Fuzzy PID Controller for a Attitude Hold System

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Overview

- Fuzzy Logic Basics
- Problem Statement
- Fuzzy PID 1st Try
  - 3 Membership Functions
- Fuzzy PID 2nd Try
  - 7 Membership Functions
- Results

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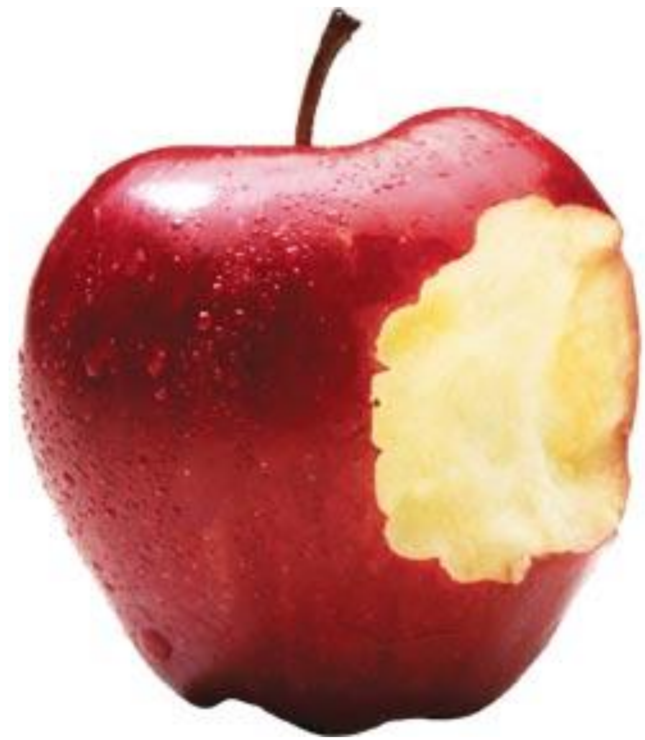
Shades of Gray

- Fuzziness is grayness
- Bivalent logic vs. Fuzzy logic
- At what point during eating an apple does the apple switch from being an apple to not being an apple?



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Fuzzy Logic Flow

Inputs

↓

Fuzzification

↓

Inference

↓

Defuzzification

↓

Outputs

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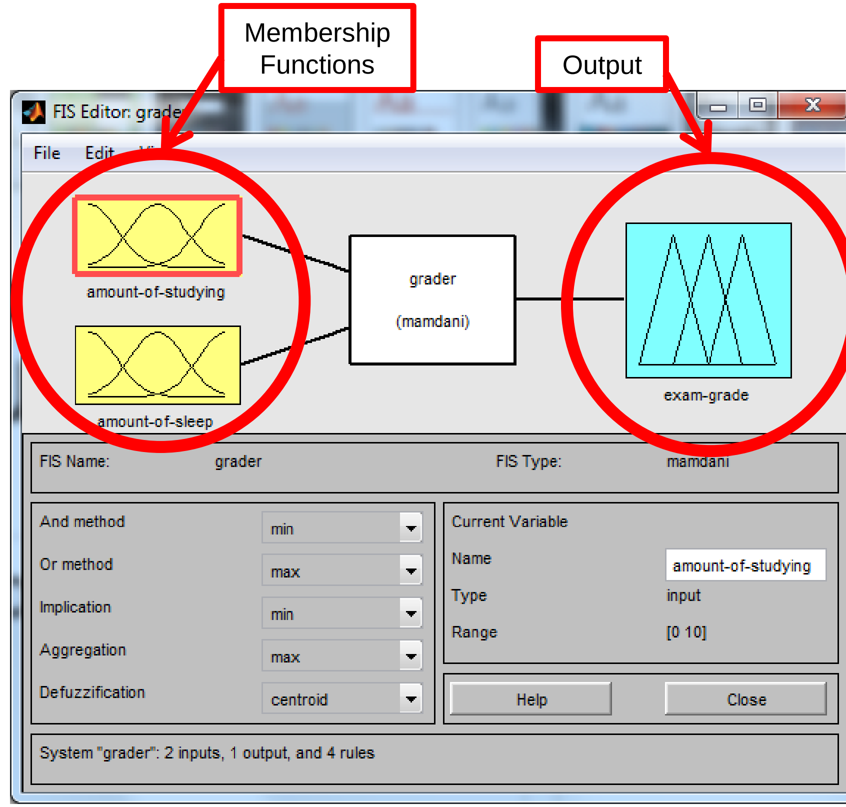
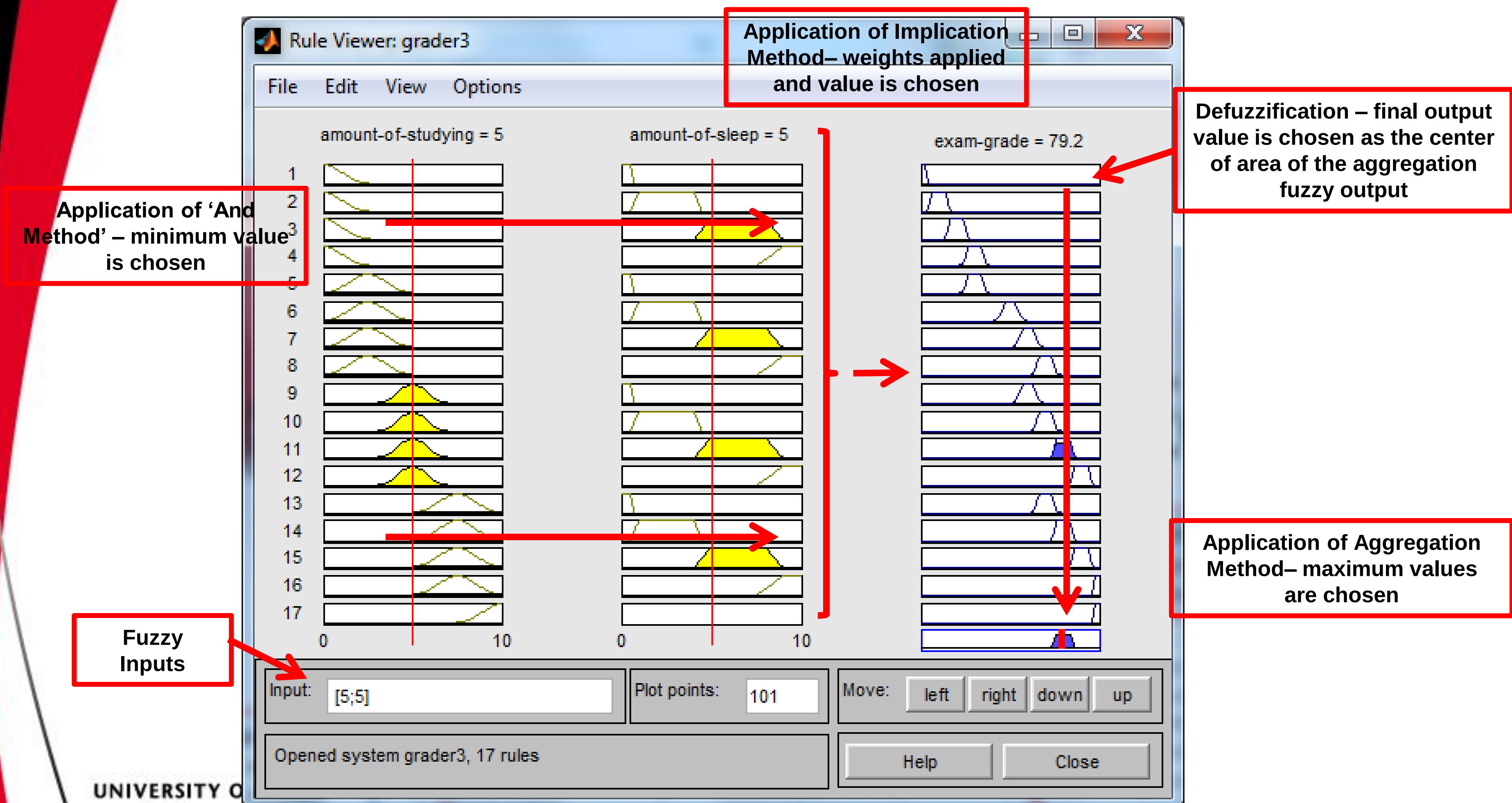
Fuzzy Grader (MATLAB)

