References:

1. Abzug, M. J. and Larrabee, E. E. (2002). Airplane Stability and Control, Second Edition: A history of the technologies that made aviation possible. UK, Cambridge University Press.
2. Anderson, J. D. (2001). Fundamentals of Aerodynamics, Third Edition. New York, McGraw-Hill.
3. Babister, A.W. 1961: Aircraft Stability and Control. Pergamon Press, London.
4. Balas, G. J. Packard, A. K. Renfrow, J. Mullaney C. Closkey R. T. M. Control of the F-14 Aircraft Lateral-Directional Axis During Powered Approach. Journal of Guidance, Control, and Dynamics. Vol. 21, No. 6, November–December 1998.
5. Bellman, R.E. 1957. Dynamic Programming. Princeton University Press, Princeton, NJ. Republished 2003: Dover.
6. Bennett, S. (2008). A History of Control Engineering 1800-1930, First Edition. The institution of Engineering and Technology.
7. Bennet, S. (1993). A history of control engineering 1930-1955. London, Peter Peregrinus Ltd., on behalf of the institution of Electrical Engineers.
8. Boiffier, J.L. (1998). The Dynamics of Flight equation. John Wiley and Sons, London.
9. Bryan, G.H. 1911: Stability in Aviation. Macmillan and Co. Limited, London.
10. Chalk, C.R. 1958: Additional Flight Evaluations of Various Longitudinal Handling Qualities in a Variable-Stability Jet Fighter. Wright Air Development Center Technical Report, WADC TR 57-719, Wright-Patterson Air Force Base, Ohio.
11. Chen,C.T. and Desoer,C.A. (1967).Controllability and Observability of Composite Systems. IEEE Trans.Autamat.Cont.,vol.AC-18,pp.74.

12. Cook, M. V. (2007). Flight dynamic principles, Second Edition. Elsevier Ltd, London.
13. Darper, C.S. and V.T. Li, (1951). Principles of Optimization Control Systems and an Application to the internal Combustion engine. American Society of Mechanical Engineers, New York.
14. Doyle, J. C. and Stein, G.(1981). Multivariable feedback design: Concept for a Classical/Modern Synthesis. IEEE Transactions on Automatic Contorl, Vol. AC-26. No. I. February.
15. Dorf, C. and Bishop, R. H. (2011). Modern control systems, Twelfth edition. New Jersey, Pearson Eduction, Prentice Hall.
16. Dutton, K. Thompson, S. Barraclough, B. (1997). The art of control engineering. Edinburgh, Pearson Education Limited.
17. Duncan, W.J. (1959). The Principles of the Control and Stability of Aircraft. Cambridge University Press, London.
18. Durand, T. S., and Wasicko, R. J. "Factors Influencing Glide Path Control in Carrier Landing," Journal of Aircraft, Vol. 4, No. 2, 1965, pp. 146–2158.
19. Eldridge, R. A. The carrier landing story. Approach,7, 1961.
20. Etkin, B. 1972. Dynamics of Atmospheric Flight. John Wiley and Sons, Inc., NewYork.
21. Evans,W.R.(1950).Control Systems Synthesis by Root Locus Method. Transactions of AIEE,vol.69,pp.66-69.
22. Friedland, B. 1987: Control System Design. McGraw-Hill Book Company, NewYork.
23. Garnel, P. and East, D. J. Guided Weapon Control Systems, 1977 (Pergamon Press, Oxford).

24. Gates, S.B. and Lyon, H.M. 1944: A Continuation of Longitudinal Stability and Control Analysis; Part 1, General Theory. Aeronautical Research Council, Report and Memoranda No. 2027. Her Majesty's Stationery Office, London.

25. Gerschgorin,S.(1931). Über die Abgrenzung der Eigenwerteeiner Matrix.Izv.Akad.Nauk.USSR Otd.Fiz.-Mat. Nauk 7, pp.749–754.

26. Cooper, G. E. and Harper, R. P. Jr. ,"The Use of Pilot Rating in the Evaluation of Aircraft HandlingQualities," NASA TN D-5153,1969

27. Helton, J.W. A spectral factorization approach to the distributed stable regulator problem; the algebraic Riccati equation," SIAM J. Control Optimization, 14 No. 4, (July1976), 639-661.

28. Hoh, R.H., Mitchell, D.G., Ashkenas, I.L., Klein, R.H., Heffley, R.K. and Hodgkinson, J. 1982: Proposed MIL Standard and Handbook – Flying Qualities of AirVehicles, Volume II: Proposed MIL Handbook. Air Force Wright Aeronautical Laboratory, Technical Report AFWAL-TR-82-3081, Vol. II, Wright-Patterson Air Force Base, Ohio.

