AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
MECHANICAL POWER DEPARTMENT

Numerical Investigation of Design Parameters for Dual Throat Fluidic Thrust Vectoring Nozzle Using Secondary Injection System

A thesis submitted in partial fulfillment of the requirement of the
M. Sc. in Mechanical Engineering

By

Rafik Tharwat Labib
B Sc. in mechanical power engineering, July 2009.

Supervised by

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STATEMENT

This thesis is submitted as partial fulfillment of M. Sc. degree in mechanical engineering, Faculty of Engineering, Ain Shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or qualification at any other scientific entity.

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Thesis Summary

Fluidic thrust vectoring (FTV) technique is an innovative method to perform thrust vectoring concept using secondary injection system, to introduce a higher level of maneuverability capabilities for high-performance supersonic aircraft and provides controlling abilities in flight regimes where the conventional aerodynamic flight control technologies lose their effectiveness. FTV is developed to substitute the currently applied mechanical thrust vectoring (MTV) method which depends on complex heavy mechanical actuators to deflect the nozzle exit jet from the centerline to the aimed axis. Dual throat nozzle (DTN) concept is introduced as a technique to enhance the FTV capability, by performing additional flow separation control to maximize the differences in pressure inside the nozzle cavity, which is controlled by injecting secondary flow from injection slot. This technique achieves large thrust vectoring efficiencies without negative effect on the system thrust ratio.

This study numerically investigates the effected parameters on the DTN concept, to reach the optimum value for each investigated parameter. The thesis presents the procedures of geometrical modeling, grid optimization and numerical solution used. Also the performance of different turbulence models for DTN were investigated and adjustments were implemented to improve the results of separation inside DTN. The results were validated with experimental measurements conducted at NASA Langley center. Results of injection system parameters investigation show improvement in the thrust vectoring capabilities of DTN to thrust vectoring the exit jet by angle of 12.8° at optimum nozzle operation conditions of Nozzle pressure ratio of NPR=4 and injection rate 3%.

Key Words:

Computational fluid dynamics CFD, Thrust vectoring, Fluidic Thrust Vectoring FTV, Dual Throat Nozzle DTN, Aeronautics, Turbulence model, shear stress limiter.

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Nomenclature and Abbreviations

Nomenclature

A_e	Downstream Nozzle exit area	[m^2]
A_t	Upstream nozzle throat area	[m^2]
C_d	Discharge coefficient	
$C_{fg,sys}$	System thrust ratio	
C_{lim}	Shear stress limiter	
D_{inj}	Injector slot width	[mm]
F_{ip}	Ideal isentropic primary nozzle thrust	[N]
F_{is}	Ideal isentropic secondary injector thrust	[N]
F_R	Resultant force	[N]
h_e	Downstream Nozzle exit throat height	[mm]
h_n	Nozzle inlet height	[mm]
h_t	Upstream nozzle throat height	[mm]
I_R	Injection Rate = $(w_s/(w_p+w_s))$ %	[%]
k	Turbulent kinetic energy	[m^2/s^2]
l	Cavity length	[mm]
l_d	Diverging section length	[mm]
L_S	Injector slot position (Distance between upstream nozzle throat and injector slot centerline)	[mm]
L_g	Injector Gap Distance (between upstream nozzle throat and the near edge of injector slot)	[mm]
L_{F1}	Exterior region : Normal to axis Far Filled	[mm]
L_{F1}	Exterior region : Normal to axis Far Filled	[mm]
p	Static pressure	[N/m^2]
P	Total pressure	[N/m^2]
P_{tj}	Primary flow total pressure	[N/m^2]
P_∞	Freestream static pressure	[N/m^2]
S_{ij}	Mean rate of strain tensor	[s^{-1}]
R_1	Nozzle throat edge curvature radius	[mm]
w_{ip}	Ideal primary weight flow	[kg]
w_{is}	Ideal secondary injection weight flow	[kg]
w_p	Actual primary weight flow	[kg]

w_S	Actual secondary injection weight flow	[kg]
X	Axial distance	[mm]
θ_1	Cavity Divergent angle	[°]
θ_2	Cavity Convergent angle	[°]
θ_P	Upstream converging angle	[°]
ϕ	Secondary flow injection Angle	[°]
ε	Turbulent dissipation rate	[m^2/s^3]
Ω	Vorticity	[s^{-1}]
ρ	Viscosity	[kg/m^3]
η	Thrust vectoring efficiency	
δp	Thrust vector angle	[°]
μ	Dynamic viscosity	[$N.s/m^2$]
μ_t	Dynamic eddy viscosity	[N.s/m2]
ν	Kinematic viscosity	[m^2/s]
ν_t	Kinematic eddy viscosity	[m^2/s]
ω	Specific turbulent dissipation rate = ε/k	[s^{-1}]

Abbreviations

BSL	Baseline model
DTN	Dual Throat nozzle
FTV	Fluidic thrust vectoring
JETF	Jet exit Test Facility
LaRC	NASA Langley Research Center
MTV	Mechanical Throat vectoring
NASA	American National Aeronautics and Space Administration
NPR	Nozzle pressure ratio
NPR_D	Design Nozzle pressure ratio
RNG	Renormalization group
SST	Shear Stress Transport
STD	Standard
SVC	Shock vector control
SWTBLI	Shock wave turbulent boundary layer interaction
TS	Throat Shifting

List of figures