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Design of Fuzzy Pitch Attitude Hold Systems for a Fighter Jet

Dr. DAVID E. BOSSERT, Lt Col, USAF*
US Air Force Academy

Dr. KELLY COHEN, Lt Col, Israeli Ministry of Defense [%]
Directorate of Defense Research and Development

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PID and Fuzzy Logic Pitch Attitude Hold Systems for a Fighter Jet

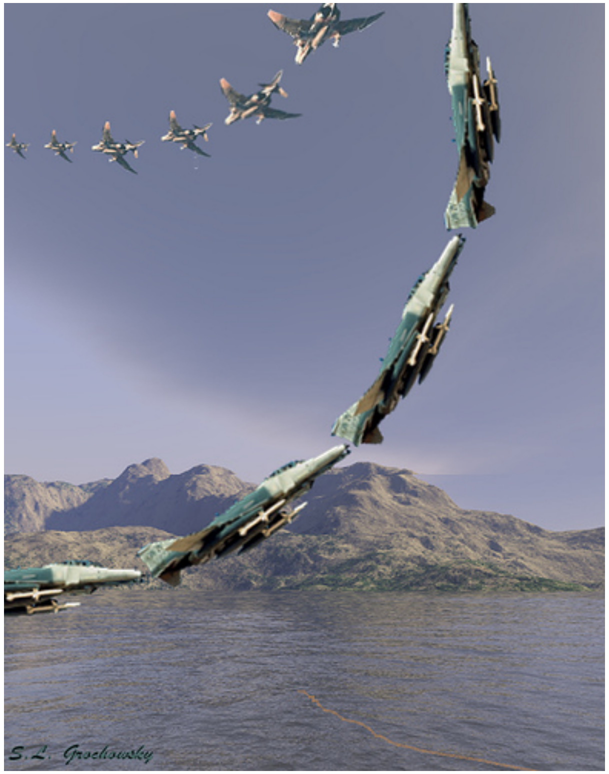
Dr. DAVID E. BOSSERT, Lt Col, USAF*
US Air Force Academy

Dr. KELLY COHEN, Lt Col, Israeli Ministry of Defense [%]
Visiting Researcher, US Air Force Academy

INTRODUCTION

- An F-4 fighter jet in the approach condition is chosen for its challenging dynamics.
- The baseline approach condition is sea level and Mach = 0.26. All plant models include actuator dynamics modeled as 10/(s+10), or an actuator with a time constant of 0.1 seconds.
- To investigate fault tolerance, several degraded variants of this basic flight condition were examined as well.
- Specifically, a 50% reduction in the following derivatives: static longitudinal stability derivative, Cm, and the pitch damping derivative, Cmq.

- **Research Objective**
  - The main aim is to examine the robustness of a root-locus based P control vs PID vs fuzzy logic based pitch attitude hold system for a F-4 fighter jet.



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PLANT MODELS

- This plant set consists of marginally stable and unstable cases, and presents an interesting control challenge.

- All plant models include actuator dynamics modeled as 10/(s+10) i.e. a time constant of 0.1 seconds.

- To investigate fault tolerance, several degraded variants of this basic flight condition are examined as well.

- A 50% reduction in the static longitudinal stability derivative, C_{ma}, and a 50% reduction in the pitch damping derivative, C_{mq}. Also, the case where both derivatives are reduced by 50% is examined.

