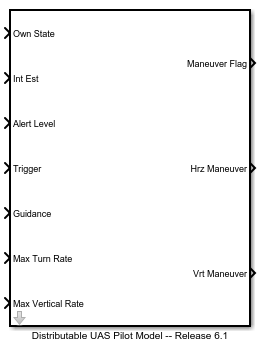
# USER’S GUIDE

UAS Pilot Model Release 6.1

18 January 2017

The UAS Pilot Model has been implemented as a Simulink® block, taking in signals of the current state of the ownship, the estimated state of the intruder, the alert status, and the suggestive guidance and returning horizontal and vertical maneuvers a UAS pilot would choose to stay well clear of the other aircraft. Timing and maneuver choices are representative of actual UAS pilot responses with a DAA display incorporating suggestive guidance.



The following software is required to use the UAS Pilot Model:

* Matlab® R2015a or later
* Simulink® R2015a or later

Note that by design the pilot model may only be used in single-intruder encounters.

**A.1 Input Signals**

|  |  |  |
| --- | --- | --- |
| **Port Name** | **Data Type** | **Description** |
| Own State | AircraftState bus | Current ownship position and attitude state |
| Int Est | AircraftEstimate bus | Current estimated intruder state |
| Trigger | Boolean | Flag activating pilot model  T – activate  F – disable  Typically this would correspond to the occurrence of an alert. Model is permanently active after first maneuver decision. |
| Alert Level | Double | DAA alert level  0 – no alert  1 – proximate traffic[[1]](#footnote-1)  2 – preventive alert  3 – corrective alert  4 – warning alert  5 – well clear violation |
| Guidance | 283x1 Double | Suggestive guidance data  Elements 1-271 – track band values for -135° to 135° from current ownship track  Elements 272-283 – (altitude, band value) pairs in order of increasing altitude; nominally in 500-ft increments with two bands below the current altitude, one at the current altitude, and three above  Band values  0 – no conflict  1 – recovery  >1 – conflict  Note: Differentiating between levels of conflict (e.g., corrective vs. warning) is optional; if used, band values should increase with severity. |
| Max Turn Rate | Double | Ownship horizontal maneuverability: maximum turn rate (in degrees per second). Should be consistent with input to suggestive guidance. |
| Max Vertical Rate | Double | Ownship vertical maneuverability: maximum vertical rate (in feet per minute). Should be consistent with input to suggestive guidance. |

**A.2 Output Signals**

|  |  |  |
| --- | --- | --- |
| **Port Name** | **Data Type** | **Description** |
| Maneuver Flag | Boolean | Flag indicating pilot model has begun issuing avoidance maneuver commands  T – pilot model active  F – pilot model in standby (initial value) |
| Hrz Maneuver | AvoidanceManeuver bus | Horizontal maneuver data |
| Vrt Maneuver | AvoidanceManeuver bus | Vertical maneuver data |

Once a maneuver has been commanded, each of these output signals is held until it is replaced by a subsequent maneuver command. Maneuver commands in one plane are not replaced by the occurrence of a subsequent command in the other plane.

**A.3 Bus Definitions**

Several custom data buses are required. The data elements of each bus are described below. Data elements not used by the pilot model are italicized below and may be filled with dummy data. The files avoidance\_maneuver\_bus\_definition.m and bus\_definitions.m are included with the model to set up these buses for Simulink®.

**A.3.1 AircraftState Bus**

|  |  |  |
| --- | --- | --- |
| **Field Name** | **Data Type** | **Description** |
| *latLonAltState* | *LatLonAltMeasurement bus* | *Geodetic state* |
| *v\_ftps* | *Double* | *Airspeed (ft/s)* |
| n\_ft | Double | Position north of a fixed reference point (ft) |
| e\_ft | Double | Position east of a fixed reference point (ft) |
| h\_ft | Double | Altitude (ft) |
| *psi\_rad* | *Double* | *Heading clockwise from north (rad)* |
| *theta\_rad* | *Double* | *Pitch (rad)* |
| *phi\_rad* | *Double* | *Bank (rad)* |
| *p\_radps* | *Double* | *Angular velocity around roll axis (rad/s)* |
| *q\_radps* | *Double* | *Angular velocity around pitch axis (rad/s)* |
| *r\_radps* | *Double* | *Angular velocity around yaw axis (rad/s)* |
| *dv\_ftps2* | *Double* | *Longitudinal acceleration (ft/s2)* |
| *dh\_ftps* | *Double* | *Vertical rate (ft/s)* |
| *ddh\_ftps2* | *Double* | *Vertical acceleration (ft/s2)* |

