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Plume Modeling and Application to Mars 2001 Odyssey Aerobraking

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A modified source flow model was used to calculate the plume flowfield from a Mars Odyssey thruster during aerobraking. The source flow model results compared well with previous detailed computational-fluid-dynamics results for a Mars Global Surveyor thruster. Using an isodensity surface for the Odyssey plume, direct simulation Monte Carlo simulations were performed to determine the effect the plumes have on the Odyssey aerodynamics. A database was then built to incorporate the plume effects into six-degree-of-freedom simulations over a range of attitudes and densities expected during aerobraking. Six-degree-of-freedom simulations that included the plume effects showed better correlation with flight data than simulations without the plume effects.

Nomenclature

Cmx	=	coefficient of moment about x
Cmy	=	coefficient of moment about y
Cmz	=	coefficient of moment about z
Cx	=	coefficient of force in x direction
Cy	=	coefficient of force in y direction
Cz	=	coefficient of force in z direction
Mx	=	moment about x, N-m
My	=	moment about y, N-m
Mz	=	moment about z, N-m
n, $n$den	=	number density, molecules/m^3
p	=	pressure, Pa
x	=	distance in x direction, m
y	=	distance in y direction, m
z	=	distance in z direction, m
ρ	=	density
∞	=	at atmosphere

Introduction

NASA'S 2001 Mars Odyssey was launched on 7 April 2001 and arrived at Mars on 24 October 2001. Odyssey's primary mission is to map the chemical elements and minerals in the Martian surface, look for signs of water, and analyze the radiation environment. The Odyssey utilized a technique known as aerobraking to reduce the spacecraft velocity enough to obtain the desired orbit for scientific research. The aerobraking occurred in the upper portions of the Martian atmosphere where the flow over the spacecraft is highly rarefied. During aerobraking, a reaction control system (RCS) was used to maintain the desired spacecraft attitude. The RCS consists of multiple thrusters that can provide moments about the three orthogonal spacecraft axes. When the jets from the thruster firings expand into the vacuum of space or a low-density atmosphere, plumes that can affect the spacecraft are created. The plumes can impinge on the spacecraft and can interact with the flow around the spacecraft, thus altering the aerodynamics. Studies of RCS interactions for Mars Global Surveyor (MGS) found that plume/flowfield interaction effects can be significant.[1,2]

The NASA Langley Research Center (LaRC) provided flight mechanics and atmospheric modeling support for the Mars Odyssey during aerobraking. Part of this support involved providing predictions for each orbit of the aerodynamic behavior of Odyssey. These predictions included a six-degree-of-freedom (DOF) analysis of the spacecraft attitude and attitude rates. All known significant forces were modeled in these analyses, including the forces caused by the RCS thrusters. An aerodynamic database was constructed based largely on direct simulation Monte Carlo (DSMC) simulations and free-molecular flow calculations. This database was initially constructed to provide the aerodynamic force and moment coefficients of Odyssey over the range of expected atmospheric densities and spacecraft attitudes during aerobraking in the absence of RCS thruster firings. The increments in forces and moments on the spacecraft caused by RCS plume impingement and flow interactions were then determined by using an "engineering" model of the plume core flow to provide a set of inflow conditions for further DSMC simulations. The purpose of this paper is to provide a description of this plume model, to describe the implementation of the model for DSMC simulations, and to present results that demonstrate the predicted RCS plume effects on the Odyssey aerodynamics. Validation of the model with a more detailed computational-fluid-dynamics (CFD) model will be discussed, and correlation with flight data will be provided.

Odyssey Spacecraft

The Odyssey spacecraft geometry is shown in Fig. 1 along with two coordinate systems. The coordinate system with the subscript M is the spacecraft mechanical coordinate system, and the system with the subscript B is the Program to Optimize Simulated Trajectories (POST) body-frame coordinate system. POST was used for both three-DOF and six-DOF simulations during LaRC support. The Odyssey RCS thruster arrangement is shown in Fig. 2. The thrusters are canted and not aligned with the mechanical axes to provide three-axis control. All of the RCS thrusters are identical. Thruster characteristics are listed in Table 1.

