

Spanwise Adaptive Wing

June 23, 2018

Agenda

- Sim Architecture
- Phase 1 Tasks
  - HQ Analysis
  - Mission Planning
  - Failure Analysis
  - Maneuver Planning
- Phase 2 Tasks
  - Completed
  - Current
  - To-do



AFRC Core Simulation

- Fixed-based engineering simulation
- Non-linear 6-Degrees-of-freedom (6-DOF)
  - Oblate, rotating earth, Low-Earth-Orbit (LEO) capable
  - Traceability to certified Shuttle simulation, X-30 (NASP), and X-33
- Oracle Linux Server release 6.9
- Server Class Hardware
  - Intel Xeon E5 2699V3 3.2 GHz
  - 72 Threads
  - 400G Ram
  - 36 Cores



Scripting

- Access to all symbol table variables
- Uses “calc” language
  - Mathematics
  - Arithmetic functions
- Can set values
  - Name=value syntax

File View Commands Tools Windows Help

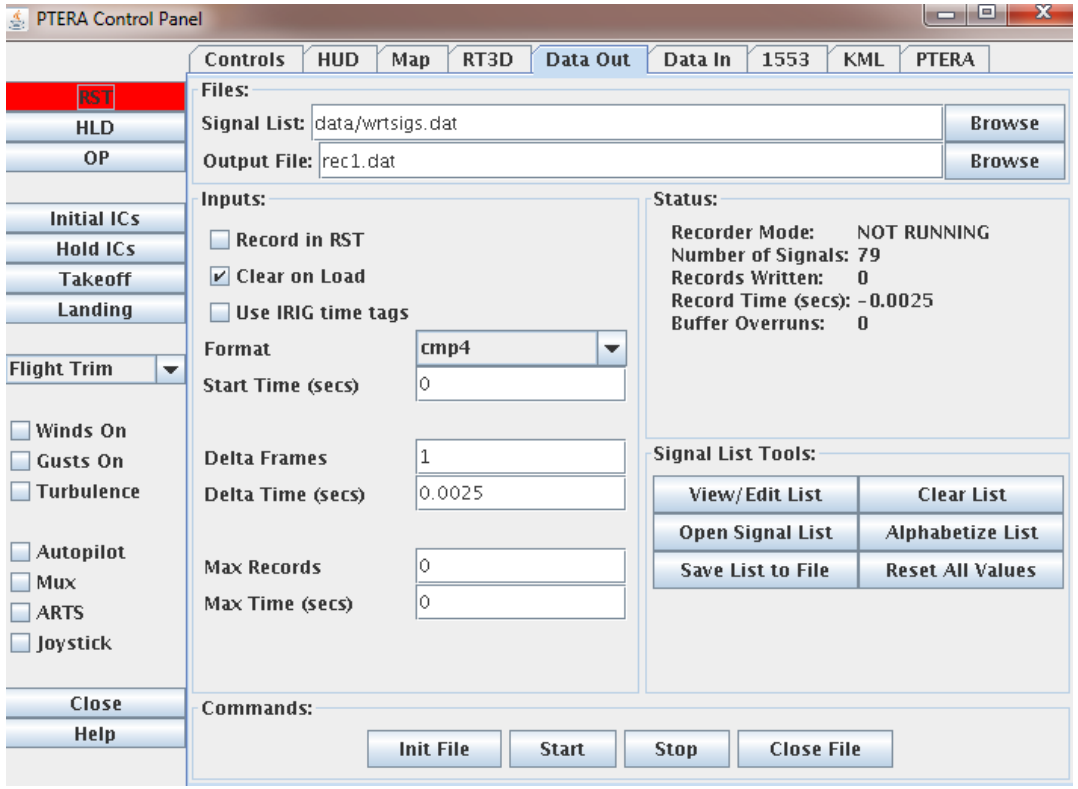
PTERA-SAW Sim V1.05 - Core V8.01 May 1, 2018 - RST intcnt=14412

Clock	Time	Type	Message	Source
15:30:42.343	0.000	VAR	Cs.out.dail_ro	script/start_ptera_sys...
15:30:42.418	0.000	VAR	Cs.out.lwinglet	script/start_ptera_sys...
15:30:42.534	0.000	VAR	Cs.out.rwinglet	script/start_ptera_sys...
15:30:42.685	0.000	MASS	nowc=false	script/start_ptera_sys...
15:30:42.760	0.000	MASS	fuel_ic=58	script/start_ptera_sys...
15:30:42.911	0.000	KML	pred_dt=.1	script/start_ptera_sys...
15:30:42.987	0.000	KML	pred_steps=500	script/start_ptera_sys...
15:30:43.093	0.000	KML	pred_wa=1	script/start_ptera_sys...
15:30:43.168	0.000	KML	range=4	script/start_ptera_sys...
15:30:43.244	0.000	KML	view_ctrl=true	script/start_ptera_sys...
15:30:43.319	0.000	KML	track_dt=.1	script/start_ptera_sys...
15:30:43.395	0.000	KML	scale=.1	script/start_ptera_sys...
15:30:43.470	0.000	KML	auto_heading=true	script/start_ptera_sys...
15:30:43.546	0.000	KML	heading=0	script/start_ptera_sys...
15:30:43.655	0.000	KML	start	script/start_ptera_sys...
15:30:43.680	0.000	INFO	TCP: HTTP server started on port 7020	SIM
15:30:43.806	0.000	CHART	0	script/start_ptera_sys...
15:30:43.881	0.000	CHART	connect	script/start_ptera_sys...
15:30:43.907	0.000	INFO	Chart: connected to '130.134.105.134'	SIM
15:30:43.957	0.000	CHART	num_panels=7	script/start_ptera_sys...
15:30:44.033	0.000	CHART	host="130.134.250.132"	script/start_ptera_sys...
15:30:44.108	0.000	CHART	start	script/start_ptera_sys...
15:30:44.212	0.000	CHART	1	script/start_ptera_sys...
15:30:44.288	0.000	CHART	add phi*180/3.14	script/start_ptera_sys...
15:30:44.363	0.000	CHART	signal_max=50	script/start_ptera_sys...
15:30:44.439	0.000	CHART	signal_min=-50	script/start_ptera_sys...
15:30:44.514	0.000	CHART	2	script/start_ptera_sys...
15:30:44.590	0.000	CHART	add p*180/3.14	script/start_ptera_sys...
15:30:44.665	0.000	CHART	signal_max=70	script/start_ptera_sys...
15:30:44.772	0.000	CHART	signal_min=-70	script/start_ptera_sys...
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15:30:44.923	0.000	CHART	add tha*180/3.14	script/start_ptera_sys...
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15:30:45.975	0.000	CHART	signal_max=130	script/start_ptera_sys...
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15:30:46.126	0.000	CHART	7	script/start_ptera_sys...
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15:30:46.457	0.000	CHART	0	script/start_ptera_sys...



