Team DR2

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AAE451 Aircraft Design
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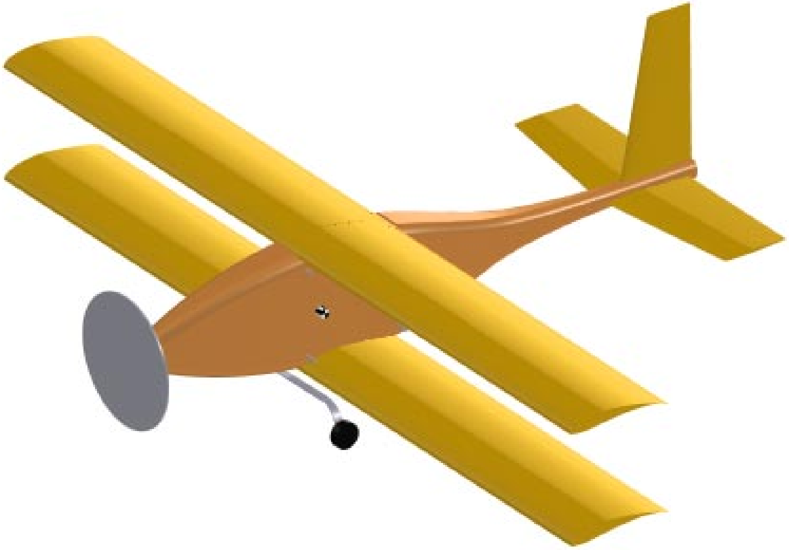


Mission Specification for
A&AE 451 Aircraft Design, Fall 2000

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.

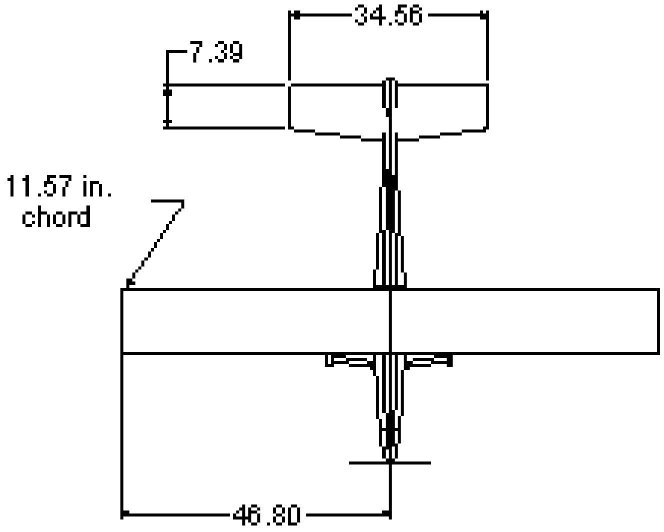
The variable stability aircraft is intended to be marketed to existing companies who sell and manufacture model aircraft and to be used in other coursework at Purdue and other universities.

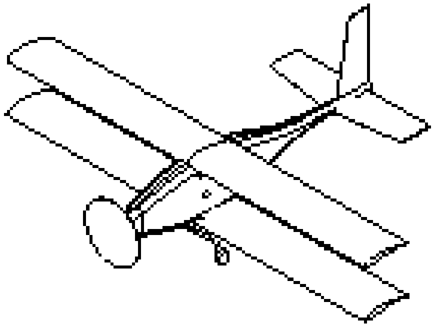
Design Constraints: Flight of the variable stability aircraft must be safely demonstrated within the Mollenkopf Athletic Center. The vehicle should be stable under all flight conditions and nominal feedback gains. It must be robust to crashes, easy to fly (i.e., have exceptional flying qualities), and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

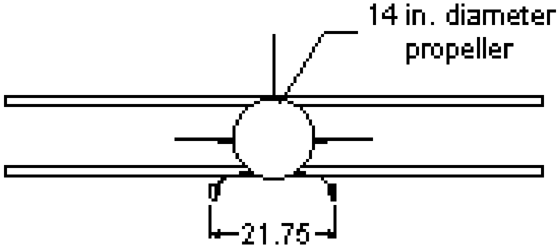
Rate gyroscopes are compatible with our radio control electronics are available from Futaba (see http://www.futaba-rc.com/radioaccys/futm0501.html). A Tattletale 8 data logger with software will be provided (see http://www2.vsi.net/waetjen/onset/Products/Product_Pages/Tattletale_pages/data_sheets/TT8.html).

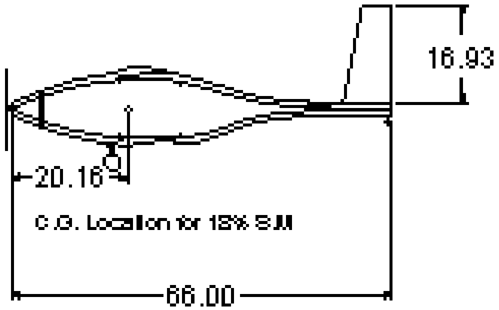
Any deviation from the design constraints must be formally requested in writing to Professor Andrisani and justified using sound engineering and business logic.

