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14. ABSTRACT

For the past several years, Advatech Pacific. has been maintaining and enhancing the COLISEUM plume simulation environment under the direction of AFRL/PRSS. COLISEUM is a software environment used to model the propagation of a plasma plume and its interactions with solid surfaces (including both sputtering and re-deposition). A recent addition to the capabilities of COLISEUM is its integration with ModelCenter, the optimization and integration framework developed by Phoenix Integration. With the help of ModelCenter, the thrust directions of four Hall Effect Thrusters (HETs) for a representative satellite geometry are optimized such that the overall sputtering on the solar panels is minimized, subject to performance constraints on the overall thrust and torque. The satellite is assumed to be in a geosynchronous orbit, with the solar panels always facing the sun. Different positions in the satellite's orbit are considered, as is a case where one thruster is disabled. All cases considered showed smooth convergence behavior, and sputtering on the solar panels could be reduced significantly while meeting all performance constraints.

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MINIMIZATION OF THRUSTER PLUME EFFECTS ON SPACECRAFT SURFACES

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ABSTRACT

For the past several years, Advatech Pacific. has been maintaining and enhancing the COLISEUM plume simulation environment under the direction of AFRL/PRSS. COLISEUM is a software environment used to model the propagation of a plasma plume and its interactions with solid surfaces (including both sputtering and re-deposition). A recent addition to the capabilities of COLISEUM is its integration with ModelCenter, the optimization and integration framework developed by Phoenix Integration. With the help of ModelCenter, the thrust directions of four Hall Effect Thrusters (HETs) for a representative satellite geometry are optimized such that the overall sputtering on the solar panels is minimized, subject to performance constraints on the overall thrust and torque. The satellite is assumed to be in a geosynchronous orbit, with the solar panels always facing the sun. Different positions in the satellite's orbit are considered, as is a case where one thruster is disabled. All cases considered showed smooth convergence behavior, and sputtering on the solar panels could be reduced significantly while meeting all performance constraints.

INTRODUCTION

Electric Propulsion (EP) devices are gaining increasing acceptance for use on both US military and commercial spacecraft. Hall-effect thrusters, in particular, have been used extensively on Russian and former Soviet spacecraft[1]. They are of particular interest due to their high specific impulse compared to chemical thrusters. However, high-energy ions emitted by EP devices can potentially cause significant damage when impacting with components of the spacecraft. For example, sputtering of solar panels located in the plume can significantly reduce their life. The COLISEUM framework, developed under guidance of the U.S. Air Force Research Laboratory (AFRL) at Edwards AFB, was developed to address these concerns. The present work introduces the integration of COLISEUM into an optimization environment, so that EP plume effects on spacecraft components can be minimized while maintaining mission performance constraints. This is achieved by rotating the thrust angle of the EP devices away from sensitive spacecraft components. Alternatively, the setup can be used to place sensors, solar panels and the thrusters themselves in such a way that they will not interfere with each other during operation of the spacecraft.

THE COLISEUM FRAMEWORK

COLISEUM is a computational application framework that performs calculations of plasma propagation and interaction with arbitrary 3D surfaces[2,3,4]. The primary focus of COLISEUM is to investigate the erosion associated with the plasma particles impacting surfaces, known as sputtering, as well as the re-deposition of this material on other surfaces. Surface interaction parameters, such as ion flux, ion energy, sputtering, and re-deposition, are computed based on surface properties and plume data.

The surfaces from user-defined CAD models of the spacecraft are loaded into COLISEUM, which calculates plasma expansion from electric thrusters using a variety of functional modules. These functional modules are interchangeable, and can range from low fidelity simulations like PRESCRIBED_PLUME, which imports and superimposes a plume distribution field, and RAY, which performs collisionless ray tracing of flux from point sources to high fidelity plasma simulations like Particle-In-Cell with Direct Simulation Monte Carlo (PIC-DSMC) including wall collisions and wall recombination. This paper is based on line-of-sight sputtering predictions using the RAY module.

SATELLITE MODEL AND MISSION DESCRIPTION

The satellite configuration presented in this paper was chosen to provide a representative model of a typical communication satellite. A simplified set of materials was used to represent the individual elements of the spacecraft – in this case, the spacecraft body and solar panels have the sputtering profile of aluminum using the Roussel sputtering model[5]. However, given the sputtering profile of a particular material, it is possible to easily modify the sputtering behavior of individual spacecraft components for more physically realistic simulations. While the position of the four Hall thrusters at the corners of the back face (see Fig. 1) of the spacecraft body is not necessarily optimum for a north-south station keeping (NSSK) role, it is a flight-tested thruster configuration and serves to demonstrate the capabilities of COLISEUM optimization. Each Hall thruster is rated at 17 mN of thrust and has a flux density profile provided in Fig. 2. It is assumed that the thrusters can be throttled down to 5mN. Although there are no sensor packages on the back face of the spacecraft body, more detailed satellite configurations require little additional effort to run and optimize under the existing optimization framework. *Note: Thruster gimbaling was permitted so long as the thrust body did not impact the main spacecraft or the solar panels. While this often led to orientations of thrusters 3 and 4 which are highly unorthodox, constraining this motion within the optimization framework is very straightforward.*

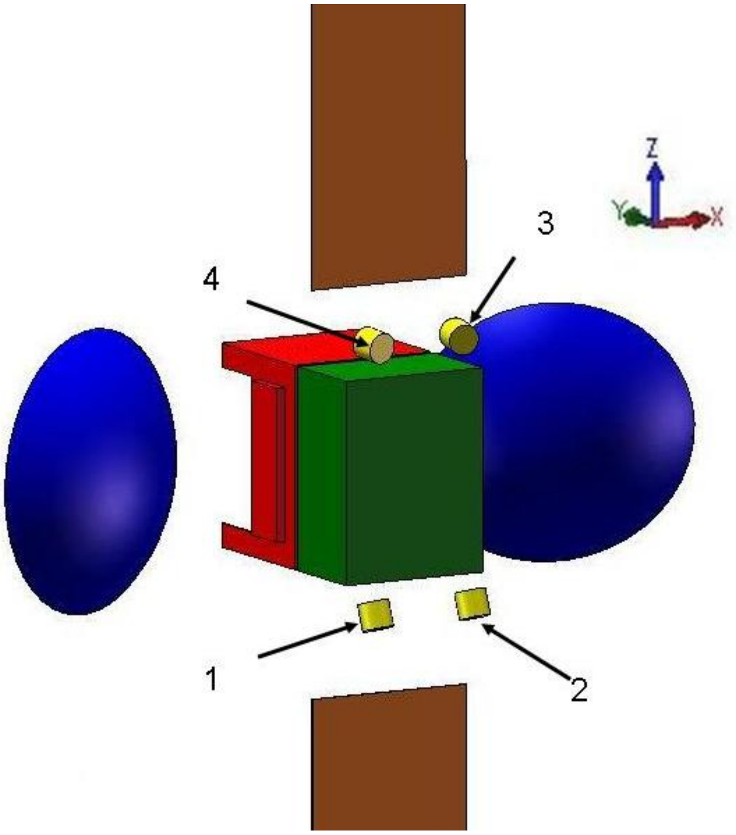


Fig. 1: View of back face of spacecraft

The mission profile chosen for this work is NSSK on an ideal geostationary (GEO) orbit. For simplicity, but without loss of generality of the work, the inclination of the orbital plane is neglected. The main payload on the front face of the spacecraft body is always pointed towards the earth. An illustration of this configuration is provided in Fig. 3. The particular optimization challenge is to meet a target NSSK thrust magnitude while minimizing sputtering of the solar arrays through manipulation of the thrust vectors of the four Hall thrusters. To facilitate sun-tracking over the course of an orbit, the satellite is maintained in an orientation with the solar arrays perpendicular to the orbital plane.

Although rotating the satellite to align the solar panels with the satellite velocity vector during the NSSK maneuvers would lead to a global minimum sputter rate, performing such a rotation for each NSSK maneuver decreases mission planning flexibility. Thus, the chosen mission profile demonstrates the ability of the COLISEUM optimization framework to handle unconventional scenarios which might improve the overall effectiveness of a mission.

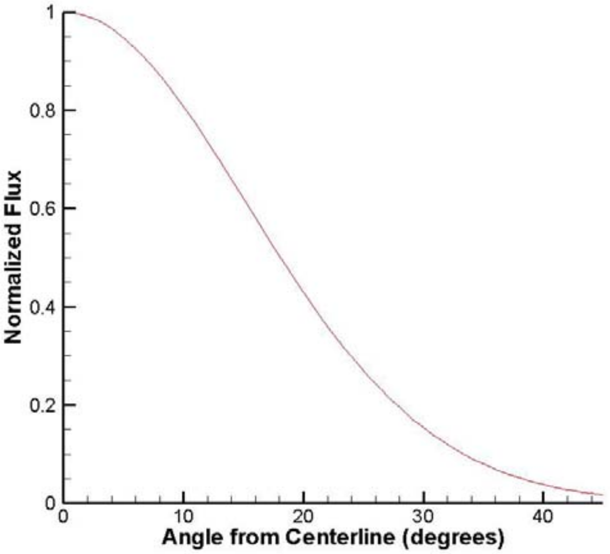


Fig. 2: Normalized Xe+ flux of HET thruster source model

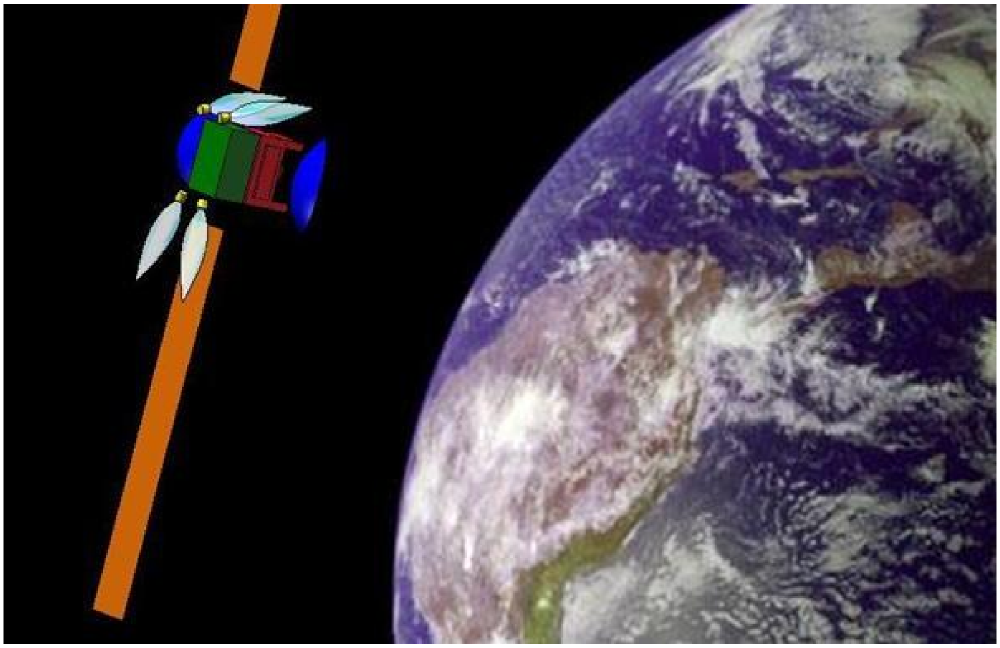


Fig. 3: Satellite model

OPTIMIZATION ENVIRONMENT

MODELCENTER

ModelCenter is a visual environment for process integration and optimization developed by Phoenix Integration, Inc. of Blacksburg, VA[6]. With ModelCenter, one can quickly create an engineering process and then perform complex design exploration techniques to find the best design. ModelCenter is adaptable and works well with groups whose design processes change frequently.

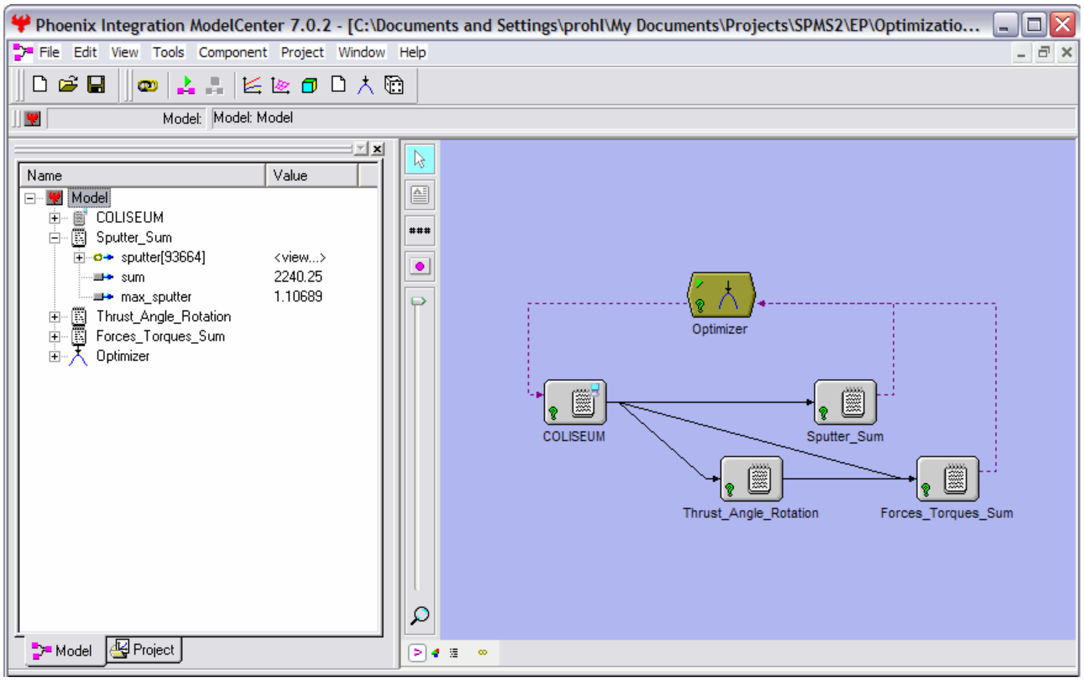
ModelCenter automates the process of running multiple simulation programs in a typical design project. Using ModelCenter, design data is automatically passed from one program to another, freeing the engineer to concentrate on the results of the design and not the drudgery of running individual programs.