Data Recording

- Access any symbol table variable; calc expressions
- Selectable signal list file
- Selectable recording rate
- Selectable recording duration
- Disk access by separate thread avoids frame overruns





Linear Model Generator

- Creates a linear model to be imported into Matlab/Simulink.
- State Matrices
  - X = [q, alpha, v, theta, h, p, r, beta, phi, psi]
  - U = [differential inboard ailerons, differential outboard ailerons, elevator, rudder, flap, left winglet, right winglet]
  - Y = [an, anx, anz_cs, any, any_cs]
  - Coef = [cXb, cyb, cZb, cl, cm, cn]
- Output Matrices
  - A, B, H, F, A coefficients, B coefficients
- Each state variable is perturbed and output states are recorded



LIN - Linear Model Generator

```
%  PTERA-SAW Sim Version 1.05 - Linearized Model
%  Altitude = 4300.02 ft,    Mach = 0.14548
%
%  Xdot = [A] X    + [B] U
%  Y    = [H] X    + [F] U
%  Coef = [Acof] X + [Bcof] U
%
%  [A]  = D(Xdot) / D(X)          [H]  = D(Y) / D(X)          [Acof] = D(Coef) / D(X)
%  [B]  = D(Xdot) / D(U)          [F]  = D(Y) / D(U)          [Bcof] = D(Coef) / D(U)
%
%  cm_alpdot   = d(cm)   / d(alpdot)
%  clft_alpdot = d(clft) / d(alpdot)
%  cd_alpdot   = d(cd)   / d(alpdot)
%
%
%  X    = [q,  alp,  v,  tha,  h,  p,  r,  bta,  phi,  psi]
%
%  U    = [dail_i_dif,  dail_o_dif,  elv,  rud,  flaps,  lwinglet,  rwinglet]
%
%  Y    = [an,  anx,  anz_cs,  any,  any_cs]
%
%  Coef = [CXb,  CYb,  CZb,  Cl,  Cm,  Cn]

Inputs/Commands:
  calc         --> put simulation into hold and calculate matrices
  save <file>  --> save results to <file> (default=linear.m)
  load <file>  --> load the config file (default=../../src/lin/LinData.cfg)
  help         --> display help information


Configuration File:  ../../src/lin/LinData.cfg

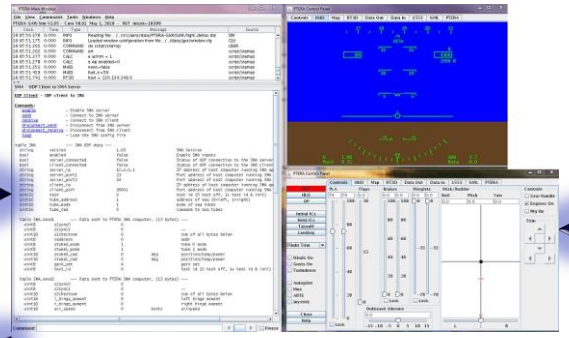

  X =
                      Trimmed       Delta               Delta
  i   Name            Value         Value               Value                  Label
   0   q               0.0000        1.0000 deg/sec      0.0175 rad/sec          Body axis pitch rate (ra
   1   alp             0.0827        1.0000 deg          0.0175 rad              Angle of attack (rad)
   2   v             160.0000        1.0000 ft/sec       1.0000 ft/sec           True airspeed relative t
   3   tha             0.0857        1.0000 deg          0.0175 rad              Pitch angle (rad)
   4   h            4300.0213        1.0000 ft           1.0000 ft               Altitude (ft)
   5   p              -0.0001        1.0000 deg/sec      0.0175 rad/sec          Body axis roll rate (rad
   6   r              -0.0000        1.0000 deg/sec      0.0175 rad/sec          Body axis yaw rate (rad/
   7   bta             0.0000        1.0000 deg          0.0175 rad              Angle of sideslip (rad)
```