DR2


34.56
7.39
11.57 in. chord
46.80




14 in. diameter propeller
21.75


16.93
20.16
C.G. Location for 15% S.M.
66.00

Design of the Yaw Axis Control System
Team DR2 Aircraft

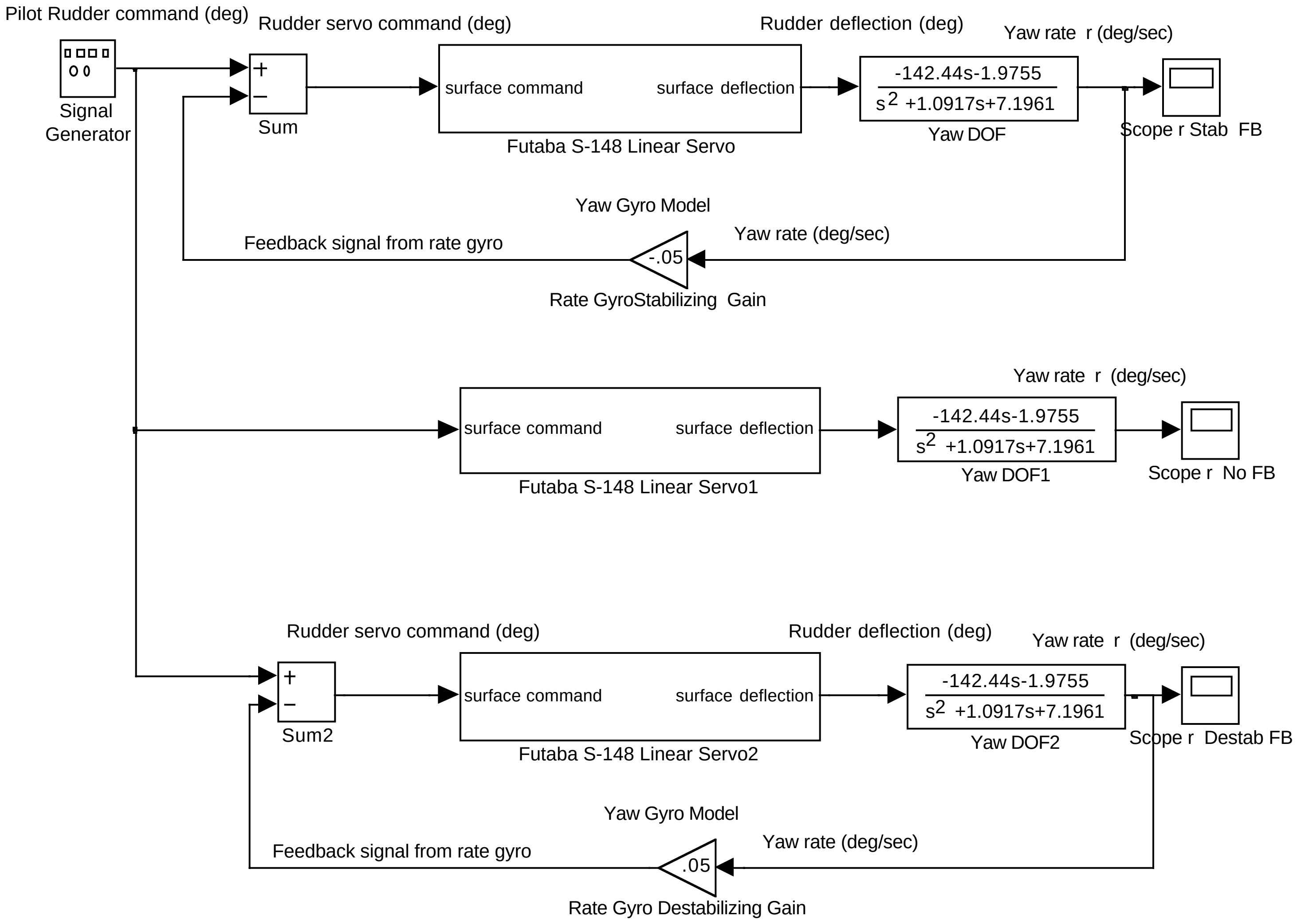
Control action: Yaw Rate Feedback to the rudder.

Purpose: The purpose of this control system is to modify the stability properties of the **Dutch Roll Mode of motion**. For the Team DR2 bi-plane the Dutch Roll mode is characterized by a complex pair of poles ($s=-0.55\pm 2.6i$).

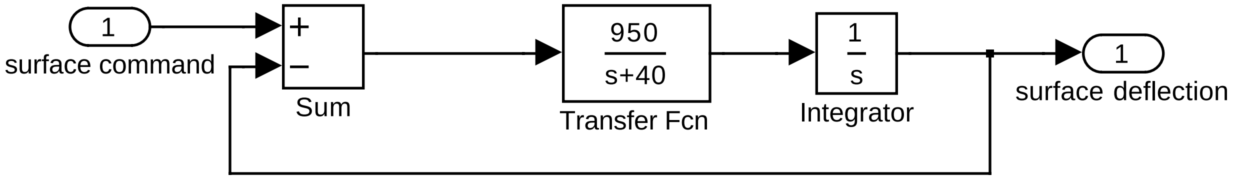
When the feedback gain is stabilizing, we expect that the Dutch Roll poles will move away from the $j\omega$ axis. Conversely, when the feedback gain is de-stabilizing we expect one of the Dutch Roll poles to move towards the $j\omega$ axis.