- Fuzzy Grader calculates an exam grade as a function of the amount of studying done and the amount of sleep the night prior to the exam



Applications of FIS Editor Values



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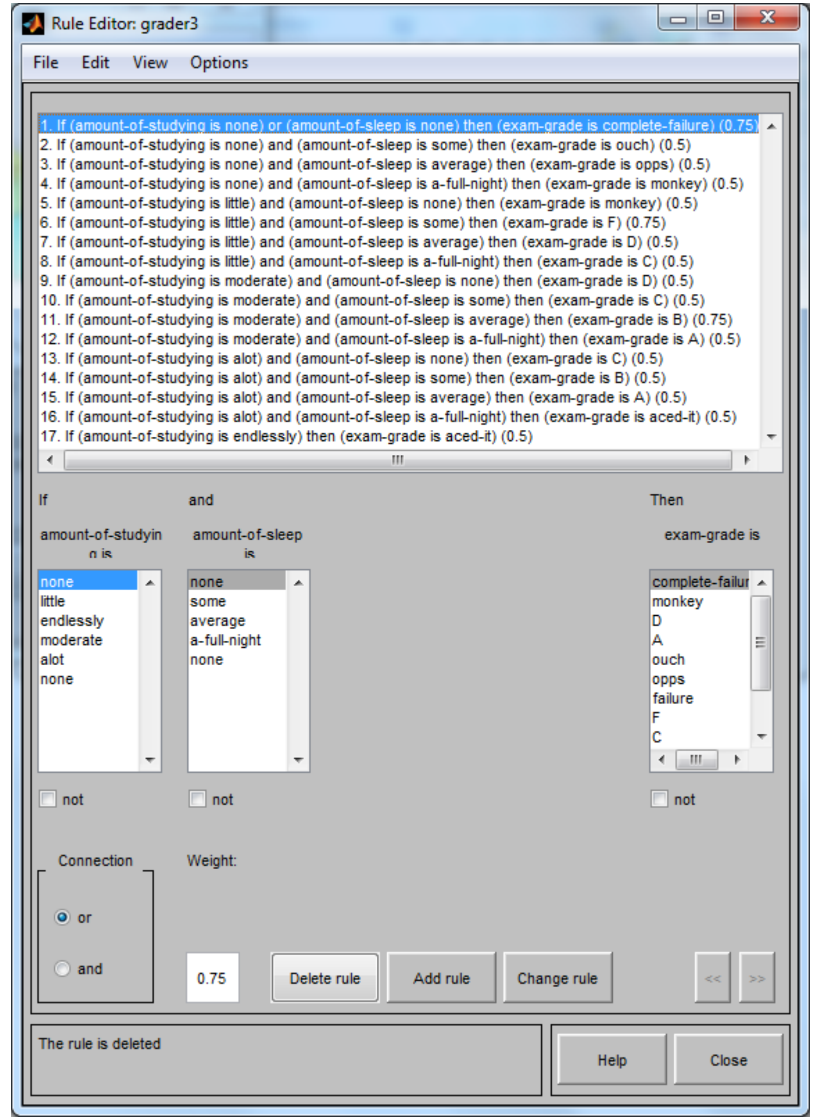
Fuzzy Grader (MATLAB) – Rule Editor

- Seventeen rules are defined in the rule editor, i.e.
  - If there is little studying and some sleep then the exam is failed
  - If there is no studying or no sleep then the exam is completely failed
  - If there is moderate studying and a full night's sleep then the exam grade is an A
  - If there is an endless amount of studying then the exam is aced
- Each rule has a weighted value which is a constant that is multiplied by the result of the fuzzy operator and is applied directly before implication



FUZZY FLIGHT CONTROL

Motivation

- A fly-by-wire flight control system for a modern fighter aircraft allows for implementation of stability augmentation for dynamic performance and also for autopilot modes.
- Robust control laws have the potential to be effective for multiple flight conditions, including degraded performance due to partial aircraft failure.

Research Objective

- The main aim is to examine the effectiveness of a fuzzy logic based PID pitch attitude hold system for a F-4 fighter jet.

Method

- MATLAB/SIMULINK models were used to compare the effectiveness of fuzzy PID controller to a more conventional PID controller

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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.
- Investigate several degraded variants of this basic flight condition.
- A 50% reduction in the static longitudinal stability derivative, $C_{m\alpha}$, and a 50% reduction in the pitch damping derivative, C_{mq}.

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Plant Cases

Flight Condition	Transfer Function
Approach	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	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	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	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

