ORION AEROSPACE

First Flight

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Mission Specification for
A&AE 451 Aircraft Design, Fall 2000

Design of a Small Remotely-Piloted Variable Stability Aircraft (dated 8/20/00)

Background: Feedback control is often employed to improve the dynamic response of aircraft and guide the trajectory of autonomous aircraft. An aircraft that uses feedback control and has easy-to-modify feedback gains is called a variable stability aircraft. The stability of the aircraft motion depends on the easy-to-modify feedback gains.

A variable stability small aircraft would be a useful tool for teaching students about dynamic stability and feedback control. Courses at Purdue University that would benefit from such an airplane include AAE 364 Control Systems Analysis, AAE 421 Flight Dynamics and Control, and AAE 490A Flight Testing.

The Design Challenge: The remotely piloted aircraft to be designed must use feedback to modify the dynamic response of the aircraft. The vehicle must have at least one feedback sensor (e.g., an angular rate gyro). It must feed back the sensor signal to one controller (e.g., pitch rate feedback to the elevator, or yaw rate feedback to the rudder, or roll rate feedback to the aileron). The system must have least two feedback gains (off and nominal) that are selectable from the remote pilot.

Students must analytically predict the dynamic motion of the aircraft with and without feedback. They must record in-flight the pertinent motion variables (e.g., pitch rate and elevator motion, or yaw rate and rudder motion, or roll rate and aileron motion). They must update their analytical models of the aircraft to reflect what they learned in-flight. Measurement in-flight of airspeed would also be desirable.

The variable stability aircraft is intended to be marketed to existing companies who sell and manufacture model aircraft and to be used in other coursework at Purdue and other universities.

Design Constraints: Flight of the variable stability aircraft must be safely demonstrated within the Mollenkopf Athletic Center. The vehicle should be stable under all flight conditions and nominal feedback gains. It must be robust to crashes, easy to fly (i.e., have exceptional flying qualities), and easily transportable in a compact automobile. In all aspects of design and construction, cost must be minimized. The cost to build the fixed-wing aircraft must not exceed $200 (excluding radio-control gear, electric motor, speed controller, rate gyro and data recording system). Because the aircraft will be flown in an enclosed space, the powerplant must be electric (battery powered). Following a conventional rolling take-off, the aircraft must have an endurance of 12 minutes. Take-off rate-of-climb must be sufficient for satisfactory flight in the Mollenkopf Athletic Center.

Rate gyroscopes are compatible with our radio control electronics are available from Futaba (see http://www.futaba-rc.com/radioaccys/futm0501.html). A Tattletale 8 data logger with software will be provided (see http://www2.vsi.net/waetjen/onset/Products/Product_Pages/Tattletale_pages/data_sheets/TT8.html).

Any deviation from the design constraints must be formally requested in writing to Professor Andrisani and justified using sound engineering and business logic.

Team Orion Aerospace

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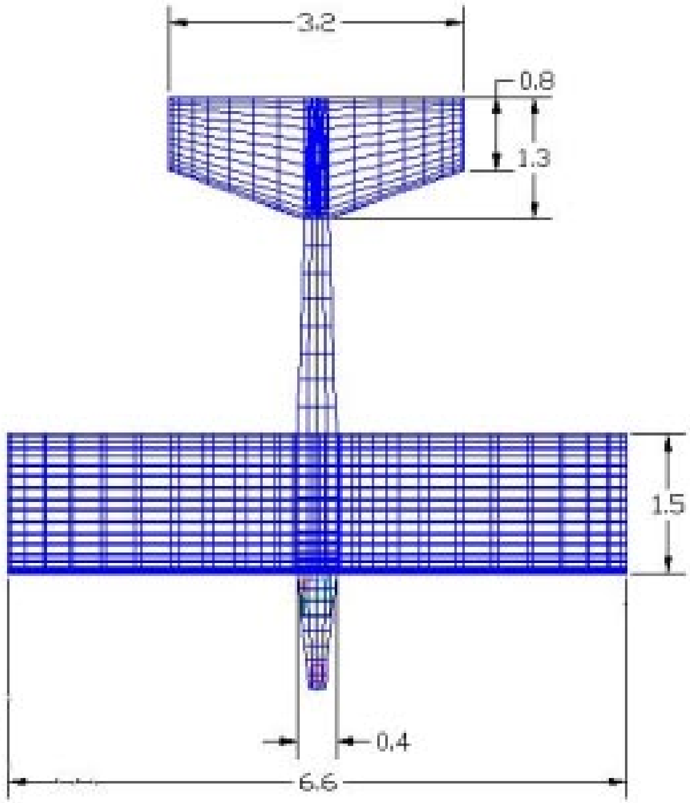
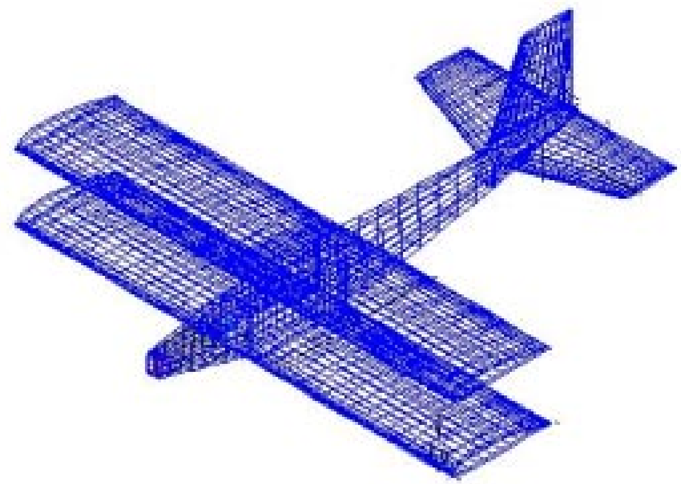
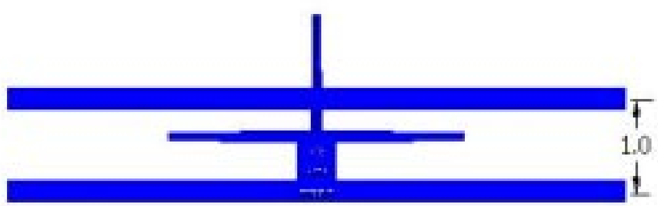
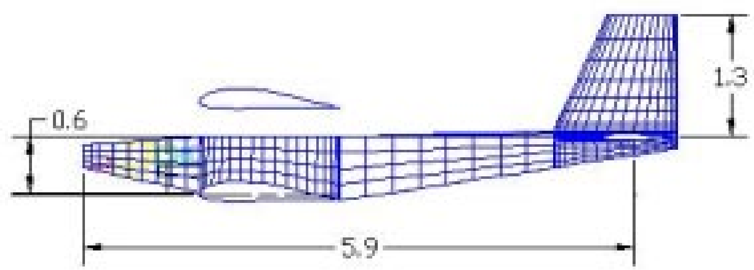