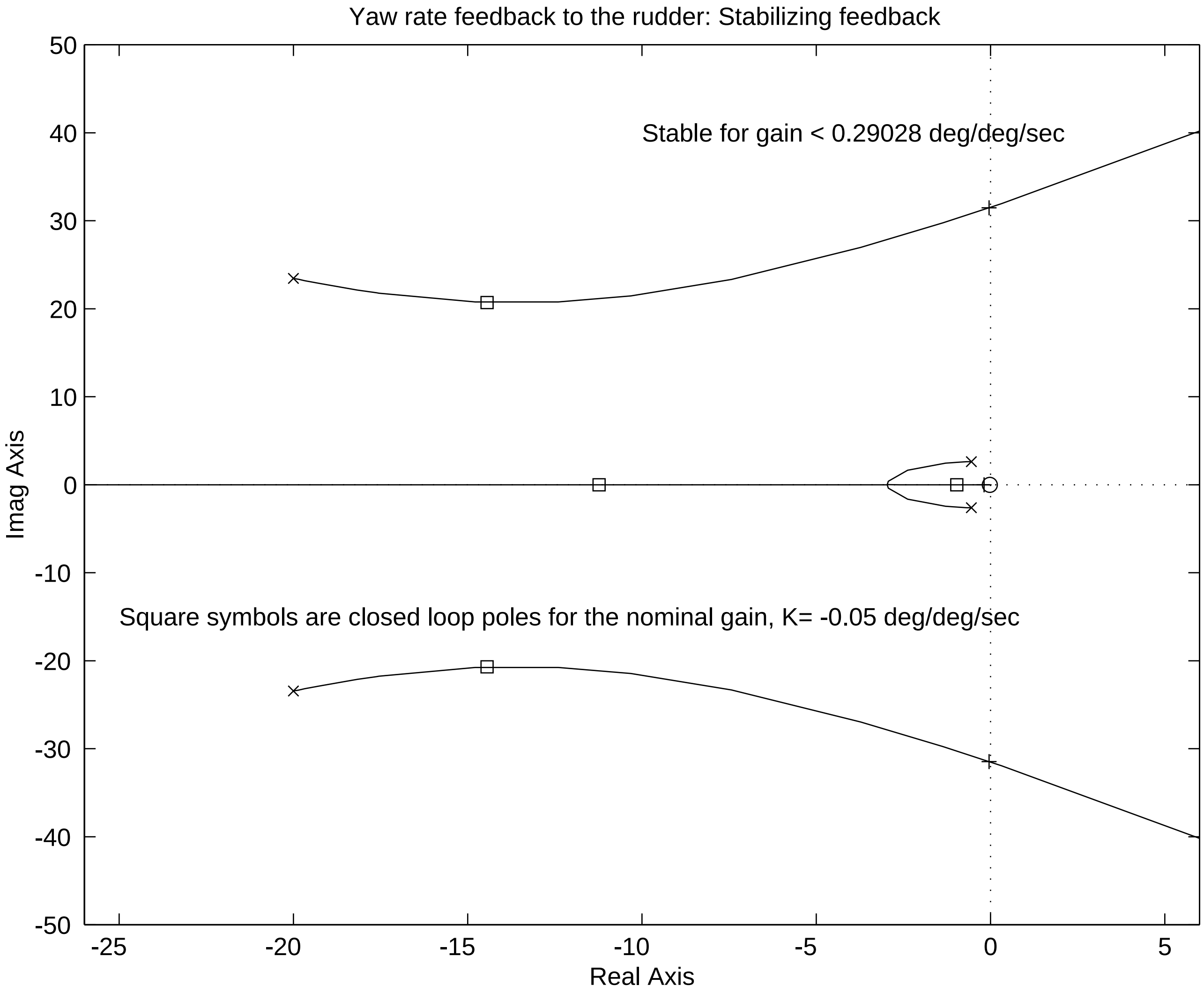
A simple test is possible with the aircraft to insure that the feedback gain is set to the sign for stabilizing feedback. If the aircraft is yawed nose right, the rudder should automatically deflect to oppose the motion. To oppose a right yaw, the rudder should deflect trailing edge left.

