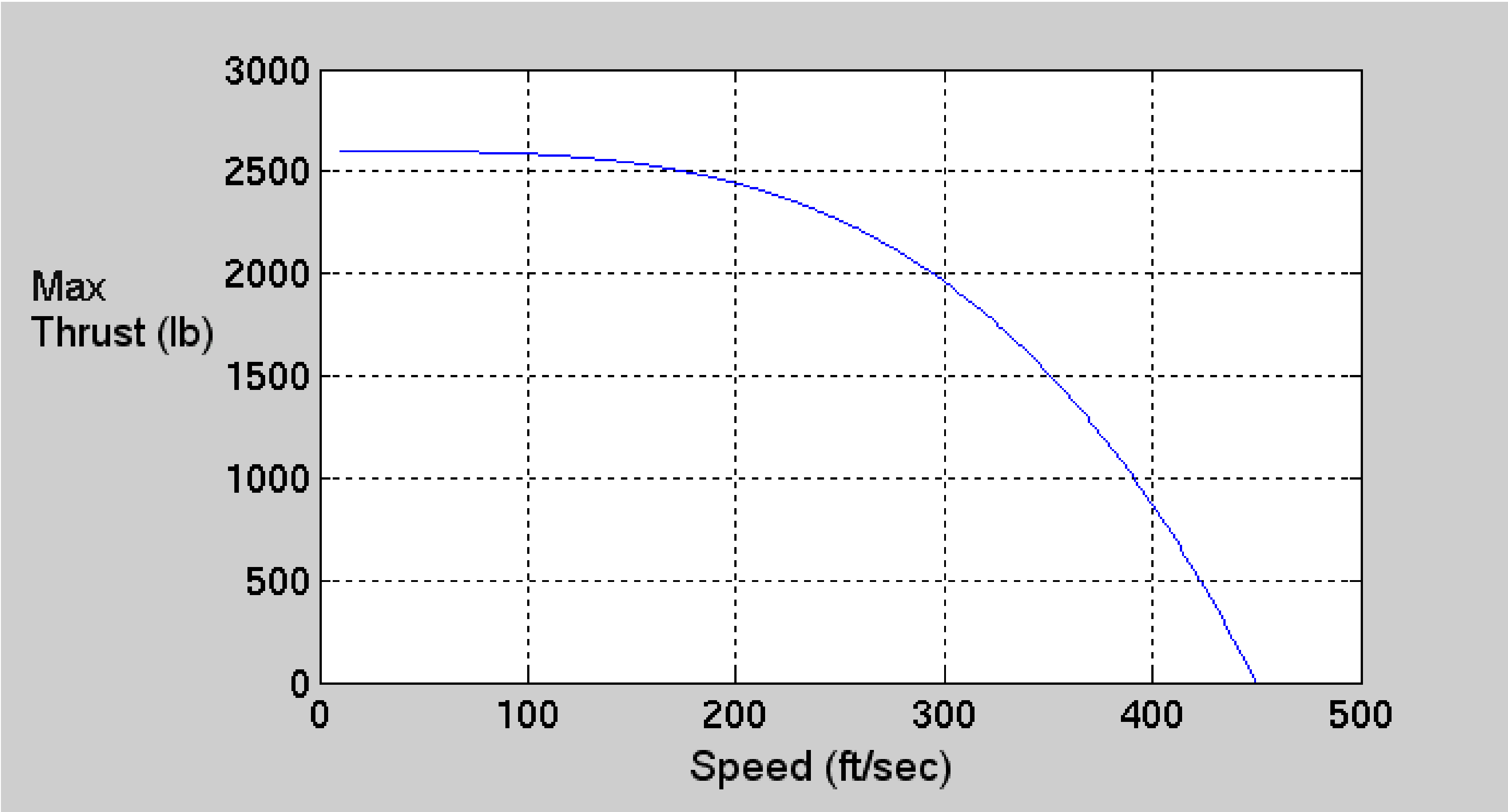
- Also used as an “icing characterization” surrogate