ModelCenter allows the engineer to easily construct a design process as a series of linked applications with a simple interface. Users can connect to their applications that are wrapped with the Analysis Server to build the process.

INTEGRATION OF COLISEUM

Modelcenter has several ways to communicate with simulation programs. If the simulation program is executable via the command line, reads one or more ASCII input files and produces one or more ASCII output files, the simulation code is “wrapped” by a ModelCenter file or script wrapper. The wrapper facilitates the communication between the simulation code and the ModelCenter environment. The wrapper uses a template file for each input file, which is a static copy of the input file for the simulation code, and replaces data items in the template file with ModelCenter-generated values of those parameters that ModelCenter controls. It then generates the input file and invokes the simulation code. Once the simulation code terminates, the wrapper parses the output file(s) for those data items that have been exposed to the wrapper and transmits the current values to the ModelCenter environment.

In the case of COLISEUM, the wrapper generates a copy of the command file. Other input files needed by COLISEUM, like the material database, do not need to be modified by the wrapper. Only one of COLISEUM’s output files, which contains the sputter rates for each node of the finite element surface mesh, is parsed by the file wrapper. Fig. 4 shows a screen capture of the ModelCenter User Interface (UI) for the COLISEUM integration. The vector of sputter rates is processed in the ModelCenter-internal script component “Sputter_Sum”, which sums the sputter rates over all nodes, and determines the maximum sputter rate. “Thrust_Angle_Rotation” calculates the unit vectors of the thrust directions of all thrusters based on the rotation values of the thrusters around the Cartesian coordinate axes. With the help of these unit vectors, “Forces_Torques_Sum” sums all thruster forces and torques around the center of gravity (c.g.) of the satellite so that we can impose performance constraints on the forces and moments.



Name	Value
Model	
COLISEUM	
Sputter_Sum	
sputter[93664]	<view...>
sum	2240.25
max_sputter	1.10689
Thrust_Angle_Rotation	
Forces_Torques_Sum	
Optimizer	

Fig. 4: ModelCenter view of COLISEUM sputtering optimization

OPTIMIZATION PROBLEM

In general, a constrained optimization problem takes the following form: Minimize (or maximize) some measure of performance or cost function subject to any number of constraints, or, mathematically:

$$Min\ F(\vec{x})$$

$$Subj.\ to\ \vec{g}(\vec{x}) \le \vec{0}$$

$$\vec{x}_{\min} \le \vec{x} \le \vec{x}_{\max}$$

There are several ways to formulate the sputter optimization problem. One is to minimize the total sputtering (as expressed by the sum of the instantaneous sputter rate over all affected nodes) subject to constraints on the total thruster force and moment. A second is to maximize the thruster north (or south) force with a constraint on the total sputtering and constraints on the other forces and moments. Both scenarios have been exercised in the present work. Apart from all thrusters being operational, cases considered also include the situation when a thruster is disabled, i.e. the remaining thrusters need to be scheduled in such a way that they can still meet the performance constraints while minimizing sputtering. The baseline case looks at a position in the satellite's geosynchronous orbit where it is directly between the earth and sun, i.e. the solar panels are rotated away from the earth towards the thrusters on the back side of the satellite, see Fig. 3. Several scenarios with the solar panels at varying angles from this baseline case have also been studied. The number of cases is by no means exhaustive, and no claims are made that the most critical case has been covered. The main purpose is to show that any configuration can be analyzed and optimized without modification to the environment; only user inputs to Modelcenter need to be adjusted.

RESULTS AND DISCUSSION

Several cases have been investigated, both with the solar panels rotated directly away from the earth, i.e. a position in the satellite's orbit where it is located directly between the earth and sun, and cases where the solar panels are rotated at some angle with respect to this case. In addition, cases have been investigated where one thruster is disabled and cannot be used to provide thrust. The optimizer then needs to compensate with the remaining thrusters. Fig. 5 shows a contour plot of the instantaneous sputter rate observed on the solar panel affected when thrusters 1 and 2 are firing in the negative z-direction. The solar panels are facing away from earth, i.e. its face normal points in the negative y-direction. Thrusters 3 and 4 are used to compensate the torque created by thrusters 1 and 2. In addition to the (desired) net resulting force in the z-direction for station keeping, a parasitic force in the y-direction is created which lowers the orbit of the satellite. This needs to be compensated for once the north-south maneuver is completed.

CASE 1: ALL THRUSTERS OPERATIONAL, SOLAR PANELS FACING AWAY FROM EARTH

Case 1 is a symmetric case where the satellite is directly between the earth and sun, i.e. the soar panels are facing away from earth with their face normals pointing in the negative y-direction. Since the case is symmetric, the optimization was run only with thruster 1 active. Thruster 2 (and thrusters 3 and 4 for torque compensation) were turned on only for a rerun of the final iteration. This reduces the run time of the optimization by almost a factor of four. The maximum instantaneous sputter rate, normalized with the baseline maximum value, is reduced to about 6% of the baseline case, see Fig. 6. Note the modified contour levels with respect to the baseline in Fig. 5 – with identical levels, the whole solar panel would have been at the lowest level. Thrusters 1 and 2 are rotated 17.1^0 around the x-axis and $+/-22.6^0$ around the y-axis, respectively. Fig. 7 shows the smooth convergence history of the objective function, with the history of the two design constraints displayed in Fig. 8. A constraint of 15 mN minimum thrust in the z-direction and a maximum parasitic thrust of 5 mN in the y-direction was imposed on thruster 1 used for the optimization. Thruster 2 is fired in symmetric fashion, so that the thrusts in z- and y-direction are additive, while the thrust in x-direction cancels out, so that we don't need to impose a constraint on it. The case converges in 3 design iterations. A design iteration consists of one analysis of the current design point, n gradient runs (where n is the number of design variables) and a number of analyses in the search direction that the optimizer determines based on the gradients of the objective function and constraints. The optimization technique used here is the modified method of feasible direction of the DOT[7] optimization package, one of the optimization packages inside the ModelCenter framework.

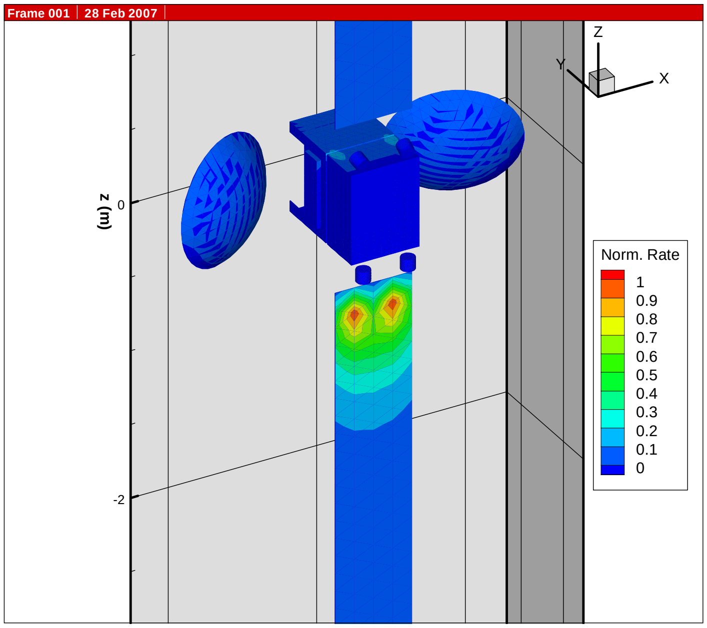


Fig. 5: Baseline case: thrusters 1 and 2 firing in negative z-direction

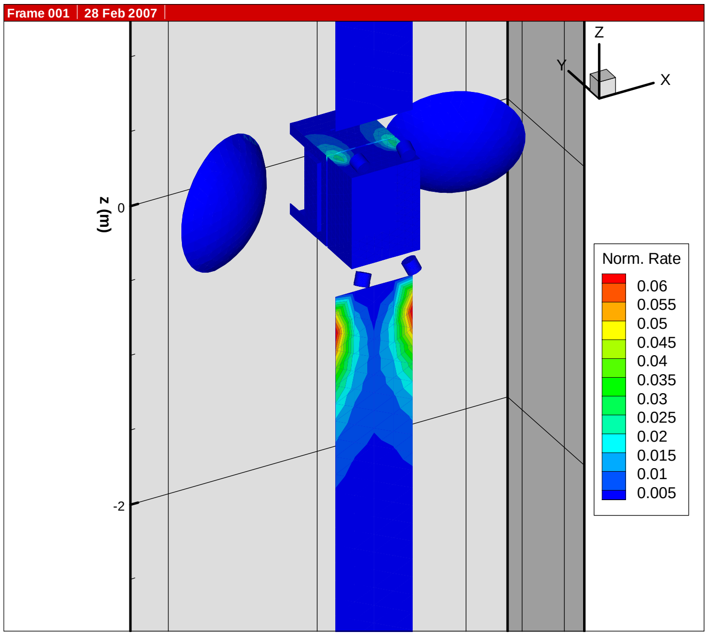


Fig. 6: Normalized sputtering for optimized thruster angles, case 1

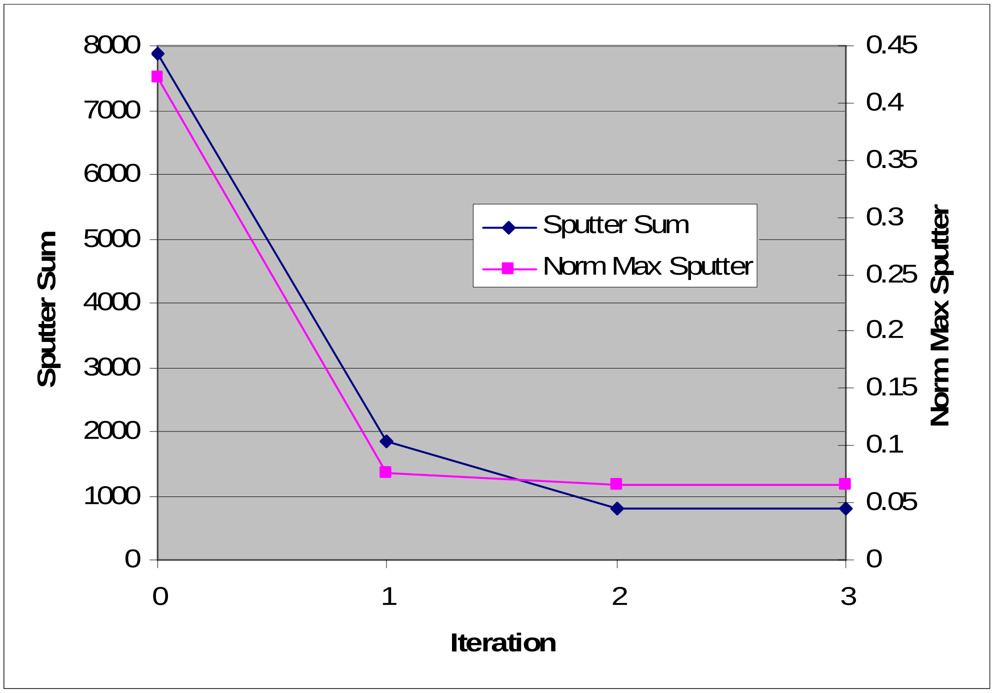


Fig. 7: Objective function convergence history for case 1

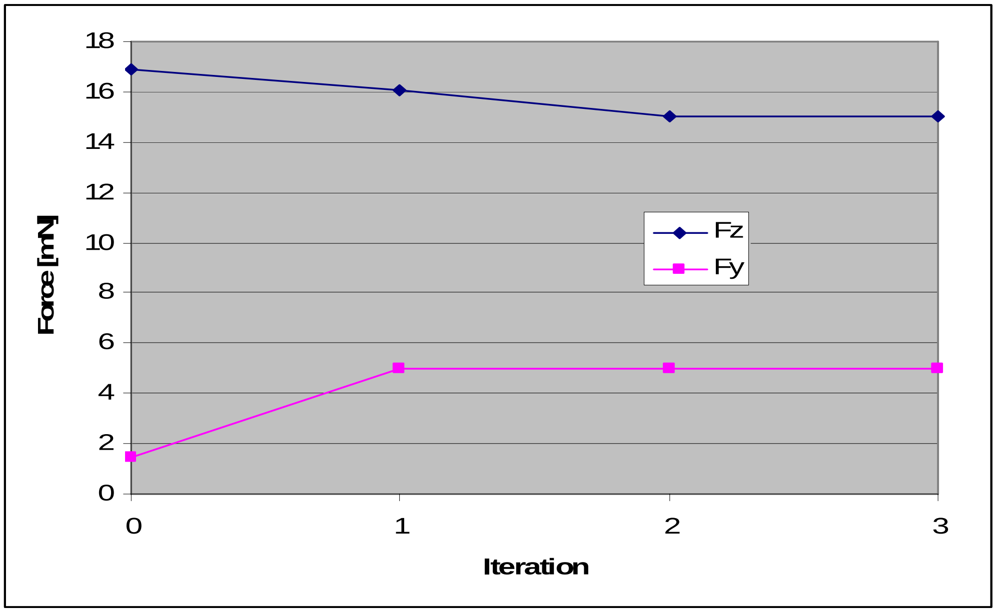


Fig. 8: Constraint history for case 1

CASE 2: ALL THRUSTERS OPERATIONAL, SOLAR PANELS AT 30 DEGREES

Case 2 is a non-symmetric case where the face normals of the solar panels are rotated 30^0 with respect to the negative y-direction. Performance constraints are identical – a minimum

30mN thrust in the z-direction is to be maintained, while the thrust in the y-direction is to be kept below 10mN. Again, thrusters 1 and 2 are used to provide the desired north-south (z-direction) thrust, while thrusters 3 and 4 are used for torque compensation. Fig. 9 shows the normalized sputter rate for the optimized configuration. Only sputtering on the solar panel was considered for optimization. The sputtering caused by thruster 3 on the satellite structure and backside of the dish antenna was not included in the optimization. Depending on the particular case and location of sensors and other equipment on an actual satellite, the decision needs to be made where sputtering is of concern.

