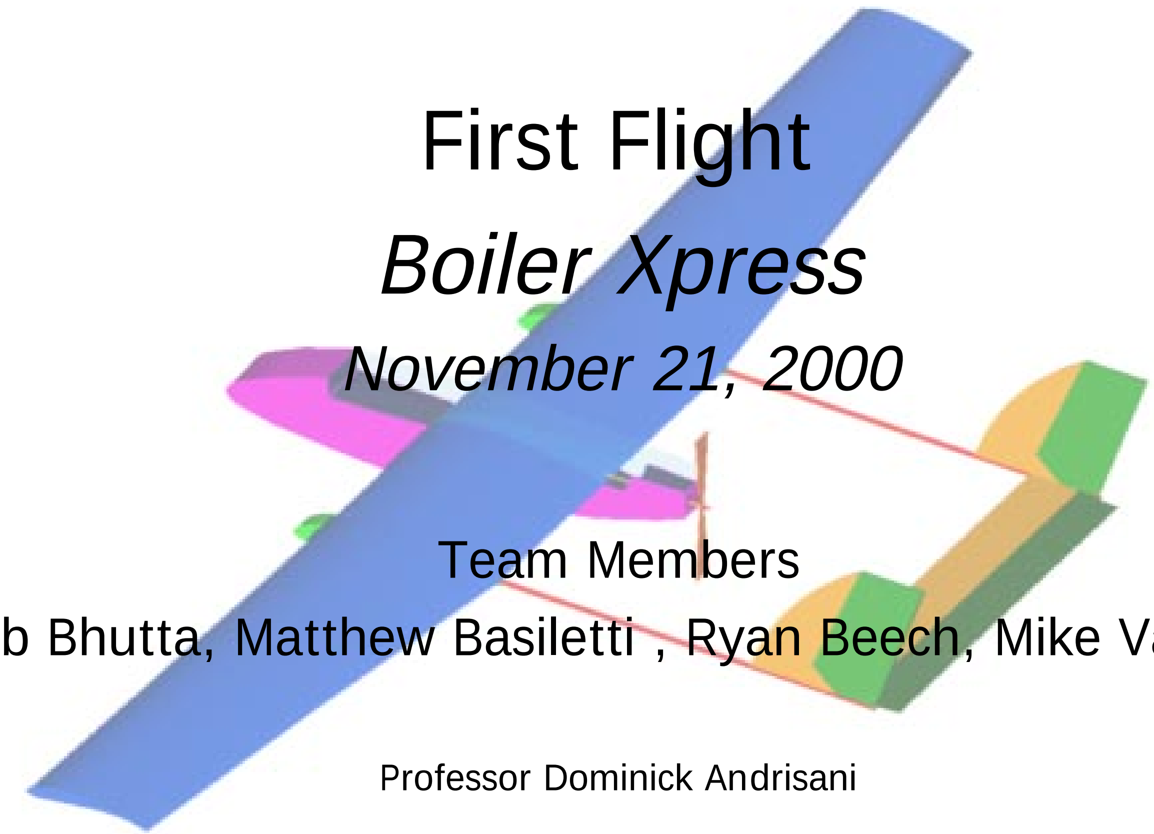
# AAE 451 Aircraft Design



First Flight

*Boiler Xpress*

*November 21, 2000*

Team Members

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Professor Dominick Andrisani

## 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.

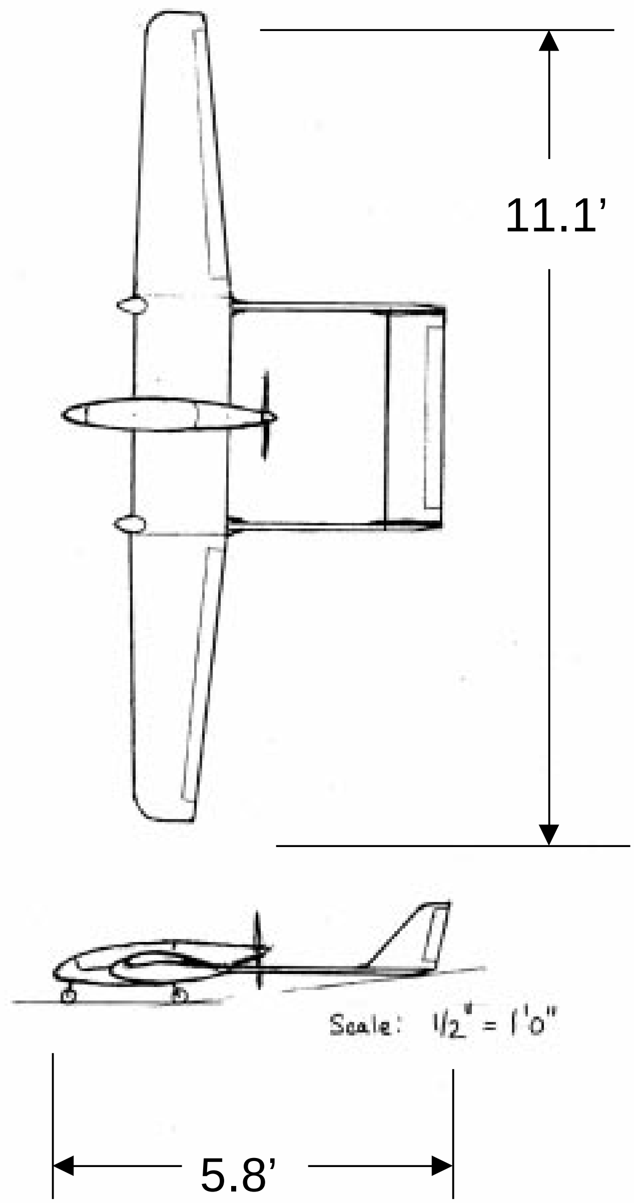
**Design Constraints:** Flight of the variable stability aircraft must be safely demonstrated within the Mollenkopf Athletic Center. The vehicle should be stable under all flight conditions and nominal feedback gains. It must be robust to crashes, easy to fly (i.e., have exceptional flying qualities), 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.