Longitudinal Icing Model



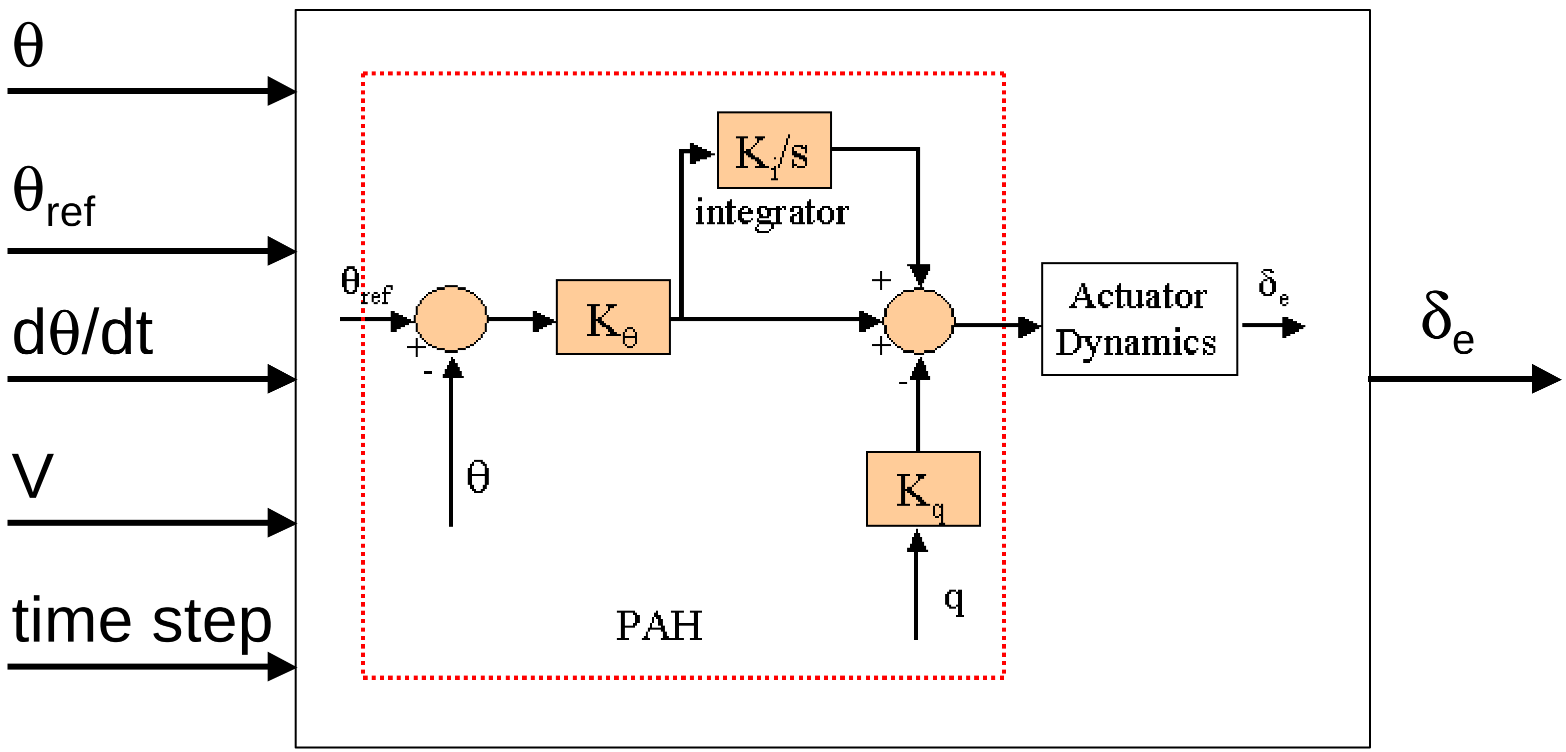
Simple Engine Model

- Matches max rate of climb (1600 ft/min)
- Matches max speed (160 knots)