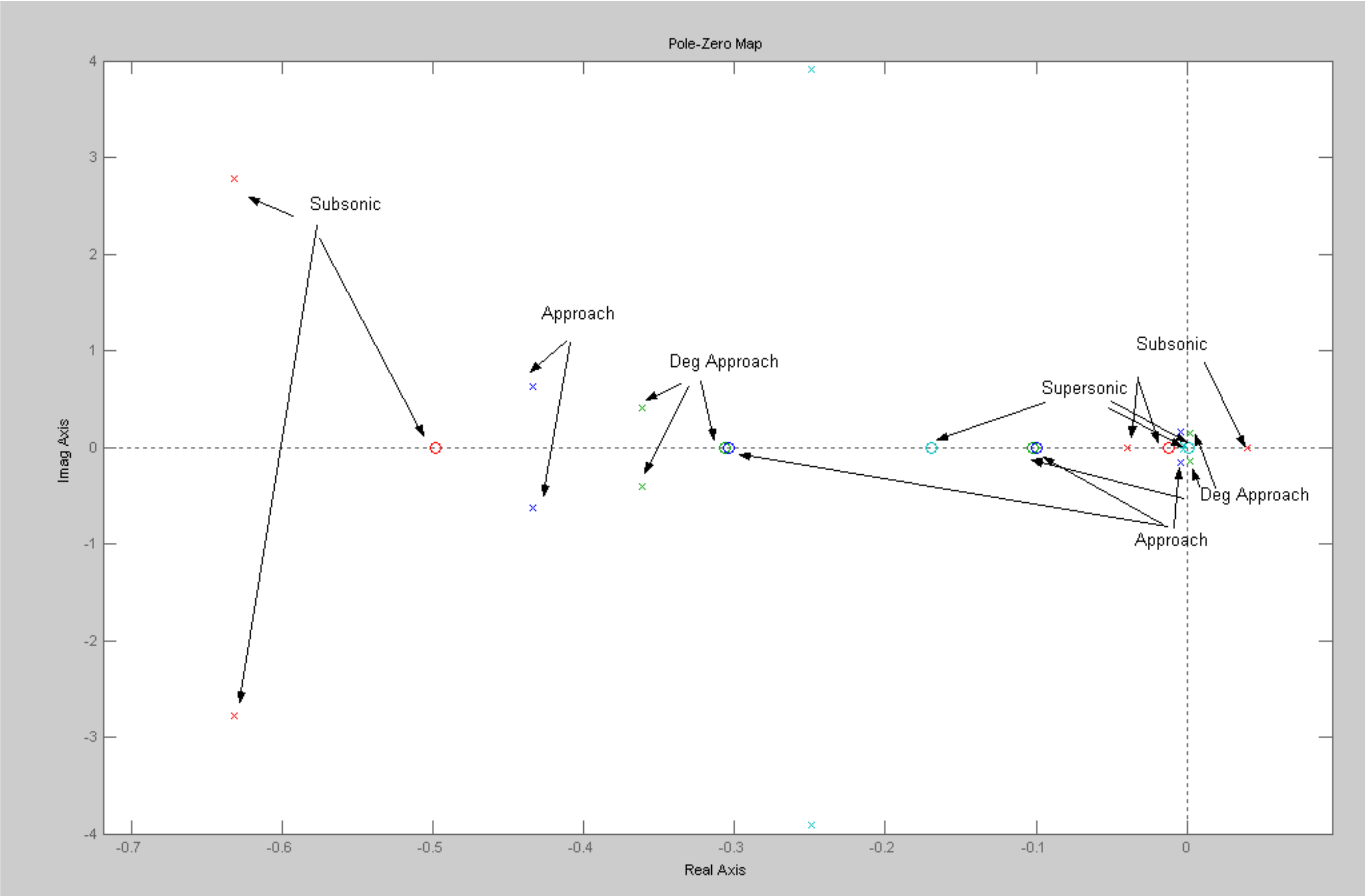
Plant Cases – Open Loop

Flight Condition	Transfer Function
Approach	$\dfrac{3361 s^2 + 1357 s + 102.2}{230.6 s^5 + 2508 s^4 + 2161 s^3 + 1406 s^2 + 63.04 s + 32.01}$
Approach, Deg Cma	$\dfrac{3361 s^2 + 1372 s + 105}{230.6 s^5 + 2508 s^4 + 2110 s^3 + 895.9 s^2 + 48.57 s + 16}$
Approach, Deg Cmq	$\dfrac{3361 s^2 + 1357 s + 102.2}{230.6 s^5 + 2472 s^4 + 1782 s^3 + 1255 s^2 + 51.39 s + 32.01}$
Approach, Deg Cma, Cmq	$\dfrac{3361 s^2 + 1372 s + 105}{230.6 s^5 + 2472 s^4 + 1731 s^3 + 744.8 s^2 + 36.92 s + 16}$

Robustness Tests

Flight Condition	Transfer Function
Approach	$\dfrac{3361 s^2 + 1357 s + 102.2}{230.6 s^5 + 2508 s^4 + 2161 s^3 + 1406 s^2 + 63.04 s + 32.01}$
Approach, 50% Deg Cma, Cmq	$\dfrac{3361 s^2 + 1372 s + 105}{230.6 s^5 + 2472 s^4 + 1731 s^3 + 744.8 s^2 + 36.92 s + 16}$
F4 Subsonic Cruise	$\dfrac{9.99e004 s^2 + 5.105e004 s + 623.4}{877.6 s^5 + 9884 s^4 + 1.82e004 s^3 + 7.114e004 s^2 - 61.19 s - 114.1}$
F4 Supersonic Cruise	$\dfrac{1.3e005 s^2 + 2.183e004 s - 31.29}{1742 s^5 + 1.83e004 s^4 + 3.553e004 s^3 + 2.677e005 s^2 + 1247 s + 123.9}$