# Geometry and Configuration

## Boiler *Xpress*




Wing:

- Sref = 13.5 sq.ft.
- Span = 11 ft.
- Aspect Ratio = 9
- Taper Ratio = 0.6 tip section
- Airfoil: S1220

Horizontal Stabilizer:

- Area = 2.1 sq ft.
- Span = 3.0 ft.

Vertical Stabilizer:

- Total Area: 2.0 sq.ft.

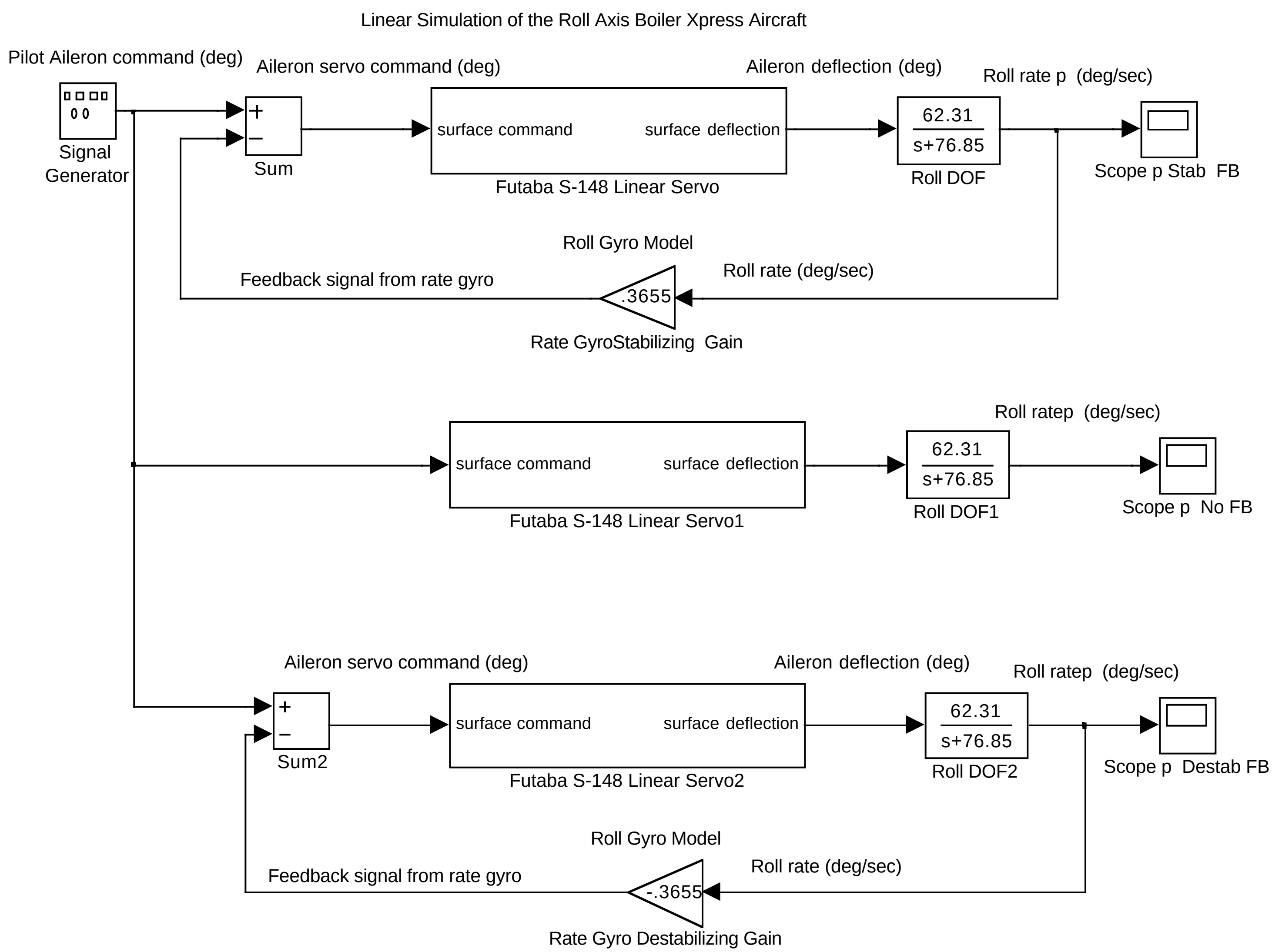
**Design of the Roll Axis Control System**
**Team Boiler Xpress Aircraft**