Linear Simulation of theYaw Axis DR2 Aircraft



Futaba S-148 Servo Linear Model

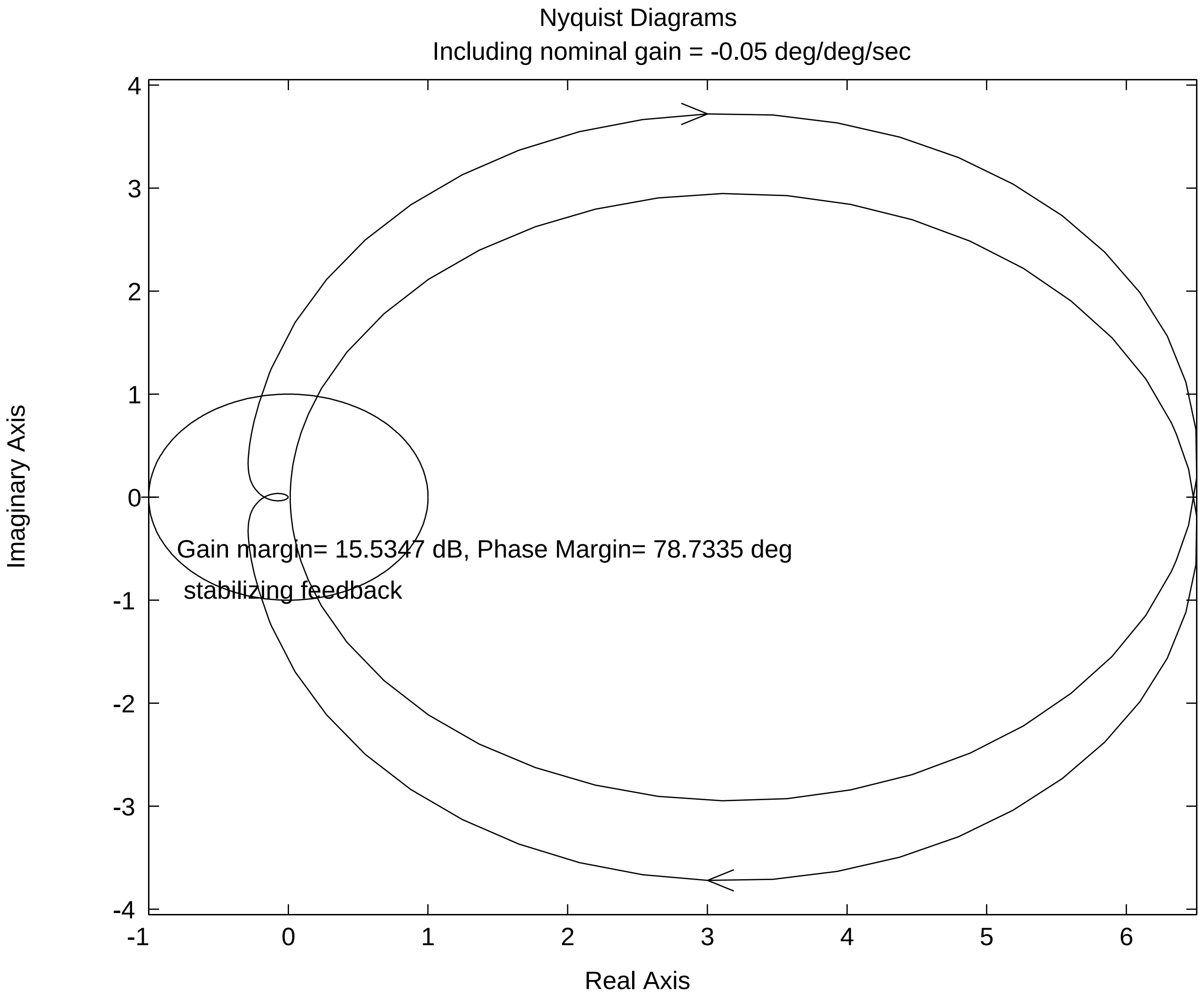




Yaw rate feedback to the rudder: Stabilizing feedback

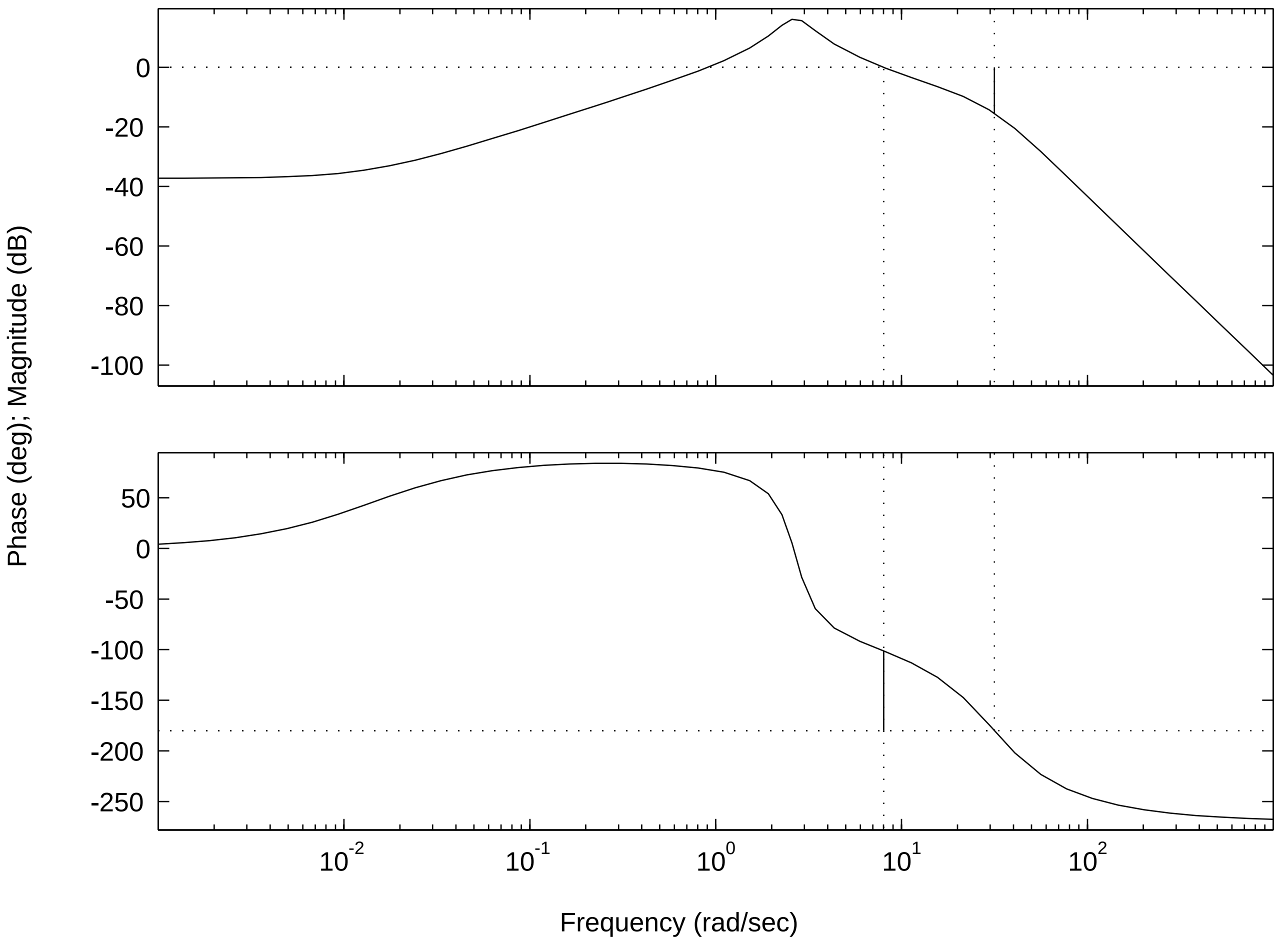
