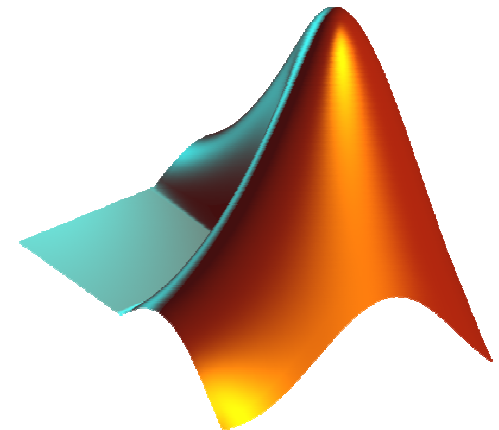


Rapid Prototyping a Two Channel Autopilot for a Generic Aircraft

YOGANANDA JEPPU

Head R&D Systems

Moog India Technology Center



The Team

Atit Mishra
Basavaraj M
Chethan CU
Chinmayi J
Manjunatha L Rao
Surya Karthik
Vanishree
Yogananda



at flights 4 fantasy, forum mall . . .

Agenda

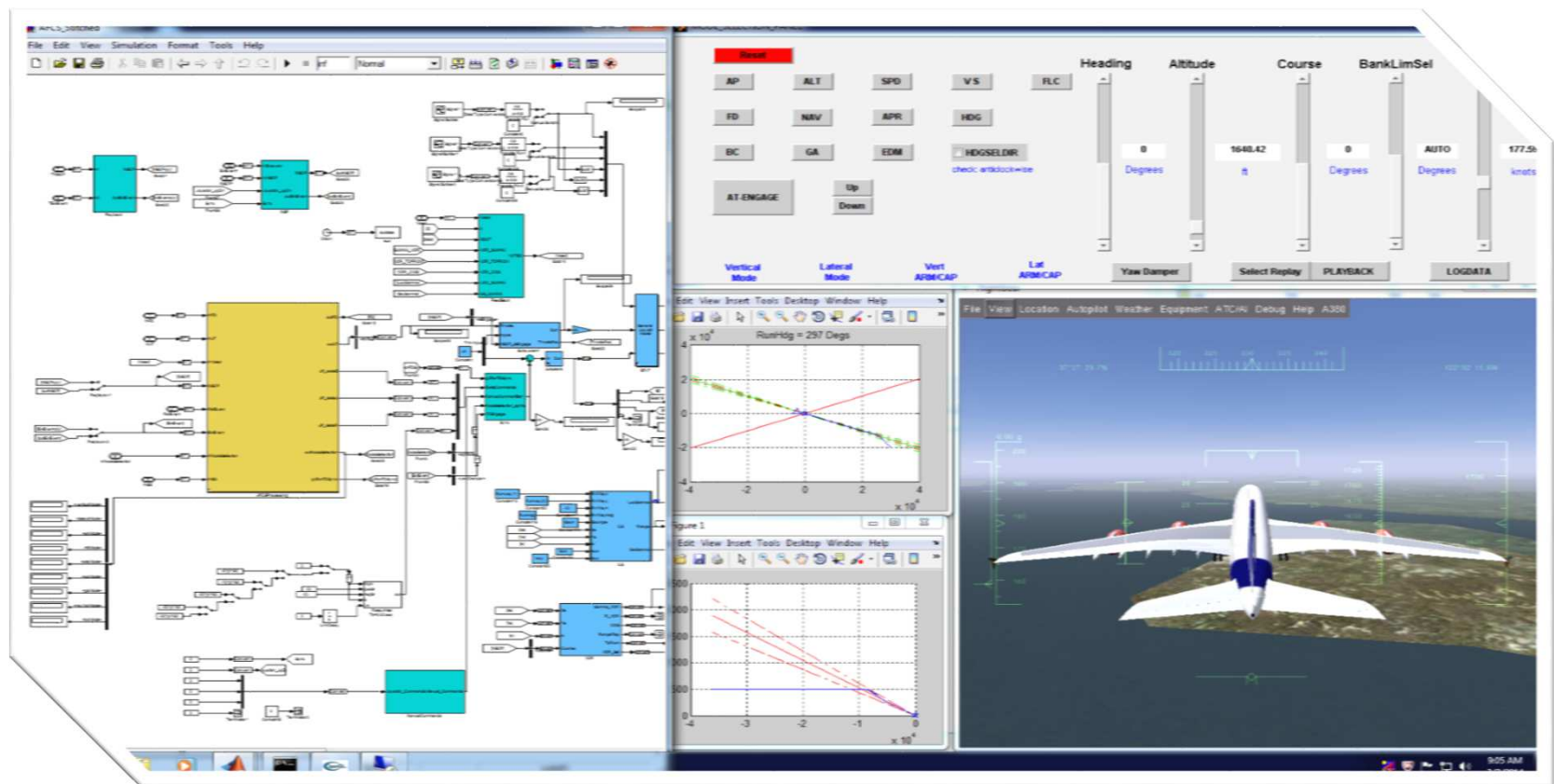
- What are autopilots
- Design Process
- Aircraft Model, Trims and Envelope
- Control Design
- Mode Transition Logic
- Code and Test
- 2 Channel Operation
- Demo

*I am not here
to praise
Matlab but its
users who
have done so
much with it ...*

Take away

- How a small team has been able to design a full fledged two channel autopilot with all the modes in a time frame of 8 months
- How Matlab and Simulink and the user community has helped us achieve this task
- Some things we have given back to the community

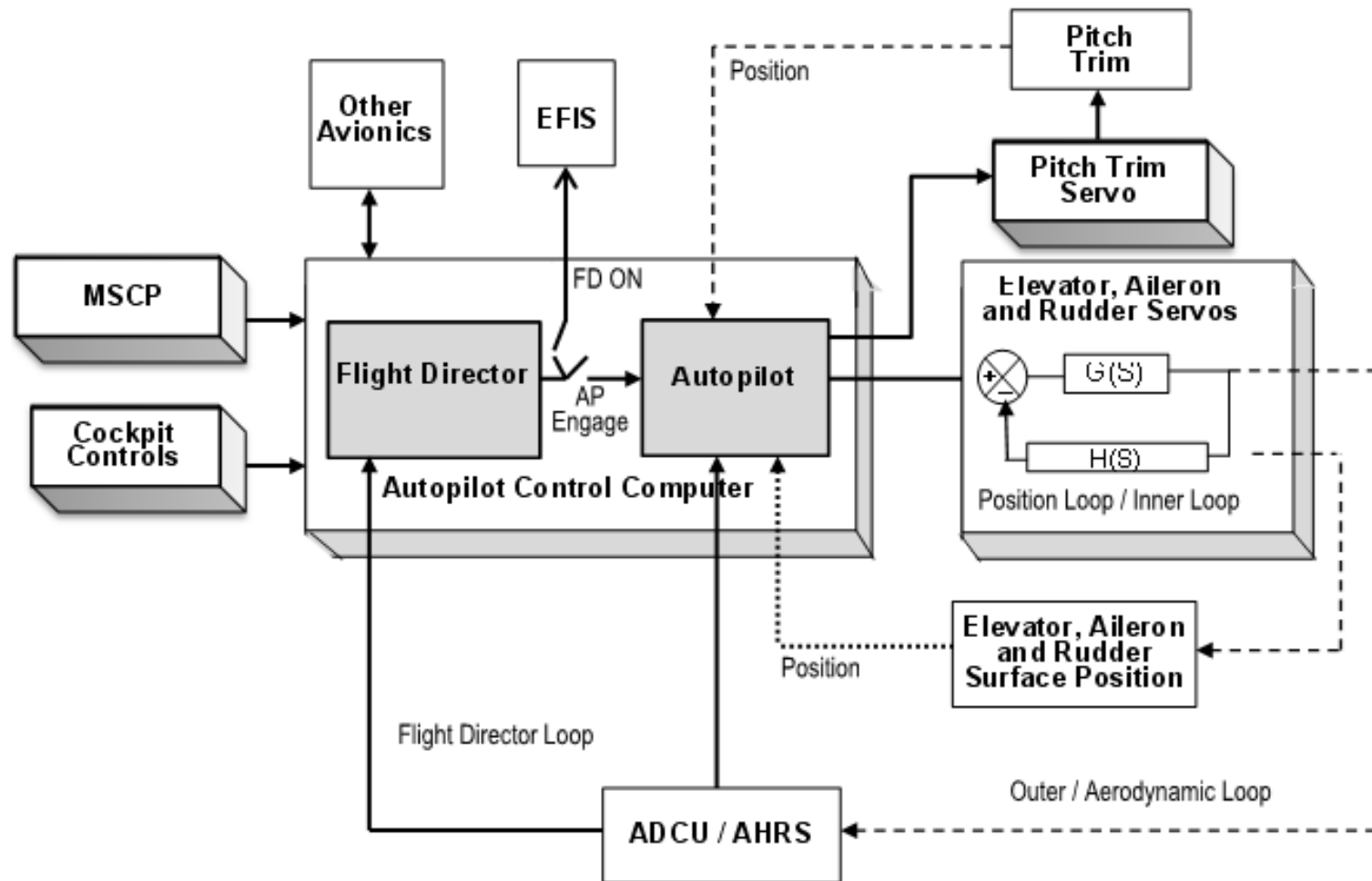
Autopilots



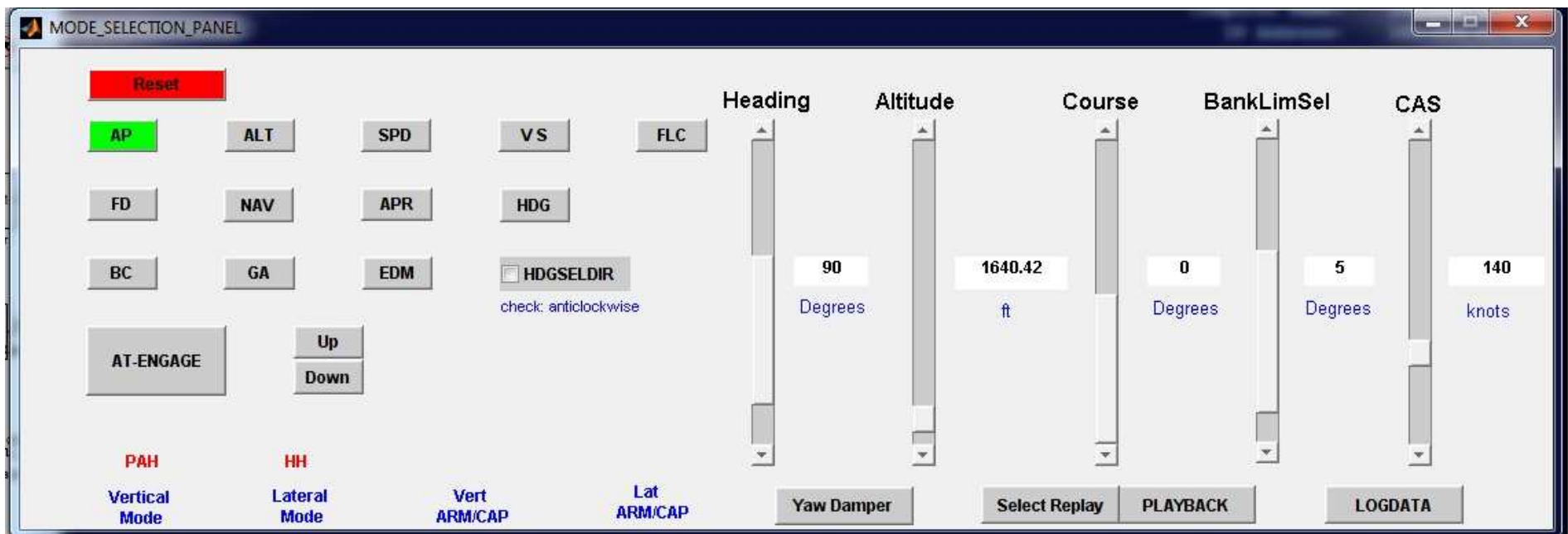
Autopilot

- Autopilot system is a mechanical, electrical or hydraulic system used to guide an airplane with minimal or no assistance from the pilot. It also reduces the fuel consumption and increases flight safety.
- Flight Director is a navigational aid that is overlaid on the attitude indicator that shows the pilot of an aircraft the attitude required to follow a certain trajectory.