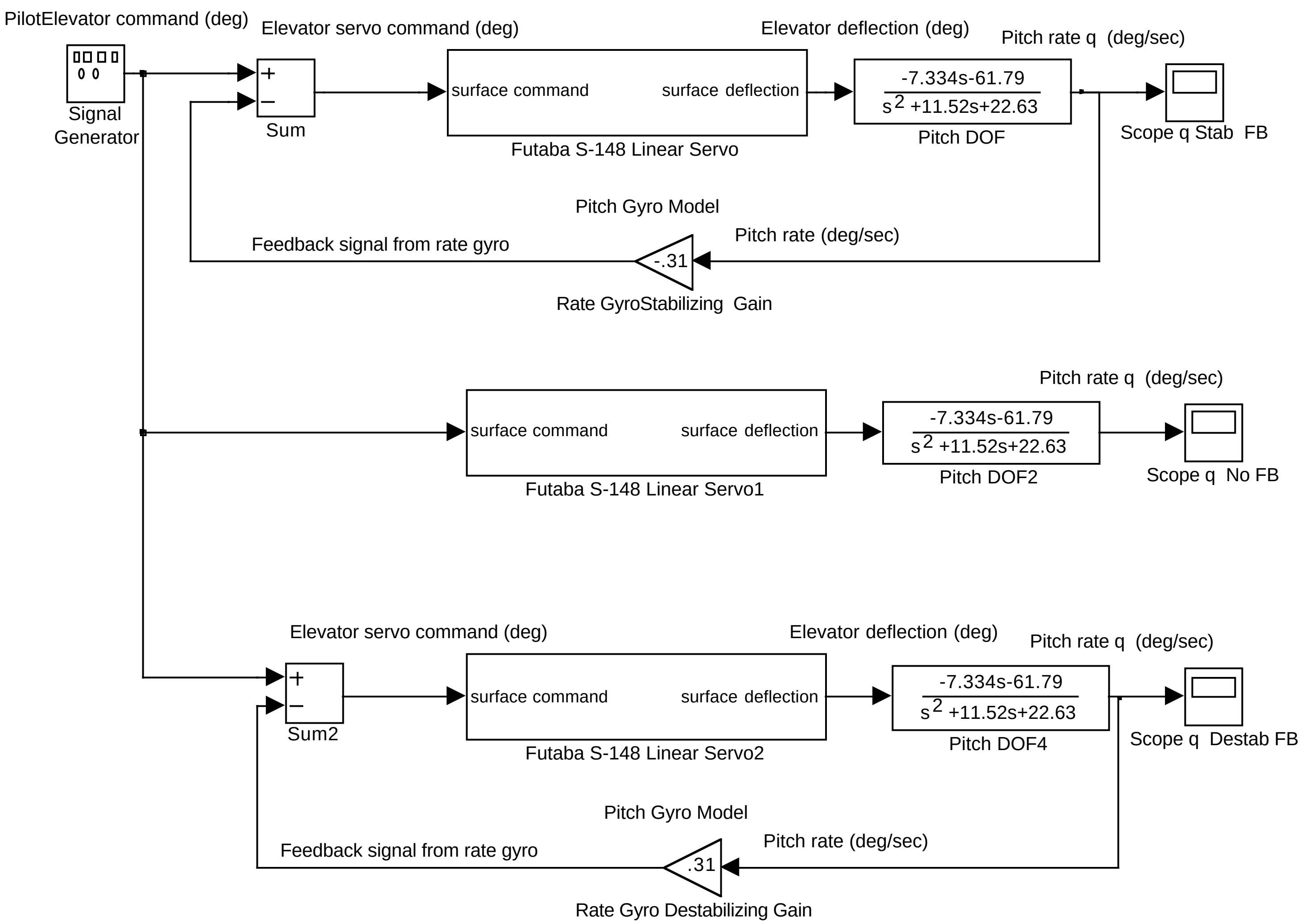
Design of the Pitch Axis Control System
Orion Aerospace Aircraft