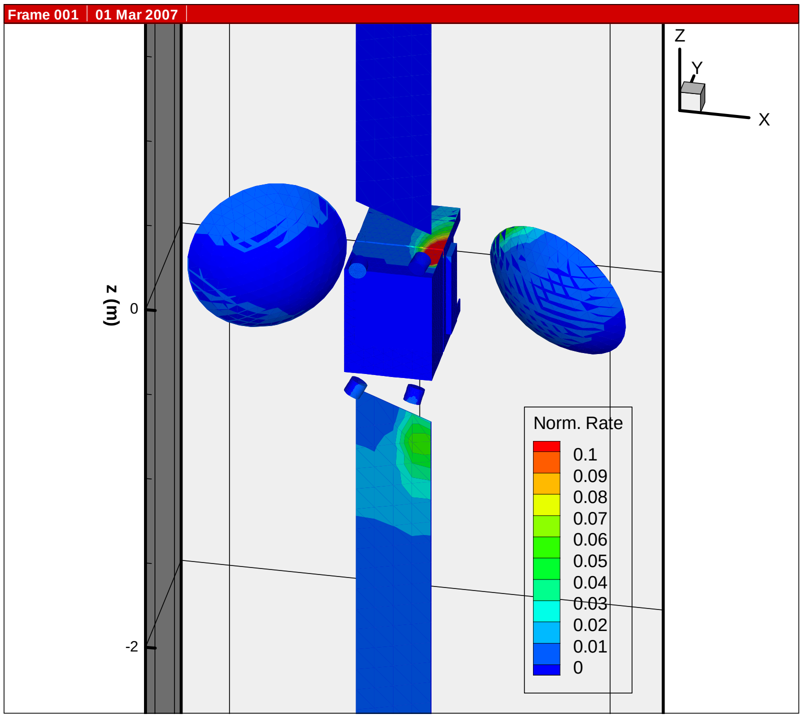


Fig. 9: Normalized sputtering for optimized thruster angles, case 2

The optimization converged in 8 iterations. Fig. 10 shows the history of the objective function (sputter sum) and normalized maximum sputter rate, which are very closely correlated. The optimizer satisfies the force constraints (Fz min = 30mN, Fy max = 10mN) within the first two iterations (see Fig. 11) and slowly reduces the objective function, marching along the constraint boundaries, by slightly adjusting the thruster angles (Fig. 12).

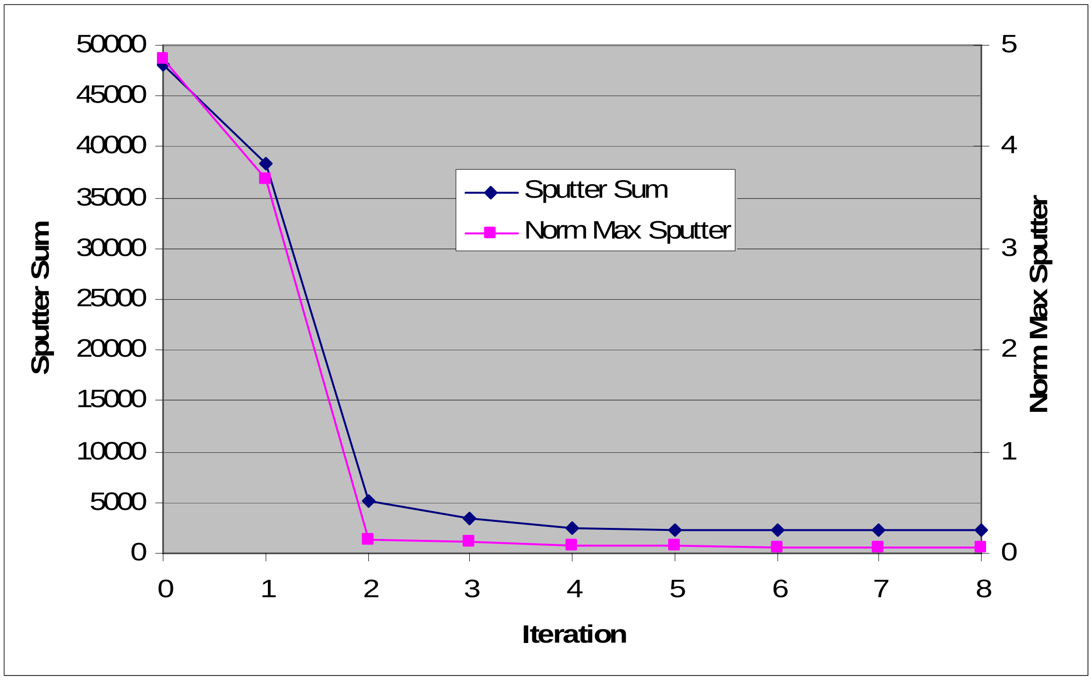


Fig. 10: Sputter sum and maximum sputtering history for case

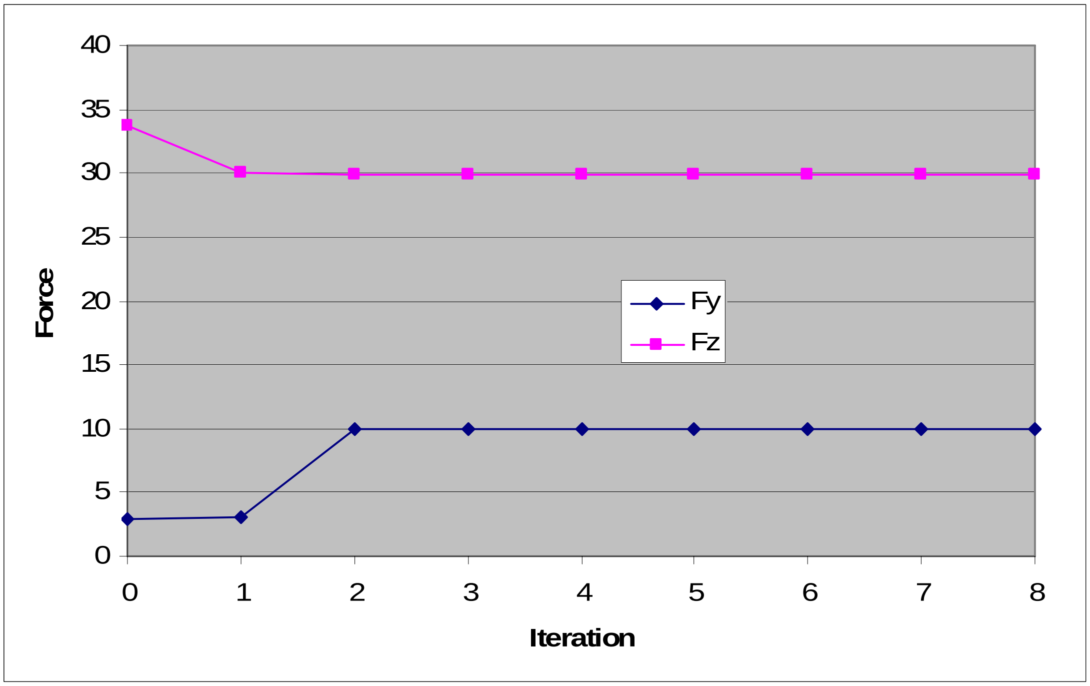


Fig. 11: Constraint history for case 2

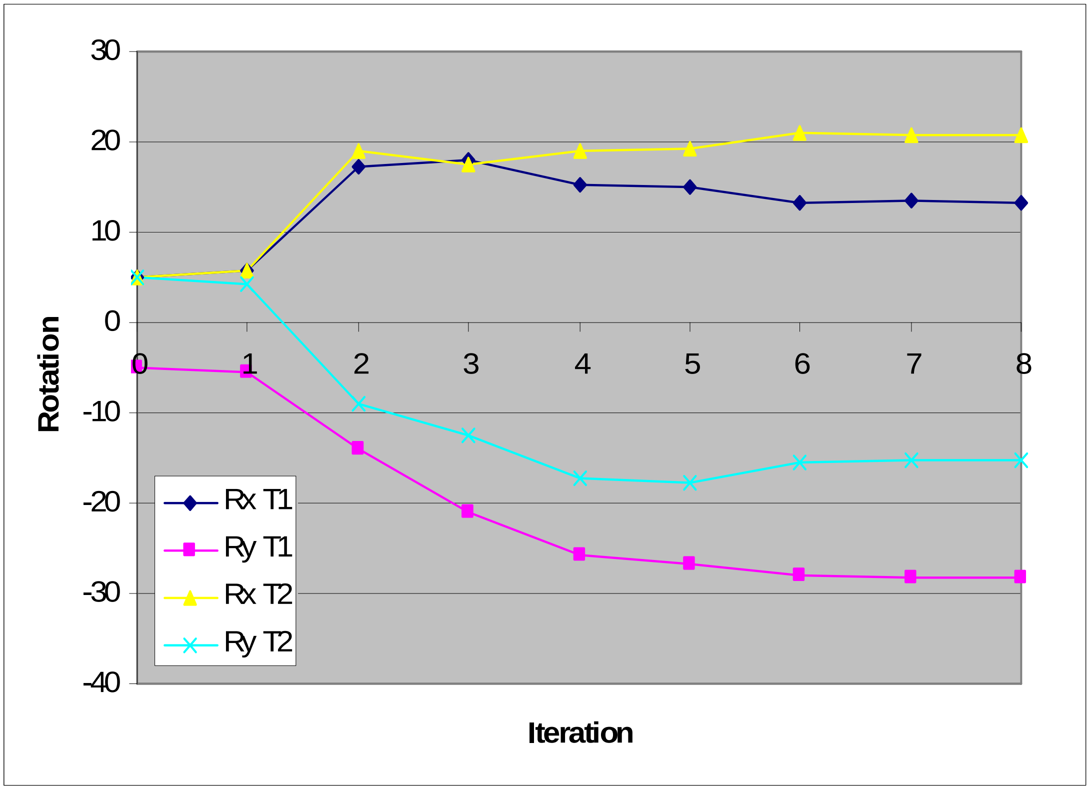


Fig. 12: Design variable history for case 2

Final values for the thruster rotations are 13.37^0 around the x-axis and -28.23^0 around the y-axis for thruster 1 and 20.81^0 around the x-axis and -15.16^0 around the y-axis for thruster 2, respectively. Thrusters 3 and 4 manage to reduce the torque around the y- and z-axis to zero, merely a torque of -4.71mNm around the x-axis remains. This comes at a cost of reduction of net z-Force from 30mN to 28mN.

CASE 3: ONE THRUSTER DISABLED, SOLAR PANELS FACING AWAY FROM EARTH

In case 3, one of the thrusters, in this case thruster 2, is disabled, and the remaining three thrusters need to accomplish the maneuver. A constraint of a minimum net thrust of 15mN in the z-direction is imposed. No constraint is imposed on the x- or y-forces, so that the optimizer rotates thruster 1 as far away from the solar panel as possible to achieve minimum sputtering. The maximum sputter rate is reduced to 1.3% of the baseline case, see Figs. 13 and 14. However, since only thruster 1 is performing the station keeping maneuver, only half the thrust is available and needs to fire twice as long to impart the same impulse. Fig. 15 shows the history of the two design variables, rotation of thruster 1 around the x- and y-axis, respectively. Thrusters 3 and 4 were used for torque compensation. In this case, thrusters 3 and 4 were restricted to only rotate in the x-y-plane so no additional thrust was lost in the z-direction. The optimizer determined it needed only thruster 3 for torque compensation, and it turned off thruster 4.