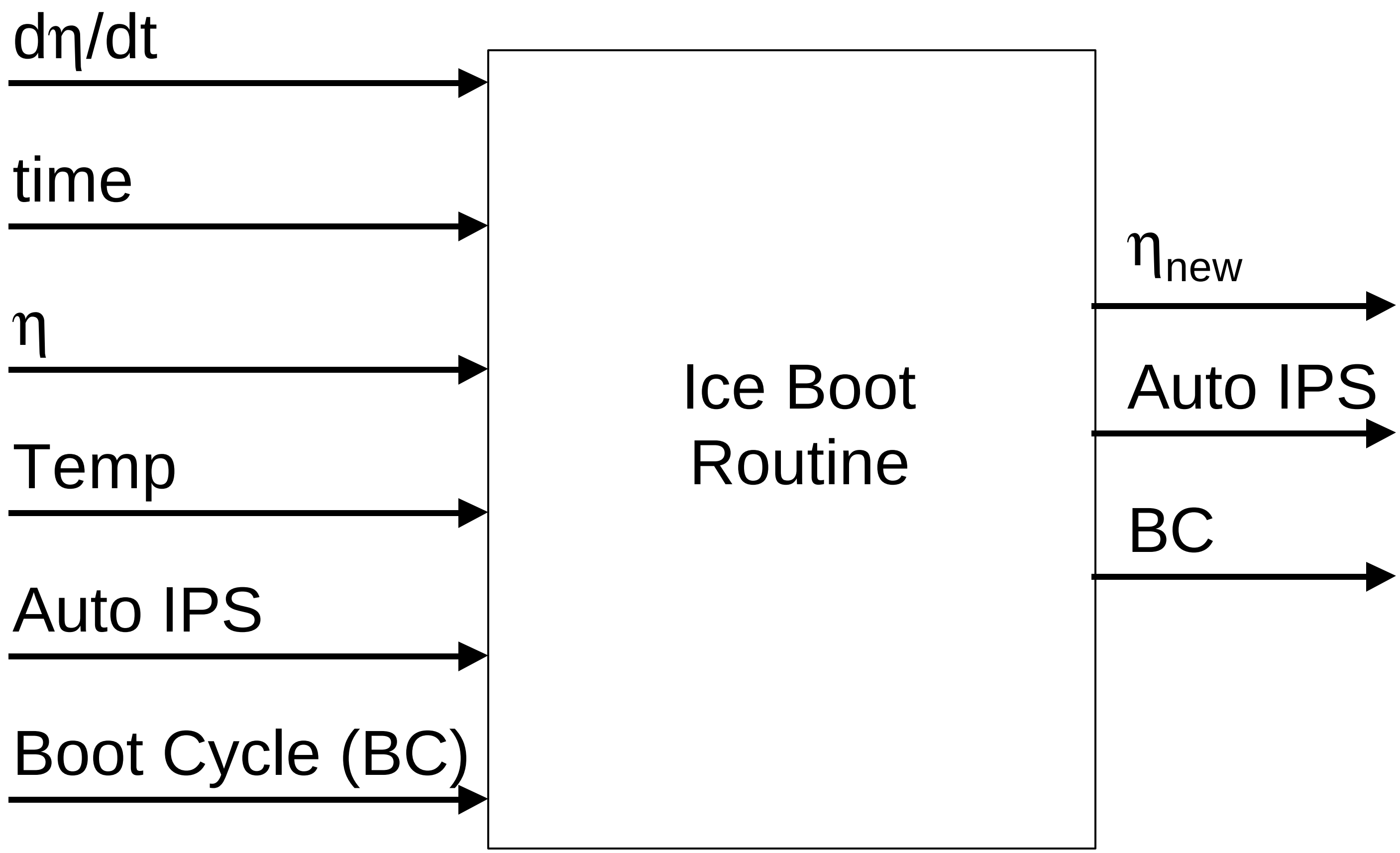


Pitch Attitude Hold Autopilot

- PAH A/P



Ice Protection System



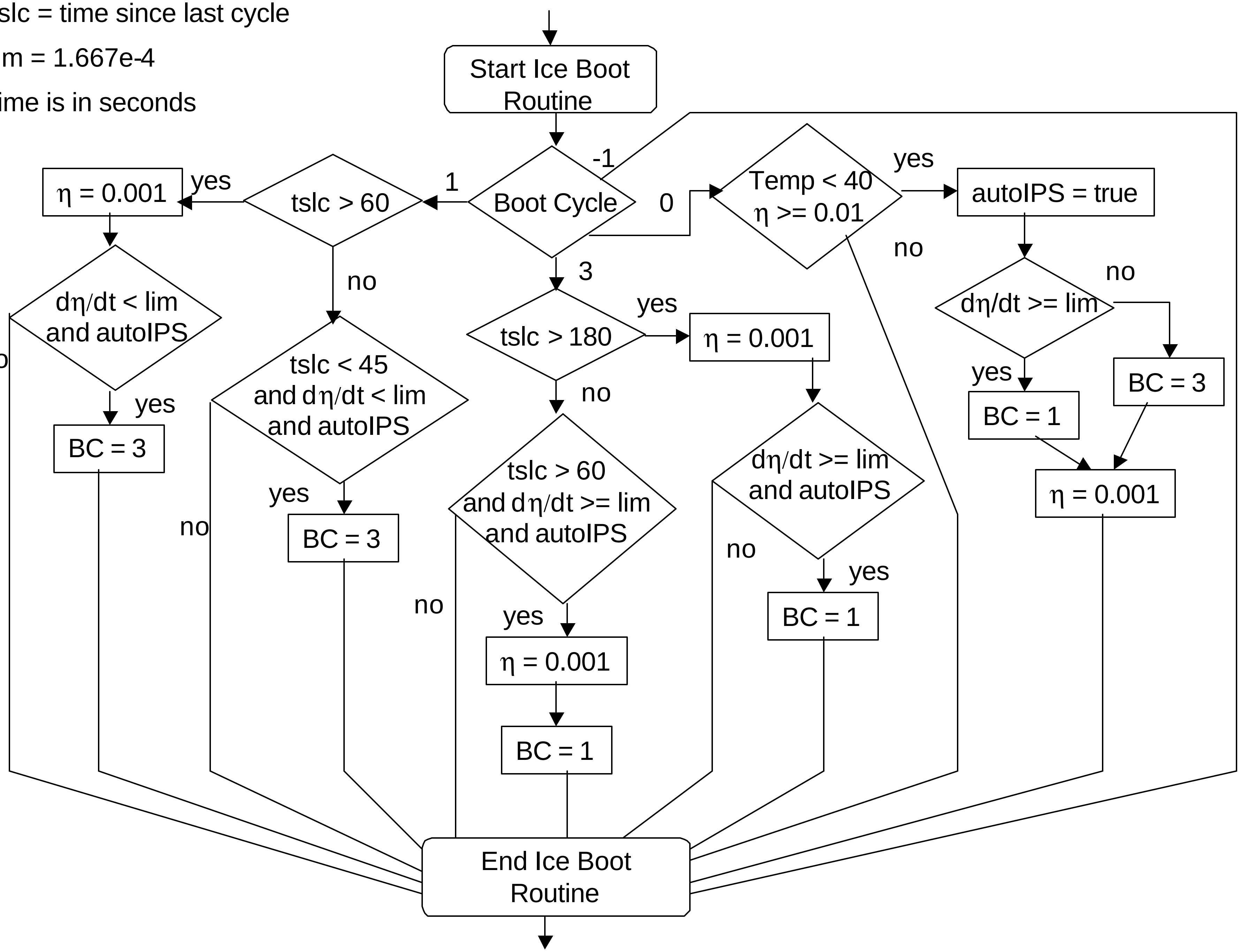
BC = 0, off unless overide
BC = 1, 1-min cycle
BC = 3, 3-min cycle
BC = -1, failure