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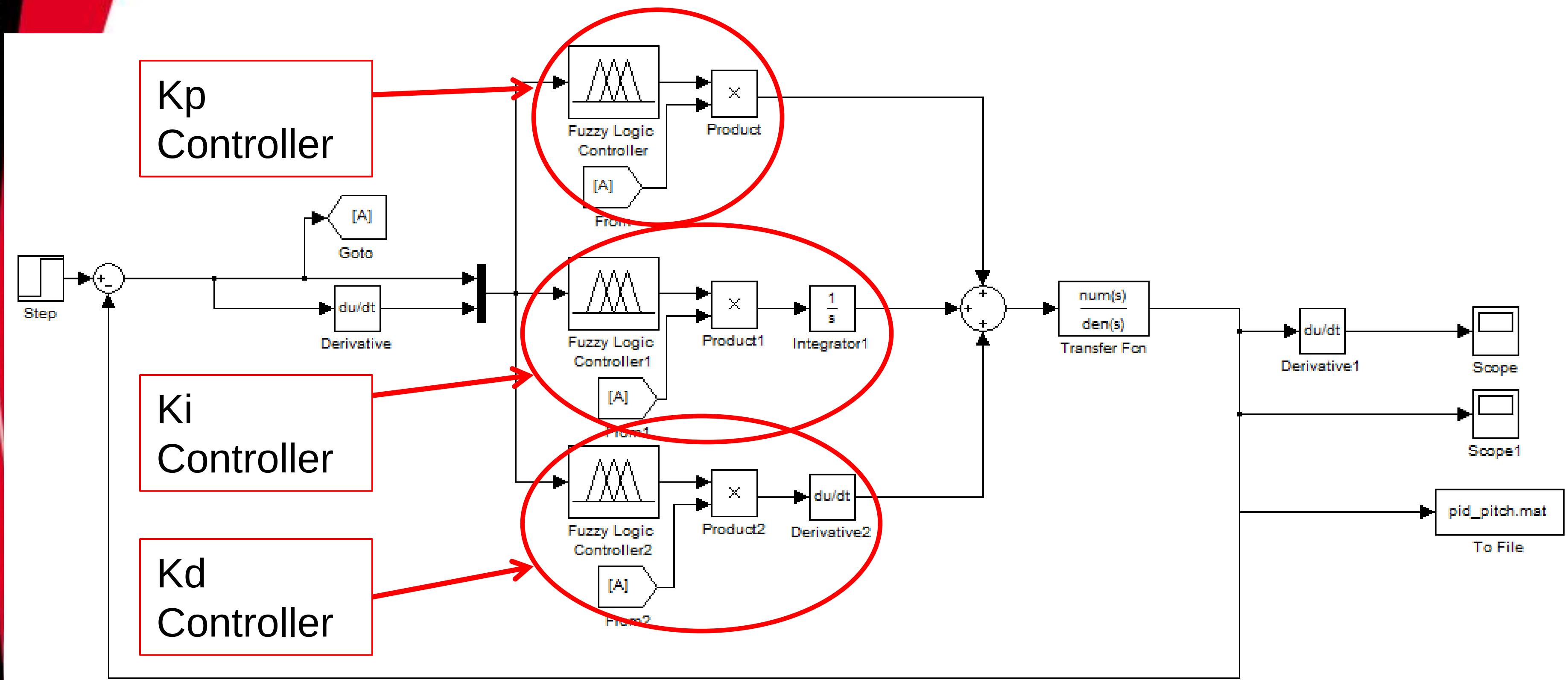
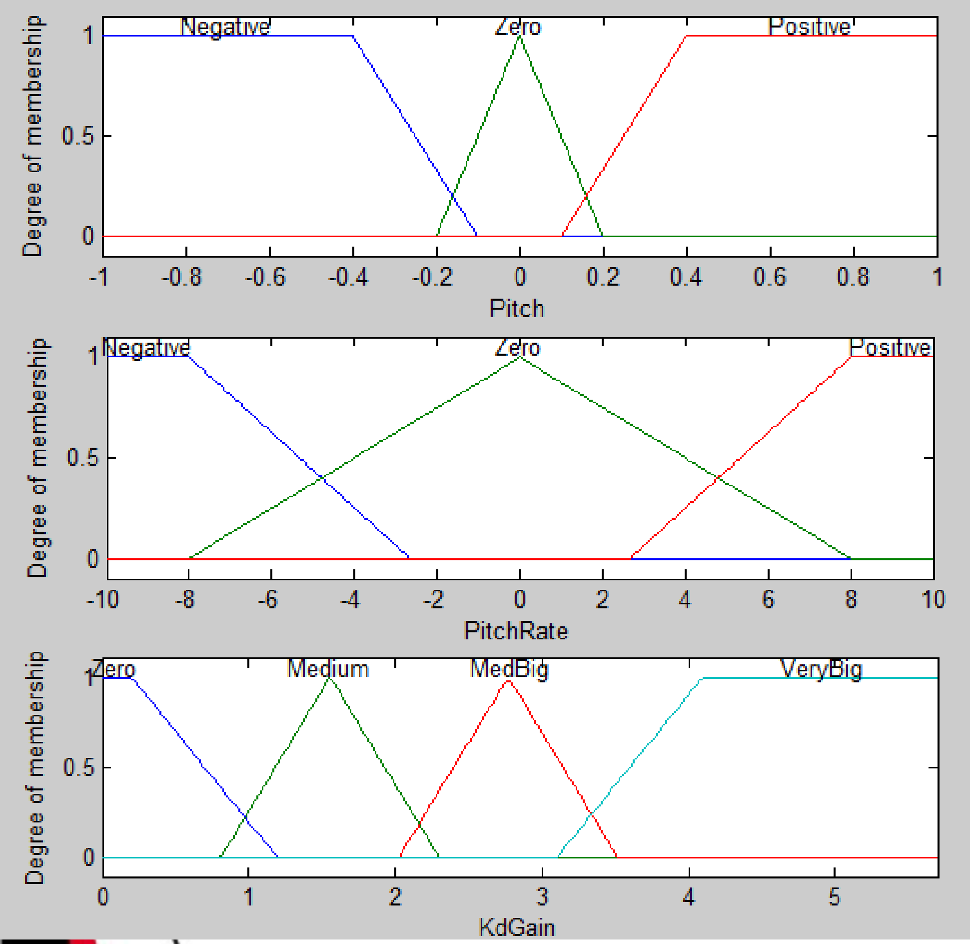
Simulink Model



Kd Membership Functions and Rules

Membership Functions



Rules

1st Try

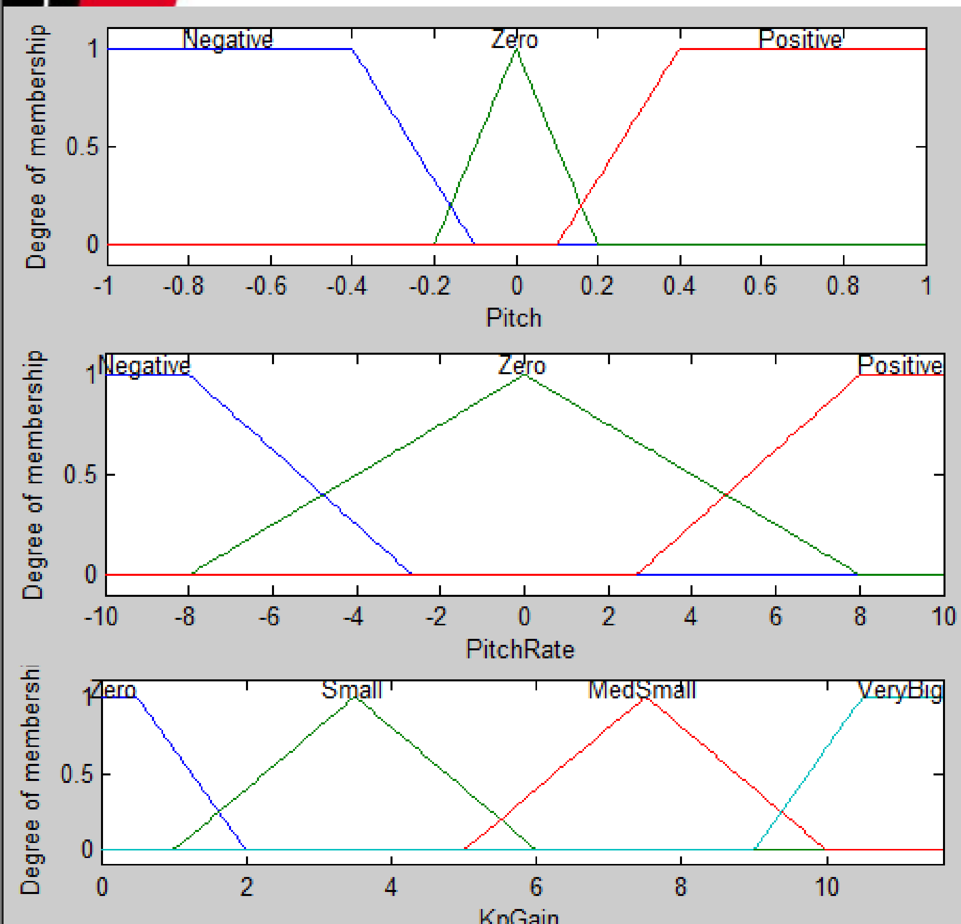
	Kd	Rate		
		Negative	Zero	Positive
Error	Negative	Negative Big	Zero	Negative Small
	Zero	Zero	Zero	Zero
	Positive	Positive Small	Zero	Positive Big