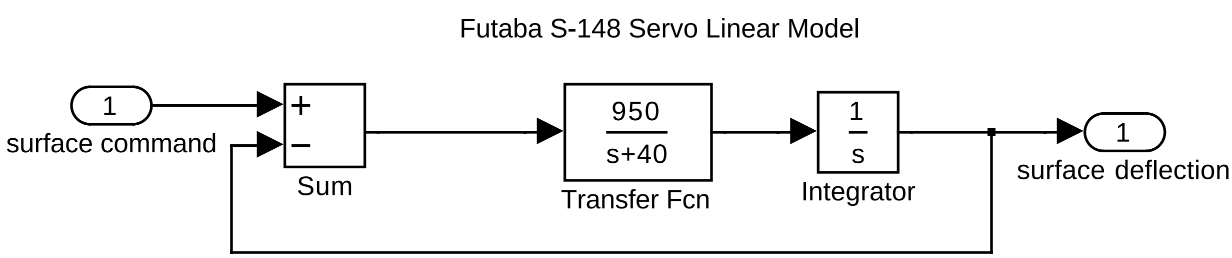
Control action: Pitch Rate Feedback to the elevator.

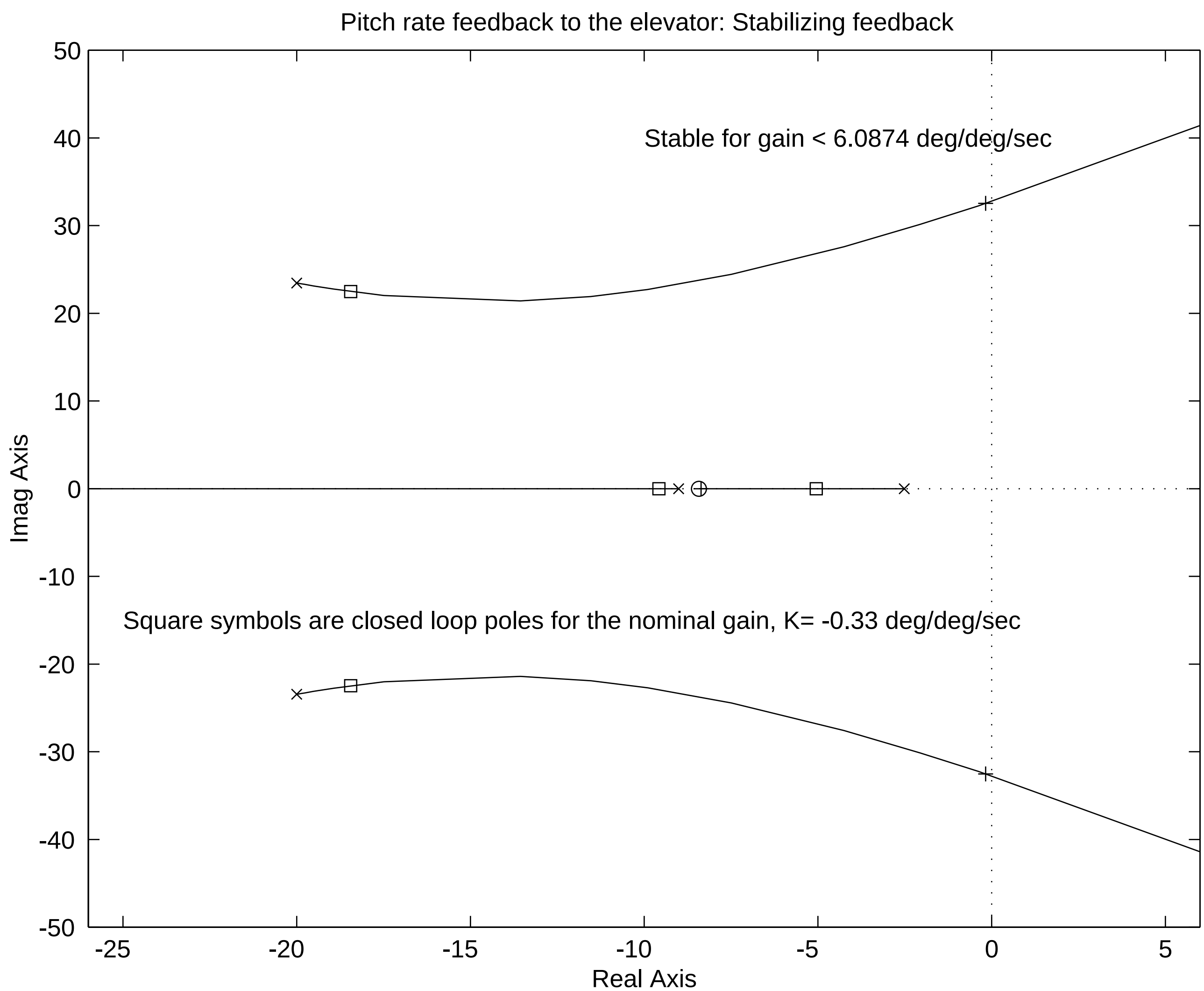
Purpose: The purpose of this control system is to modify the stability properties of the short period mode of motion. For the Orion Aerospace bi-plane the short period mode is characterized by two real poles (s=-9.01 and s=-2.51).