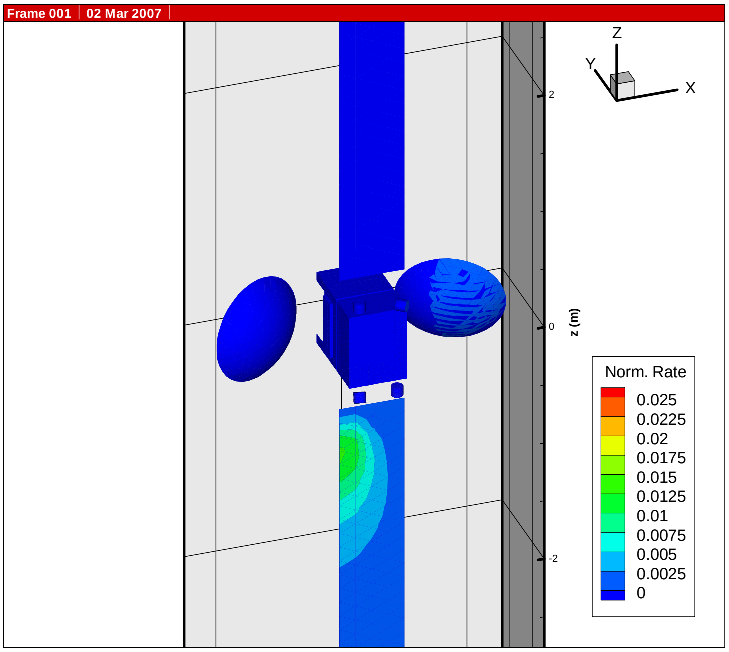


Fig. 13: Normalized sputtering for optimized thruster angles, case 3

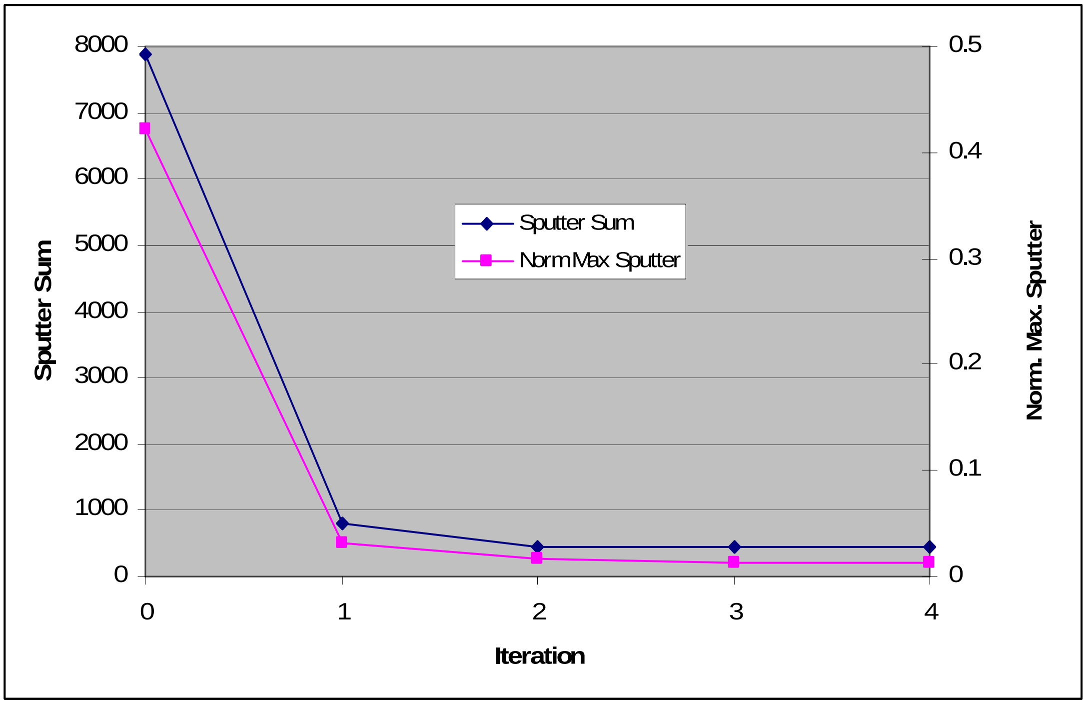


Fig. 14: Sputter sum and normalized maximum sputtering history for case 3

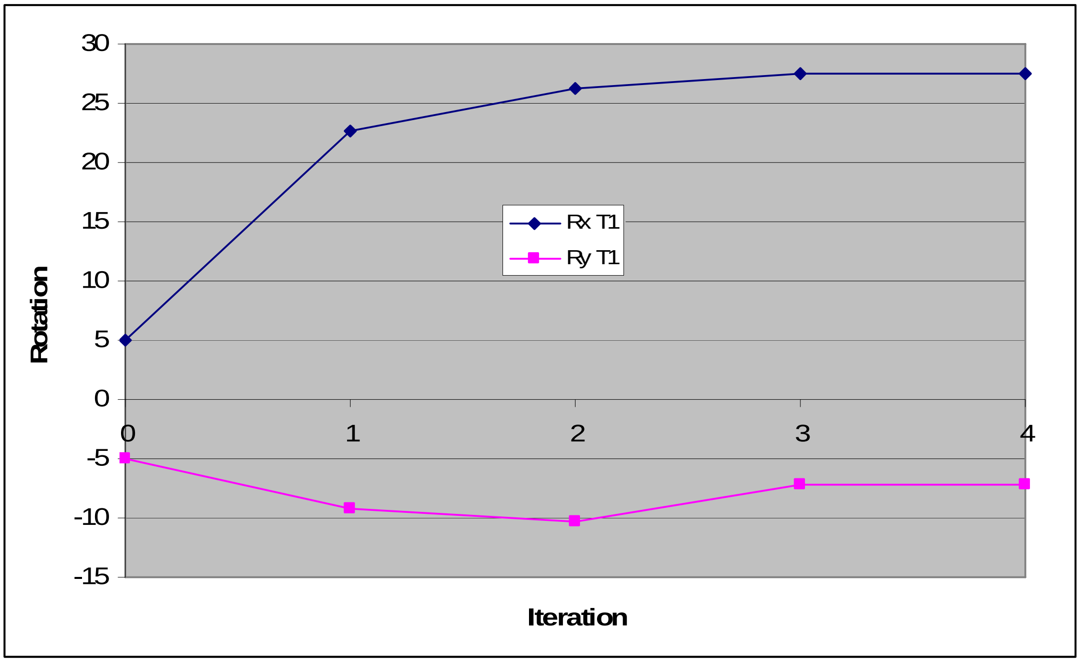


Fig. 15: Design variable history for case 3

SUMMARY AND CONCLUSIONS

The objective of this work was to demonstrate the capabilities of the COLISEUM framework in conjunction with an optimization package. The three cases considered were: the baseline symmetric case with the satellite directly between earth and sun, a non-symmetric case with the solar panels rotated, and a case with a disabled thruster. In general, these optimization cases are very well behaved from the point of view of topology of the constrained objective function space, so that the default optimizer settings in ModelCenter for the modified method of feasible directions provided for fast and smooth convergence in all cases. With this capability in place, it is now possible to optimize very realistic models of actual satellites. Both actual satellite geometry and actual mission/orbital data do not make the problem more difficult from the optimizer's point of view; it merely shifts the objective function and constraint boundaries. Any number of thrusters with any type of limitations on their movements can be accommodated. The same setup can also be used for a design scenario, where the placement of thrusters, sensors and solar panels or other sensitive equipment on the satellites is to be optimized. Since this work used a notional thruster plume profile and a single aluminum surface model to evaluate sputter rates for the optimization framework, this work does not provide physically meaningful sputter profiles; however, work performed by the Air Force Institute of Technology[8] (and presented at this same conference) using COLISEUM demonstrates physically reasonable sputtering and redeposition profiles for the TACSAT-2 spacecraft. Nevertheless, this work illustrates just some of the possibilities provided to mission and spacecraft designers provided by coupling plume simulation with robust optimization techniques.

FUTURE WORK

Planned future improvements for COLISEUM optimization include:

- Minor improvements to the geometry handling for easier identification of individual spacecraft components
- Investigating the use of a non-commercial optimization package in place of Modelcenter.

- Coupling a spacecraft mission and performance code with the optimization setup, so that actual orbit and mission data can be computed and used as performance constraints for the optimization problem.

ACKNOWLEDGMENTS

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Minimization of Thruster Plume Effects on Spacecraft Surfaces

54th JANNAF Propulsion Meeting
Denver, CO
May 2007

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Outline

- Introduction and Objective
- COLISEUM Framework
- Sputter Model
- Satellite Model and Mission
- Optimization and Integration Framework
- Sample Results
- Conclusion
- Outlook

Motivation and Objective

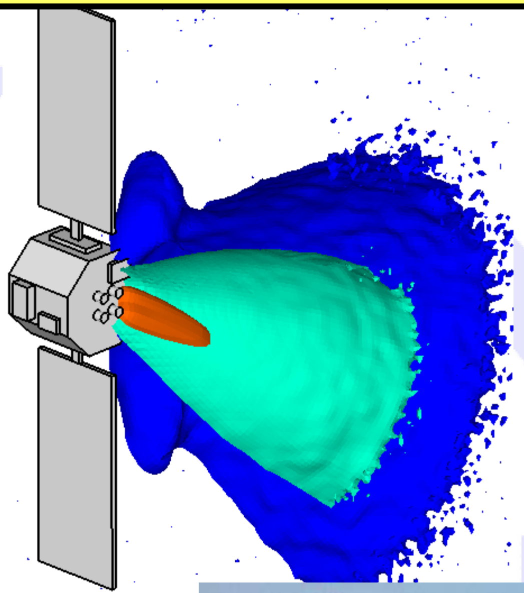
- Electric propulsion devices are increasingly used on both U.S. military and commercial satellites, in particular Hall-Effect Thrusters (HET), due to their high specific impulse
- High-energy ions emitted by the devices can cause significant damage when impacting the spacecraft
- Therefore, knowledge of the thruster plume propagation in vacuum is essential. COLISEUM is a software package developed under AFRL Edwards leadership that simulates plume propagation, sputtering and redeposition of material
- The coupling of COLISEUM with an optimization framework enables us to minimize the impact of the thruster plume on the spacecraft while satisfying performance constraints

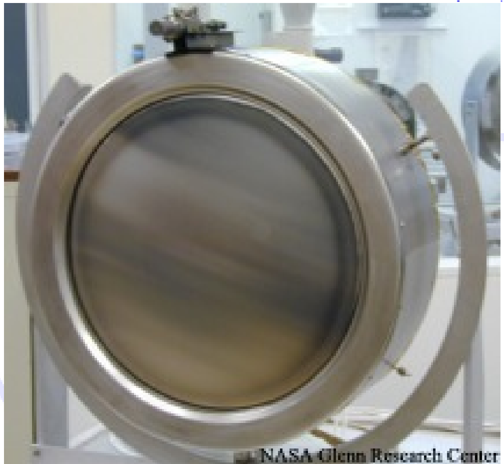
COLISEUM - Introduction

COLISEUM: 3D simulation framework for modeling of electric thruster plumes and their interaction with spacecraft components

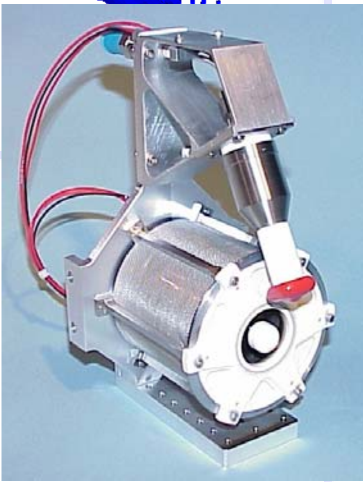
Electric propulsion overview

- Propellant is accelerated using electro-thermal, electro-static or electro-magnetic forces
  - Electro-thermal: arcjet, PPT
  - Electro-static: ion thruster, Hall thruster
  - Electro-magnetic: MPD, FRC
- Common feature: high exhaust velocity
  - High ISP = high fuel economy
  - Increased risk for surface contamination
    - Surface bombardment by energetic particles
    - Surface charging from current collection
- Contamination NOT limited to components located within thruster line-of-sight
  - Backflow of charge-exchange (CEX) ions
  - Requires self-consistent plasma modeling: particle-in-cell (PIC) method

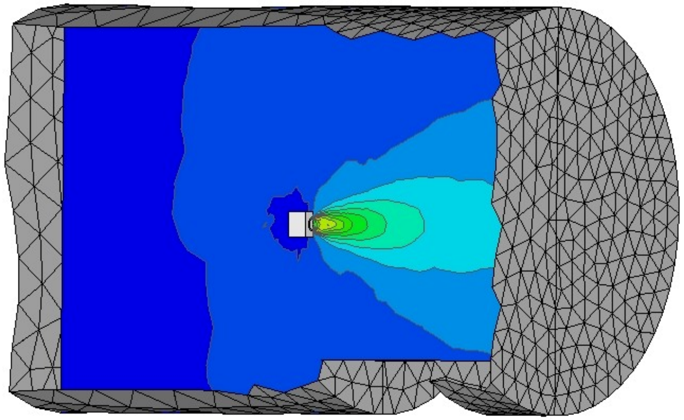


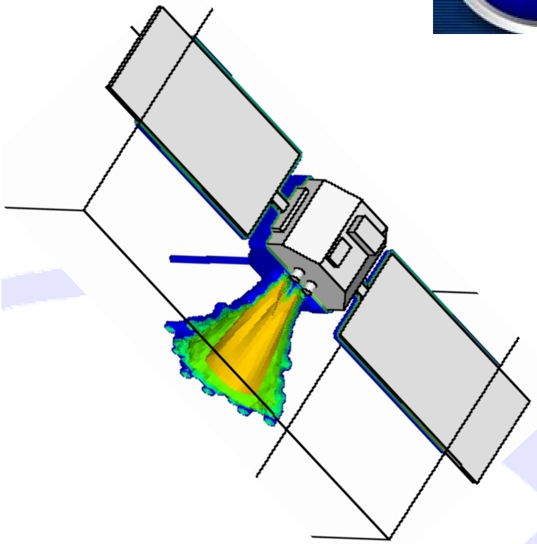


NASA Glenn Research Center



COLISEUM - Architecture





Surface
- Simulation mesh
- Material specs

Particle Sources
- Exp profile: LIF, j
- HPHall, CHETC

Sputter Model
- Lab measurements
- Model, ***f(E,θ)***

Plasma Simulation:
- **RAY (sputtering / deposition)**
- PRESCRIBED_PLUME
- AQUILA (Hybrid PIC-DSMC)
- DRACO (Full/Hybrid PIC-MCC)

