SUMMARY:

This report provides an introduction to the expanded GeoSurv II dynamic simulation model. It contains the simulation system overview, the model structure, the model component details, and descriptions of the functionality of the dynamic model.

Revision History

Version	Date	Description
A	09 APR 08	Initial Release

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Appendices

Scope

This report provides an introduction to the expanded GeoSurv II dynamic simulation model. It contains the simulation system overview, the model structure, the model component details, and descriptions of the functionality of the dynamic model.

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1.0 References

1. Tischler, M. B. *Advances in Aircraft Flight Control*, Taylor & Francis, London, UK. 1996.
2. Unmanned Dynamics. *AeroSim Aeronautical Simulation Blockset (Version 1.2) User's Guide*, March 2008 www.u-dynamics.com/aerosim
3. Koning, J. *Report - GeoSurv II flight control system project,* Carleton University / Delft University of Technology, July 2007
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2.0 Nomenclature

b	wing span
β	sideslip angle
δ_a	aileron deflection
δ_e	elevator deflection
δ_r	rudder deflection
δ_t	thrust setting
$\mathrm{C_L}$	lift coefficient
$C_{l\beta}$	rolling moment due to sideslip
$C_{l\delta a}$	rolling moment due to aileron deflection
$C_{l\delta r}$	rolling moment due to rudder deflection
C_{lp}	roll damping derivative
C_{lr}	rolling moment due to yaw rate
C_{m0}	pitching moment at zero angle of attack

$C_{m\alpha}$	aircraft pitching moment curve slope
$C_{m\dot{\alpha}}$	pitching moment due to angle of attack rate of change
$C_{m\delta e}$	pitching moment due to elevator deflection
C_{mq}	pitch damping derivative
C_{m_u}	pitching moment coefficient due to flight velocity
$C_{N\delta a}$	yawing moment due to aileron deflection
$C_{n\beta}$	yawing moment due to sideslip
$C_{n\dot{\beta}}$	yawing moment due to sideslip rate
$C_{n\delta a}$	yawing moment due to aileron deflection
$C_{n\delta r}$	yawing moment due to rudder deflection
C_{nr}	yaw moment damping derivative
C_{np}	yaw moment due to roll
C_{X0}	force coefficient in x-direction at zero angle of attack
C_{Xu}	force variance coefficient in x-direction due to flight velocity
$C_{X\alpha}$	force variance coefficient in x-direction due to angle of attack
$C_{X\delta e}$	force variance coefficient in x-direction due to elevator deflection
$C_{X\delta t}$	force variance coefficient in x-direction due to thrust
C_{Yr}	side force due to yaw rate
$C_{Y\beta}$	side force due to sideslip
$C_{Y\dot{\beta}}$	side force due to sideslip rate
$C_{Y\delta a}$	side force due to aileron deflection
$C_{Y\delta r}$	side force due to rudder deflection
C_{Yp}	side force due to roll
$C_{Y\delta t}$	variance coefficient in y-direction due to thrust
C_{Z0}	force coefficient in z-direction at zero angle of attack
$C_{Z\alpha}$	force variance coefficient in z-direction due to angle of attack
$C_{Z\dot{\alpha}}$	force variance coefficient in z-direction due to angle of attack rate
C_{Zq}	force variance coefficient in z-direction due to pitch rate
C_{Zu}	force variance coefficient in z-direction due to flight velocity
$C_{Z\delta e}$	force variance coefficient in z-direction due to elevator deflection
$C_{Z\delta t}$	variance coefficient in z-direction due to thrust
$\bar{c}$	mean wing aerodynamic chord
φ	roll angle

ψ	yaw angle
μ_c	mass ratio non-dimensionalized to wing chord
μ_b	mass ratio non-dimensionalized to wing span
p	roll rate
q	pitch rate
r	yaw rate
θ	pitch angle
u	velocity in x-direction
$\hat{u}$	non-dimensional velocity in x-direction
V	freestream velocity
g	gravity
w	velocity in z-direction
W	weight
6DOF	six-degree-of-freedom
DCM	direct cosine matrix
WGS-84	World Geodetic System defined in 1984
R/C	radio control
trueHWIL	MicroPilot true hardware in the loop

3.0 Introduction to "Rapid Prototyping Aircraft Simulation"

The simulation-based aircraft design and analysis are advanced engineering techniques that utilize computation-based simulation software (MATLAB, in our case) to aid the project team in design evaluation. The simulation model is constructed based on the mathematical expressions of the aircraft characteristics and responds to real-time control inputs in the manner that reflects the actual aircraft's behaviour. The concept of "Rapid Prototyping Aircraft Simulation" was first introduced by Boeing in an attempt to solve the problems in the lengthy and error-prone development of flight control systems. It involves a single general-purpose simulation model that can be used throughout the design process, from batch testing at the designer's computer to the piloted real-time flight simulation at the simulator. A typical setup of such simulation system is illustrated in Figure 1 [1].

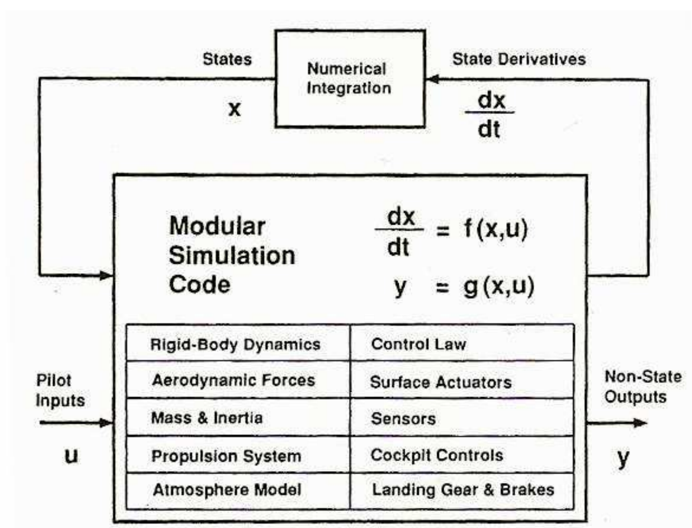


Figure 1. Rapid Prototyping Aircraft Simulation Structure

The GeoSurv II is an unmanned aerial vehicle system that possesses high level of autonomy, as well as a robust, simple, low-cost, and low magnetic signature aircraft design. All these requirements dictate a well-integrated aircraft system and a state-of-the-art avionics system. By introducing the techniques of simulation-based aircraft design and analysis, the design team can ensure the satisfactory aircraft performance and the seamless integration of the aircraft system prior to its first autonomous flight.