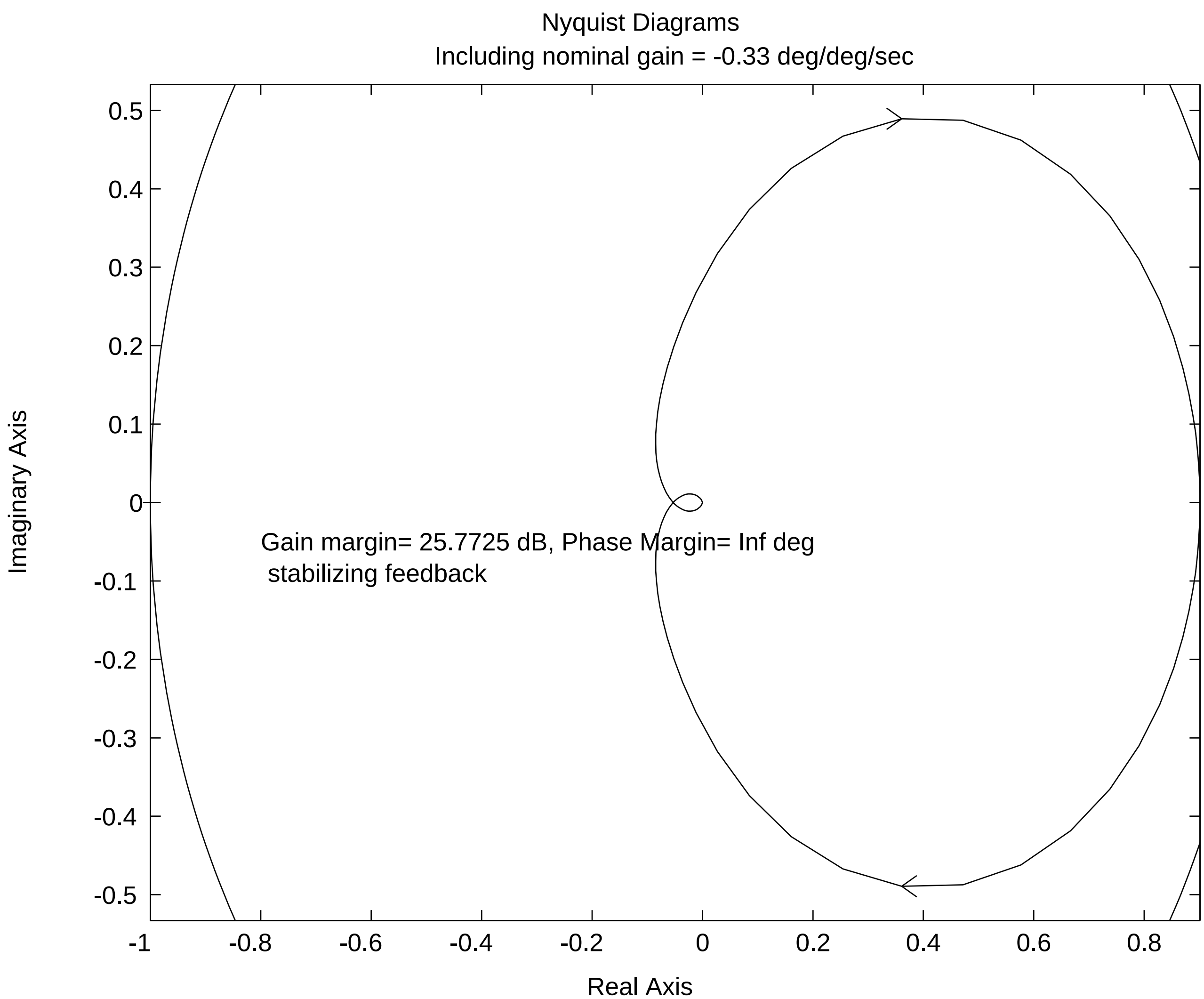
When the feedback gain is stabilizing, we expect that the short period poles will move away from the $j\omega$ axis. Conversely, when the feedback gain is de-stabilizing we expect one of the short period poles to move towards the $j\omega$ axis.