Autopilot overview



MSCP



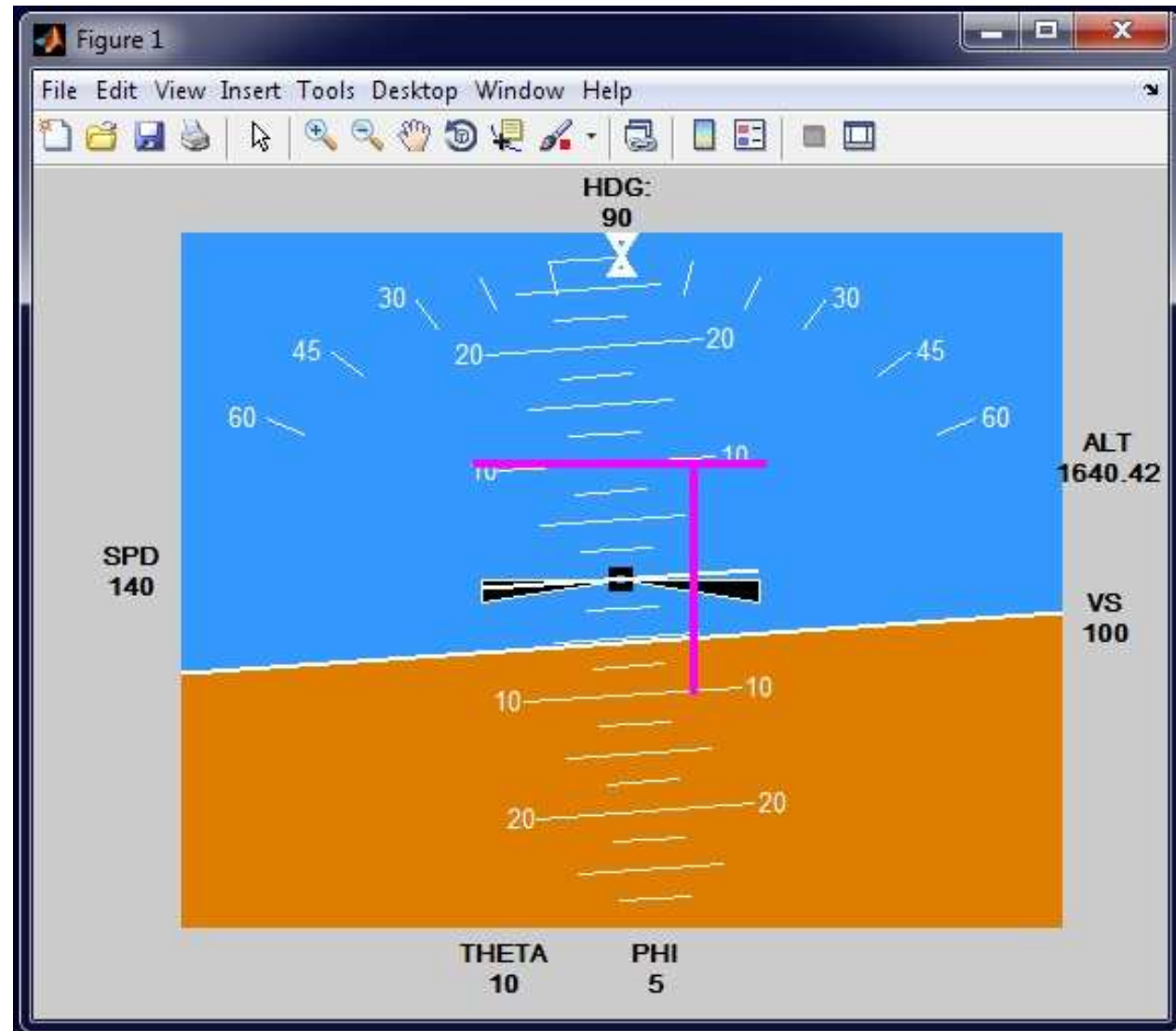
Mode Select Control Panel

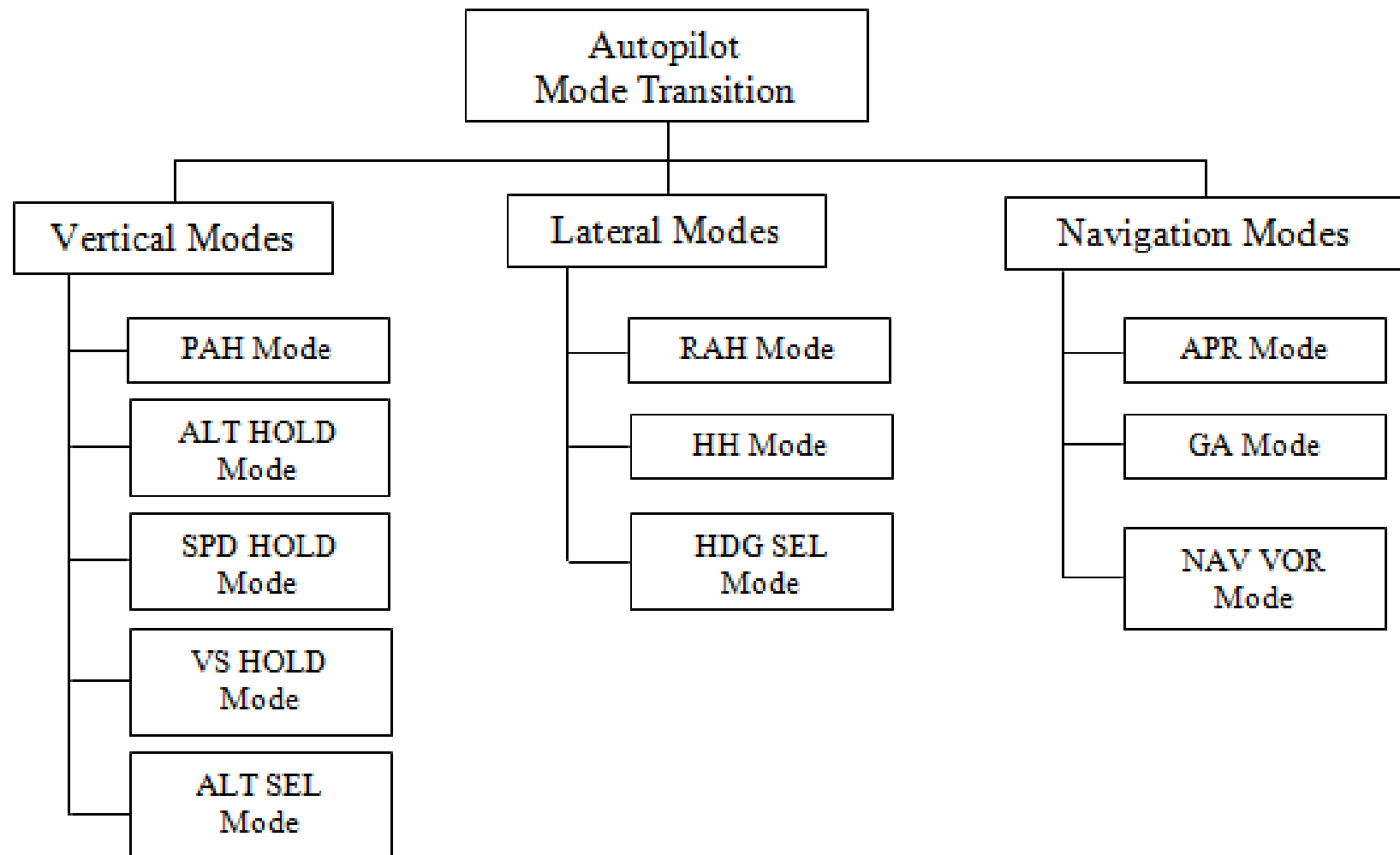
This is developed using Matlab UI and has a real time interface with the Simulink simulation. It has a record and playback capability for system tests

PFD

Primary Flight Display

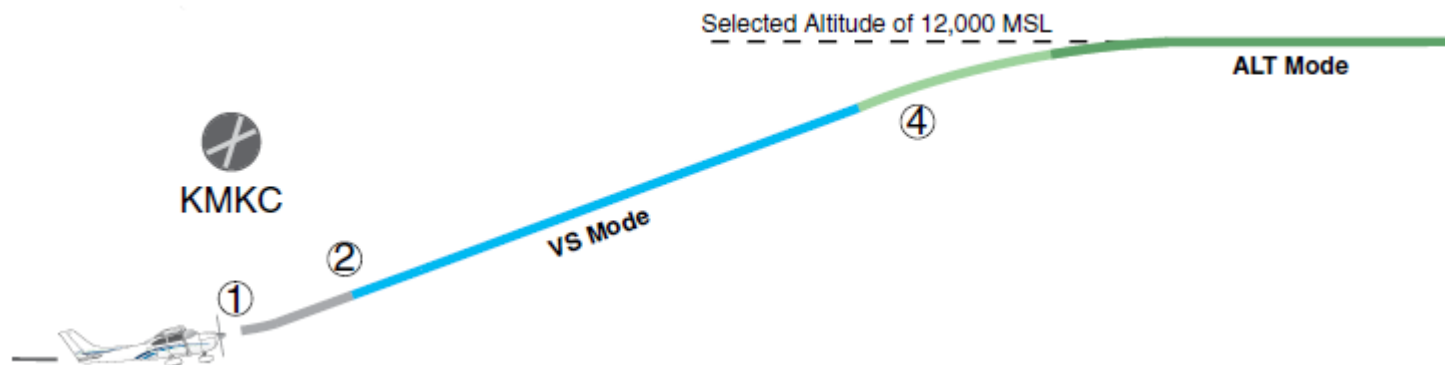
This is developed using the simple plot program and runs in real time displaying the Simulink data





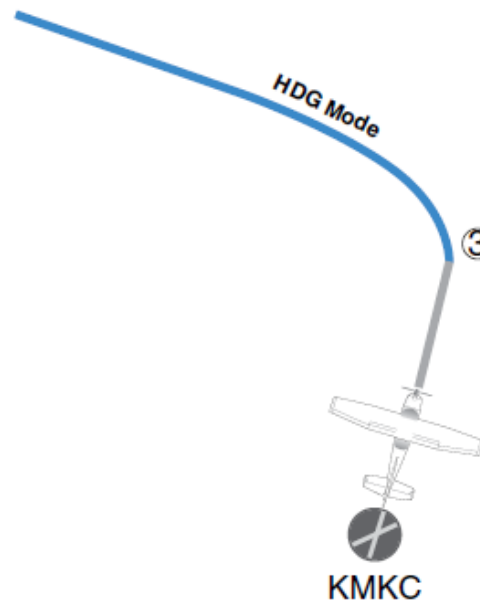
Vertical Modes

- PAH mode – This is the basic autopilot mode in vertical axis. This mode holds the current pitch angle.
- Altitude Hold mode – This mode holds the aircraft at the current altitude reference.
- Speed Hold mode – This mode maintains the present airspeed.
- Vertical Speed mode – This mode is used to automatically maintain the aircraft at a selected vertical speed (climb rate) reference.
- Altitude Select mode – This mode captures the Selected Altitude. The 3 phases are, Arming, Capture and Hold.



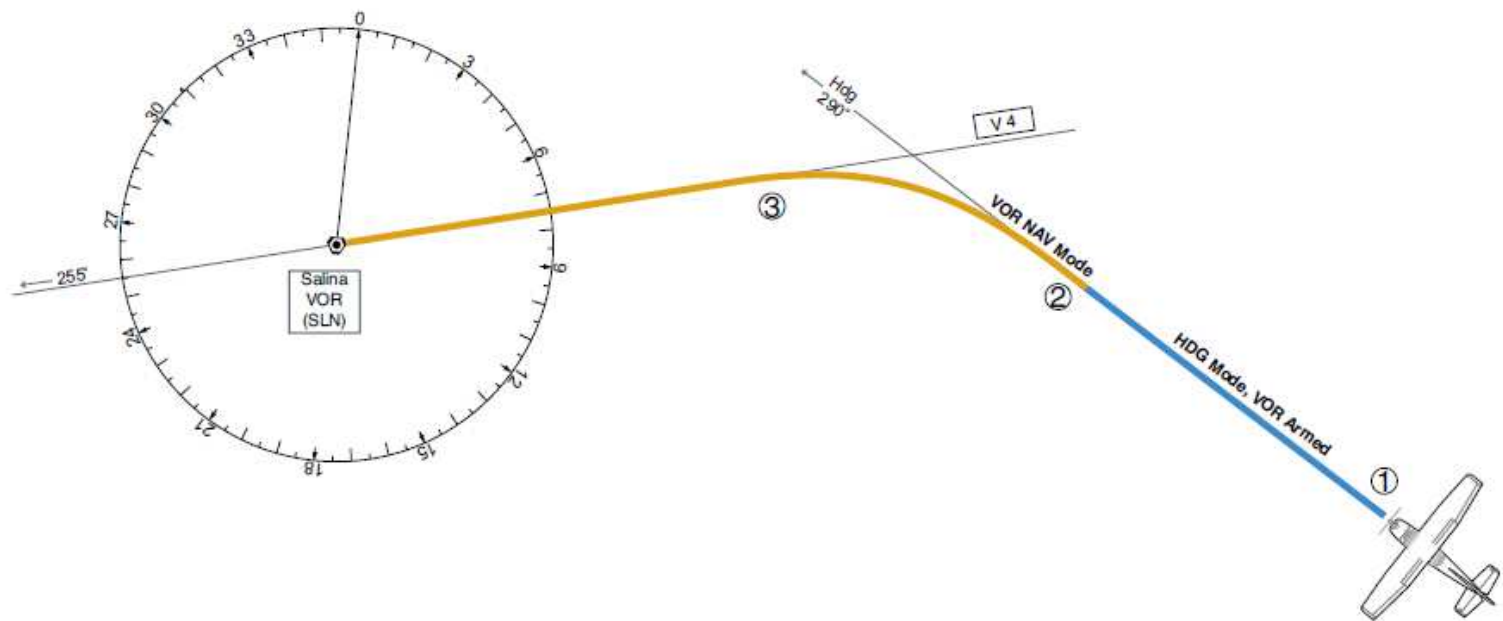
Lateral Modes

- RAH mode – This is the basic autopilot mode in lateral axis. This mode holds the current roll angle of the aircraft.
- Heading Hold mode – This mode is used to hold the heading of the aircraft.
- Heading Select mode – This mode is used to turn towards the Selected Heading.



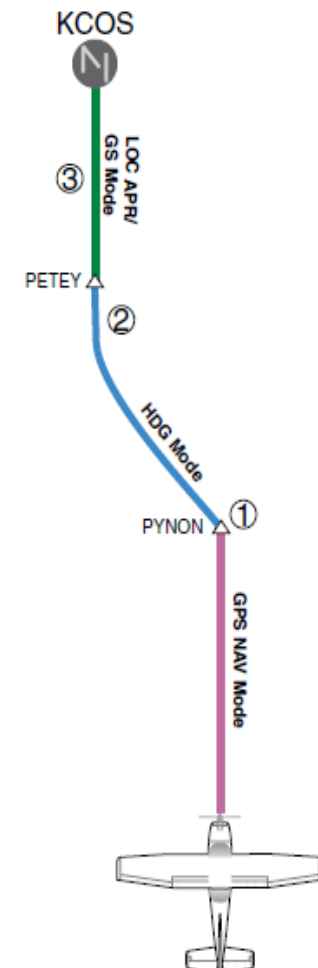
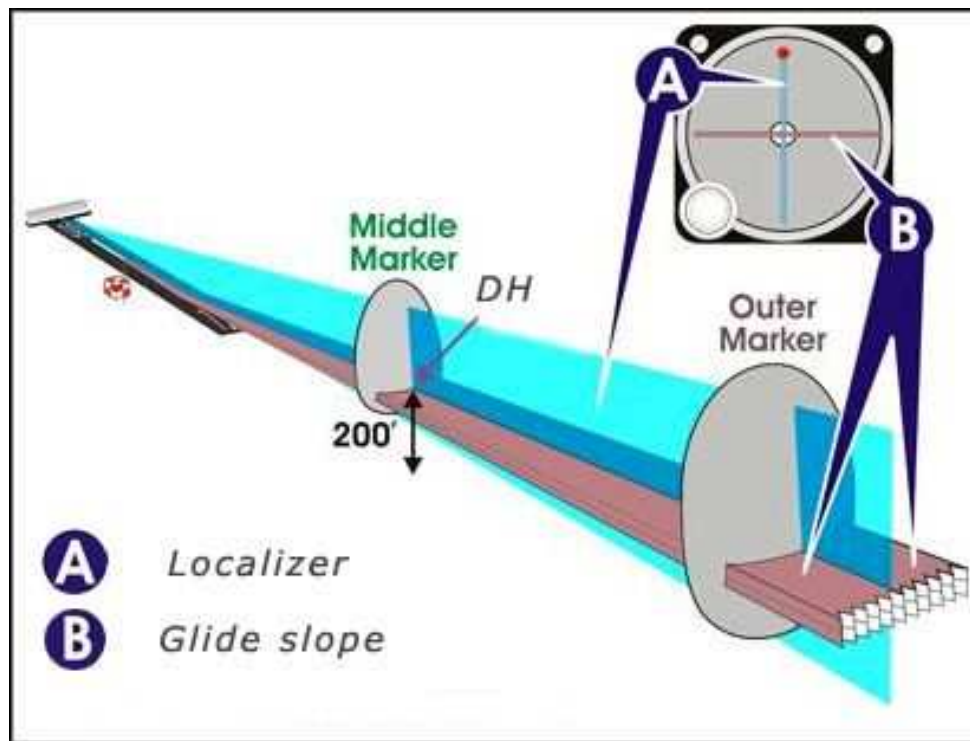
Navigational Modes

- Go-Around mode – The Go-Around mode is used transition from an approach mode to a climb mode when a missed approach occurs.
- Navigation VOR - This is a type of short-range radio navigation system for aircraft which defines the radials in space for tracking.



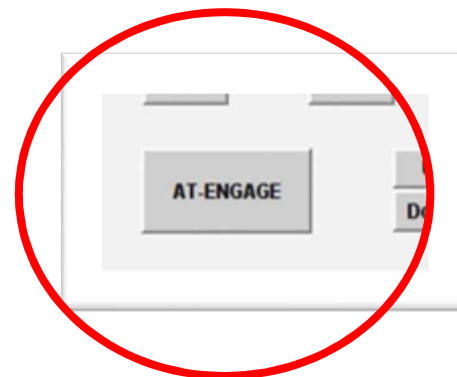
Approach Modes

- Approach mode – This mode is used to approach the runway. Glide-slope and Localizer modes assist in vertical and lateral guidance.