4.0 Expanded Simulation System Overview

The primary objective of the work has been the development of the simulation model framework that integrates the Six-Degree-Of-Freedom (6DOF) model of the aircraft, autopilot, flight management computer, the autonomy algorithm, and the obstacle avoidance algorithm in a pseudo-real-time and hardware-in-the-loop testing environment. The MathWorks Inc. MATLAB/Simulink is the primary software used for the development of the dynamic model. Figure 2 illustrates the functionality of the GeoSurv II dynamic model, and its role in the whole aircraft development process.

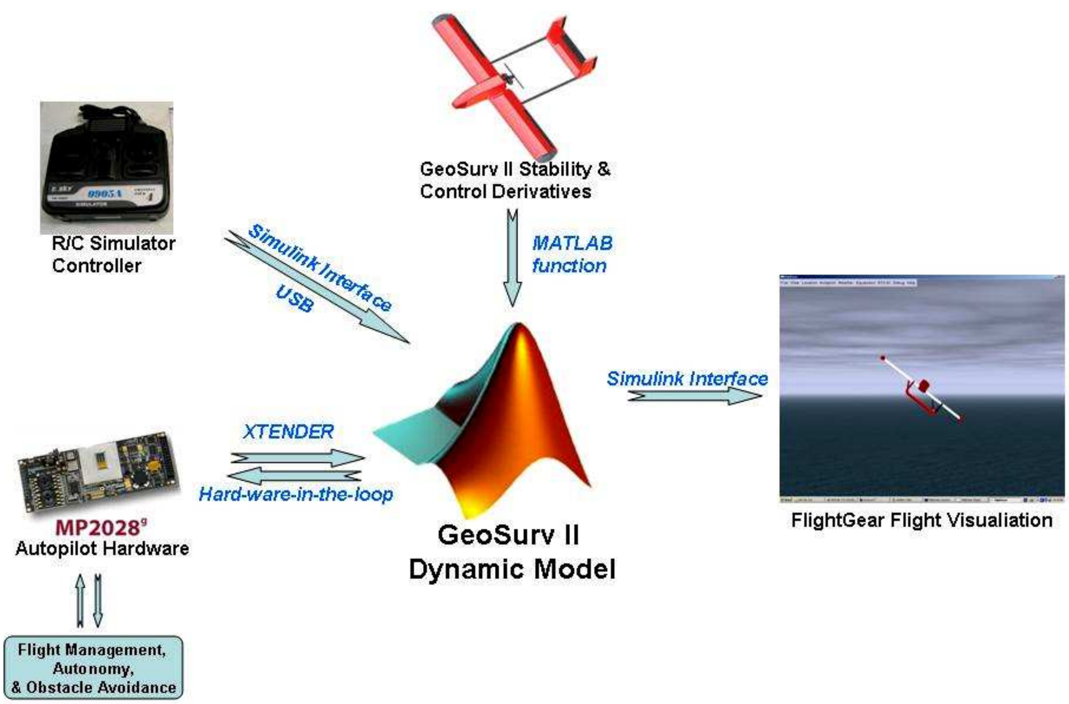


Figure 2. GeoSurv II Simulation System Overview

This model can aid the aerodynamics group in making design decisions by providing dynamic stability and control analyses and performance assessments. The high level of autonomy is a unique and important element of this aircraft. The aircraft control, navigation, flight management, obstacle detection and obstacle avoidance are solely dependent on the on-board avionics, without any human interaction during the missions. It is therefore vital to ensure that the avionics operate without error, and that all subsystems are correctly integrated. The significance of this hardware-in-the-loop setup is that the design team can investigate and solve hardware integration issues before the first flight, and possibly even before the manufacturing of aircraft.

5.0 Dynamic Model Structure and Components

The GeoSurv II dynamic simulation model consists of an R/C Transmitter Interface, Scheduled Command Block, Command Switch Logic, Aircraft 6DOF Linear Model, Kinematics, Body-inertial DCM, WGS-84, Navigation, and FlightGear Interface. The simplified layout of the current model is shown in Figure 3.

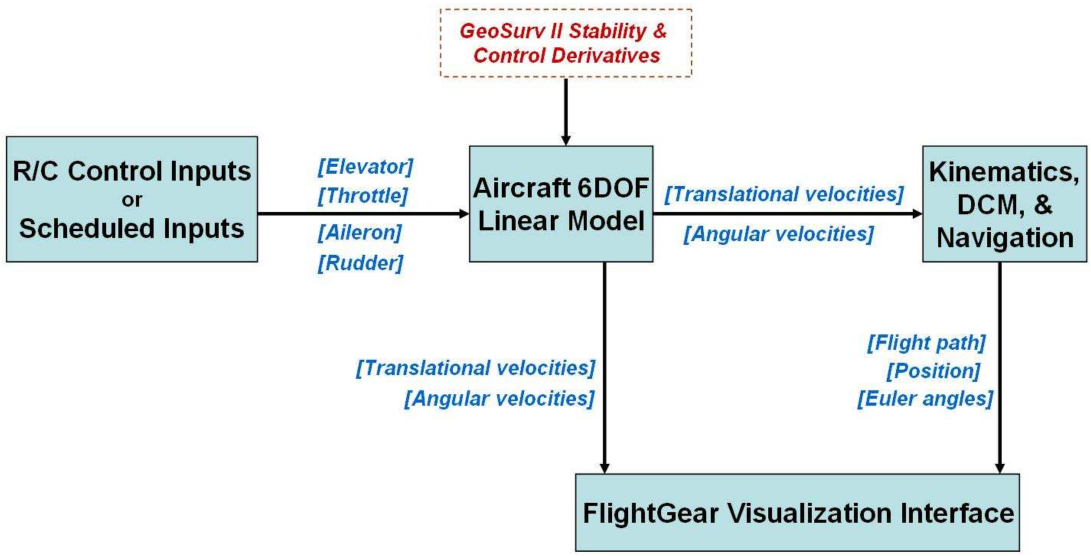


Figure 3. GeoSurv II Dynamic Model Layout

The implementation of this model has been completed using a few aerospace application Simulink blocks from the AeroSim block set [2]. A number of additional modules are also planned to be incorporated when specifications become available, and these include: autopilot, sensors, servos, autonomy, avionics, a flight management computer, a terrain module, and an autopilot hardware interface. The first level MATLAB Simulink model block diagram is included in Appendix A.