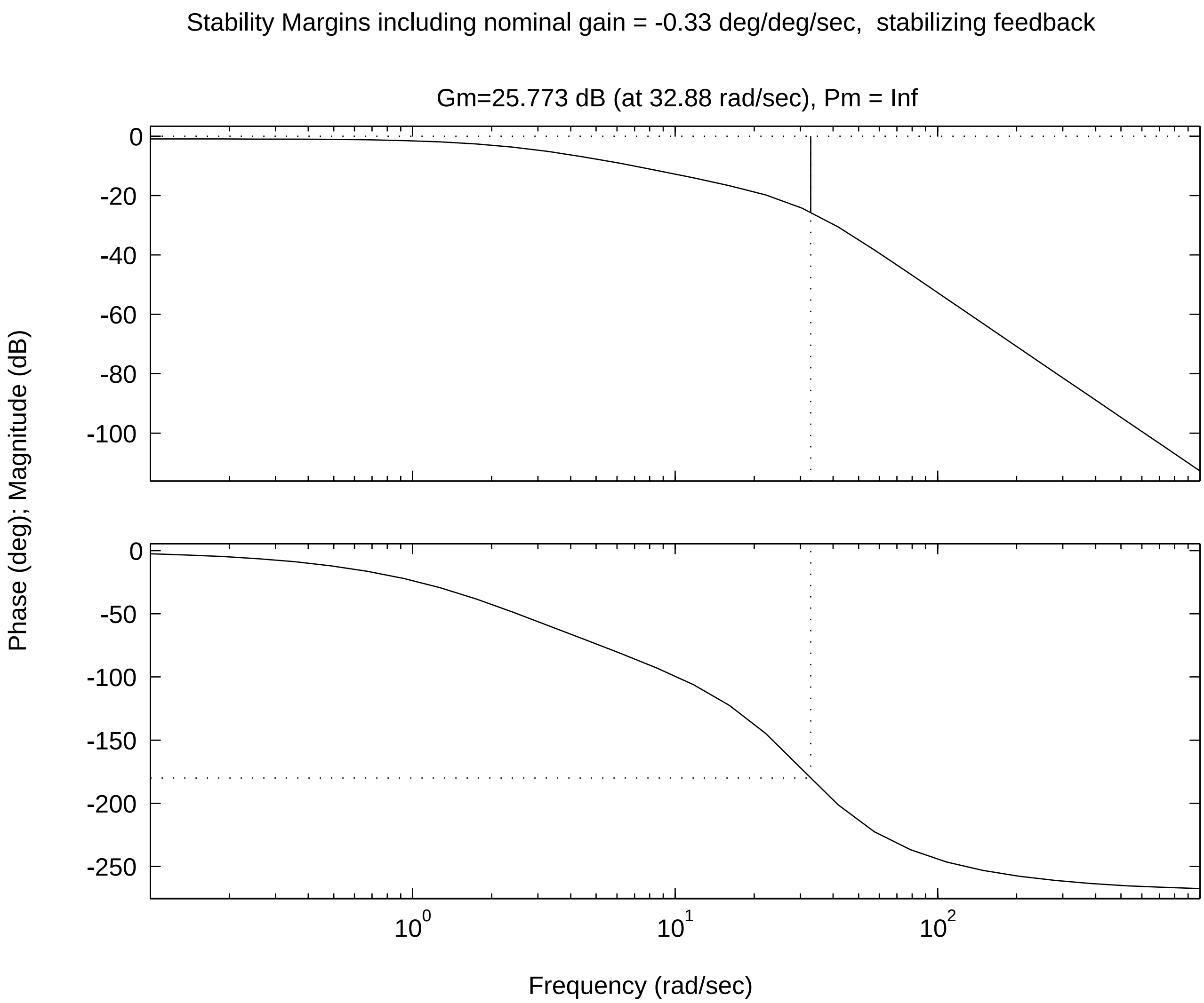
Linear Simulation of the Pitch Axis for the Orion Aerospace Aircraft