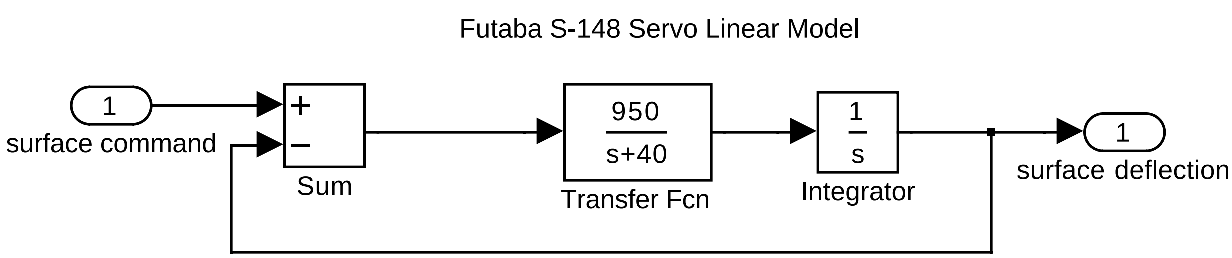
Control action: Roll Rate Feedback to the aileron.

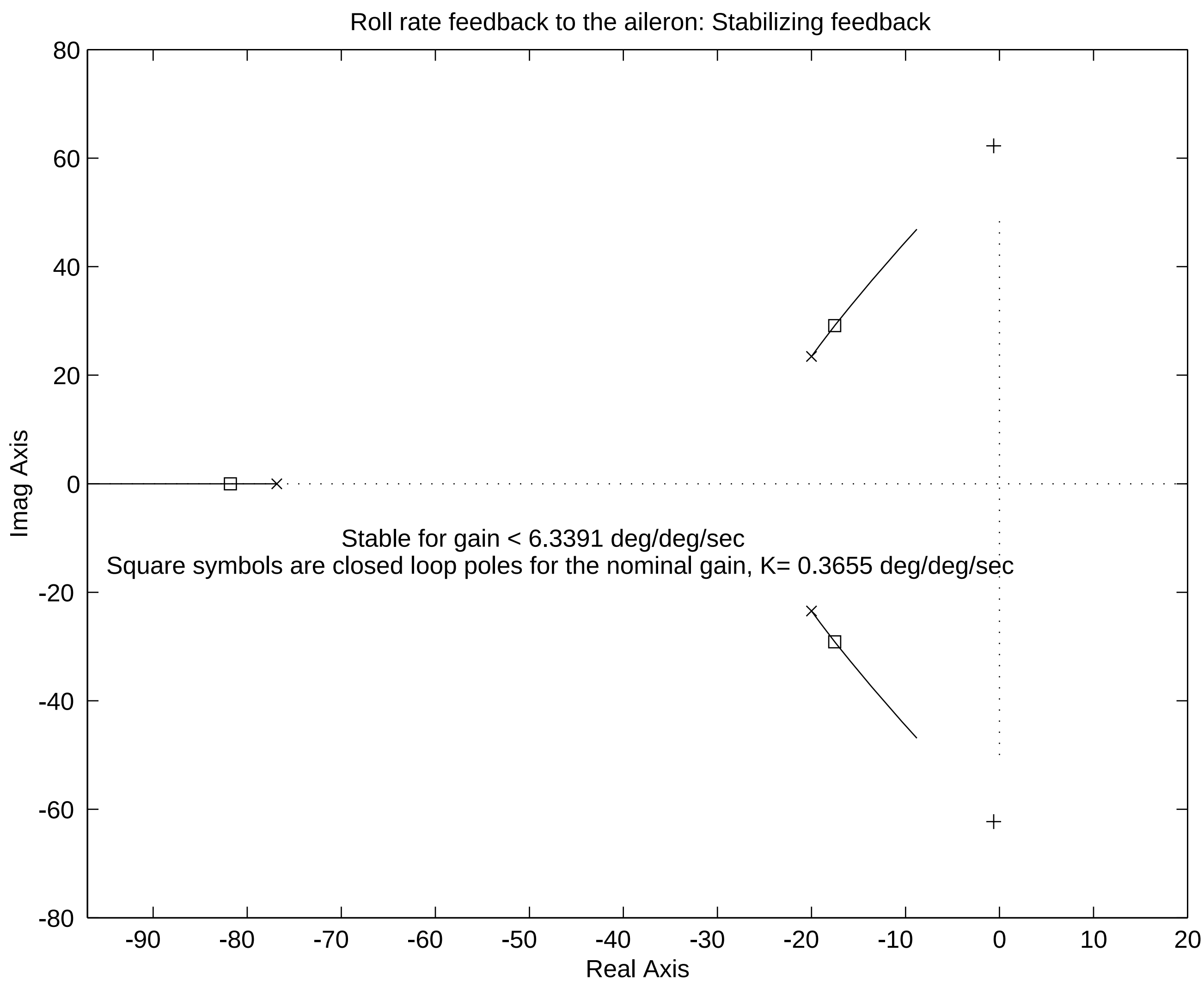
Purpose: The purpose of this control system is to modify the stability properties of the **Roll Mode of motion**. For the Team Boiler Xpress monoplane the Roll Mode is characterized by a real pole (s=-76.85).