- # IPS Boot Cycle Routine

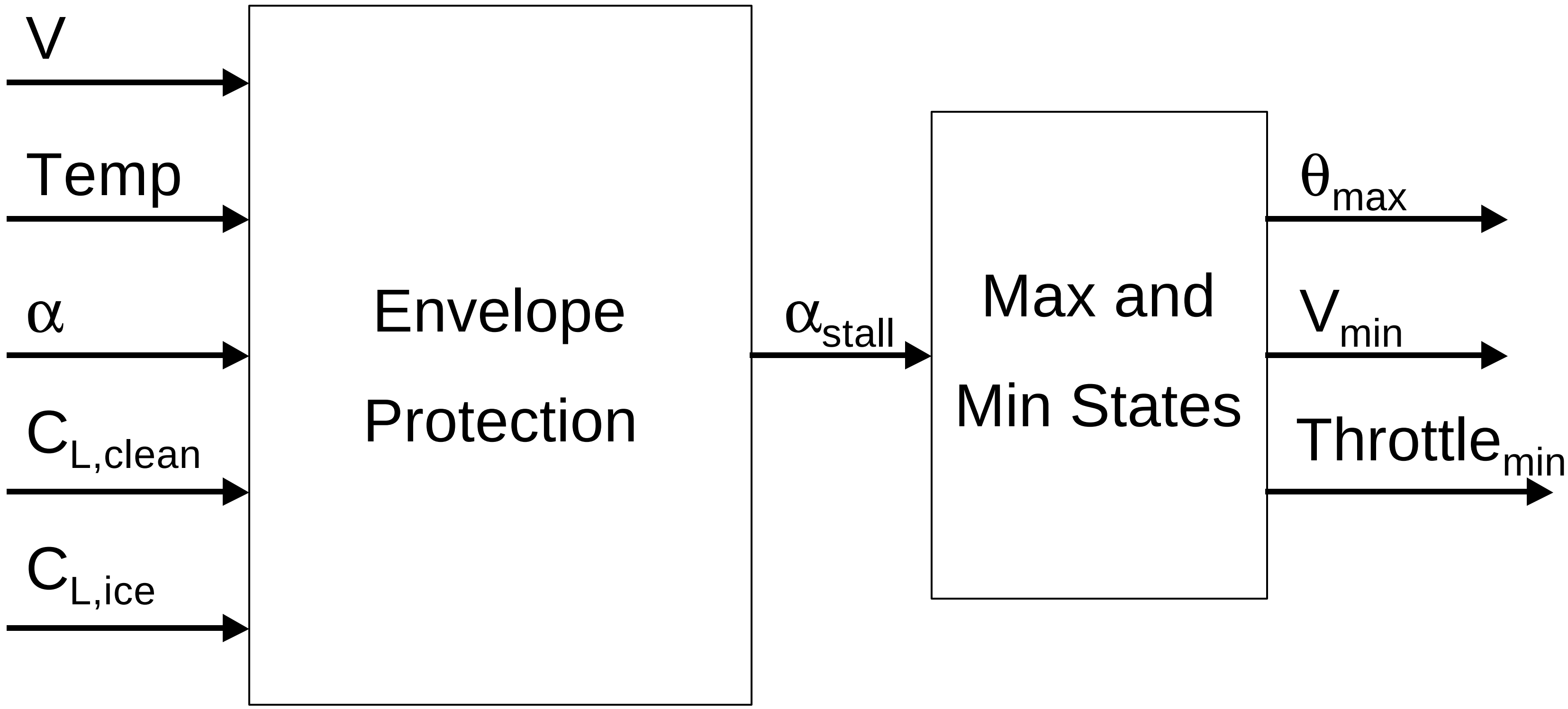
tslc = time since last cycle

lim = 1.667e-4

time is in seconds



Envelope Protection (Longitudinal)



Other Parameters and Models

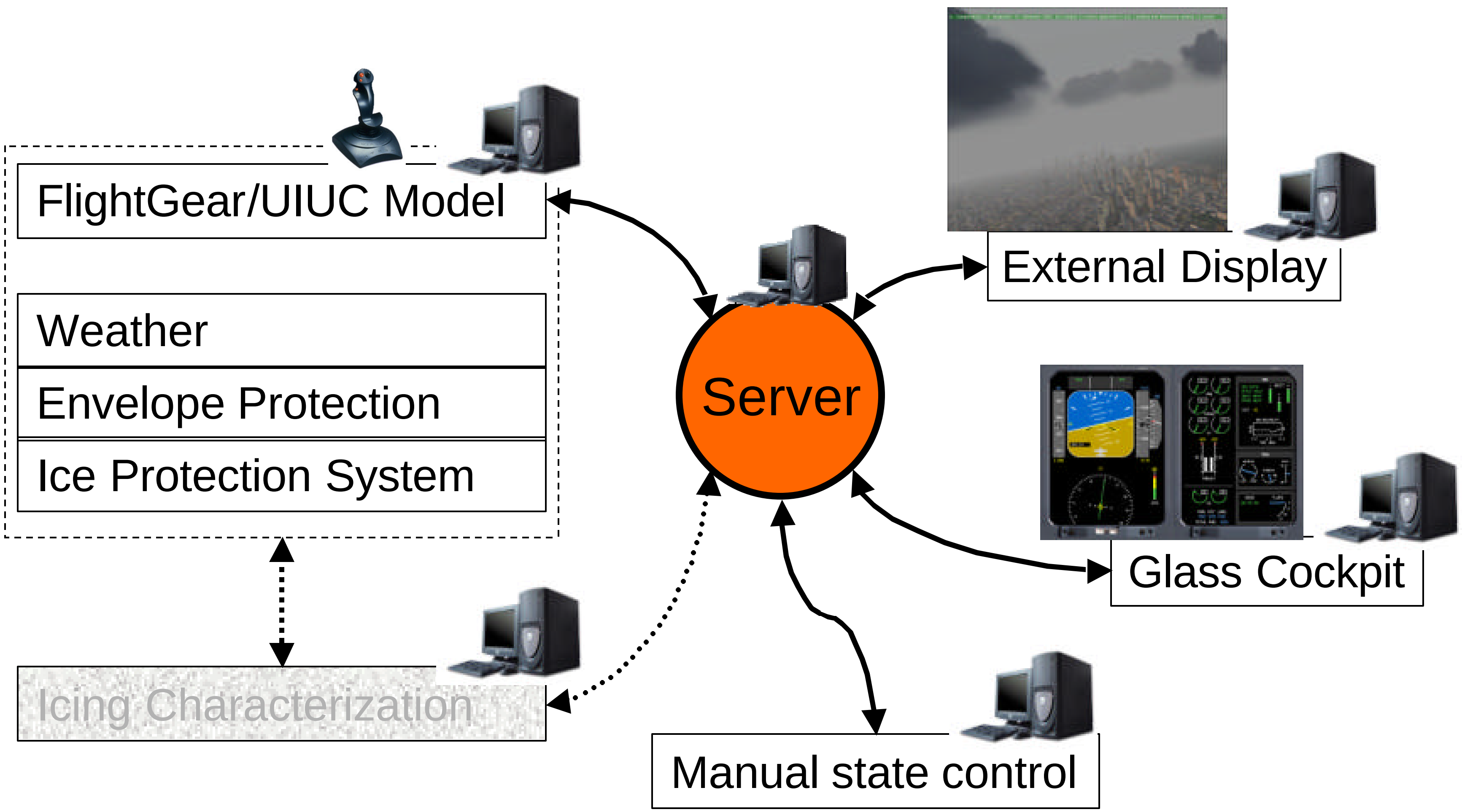
- Ground reactions (landing gear) model
- Control deflection limits
- Aircraft weight
- Mass moments of inertia