PTERA-SAW Simulation Architecture

Boeing SMA Emulator



AFRC SAW Simulation



Area-I Multiplexer Application

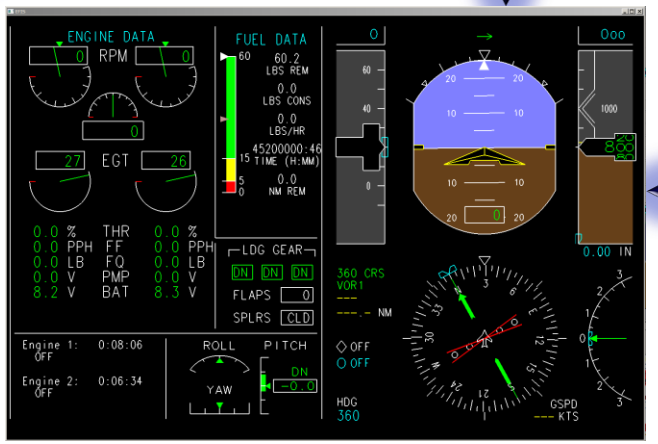
AFRC ARTS V Controller



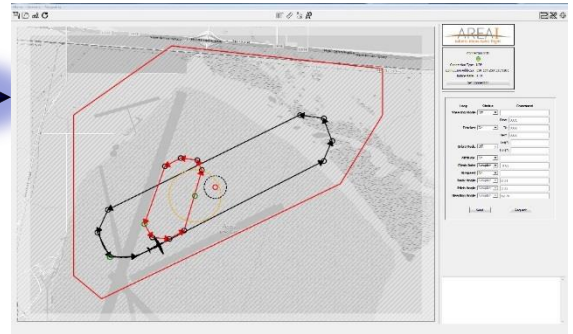
Area-I FCC Emulator



Area-I GCS



Area-I Map

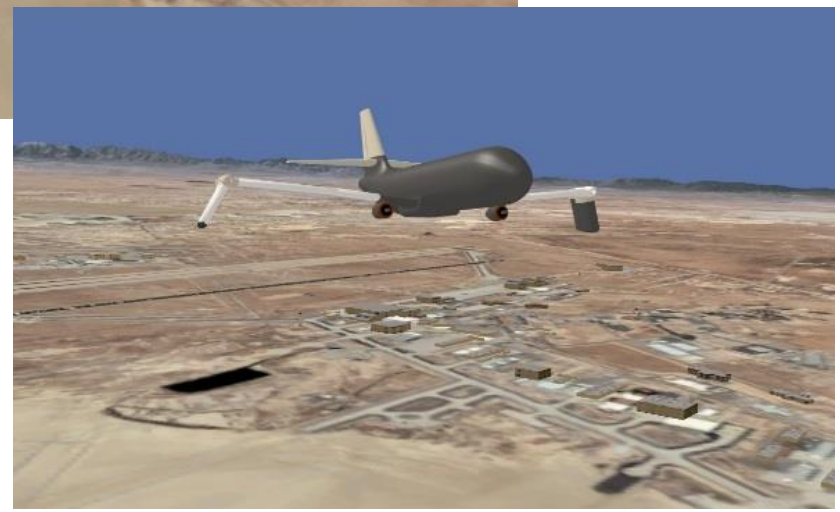


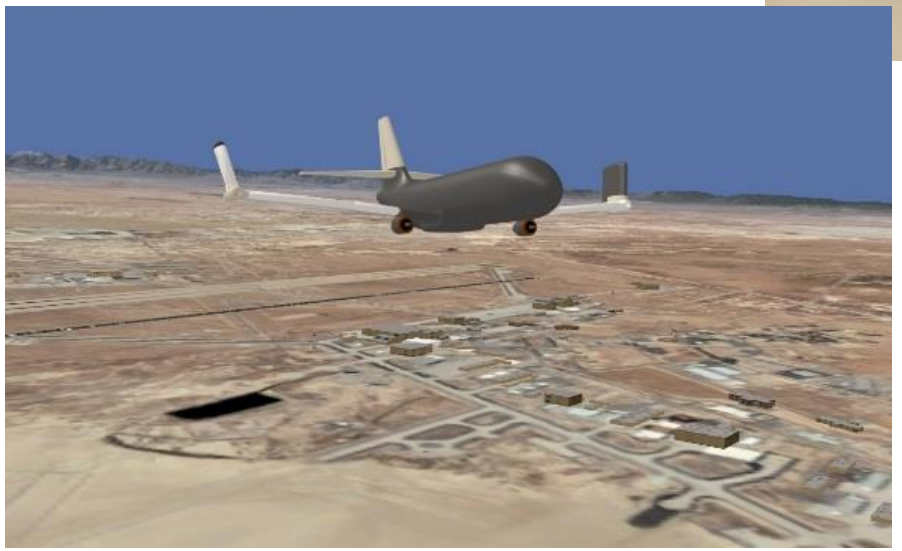


Phase 1 Handling Qualities Analysis

- Verification & Validation of Area-I control laws for phase 1 flight
  - Margins of control laws
  - Performance at various speeds and winglet angles
  - SMA hinge moment effects
  - Linear Model Generator
  - Pilot testing and evaluation



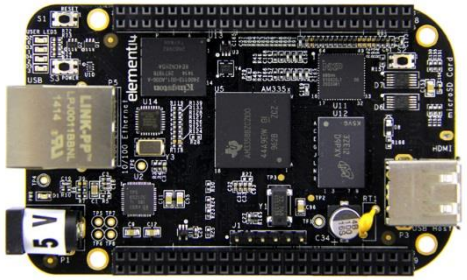






Boeing SAW SMA Controller

- Shape Memory Alloy (SMA)
- SAW Actuator Model
- Inputs
  - Tube command (degrees)
  - Hinge moments
  - Air speed
- Outputs
  - Tube Position
- Beagle Bone Hardware
  - Simulink Model
  - UDP interface