5.1. Aircraft 6DOF Linear State-space Model

The core of this dynamic model is the aircraft 6DOF state-space linear model. The implementation of this model was initiated by previous graduate student, and the details of the work can be found in document [3]. This model is based on the equations of motions of the aircraft, linearised and decoupled into longitudinal (symmetrical) and lateral (asymmetrical) components, as shown in Figure 4.

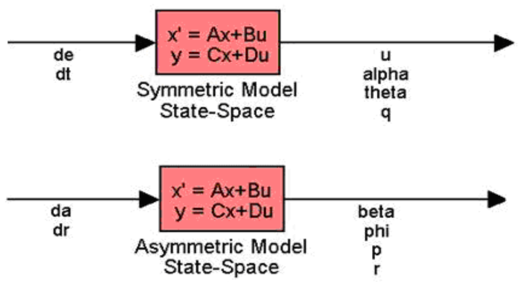


Figure 4. Aircraft Longitudinal and Lateral State-Space Models

The linear models take the state-space form and are expressed in terms of non-dimensional stability derivatives and control derivatives. These two expressions are shown in the matrix equations below [4]:

Longitudinal expression

$$\begin{bmatrix} C_{X_u}-2\mu_c D_c & C_{X_\alpha} & C_{Z_0} & 0 \\ C_{Z_u} & C_{Z_\alpha}+\left(C_{Z_{\dot\alpha}}-2\mu_c\right)D_c & -C_{X_0} & C_{Z_q}+2\mu_c \\ 0 & 0 & -D_c & 1 \\ C_{m_u} & C_{m_\alpha}+C_{m_{\dot\alpha}}D_c & 0 & C_{m_q}-2\mu_c K_Y^2 D_c \end{bmatrix} \begin{bmatrix} \hat{u} \\ \alpha \\ \theta \\ \frac{q\bar{c}}{V} \end{bmatrix} =$$

$$= \begin{bmatrix} -C_{X_{\delta_e}} & -C_{X_{\delta_t}} \\ -C_{Z_{\delta_e}} & -C_{Z_{\delta_t}} \\ 0 & 0 \\ -C_{m_{\delta_e}} & -C_{m_{\delta_t}} \end{bmatrix} \begin{bmatrix} \delta_e \\ \delta_t \end{bmatrix}$$

Lateral expression

$$\begin{bmatrix} C_{Y_\beta}+\left(C_{Y_{\dot\beta}}-2\mu_b\right)D_b & C_L & C_{Y_p} & C_{Y_r}-4\mu_b \\ 0 & -\frac{1}{2}D_b & 1 & 0 \\ C_{\ell_\beta} & 0 & C_{\ell_p}-4\mu_b K_X^2 D_b & C_{\ell_r}+4\mu_b K_{XZ} D_b \\ C_{n_\beta}+C_{n_{\dot\beta}}D_b & 0 & C_{n_p}+4\mu_b K_{XZ} D_b & C_{n_r}-4\mu_b K_Z^2 D_b \end{bmatrix} \begin{bmatrix} \beta \\ \varphi \\ \frac{pb}{2V} \\ \frac{rb}{2V} \end{bmatrix} =$$

$$\begin{bmatrix} -C_{Y_{\delta_a}} & -C_{Y_{\delta_r}} \\ 0 & 0 \\ -C_{\ell_{\delta_a}} & -C_{\ell_{\delta_r}} \\ -C_{n_{\delta_a}} & -C_{n_{\delta_r}} \end{bmatrix} \begin{bmatrix} \delta_a \\ \delta_r \end{bmatrix}$$

Each aircraft design has its unique set of stability and control derivatives. These derivatives are calculated by external MATLAB functions based upon the configuration, aerodynamic characteristics, inertial properties, and propulsive characteristics of the aircraft. These functions are mentioned in [3]. Modification has been done to incorporate the effects of variable thrust. Due to the lack of thrust information, the related coefficients were estimated and will need to be updated when data becomes available after engine testing. It is very important to note that the method used to generate the stability and control derivatives is purely analytical. In order to represent the aircraft's actual characteristics accurately, it is required to validate the derivatives with the results from wind tunnel testing, computational fluid dynamics, and possibly flight test. Details regarding this module's inputs and outputs are included in Appendix B.

Certain assumptions are made using the above linear state-space expressions and they are: rigid airframe, flat and non-rotating earth, no effects of rotating masses, and the thrust is acting on the plane of symmetry. Further, the aircraft is linearized about the steady level flight conditions, and the model is only valid for small perturbations (i.e. small control deflections or minor wind effects). As a result, the simulation of full flight envelope is not possible. Regions such as stall and large perturbations cannot be simulated using the linear model; a non-linear model would be required for these scenarios.

Although the linear model is not as accurate as the non-linear model, it has a number of advantages. As mentioned previously, the ultimate goal of this dynamic model is to aid the avionics development group in the design and integration of the autopilot and flight management computers. A linear state-space model allows the use of linear analysis tools available for control design of the autopilot. These methods are well-established and can be readily used for the GeoSurv II UAV. Also, a linear state-space model makes the analysis of aircraft characteristic modes more convenient. The eigenvalues of the aircraft's longitudinal and lateral modes can be easily calculated from matrix manipulations. Therefore, the damping ratios and time constants, which represent the aircraft's stability characteristics, can be easily obtained. Frequency analysis can be also done without any difficulty to assess the aircraft's stability. Impulse and step analysis are easily done using available MATLAB functions.

5.2. R/C Transmitter Interface

The R/C transmitter interface accepts inputs from the USB R/C Simulator through the operating system [2]. It allows the real-time control command inputs to the aircraft dynamic model.

5.3. Scheduled Control Commands

The scheduled control commands can be used to analyze the aircraft's response to specific control inputs, such as impulse, step, doublet, harmonic and sinusoidal inputs.