29. Hopkin, H.R. 1970: A Scheme of Notation and Nomenclature for Aircraft Dynamics and Associated Aerodynamics. Aeronautical Research Council, Reports and MemorandaNo. 3562. Her Majesty's Stationery Office, London.

30. John H. Lumkes, Jr. (2002). Control Strategies for Dynamic Systems, Design and implementation. New York, Marcel Dekker.

31. H. Ramirez, "Feedback Controlled Landing Maneuvers," IEEE Transactions on Automatic Control, April 1992, pp. 518-523.

32. Kalman, R.E.(1960). On the General Theory of Control Systems. Proceedings of the 1st International Congress of Automatic Control, Russia.
33. Kroo, I. (2001). Aircraft Design, Synthesis and Analysis. Version 0.99, January 2001.
34. Lanchester, F.W. 1908: Aerodonetics. Constable and Co. Ltd, London.
35. Macfarlan, A. G. J. Kouvaritakis, B. (1977). A Design technique for linear multivariable feedback system. Int, J. Contr. 25, pp. 837-74
36. Maciejowski,J.M.(1989).Multivariable Feedback Design. Addison-Wesley Publishing Company.
37. Maciejowski M. J. (1994). Multivariable Feedback Design. Pearson Education, London.
38. Maine, R. E., and K. W. Iliffe, "Formulation and implementation of a practical algorithm for parameter estimation with process and measurement noise," paper 80-1603. AiAA Atoms, flight Mech. Conf., Aug. 11-13, 1980, pp. 397-411
39. Mayne D.Q.(1979). Sequential design of linear multivariable systems: Proceeding of the Institute of Electrical Engineers.l26, 568-572.
40. Maxwell, J.C.(1868). On Governors. Proceedings of the Royal Society, vol.16, No.100, pp.105-
41. McDonald, D.C 1950. "Nonlinear techniques for improving servo performance." Proc. Nat. Electron. Conf. 6, 400-421. New York.
42. McRuer, D. Ashkenas, I. and Graham, D. 1973: Aircraft Dynamics and Automatic Control. Princeton, NJ: Princeton University Press.
43. Megson, T.H.G. (2007). Aircraft Structures for Engineering Students, Fourth Edition. UK, Elsevier Ltd.

44. Melville, J. B. Kerver, L. V. (1934). Aerodynamic Theory: Dynamics of the airplane-Airplane performance. Springer Ltd, London.

45. Milne, G.W. Grumman F-14 benchmark control problem solution using BLRLAB . in proceedings of IEEE Control System Design Workshop, Tampa, Florida, 1989, pp. 94-101.

46. Moorhouse, D. J., and R. J. Woodcock, "Background information and user guide for MIL-F-8785C," AFWAL-TR-81-3109 (AD-A119-421), Wright-Patterson AFB, Ohio, July 1982.

47. Nagrath, I.J. Gopal, M. (2007). Control Systems Engineering (Fifth Edition). Published by New age International (P) Ltd. New Delhi.

48. Naidu, D. S. (2003). Optimal Control Design. CRS Press LLC, New York.

49. Nyquist, H.(1932). Regeneration Theory.*Bell System Technical Journal,* vol.11,pp.126-147.

50. Owens, D. H. (1979). Approximately commutative control and the method of dyadic expansion. Proceedings of the Institution of Electrical Engineers, Volume 126, Issue 6, June 1979, p. 563 – 567

51. Postlethwaite, I. Edmunds, John M. MacFarlane, A. (1981), Principal gains and principal phases in the analysis of linear multivariable feedback systems. IEEE Transactions on automatic control. VOL. AC-26, NO. 1.

52. Queijo, M. J. (1968). Theory for computing span loads and stability derivatives due to sideslip, yawing, and rolling for wings in subsonic compressible flow.: National Aeronautics and Space Administration, Washington, D.C.