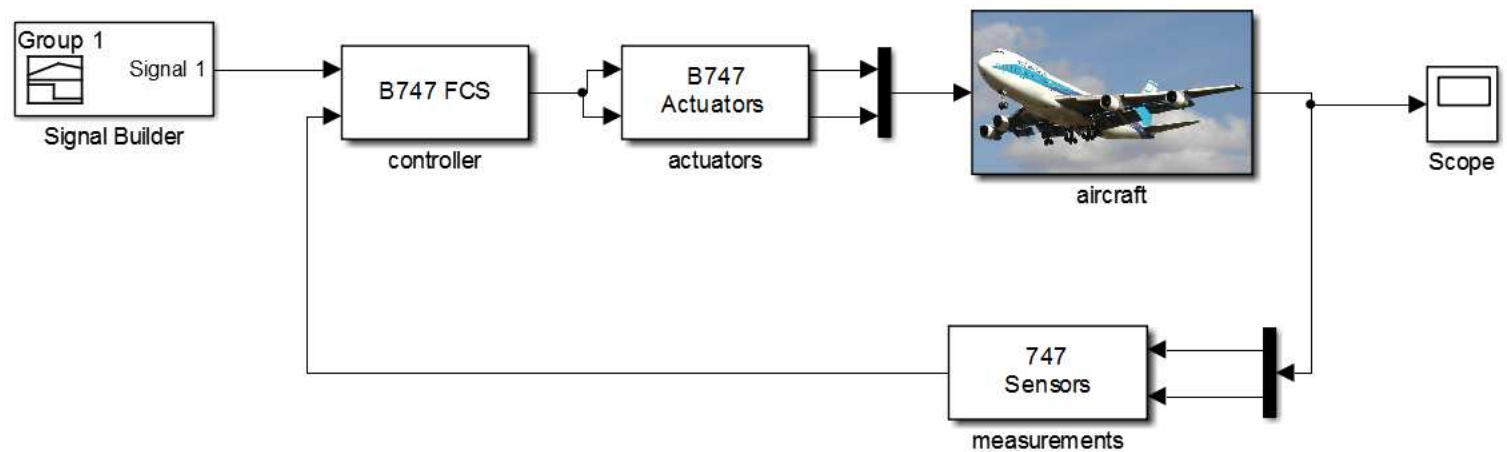


Autothrottle and Yaw Damper

- An autothrottle mode is available to ensure that the engine maintains the speed or vertical speed reference.
- The yaw damper mode is also available to damp out the Dutch roll oscillation in yaw and maintain a low value of sideslip angle.
- In the yaw damper mode the commands are given to the rudder.
- These modes can be engaged with the main autopilot being off

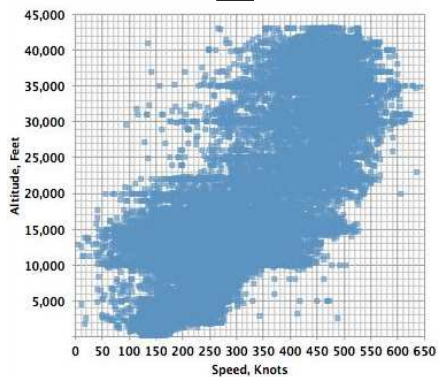


Design Process



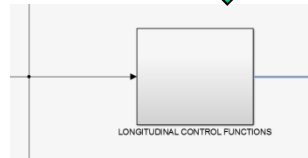
Requirements

Linear Models

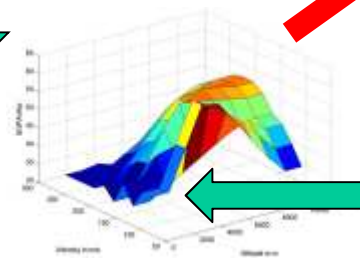
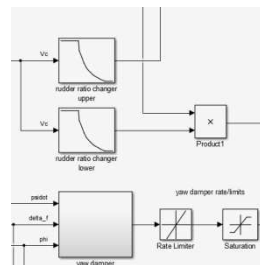


Flight Envelope

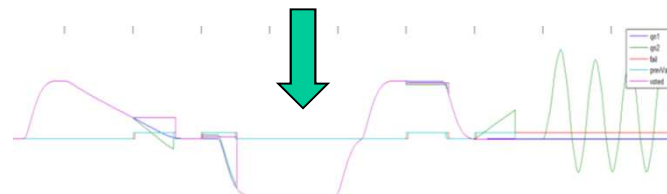
3.4.8.4.3	Exit Criteria	48
3.4.8.5	Speed Hold Mode (SPH)	49
3.4.8.5.1	Entry Criteria	49
3.4.8.5.2	Operating Logic	49
3.4.8.5.3	Exit Criteria	50
3.4.8.5.4	Annunciations	50
3.4.8.6	Vertical Speed Hold	51
3.4.8.6.1	Entry Criteria	51
3.4.8.6.2	Operating Logic	51
3.4.8.6.3	Exit Criteria	52
3.4.8.6.4	Annunciations	52
3.4.8.7	Glideslope (GS)	52
3.4.8.7.1	Entry Criteria	52
3.4.8.7.2	Operating Logic	53
3.4.8.7.3	Exit Criteria	53
3.4.8.7.4	Annunciations	53
3.4.8.8	Vertical Navigation (VNAV)	54
3.4.8.8.1	Entry Criteria	54
3.4.8.8.2	Operating Logic	54
3.4.8.8.3	VNAV Altitude Capture Mode (VALTS)	55
3.4.8.8.4	VNAV Altitude Hold Mode (VAHT)	56
3.4.8.8.5	VNAV Speed Hold Mode (VSPH)	57
3.4.8.8.6	VNAV Path Mode (VPAth)	58
3.4.8.8.7	VNAV Climb/Descent Mode (VNCM)	58



Linear Control



Non Linear Shaping



Simulations

Code

```
#include "APUTLRateLimit.h"
#include "APUTLSysDefs.h"

// Local Defines

// Global Variables

// Global Functions

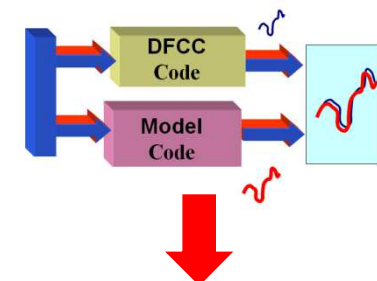
FUNCTION NAME: RateLimit

NOTES:

*****
TFloat32 RateLimit(TRateLimit *thisPtr, TFloat32 input,
                  TFloat32 posSr, TFloat32 negSr,
                  TBool init)
{
    TFloat32 lowerLim = 0.0f;
    TFloat32 upperLim = 0.0f;
    // Initialization
    if (init == TRUE)

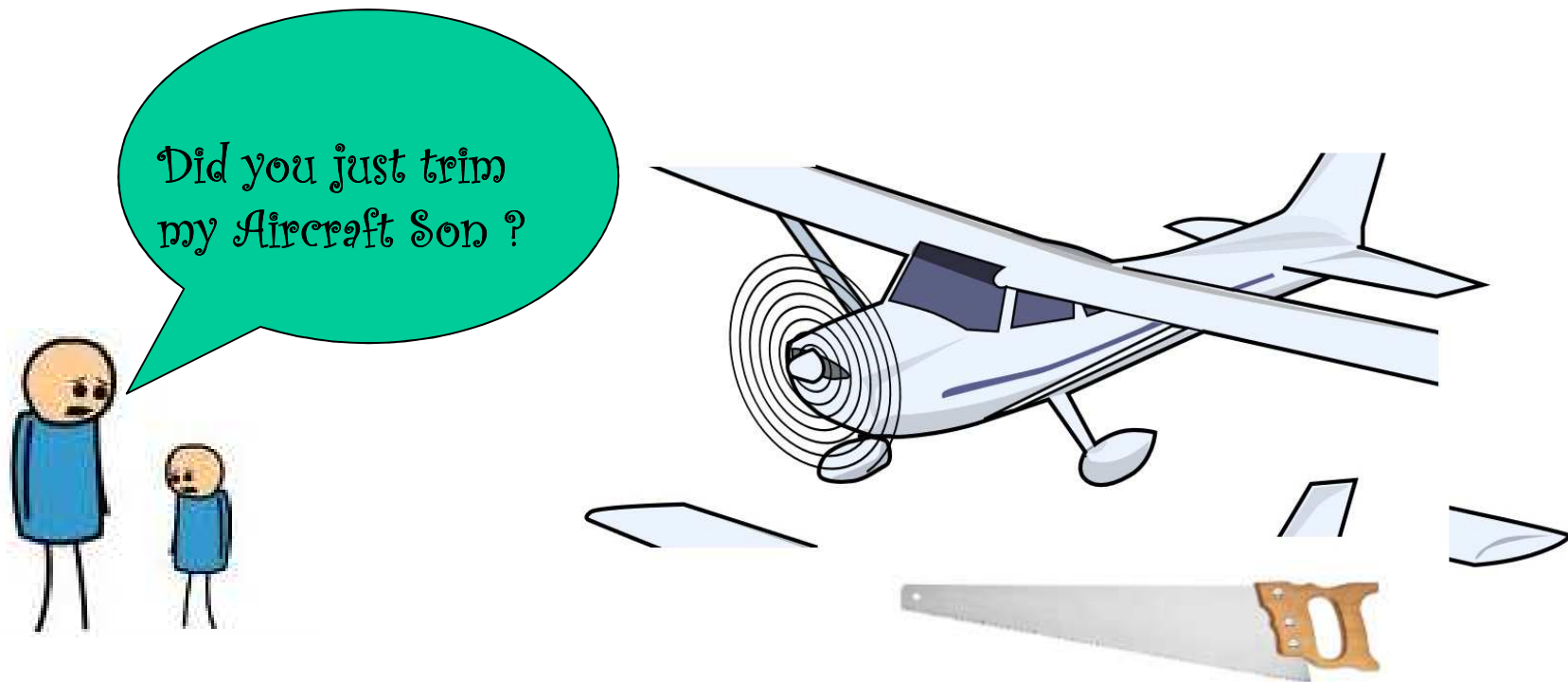
```

Test



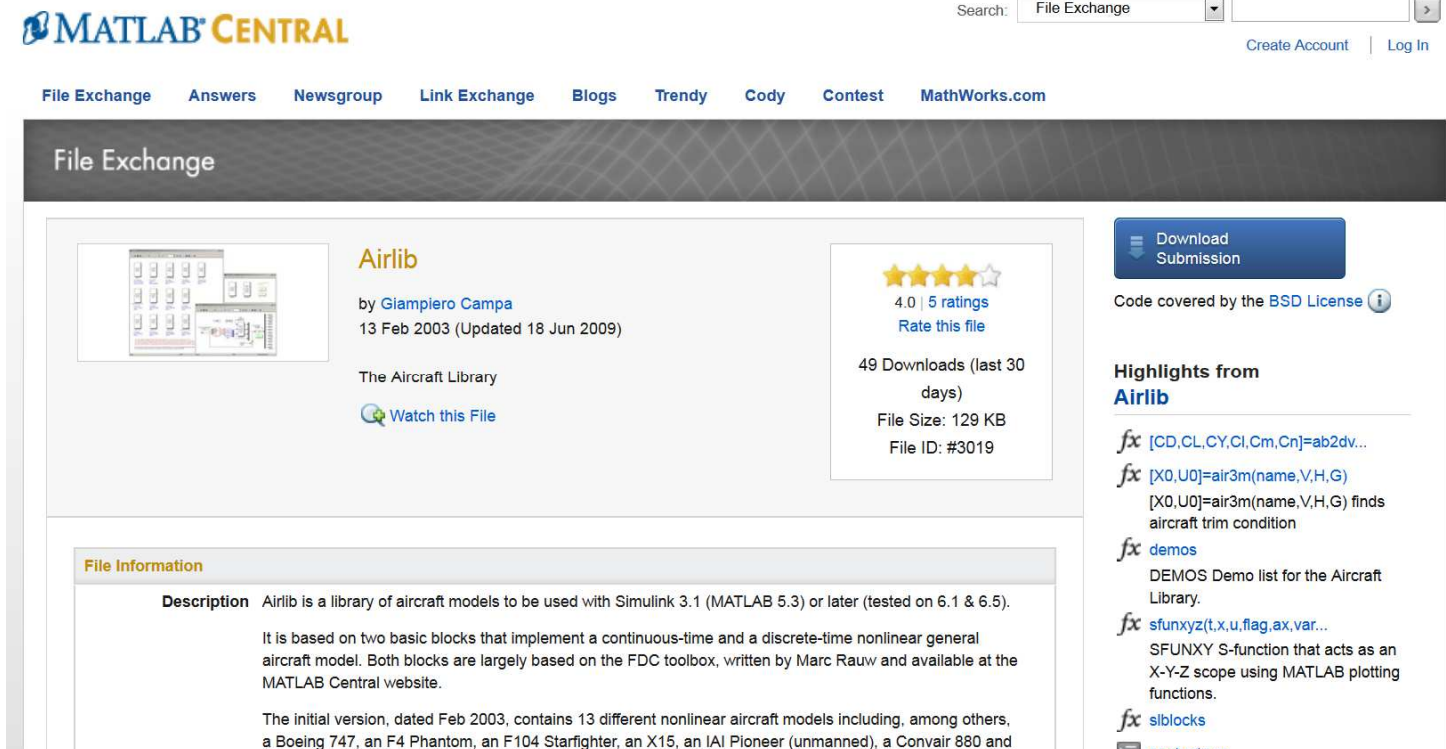
Deploy and Test

Aircraft Model, Trim, Envelope



Aircraft Model

■ Airlib – by Giampiero Campa




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File Exchange



Airlib

by [Giampiero Campa](#)

13 Feb 2003 (Updated 18 Jun 2009)

The Aircraft Library

[Watch this File](#)

★★★★★

4.0 | 5 ratings

[Rate this file](#)

49 Downloads (last 30 days)

File Size: 129 KB

File ID: #3019

[Download Submission](#)

Code covered by the [BSD License](#)

Highlights from Airlib

- `[CD,CL,CY,Ci,Cm,Cn]=ab2dv...`
- `[X0,U0]=air3m(name,V,H,G)`
[X0,U0]=air3m(name,V,H,G) finds aircraft trim condition
- `demos`
DEMOS Demo list for the Aircraft Library.
- `sfunxyz(t,x,u,flag,ax,var...`
SFUNXY S-function that acts as an X-Y-Z scope using MATLAB plotting functions.
- `slblocks`
- `contents.m`

File Information

Description Airlib is a library of aircraft models to be used with Simulink 3.1 (MATLAB 5.3) or later (tested on 6.1 & 6.5). It is based on two basic blocks that implement a continuous-time and a discrete-time nonlinear general aircraft model. Both blocks are largely based on the FDC toolbox, written by Marc Rauw and available at the MATLAB Central website.