5.4. Control Switch Logic

The control switch logic selects control inputs between R/C transmitter interface and scheduled control commands depending on the desired testing scenario. A combination of the two input sources can also be used. (e.g. R/C elevator & throttle inputs and scheduled aileron & rudder inputs)

5.5. Kinematics (Euler)

The kinematics (Euler) module Integrates the aircraft angular rates to obtain the Euler angles, which expresses the aircraft's attitude [2]. This is expressed as:

$$\begin{vmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{vmatrix} = \begin{vmatrix} 1 & \tan(\theta)\sin(\phi) & \tan(\phi)\cos(\phi) \\ 0 & \cos(\phi) & -\sin(\phi) \\ 0 & \dfrac{\sin(\phi)}{\cos(\theta)} & \dfrac{\cos(\phi)}{\cos(\theta)} \end{vmatrix} \bullet \begin{vmatrix} p \\ q \\ r \end{vmatrix}_b$$

5.6. Body-Inertial DCM

This module takes the Euler angles to compute the Direct Cosine Matrix (DCM), which can be used for the transformations between inertial reference frame and body reference frame [2]. It can be expressed as:

$$DCM = \begin{bmatrix} C_\theta C_\psi & C_\theta S_\psi & -S_\theta \\ S_\phi S_\theta C_\psi - C_\phi S_\psi & S_\phi S_\theta S_\psi + C_\phi C_\psi & S_\phi C_\theta \\ C_\phi S_\theta C_\psi + S_\phi S_\psi & C_\phi S_\theta S_\psi - S_\phi C_\psi & C_\phi C_\theta \end{bmatrix}$$

5.7. WGS-84

This module computes the local Earth radius and gravity at current aircraft location using the WGS-84 Earth model coefficients. It includes the following calculations:

$$R_{meridian} = \frac{r_e(1-\varepsilon^2)}{(1-\varepsilon^2\sin^2\phi)^{\frac{3}{2}}}$$

$$R_{normal} = \frac{r_e}{(1-\varepsilon^2\sin^2\phi)^{\frac{1}{2}}}$$

$$R_{equiv} = \sqrt{R_{meridian}R_{normal}}$$

$$g = g_{WGS_0}\frac{1+g_{WGS_1}\sin^2\phi}{(1-\varepsilon^2\sin^2\phi)^{\frac{1}{2}}}$$

Where equatorial radius r_e = *6378137 m*, first eccentricity *e = 0.0818191908426*, gravity at equator $gWGS_0$ = 9.7803267714 m/s^2, gravity formula constant $gWGS_1$ = 0.00193185138639, and ϕ is the latitude of current aircraft location [2].

5.8. Navigation

This module integrates the navigation equations to produce the aircraft locations [2]. They can be expressed as:

$$\begin{bmatrix} V_{North} \\ V_{East} \\ V_{Down} \end{bmatrix} = DCM^T \cdot \begin{bmatrix} u \\ v \\ w \end{bmatrix}$$

The geographic location can be obtained as:

$$\dot{Lat} = \frac{V_{North}}{R_{meridian}+Alt}$$

$$\dot{Lon} = \frac{V_{East}}{(R_{normal}+Alt)\cos Lat}$$

$$\dot{Alt} = \begin{cases} -V_{Down}, AConGnd = 0 \\ 0, AConGnd = 1 \end{cases}$$

5.9. FlightGear 0.9.8 Interface

This module interfaces the dynamic model with the FlightGear 0.9.8 software for real-time flight visualization. Section 6 will provide details of the configuration of the FlightGear software.

6.0 Dynamic Analysis

In order to evaluate the GeoSurv II design, the aircraft stability and control qualities are very important criteria. They determine the performance of the aircraft, and thus determine whether the design can meet the customer's requirements. The stability of the aircraft has been assessed by analyzing the longitudinal motions and lateral motions. The aircraft's longitudinal dynamic response to an elevator doublet input is shown in Figure 8.

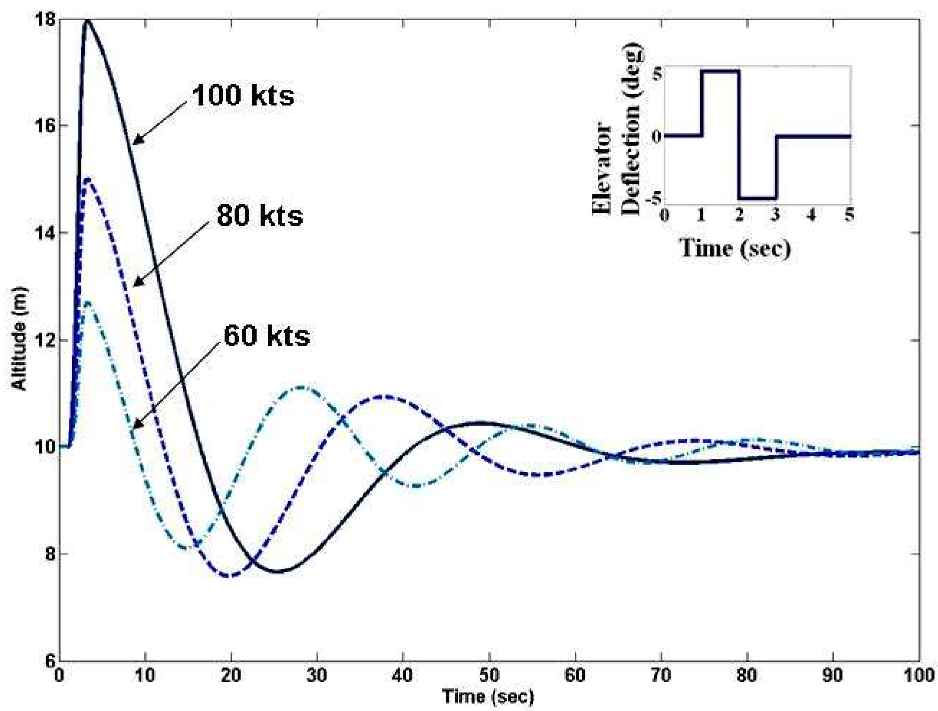


Figure 8. Aircraft Response to an Elevator Doublet Input

The analysis was done using cruise speeds of 60 knots, 80 knots, and 100 knots. The altitude versus time plot illustrates clearly the aircraft's phugoid motion, where the vehicle pitches up and climbs, and then pitches down and descends in an oscillatory pattern. The calculated damping ratios are 0.1538, 0.2553, and 0.3904 for the above speeds respectively. The result indicates that the aircraft is statically and dynamically stable in longitudinal direction. It can be observed that when the aircraft is cruising at higher speeds, the oscillatory motion is more damped.

The aircraft's lateral dynamic response to an aileron doublet input is shown in Figure 9.

