

THRUST CONTROL USING COMBINED VANES AND PLUG ARRANGEMENTS

by

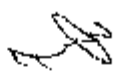
Walid Aniss Mahmoud Aissa

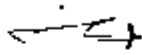
A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY

in

AEROSPACE ENGINEERING

Under the Supervision of

Prof. Dr. Ibrahim Mohamed Aly Shabaka 
Professor, Department of Aerospace Engineering

Dr. Aly Abdel-Fatah Hashem 
Associate Professor, Department of Aerospace Engineering



Faculty of Engineering , Cairo University
GIZA , EGYPT
1999

THRUST CONTROL USING COMBINED VANES AND PLUG ARRANGEMENTS

by

Walid Aniss Mahmoud Aissa

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY

in

AEROSPACE ENGINEERING

Approved by the
Examining Committee

Prof. Dr. Ibrahim Mohamed Aly Shabaka, Thesis Main Advisor



Prof. Dr. Mohamed Kadry Saad, Member, Military Technical College



Prof. Dr. Mohamed Madbouly Abdel-Rahman, Member



Faculty of Engineering , Cairo University
GIZA , EGYPT
1999

ABSTRACT

Thrust vector control can be used to augment or replace aerodynamic control forces and moments generated by airframe control surfaces. Moreover, it is the only key to post-stall maneuverability. A static test is made to investigate the internal performance of axisymmetric convergent sonic nozzles under the effect of vectoring two externally mounted vanes. The internal performance is also investigated when a central plug; fixed or floating of conical or contoured profile is moved along the nozzle axis relative to the nozzle exit for a range of nozzle pressure ratios and vane deflection angles. It is found that configurations of larger nozzle throat area have higher vane pressure distribution, greater vane hinge moment than those of smaller nozzle throat area. They also have upstream center of pressure location and greatest aerodynamically heated region toward the vane leading edge than those of smaller nozzle throat area. Plug nozzles have relatively higher pressure distribution, more forward vane center of pressure location compared to plugless nozzle of the same throat area. In addition, they have larger nozzle discharge coefficient, axial force, side force and hinge moment compared to plugless nozzle of the same throat area. Moreover, plug nozzles have closer effective vane angle to geometric vane angle and side force effectiveness to the ideal value. Contouring the plug further enhances the nozzle performance. Full model side force and hinge moment can be estimated from the corresponding scale model values. Empirical formulas are estimated for nozzle discharge coefficient, side force generation effectiveness, and hinge moment coefficient for the tested configurations. Flow visualization studies indicate reversed flow for the lower vane of plugless nozzle which is not observed for configurations having the same throat area but utilizing plug arrangement.

ACKNOWLEDGMENT

The author is greatly indebted to Prof. Dr. I. M. Shabaka for his continuous encouragement and his valuable guidance throughout the work. Particular thanks for Assoc. Prof. Dr. A. A. Hashem for his assistance, and guidance which helped to overcome all problems encountered during this research. The author is very thankful for the time he devoted for the completion of this work.

Special thanks for Prof. Dr. M. Z. Elsadek and Prof. Dr. Salama. Abd Elhady (Aswan higher institute of energy, for their encouragement and understanding. A lot of thanks to all friends in department of validation, ABD company for their great help in authorizing the use of their facilities to construct the test rig and provide the necessary instrumentation. A final tribute must go to my family for their cooperation and understanding throughout all steps of this work.