Distributed Simulation

- Motivation: Single computer not fast enough to run all IEFS components in real-time
- Objective: Distribute processor-intensive modules across multiple CPUs

Networked IEFS Components

Smart Icing System Review, September 30 – October 1, 2002



FlightGear Baseline Code

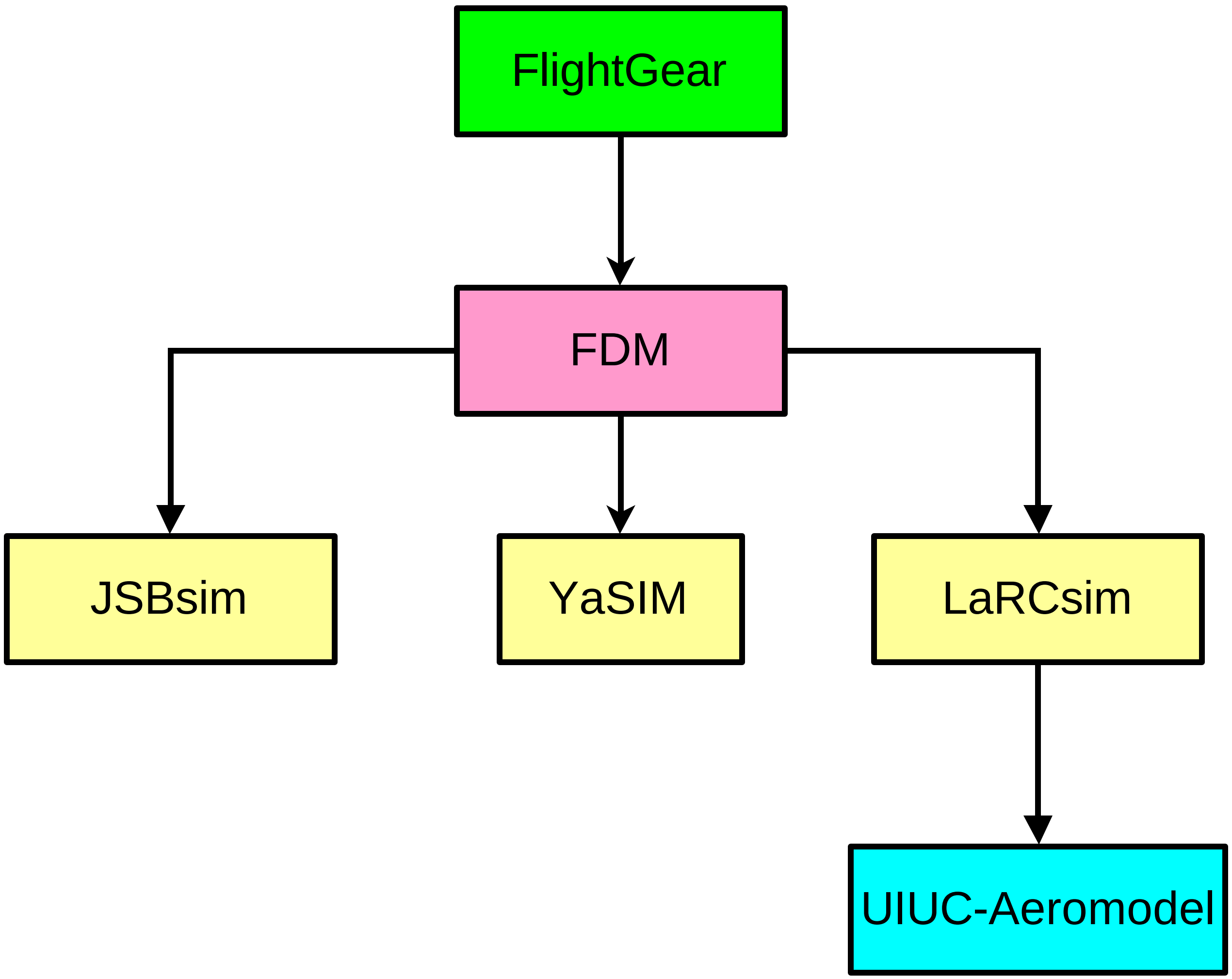
- Open-source flight simulator http://www.flightgear.org
- C/C++ coding, OpenGL graphics, Multi-platform
- Includes several flight dynamics model (FDM) solvers and associated aircraft flight models
- SIS IEFS uses the NASA Langley LaRCsim FDM (NASA TM 110164, April 1995)