2nd Try

	Kd	Rate		
		Negative	Zero	Positive
Error	Negative	Zero	Medium	Very Big
	Zero	Medium	Medium Big	Very Big
	Positive	Very Big	Very Big	Very Big

Kp Membership Functions and Rules

Membership Functions



Rules

1st Try

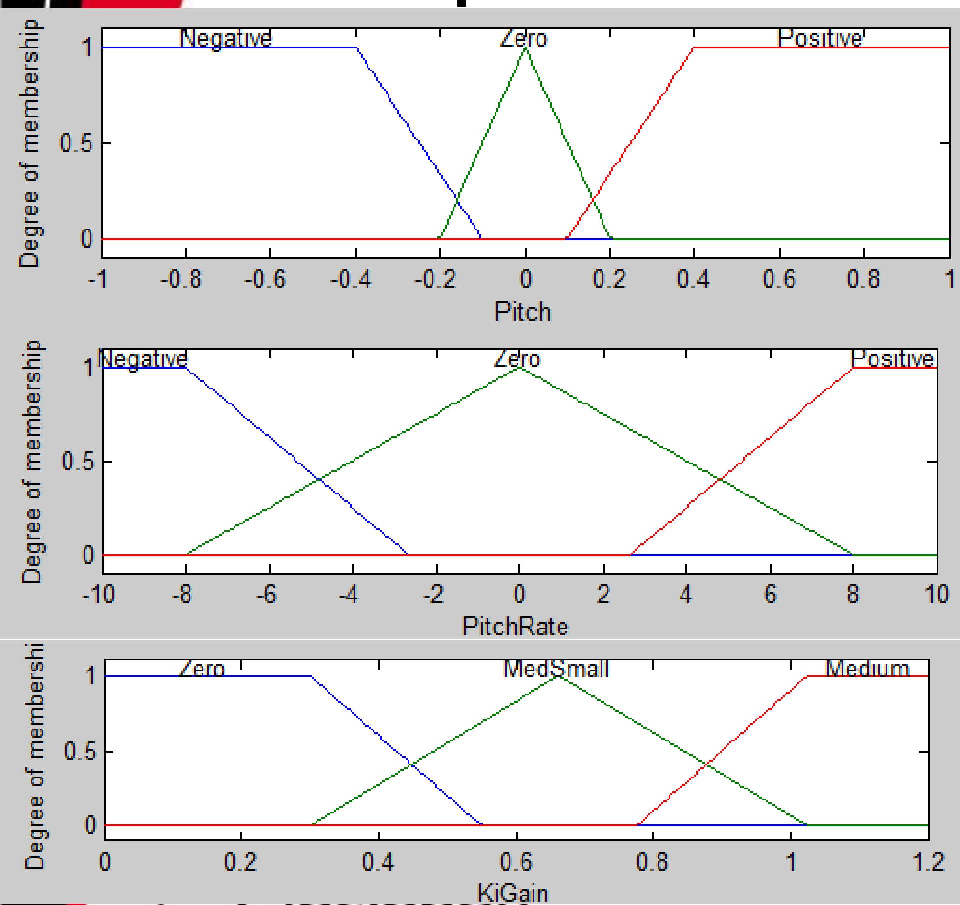
	Kp	Rate		
		Negative	Zero	Positive
Error	Negative	Negative Big	Zero	Negative Small
	Zero	Zero	Zero	Zero
	Positive	Positive Small	Zero	Positive Big

2nd Try

	Kp	Rate		
		Negative	Zero	Positive
Error	Negative	Very Big	Very Big	Very Big
	Zero	Zero	Medium Small	Small
	Positive	Very Big	Very Big	Very Big

Ki Membership Functions and Rules

Membership Functions



Rules

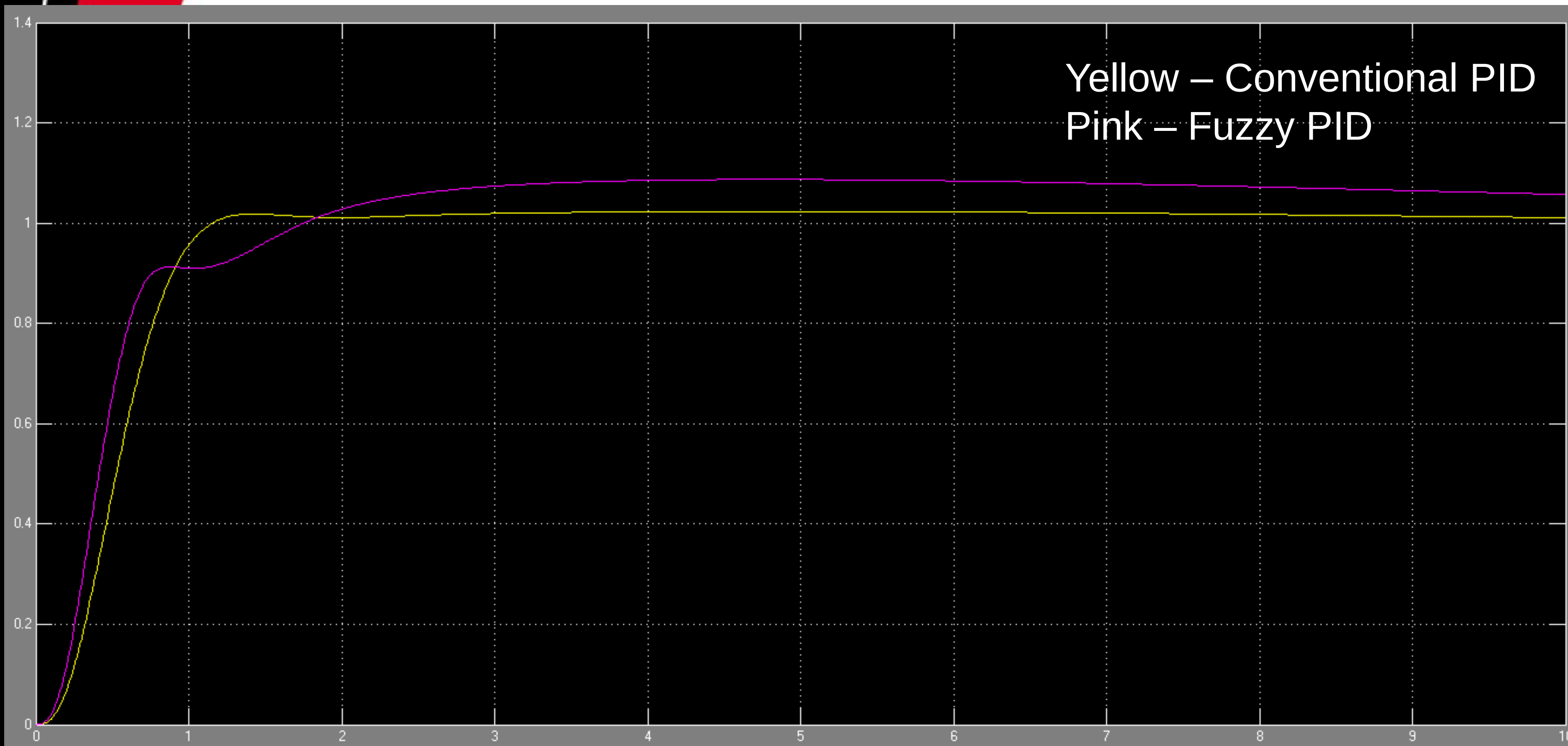
1st Try

	Ki	Rate		
		Negative	Zero	Positive
Error	Negative	Negative Big	Zero	Negative Small
	Zero	Zero	Zero	Zero
	Positive	Positive Small	Zero	Positive Big

