

Table of Contents

Abstract	iii
Zusammenfassung	v
Acknowledgement	vii
Symbols	xxi
Acronyms and Abbreviations	xxv
1. Introduction	1
1.1. Description of the Problem	2
1.1.1. State of the Art	2
1.1.2. Objectives	3
1.1.3. Methods	4
1.1.4. Outline of the Thesis	5
1.1.5. Contributions	5
2. The Generic Simulator	7
2.1. Simulator Structure and Interfaces	7
2.2. Model Assessment	9
2.2.1. Gravity Models	11
2.2.2. Atmospheric Models	12
2.2.3. Magnetic Field	12
2.2.4. Radiation Models	12
2.2.5. Development Outlook	13
2.3. Simulator Overview	13
2.4. Reference Coordinate Frames	14
2.5. Generic Modules	19
2.5.1. Multi-body Spacecraft and Test Mass Dynamics Core	20
2.5.2. Modeling Considerations for the Dynamics Core	25
2.5.3. Environmental Models	28
2.5.4. Calculation of Ephemerides	31
2.5.5. Transformation Libraries	31
2.5.6. Mathematics Modules	31
2.5.7. Controllers, Sensors and Actuators	31
2.5.8. Preprocessing	31

3. General Model Development	37
3.1. Common Modules and Interfaces	37
3.2. Core Development	37
3.2.1. Satellite and Test Mass Internal Disturbances	40
3.2.2. Introduction of Mechanical Reference Frame	40
3.2.3. Coupling Model Improvement	41
3.3. Gravity Model Update	41
3.3.1. Calculation Method	41
3.3.2. Simple Gravity Model	42
3.3.3. Higher-Order Gravity Models	42
3.4. Gravity Force Extension	45
3.4.1. Gravity Force	45
3.4.2. Gravity-Gradient Torque	51
3.5. Gravity Model Singularity Treatment	53
3.6. Alternate Gravity Formulation	55
3.7. Update of Other Environmental Sublibraries	56
3.7.1. Atmospheric Density	56
3.7.2. Magnetic Field	57
3.8. Preprocessing	58
4. Gravity Probe B	61
4.1. Background	61
4.2. Mission Overview	61
4.3. The Spacecraft	64
4.4. Preparation for On-Orbit Operation	67
4.5. Mission Phases	69
4.5.1. IOC Phase	69
4.5.2. Extension of the IOC Timeline	69
4.5.3. Science Phase	70
4.5.4. Calibration Phase	72
4.6. GP-B Data Analysis Process	72
5. Application to Gravity Probe B	75
5.1. Reference Coordinate Frames and Transformations	75
5.1.1. Elementary Transformations	76
5.1.2. Reference Frames	76
5.1.3. Reference Frame Transformations	78
5.2. Control Modules	80
5.2.1. The Gyroscope Suspension System	80
5.2.2. Sensors	81
5.2.3. The ATC	81
5.2.4. Actuators	82
5.3. Environmental Preprocessing	82
5.3.1. Model preparation	83

5.3.2. Look-up table creation	87
5.3.3. Re-iteration of model and mesh	89
5.3.4. Simulation in Matlab/Simulink	104
5.4. Simulator Adaptation to Gravity Probe B	106
5.4.1. 1-gyro Dynamics Simulator	108
5.4.2. 4-gyro Dynamics Simulator	109
5.4.3. Modeling of the Environment	111
5.5. Post-Mission Simulation	113
5.6. Modeling Limitations	114
6. Simulator Verification and Model Improvement	119
6.1. Verification of Dynamics Core Module Updates	120
6.1.1. Baseline Tests	120
6.1.2. Validation of Mechanical Reference Frame Introduction	121
6.1.3. Validation of Coupling Force through Lever Arm	123
6.1.4. Validation of Quadrupolar Force Term Extension	124
6.2. Simulator Cross-Check	124
6.3. Validation of Spacecraft and Gyroscope Dynamics	127
6.3.1. Simulation Results and Comparison with Science Data	128
6.4. Simulator Application and Improvement	132
6.5. Validation of Environmental Modeling	139
6.5.1. Cross-Check between Gravity Models	139
6.6. Investigation of Environmental Modeling Regarding Real Data	142
6.6.1. Theoretical Considerations	143
6.6.2. Gravity Model Parameter Variation	144
6.6.3. Science Data Preparation for Comparative Purpose	146
6.6.4. Force and Torque Extraction	153
6.6.5. Estimation of Material Coefficients	156
6.7. Preliminary Conclusion and Remarks	160
7. Conclusion	163
7.1. Summary	163
7.2. Outlook	166
A. Module and Feature Verification	169
A.1. Validation of Lever Arm	169
A.2. Constant Variation of Satellite Mass	172
A.3. Constant Variation of Satellite Center of Mass	176
A.4. Validation of Quadrupolar Force Term Extension	179
A.4.1. Definition of Test Cases	179
A.4.2. Equal Satellite Inertia	179
A.4.3. Dumbbell Satellite	181
A.4.4. Application to a Twin-Dumbbell Satellite	185