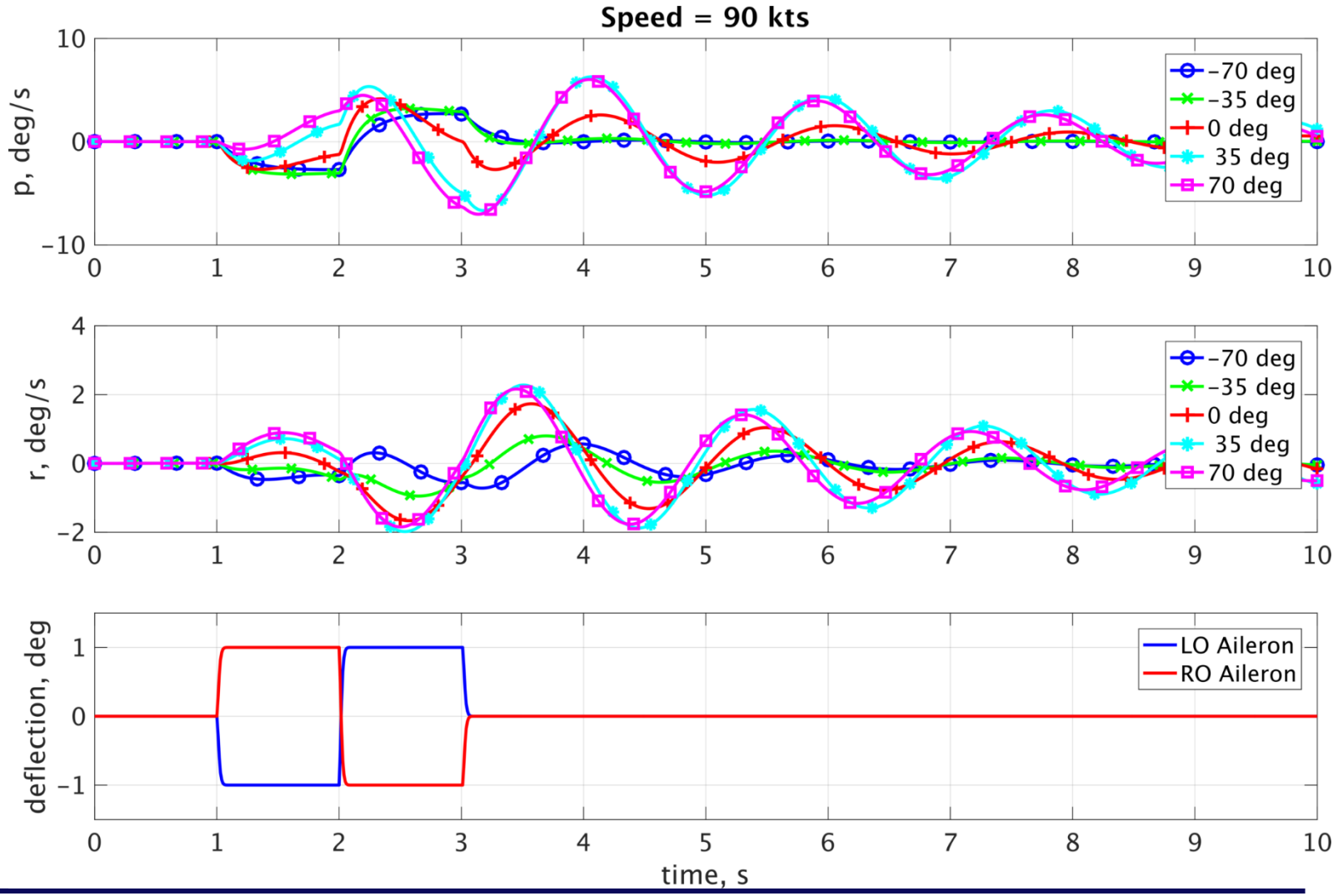




Phase 1 Preflight Predictions

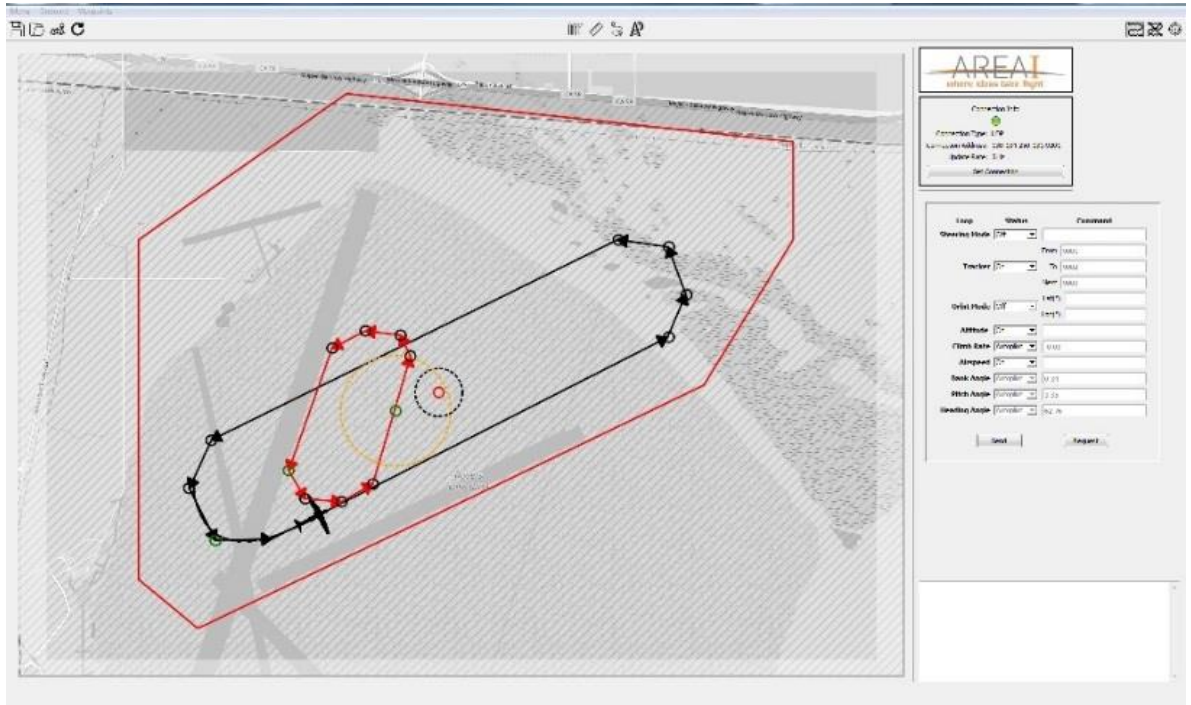
- Sim runs were used to determine responses of the aircraft to perturbations to the outboard ailerons at different winglet cant angles
  - Useful for control design and flight prediction