Stable for gain < 0.29028 deg/deg/sec

Square symbols are closed loop poles for the nominal gain, K= -0.05 deg/deg/sec



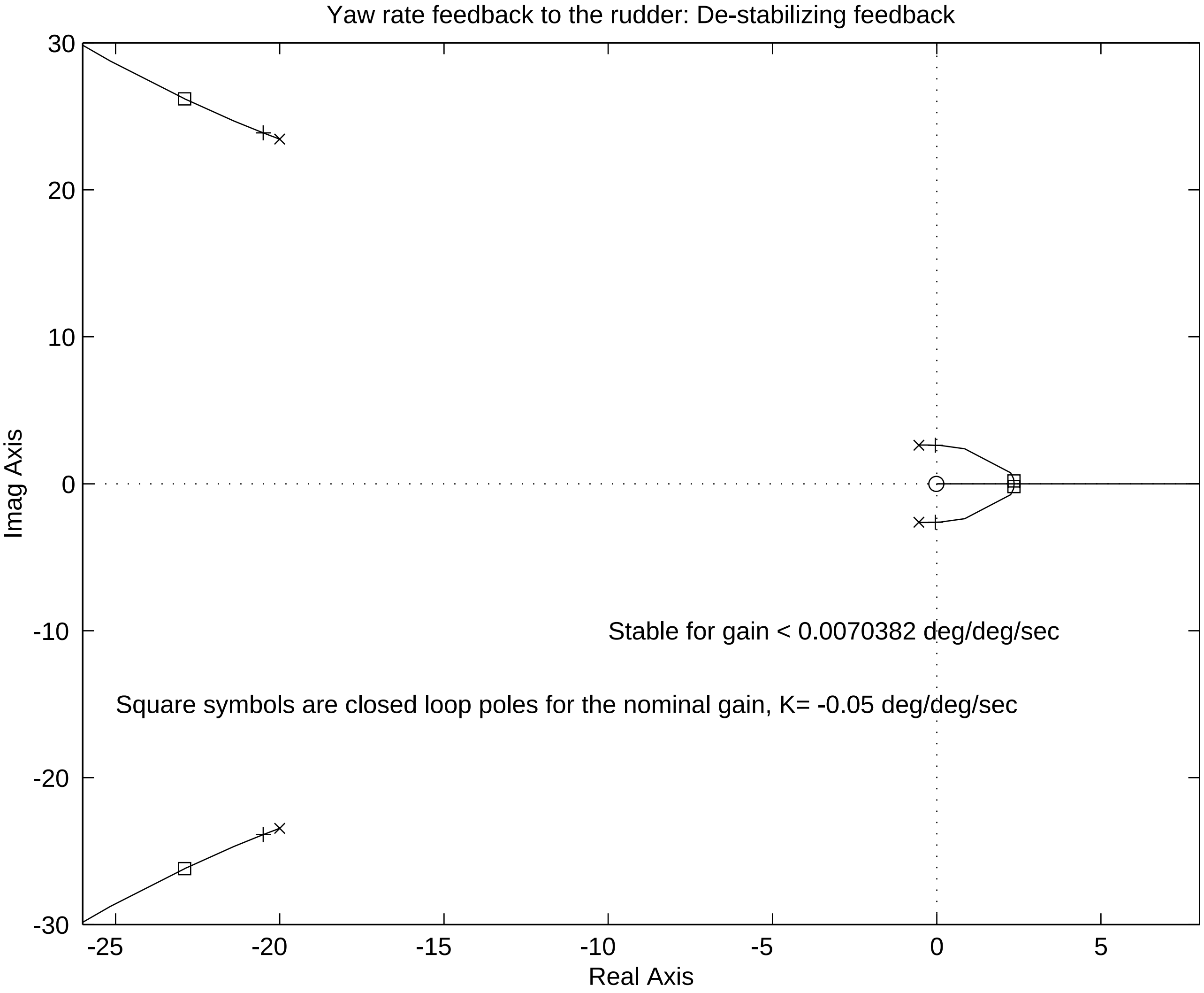
Nyquist Diagrams
Including nominal gain = -0.05 deg/deg/sec