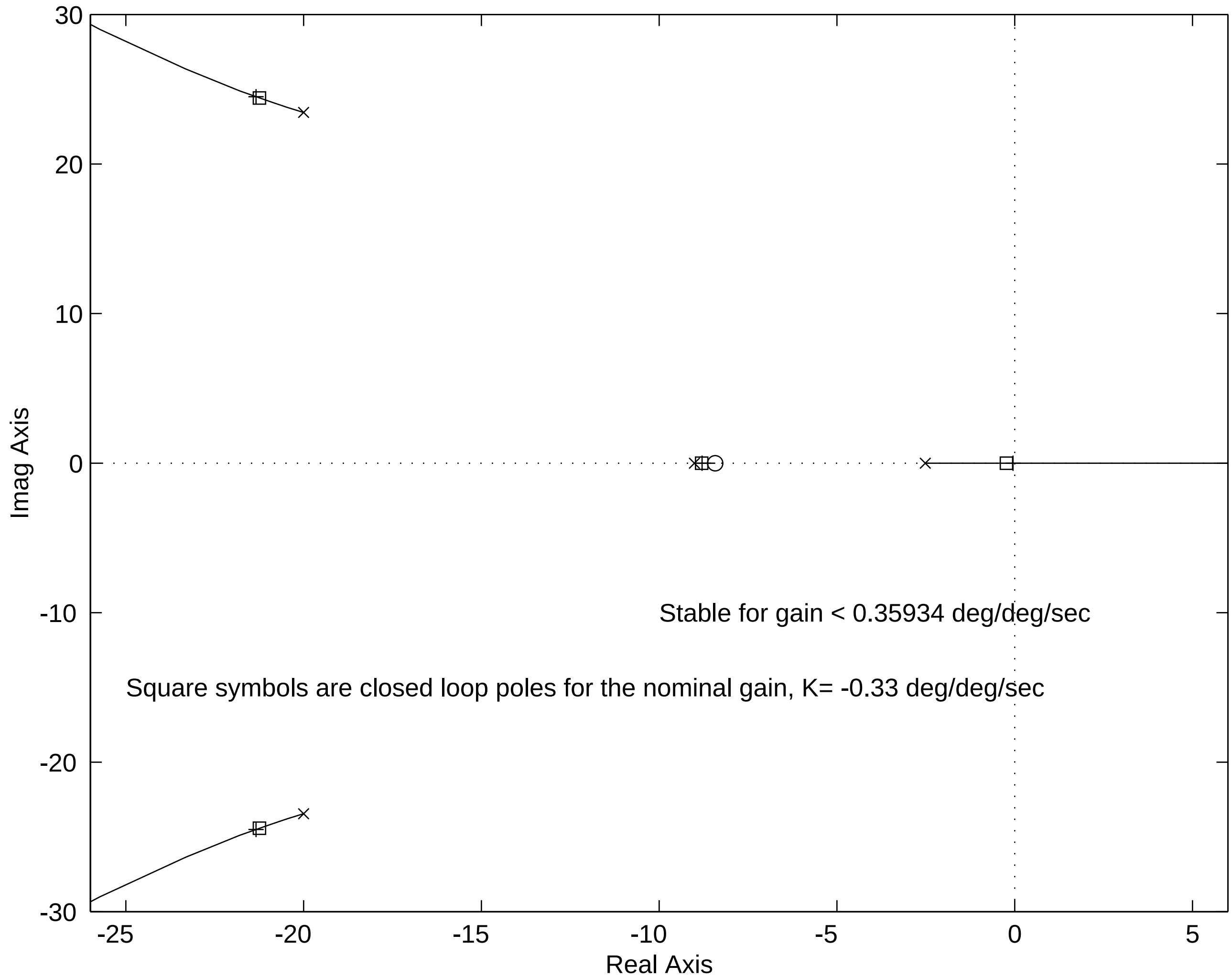

Futaba S-148 Servo Linear Model
1
surface command
+
–
Sum
950
s+40
Transfer Fcn
1
s
Integrator
1
surface deflection