Phase 1 Mission Planning

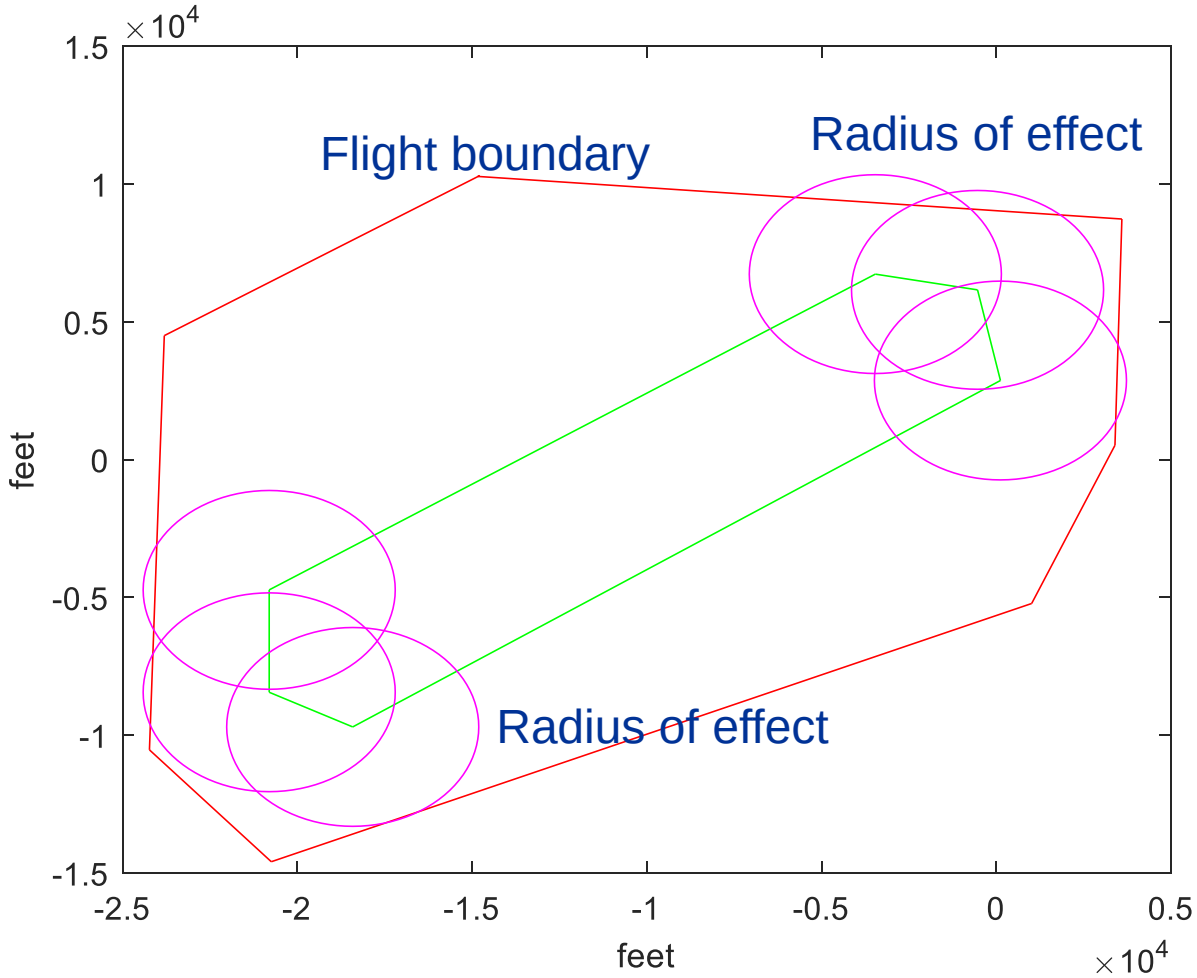
- Various flight patterns were assessed to determine the most desirable routes
  - Circular pattern with steady G's were studied
  - Oval pattern with long straightaways were determined to be better





Phase 1 Sim Failure analysis

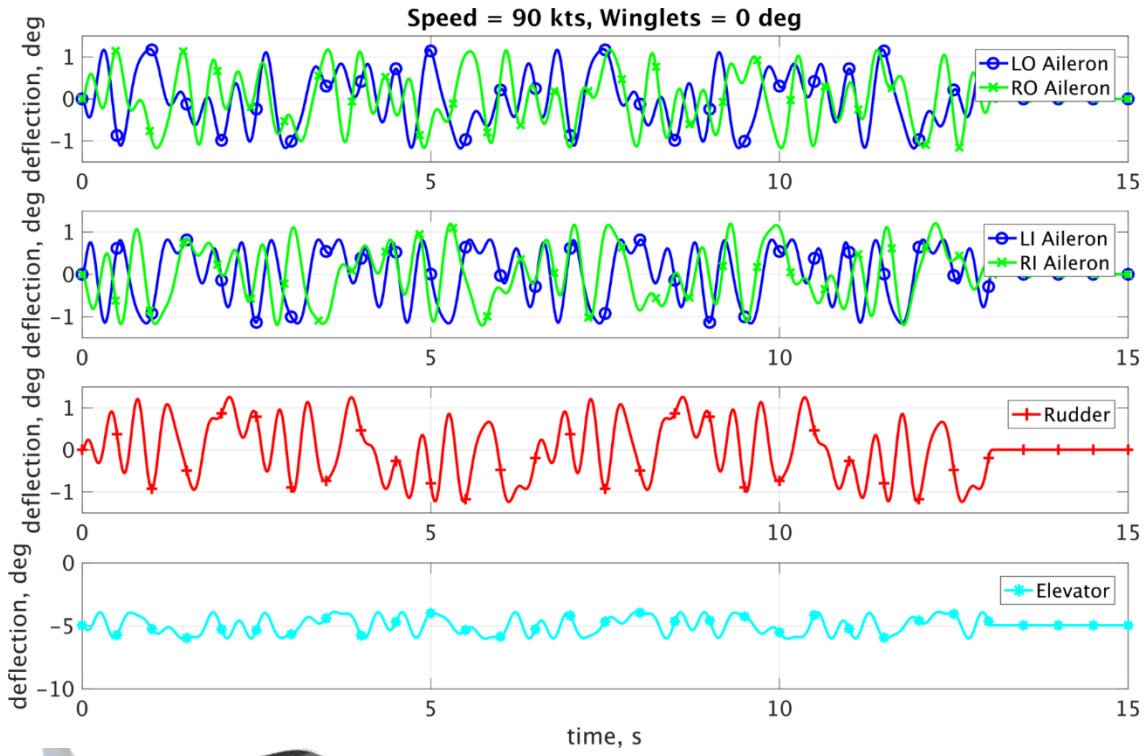
- Various failure studies were conducted to determine the range of the aircraft in the event of a flight failure
  - Engine Out
  - Lost communication
  - In this case, it was assumed the servo control box had failed and the engines were cut to terminate the system immediately