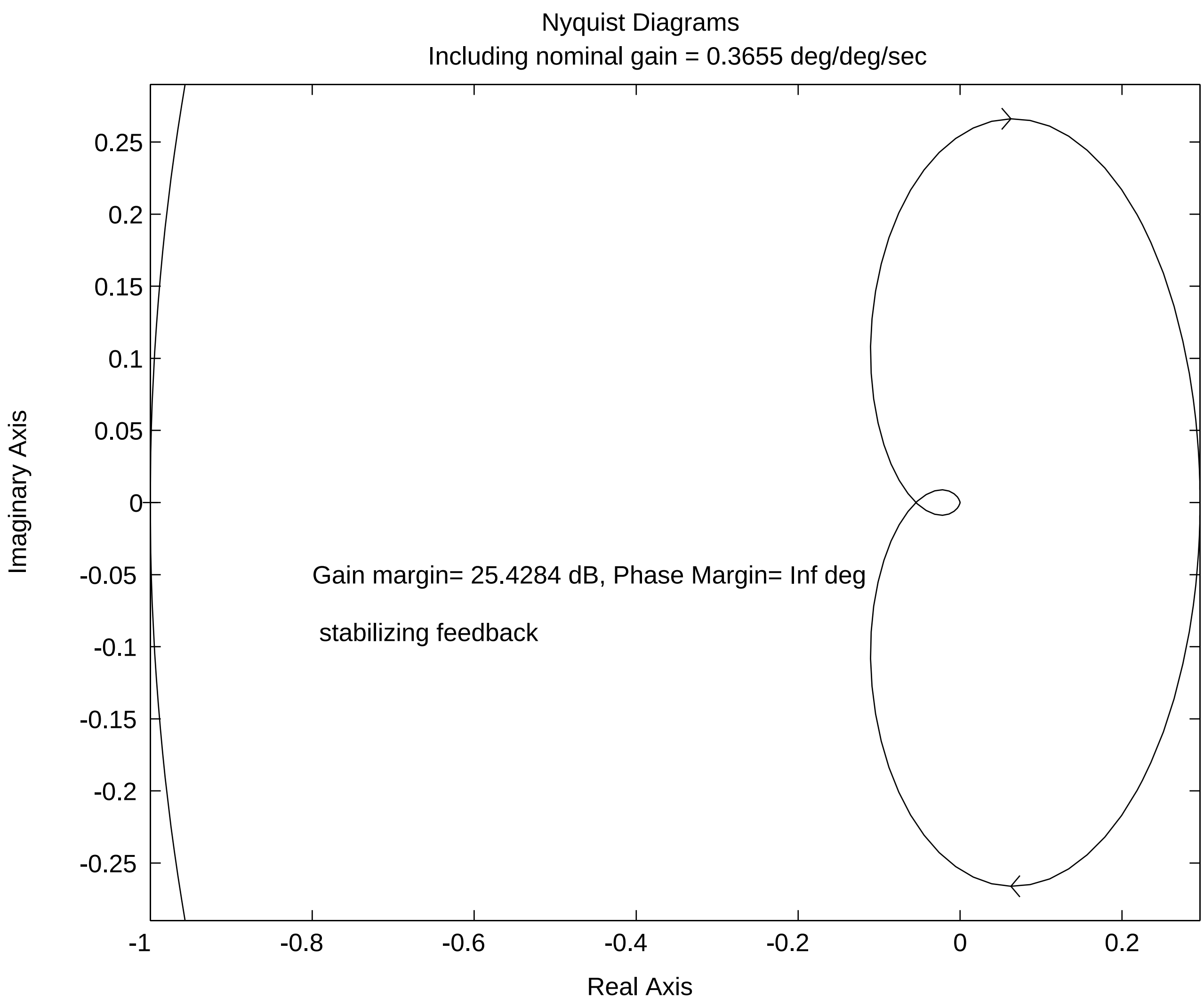
When the feedback gain is stabilizing, we expect that the Roll mode pole will move away from the $j\omega$ axis. Conversely, when the feedback gain is de-stabilizing we expect the Roll mode pole to move towards the $j\omega$ axis.

A simple test is possible with the aircraft to insure that the feedback gain is set to the sign for stabilizing feedback. If the aircraft is rolled right wing down, the aileron should automatically deflect to oppose the motion. To oppose a right wing down, the aileron on the right wing should move trailing edge down, and the aileron on the left wing should move trailing edge up.


Linear Simulation of the Roll Axis Boiler Xpress Aircraft
Pilot Aileron command (deg)
Signal Generator
Aileron servo command (deg)
Sum
surface command
surface deflection
Futaba S-148 Linear Servo
Aileron deflection (deg)
62.31
s+76.85
Roll DOF
Roll rate p (deg/sec)
Scope p Stab FB
Roll Gyro Model
Feedback signal from rate gyro
.3655
Roll rate (deg/sec)
Rate GyroStabilizing Gain
surface command
surface deflection
Futaba S-148 Linear Servo1
62.31
s+76.85
Roll DOF1
Roll ratep (deg/sec)
Scope p No FB
Aileron servo command (deg)
Sum2
surface command
surface deflection
Futaba S-148 Linear Servo2
Aileron deflection (deg)
62.31
s+76.85
Roll DOF2
Roll ratep (deg/sec)
Scope p Destab FB
Roll Gyro Model
Feedback signal from rate gyro
-.3655
Roll rate (deg/sec)
Rate Gyro Destabilizing Gain