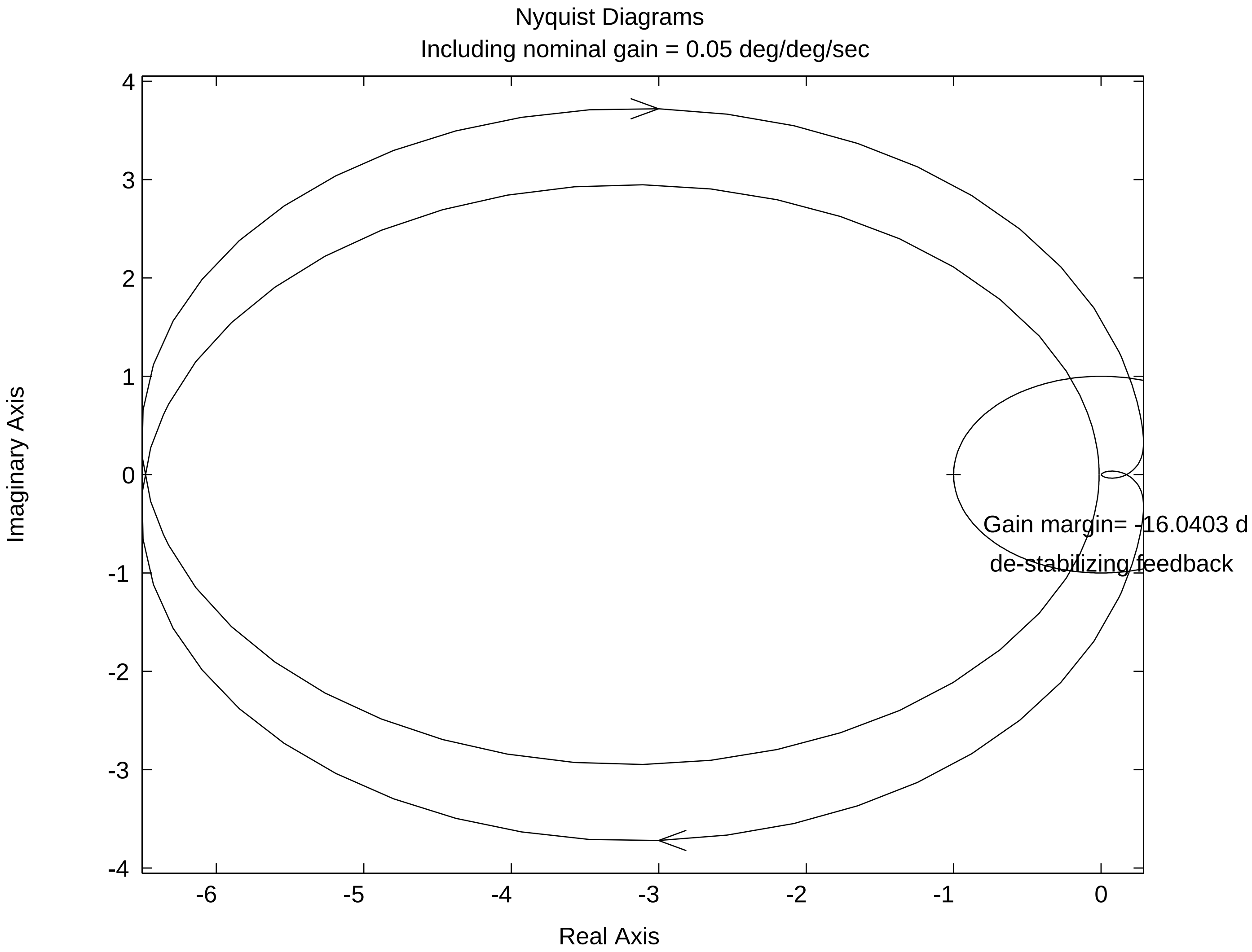
Gain margin= 15.5347 dB, Phase Margin= 78.7335 deg
stabilizing feedback