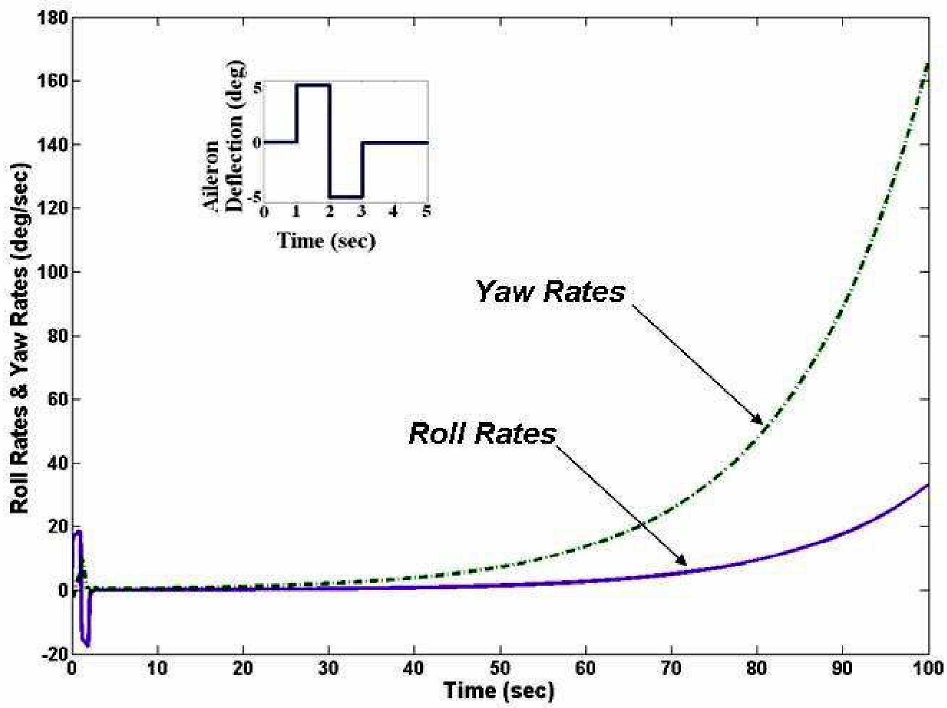


Figure 9. Aircraft Response to an Aileron Doublet Input

This analysis has shown that the yaw and roll responses of the aircraft to the aileron doublet input are divergent, which indicated the unstable lateral behaviour of the aircraft. To counteract this, continuous corrections of lateral controls will be required. These results are reasonable since GeoSurv II does not feature wing dihedral, wing sweep, or high wing, which can provide aircraft lateral stability. In a sense, this behaviour is desired to offer the aircraft high manoeuvrability in lateral motions. But this is a stability issue for maintaining steady level flight after the aircraft responds to lateral controls or a side wind. In order to solve this problem, it is required to introduce some stability augmentation from the GeoSurv II's autopilot to add artificial lateral stability whenever necessary. It is known that the *Micropilot MP2028* autopilot system on-board the GeoSurv II is capable of offering such functions. The stability augmentation can be realized through *Heading Hold* or *Bank Hold* modes to keep the aircraft wing-level and heading-straight. Here again shows the importance of the proper functionality of the aircraft's avionics systems. The tuning of the autopilot and the design of the control laws can be done using the GeoSurv II dynamic model.

7.0 FlightGear Visualization and Setup

The pseudo-real-time flight visualization is a very useful feature of this dynamic model. In order observe the real-time response of the simulation to R/C control, timing of the simulation is important and we have to ensure that the simulation time is synchronized with the real-time. After this is done properly, the visualization will help us understand the aircraft's behaviour in virtual environment. This is shown in Figure 5.

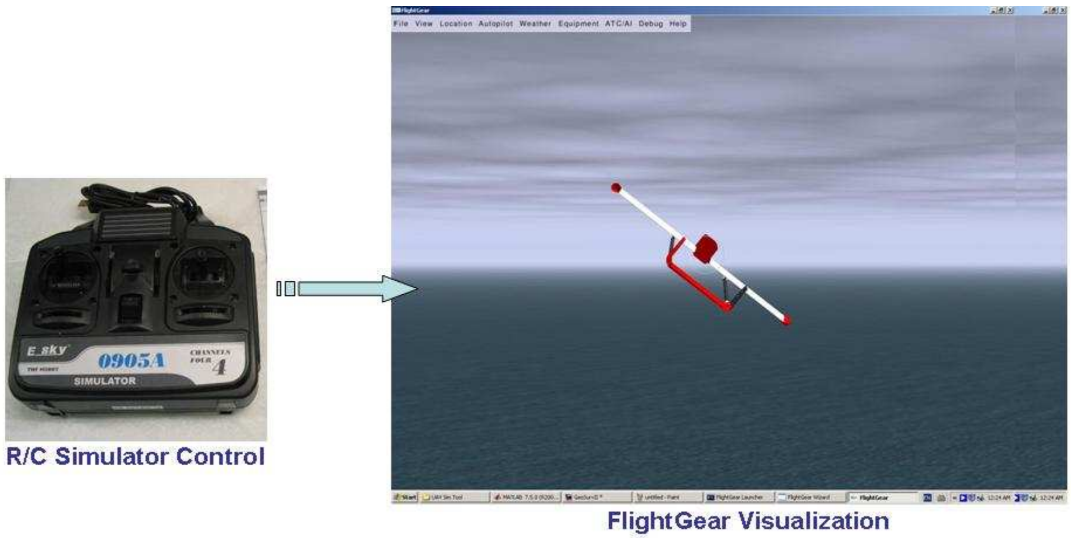


Figure 5. Pseudo-real-time Flight Simulator

Since the R/C simulator control has identical control functions as the actual R/C control that will be used for the human piloted GeoSurv II prototype flight test, this real-time simulator system can be readily used for the practice of piloted flight. With this tool, we are able to assess the aircraft's controllability and to provide recommendations on the augmentation required from the autopilot, based on the flight quality rating given by experienced R/C pilot. In addition to the flight visualization, the GeoSurv II dynamic model can also provide flight path plots for further flight analysis. The flight path induced by an R/C controlled aileron doublet input is shown in Figure 6.