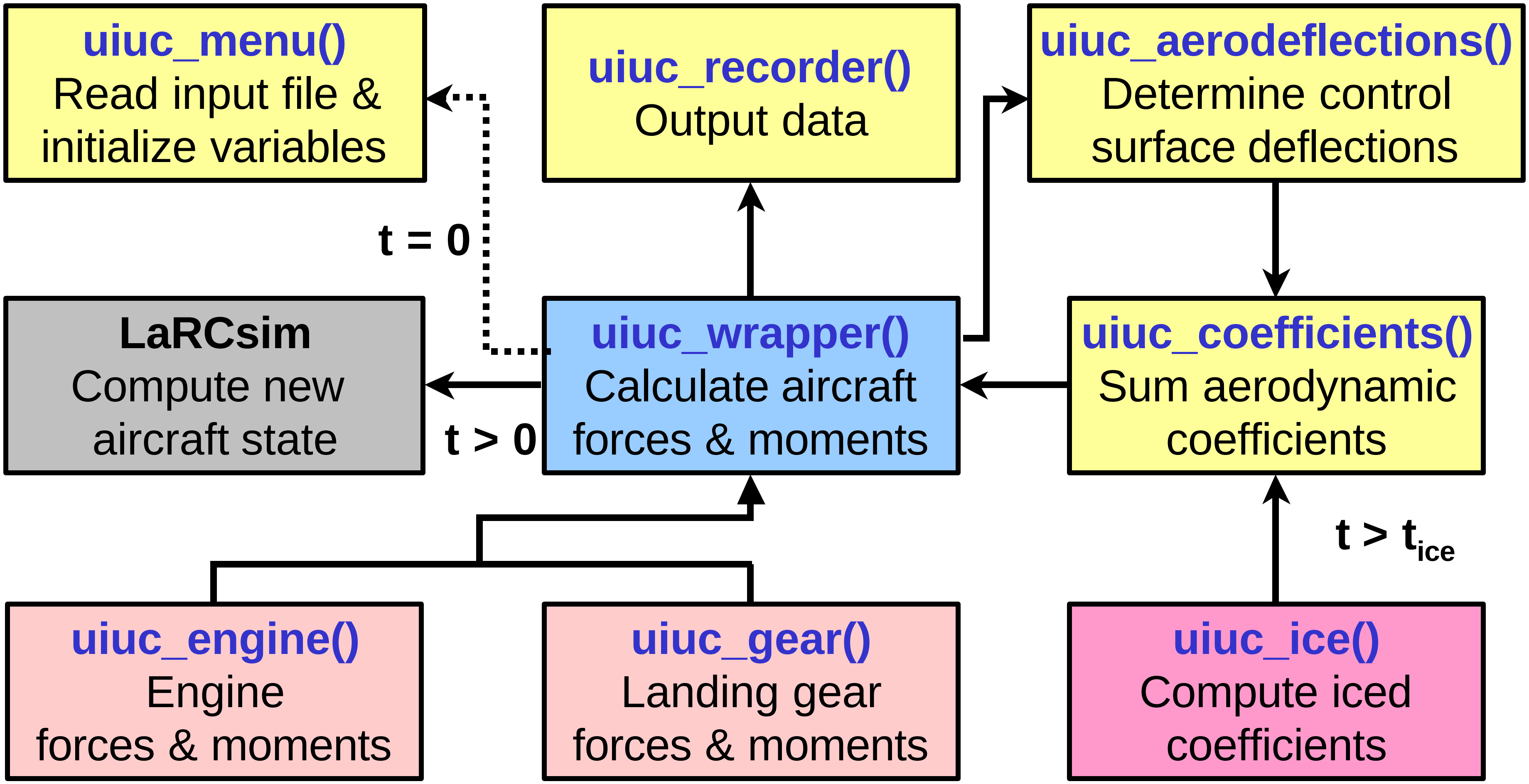
UIUC FGFS Modifications

- Integration of SIS components
- Reconfigurable aircraft model description (over 20 aircraft models exist)
- Multiple aero-data formats
  - Linear, nonlinear table lookup, mixture
  - Wind or body axis data
  - Full aircraft or component based data

- Engine torque, engine gyroscopic effects, tail downwash, apparent mass effects, and more modeled (not all with the Twin Otter)
- Batch mode simulation
- Play-back mode using FDR stream
- Networked with server

FGFS/UIUC Code Architecture




uiuc_menu()
Read input file & initialize variables
uiuc_recorder()
Output data
uiuc_aerodeflections()
Determine control surface deflections
t = 0
LaRCsim
Compute new aircraft state
t > 0
uiuc_wrapper()
Calculate aircraft forces & moments
uiuc_coefficients()
Sum aerodynamic coefficients
t > tice
uiuc_engine()
Engine forces & moments
uiuc_gear()
Landing gear forces & moments
uiuc_ice()
Compute iced coefficients