Pole –Zero Maps for Robustness Tests



BASIC ROOT-LOCUS DESIGN

Root-locus design is a classical design technique which is well documented [10] and is usually first taught at the undergraduate level. The pitch attitude hold system design uses a single gain chosen by closing the feedback loop, as shown in Figure 3. The design is accomplished using the MATLAB root-locus tool which allows analysis of closed loop response as the gain varies [11]. The gain was varied until the "best" response to a step input was achieved. The definition of "best" in this case was lowest steady-state error, fastest rise time, and fastest settling time. For the single loop case, a gain of 0.5 is chosen. The step response is shown in comparison to the fuzzy controller in Figure 6. In addition, the response to changes in plant conditions for 50% degrades in Cmα, Cmq, and both is shown in Figures 7, 8, and 9, respectively.

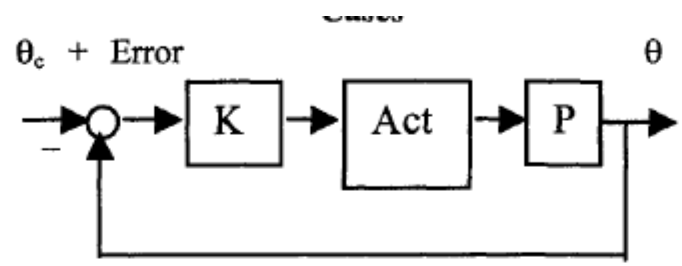


Figure 3 – Basic Pitch Attitude Hold System

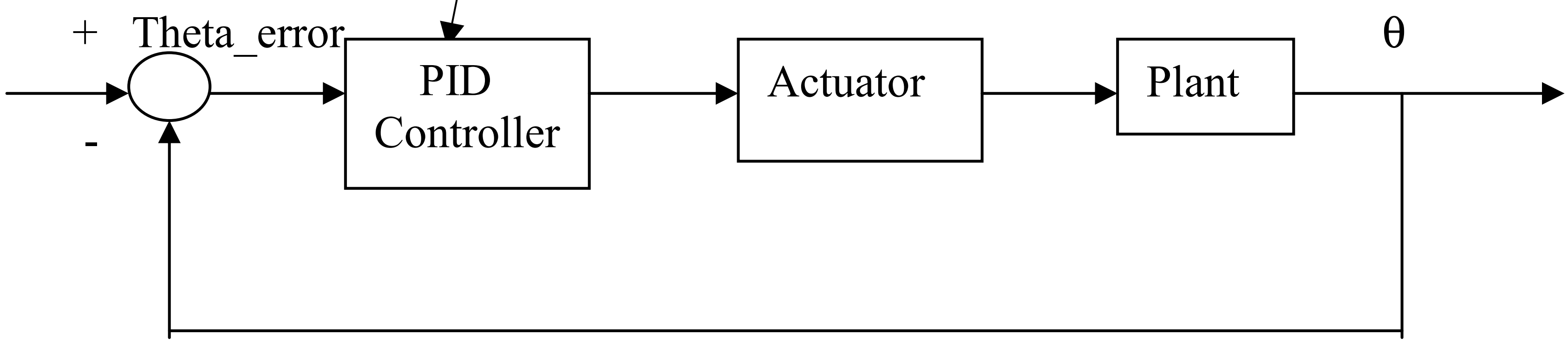
PID Pitch Attitude Hold System

$K_P = 5.80$

$K_I = 0.47$

$K_D = 2.85$

$$K_P + K_I/s + K_D\,s$$



Why Fuzzy Logic

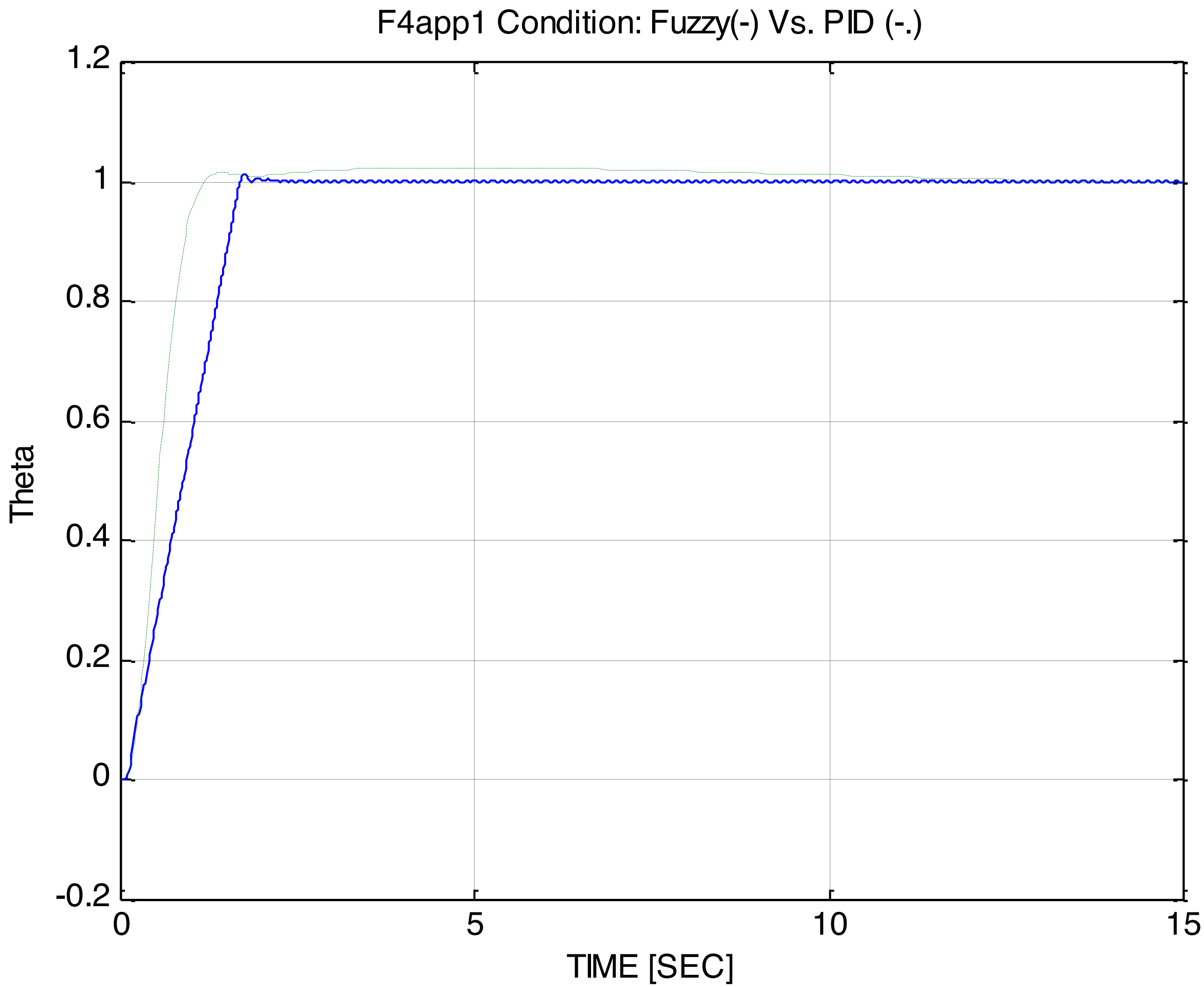
Controllers using fuzzy logic techniques provide:

- Robustness characteristics for systems having plant uncertainties and noisy sensors.
- Near-optimal behavior ("smaller" actuators).
- Real-time implementation and easy to incorporate additional sensors.
- Utilization of expert knowledge by the integration of logic into control system design.