53. Raymer, D. P. (1992). Aircraft Design: a conceptual approach, Second Edition. United States. American institute of Aeronautics and Astronautics, Inc. Washington, DC.
54. Roskam, J. (2001). Airplane Flight dynamics and automatic flight controls. Design, Analysis and Research Corporation (DAR corporation), New York.
55. Rosenbrock, H.H.(1969). Design of multivariable control systems using the inverse Nyquist array.*Proc.IEE*, vol.116, No.11, pp.1929-1936.
56. Rimer, M. Fredrick, D.K. solution of the Grumman F-14 benchmark control problem. IEEE Control Syst., August 1987, 30-40.
57. Shinners, S.M. 1980: *Modern Control System Theory and Application.* Addison-Wesley Publishing Co., Reading, Massachusetts.
58. Shinners S. M. (1998). Advanced modern Control System Theory and design. New York, John Wiley & Sons, INC.
59. Stevens, B. L. Lewis, F. L. (2003). Aircraft Control and Simulation, second edition. Hoboken, New Jersey, John Wiley.
60. Skogestad, S. Postlethwaite, I. (2005). Multivariable Feedback Control, Analysis and Design. John Wiley &Sons, Ltd, London.
61. Tewari, A. (2007). Atmospheric and space flight Dynamics, Modeling and Simulation with Matlab and Simulink© . Printed by Berkauser, Boston.
62. Tewari, A. (2011). Advance control of aircraft, spacecraft, and rockets. J. Wiley, London.
63. Tischler, M. B. Digital control of highly augmented combat aircraft. NASA TM 88346, May 1987.

64. Whalley, R. “Application of Multivariable System Techniques”. Proc IMechE Pub, London 1990.
65. Whalley, R. Ebrahimi, M. (2000). Aircraft Pitch and heave rate control. Proc IMechE pt G, London.
66. Whalley, R. (2006). Multivariable System Regulation. Proceedings of the Institution of Mechanical Engineering, Part C: Journal of Mechanical Engineering Science, May 1, 2006 vol. 220 no. 5, pp. 653-667.
67. Whalley, R. (1988) . The Application of multivariable System Techniques. IMechE part E, London.
68. Whalley and M Ebrahimi (1997). The Dynamic analysis of mechanical systems and structures with large parameter variations. IMechE Part G: Journal of Aerospace Engineering
69. Whalley, R. Mitchell, D. Ebrahimi, M. (1999). IMechE Part I. Journal of Systems and Control Engineering.
70. Wiener, N. 1949. The extrapolation, interpolation and smoothing of stationery Time series. MIT technology Press, Cambridge, MA, 1949.
71. Winchester, J. (2004). Modern Military Aircraft. London, Amber Books Ltd.
72. Zames, G. (1981). “Feedback and optimal Sensitivity; Model Reference Transformations, Multiplicative Seminorms, and Approximate Inverses, “ IEEE Transaction on Automatic Control, AC-26, 301-320”.
73. Ziegler,J.B. &Nichols,N.B.(1942).Optimum Settings for Automatic Controllers.ASME Transactions, vol.64 , pp. 759-768.

74. Zhou, K., J. C. Doyle and K. Glover (1996). *Robust and Optimal Control*. Prentice-Hall. Upper Saddle River.

75. http://www.anft.net/f-14/f14-detail-dimensions-01.htm

76. http://www.anft.net/f-14/f14-detail-dimensions.htm

77. http://www.combataircraft.com/aircraft/ff14_p_04_l.jpg

78. [http://upload.wikimedia.org/wikipedia/en/c/c2/Cayley_Glider_Replica_Flown_By_Derek_Piggott_2.jpg]