The initial version, dated Feb 2003, contains 13 different nonlinear aircraft models including, among others, a Boeing 747, an F4 Phantom, an F104 Starfighter, an X15, an IAI Pioneer (unmanned), a Convair 880 and

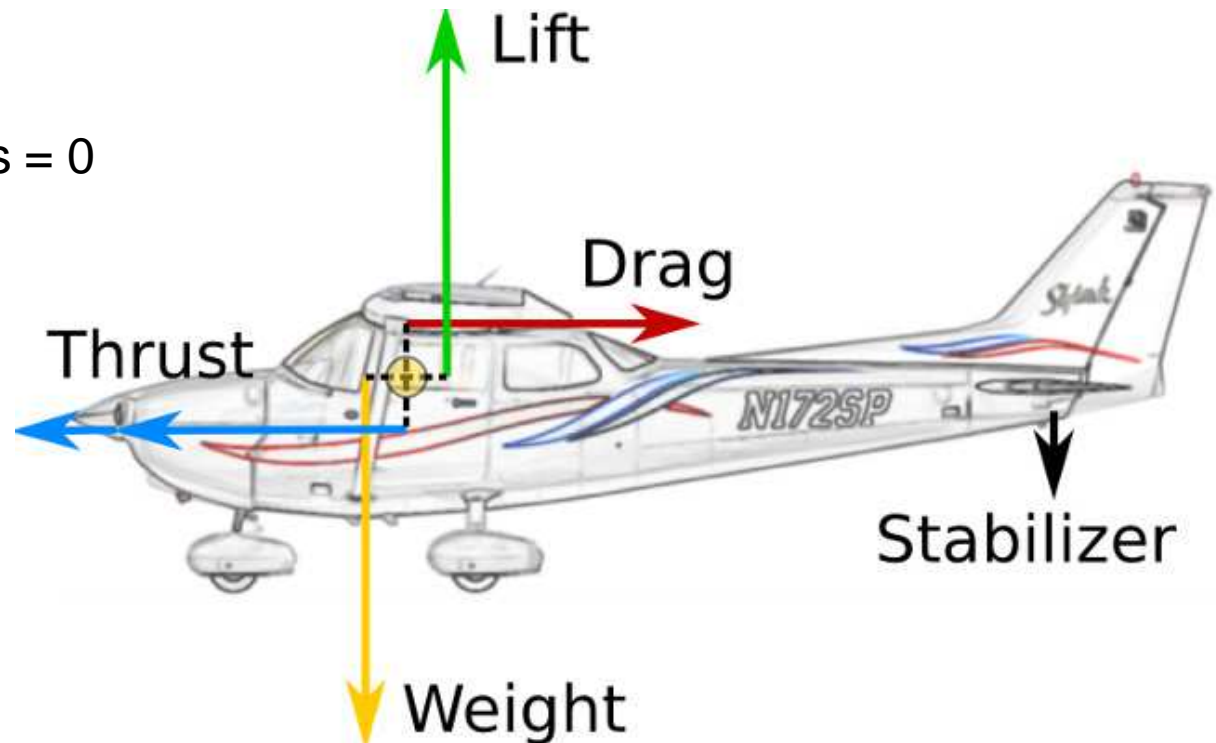
Aircraft Trim

Equilibrium point is computed optimally for a specific velocity(Mach) and Altitude

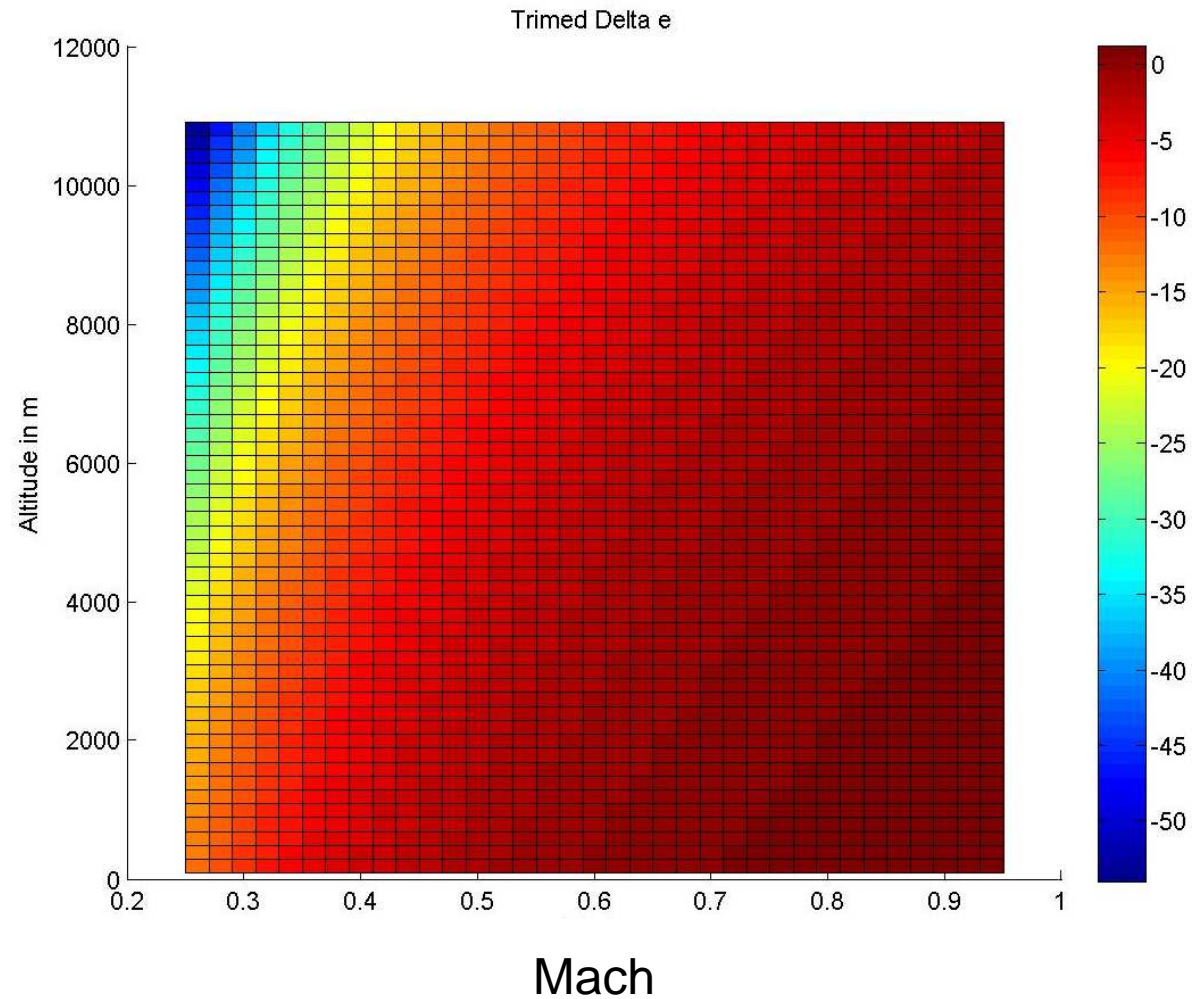
Lift = Weight

Thrust = Drag

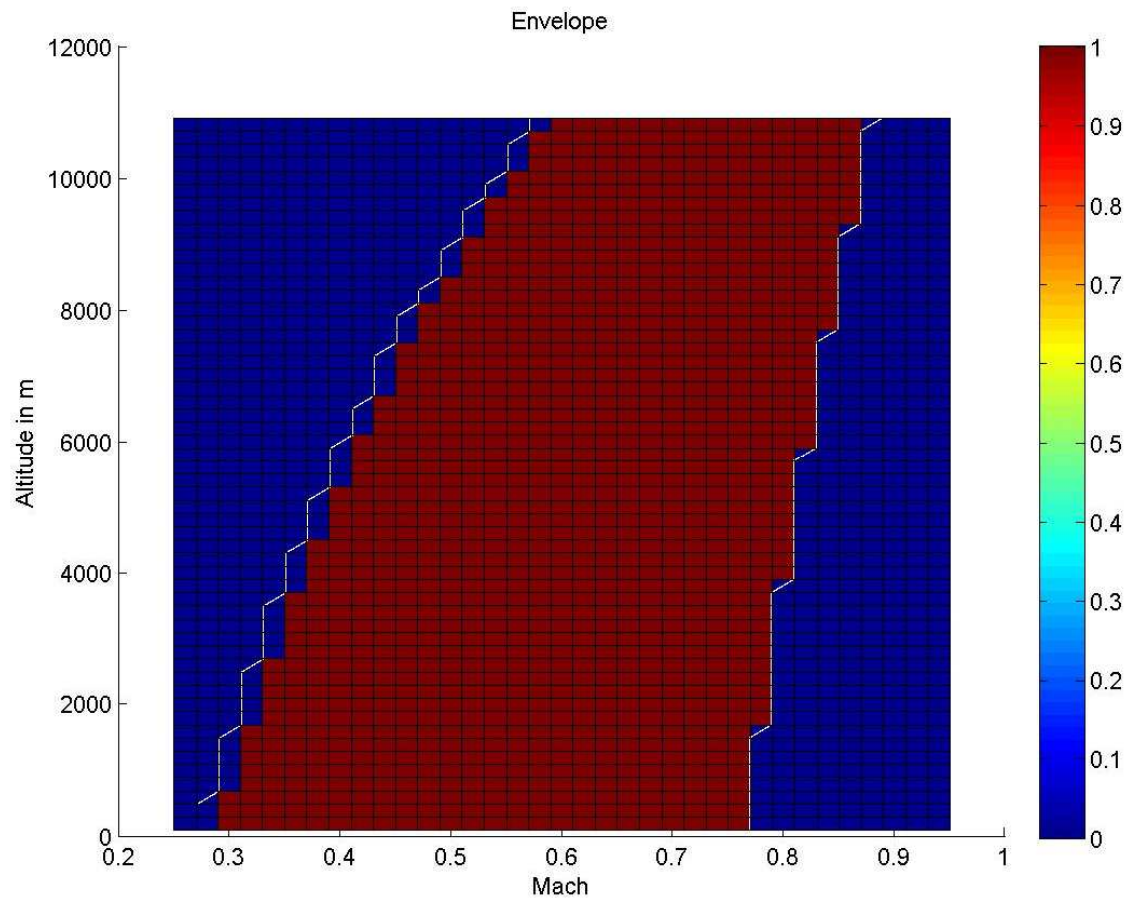
All rates and Accelerations = 0



Flight Envelope

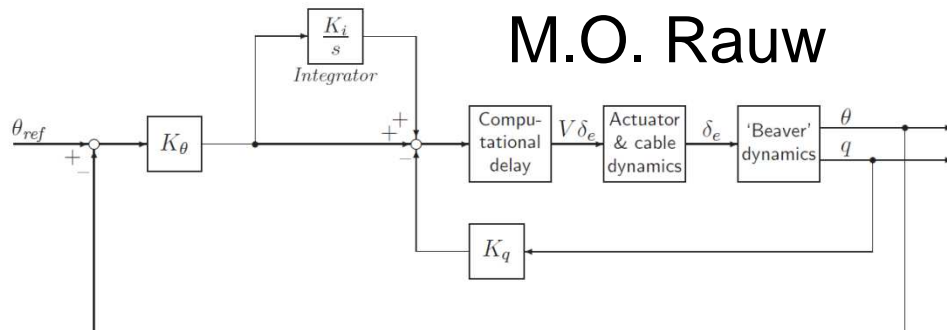


Flight Envelope



The FDC Toolbox

M.O. Rauw



Amy Jo

The Flight Dynamics & Control Toolbox

Home

News

Info

The author
History
Objectives
Dials & Gauges
FAQ
Known problems
Thanks!

Downloads

Licenses
FDC toolbox
FDC manual
DUBSI blockset

FDC toolbox downloads

Currently there are two versions of the Flight Dynamics and Control toolbox available for download: [FDC 1.3.3](#), which was designed for Matlab 5.1 / Simulink 2.1 ("Release 9") or newer, and [FDC 1.2.1](#), which is compatible with Matlab 4.2 / Simulink 1.3. The toolbox is open source software; see the [License Agreement](#) for details.

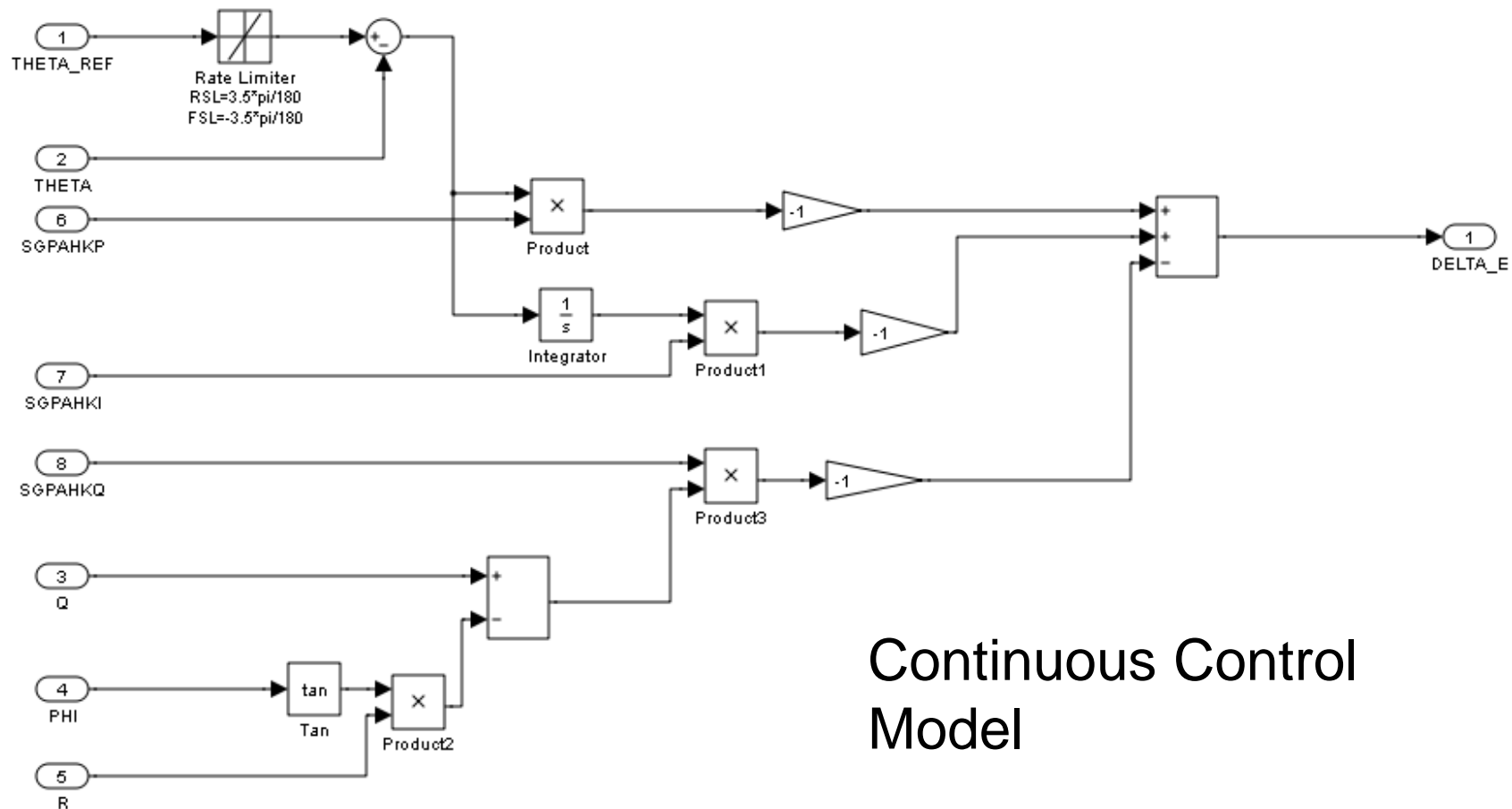
In addition to these current FDC versions, there is also a 'beta release' of the upcoming FDC 1.4, which can be obtained from the [Dutchroll CVS tree](#) at SourceForge, or as a [zipped archive](#). FDC 1.4 beta is compatible with Matlab R11 or newer; it is subject to the terms of the [Open Software License](#). Although the development of this version is not entirely completed and its user-manual is still under construction, it is deemed superior to FDC 1.3.

Before using the software, it is recommended to take a look at the [frequently asked questions](#) and [known problems](#) pages too.