TABLE OF CONTENTS

	Page
ABSTRACT	ii
ACKNOWLEDGMENT	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	viii
LIST OF FIGURES	ix
NOMENCLATURE	xix
1. INTRODUCTION	1
2. LITERATURE SURVEY	4
2.1. Methods of Thrust Vector Control for Missiles	4
2.1.1. Mechanical TVC Methods	5
2.1.1.1. TVC by Moving of The Whole Thrust Producing Device	5
a) Gimballed Motor	6
b) Moving Nozzle	6
1- Flexible Nozzle	6
2- Ball and Socket Swivel Nozzle	7
3- Rotating Nozzle	7
2.1.1.2. TVC by Direct Mechanical Interference with the Exhaust Gases	9
a) Jetavator	9
b) Axial Jet Deflector	9
c) Spoiler	10
d) Domed Deflector	11
e) Jet Vane	11
f) Paddle Vane	12
g) Tubular Extension	12

	Page
h) Oblique Exit Plane Nozzle	13
2.1.2. Non-mechanical TVC Methods	14
a) Gas Bleeding	14
b) Fluid Injection	15
c) Magnethormodynamic Effect	16
2.2. Comparison Between Various TVC Methods	17
2.3. Survey of Missiles TVC Research Activity	17
2.4. Thrust Vector Control for Aircrafts	28
 3. TEST RIG	 32
3.1. Test Rig Layout	32
3.1.1. Air Supply Unit	32
3.1.2. Venturi Meter	35
3.1.2.1. Calculation of Mass Flow Rate	39
3.1.3. Plenum Chamber	41
3.1.4. Nozzle	41
3.1.5. Vanes	46
3.2. Sensors	52
3.2.1. Pressure transducers	52
3.2.2. Load cells	59
3.2.2.1. Spring-Potentiometer Type Load Cells	59
3.2.2.2. Strain Gage Type Load Cell	64
3.2.3. Thermocouple	73
3.3. Data Acquisition System	77
3.4. Test Matrix	80
 4. APPROXIMATE ANALYSIS OF THE FLOW PAST THE VANES	 81
4.1. Modeling of the Flow Field for Convergent Nozzles	81
4.1.1. For Zero Vane Deflection Angle	81
4.1.2. Case of Vane Deflection	82
4.2. Simplified Modeling of the Flow Past the Vanes	84
4.2.1. For Zero Vane Deflection Angle	84
4.2.2. Case of Vane Deflection	87

	Page
5. EXPERIMENTAL WORK	89
5.1. Testing Sequence	89
5.2. Experimental Data Processing	89
5.2.1. Pressure Integration	90
5.3. Results and Discussion	95
5.3.1. Thrust Control Nozzles at Military Condition	101
5.3.1.1. Convergent nozzle	101
a) Performance parameters	110
b) Empirical formulas	116
5.3.1.2. Convergent nozzle with floating conical plug	117
a) Introduction	118
b) Vane pressure distribution	119
c) Performance parameters	120
d) Empirical formulas	135
5.3.1.3. Convergent nozzle with floating contoured plug	136
a) Empirical formulas	149
5.3.2. Thrust Control Nozzles at Cruise Condition	150
5.3.2.1. Convergent nozzle with floating conical plug	150
a) Empirical formulas	162
5.3.2.2. Convergent nozzle with floating contoured plug	163
a) Empirical formulas	176
5.3.3. Thrust Control Nozzles at Afterburner Condition	177
5.3.3.1. Convergent nozzle	177
a) Empirical formulas	189
5.3.3.2. Convergent nozzle with fixed conical plug	190
a) Empirical formulas	202
5.3.3.3. Convergent nozzle with floating conical plug	203
a) Empirical formulas	215
5.3.3.4. Convergent nozzle with floating contoured plug	216
a) Empirical formulas	229
5.4. Flow Visualization	230
6. CONCLUSIONS	232

REFERENCES	Page 235
APPENDIX A	238
APPENDIX B	244
APPENDIX C	245

LIST OF TABLES

	page
Table (2-1) Comparison of the Performance of Practical TVC Systems for Missiles	18
Table (3-1) Values of the Discharge Coefficient and the Uncertainty as a Function of Re_D	40
Table (3-2) Some Common Thermocouples	76
Table (5-1) Nozzle Throat Area for Different Configurations	95
Table (5-2) Figures of Pressure Distribution of Different Configurations	96
Table (5-3) Figures Indicating Variation of Vanes Forces and Moments	97
Table (5-4) Figures of Comparison Between Properties of Different Configurations	99