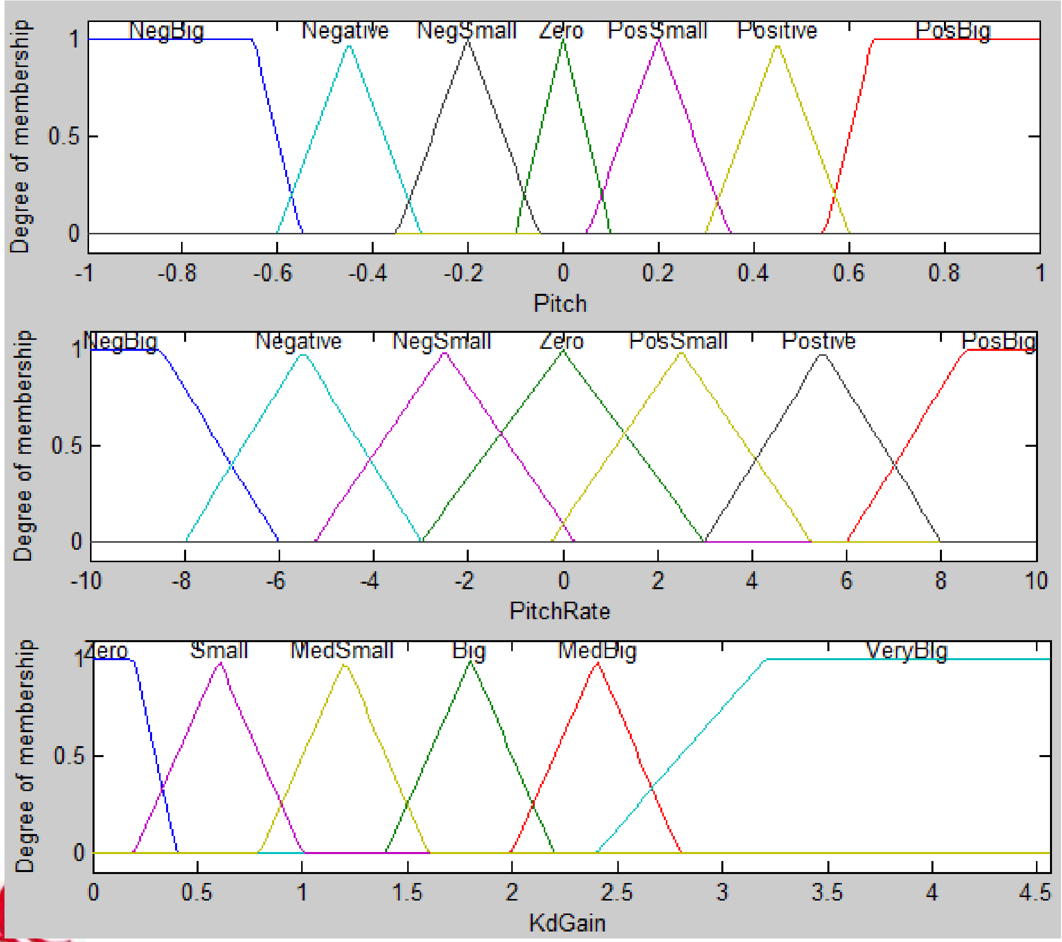
2nd Try

	Ki	Rate		
		Negative	Zero	Positive
Error	Negative	Medium	Medium	Medium
	Zero	Medium Small	Zero	Medium Small
	Positive	Medium	Medium	Medium

Results for Approach Condition



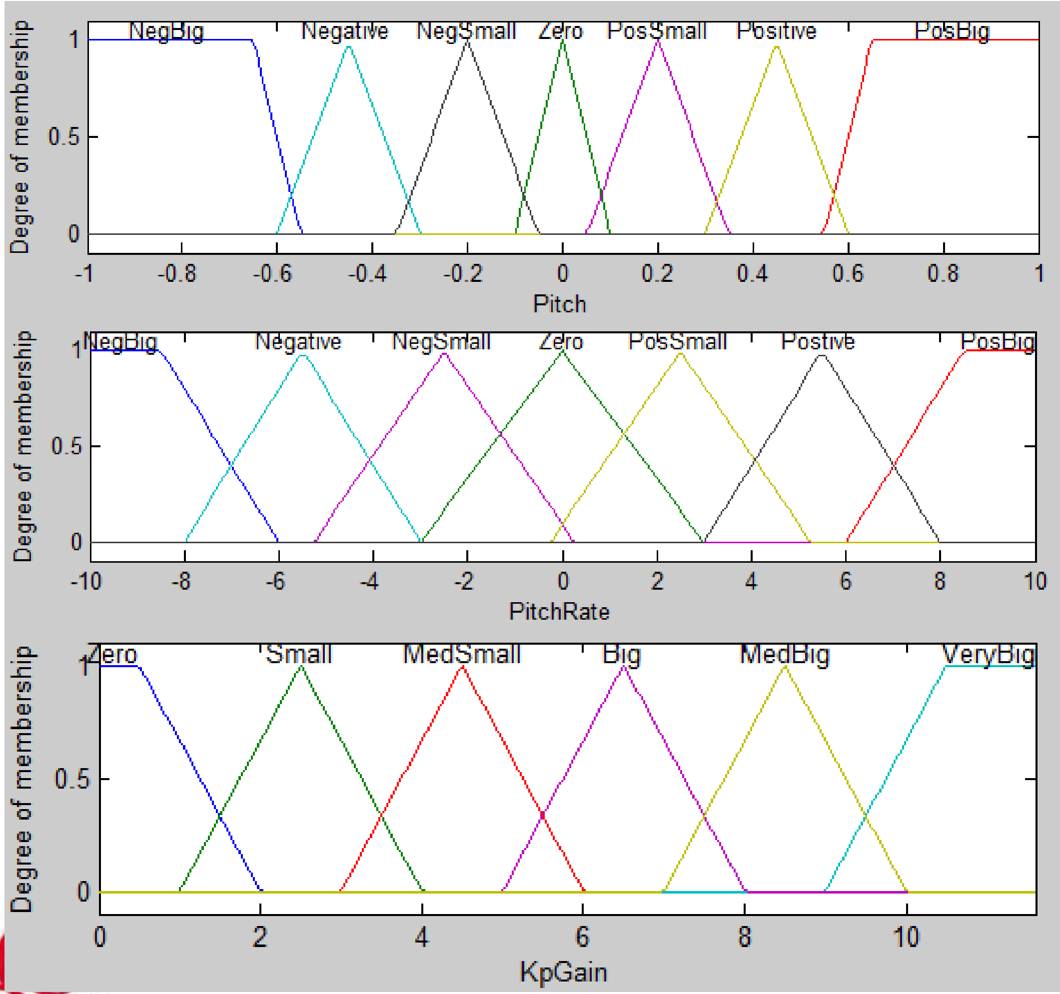
New Kd7 Membership Functions



New Kd7 Rules

	Kd	Rate: Negative Big	Negative	Negative Small	Zero	Positive Small	Positive	Positive Big
Error	Negative Big	Zero	Small	Small	Medium Small	Big	Big	Very Big
	Negative	Small	Small	Medium Small	Medium Small	Big	Medium Big	Very Big
	Negative Small	Small	Medium Small	Big	Big	Big	Very Big	Very Big
	Zero	Medium Small	Big	Big	Medium Big	Medium Big	Very Big	Very Big
	Positive Small	Big	Big	Big	Medium Big	Very Big	Very Big	Very Big
	Positive	Big	Medium Big	Very Big	Very Big	Very Big	Very Big	Very Big
	Positive Big	Very Big	Very Big	Very Big	Very Big	Very Big	Very Big	Very Big