Collisions
- Cross-sections, literature
- User-added through .dat

Results
- Plume properties
- Surface erosion/deposit

Advatech Pacific, Inc.
Solutions Beyond Services

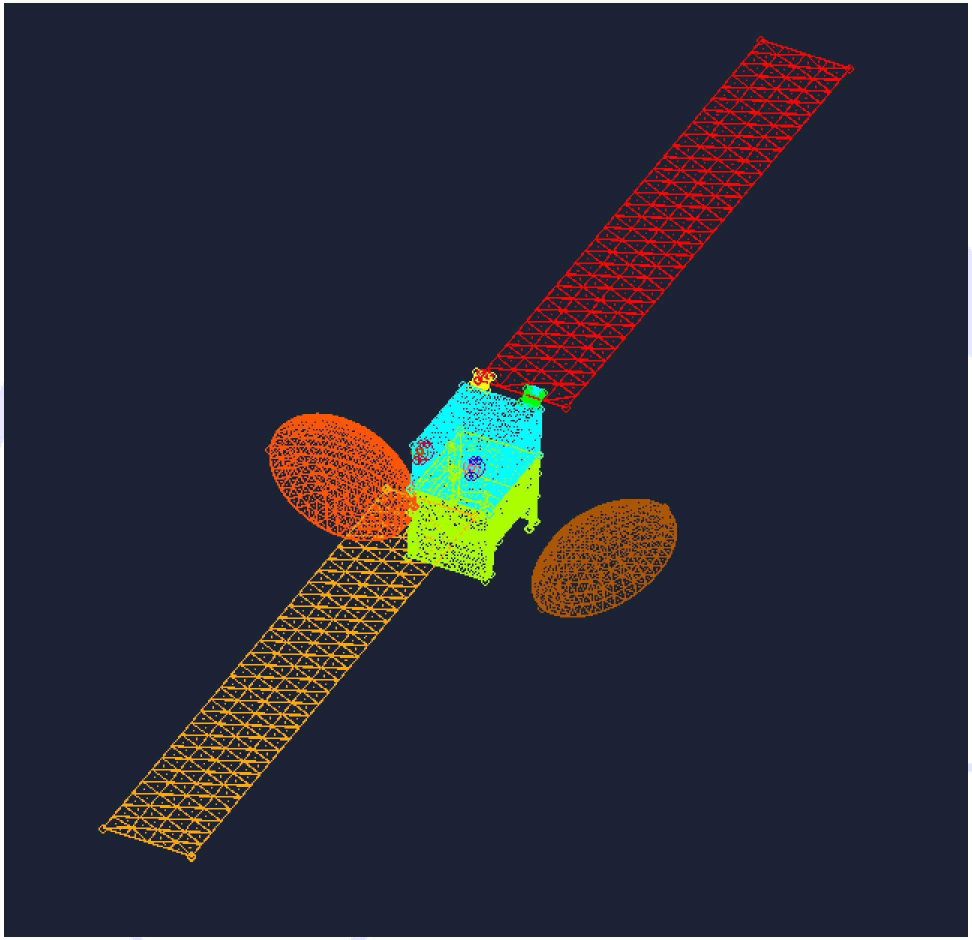
Core COLISEUM Library

SURFACE

PURPOSE: STANDARDIZE THE STORAGE AND MANIPULATION OF 3-D SURFACE DATA

Triangular elements

- Automatic zone decomposition. A zone is defined as:
  - Contiguous
  - Radius of curvature > *x*
  - Same material
- Calculated values:
  - Area
  - Centroid
  - Normal vector
- Surface elements are tagged with a component number which connects the surface geometry to the surface property databases



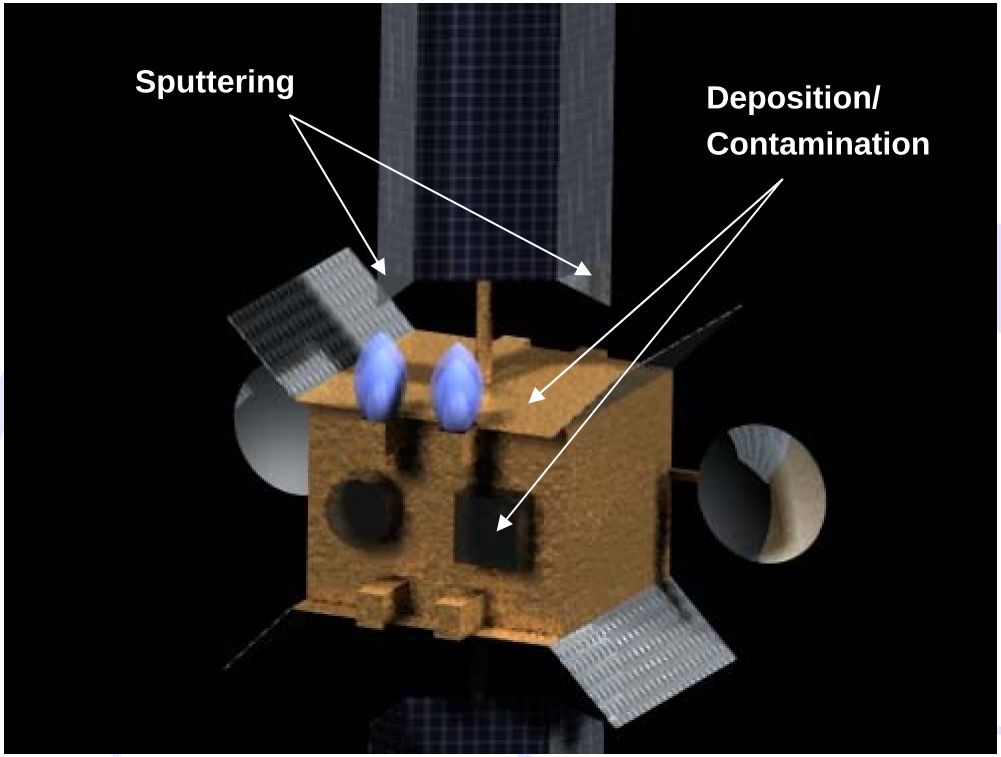
Model imported from SolidWorks and meshed in Altair Hyperworks

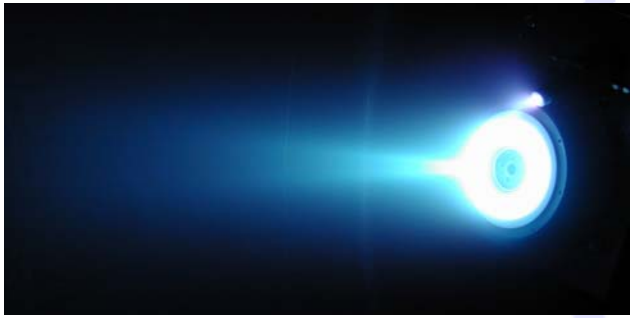
COLISEUM Capabilities

Electric Thrusters Emit Energetic (~20km/s) Particles

COLISEUM Predicts:

- Contamination and Sputtering of Spacecraft Surfaces
  - Solar Arrays
  - Radiators
  - Sensors
  - Optics
- Cross-Contamination (Clusters of Spacecraft)

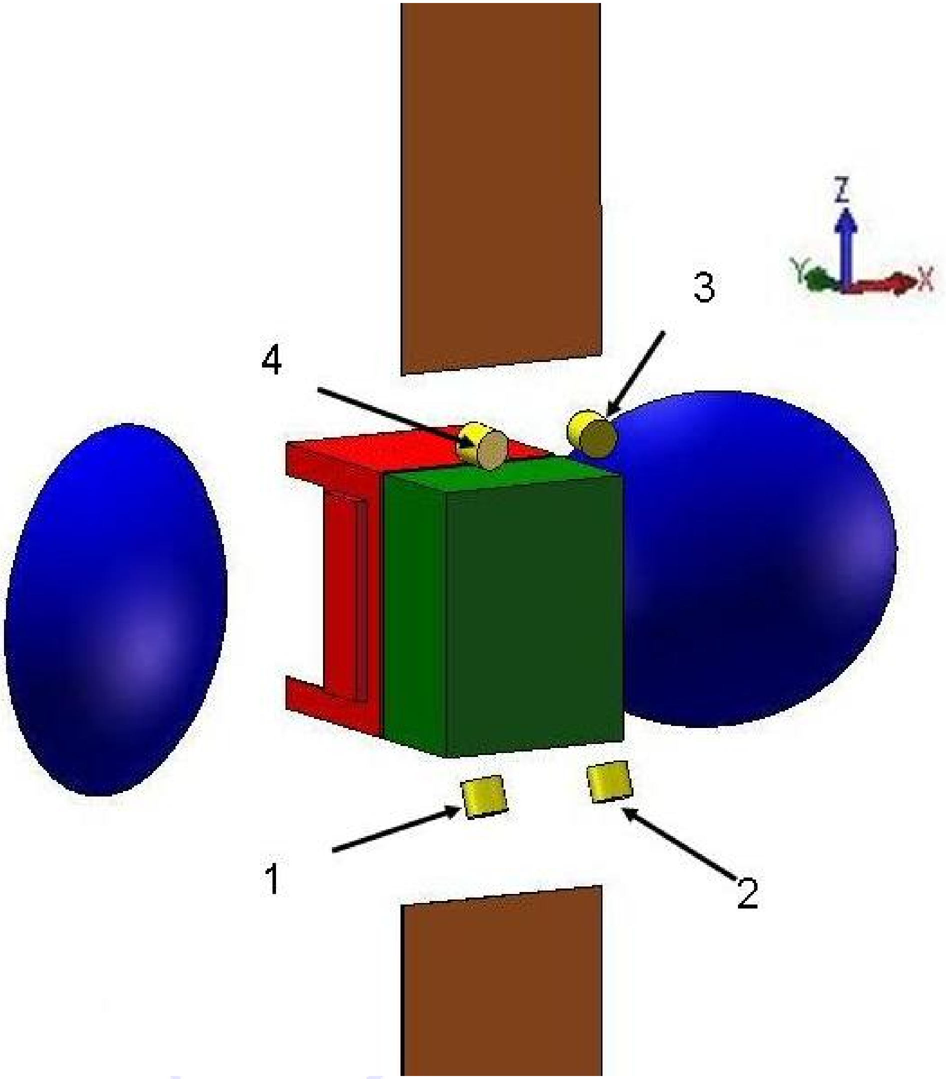




Hall Thruster Plume (SPT-140 DM3)
Emits 300eV Xenon Ions

Spacecraft Model

- Representative communications satellite
- On-orbit propulsion system of four Hall thrusters on back face of spacecraft
- Assumed aluminum surfaces everywhere
- Primary concern is sputtering on the solar arrays during NSSK maneuvers

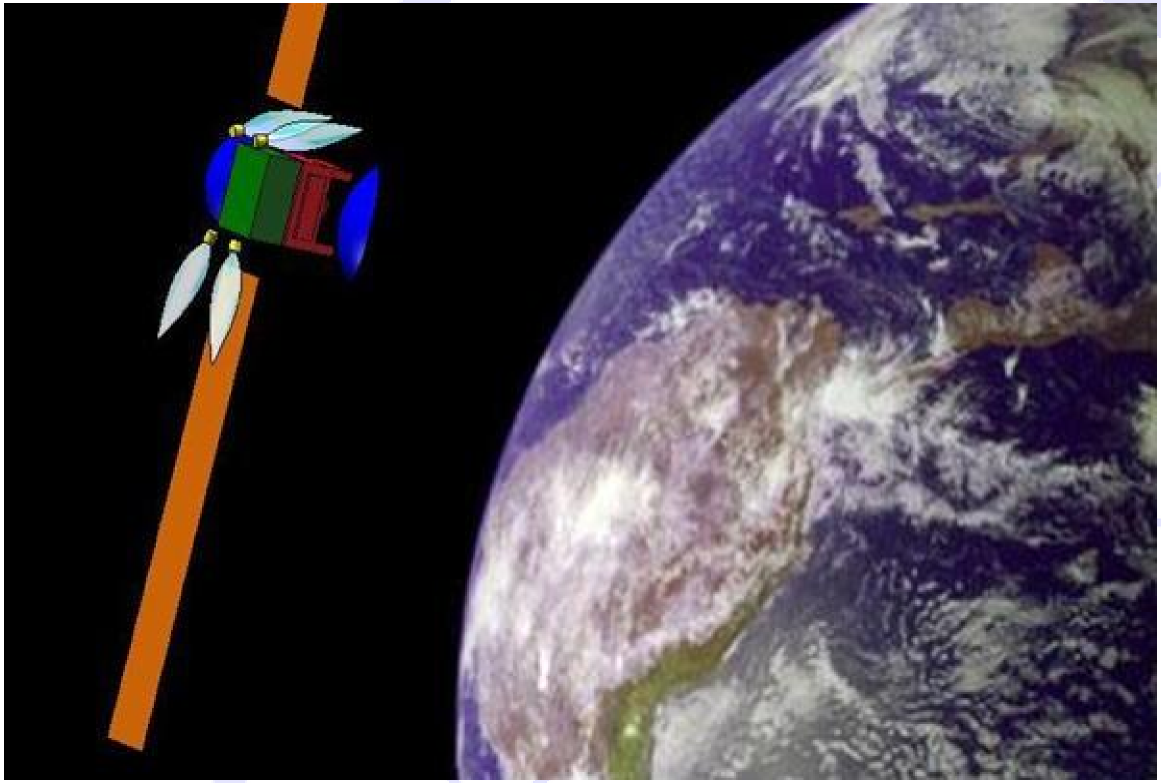


Mission Description

- Ideal geosynchronous orbit (zero inclination)
- Keep sensor package facing towards Earth while maintaining solar arrays perpendicular to velocity track
- North-south station keeping (NSSK) maneuvers to be accomplished