FUZZY LOGIC RULE BASE

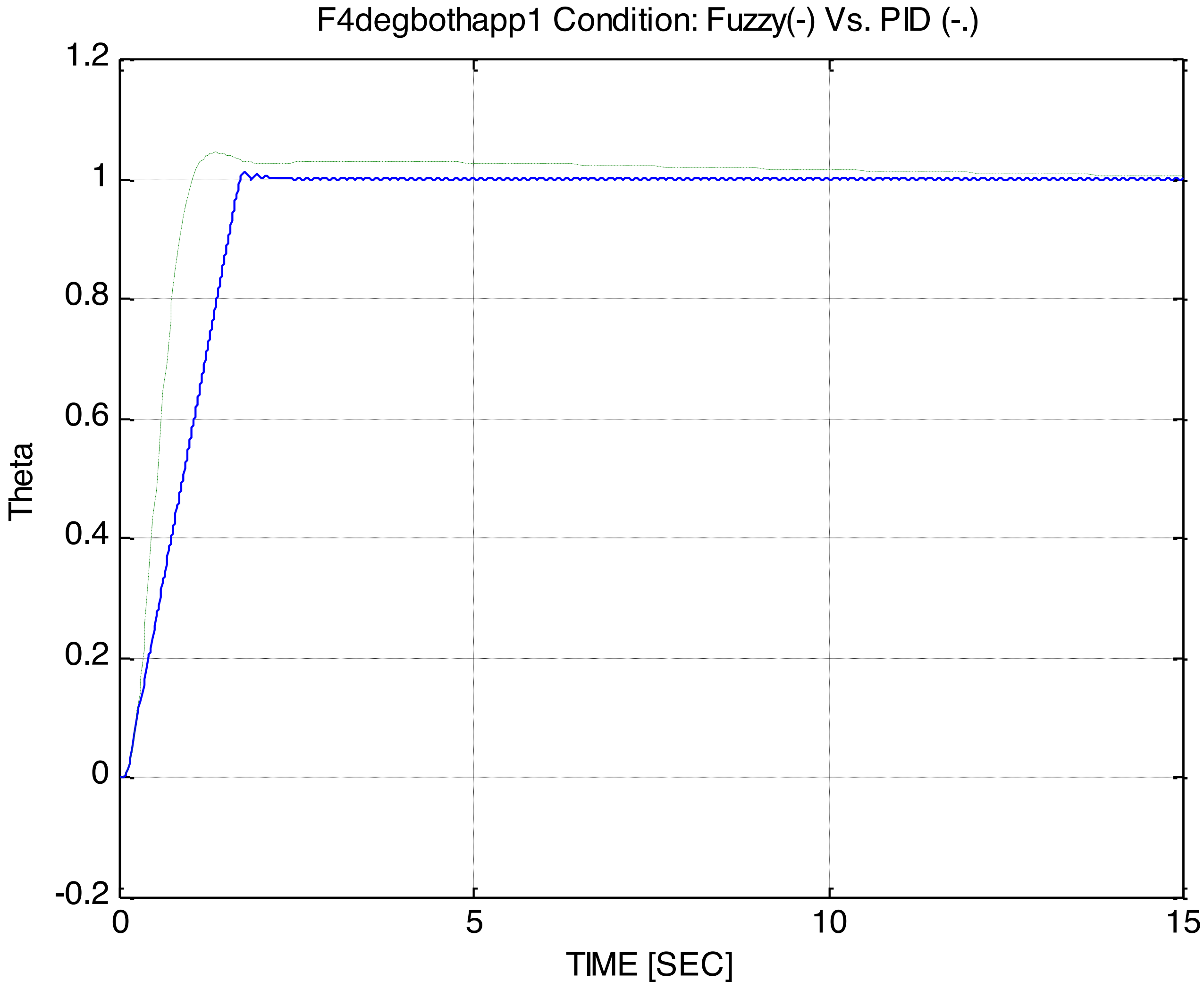
	theta_error **Negative**	theta_error **Negative Small**	theta_error **Zero**	theta_error **Positive Small**	theta_error **Positive**
Theta_rate **Positive**	SMALL NEGATIVE	SMALL NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE
Theta_rate **Positive Small**	SMALL POSITIVE	SMALL NEGATIVE	SMALL NEGATIVE	SMALL NEGATIVE	NEGATIVE
theta_rate **Zero**	POSITIVE	SMALL POSITIVE	ZERO	SMALL NEGATIVE	NEGATIVE
Theta_rate **Negative Small**	POSITIVE	SMALL POSITIVE	SMALL POSITIVE	SMALL POSITIVE	SMALL NEGATIVE
Theta_rate **Negative**	POSITIVE	POSITIVE	POSITIVE	SMALL POSITIVE	SMALL POSITIVE

Fuzzy Logic Control(-) vs. PID control(-.)
F-4 approach (design condition)