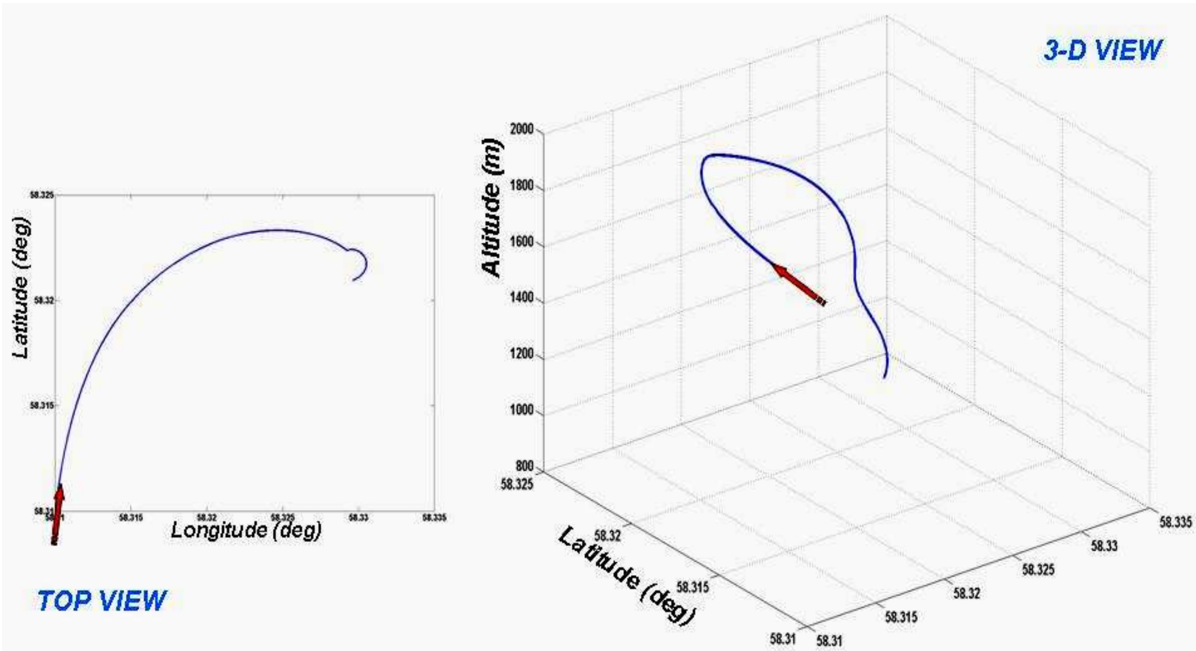


Figure 6. Aircraft Flight Path due to a Doublet R/C Aileron Control

With these two visual tools, we can verify one result with the other and make sense of the aircraft's behaviour by looking at the flight from the two different perspectives. The final goal of all these exercises is to ensure the proper functionality of the aircraft system and the success of the first piloted flight.

The following setup ensures the proper simulation functionality with FlightGear (FG) on station 218 in AA514:

- Load the *60kts.mat* files (or any of them) from *UAV Sim Tool /StateSpace Mat files* directory
- Run *GeoSurvII.mdl* from *UAV Sim Tool/Models* directory
- Enter dt = 0.005 in MATLAB Command Window
- FG *General* page, set *Control* to 'joystick'
- FG *Flight Model* page, set *FDM* to 'external', and set *Model Hz* to '200'
- FG *Initial Position page*, set to corresponding model values
- FG *Input/Output* page, set *Protocol* to 'native-fdm', set *Medium* to 'socket', set *Direction* to 'in', set *Hz* to '200', set *Hostname* to '"localhost"', set *Port* to '5500', and select 'UDP'

8.0 Non-linear Model

As mentioned previously, the current aircraft 6DOF model is linear. In order to simulate the aircraft behaviour for the full flight envelope, a non-linear model is required. With this model, the scenarios such as take-off/landing, high wind conditions and very high angle of attack can be simulated for testing. This model will utilize the results from computational fluid dynamics, wind tunnel testing, and engine testing to develop a large set of non-linear look-up tables for varying stability and control derivatives to represent the aircraft more accurately. Model validation is a very important process of simulation model development. In the industry, this process is done by matching the simulation results to the testing results of the real system. In the case of GeoSurv II, flight data can be collected from the initial flight test of the prototype. After the validation of the model, further analysis can be done and further improvement of the design can be made. Clearly, the process of the design perfection is iterative. With the tool of the dynamic simulation-based design and analysis, this process can be greatly shortened.

9.0 Autopilot Hardware-In-The-Loop

In order to aid in the design of the avionics hardware and its integration with the aircraft system, a hardware-in-the-loop setup needs to be implemented. A proposed implementation plan is illustrated in Figure 7.

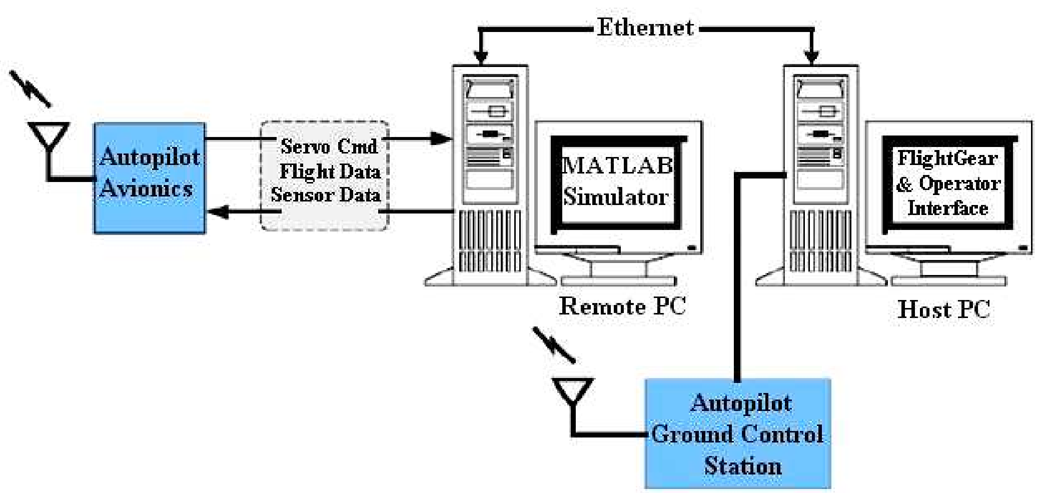


Figure 7. Hardware-In-The-Loop Interface between the Autopilot Hardware and the Dynamic Simulation Model

This configuration separates the simulation model from the operator interface and visualization platform for improved simulation performance on two computers, and the two computers communicate via a host-remote setup through Ethernet connection. The host PC is connected to the Autopilot Ground Control Station and can be used to control the simulator and to monitor the communications between the autopilot avionics and the control station. The autopilot collects aircraft data from the simulator and issues control commands through the hardware-in-the-loop connection with the simulator.