**A.3.2 AircraftStateRate Bus**

|  |  |  |
| --- | --- | --- |
| **Field Name** | **Data Type** | **Description** |
| *vdot\_fpss* | *Double* | *Longitudinal acceleration (ft/s2)* |
| Ndot\_ftps | Double | Velocity north (ft/s) |
| Edot\_ftps | Double | Velocity east (ft/s) |
| hdot\_ftps | Double | Vertical rate (ft/s) |
| psidot\_radps | Double | Heading rate (rad/s) |
| thetadot\_radps | Double | Pitch rate (rad/s) |
| phidot\_radps | Double | Roll rate (rad/s) |

**A.3.3 AircraftEstimate Bus**

|  |  |  |
| --- | --- | --- |
| **Field Name** | **Data Type** | **Description** |
| *latLonAltEst* | *LatLonAltMeasurement bus* | *Geodetic state* |
| *timeOfValidity* | *Double* | *Simulation time (s)* |
| *isValid* | *Boolean* | *Flag indicating validity of state estimate*  *0 – invalid, do not use*  *1 – valid* |
| enuStateEstimate | StateEstimate bus | State estimate in ENU coordinates |
| *covEstimate* | *CovarianceEstimate bus* | *Covariance estimate in ENU coordinates* |

**A.3.4 AvoidanceManeuver Bus**

|  |  |  |
| --- | --- | --- |
| **Field Name** | **Data Type** | **Description** |
| time | Double | Time of maneuver selection (note, usually not the time the maneuver is commanded) |
| type | Double | Type of maneuver  0 – none  1 – horizontal  2 – vertical |
| desired\_state | Double | Desired heading/altitude (deg/ft) |
| reference\_state | Double | Heading/altitude prior to maneuver (deg/ft) |
| wc\_flag | Double | Expected well clear state after maneuver  0 – well clear  >0 – not well clear |

**A.3.5 LatLonAltMeasurement Bus**

|  |  |  |
| --- | --- | --- |
| **Field Name** | **Data Type** | **Description** |
| *lat\_rad* | *Double* | *Latitude (rad)* |
| *lon\_rad* | *Double* | *Longitude (rad)* |
| *dlat\_radps* | *Double* | *Latitude rate (rad/s)* |
| *dlon\_radps* | *Double* | *Longitude rate (rad/s)* |
| *alt\_ft* | *Double* | *Altitude (ft)* |
| *dalt\_ftps* | *Double* | *Vertical rate (ft/s)* |

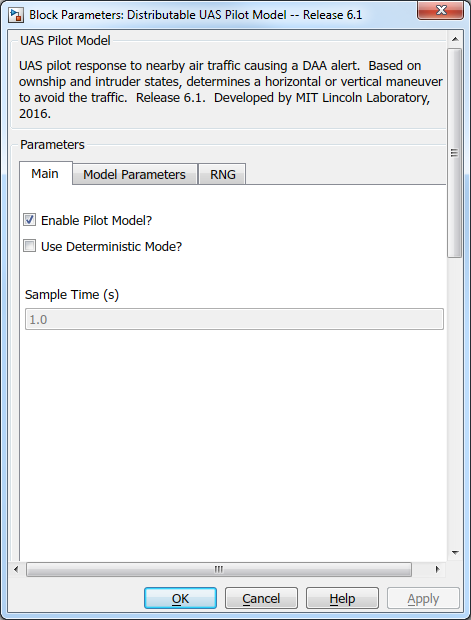
**A.3.6 StateEstimate Bus**

|  |  |  |
| --- | --- | --- |
| **Field Name** | **Data Type** | **Description** |
| n\_ft | Double | Estimated position north of reference point (ft) |
| e\_ft | Double | Estimated position east of reference point (ft) |
| h\_ft | Double | Estimated altitude (ft) |
| dn\_ftps | Double | Estimated velocity north (ft/s) |
| de\_ftps | Double | Estimated velocity east (ft/s) |
| dh\_ftps | Double | Estimated vertical rate (ft/s) |