New Kp7 Membership Functions



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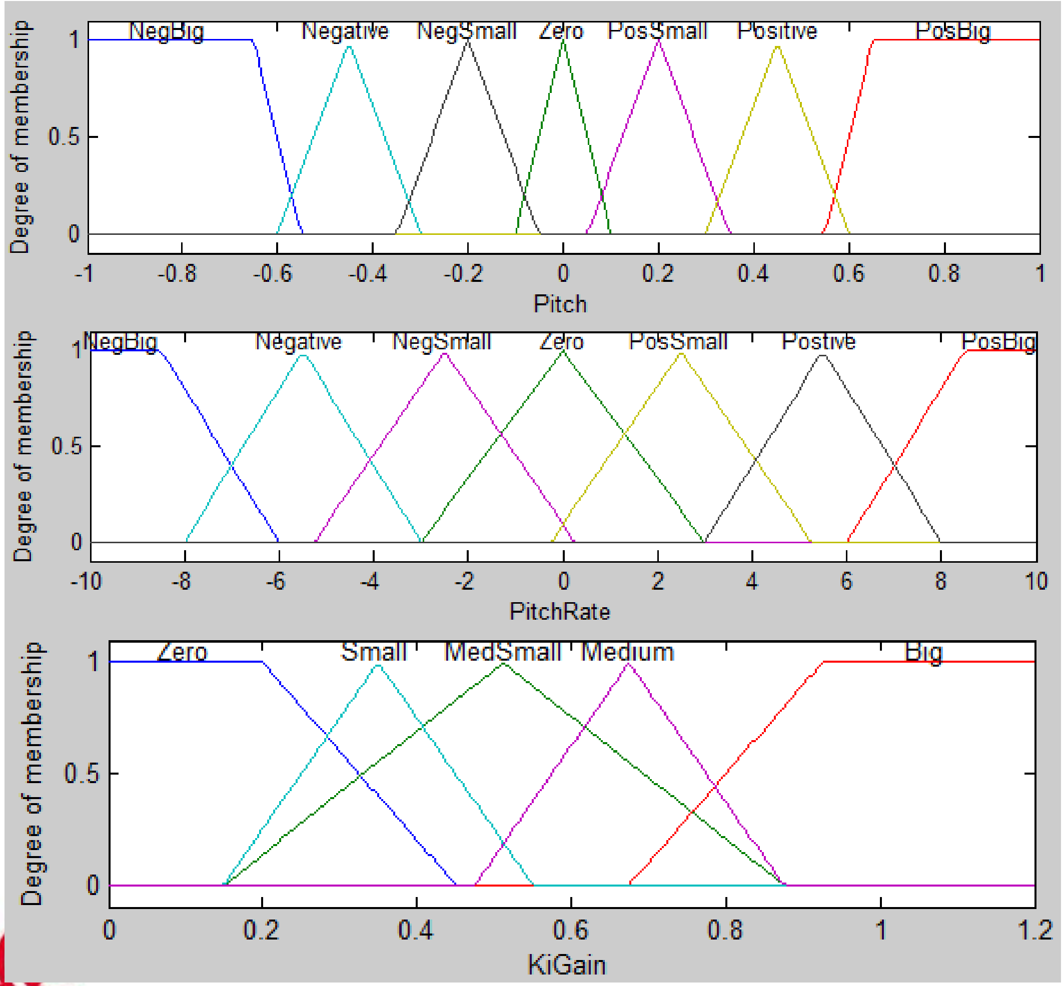
New Kp7 Rules

	Kp	Rate						
		Negative Big	Negative	Negative Small	Zero	Positive Small	Positive	Positive Big
Error	Negative Big	Very Big	Very Big	Very Big	Very Big	Very Big	Very Big	Very Big
	Negative	Medium Big	Medium Big	Medium Big	Very Big	Very Big	Very Big	Very Big
	Negative Small	Big	Big	Big	Big	Medium Big	Medium Big	Very Big
	Zero	Zero	Small	Medium Small	Big	Big	Big	B
	Positive Small	Big	Big	Big	Big	Medium Big	Medium Big	Very Big
	Positive	Medium Big	Medium Big	Medium Big	Very Big	Very Big	Very Big	Very Big
	Positive Big	Very Big	Very Big	Very Big	Very Big	Very Big	Very Big	Very Big