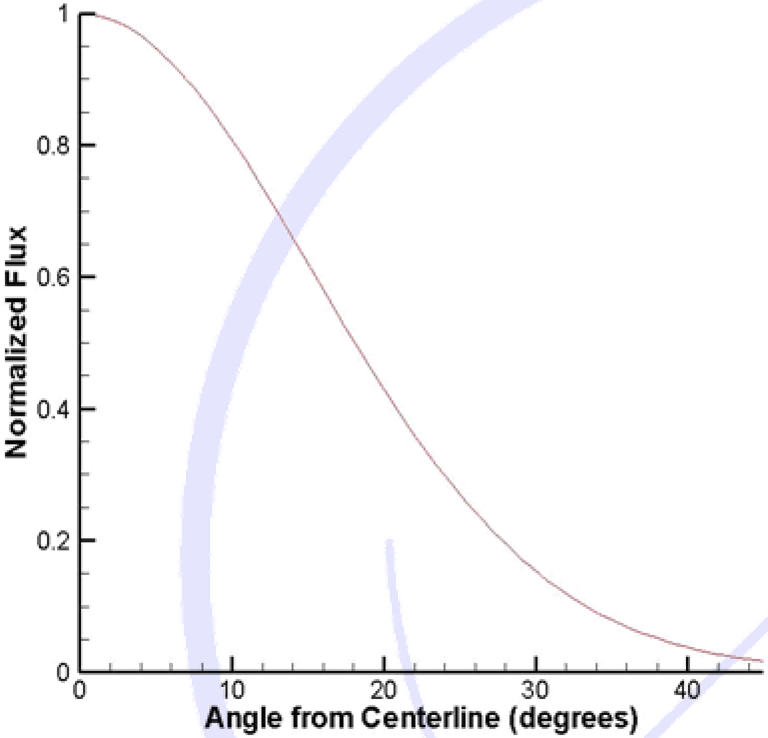
  using

  Hall thrusters



HET Source Model

- Used an internal COLISEUM (MAXSTREAM) Xe^+ source to provide a representative HET source model as input condition at thruster exit plane
- Plume divergence angle of ~40 degrees
- Throttled capability incorporated into code by changing the mass flow rate

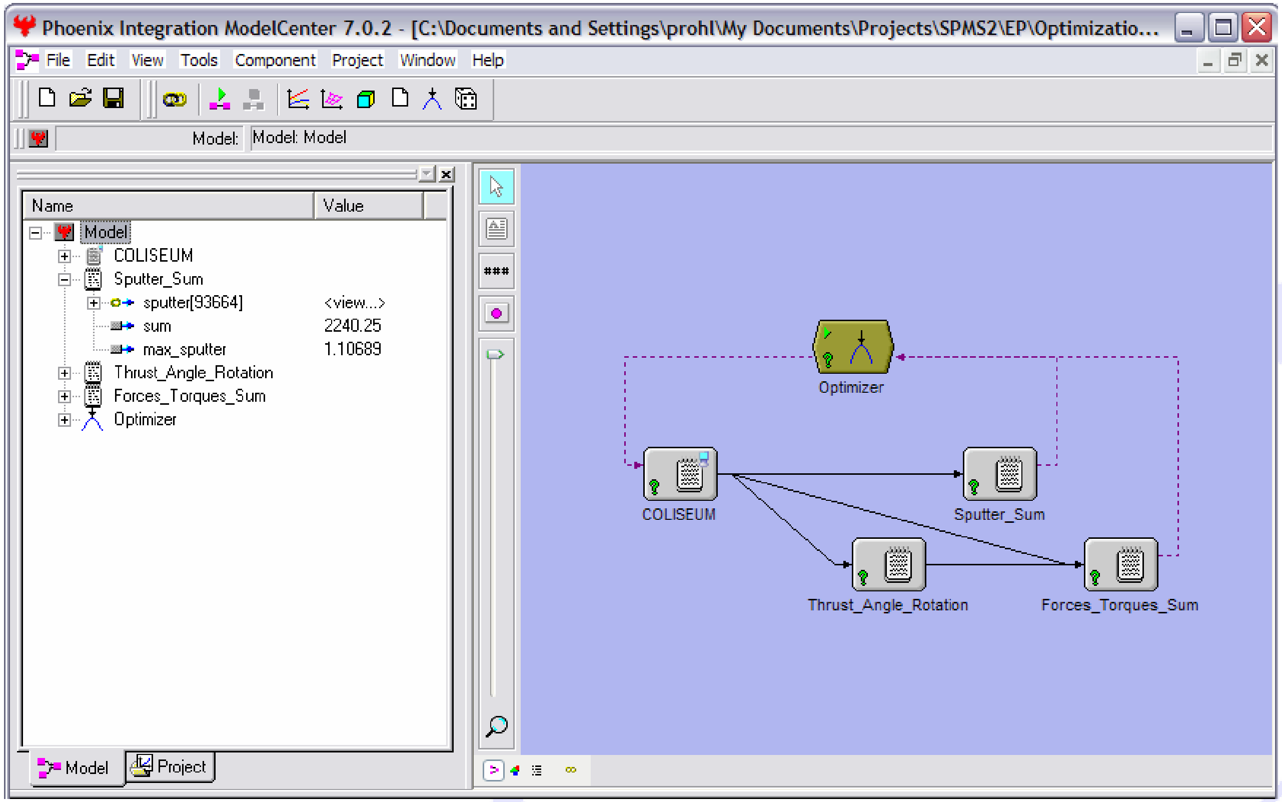


Normalized Xe+ flux of HET thruster source model

Phoenix ModelCenter

- ModelCenter is a commercial software integration and optimization framework developed by Phoenix Integration
- Software tools are integrated into ModelCenter by “wrapping” them, so that ModelCenter can send parameters to the codes, execute them, and extract results from the codes.
- ModelCenter builds a workflow of software tools by linking them and their parameters. Looping, branching, etc. can be specified
- ModelCenter executes this workflow with the help of drivers that implement optimization, DOE, quality methods like Monte Carlo simulation etc.

Integration of COLISEUM into MC

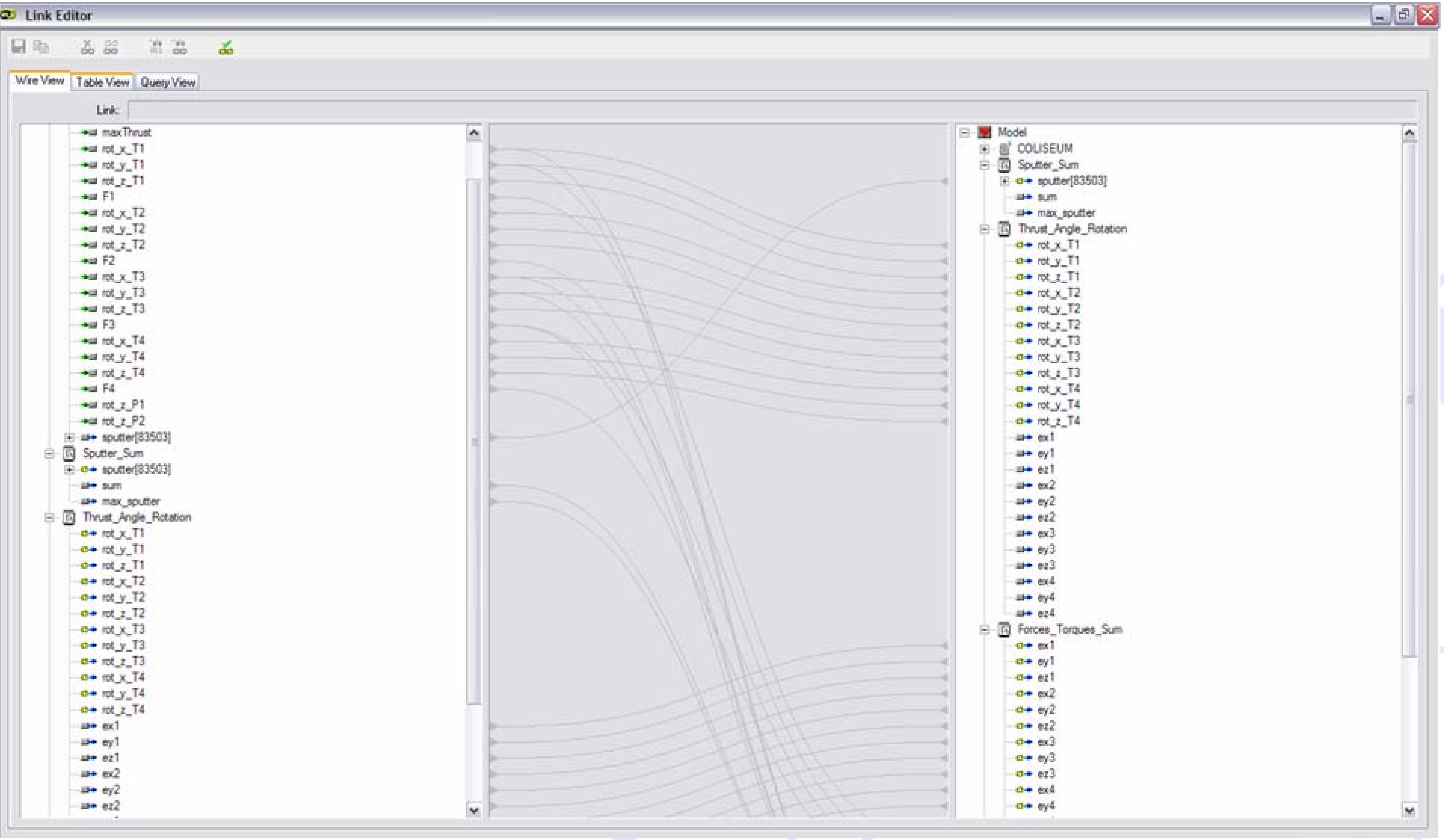


Model: Model

Name	Value
Model	
COLISEUM	
Sputter_Sum	
sputter[93664]	<view...>
sum	2240.25
max_sputter	1.10689
Thrust_Angle_Rotation	
Forces_Torques_Sum	
Optimizer	

The COLISEUM component represents the wrapped COLISEUM code. ModelCenter generates the COLISEUM command file and executes the code. The remaining components are internal ModelCenter script components that process the COLISEUM output (Sputter_Sum), calculate the thrust vector directions (Thrust_Angle_Rotation) and sum all forces and moments (Forces_Torques_Sum).