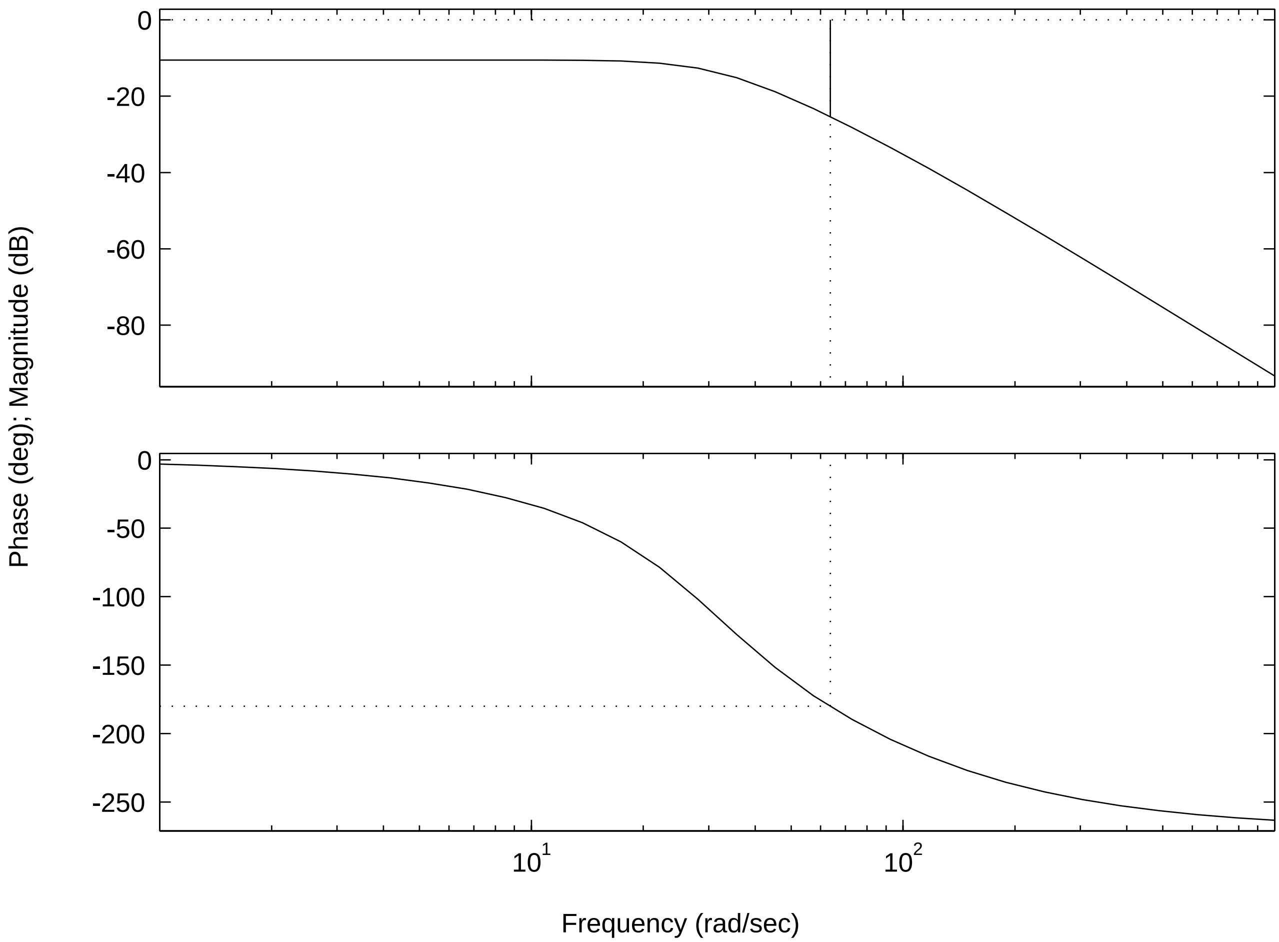

Futaba S-148 Servo Linear Model
1
surface command
+
–
Sum
950
s+40
Transfer Fcn
1
s
Integrator
1
surface deflection