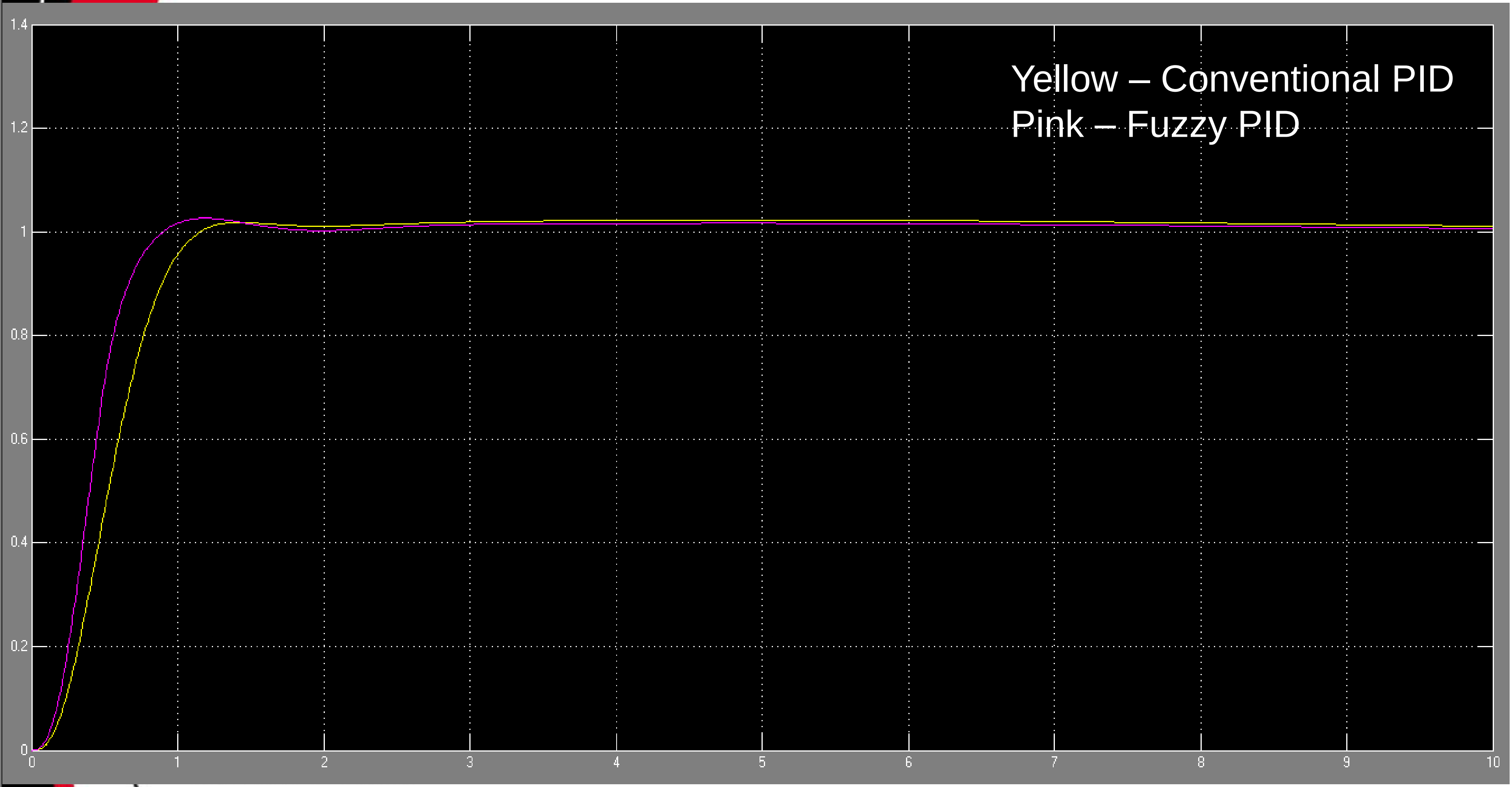
New Ki7 Membership Functions



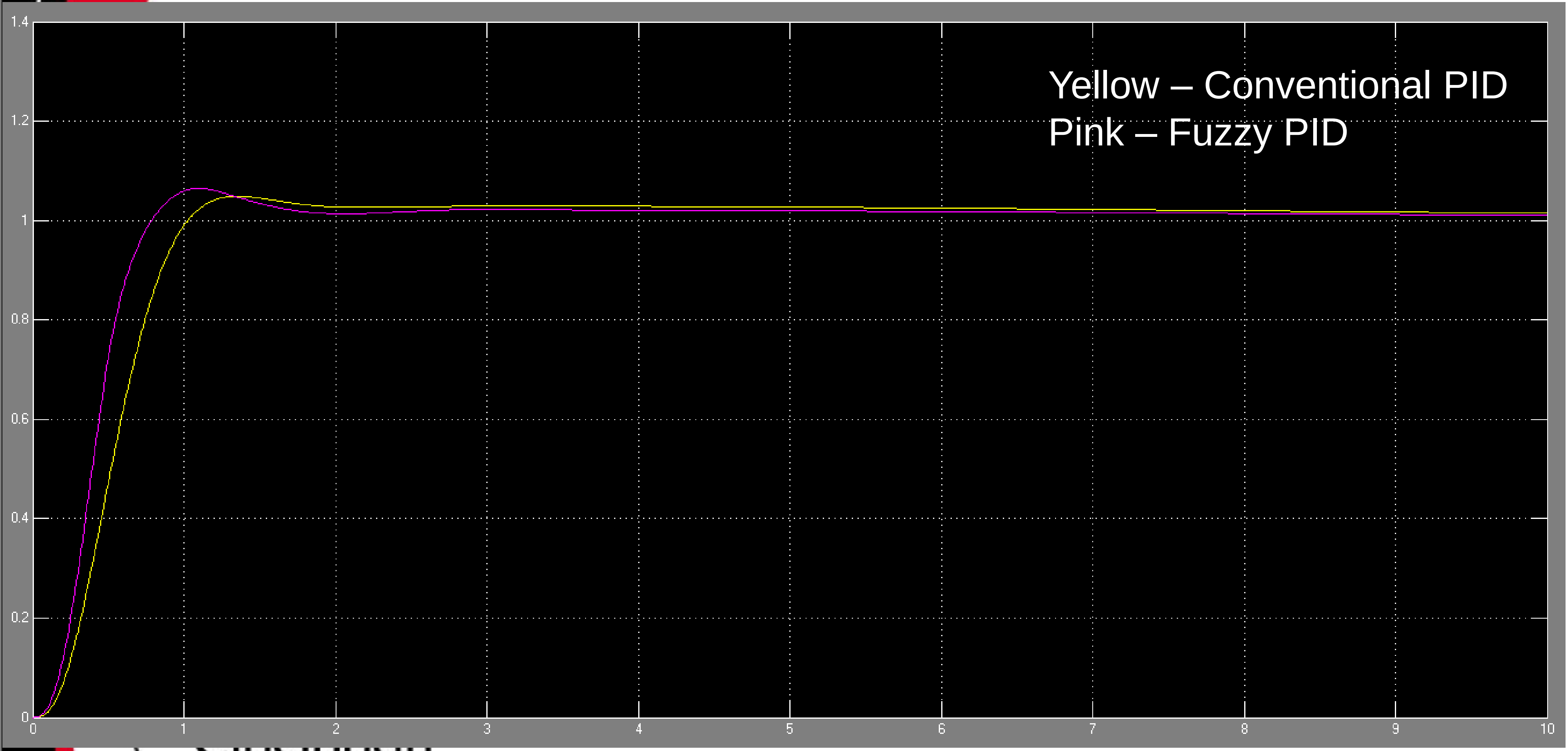
New Ki7 Rules

	Ki	Rate						
		Negative Big	Negative	Negative Small	Zero	Positive Small	Positive	Positive Big
Error	Negative Big	Medium Small	Medium Small	Medium Small	Medium Small	Medium Small	Medium Small	Medium Small
	Negative	Medium	Medium	Medium	Medium	Medium	Medium	Medium
	Negative Small	Medium	Medium	Medium Small	Medium Small	Medium Small	Medium	Medium
	Zero	Big	Big	Zero	Medium Small	Zero	Big	Big
	Positive Small	Medium	Medium	Medium Small	Medium Small	Medium Small	Medium	Medium
	Positive	Medium	Medium	Medium	Medium	Medium	Medium	Medium
	Positive Big	Medium Small	Medium Small	Medium Small	Medium Small	Medium Small	Medium Small	Medium Small