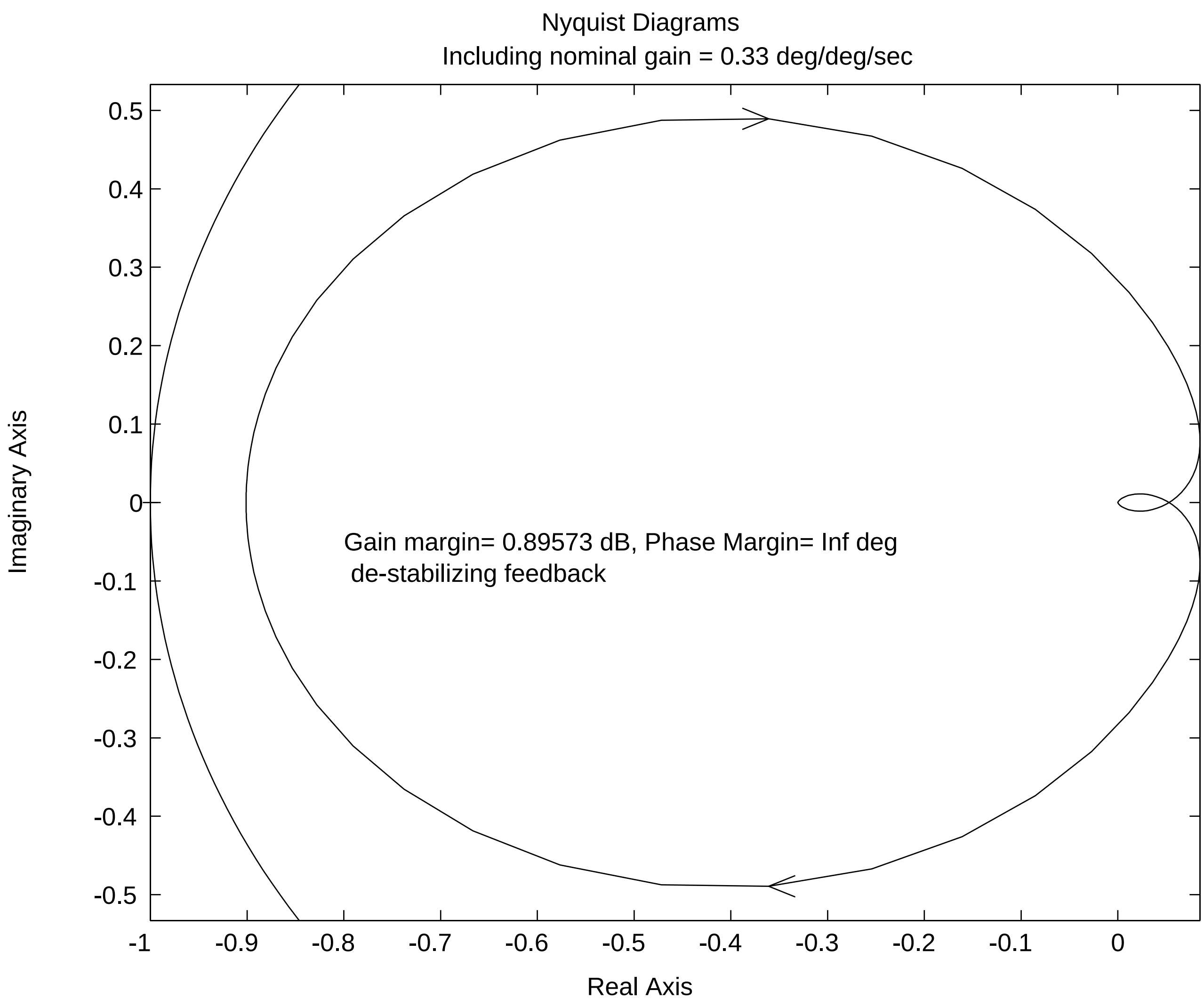

Pitch rate feedback to the elevator: Stabilizing feedback
Stable for gain < 6.0874 deg/deg/sec
Square symbols are closed loop poles for the nominal gain, K= -0.33 deg/deg/sec
Imag Axis
Real Axis
50
40
30
20
10
0
-10
-20
-30
-40
-50
-25
-20
-15
-10
-5
0
5

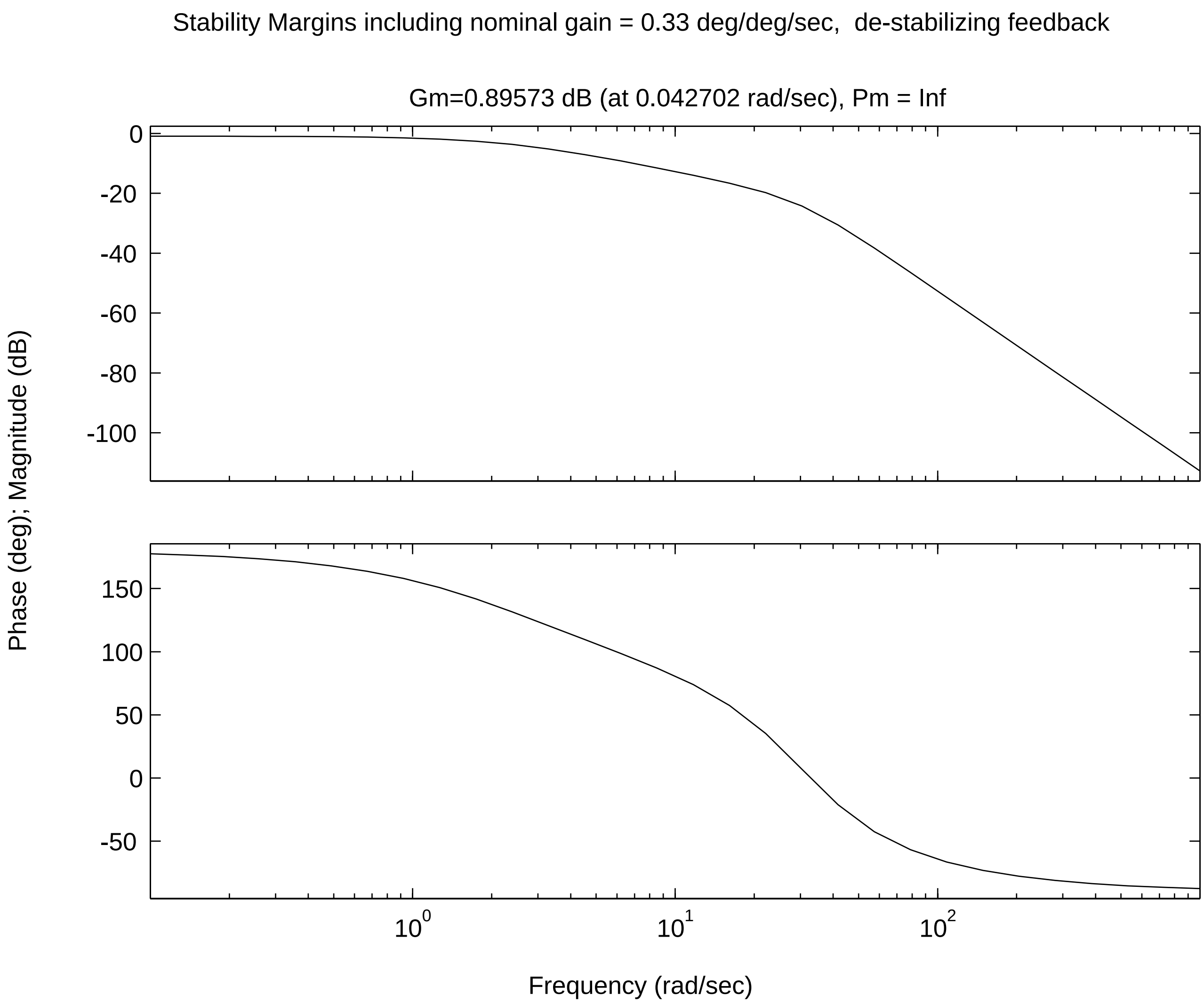

Nyquist Diagrams
Including nominal gain = -0.33 deg/deg/sec
Imaginary Axis
Real Axis
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
Gain margin= 25.7725 dB, Phase Margin= Inf deg
stabilizing feedback