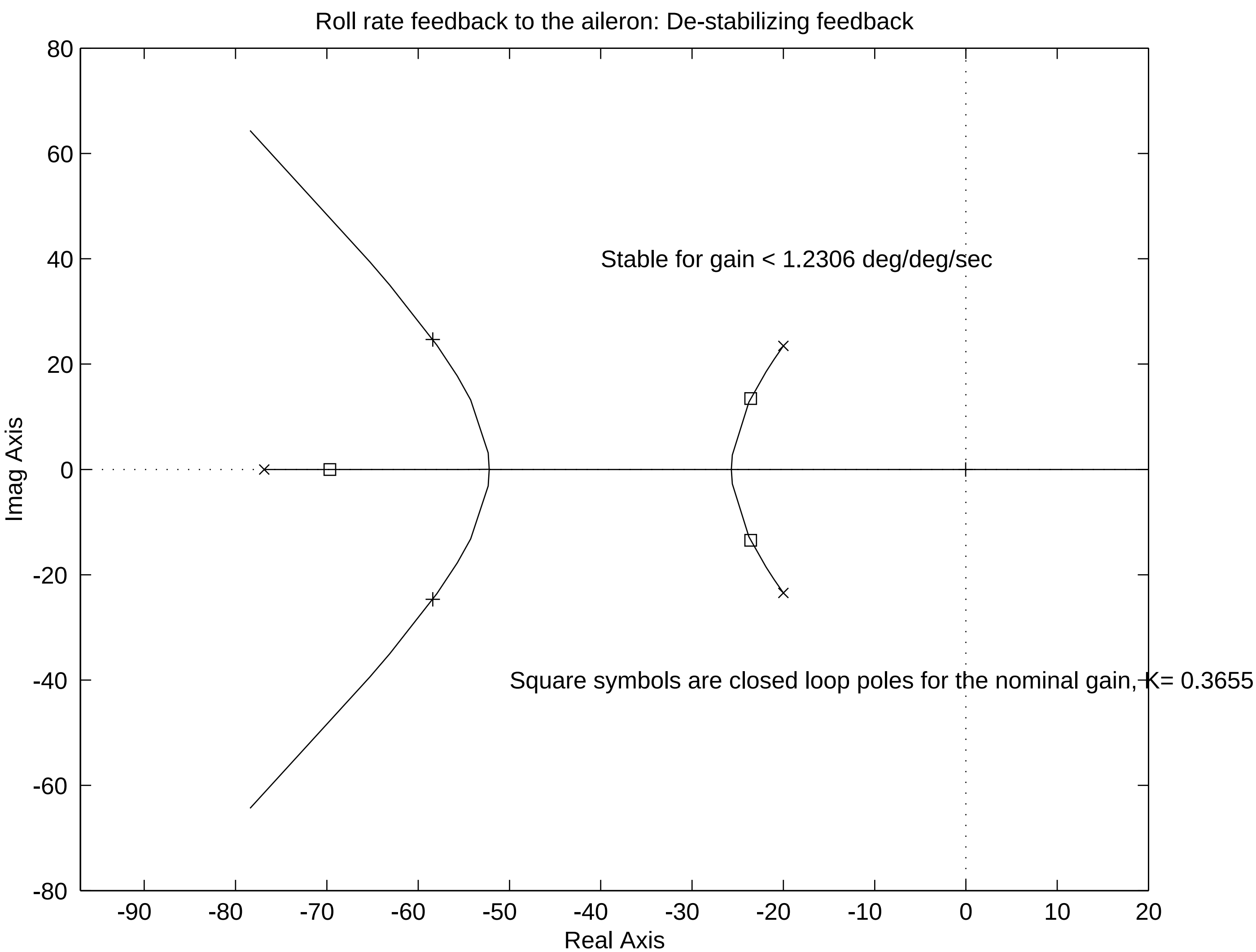

Roll rate feedback to the aileron: Stabilizing feedback
Stable for gain < 6.3391 deg/deg/sec
Square symbols are closed loop poles for the nominal gain, K= 0.3655 deg/deg/sec
Imag Axis
Real Axis
80
60
40
20
0
-20
-40
-60
-80
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20


Nyquist Diagrams
Including nominal gain = 0.3655 deg/deg/sec
Imaginary Axis
Real Axis
Gain margin= 25.4284 dB, Phase Margin= Inf deg
stabilizing feedback
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-1
-0.8
-0.6
-0.4
-0.2
0
0.2

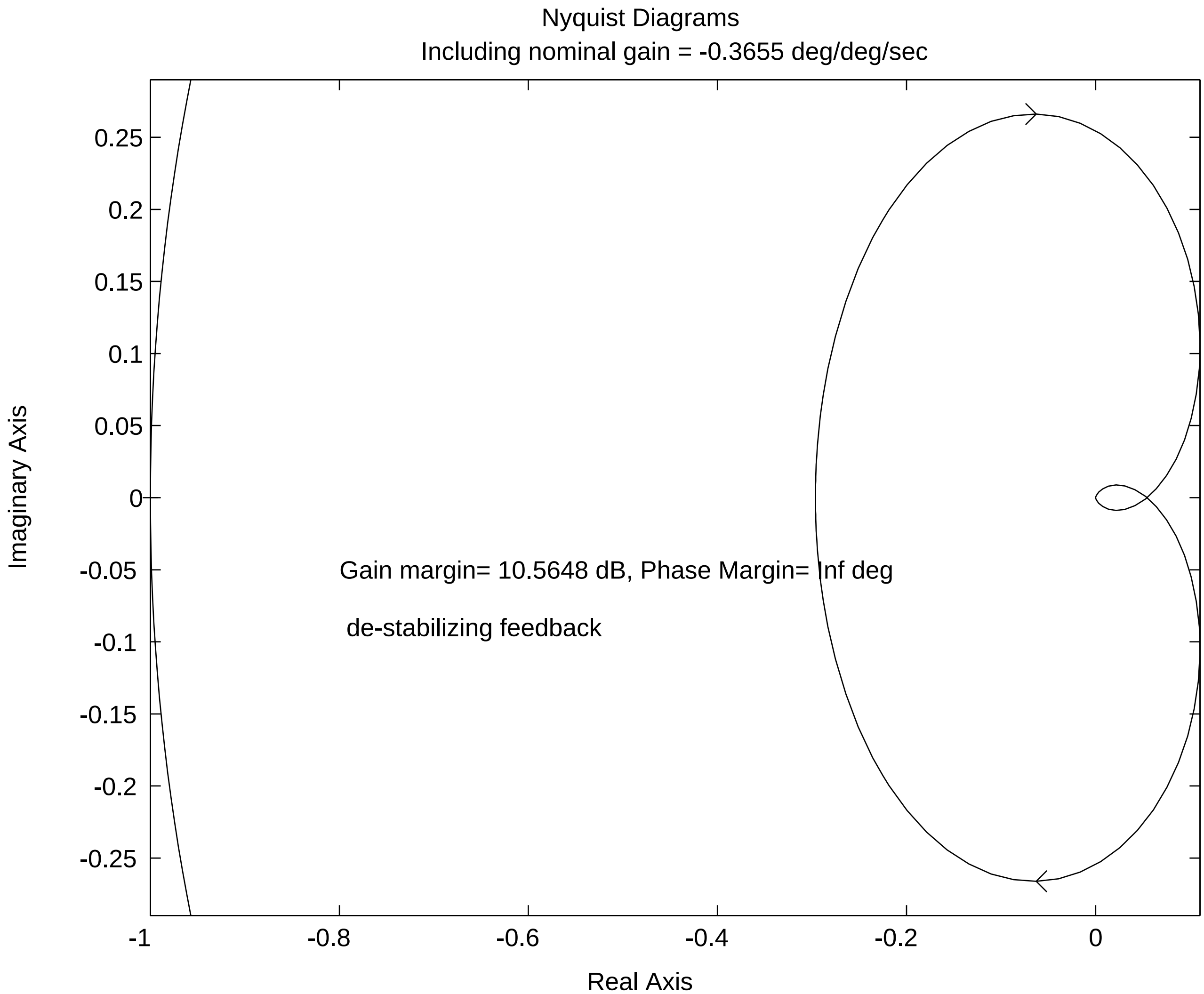
Stability Margins including nominal gain = 0.3655 deg/deg/sec,  stabilizing feedback