Preview of the next version: FDC 1.4 beta 3

FDC 1.4 beta 3 is the second 'official' beta of the next FDC release. Compared to the previous two beta's, several heltexts

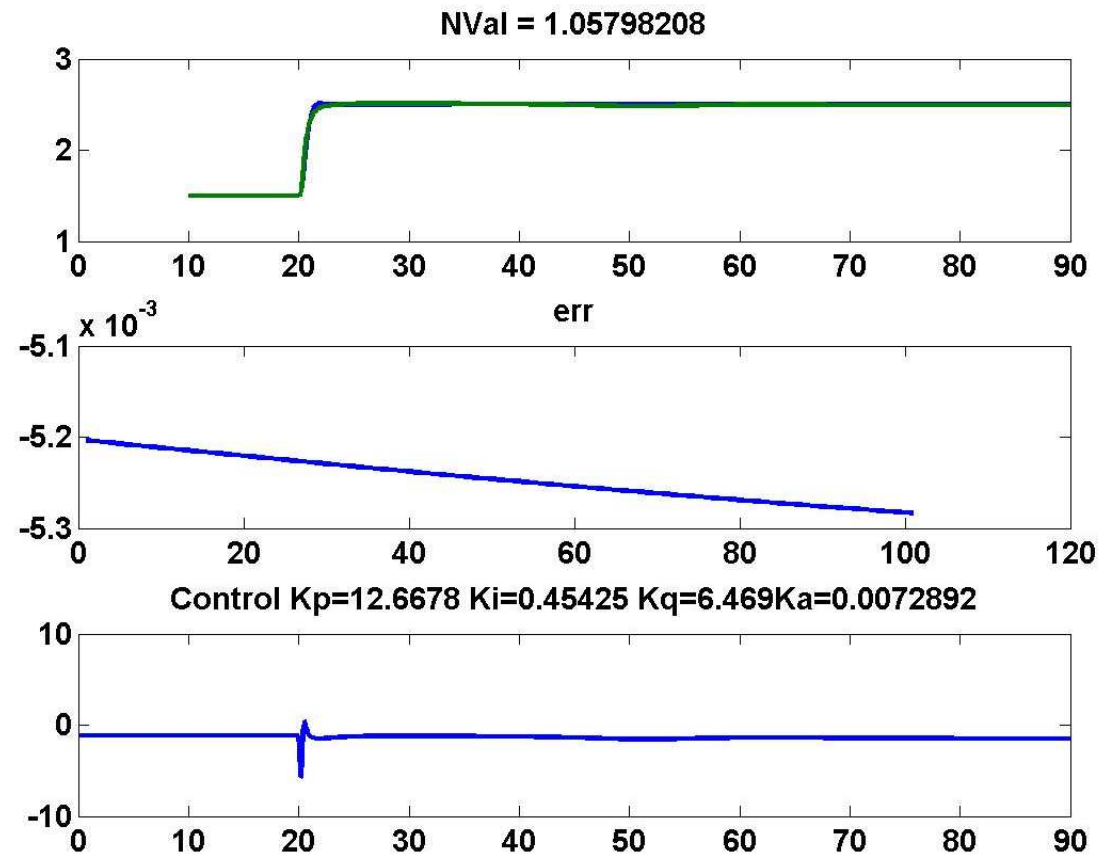
Pitch Attitude Hold



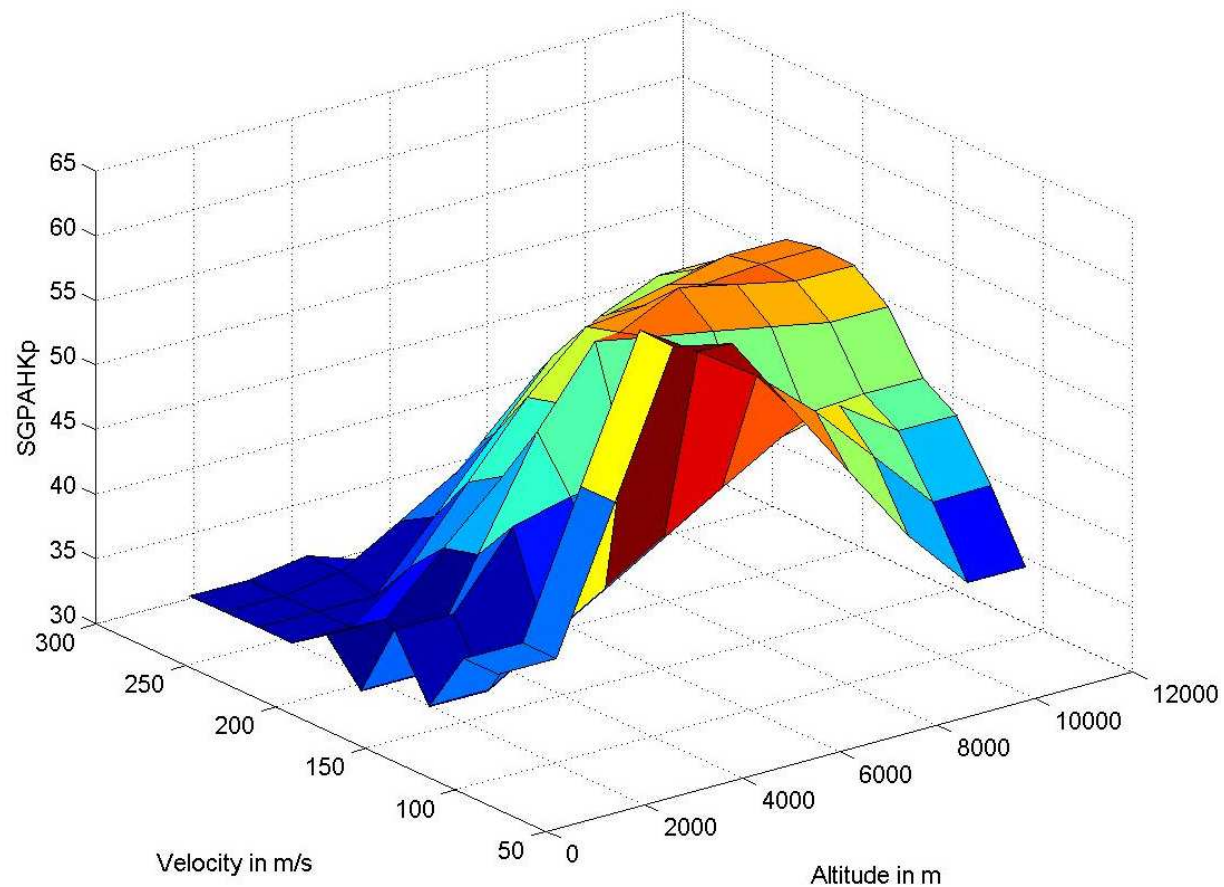
Continuous Control Model

Rapid Prototyping

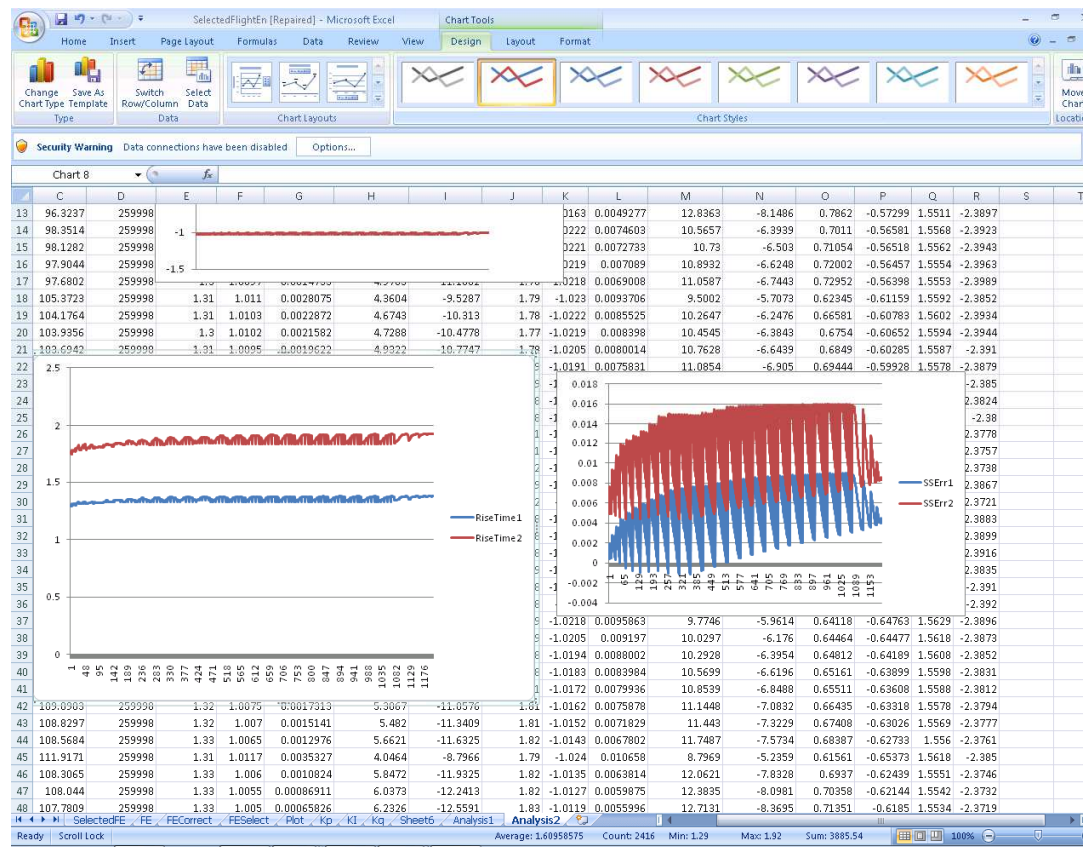
fminsearch()



Scheduled Gains

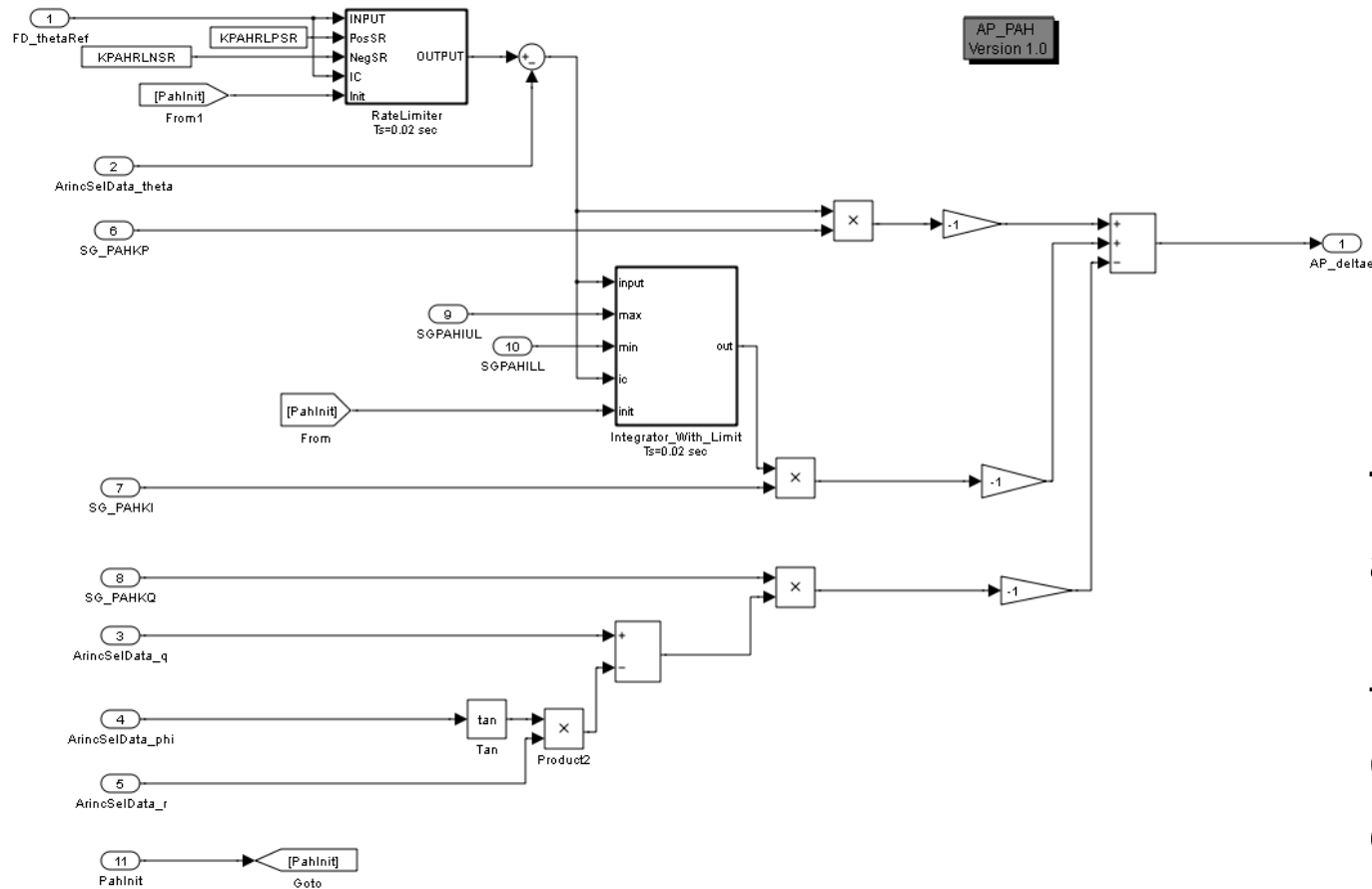


Validation of Schedule Gains



Scheduled
gains
validated
against
1200
models in
the flight
envelope

Digital PAH



These models are the SDD Requirements from which the C code is hand coded.

Mode Transition Logic

- Mode Transition table indicates the possible transitions from any operational mode to another mode due to an event.
- Event can be a software trigger or button press from the pilot.
- Condition table indicates the conditions that must be TRUE for the respective transition to occur.
- Conditions are tabulated in a separate table.

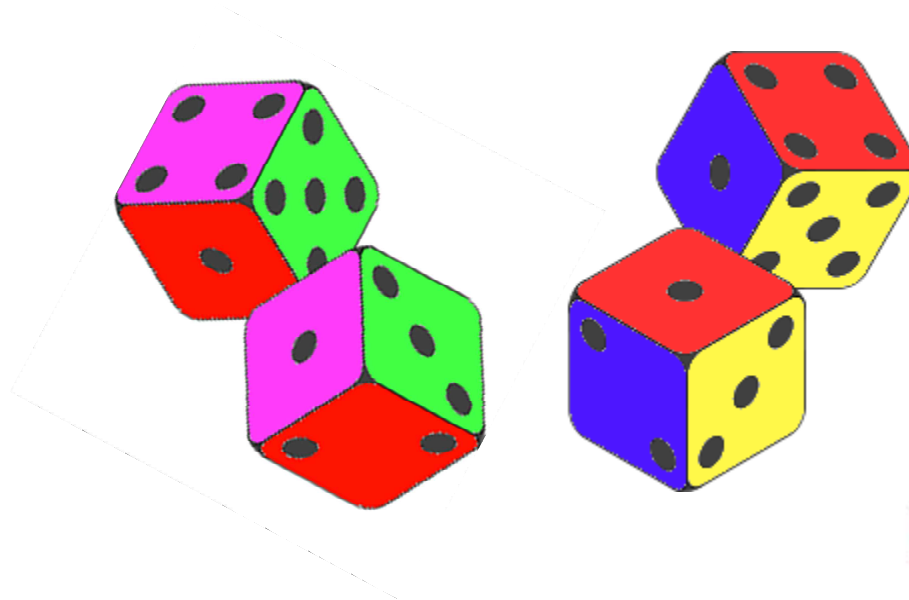
	A	B	C	D	E	F	G	H	I	J	K	L	
1	States	Sl. No.	Modes	01	02	03	04	05	06	07	08	09	10
2				AP	FD	SPD	VS	ALT	ALTS	ALTCAP	ALTCPDN	GA	AL
3													
4	Vertical	01	DIS(Vertical)	02	02	00	00	00	00	00	00	00	0
5		02	PAH	010202	010202	03	04	05	00	07	00	0601	0
6		03	SPD HOLD	010303	010303	02	04	05	00	07	00	0601	0
7		04	VS	010404	010404	03	02	05	00	07	00	0601	0
8		05	ALT HOLD	010505	010505	03	04	02	00	00	00	0601	0
9		06	GA(Vertical)	02	01	00	00	00	00	00	00	00	0
10		07	ALTS CAP	010707	010707	00	00	05	00	00	05	0601	0
11		08	APR GS(CAP & ACT)	010808	010808	00	00	00	00	00	00	0601	0
12		09	EDM(Vertical)	02	01	00	00	00	00	00	00	00	0
13	Lateral	01	DIS(Lateral)	0203	0203	00	00	00	00	00	00	00	0
14		02	RAH	010202	010202	00	00	00	00	00	00	0501	0
15		03	HH	010303	010303	00	00	00	00	00	00	0501	0
16		04	HDG SEL	010404	010404	00	00	00	00	00	00	0501	0
17		05	GA(Lateral)	0203	01	00	00	00	00	00	00	00	0
18		06	APR LOC(CAP & ACT)	010606	010606	00	00	00	00	00	00	0501	0
19		07	NAV VOR	010707	010707	00	00	00	00	00	00	0501	0
20		08	EDM(Lateral)	0203	01	00	00	00	00	00	00	00	0
21	AP	01	AP ON	02	00	00	00	00	00	00	00	02	0
22		02	AP OFF	0103	00	00	00	00	00	00	00	00	0
23		03	AP SYNC	02	00	00	00	00	00	00	00	00	0