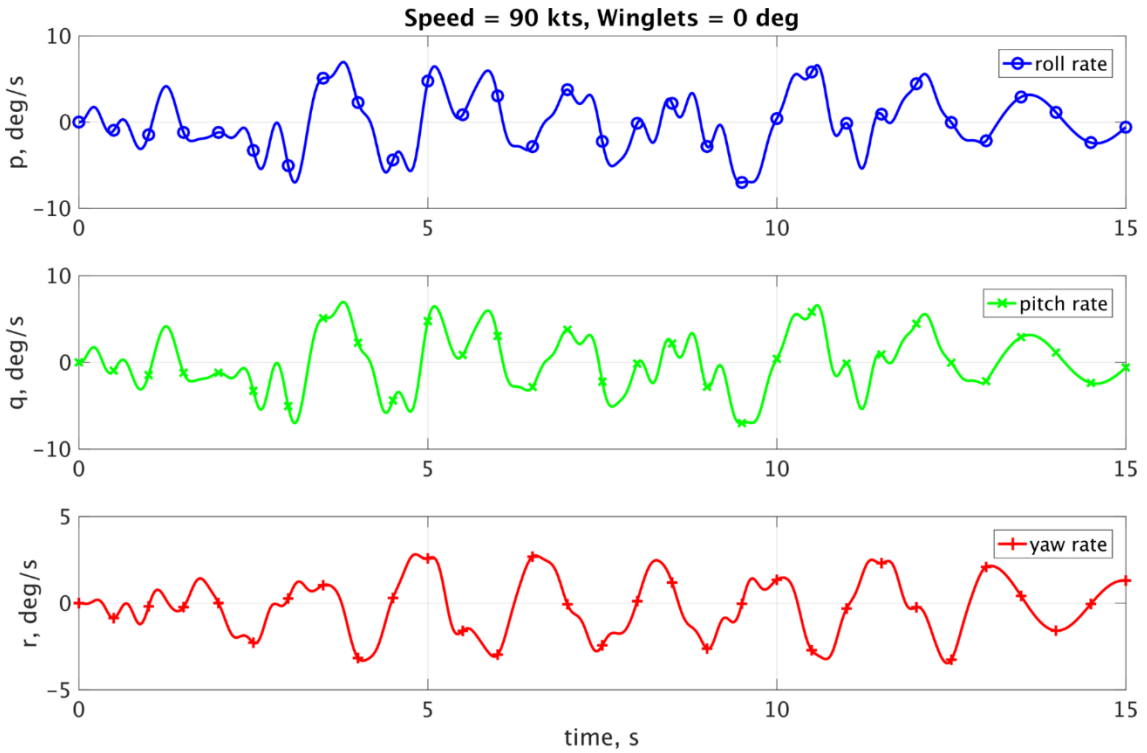
Multisine Maneuver Design

Inputs



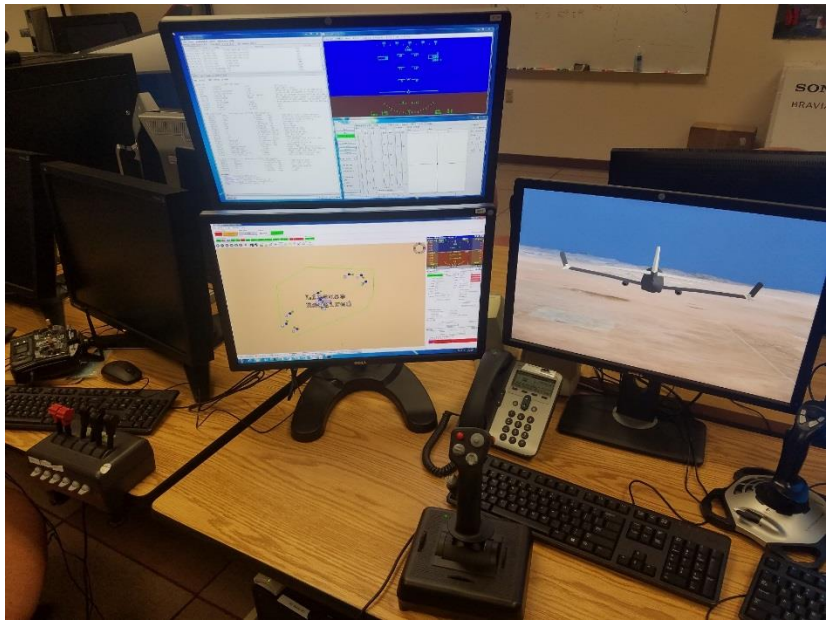


Outputs



Phase 2 Sim Tasks

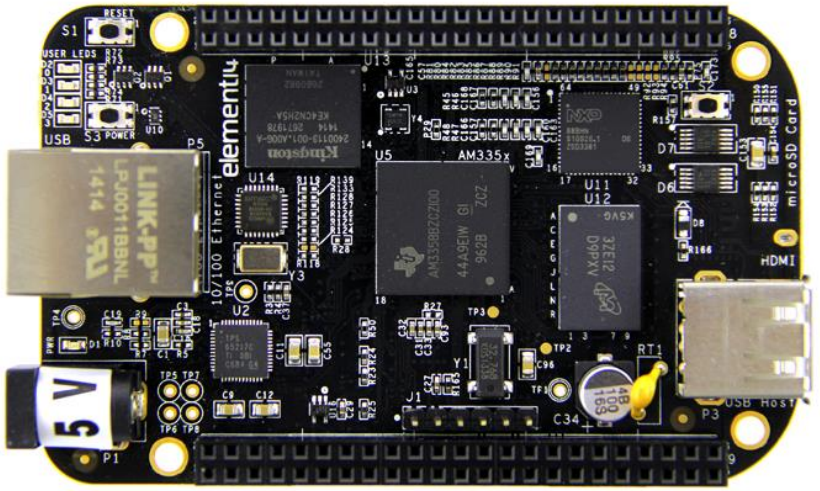
- Incorporate flight data in new SAW Version 1.05
- Ongoing work
  - Design and testing of ARTS control laws for flight
  - Determination of ARTS ICD to PTERA flight computer
  - Maneuver design
- Future work
  - V&V of ARTS control laws





