

Forschungsbericht 2015-19

Hot Stage Separation of Rockets Using Coupled CFD and Flight Mechanics Method

Yi Li

Deutsches Zentrum für Luft- und Raumfahrt
Institut für Aerodynamik und
Strömungstechnik
Braunschweig

145 Seiten
99 Bilder
5 Tabellen
106 Literaturstellen



Deutsches Zentrum
für Luft- und Raumfahrt

Contents

Abstract	I
Kurzfassung.....	II
Acknowledgements	III
Nomenclature	VII
1. Introduction.....	1
1.1 Background.....	1
1.2 Stage Separation.....	3
1.2.1. Cold Separation	3
1.2.2. Hot Separation (Fire-In-The-Hole).....	4
1.2.3. Separation Dynamics	6
1.3 Study Approaches for Staging Dynamics.....	7
1.4 Objectives of this Study	9
2. Applied Numerical Methods	11
2.1 Governing Equations	11
2.1.1 Calorically Perfect Gas.....	14
2.1.2 Thermally Perfect Gas	15
2.1.3 Chemically Nonequilibrium Mixture of Perfect Gases	16
2.1.4 Equilibrium and Nonequilibrium Flows.....	19
2.2 Flight Mechanics Equations.....	20
2.2.1 Coordinate Systems	20
2.2.2 The Equations of Motion.....	26
2.3 The Chimera Methodology	28
2.4 The Moving System	30

2.5	Coupled Simulation of CFD and Flight Mechanics.....	31
2.5.1.	Sequential-static Simulation.....	31
2.5.2.	Fully-coupled, Time-accurate Simulation.....	32
3.	Aerodynamic Characterization of VLM-1.....	35
3.1	Computational Geometry.....	36
3.2	Computational Mesh.....	37
3.3	Computation and Analysis.....	42
4.	Numerical Modeling of the Rocket Motor.....	46
4.1	Flow Patterns of Hot Staging.....	46
4.2	Gas Models for the Simulation of Rocket Plume.....	50
4.3	Comparison of the Proposed Gas Models.....	55
4.3.1.	Computation of Flow Separations.....	55
4.3.2.	Computation of the Aerodynamic Forces on the First Stage.....	60
4.3.3.	Evaluation of the gas models with Experiments Data.....	69
4.4	Summary.....	81
5.	Staging Simulation.....	82
5.1	Staging Procedure.....	82
5.1.1.	Start-up Simulation.....	82
5.1.2.	Results and Analysis.....	86
5.2	Meshing Strategy.....	91
5.3	6-DoF Simulation.....	94
5.3.1.	Staging Dynamics.....	96
5.3.2.	Time step size for the staging simulation.....	113
5.3.3.	Effects of the Center of Mass.....	117
5.4	Study of the Computational Models for 6-DoF Simulation.....	120

5.5	Summary	128
6.	Conclusions	129
6.1	Summary of the Work.....	129
6.2	Contributions of this Work	131
6.3	Shortages of this Work.....	132
6.4	Suggestions for Future Work	133
	References	134