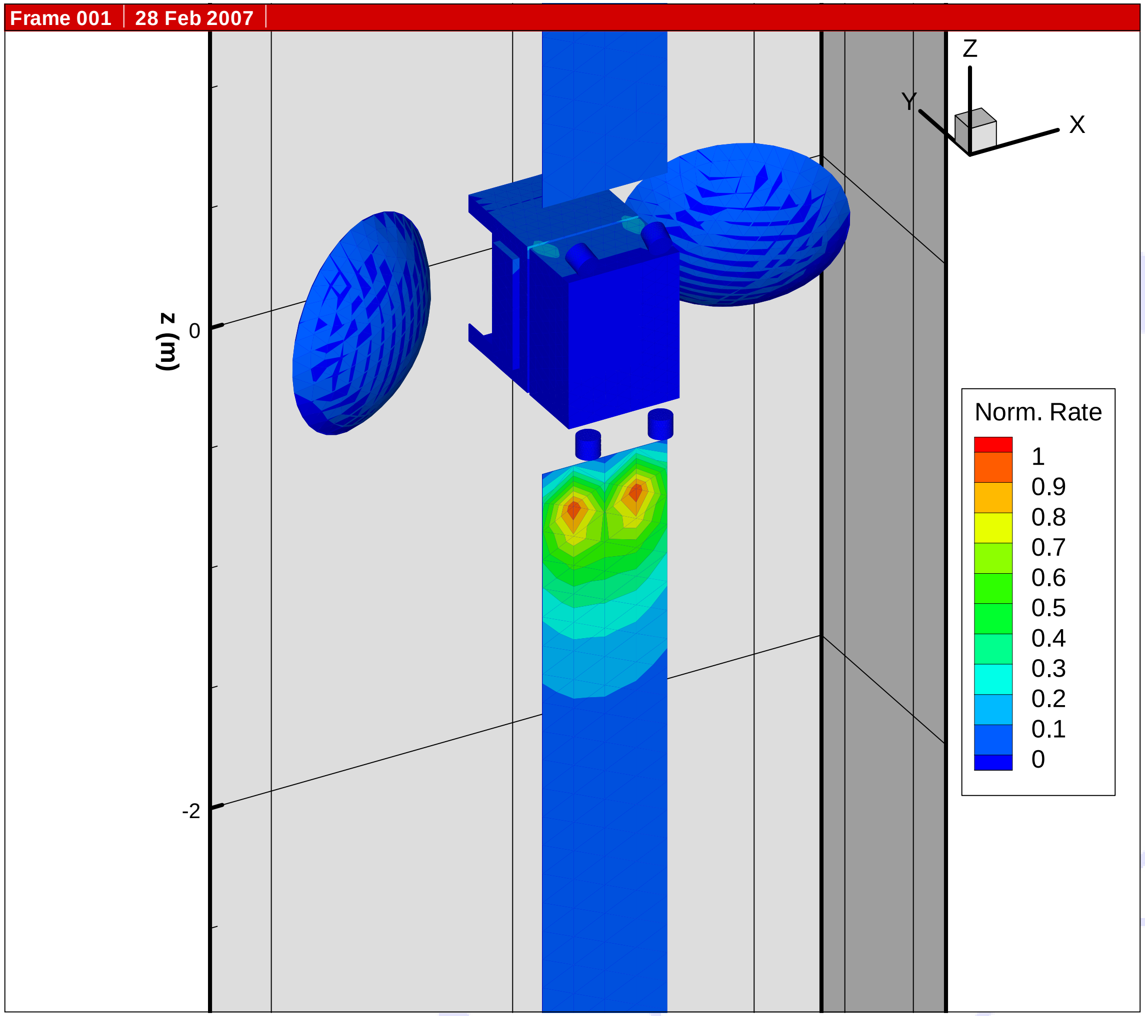
Variable linking in ModelCenter



Cases Analyzed

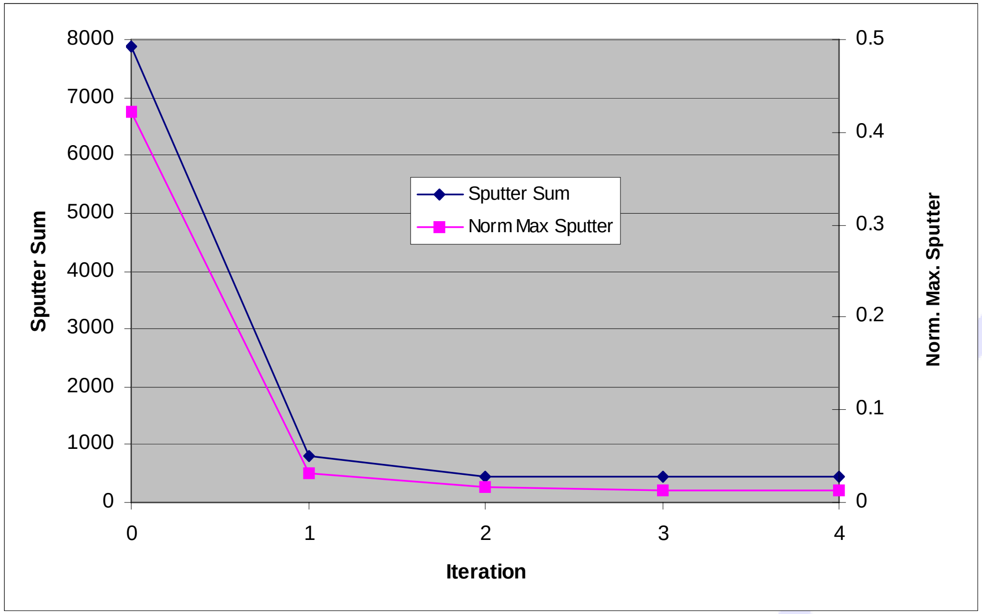
- Case 0: Baseline Case.
  Thrusters 1 and 2 firing in NS-direction, providing thrust for NSSK, thrusters 3 and 4 used for torque compensation
- Case 1: Symmetric Case.
  Thrust angle of thrusters 1 and 2 optimized to minimize sputtering. Thrusters 3 and 4 used for torque compensation.
- Case 2: Solar panels 30 degrees rotated.
  Same as case 1, but non-symmetric.
- Case 3: One Thruster Disabled.
  Only thruster 1 provides thrust for NSSK. Thrusters 3 and 4 used for torque compensation.

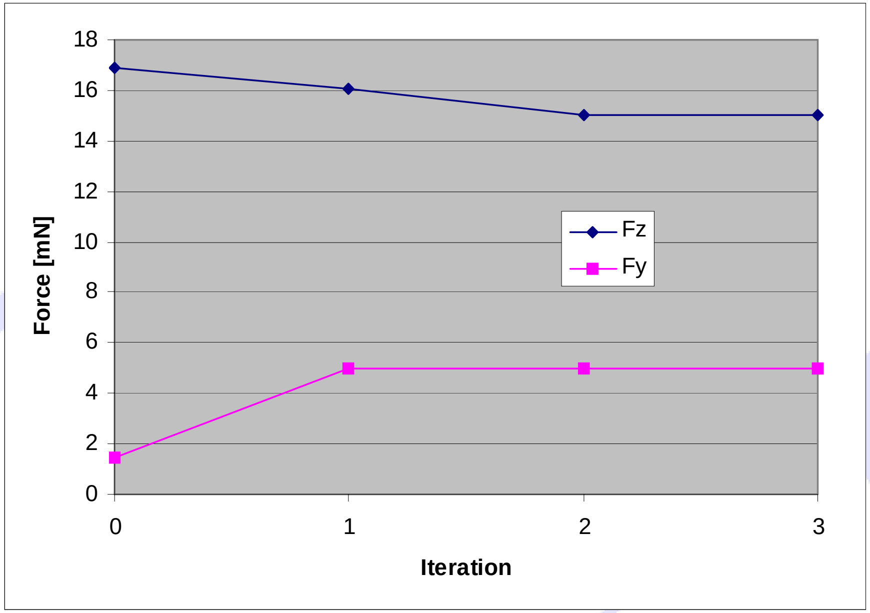
Case 0: Baseline Case



T1 and T2 firing along N-S axis (z), no rotation of thrusters or solar panels. T3 and T4 used for torque compensation. Note sputtering on solar panel.

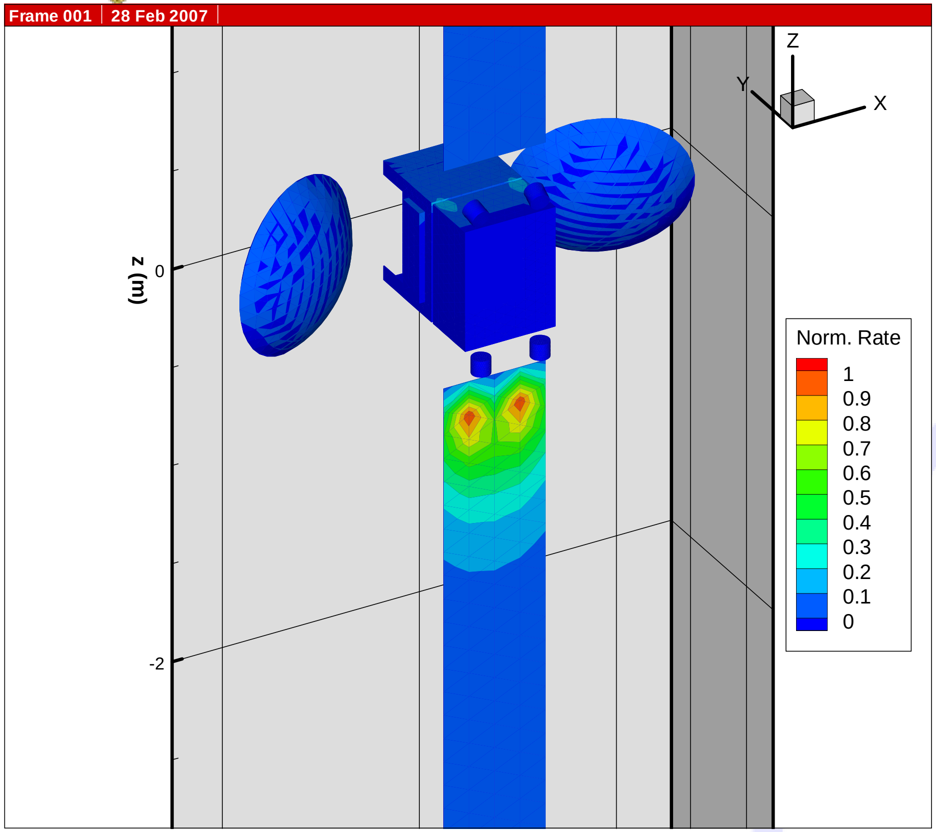
Case 1 Optimization History



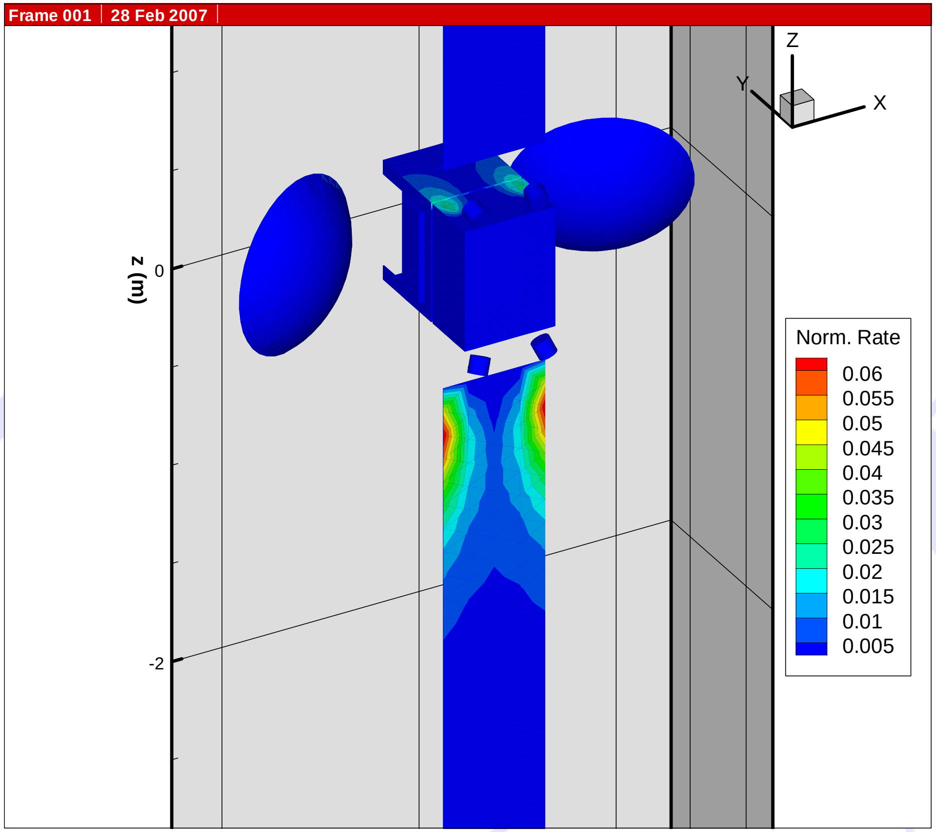


- Sputter sum reduced from 7875 to 808.
- Normalized max sputter reduced from 0.423 to 0.013.
- Fz=15mN/thruster. Fy=5mN (Fx compensated by opposite thruster).
- Rotation angles: rotX=17.1 deg, rotY=-22.6 deg
- Optimizer converged in 3 iterations.