NASA ARTS V

- Airborne Research Test System V
- NASA Control System
  - Interfaces to Area-I Maestro in the aircraft
  - Bypasses Area-I applications in the simulation environment
    - Interfaces to the control system model in the simulation
- Beagle Bone Hardware
  - Simulink Model
  - UDP interface



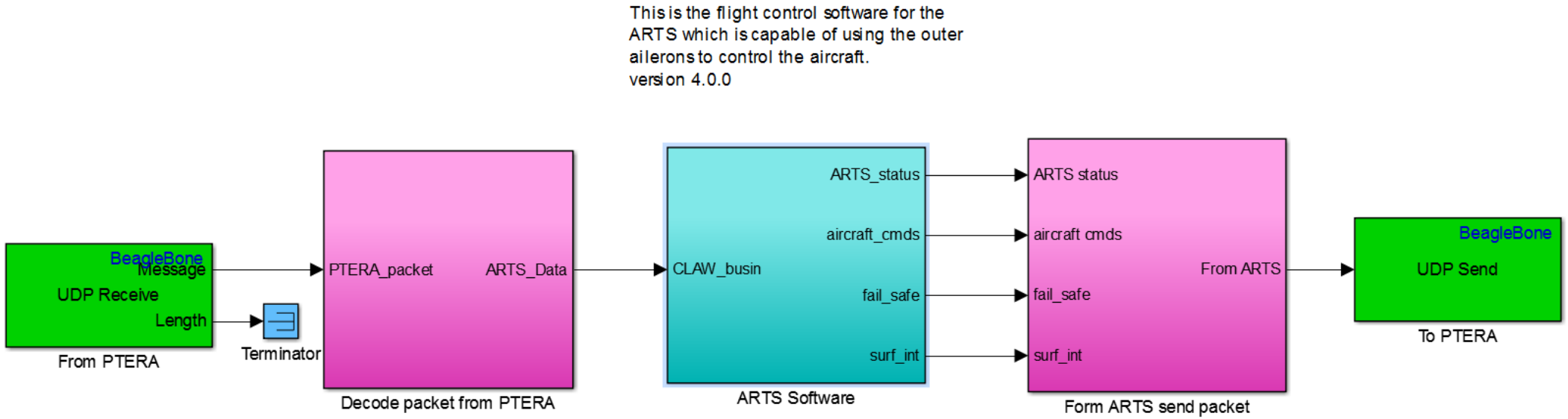


Phase 2 ARTS Design

- Design and testing of ARTS control laws for phase 2 flight
  - Added capability to control the ailerons on the SAW winglet surface
  - Upgraded the ARTS ICD for flight
  - Added safety features for enabling arts
    - Improved trim functionality
    - Trim to Area-I controller's last surface command before handoff
  - Added safety features for maneuvers
    - Added a runtime assurance module
    - If the ARTS exceeds limits, control will switch back to Area-I controller



ARTS Controller





Phase 2 Handling Qualities Analysis

- Maneuver design for phase 2 flights
  - Crosswind design experiment using control surfaces only to model a crosswind
  - Doublets to Dutch Roll using aileron or rudder
  - Open-loop testing to get the comparative benefits of using NASA's outer aileron yaw control system







Phase 2 To-Do

- V&V of ARTS control laws
  - Margins
  - Performance
- Simulation of PTERA flight computer talking to ARTS control laws
  - Commands from PTERA autopilot to ARTS control laws

AFRC ARTS V Controller



Area-I FCC Emulator






Questions

Backup Slides



ARTS Interface

Inputs

- Roll, pitch, yaw stick
- Roll, pitch, yaw angles
- Roll, pitch, yaw rates
- Angle of attack
- True Velocity
- Winglet Positions
- Maneuver controls

Outputs

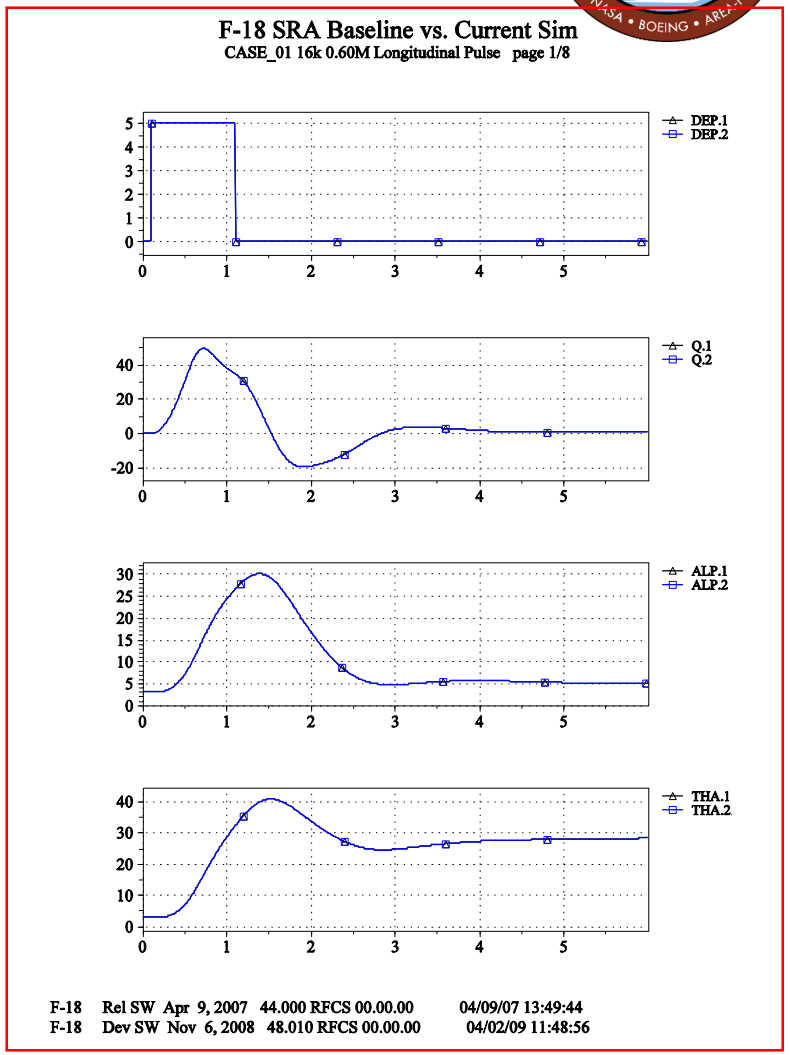
- Outboard aileron positions
- Inboard aileron positions
- Elevator positions
- Rudder position