**A.3.7 CovarianceEstimate Bus**

|  |  |  |
| --- | --- | --- |
| **Field Name** | **Data Type** | **Description** |
| *nVar\_ft2* | *Double* | *Variance of position north estimate (ft2)* |
| *eVar\_ft2* | *Double* | *Variance of position east estimate (ft2)* |
| *hVar\_ft2* | *Double* | *Variance of altitude estimate (ft2)* |
| *dnVar\_ft2ps2* | *Double* | *Variance of velocity north estimate (ft2/s2)* |
| *deVar\_ft2ps2* | *Double* | *Variance of velocity east estimate (ft2/s2)* |
| *dhVar\_ft2ps2* | *Double* | *Variance of vertical rate estimate (ft2/s2)* |

**A.4 Parameters**



**A.4.1 Main Tab**

#### Enable Pilot Response?

Select to enable the pilot model. Default: On.

#### Use Deterministic Mode?

Select to use the pilot model deterministic mode rather than the stochastic mode. Default: Off.

#### Sample Time

The pilot model is designed to run once a second. This value should not be changed.

**A.4.2 Model Parameters Tab**

The parameters of the pilot model have been identified through HITL experimentation as described elsewhere. The parameter values have been preset in the model’s Simulink® block mask but are summarized here for reference. Parameter values may be changed for experimentation purposes but only the values here have empirical grounding.

| **Parameter** | **Description** | **Mode** | |
| --- | --- | --- | --- |
| **Stochastic** | **Deterministic** |
| initialDelayMin | Minimum time of initial delay from alert to beginning of ATC coordination. | 0.0 | 5.0 |
| initialDelayMu | Mean of exponentially distributed random component of initial delay before beginning ATC coordination. | 5.0 | 0.0 |
| coordDelayMin | Minimum time of delay for coordination with ATC. | 0.0 | 11.0 |
| coordDelayK | Shape parameter of gamma distributed random component of ATC delay. | 5.5 | 0.0 |
| coordDelayTheta | Scale parameter of gamma distributed random component of ATC delay. | 2.0 | 0.0 |
| executionDelayMin | Minimum time of execution delay from end of ATC coordination to transmission of maneuver command to own aircraft. | 0.0 | 3.0 |
| executionDelayMu | Mean of exponentially distributed random component of execution delay. | 3.0 | 0.0 |
| minUpdateTime | Minimum time to next maneuver decision by alert level. | [12,12,9,6,6,0] | [12,12,9,6,6,3] |
| meanUpdateTime | Mean time *in addition to minimum* to next maneuver decision by alert level. | [12,12,6,3,3,3] | [12,12,6,3,3,0] |
| probFollowMinDev | Preference weight for maneuvering in the direction of the smaller suggestion for each maneuver plane. | 0.8 | 1.0 |
| probLeftTurn | Preference weight for choosing left turn over right if minimum suggestion is inconclusive. | 0.6 | 1.0 |
| maxRelativeHdg | Maximum heading difference for which the larger of the heading suggestions may be selected. | 40.0 | 40.0 |
| probDescend | Preference weight for choosing to descend rather than climb if minimum suggestion is inconclusive. | 0.5 | 0.0 |
| probTurn | Preference weight for choosing to turn rather than climb or descend as a function of ownship maneuverability. | [0.5, 1.0, 1.0;  0.0, 0.5, 0.65;  0.0, 0.5, 0.4 ] | [1, 1, 1;  1, 1, 1;  1, 1, 1] |
| turnK | Shape parameter for gamma distributed horizontal maneuver magnitude relative to the minimum suggestion when direction selected complies with the minimum suggestion heuristic (primary turn direction). | 6.21 | 0.0 |
| turnTheta | Scale parameter for gamma distributed horizontal maneuver magnitude relative to the minimum suggestion in the primary turn direction. | 9.67 | 0.0 |
| turnOffset | Offset of turn magnitude gamma distribution for turns in the primary direction. | -30.0 | 30.0 |
| turnK\_alt | Shape parameter for gamma distributed horizontal maneuver magnitude relative to the minimum suggestion for turns opposite the primary direction. | 5.47 | 0.0 |
| turnTheta\_alt | Scale parameter for gamma distributed horizontal maneuver magnitude relative to the minimum suggestion for turns opposite the primary direction. | 8.25 | 0.0 |
| turnOffset\_alt | Offset of turn magnitude gamma distribution for turns opposite the primary direction. | -30.0 | 15.0 |
| altitudeK | Shape parameter for gamma distributed vertical maneuver magnitude relative to the minimum suggestion in the selected direction. | 9.73 | 0.0 |
| altitudeTheta | Scale parameter for gamma distributed vertical maneuver magnitude relative to the minimum suggestion in the selected direction. | 207.98 | 0.0 |
| altitudeOffset | Offset of vertical maneuver magnitude gamma distribution. | -1500.0 | 0.0 |