Validated with Assertions

- Starting from a safe state the autopilot modes have to transition to a safe state.
- The correctness of the safe state is verified by reviews
- Violation of any assertion for all combination of states, triggers and conditions requires a redesign of that transition
- This amounts to 36,391,680 executions during the validation process. 2 days of weekend runs

```
% ----- ASSERTION 4 -----  
% When ALT SEL is captured, then  
% vertical mode need to be ALT CAP.  
if(ALTS(i5) ==3)  
    if(Vertical(i1)~=7)  
        assert = 1;  
    end  
end % END ASSERTION 4  
  
% ----- ASSERTION 5 -----  
% During ALT HOLD mode ALT  
% SEL is turned OFF.  
if(Vertical(i1) == 5)  
    if(ALTS(i5) ~=1)  
        assert = 1;  
    end  
end % END ASSERTION 5  
  
% ----- ASSERTION 6 -----  
% Deals with ALT SEL Capture scenario.  
if(Vertical(i1) == 7)  
    if(ALTS(i5) ~=3)  
        assert = 1;  
    end  
end % END ASSERTION 6
```

Code and Random Test



पूर्णक मुख्य()

{

जानवर ज,*ज1;

शोर श;

चीता च;

ज.लिखो();

श.लिखो();

ज1->लिखो();

ज1=&च;

ज1->लिखो();

वापस();

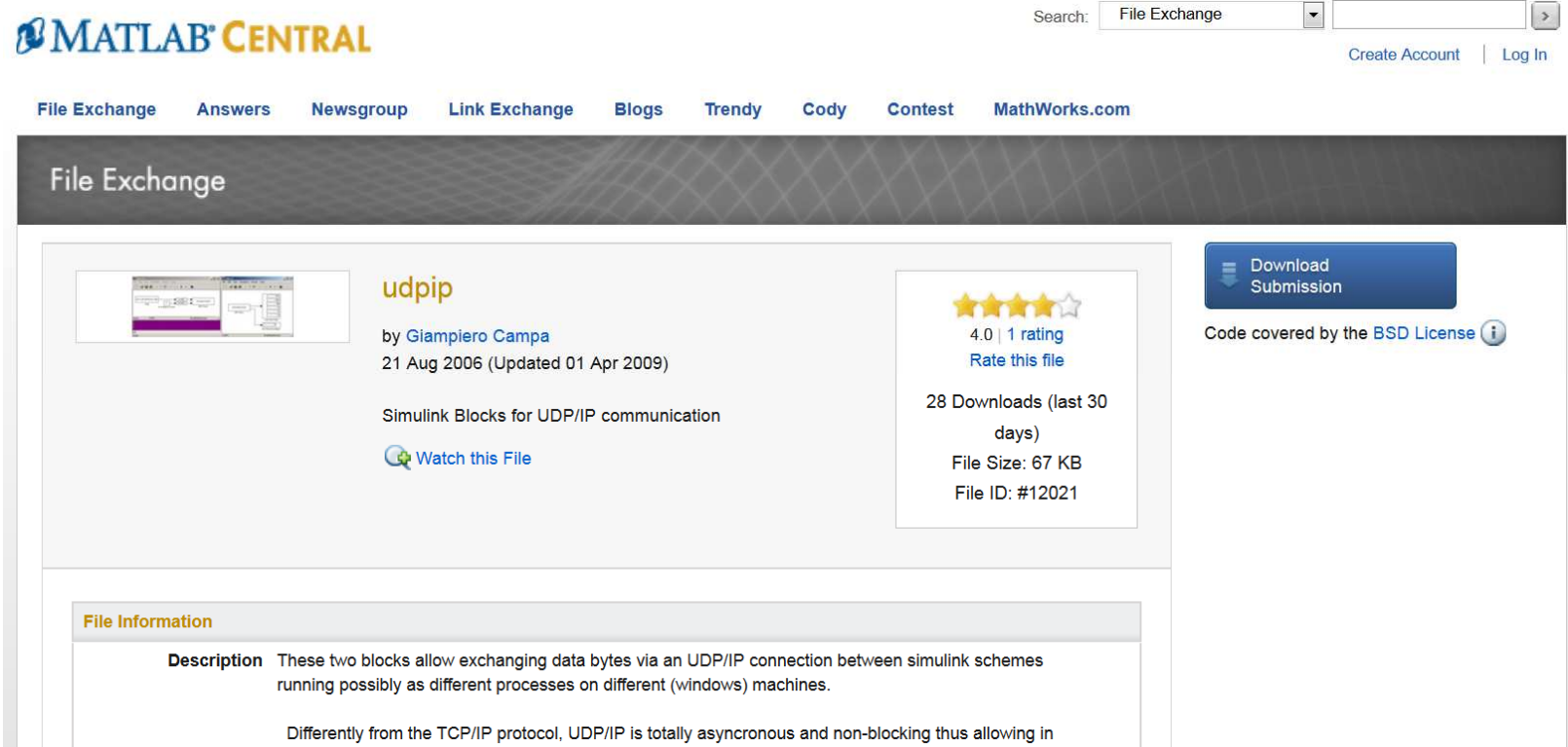
}

C Code and Test

- Manual coding with the utility functions for the various blocks
- Build each block using the utility functions
- Test each block using the mex function
- Random sinusoidal waveforms for float signals and random toggles for Boolean signals used to test the C code with the Simulink models
- Overnight runs cleared the code

UDP

■ UDPIP – by Giampiero Campa




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udpip

by [Giampiero Campa](#)
21 Aug 2006 (Updated 01 Apr 2009)

Simulink Blocks for UDP/IP communication

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4.0 | 1 rating
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28 Downloads (last 30 days)
File Size: 67 KB
File ID: #12021

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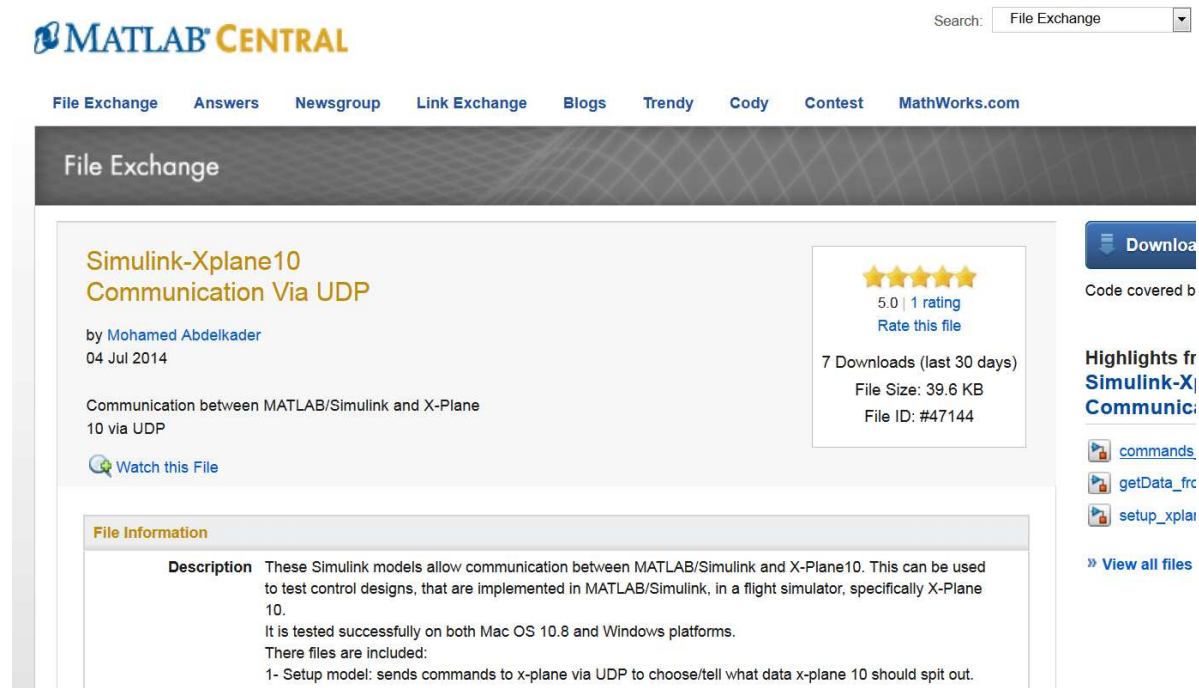
File Information

Description These two blocks allow exchanging data bytes via an UDP/IP connection between simulink schemes running possibly as different processes on different (windows) machines.

Differently from the TCP/IP protocol, UDP/IP is totally asynchronous and non-blocking thus allowing in

UDP – X-planes

- Simulink – X-plane 10 UDP – by Mohamed Abdelkader

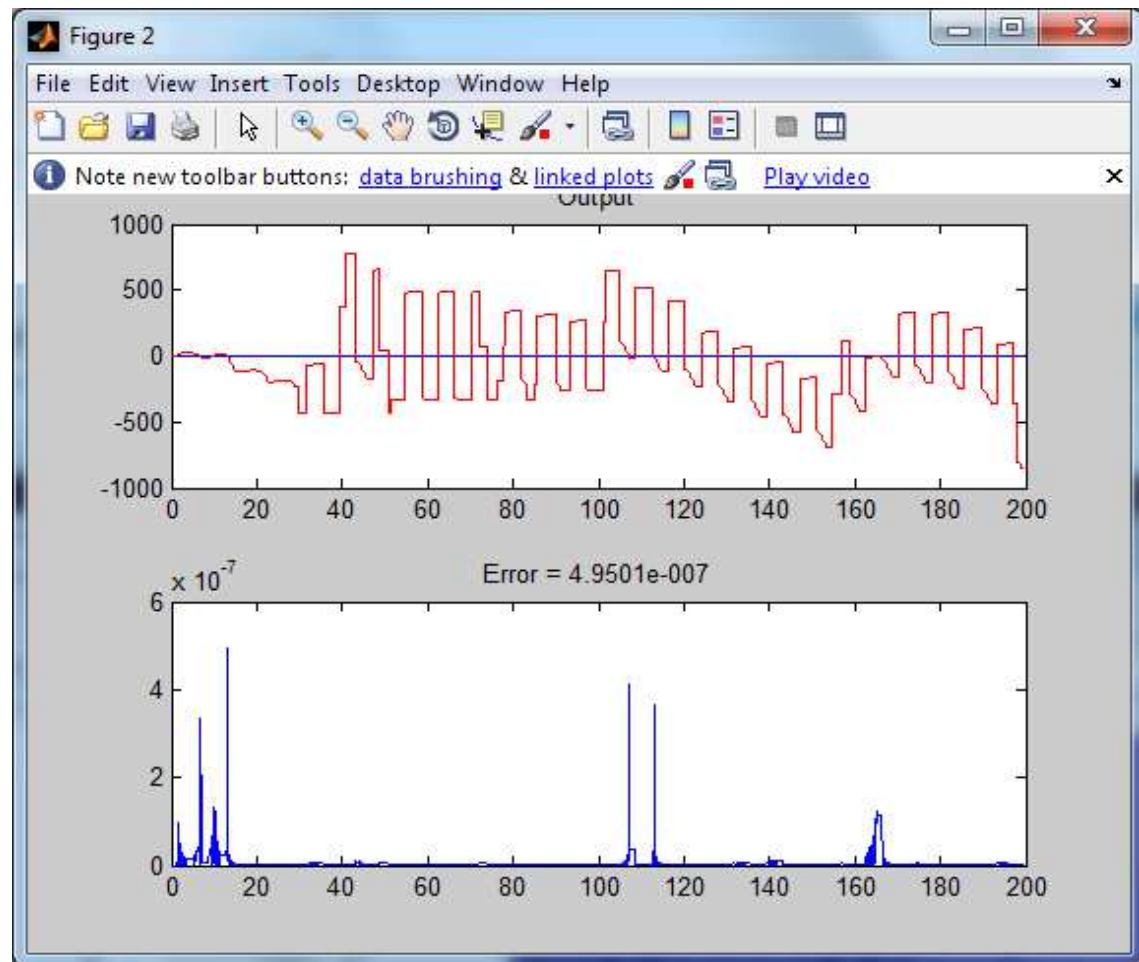


The screenshot shows the MATLAB Central File Exchange page for a file titled "Simulink-Xplane10 Communication Via UDP" by Mohamed Abdelkader, dated 04 Jul 2014. The page features a 5-star rating (5.0 / 1 rating) and 7 downloads in the last 30 days. The file size is 39.6 KB and the ID is #47144. The description states that these Simulink models allow communication between MATLAB/Simulink and X-Plane 10, tested on Mac OS 10.8 and Windows. The included files are: 1- Setup model: sends commands to x-plane via UDP to choose/tell what data x-plane 10 should spit out. The page also includes a "Download" button, a "Watch this File" link, and a list of highlights for the file: commands, getData_frc, and setup_xplar.

Model in Loop Tests

- We have tried something new with the C code compiled as an exe and communicating with the Simulink model using UDP
- In a two channel operation we have two exe files communicating with each other and the expected result generated from the two channel stitched model

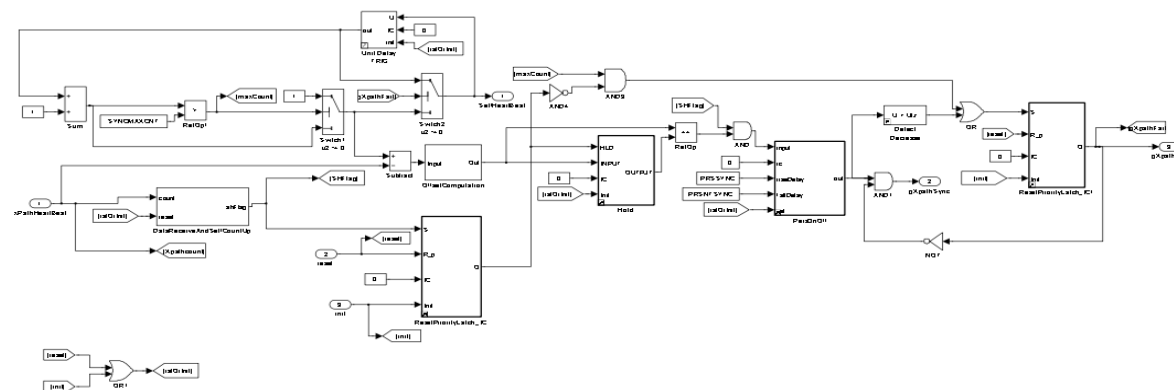
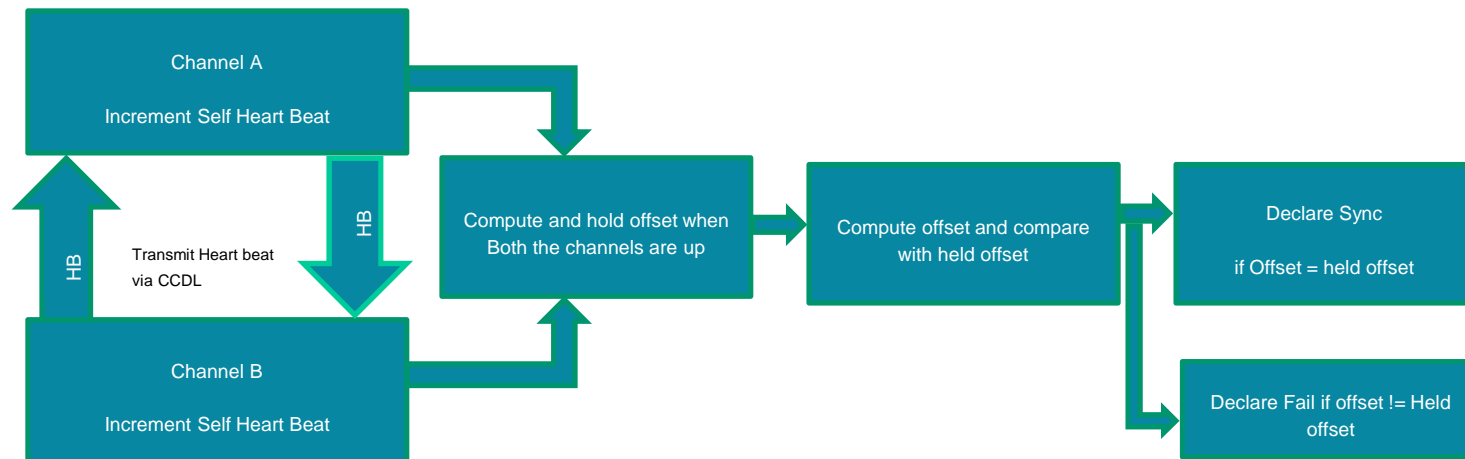
Error plots