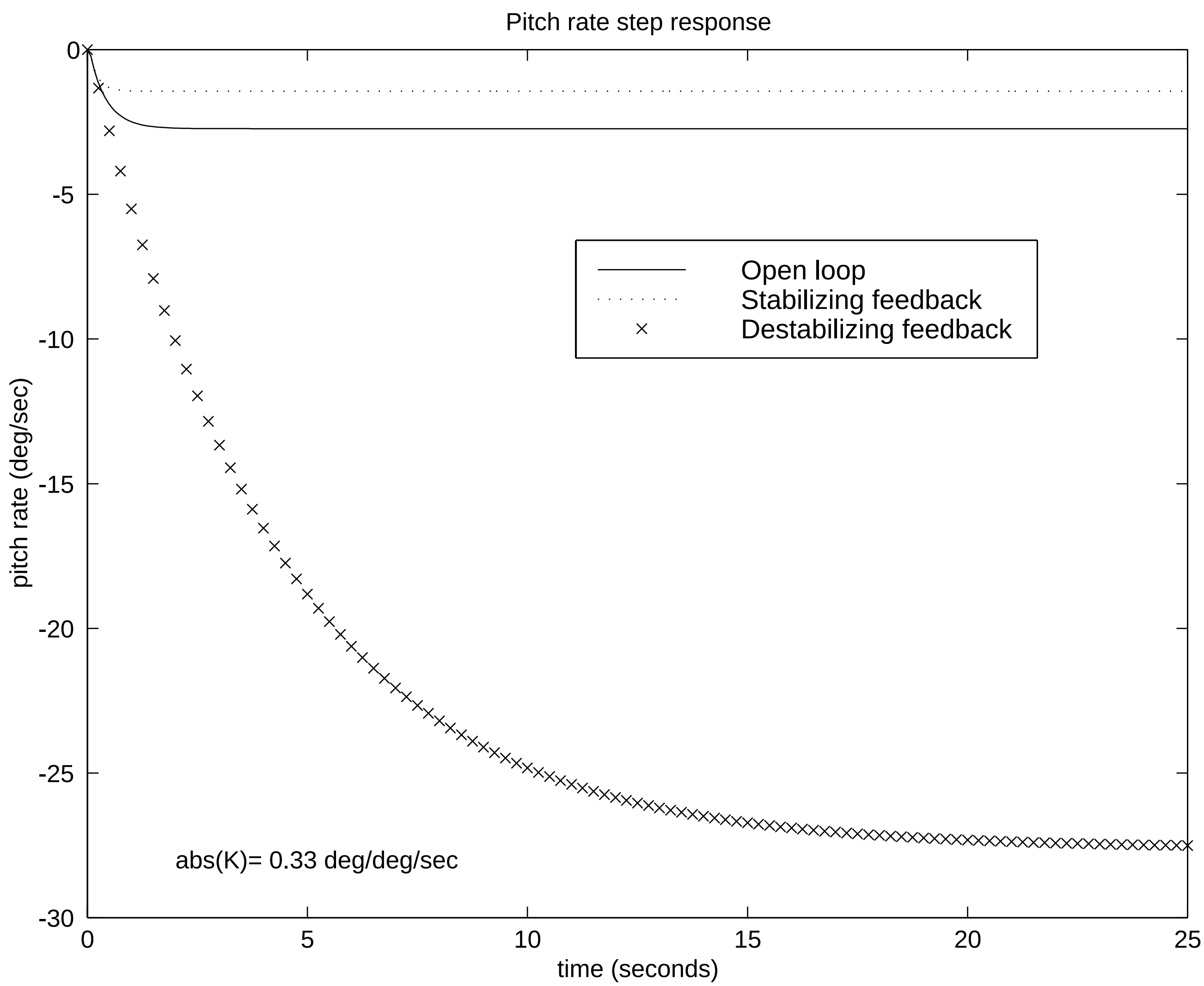

Stability Margins including nominal gain = -0.33 deg/deg/sec, stabilizing feedback
Gm=25.773 dB (at 32.88 rad/sec), Pm = Inf
Phase (deg); Magnitude (dB)
0
-20
-40
-60
-80
-100
0
-50
-100
-150
-200
-250
10^0
10^1
10^2
Frequency (rad/sec)

Pitch rate feedback to the elevator: De-stabilizing feedback




Nyquist Diagrams
Including nominal gain = 0.33 deg/deg/sec
Gain margin= 0.89573 dB, Phase Margin= Inf deg
de-stabilizing feedback
Imaginary Axis
Real Axis
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-1
-0.9
-0.8
-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0


Stability Margins including nominal gain = 0.33 deg/deg/sec, de-stabilizing feedback
Gm=0.89573 dB (at 0.042702 rad/sec), Pm = Inf
Phase (deg); Magnitude (dB)
Frequency (rad/sec)
0
-20
-40
-60
-80
-100
150
100
50
0
-50
10^0
10^1
10^2


Pitch rate step response
pitch rate (deg/sec)
time (seconds)
0
-5
-10
-15
-20
-25
-30
0
5
10
15
20
25
Open loop
Stabilizing feedback
Destabilizing feedback
abs(K)= 0.33 deg/deg/sec