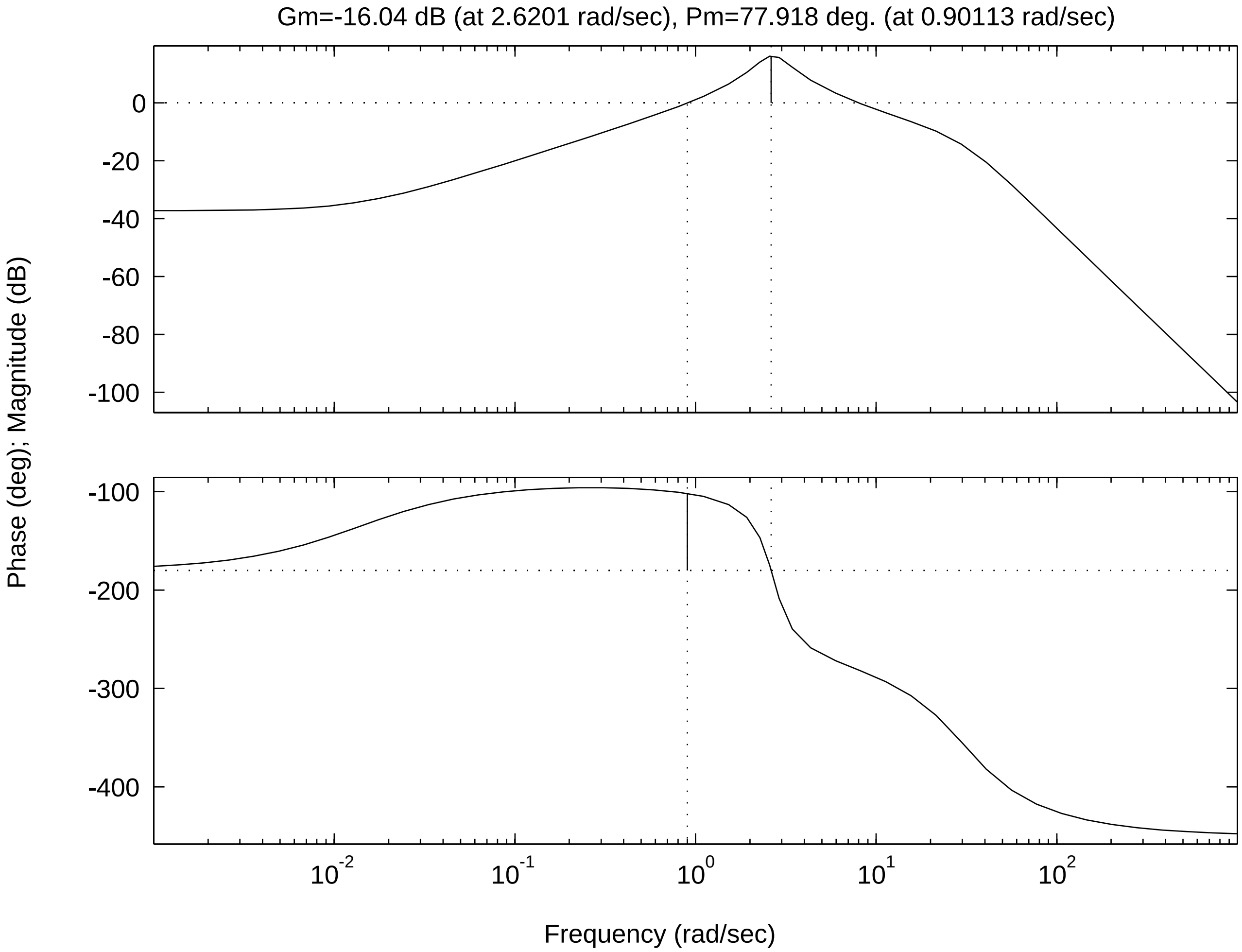
Stability Margins including nominal gain = -0.05 deg/deg/sec, stabilizing feedback