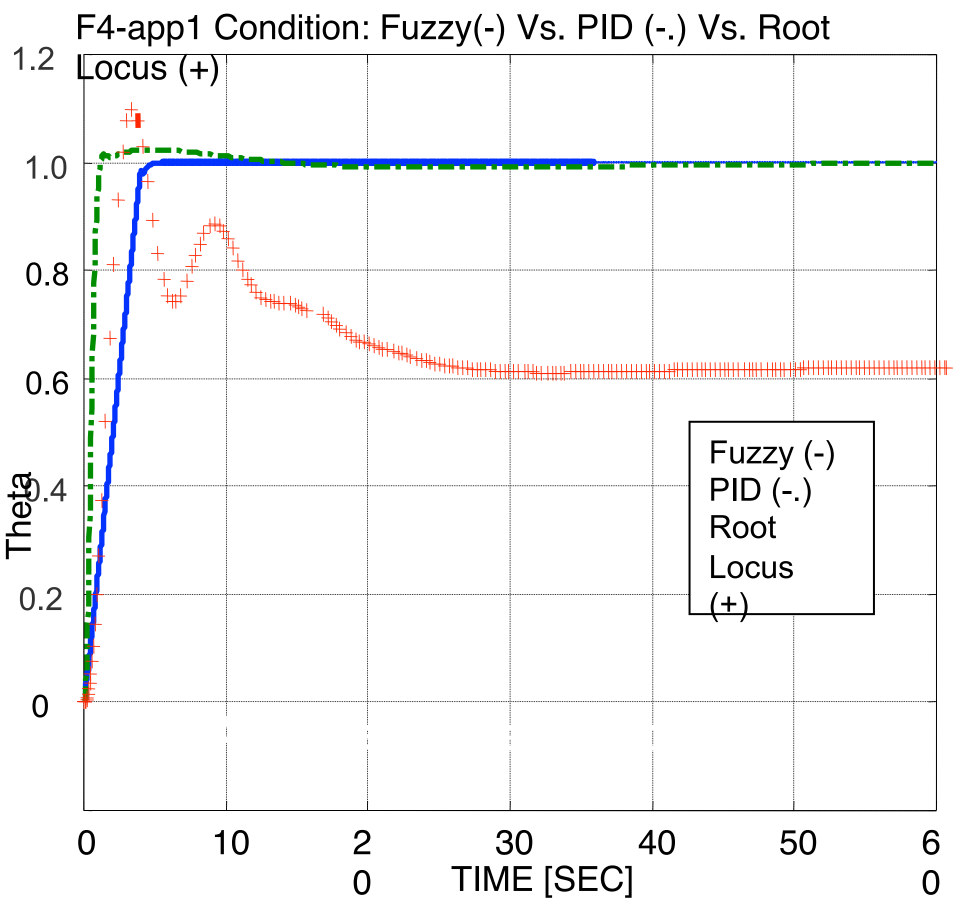


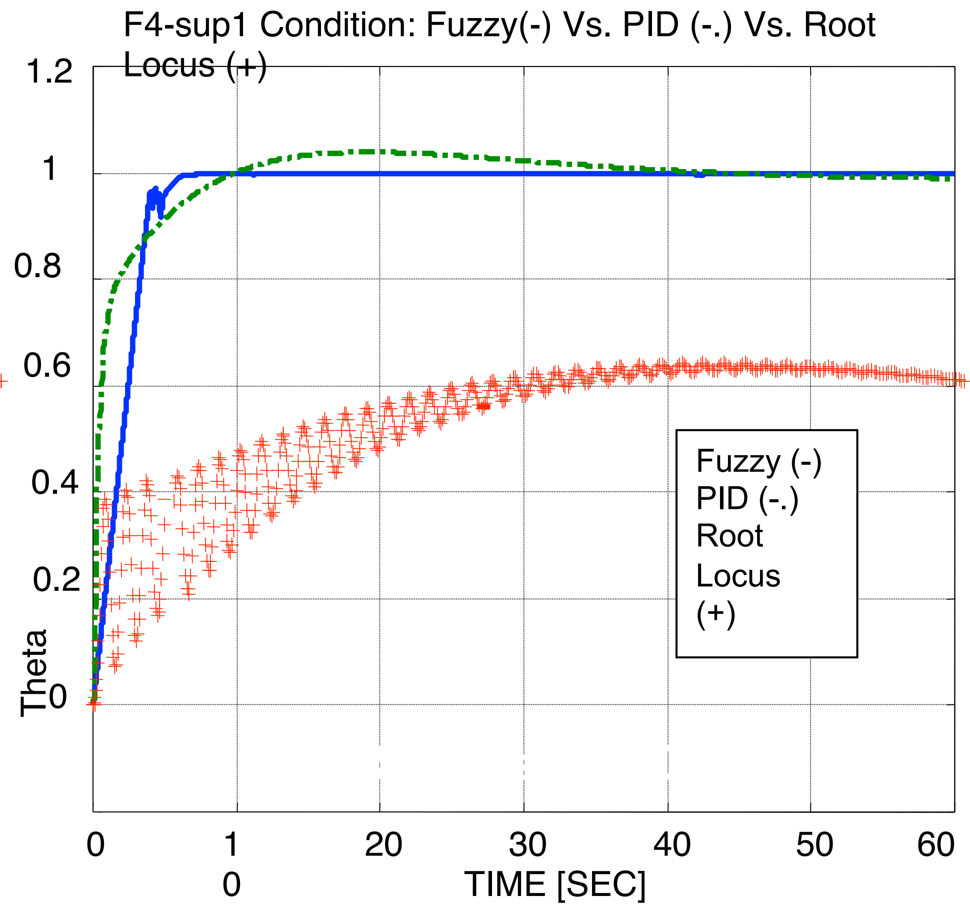
Fuzzy Logic Control(-) vs. PID control(-.)