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Appendix A

1. Least Effort controller methodology M-file:

```
%%Dissertation: Pitch and Heave Control, 2014

%% finding open loop heave rate due to control surface on wing and tail
wing_heave=[63.9979  4769.161907];
den=[1  1.2956 4.4867];
sys1=tf(wing_heave,den); %%Given Transfer function in Whalley &Ebrahimi,2000)



tail_heave=[2 149.02412]; %%heave response to suggested input on tail
sys2=tf(tail_heave,den);


%% finding open loop pitch rate due to control surface on wing and tail
wing_pitch=[-6.8847 -4.77316];
sys3=tf(wing_pitch,den);   %%Given Transfer function in (Whalley
&Ebrahimi,2000)

tail_pitch=[-100  -69.33];
sys4=tf(tail_pitch,den);


%%Optimization
clc
syms n;
format shorteng
Q1=[wing_heave(1,2)+(tail_heave(1,2)*(n))
wing_pitch(1,2)+(tail_pitch(1,2)*(n));wing_heave(1,1)+(tail_heave(1,1)*(n))
wing_pitch(1,1)+(tail_pitch(1,1)*n)];
k1=50;
b=k1*[6;1]

%%Find minimum J

J=(1+(n^2))*transpose(b)*transpose(inv(Q1))*(inv(Q1))*b;
[N,D]=numden(J);
NUM=sym2poly(N);
DEN=sym2poly(D);
[q,d]=polyder(NUM,DEN);
J=tf(NUM,DEN);


%%Plot J
n=-100:0.01:100;
num=[NUM(1,1).*n.^4+NUM(1,2).*n.^3+NUM(1,3).*n.^2+NUM(1,4).*n.^1+NUM(1,5)];
den=[DEN(1,1).*n.^4+DEN(1,2).*n.^3+DEN(1,3).*n.^2+DEN(1,4).*n.^1+DEN(1,5)];
X=num./den;
```

```
a=tf(q,d);
P1=roots(q)

%finding J at n1
c1=(P1(1,1))
Q=[wing_heave(1,2)+tail_heave(1,2)*(c1)
wing_pitch(1,2)+tail_pitch(1,2)*(c1);wing_heave(1,1)+tail_heave(1,1)*(c1)
wing_pitch(1,1)+tail_pitch(1,1)*c1];
J10=(1+(c1)^2)*transpose(b)*transpose(inv(Q))*(inv(Q))*b;

%finding J at n2
c2=(P1(2,1))
Q=[wing_heave(1,2)+tail_heave(1,2)*(c2)
wing_pitch(1,2)+tail_pitch(1,2)*(c2);wing_heave(1,1)+tail_heave(1,1)*(c2)
wing_pitch(1,1)+tail_pitch(1,1)*c2];
J20=(1+(c2)^2)*transpose(b)*transpose(inv(Q))*(inv(Q))*b;

%finding J at n3
c3=(P1(3,1))
Q=[wing_heave(1,2)+tail_heave(1,2)*(c3)
wing_pitch(1,2)+tail_pitch(1,2)*(c3);wing_heave(1,1)+tail_heave(1,1)*(c3)
wing_pitch(1,1)+tail_pitch(1,1)*c3];
J30=(1+c3^2)*transpose(b)*transpose(inv(Q))*(inv(Q))*b;

%finding J at n4
c4=(P1(4,1))
Q=[wing_heave(1,2)+tail_heave(1,2)*(c4)
wing_pitch(1,2)+tail_pitch(1,2)*(c4);wing_heave(1,1)+tail_heave(1,1)*(c4)
wing_pitch(1,1)+tail_pitch(1,1)*c4];
J40=(1+c4^2)*transpose(b)*transpose(inv(Q))*(inv(Q))*b;

%finding J at n5
c5=(P1(5,1))
Q=[wing_heave(1,2)+tail_heave(1,2)*(c5)
wing_pitch(1,2)+tail_pitch(1,2)*(c5);wing_heave(1,1)+tail_heave(1,1)*(c5)
wing_pitch(1,1)+tail_pitch(1,1)*c5];
J50=(1+c5^2)*transpose(b)*transpose(inv(Q))*(inv(Q))*b;

%finding J at n6
c6=(P1(6,1))
Q=[wing_heave(1,2)+tail_heave(1,2)*(c6) wing_pitch(1,2)+tail_pitch(1,2)*(c6);
wing_heave(1,1)+tail_heave(1,1)*(c6) wing_pitch(1,1)+tail_pitch(1,1)*c6];
J60=(1+c6^2)*transpose(b)*transpose(inv(Q))*(inv(Q))*b;
J=[J10;J20;J30;J40;J50;J60]

%J minimum after simulation is at gain ratio n2
n1=c2;
Q=[wing_heave(1,2)+tail_heave(1,2)*(n1)
wing_pitch(1,2)+tail_pitch(1,2)*(n1);wing_heave(1,1)+tail_heave(1,1)*(n1)
wing_pitch(1,1)+tail_pitch(1,1)*n1];

h=(inv(Q)*b)' %Feedback marix
k=[1;n1];
I=[1 0;0 1];
```

```
f=0.8         %outer loop feeback gain
G=[wing_heave(1,2) tail_heave(1,2);wing_pitch(1,2) tail_pitch(1,2)]/x;
F=[f 0;0 f];
S=[1 0.005;-.005 1];
F=[f 0;0 f];
P=(inv(G)+k*(h))*S*inv(I-F*S)
H=inv(P)*k*h+F;
y=inv(I+G*P*H)*G*P
dis=inv(I+G*P*H)
a=P*H;
g11=sys1*a(1,1)+sys2*a(2,1);
g12=sys1*a(1,2)+sys2*a(2,2);
g21=sys3*a(1,1)+sys4*a(2,1);
g22=sys3*a(1,2)+sys4*a(2,2);
sys=[sys1 sys2; sys3 sys4];
Gss=[g11 g12;g21 g22];
z=inv(I+Gss)*sys*P;
z1=inv(I+Gss);
```