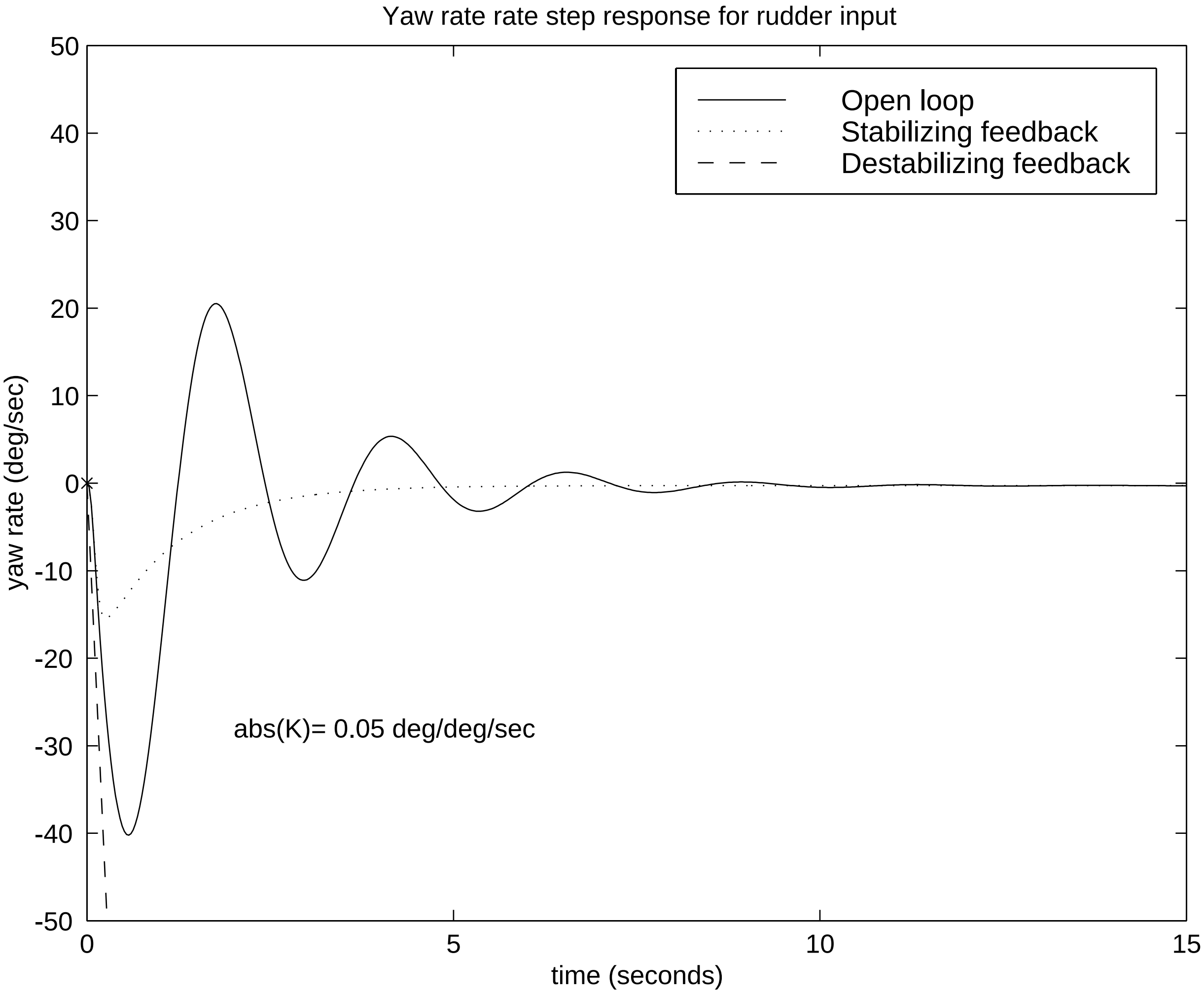
Gm=15.535 dB (at 31.603 rad/sec), Pm=78.734 deg. (at 8.0138 rad/sec)


Yaw rate feedback to the rudder: De-stabilizing feedback
30
20
10
0
-10
-20
-30
Imag Axis
-25
-20
-15
-10
-5
0
5
Real Axis
Stable for gain < 0.0070382 deg/deg/sec
Square symbols are closed loop poles for the nominal gain, K= -0.05 deg/deg/sec


Nyquist Diagrams
Including nominal gain = 0.05 deg/deg/sec
Imaginary Axis
4
3
2
1
0
-1
-2
-3
-4
-6
-5
-4
-3
-2
-1
0
Real Axis
Gain margin= -16.0403 d
de-stabilizing feedback

Stability Margins including nominal gain = 0.05 deg/deg/sec, de-stabilizing feedback



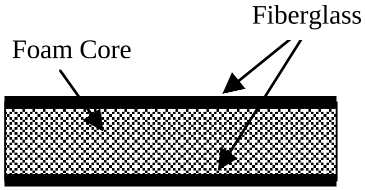

Yaw rate rate step response for rudder input
Open loop
Stabilizing feedback
Destabilizing feedback
abs(K)= 0.05 deg/deg/sec
yaw rate (deg/sec)
50
40
30
20
10
0
-10
-20
-30
-40
-50
time (seconds)
0
5
10
15

Composite Wing

The composite wing of DR2 consists of a foam core with a fiberglass skin on each side. This produces a very stiff and stable wing structure. To obtain the proper airfoil shape wood molds were fabricated on a computer controlled 5-axis mill. The fiberglass was “wet-out” by applying epoxy to the fiberglass. Once the bottom layer of fiberglass was wet-out the foam was placed on top of the fiberglass and the final layer of fiberglass was positioned and wet-out on top of the foam. The fiberglass and foam was then placed in a large bag and a vacuum was created around the part forcing the fiberglass and foam against the mold.

The wing has only one main spar fabricated from balsa and plywood with an layer of fiberglass on each side. The spar was bonded to the lower wing skin prior to the joining of the two wing halves.

The upper and lower halves of the wing were bonded together using epoxy and the molds to assure an accurate alignment between the upper and lower halves.



Foam and fiberglass construction technique

Foam and fiberglass for lower half of wing ready to be vacuum bagged

Upper and lower half of a wing in vacuum bags with vacuum applied.