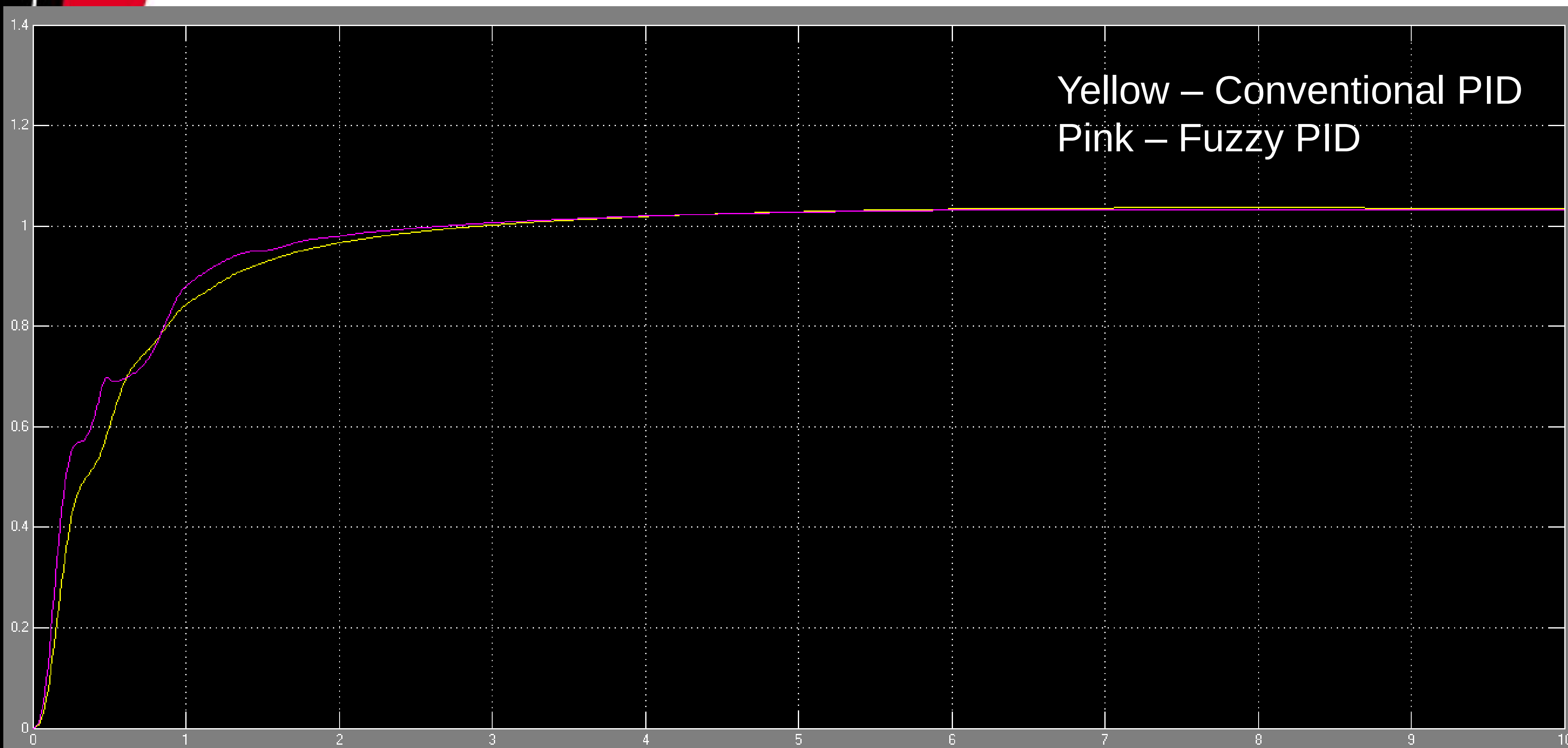
Results for 7 Membership Functions – Approach Condition



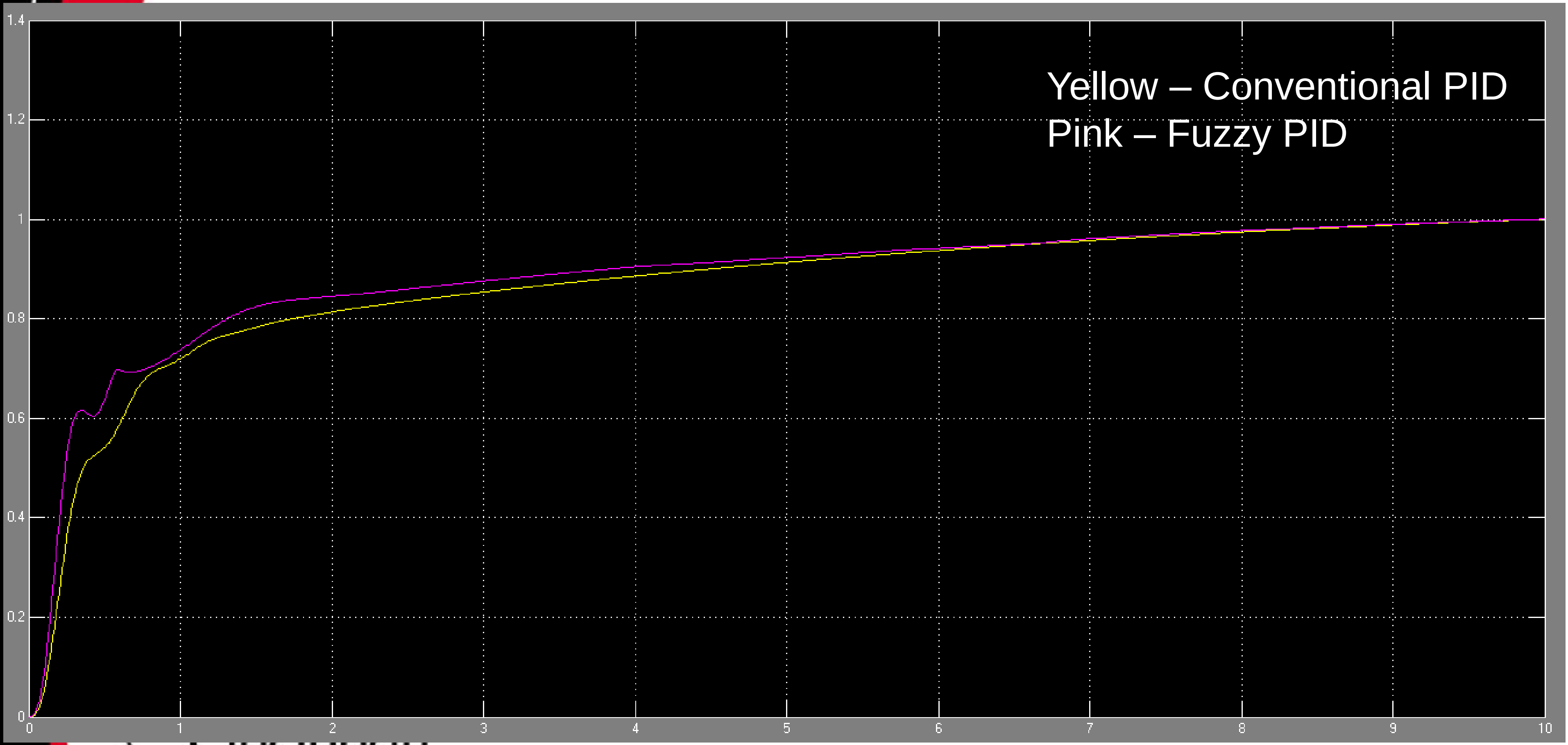
Results for 7 Membership Functions – Degraded Approach Condition



Results for 7 Membership Functions – Subsonic Cruise Condition



Results for 7 Membership Functions – Supersonic Cruise Condition



Conclusions

- For both approach cases examined the fuzzy PID controller had a faster rise time and a faster settling time than the conventional controller
- Fuzzy PID also has a larger overshoot than the conventional PID controller
- For both the subsonic and supersonic cases the fuzzy PID controller has a greater overshoot than the conventional PID controller, but both controllers settle to about the same value in the same amount of time

Lessons Learned

- Order of inputs into the fuzzy controller matter
- The complexity of the controller increases proportionally to the number of membership functions
- Tuning the membership functions and rules becomes easier with a greater number of membership functions (more controllable)
- Next Steps:
  - Improve controller for subsonic and supersonic cruise conditions
  - Investigate stability of results

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References

- Bossert D. E., and Cohen K., 2001, “Design of Fuzzy Pitch Attitude Hold Systems for a Fighter Jet”, AIAA - 2001 – 4084, AIAA Guidance, Navigation, and Control Conference, The Queen Elizabeth Hotel, Montreal, Quebec, Canada, 6 - 9 August 2001
- Bossert D. E., and Cohen K., 2002, “PID and Fuzzy Logic Pitch Attitude Hold Systems for a Fighter Jet”, AIAA-2002-4646, AIAA Guidance, Navigation, and Control Conference, Monterey, California, 5-8 August 2002
- Cohen K., Vick A., “Longitudinal Stability Augmentation using a Fuzzy Logic based PID Controller”

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Questions?

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