2. Inverse Nyquist Array methodology m.file :

```
G=tf({14.96 [95150 95150*1.898];85.2 [124000 124000*2.037]},{[1 12 20]
[1.0000 103.2250 325.0250 252.5000];[1 12 20] [1.0000 103.2250 325.0250
252.5000]}); % Transfer Function Matrix
k1=[1000 0;0 1];% first precompensator
k2=tf({[-1.57 -1.57*20.6] [1.205 1.205*11.6];[1.08 1.08*146.3] [-0.189 -
0.189*101.4]},{[1 158.5] [1 158.5];[1 158.5] [1 158.5]});%2nd Compensator
Q=inv(G*k1*k2);% Inversed Overall Transfer Function Matrix
gershband(Q);% creates Figures 4.11 and 4.12
function gershband(a,b,c,d,e)
%GERSHBAND - Finds the Gershorin Bands of a nxn LTI MIMO SYS model
% The use of the Gershorin Bands along the Nyquist plot is helpful for
% finding the coupling grade of a MIMO system.
%
% Syntax: gershband(SYS) - computes the Gershgorin bands of SYS
% gershband(SYS,'v') - computes the Gershgorin bands and the
% Nyquist array of SYS
% Inputs:
% SYS - LTI MIMO system, either in State Space or Transfer Function
% representation.
%
% Example:
% g11=tf(2,[1 3 2]);
% g12=tf(0.1,[1 1]);
% g21=tf(0.1,[1 2 1]);
% g22=tf(6,[1 5 6]);
% G=[g11 g12; g21 g22];
% gershband(G);
%
% Other m-files required: sym2tf, ss2sym
% Subfunctions: center, radio
% See also: rga
%
% Author: Oskar Vivero Osornio
% email: oskar.vivero@gmail.com
```

```
% Created: February 2006;
% Last revision: 11-May-2006;
% May be distributed freely for non-commercial use,
% but please leave the above info unchanged, for
% credit and feedback purposes
%------------- BEGIN CODE --------------
%--------- Determines Syntax -----------
ni=nargin;
switch ni
case 1
%Transfer Function Syntax
switch class(a)
case 'tf'
%Numeric Transfer Function Syntax
g=a;
case 'sym'
%Symbolic Transfer Function Syntax
g=sym2tf(a);
end
e=0;
case 2
%Transfer Function Syntax with Nyquist Array
switch class(a)
case 'tf'
%Numeric Transfer Function Syntax
g=a;
case 'sym'
%Symbolic Transfer Function Syntax
g=sym2tf(a);
end
e=1;
case 4
%State Space Syntax
g=ss2sym(a,b,c,d);
g=sym2tf(g);
e=0;
case 5
%State Space Syntax
g=ss2sym(a,b,c,d);
g=sym2tf(g);
e=1;
end
%---------------------------------------
[n,m]=size(g);
w=logspace(-1,6,200);
q=0:(pi/50):(2*pi);
for i=1:n
for j=1:m
if i==j
figure(i)
nyquist(g(i,i));
grid on
title(['Nyquist Diagram of G(',num2str(i),',',num2str(j),')'])
for iest=1:n
for jest=1:m
if iest~=jest
hold on
```

```
C=center(g(i,j),w);
R=radio(g(iest,jest),w);
for k=1:length(C)
plot((R(k)*cos(q))+real(C(k)),(R(k)*sin(q))+imag(C(k)),'g-')
end
hold off
end
end
end
end
end
end
if e==1
figure(n+1)
nyquist(g);
grid on
end
%------------ Subfunction --------------
function C = center(g,w)
g=tf2sym(g);
C=subs(g,complex(0,w));
function R = radio(g,w)
g=tf2sym(g);
R=abs(subs(g,complex(0,w)));
%------------- END OF CODE --------------
```