Case 1 Normalized Sputter



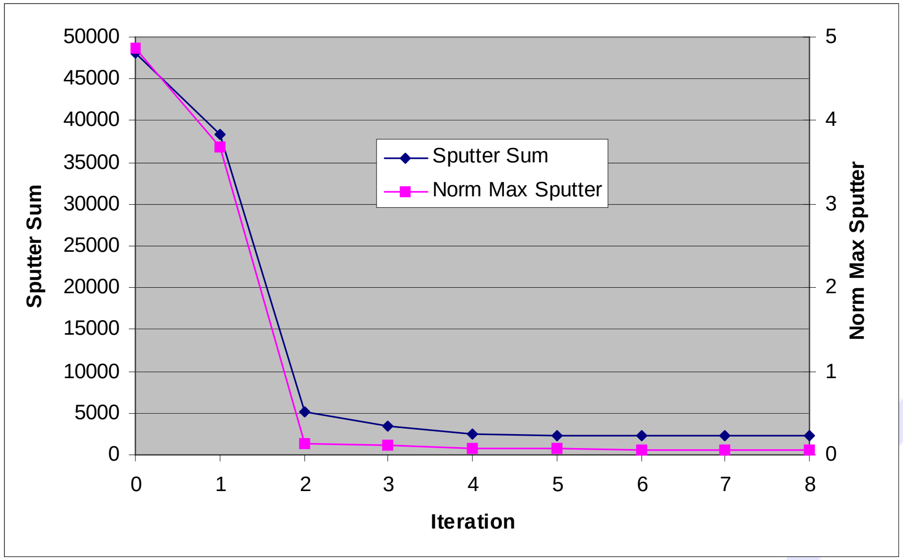
Baseline Case

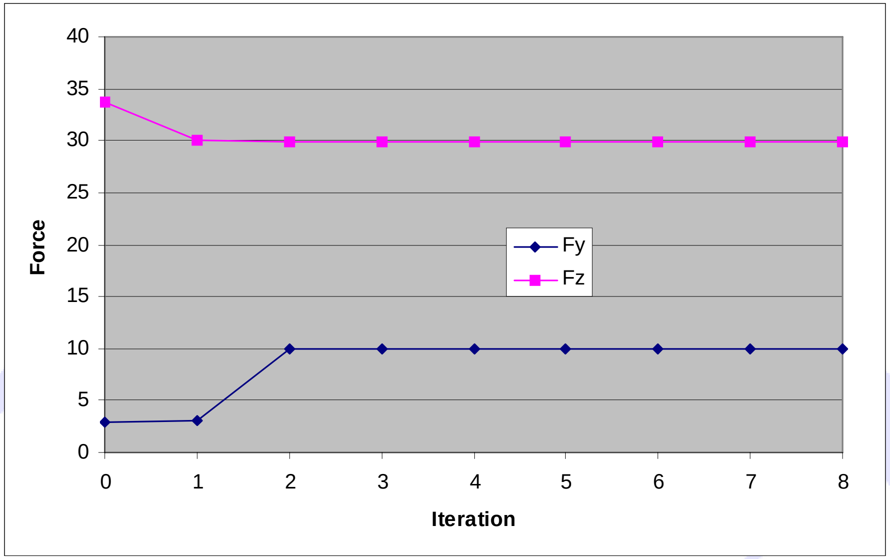


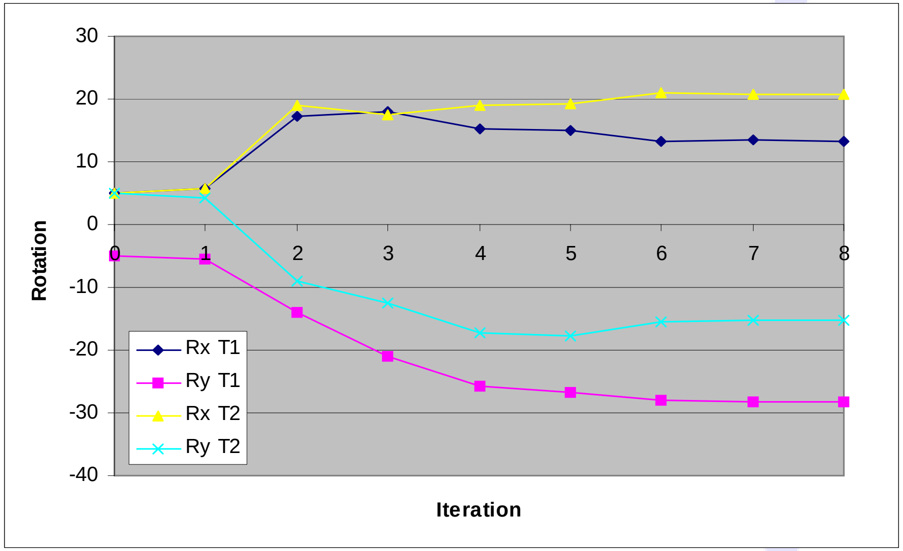
Case 1

- Maximum instantaneous sputter rate less than 6% of baseline case.
- Notice the significantly lower contour levels for the optimized configuration in case 1.

Case 2 Optimization History

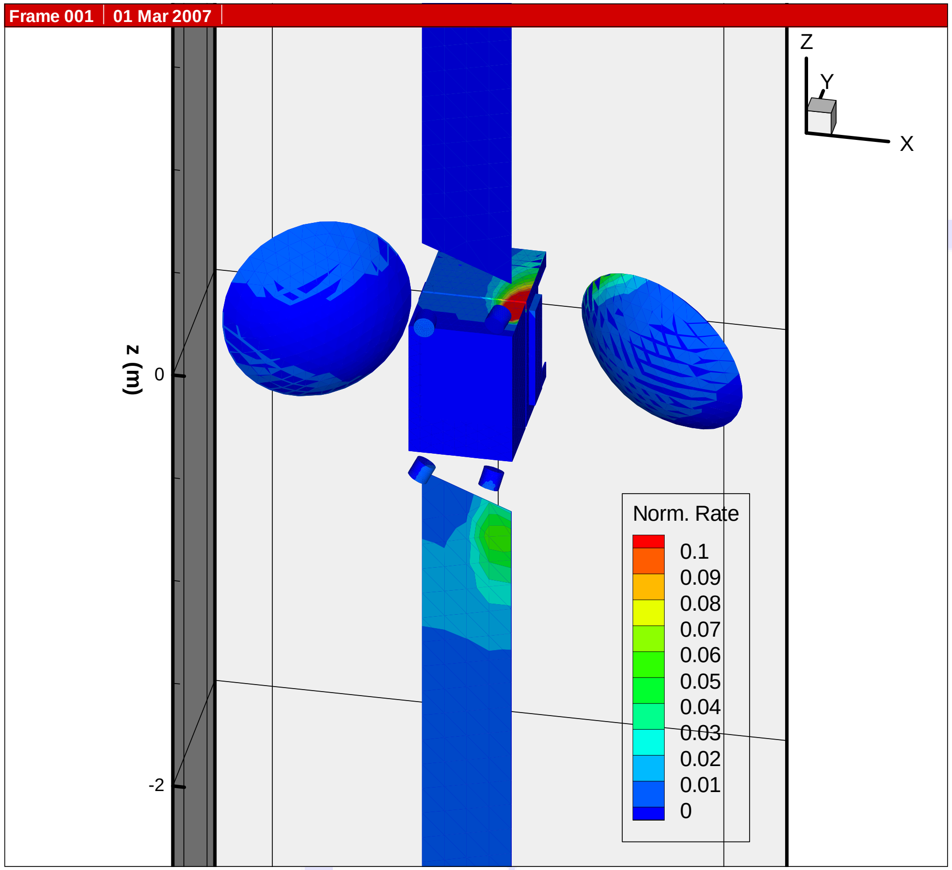






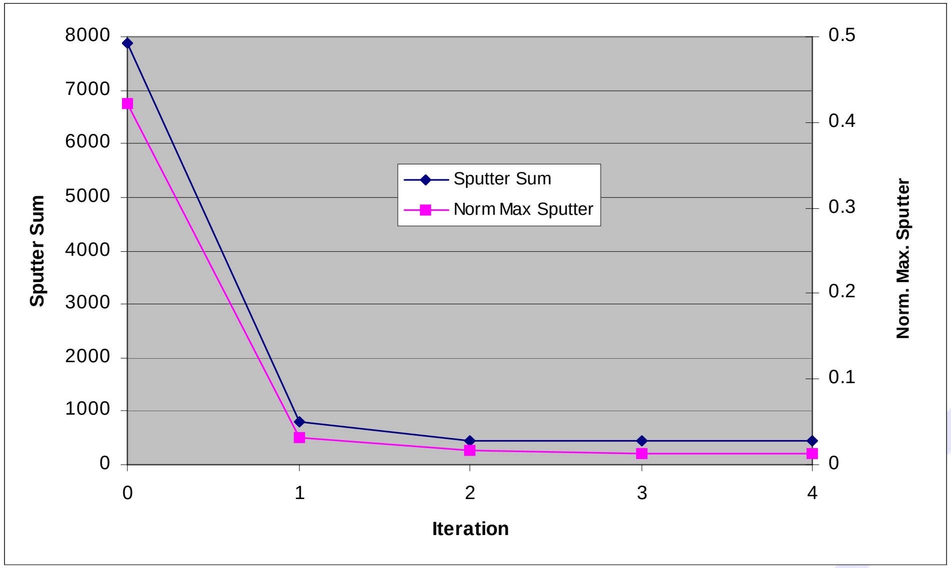
- Sputter sum reduced from 48120 to 2240.
- Normalized max sputter reduced from 4.86 to 0.06.
- Fz=15mN/thruster. Fy=5mN
- Optimizer converged in 8 iterations.

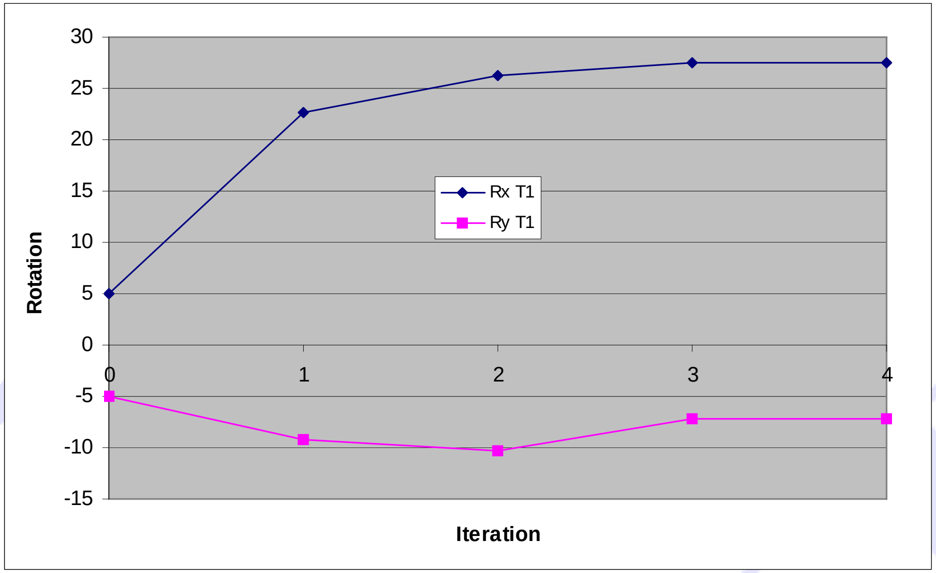
Case 2 Normalized Sputter



- Maximum sputtering caused by thruster 3 on satellite body (used for torque compensation, not considered in optimization)
- Very low sputtering on solar panel surface (the objective of the optimization)

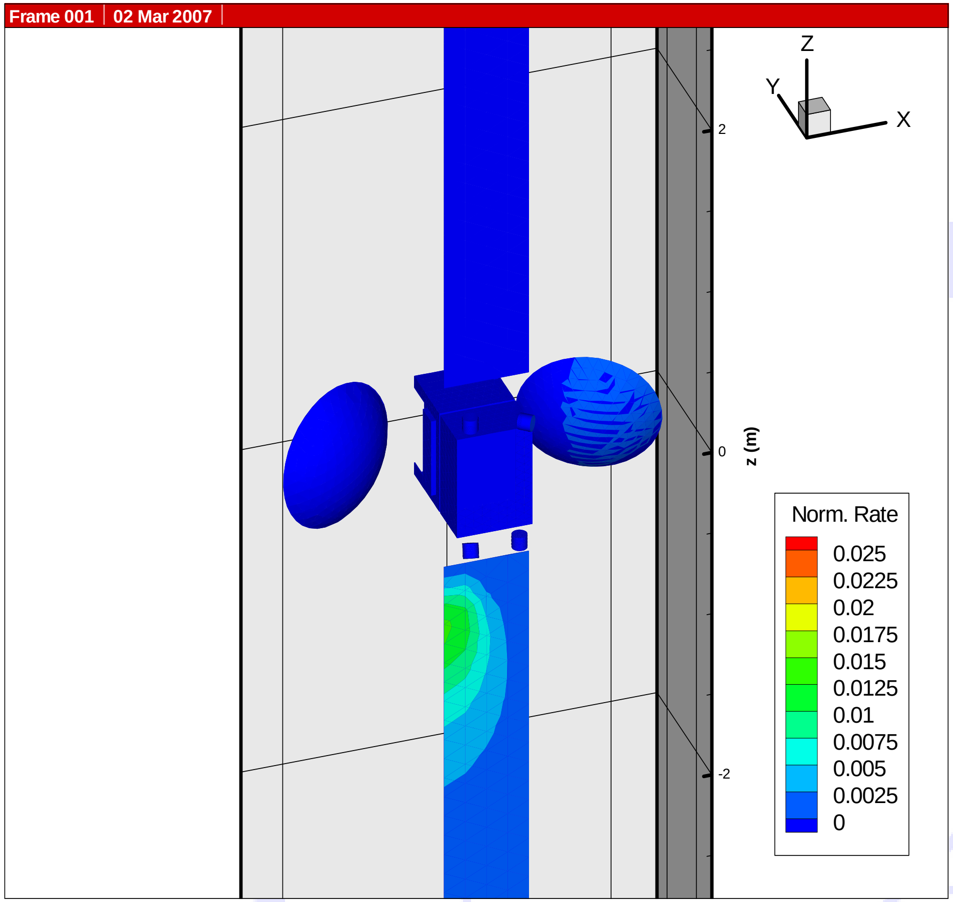
Case 3 Optimization History





- Sputter sum reduced from 7874 to 438.
- Normalized max sputter reduced from 0.423 to 0.013.
- Rotation angles: rotX=27.43 deg, rotY=-7.11 deg
- Optimizer converged in 4 iterations.

Case 3 Normalized Sputter



- Very low sputter rate achieved because no side force constraints were applied.
- Back of dish antenna gets affected by plume of thruster 3.

Conclusions

- Feasibility of sputtering optimization for satellite surfaces demonstrated
- Various sample scenarios considered
- Optimization problem well behaved, default optimizer settings adequate to solve all cases considered
- Sputter rates can be significantly reduced without sacrificing a lot of performance
- Without any changes to the setup, more complex and realistic satellite geometries can be treated
- In a satellite design scenario, placement of components (sensors, antennas) can be optimized

Outlook

- Some minor enhancements to the setup are in progress, for example tracking the COLISEUM sputtering output by component, so that sputtering can be optimized on a component-by-component basis
- We would like to integrate satellite mission/performance simulation code to provide more realistic mission data and performance constraints
- The substitution of ModelCenter with free optimization packages is being investigated so that the tool is more easily deployable to sites without ModelCenter licenses