A recommendation on the implementation of such system is the MicroPilot's True Hardware in the Loop (trueHWIL) simulator [5]. The trueHWIL simulates electrically all sensor outputs using analog-to-digital converter, signal conditioning and Pulse-Width Modulation (PWM) interface boards. It is a set of hardware and software components which provide environment for the true real-time simulation of flights of MicroPilot autopilots MP2028g. The MathWork's MATLAB Simulink model is compiled and sent to the xPC Target computer with installed input/output hardware. This acquisition hardware is connected to the autopilot and reads its outputs and stimulates its inputs. Other hardware components may also be connected to this simulator to expand its simulation capability. This hardware-in-the-loop package utilizes commercial-off-the-shelf equipment from National Instruments. The major components are NI PCI-6602 Counter/Timer Device, NI PCI-6703 Digital to Analog Converter, xPC Target, and related MATLAB toolkits. It is also possible to implement additional user interface programs using National Instruments LabVIEW software, which is compatible with MATLAB and the National Instruments hardware.

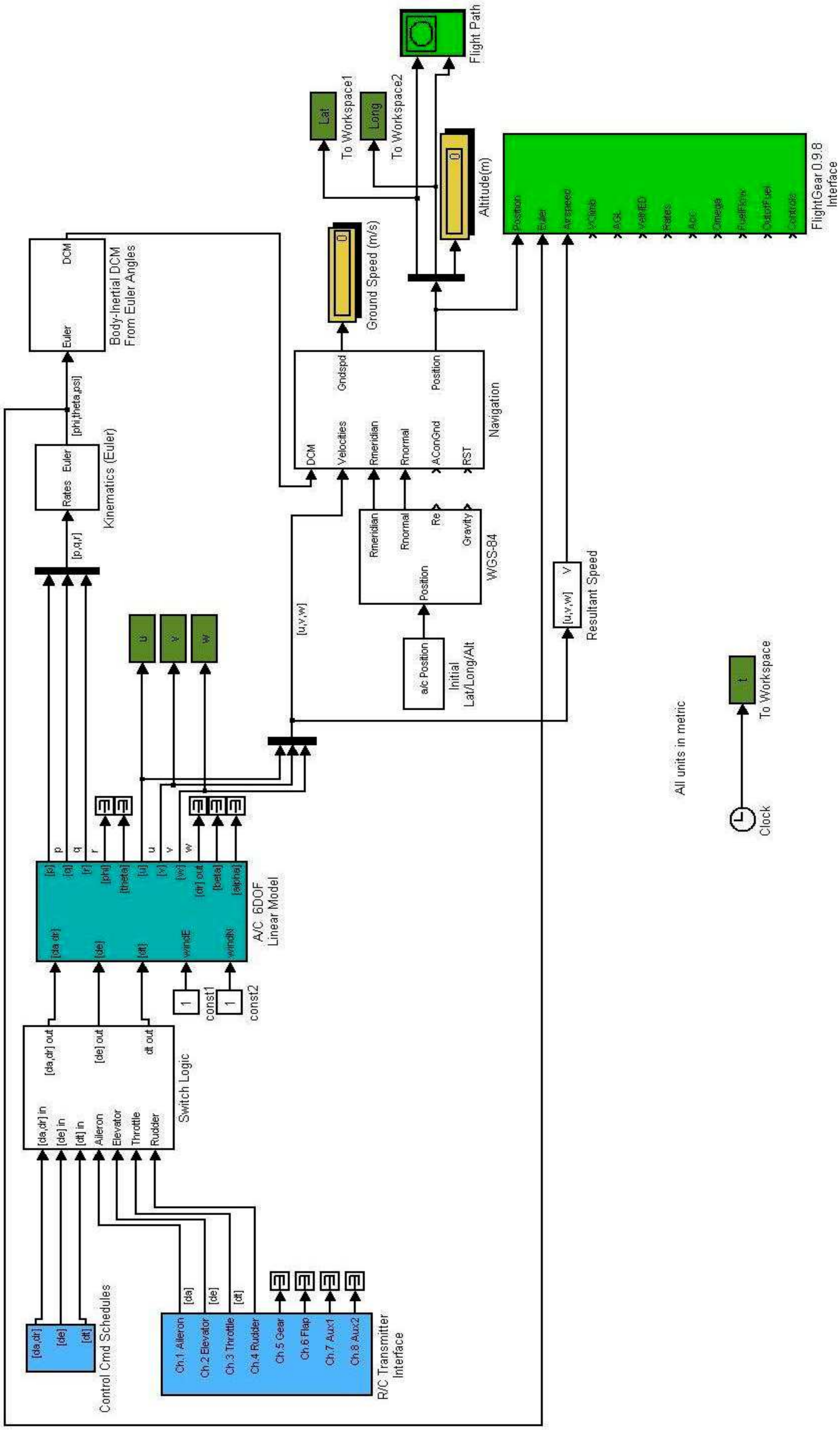
10.0 Conclusions

The GeoSurv II dynamic model has been expanded to serve a wider range of applications of dynamic simulation. In addition to impulse response analysis, the current model is capable of conducting analysis with a variety of control inputs. The incorporation of real-time R/C control and flight visualization functions as a more explicit means of demonstrating the simulated aircraft behaviour. The simulation framework is now ready integration of the autopilot, obstacle avoidance, and flight management components.

11.0 Recommendations

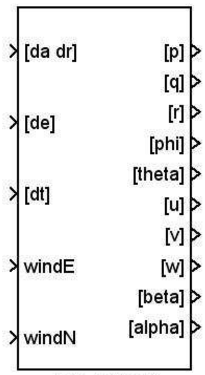
The future development should involve the completion and further expansion of this dynamic simulation model. In order to simulate the aircraft behaviour for the full flight envelope, such as stall and large perturbations, a non-linear model is required. This model will utilize the results from CFD, wind tunnel testing, engine testing, and possibly flight test to improve the accuracy of the simulation. These numerical and experimental results should also be used to update the stability and control derivatives of the linear aircraft model. Additional simulation modules mentioned in the report will need to be incorporated to complete this model. The autopilot hardware-in-the-loop will need to be implemented and it will give the avionics group the opportunity to test the autopilot hardware with the simulation model and to solve integration issues. To ensure the readiness of the aircraft for flight test, it will also be beneficial to create some testing scenarios for analysis of possible failure events, such as high wind conditions, difficult terrain, and system malfunctions.