**A.4.3 RNG Tab**

This tab identifies seed values for the various random number generators used within the pilot model. Values have been arbitrarily preset and may be changed at will. If using the model in stochastic mode for Monte Carlo analysis, a mechanism to change these seed values at each instantiation is required.

**A.5 Usage NOTES**

* The model outputs are maneuver decisions. Some of those decisions may be to maintain the current altitude or heading (i.e., do nothing).

**A.6 Summary of Changes**

**Release 2.0**

* Switched guidance algorithm from OmniBands to DAIDALUS.
* Update delay split into minimum and mean components with values that can vary with alert level.
* Mean execution delay reduced from 5 seconds to 3 seconds.

**Release 3.0**

* Removed DAIDALUS as an internal component of the model; model now takes suggestive guidance as an input.

**Release 4.0**

* Updated interface to include input of maneuverability constraints (maximum turn rate and vertical rate).
* Updated preferences and probability distributions based on results from C-ABSAA Study 4C HITL. Maneuver plane preferences now a function of ownship maneuverability constraints.

**Release 5.0**

* Horizontal maneuvers discretized into 5° heading bins; vertical maneuvers discretized into 100-ft altitude bins.
* Added separate maneuver magnitude distribution for turns in the direction of the minimum suggested turn and for turns opposite the minimum suggestion.
* Deterministic mode uses observed mean maneuver magnitude relative to suggestive guidance rather than the suggestive guidance exactly.
* Update delays reduced to account for execution delay.

**Release 5.1**

* Eliminated previously unrecognized dependency on the Statistics and Machine Learning Toolbox by replacing calls to ‘exprnd’ and ‘gamrnd’ with custom functions.

**Release 6.0**

* Fixed error in Maneuver Flag output (associated with redrawing execution delay). Flag retains value of true after execution delay for initial maneuver is complete. Hrz Maneuver and Vrt Maneuver output signals are delayed by the execution delay drawn for each maneuver (initial and updates).
* Added safeguards against descent to altitudes less than 500 feet.
* Prevented rounding of altitude to 100-ft increment when desired maneuver is to hold current altitude and currently not climbing or descending.
* Headings in Hrz Maneuver output expressed in the interval (-360, 360) degrees.

**Release 6.1**

* Fixed error in evaluation of probability of horizontal maneuver with respect to ownship maneuverability.
* Fixed error in probability of horizontal maneuver parameter table values.

**Release 6.2**

* In deterministic mode, minimum update delay must be greater than 1 second for updates to function correctly. To achieve this as well as greater clarity, moved all delay values into the minUpdateTime parameter.
* Increased minimum update delay for alert level 5 to 4 seconds to prevent an update from always superseding the initial maneuver.

1. This alert level has been eliminated from the DAA MOPS but is retained in the model. The model is configured to treat it the same as “no alert.” [↑](#footnote-ref-1)