50% reduction in longitudinal stability and pitch damping

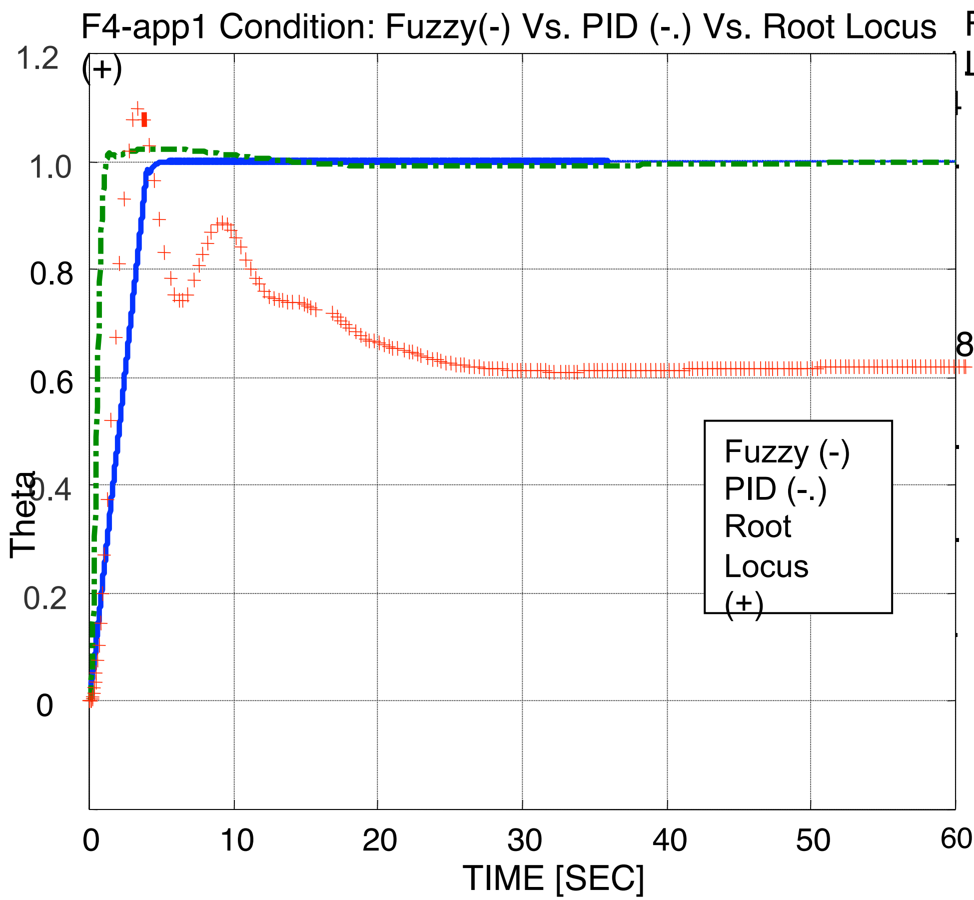


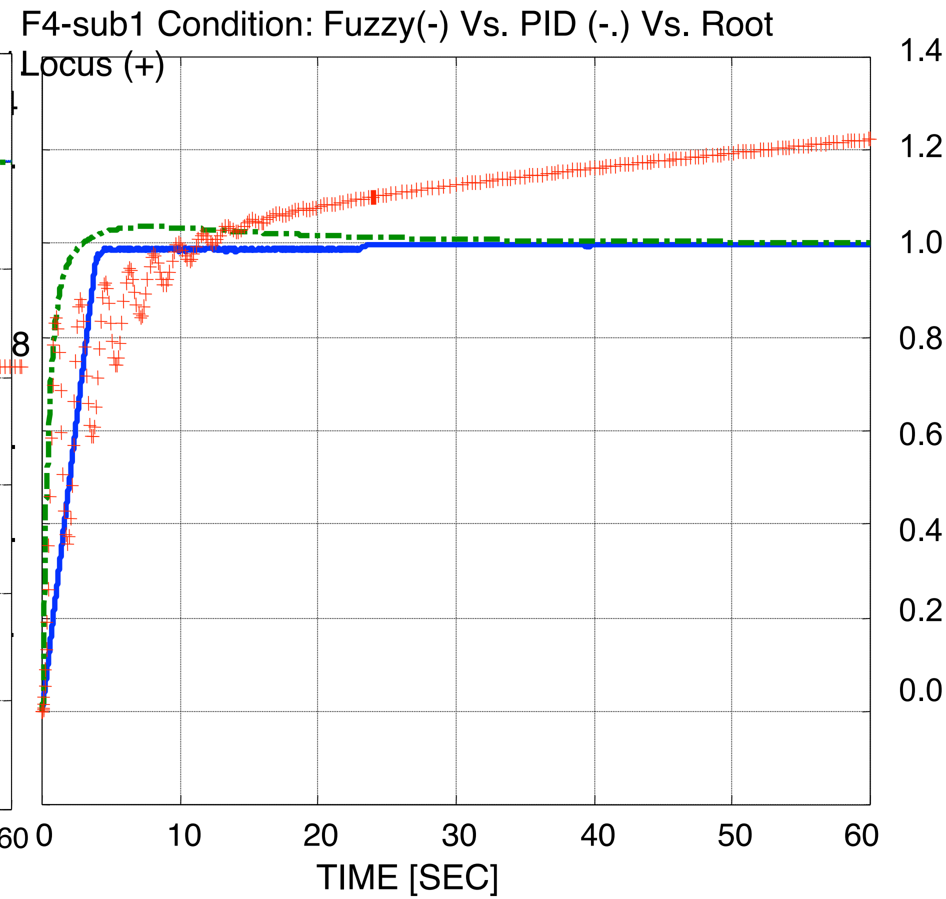
FUZZY FLIGHT CONTROL ROBUSTNESS RESULTS





FUZZY FLIGHT CONTROL
ROBUSTNESS RESULTS





TIME RESPONSE SUMMARY

Case	Ts (s)	Tr (s)	Tp (s)	Mp (Deg)	FV (Deg)
Root Locus F4 Approach (Design Condition)	23.6	1.09	3.14	1.09	.62
PID F4 Approach (Design Condition)	7.08	1.27	4.98	1.023	1.00
Fuzzy F4 Approach (Design Condition)	1.65	1.68	1.74	1.013	1.00
Root Locus 50% Red in Cmα and Cmq	25.8	1.16	3.57	1.42	.77
PID 50% Red in Cmα and Cmq	8.0	1.03	1.35	1.045	1.01
Fuzzy 50% Red in Cmα and Cmq	1.66	1.69	1.75	1.014	1.00

DESIGN OBSERVATIONS

- One of the key objectives of this series of articles on comparison of flight control techniques is to provide observations on the design process as well as the performance.
- The amount of time taken to design the root-locus constant gain controller and the PID controller was less (a couple of hours as opposed to a couple of days) than the fuzzy logic controller.
- In terms of implementation complexity, the constant gain controllers would be easier to implement.
- However, the PID control requires integration for the Integral part which is not needed for the fuzzy controller making it more computationally efficient.
- The results have shown that the fuzzy approach has provided rapid convergence of the steady-state error as opposed to the findings of Steinberg*.

*Steinberg, M. L., "A Comparison of Intelligent, Adaptive, and Nonlinear Flight Control Laws", Naval Air Warfare Center Aircraft Div., Patuxent River, MD, ADA368768, 4 June 1999, pp. 1-11.

FUZZY FLIGHT CONTROL - CONCLUSIONS

- Pitch attitude hold systems were designed using a constant gain approach (PID as well as Root Locus) as opposed to a variable gain approach based on fuzzy logic control.
- The controllers were tested for robustness for very different conditions i.e. Subsonic cruise and Supersonic cruise.
- The fuzzy logic controller provided better performance than the PID controller by having a lower settling time and a lower peak value. However, the PID controller offers quicker rise times. The Root Locus design was by far the more inferior.
- This effort shows that fuzzy logic controllers may be an attractive alternative for pitch attitude hold systems.