3. Simulation Models

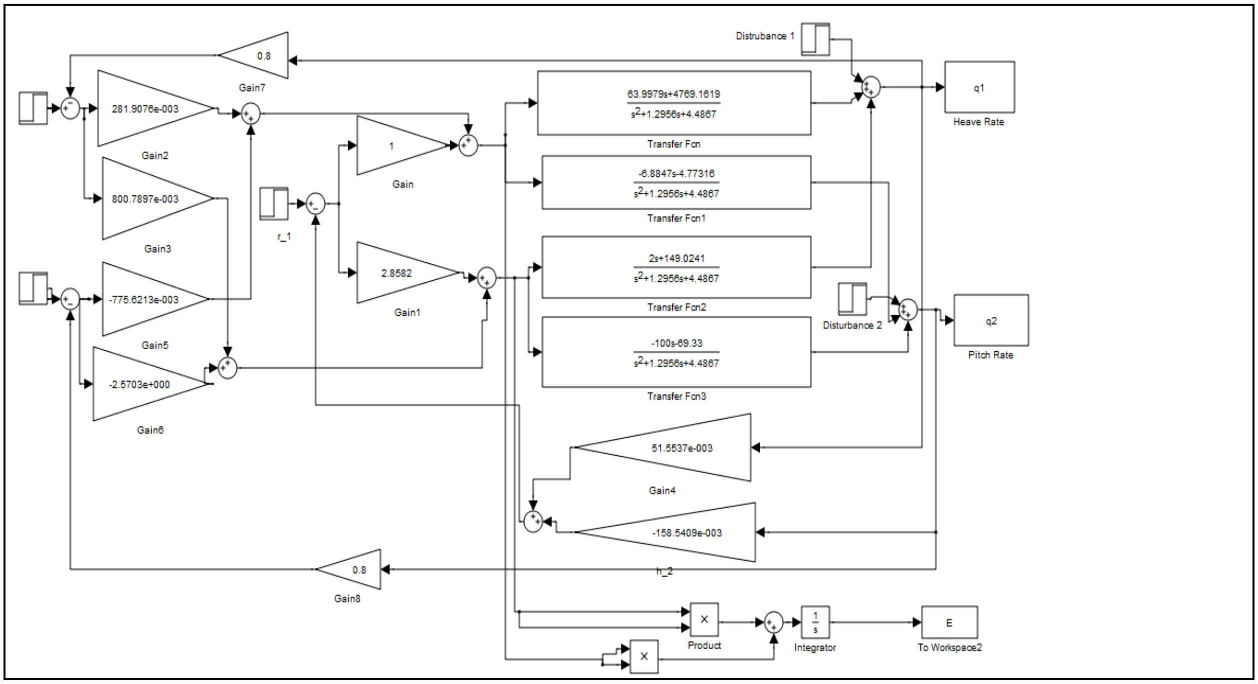

Figure A.1 Closed loop by least effort controller with $f = 0.8$ Simulation model

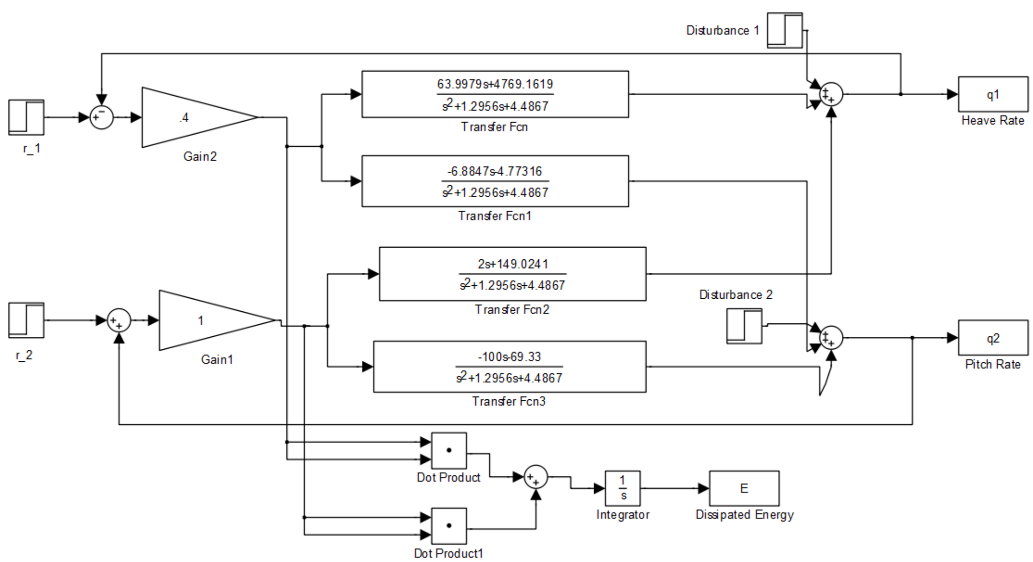

Figure A.2 Closed loop by Inverse Nyquist Array Controller Simulation Model