Data Results

- QuickPlot
  - Example at right & following page
  - Plot script files can be embedded within the simulation script
- Matlab
  - gdload() to import data





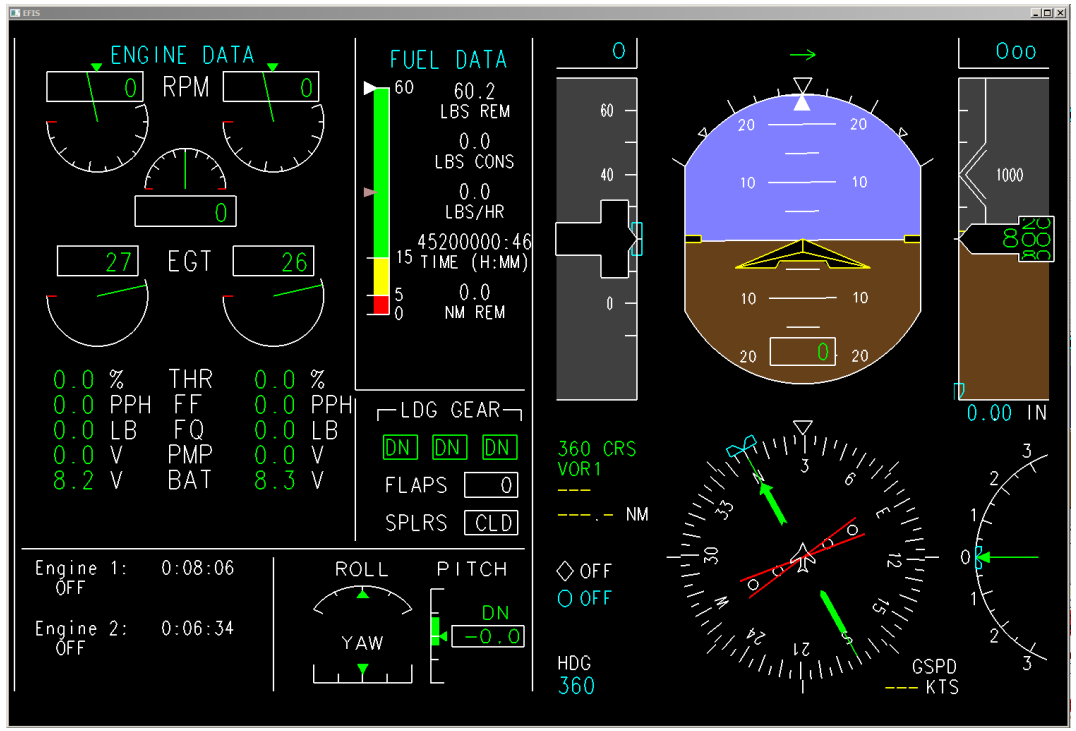
Phase 1 Sim Uses

- Handling qualities analysis
- Verification & Validation of Area-I control laws
- Failure effects analysis
- Maneuver design for phase 1 flight
- Flight pattern determination for phase 1 flight



Area-I GCS

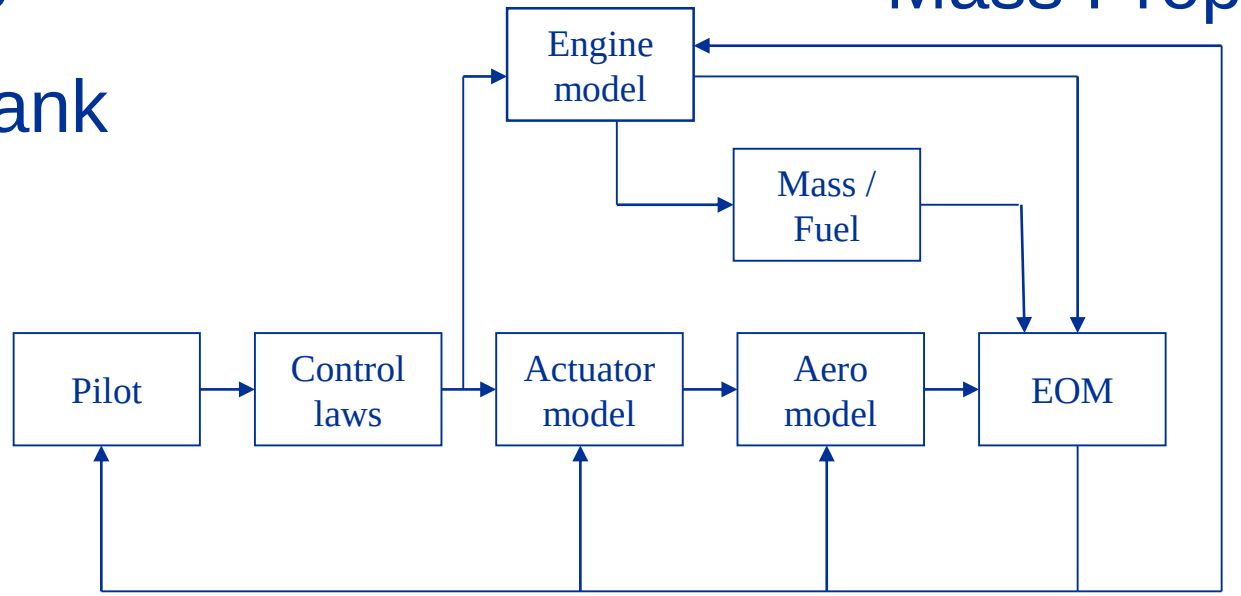
- UDP interface to the Area-I Multiplexer application
- Joystick Interface
- Autopilot controls





SAW-Specific Models

- Actuators
- Aerodynamics
- Engine
- Fuel Tank
- Control System
- Landing Gear
- Mass Properties





Simulation Images