External Display

- Microsoft Flight Simulator 2002 (MSFS) used in display mode for the out-the-window view.
- Driven over the network in so-called "slew mode" using aircraft state data from FGFS
- MSFS cannot be adapted to simulate aircraft icing


n. Temperature: 15. Dewpoint: 15. Altimeter 2992. ILS runway 13 center approach in use. Landing and departing runway 13 center . . V

Glass Cockpit

- Has gone through several iterations
- Based partly on code by Brian Fuesz, Frasca International
- Uses OpenGL
- Incorporates SIS components: IPS and Envelope Protection


PAH
AP1
151
180
160
152
140
120
0.20M
11231
299
11500
11000
112
19.59
EPS OFF
20
10
171
89
AOA
RPM
TORQUE
ITT
50.0
500
500
50
50
THRUST
95
95
OIL
FUEL QTY (LBS)
1000 1000 1000
TOTAL FUEL 3000
IMS
IPS AUTO
PITOT HEAT
INLET HEAT
PROP HEAT
L
BOOT
R
T
OAT 29
IMS RELIABILITY
LEVEL
-5.0
-2.5
0.0
TIME (MIN)
TRIM
AILERON
LWD
RWD
RUDDER
NL
NR
ELEV
NU
ND
GEAR
DN DN DN
FLAPS
0
10
20
30

Example Setup

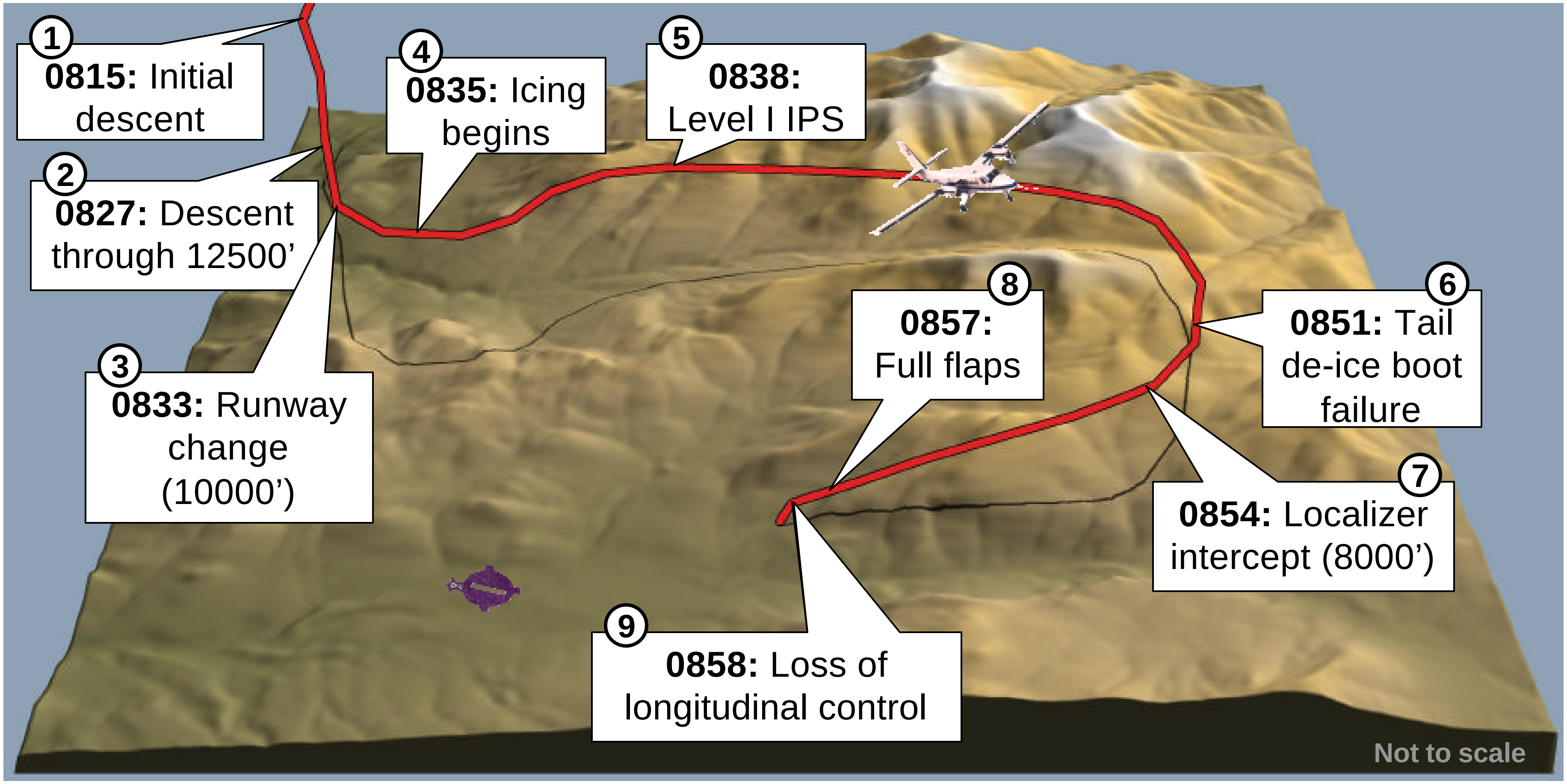
Scenarios

- Develop fictional icing encounter accident/incident (event) scenarios to demonstrate Ice Management System (IMS) capabilities and benefits
- Enact scenarios on UIUC PC-based flight simulator, with and without IMS active
- Two scenarios currently under development, based on historical event data:
  - Tailplane stall
  - Roll excursion

