Cairo University

Adaptive Fuzzy Controller for A Micro-Jet Engine

By

Yasmin Mohamed Hosny Ibrahim Selim

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE
In
Aerospace Engineering

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Title of Thesis: Adaptive Fuzzy Controller for A Micro-Jet Engine

Key Words: Engine off-design, engine simulation, adaptive fuzzy logic controller.

Summary:
The educational jet engine "AMT Olympus HP" is employed as a case study to investigate different control algorithms. Different fuel controllers are investigated with the objective of minimizing the acceleration and deceleration times while maintaining safe operation limits. The controllers design parameters are selected to cope with varying inputs along the operating line throughout the wide envelop of engine operating conditions. Three types of controller are compared. The classical PID with constant gains, fuzzy logic classical PD controller and an adaptive fuzzy logic PD controller with novel tuning of scaling factor according to selected fuzzy rules. Results show that, generally, the new developed adaptive fuzzy controller has superior time response characteristics among other controllers during both acceleration and deceleration.

Acknowledgment

I would to like to acknowledge the endless support and guidance of Prof. Ali A. Hashem, Prof. Mohamed S. Bayoumi and Dr. Tarek R. Nada in their efforts to make the body of this work possible. I am grateful for Prof. Gamal M. Bayoumi for his valuable guidance and assistance.

I would also like to give a special thanks to my colleagues at the Department of Aerospace Engineering for their valuable assistance for their suggestions, comments and help.

Finally, I am grateful for my family and friends for their support, love and encouragement.

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Nomenclature

A: Area

AFL: Adaptive Fuzzy Logic

BFLC: Basic Fuzzy Logic Controller

C_D: nozzle discharge coefficient

C_P: Specific heat at constant pressure

DHTCC: Compressor Work function

DHTCT: Turbine Work Function

E: Differential Error

EGT: Exhaust gas Temperature

FLC: Fuzzy Logic Controller

f: fuel to air ratio

F: Thrust

g_0: gravitational acceleration =9.81 m/s^2

h: Enthalpy

H: Altitude

h_{PR}: Fuel heating value

I_r: Rotor inertia

L: Volume length

m: Mass

MFP: Mass Flow Parameter

$\dot{m}$: Mass flow rate

N: engine rotational speed

N_{Q_T}: Turbine work

N_{Q_c}: Compressor work

N_Q: Engine excess torque

NPR: Nozzle Pressure ratio

NGVs: Nozzle Guide Vanes

P: Pressure

POS: Percentage overshoot

R: air constant

SLS: Sea Level Static

t: time

t_s: settling time

T: Temperature

TFF: turbine flow function

TIT: Turbine Inlet Temperature

V: volume

Z: the ratio of pressure ratio along speed line

π: Pressure Ratio Or Pressure Losses

η: Component Efficiency

γ: Specific heats ratio

τ: Temperature ratio

Subscripts:

b: Combustion Chamber (burner)

B: Base value

c: compressor

cor: Corrected

f: fuel

GG: Gas Generator

i: Station number

in: inlet condition

i: initial

isen: Isentropic

m: Mechanical

n: Nozzle

out: outlet condition

rel: relative

ref: reference

s: Static

t: Total

T: turbine

Abstract

Aircraft engines performance is ever continuously more demanding. Preserving jet engine operating limits; during dynamic operation, is a main objective of engine controller. This task has become more challenging and requires innovative control methods. This thesis focuses on the development of adaptive fuzzy controller for a micro-turbojet engine. The educational jet engine "AMT Olympus HP" is employed as a case study to investigate different control algorithms, such that they can be subsequently experimentally verified.

Nonlinear computer simulation of engine steady state and dynamic performance facilitates the design and development of new control systems. Performance maps of the engine components are employed to generate the off design operating lines, representing the steady state operation at different flight conditions. In this study the operating line is generated using a balance technique. It assumes a set of engine state variables and obtains corresponding imbalance errors. Subsequently, errors-variables sensitivity matrix is established, and used to modify the state variables to eliminate the balance errors iteratively.

A digital dynamic simulation is constructed to investigate engine variables response to time variations of fuel inputs. The model assumes each engine component to adhere to its steady state characteristics followed by a lumped volume. Through the volume the transient continuity, energy and momentum equations are solved to provide the dynamic part of the response.

Different fuel controllers are investigated with the objective of minimizing the acceleration and deceleration times while maintaining safe operation limits. The controllers design parameters are selected to cope with varying inputs along the operating line throughout the wide envelop of engine operating conditions. Three types of controller are compared. The classical PID with constant gains, fuzzy logic classical PD controller and an adaptive fuzzy logic PD controller with novel tuning of scaling factor according to selected fuzzy rules.

A comparison is held between the three controllers. The rise time, settling time and percentage overshoot are evaluated for speed response during acceleration from minimum speed to various operating points along the operating line, and during deceleration from maximum speed to various operating points along the operating line. These calculations are made for each controller at different flight operating conditions.

Results show that, the new developed adaptive fuzzy controller has superior time response characteristics over other controllers during both acceleration and deceleration. The classical fuzzy logic PD controller comes next with moderate differences. The PID controller has long settling time and long rise time that is not experienced by the fuzzy controllers.