Gm=25.428 dB (at 63.759 rad/sec), Pm = Inf

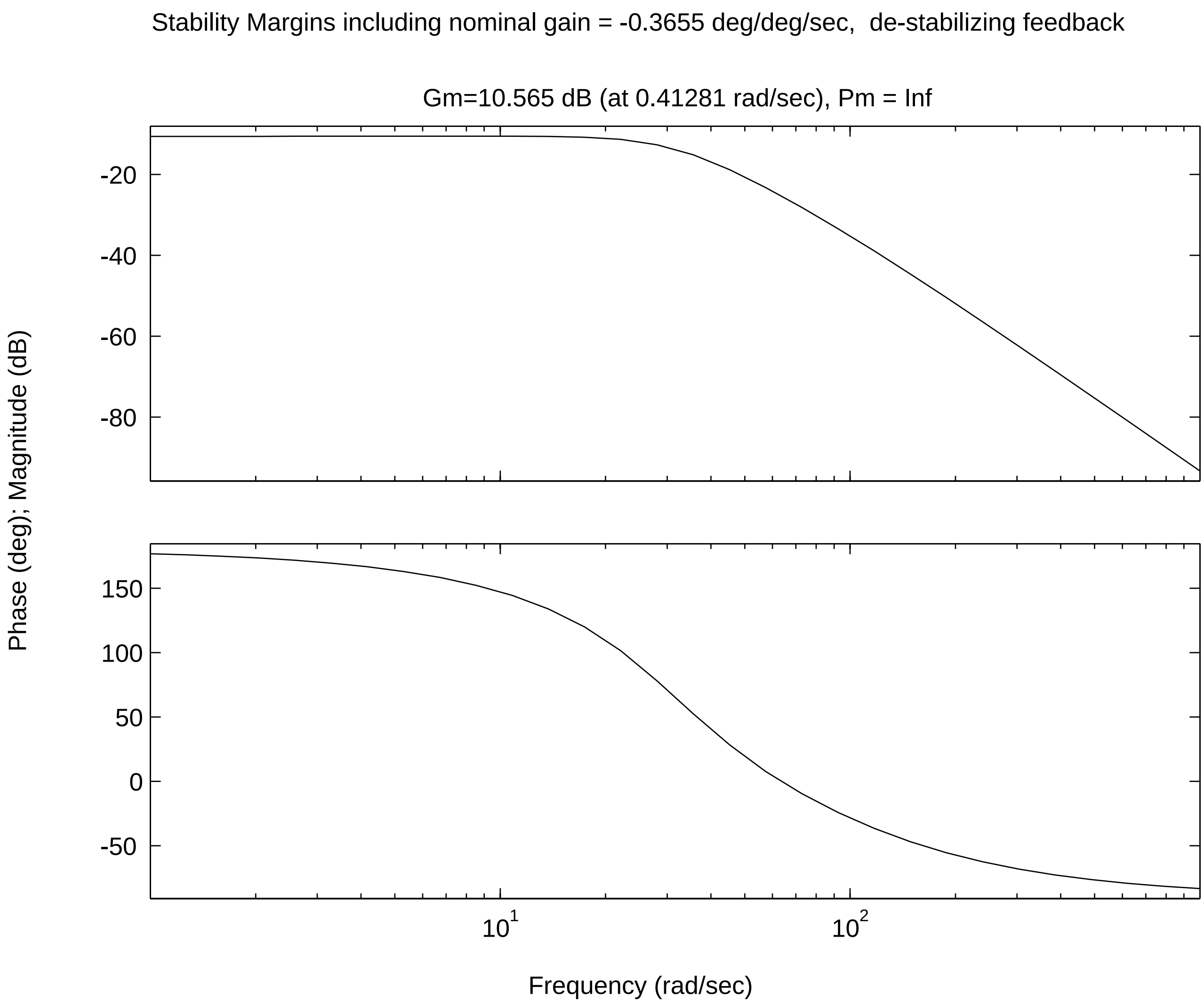


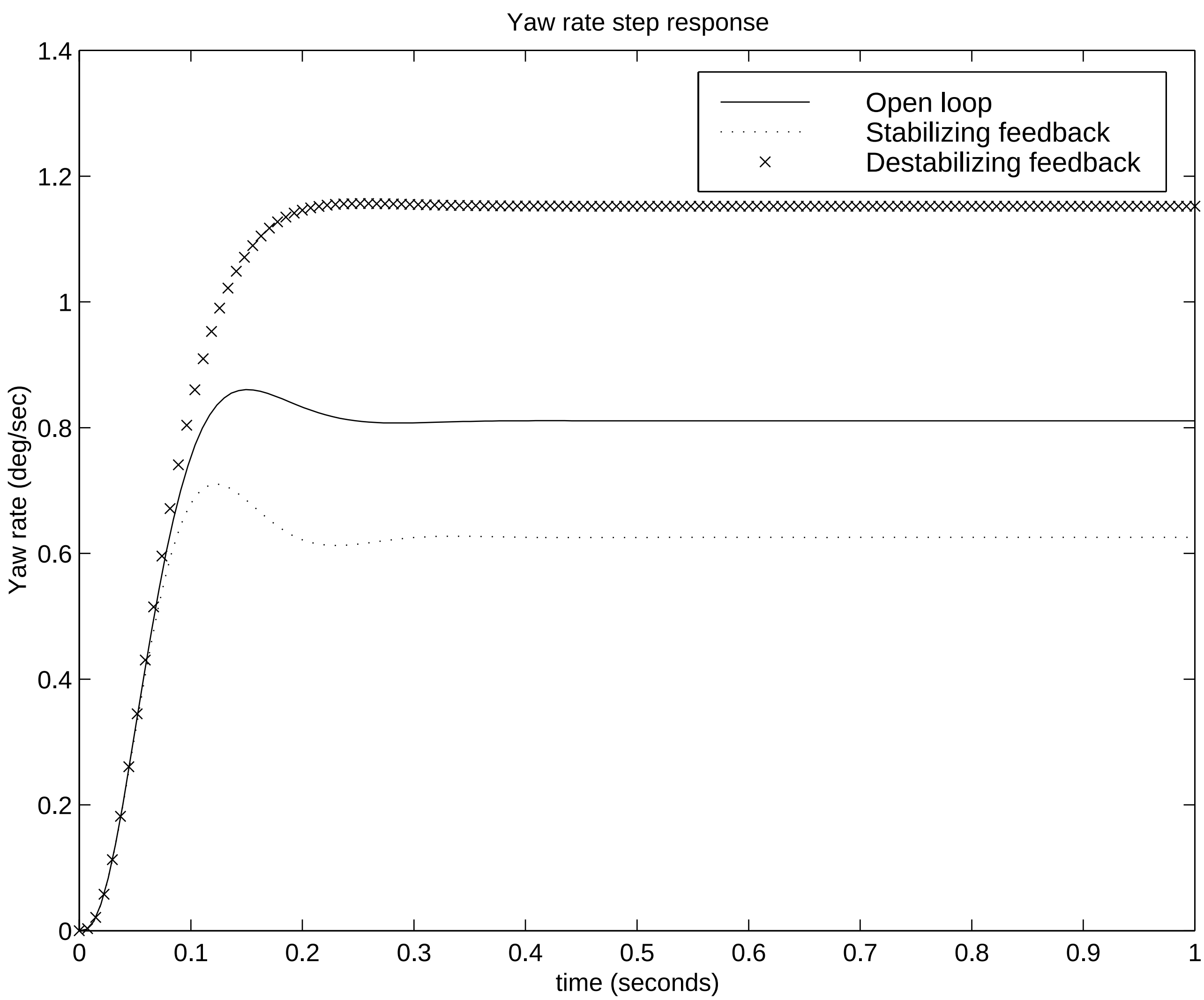


Roll rate feedback to the aileron: De-stabilizing feedback
Stable for gain < 1.2306 deg/deg/sec
Square symbols are closed loop poles for the nominal gain, K= 0.3655
Imag Axis
Real Axis
80
60
40
20
0
-20
-40
-60
-80
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20



Nyquist Diagrams
Including nominal gain = -0.3655 deg/deg/sec
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
Imaginary Axis
Gain margin= 10.5648 dB, Phase Margin= Inf deg
de-stabilizing feedback
-1
-0.8
-0.6
-0.4
-0.2
0
Real Axis


Stability Margins including nominal gain = -0.3655 deg/deg/sec, de-stabilizing feedback
Gm=10.565 dB (at 0.41281 rad/sec), Pm = Inf
-20
-40
-60
-80
150
100
50
0
-50
Phase (deg); Magnitude (dB)
$10^1$
$10^2$
Frequency (rad/sec)


Yaw rate step response
Open loop
Stabilizing feedback
Destabilizing feedback
Yaw rate (deg/sec)
time (seconds)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0.1
0.3
0.5
0.7
0.9