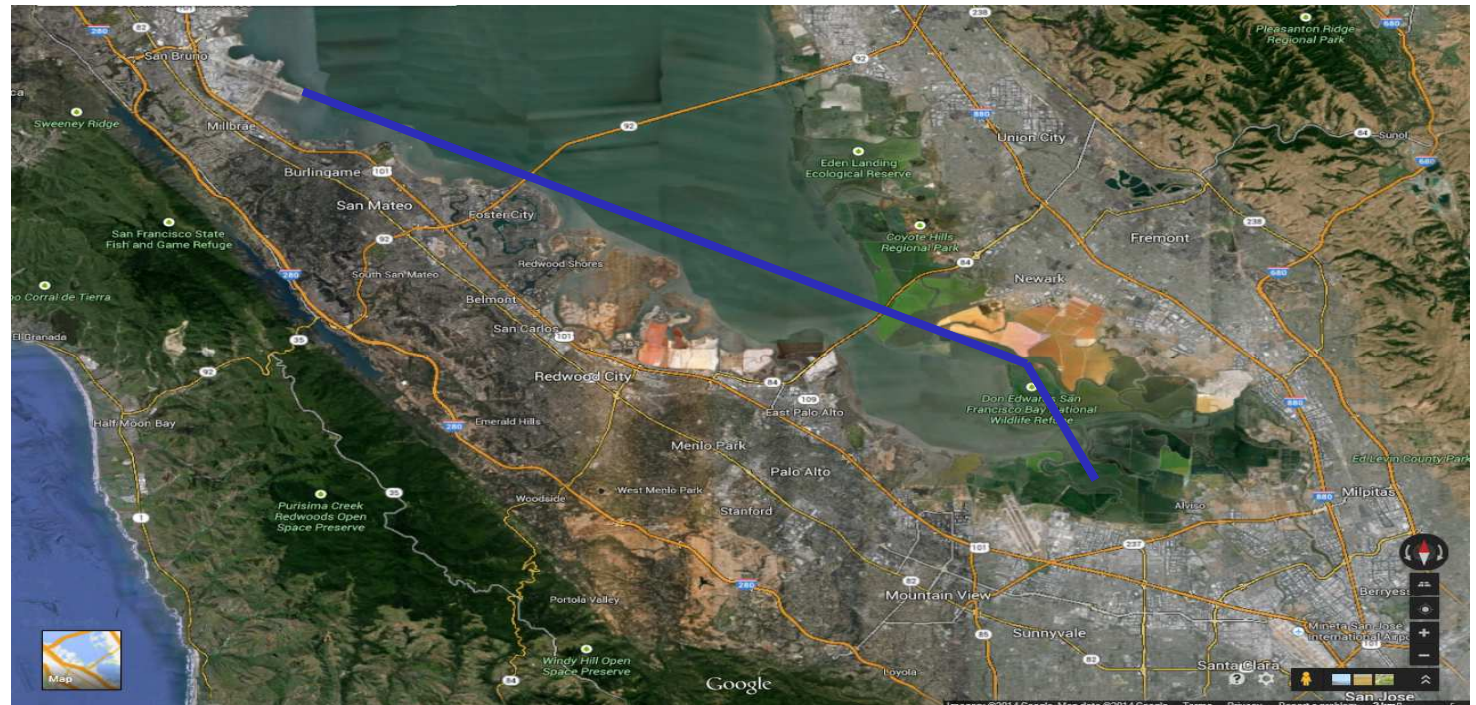
Errors

- Moog does hand coding – therefore there are going to be errors. ***Testing finds them!***
- Lookup table data mismatch in the 4th decimal place
- Logic errors between the model and code
- Input not connected properly in the model
- Initialization errors – first frame
- Errors in mode transition
- One frame delays due to call order errors

Cross Channel Sync Logic

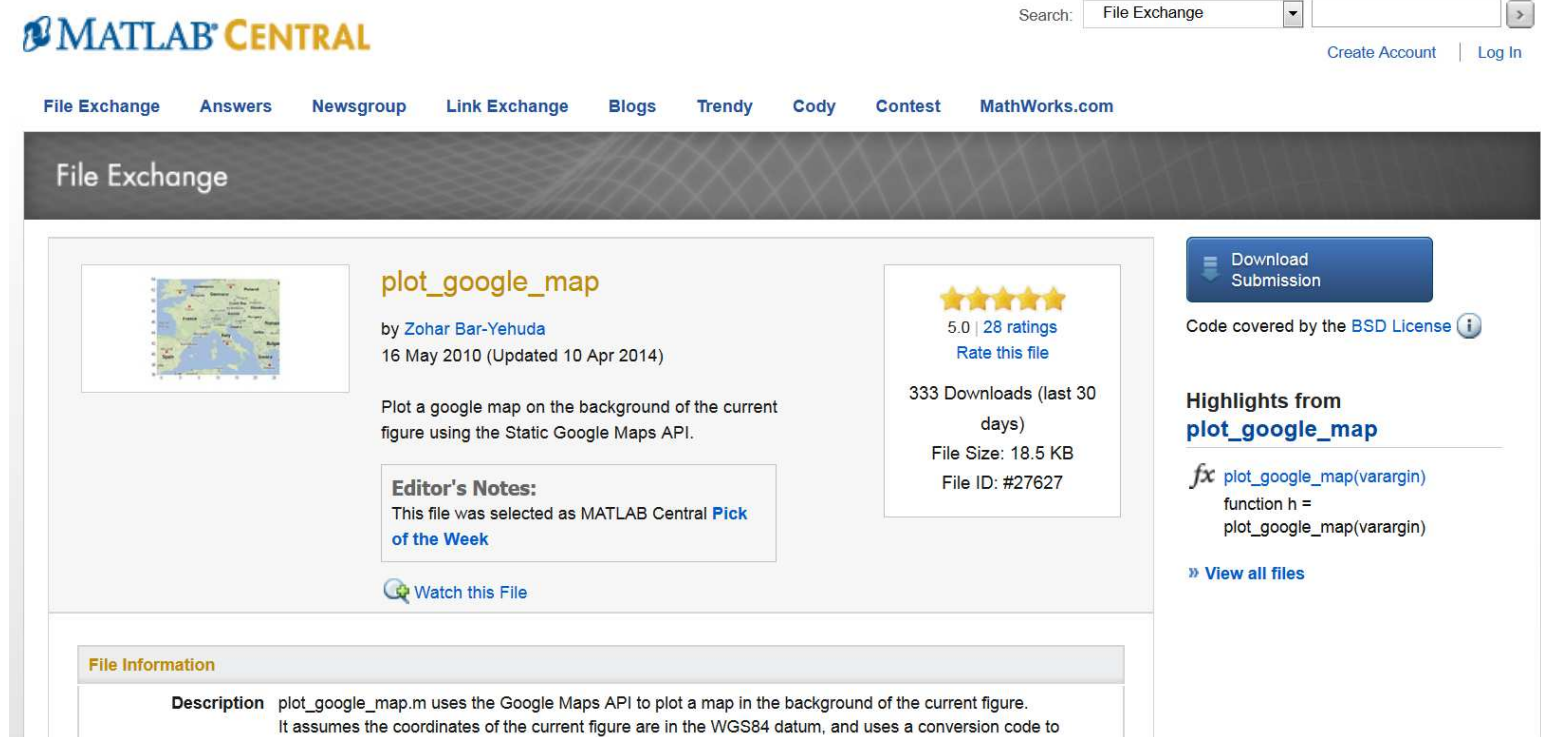


Demo



Google Maps

■ plot_google_map - by Zohar Bar-Yehuda




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File Exchange



plot_google_map

by [Zohar Bar-Yehuda](#)
16 May 2010 (Updated 10 Apr 2014)

Plot a google map on the background of the current figure using the Static Google Maps API.

Editor's Notes:
This file was selected as MATLAB Central [Pick of the Week](#)

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★★★★★
5.0 | 28 ratings
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333 Downloads (last 30 days)
File Size: 18.5 KB
File ID: #27627

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Highlights from plot_google_map

```
fx plot_google_map(varargin)
function h =
    plot_google_map(varargin)
```

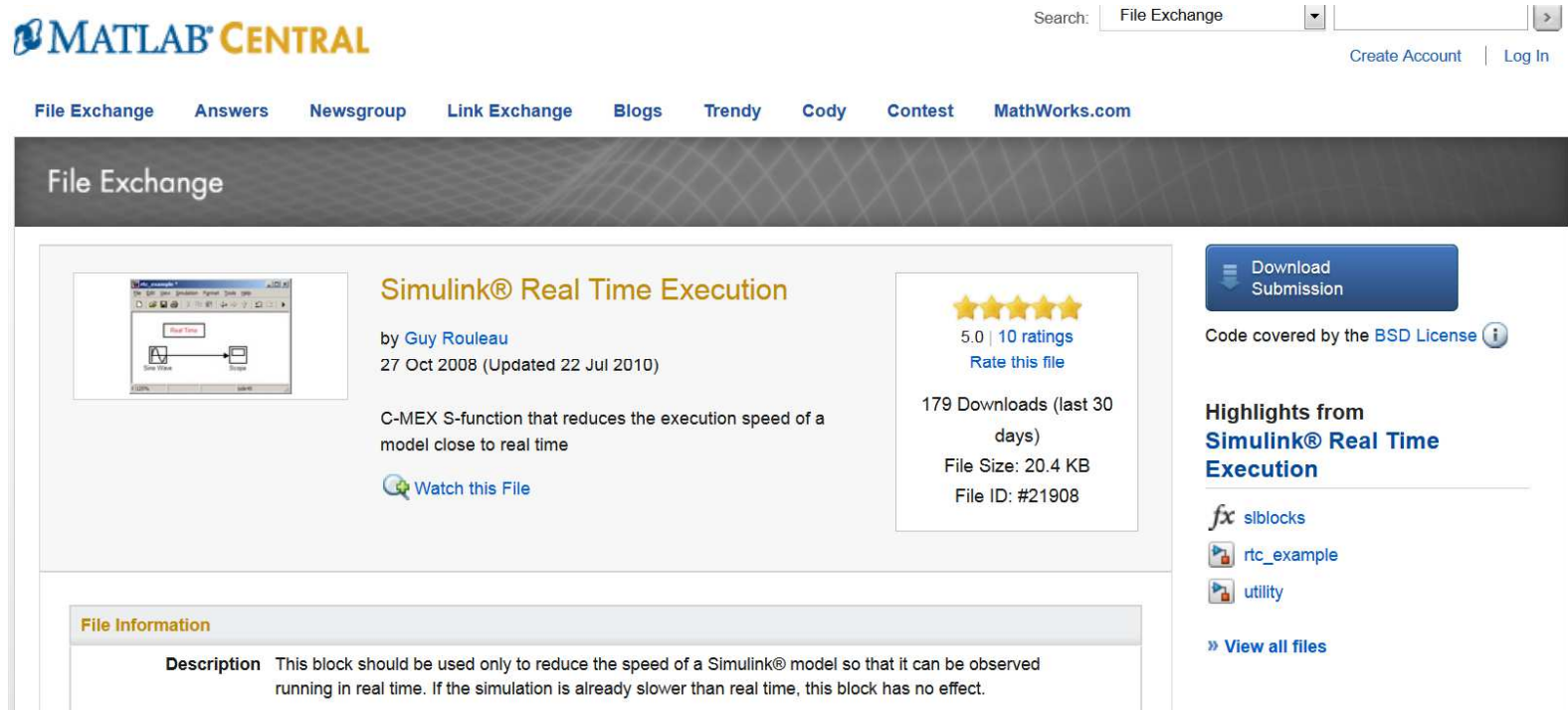
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File Information

Description plot_google_map.m uses the Google Maps API to plot a map in the background of the current figure. It assumes the coordinates of the current figure are in the WGS84 datum, and uses a conversion code to

Real time simulation

- Simulink® Real Time Execution - by Guy Rouleau



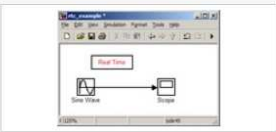
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Simulink® Real Time Execution

by [Guy Rouleau](#)
27 Oct 2008 (Updated 22 Jul 2010)

C-MEX S-function that reduces the execution speed of a model close to real time

[Watch this File](#)

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Highlights from Simulink® Real Time Execution

- [slblocks](#)
- [rtc_example](#)
- [utility](#)

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File Information

Description This block should be used only to reduce the speed of a Simulink® model so that it can be observed running in real time. If the simulation is already slower than real time, this block has no effect.

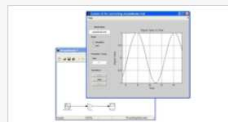
Matlab UI Interface

- Simulink Signal Viewing using Event Listeners and a MATLAB UI - by Phil Goddard



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File Exchange



Simulink Signal Viewing using Event Listeners and a MATLAB UI.

by Phil Goddard
28 May 2009 (Updated 02 Nov 2009)

This demo shows how to use block listeners to view model signals in a MATLAB user interface.

Editor's Notes:

This file was selected as MATLAB Central [Pick of the Week](#)

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4.8 | 10 ratings


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File ID: #24294

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Highlights from
Simulink Signal Viewing using Event Listeners and a MATLAB UI.

fx [simpleGUI](#)

This function creates a simple user interface for running a Simulink

 [simpleModel](#)

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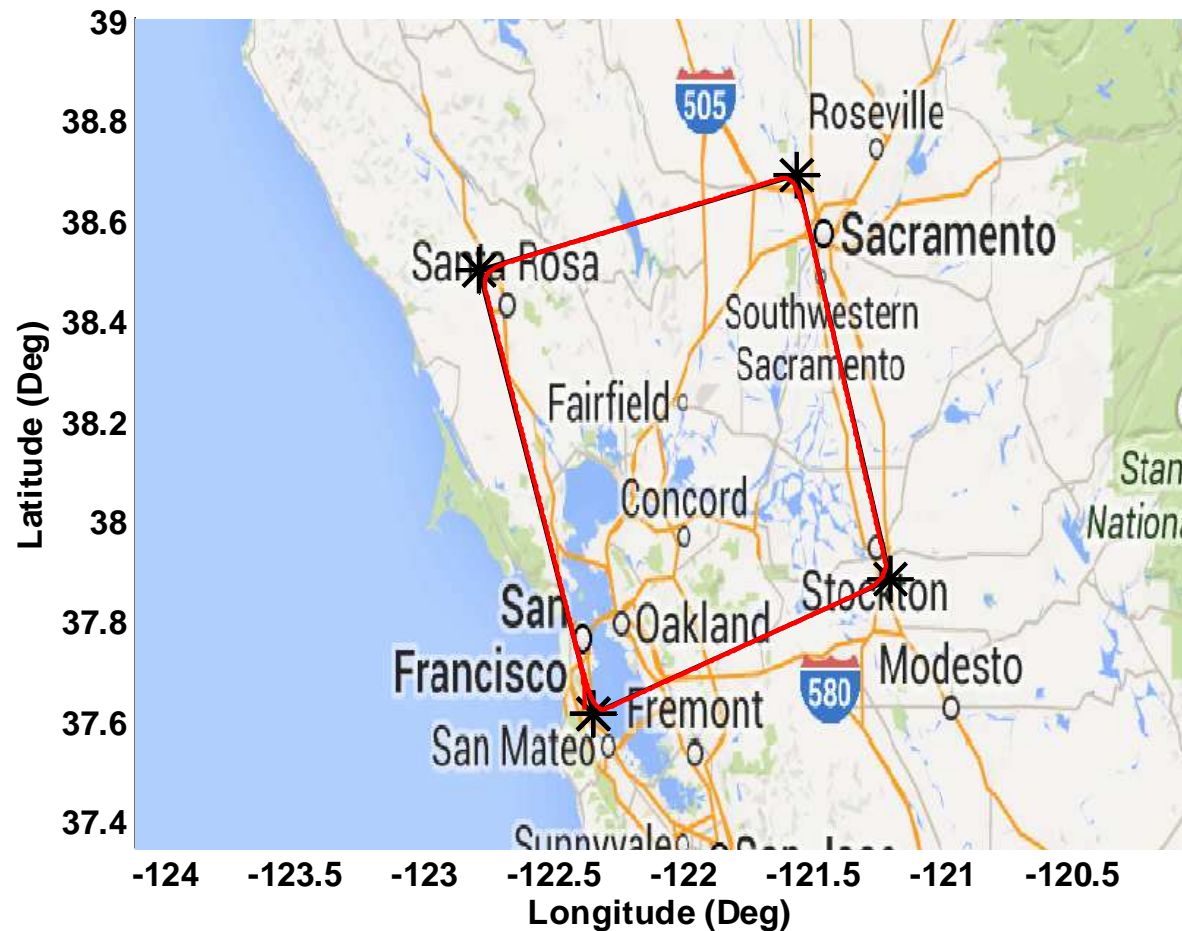
File Information