Appendix A. GeoSurv II Dynamic Model Simulink Block Diagram



Appendix B. GeoSurv II Dynamic Model Components (List of Inputs and Outputs)

Aircraft 6DOF Linear State-space Model



A/C 6DOF Linear Model

Inputs:

- Aileron and rudder controls [da, dr] in *rad*;
- Elevator control [de] in *rad*;
- Throttle control [dt] in *%*;
- Wind speed in East direction in *m/s*;
- Wind speed in North direction in *m/s*;

Outputs:

- Roll rate [p] in *rad/s*;
- Pitch rate [q] in *rad/s*;
- Yaw rate [r] in *rad/s*;
- Bank angle [phi] in *rad*;
- Pitch angle [theta] in *rad*;
- Velocity in x-direction [u] in *m/s*;
- Velocity in y-direction [v] in *m/s*;
- Velocity in z-direction [w] in *m/s*;
- Sideslip angle [beta] in *rad*;
- Angle of attack [alpha] in *rad*.

R/C Transmitter Interface

R/C Transmitter Interface

Parameters:

- Joystick ID = the joystick identifier is normally set to 1, but for reading a second joystick, it can be set to 2.
- Sample time = the time interval at which joystick information is sampled.

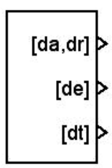
Outputs:

- Ch.1 Aileron = The channel 1 output (aileron or roll cyclic on Futaba radios), normalized to [-1, 1].
- Ch.2 Elevator = The channel 2 output (elevator or pitch

cyclic on Futaba radios), normalized to [-1, 1].

- Ch.3 Throttle = The channel 3 output (throttle and/or collective on Futaba radios), normalized to [-1, 1].
- Ch.4 Rudder = The channel 4 output (rudder or tail rotor on Futaba radios), normalized to [-1, 1].
- Ch.5 Gear = The channel 5 output (usually landing gear on Futaba radios), as a discrete 0 or 1.
- Ch.6 Flap = The channel 6 output (usually flap on Futaba radios), as a discrete 0 or 1.
- Ch.7 Aux1 = The channel 7, auxiliary, as a discrete 0 or 1.
- Ch.8 Aux2 = The channel 8, auxiliary, as a discrete 0 or 1.

Scheduled Control Commands



Control Cmd Schedules

Inputs:

- Aileron and rudder controls [da, dr] in *rad*;
- Elevator control [de] in *rad*;
- Throttle control [dt] in *%*;

Kinematics (Euler)

Kinematics (Euler)

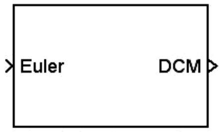
Inputs:

- Rates = the 3×1 vector of body angular rates $[\, p\ q\ r\,]^T$, given in *rad/s*.

Outputs:

- Euler = the 3×1 vector of Euler angles $[\phi\ \theta\ \psi]^T$.

Body-Inertial DCM



Body-Inertial DCM
From Euler Angles

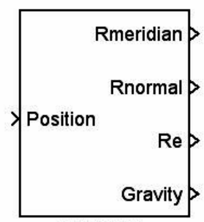
Inputs:

- Euler = the 3×1 vector of Euler angles $[\phi\ \theta\ \psi]^T$.

Outputs:

- DCM = the 3×3 direction cosine matrix.

WGS-84



WGS-84

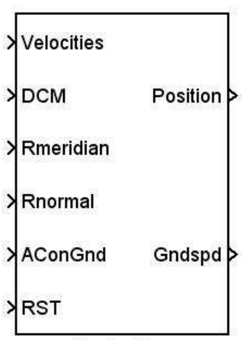
Inputs:

- Position = the 3×1 vector of geographic position [Lat Lon Alt], measured in [*rad rad m*].

Outputs:

- Rmeridian = the meridian radius, in meters.
- Rnormal = the normal radius, in meters.
- Re = the equivalent radius, in meters.
- Gravity = the local gravitational acceleration, in m/s^2.

Navigation



Navigation

Parameters:

- Initial position = the 3×1 vector of initial geographic position $[Lat_0\ Lon_0\ Alt_0]^T$, where latitude and longitude are given in radians.

Inputs:

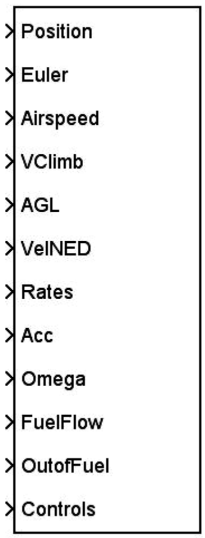
- Velocities = the 3×1 vector of body-axes velocities $[u\ v\ w]^T$.
- DCM = the 3×3 direction cosine matrix for inertialto-body transformation.
- Rmeridian = the meridian radius, in meters.
- Rnormal = the normal radius, in meters.
- AConGnd = the "Aircraft on the Ground" flag (0 or 1).

- RST = the integrator reset flag, which can be 0 or 1.

Outputs:

- Position = the 3×1 position vector $[Lat\ Lon\ Alt\ ]^T$. Latitude and longitude are provided in radians.
- Gndspd = the 3×1 ground speed vector components in geographic frame $[V_{North}\ V_{East}\ V_{Down}\ ]^T$.

FlightGear 0.9.8 Interface



FlightGear 0.9.8 Interface

Parameters:

- Host name = the name or IP address of the machine on which FlightGear is running, provided as a string. For example, if we want to run both Matlab and FlightGear on the same computer (not recommended performancewise) we would use **‘localhost’**.Otherwise, we can type a **‘hostname’** or an IP address.
- Port = the number of the port on the host machine to which this interface will attempt to connect to. The default setting is port 5500.
- Sample time = the sample time at which position and attitude data will be sent to **FlightGear Fligh Simulator**.

Inputs:

- Position = the 3×1 vector of geographic position [Lat Lon Alt] in [*rad rad m*].
- Euler = the 3×1 vector of Euler angles $[\phi\ \theta\ \psi]^T$ in *radians*.
- Airspeed = the current aircraft airspeed, in *m/s*.
- VClimb = the current climb rate, in *m/s*.
- AGL = the altitude of the aircraft above ground, in *m*.
- VelNED = the 3×1 vector of North East Down groundspeed components, in *m/s*.
- Rates = the 3×1 vector of body angular rates, in *rad/s*.
- Acc = the 3×1 vector of body linear accelerations, in m/s^2.

- Omega = the propeller rotation speed, in *rad/s*.
- FuelFlow = the instantaneous mass fuel flow, in *grams/hr*.