Scenario 1: Tailplane Stall

- Aircraft in approach configuration
- Partial or full use of flaps
- Steep and/or nonstandard approach
- Aircraft in high-weight, forward-CG configuration – high tail down-force
- Crew unaware of icing severity

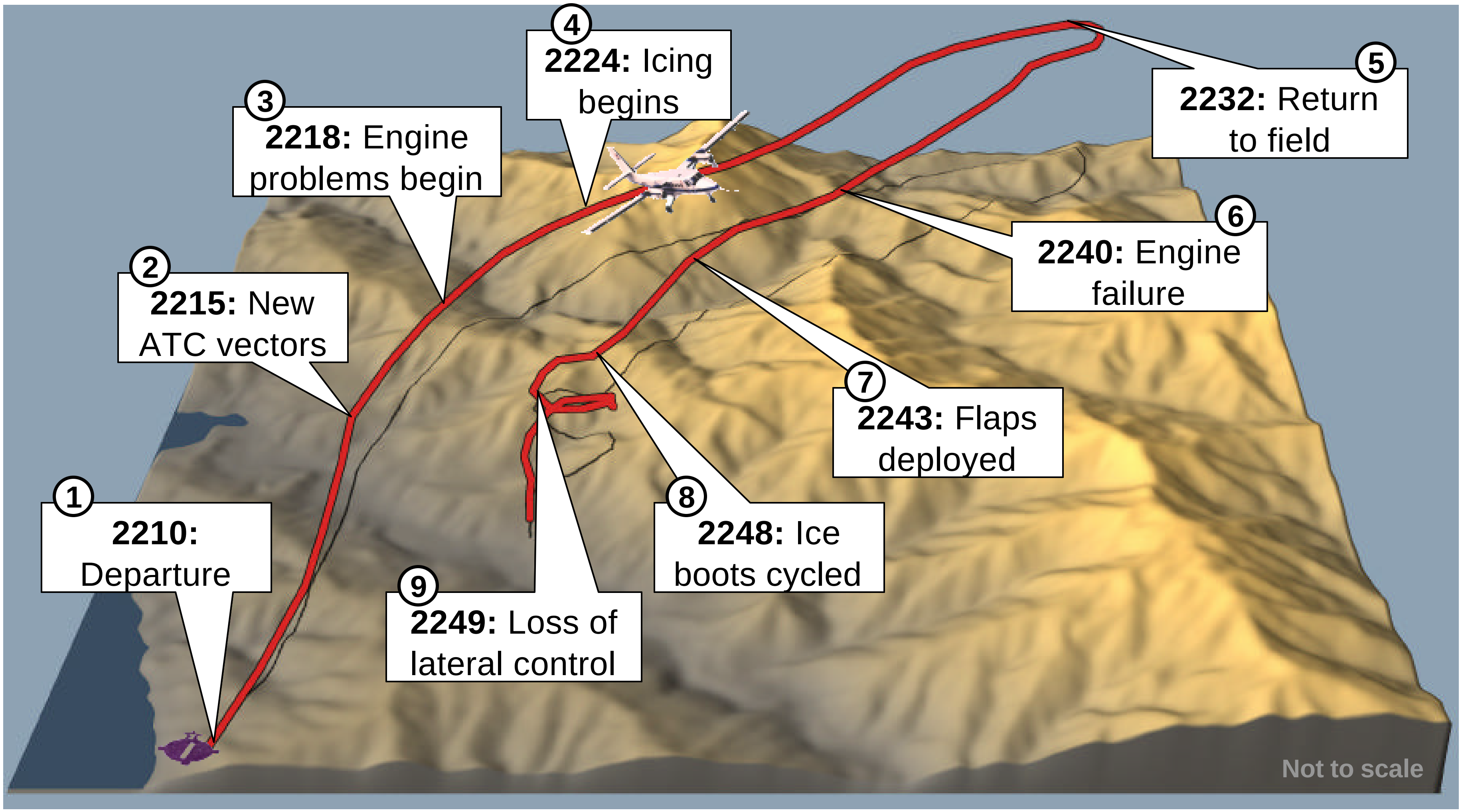
Scenario 1: Tailplane Stall



Scenario 2: Roll Upset

- Aircraft in approach configuration
- Large droplet icing conditions
- Use of autopilot during known icing conditions
- Crew unaware of icing severity
- Ice accumulation behind de-ice boots

Scenario 2: Roll Upset



Summary

- An Icing Encounter Flight Simulator (IEFS) has been created, more work is still ahead
- Distributed simulation used to ensure real-time simulation
- Scenarios are being design and SIS components are being tested
- Demo follows

Work in Progress

- Implement force feedback for envelope protection (stick shaker and soft limits on control surface deflections)
- Resolve some issues that exist with the aerodynamic data (manifested in handling qualities)
- Obtain lateral asymmetric icing model and envelope protection model when available (roll upset scenario)
- Move forward with demo development

Recommendations for Future Work

- Increase the fidelity and function of the models
  - Engine model
  - Autopilot and envelope protection models
  - Lateral aerodynamics, including spin entry due to icing
  - Incorporate icing characterization models
  - Navigation models
- Expand the number of aircraft models from one to three, including a general aviation aircraft and commuter jet

Recommendations for Future Work

- Exploit the current framework
  - Simulate real accident scenarios and study them
  - Use the simulator as an engineering tool for analysis of aircraft icing encounters