Description This application demonstrates how listeners can be attached to the blocks in a Simulink model, and how those listeners can be used to display block inputs and outputs on a MATLAB user interface. (The main

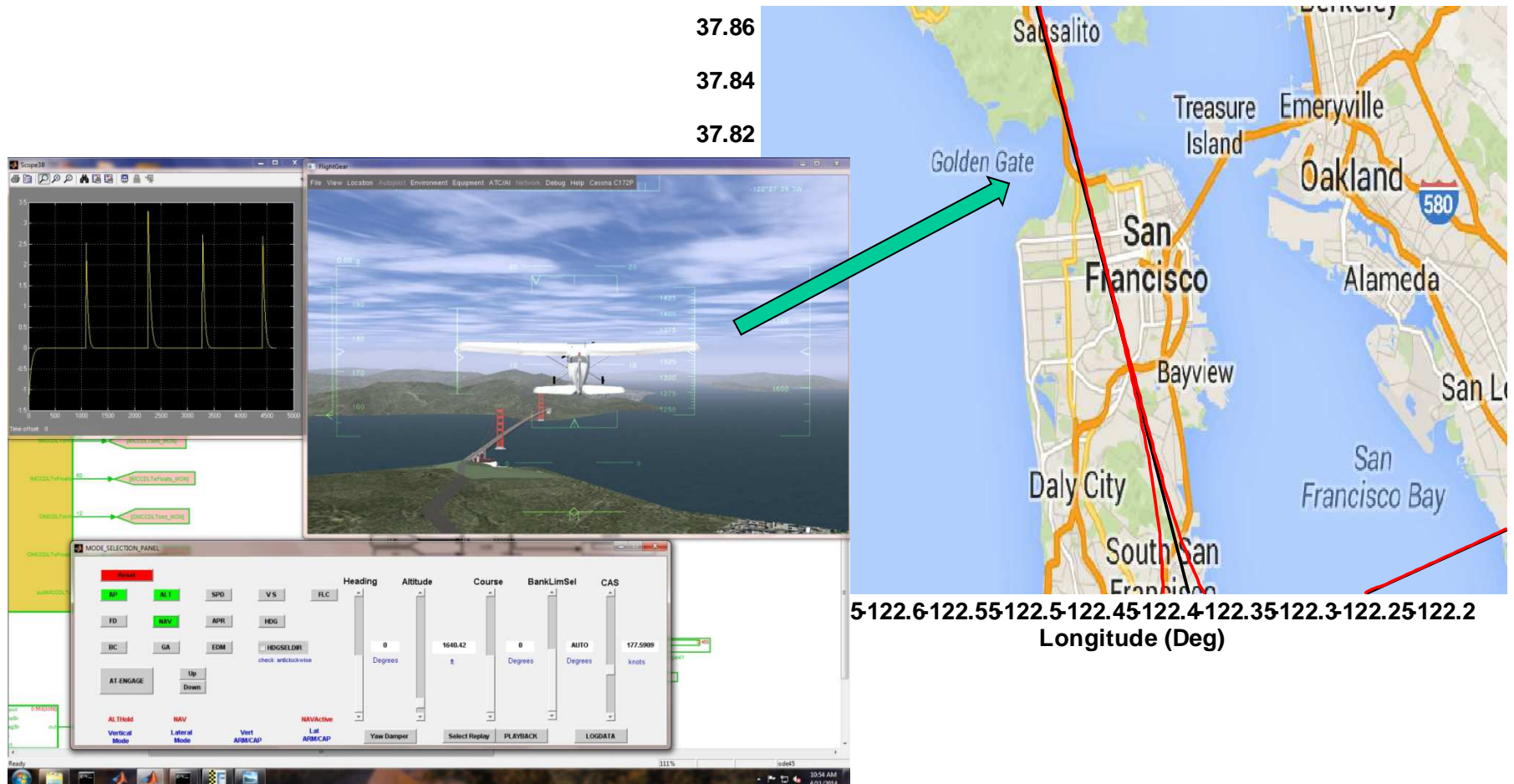
GPS Navigation

Black is
desired
track.
Each leg
is 100
Km

Red is
aircraft
trajectory



GPS Navigation



Matlab Toolboxes ...

- We used these toolboxes for our design
 - Matlab and Simulink
 - Control System Toolbox
 - Aerospace Blockset
 - Real Time Coder

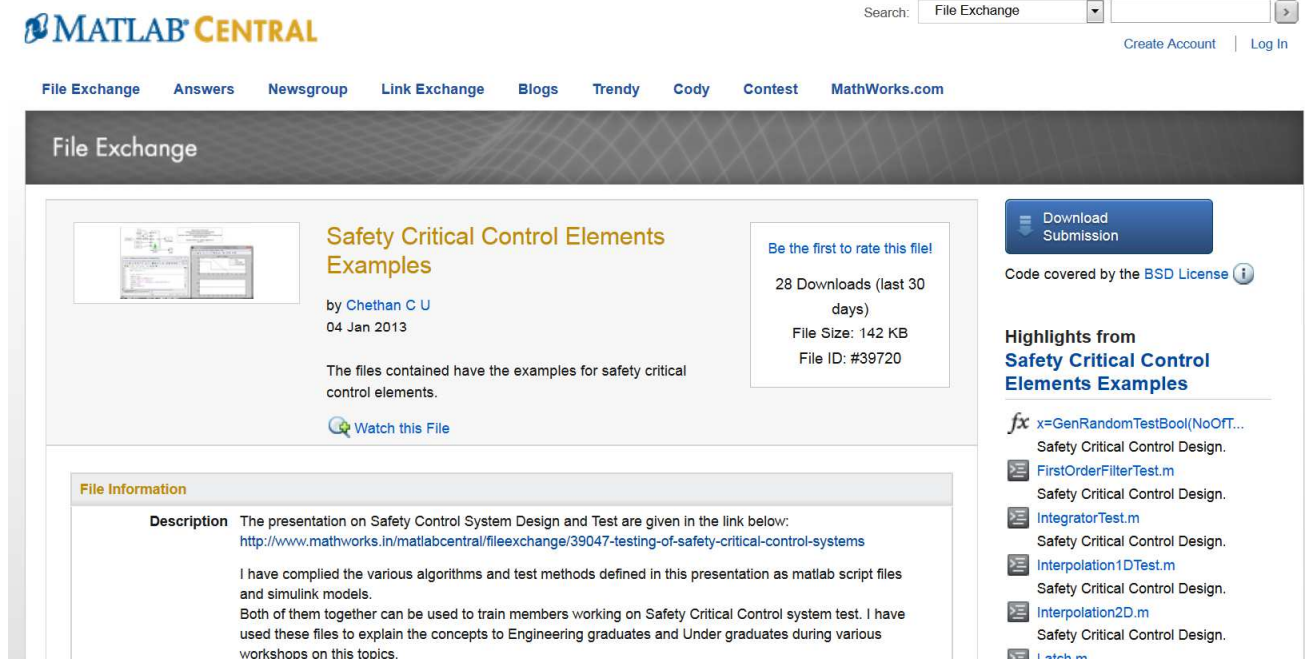
Our Contributions

We have tried to give back to the Matlab community. It has made a moderate impact going by the download rate and comments ...



Safety Critical Blocks

- Safety Critical Control Elements Examples
- by Chethan C U



The screenshot shows the MATLAB Central File Exchange interface. At the top, there's a search bar and navigation links like 'File Exchange', 'Answers', 'Newsgroup', etc. The main content area displays the file 'Safety Critical Control Elements Examples' by Chethan C U, dated 04 Jan 2013. It includes a description of the files, a 'Watch this File' button, and a 'File Information' section. On the right, there's a 'Download Submission' button and a list of highlights from the file, including various test scripts like 'GenRandomTestBool', 'FirstOrderFilterTest.m', 'IntegratorTest.m', 'Interpolation1DTest.m', 'Interpolation2D.m', and 'Latch.m'.

File Exchange

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File Exchange

Safety Critical Control Elements Examples

by Chethan C U
04 Jan 2013

The files contained have the examples for safety critical control elements.

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File Size: 142 KB
File ID: #39720

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Code covered by the BSD License

Highlights from Safety Critical Control Elements Examples

- `x=GenRandomTestBool(NoOfT...`
Safety Critical Control Design.
- `FirstOrderFilterTest.m`
Safety Critical Control Design.
- `IntegratorTest.m`
Safety Critical Control Design.
- `Interpolation1DTest.m`
Safety Critical Control Design.
- `Interpolation2D.m`
Safety Critical Control Design.
- `Latch.m`

File Information

Description The presentation on Safety Control System Design and Test are given in the link below:
<http://www.mathworks.in/matlabcentral/fileexchange/39047-testing-of-safety-critical-control-systems>

I have compiled the various algorithms and test methods defined in this presentation as matlab script files and simulink models.

Both of them together can be used to train members working on Safety Critical Control system test. I have used these files to explain the concepts to Engineering graduates and Under graduates during various workshops on this topics.

Random Signal Generation

- Random Signal Generation-
by Chethan C U

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File Exchange



Random Signal generation

by Chethan C U
04 Nov 2013

A compilation of random signal generation scripts that can be used for Testing various algorithms

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29 Downloads (last 30 days)

File Size: 6.92 KB

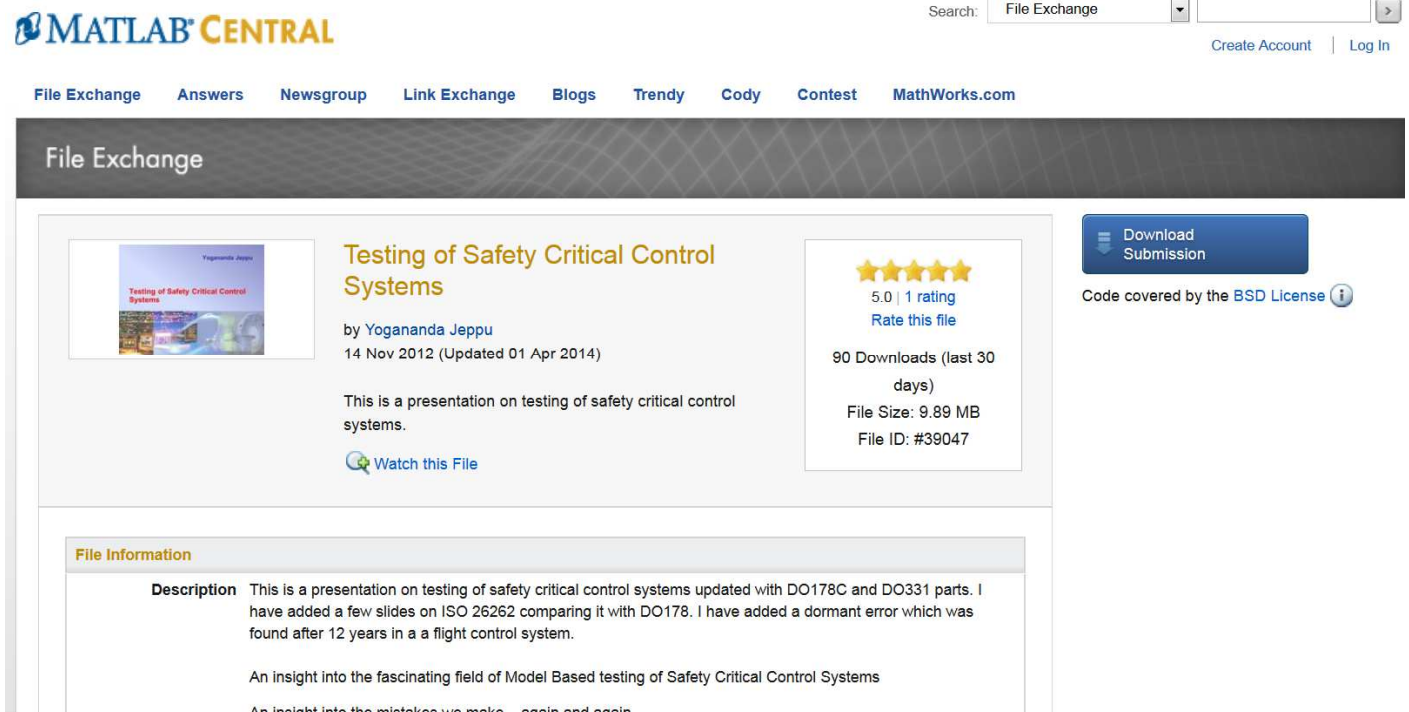
File ID: #44168

File Information

Description: Random testing has a great advantage as the input signals are Random. I hope there is no effort

Testing Safety Critical Systems

- Testing of Safety Critical Control Systems
- by Yogananda Jeppu



The screenshot shows the MATLAB Central File Exchange interface. At the top, there's a search bar with 'File Exchange' selected and a dropdown menu. Below the search bar are links for 'Create Account' and 'Log In'. The main navigation bar includes 'File Exchange', 'Answers', 'Newsgroup', 'Link Exchange', 'Blogs', 'Trendy', 'Cody', 'Contest', and 'MathWorks.com'. The 'File Exchange' section is highlighted. The main content area displays the file 'Testing of Safety Critical Control Systems' by Yogananda Jeppu. It includes a thumbnail image, the file title, the author's name, the date (14 Nov 2012), and a description. The file has a 5.0 rating and 90 downloads in the last 30 days. A 'Download Submission' button is visible. The 'File Information' section provides a detailed description of the presentation, mentioning updates with DO178C and DO331 parts, and a dormant error found after 12 years in a flight control system.


File Exchange

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File Exchange

 **Testing of Safety Critical Control Systems**

by [Yogananda Jeppu](#)
14 Nov 2012 (Updated 01 Apr 2014)

This is a presentation on testing of safety critical control systems.

[Watch this File](#)

5.0 | 1 rating
[Rate this file](#)

90 Downloads (last 30 days)
File Size: 9.89 MB
File ID: #39047

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Code covered by the [BSD License](#) ⓘ

File Information

Description This is a presentation on testing of safety critical control systems updated with DO178C and DO331 parts. I have added a few slides on ISO 26262 comparing it with DO178. I have added a dormant error which was found after 12 years in a flight control system.

An insight into the fascinating field of Model Based testing of Safety Critical Control Systems

An insight into the mistakes we make, again and again.

Final Words

- *The idea is to try to give all the information to help others to judge the value of your contribution; not just the information that leads to judgment in one particular direction or another. - Richard P. Feynman*
- Finally - Thank you Mathworks for making this possible
- jyogananda@moog.com

Video – 3 Mins. Questions?