Aerobraking Conditions

As mentioned earlier, aerobraking occurred in the upper Martian atmosphere where the flow over the spacecraft is rarefied. The flight conditions were chosen to anticipate the range of densities and attitudes the spacecraft would experience during aerobraking. The densities chosen were 1, 3, 10, 32, and 100 kg/km^3, which form

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Table 1 Odyssey RCS nozzle specifications parameters

Parameter	Specification
Thrust	0.8896 N
Exit radius	0.29 cm
Area ratio	100:1
Chamber pressure	2.034 MPa
Chamber temperature	1166.7 K
Exit half-angle	15 deg
Exit Mach number	6.41

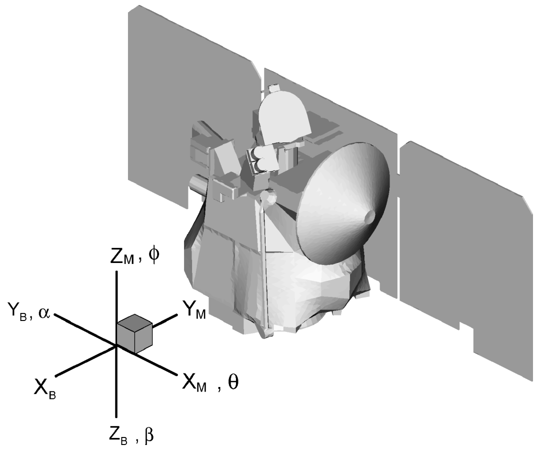

Fig. 1 Odyssey coordinate frames.

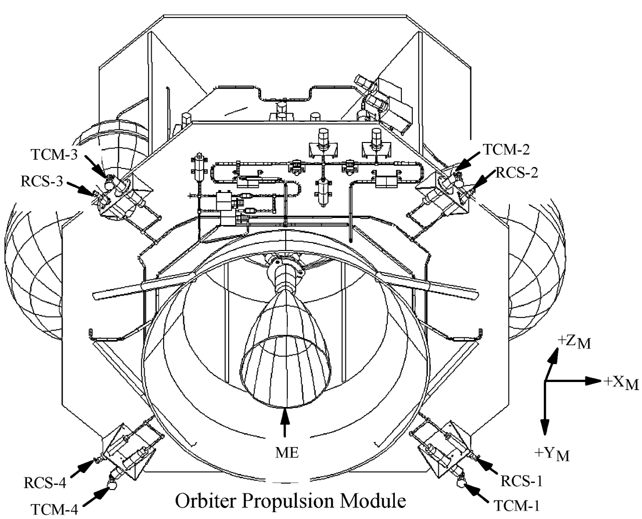

Fig. 2 Odyssey thruster arrangement.

evenly spaced intervals on a log base 10 scale. The range for the attitude chosen was −20 to 20 deg in both pitch and yaw. Other parameters that were used during the DSMC simulations are listed in Table 2.

DSMC

DSMC directly models the molecular physics of a gas flow by simulating the flow of particles. To model the rarefied flow of the Martian atmosphere, DSMC analysis code (DAC) was used.[3] DAC is able to simulate rarefied gas dynamic environments with complex geometries and flowfield characteristics. DAC also has the ability for parallel implementation, thus greatly reducing the amount of wall-clock time for a simulation. The model shown in Fig. 1 represents the actual geometry used for the DSMC simulations. All DSMC simulations were performed by using a variable-hard-sphere model and assumed diffuse wall reflections with full thermal accommodation. The surface temperature was assumed to be constant at 300 K. The DSMC simulations were first run to provide a baseline set of forces and moments without RCS plume effects at the conditions just described. These simulations were then repeated by using the plume model described next to provide inflow conditions representing steady-state plume flow. Simulations were also performed at complete vacuum conditions to provide the forces and moments resulting from plume impingement without any atmospheric flow over the spacecraft. These forces and moments were converted to coefficient form where appropriate based on a spacecraft reference area of 11.03 m^3 and a reference length of 4.74 m.

Table 2 DSMC

Parameter	Specification
Freestream velocity	4,811 m/s
Translational temperature	144.77 K
CO_2 mole fraction	0.9537
N_2 mole fraction	0.0463

Plume Model

RCS plume flows are typically characterized as continuum near the nozzle and then pass though the transition regime before becoming free-molecule flow. In a near vacuum, this expansion occurs within a relatively short distance from the nozzle exit. The plume-flow model used in the present study is based on source-flow principles and was devised by Woronowicz and Rault.[4] Because the model requires the nozzle-exit plane properties, it was necessary to determine the internal nozzle flow.

The internal nozzle flow was computed by using a CFD program called Viscous Nozzle Analysis Program (VNAP).[5] VNAP solves the Navier–Stokes equations with a two-step, predictor-corrector explicit finite difference method. The two-dimensional axisymmetric geometry for one of the RCS thrusters was created with the information about the thrusters listed in Table 1. The nozzle geometry upstream of the throat was approximated for the purpose of the CFD simulation. Source-flow models are basically spatial distribution functions for plume flowfield properties derived from conservation of mass and energy.[4] The Woronowicz model divides the exit plane into many point sources. Each point represents a small section of the nozzle exit and has properties based on the local flow in the nozzle. In the current implementation, an arbitrary plume mesh is created downstream of the nozzle exit. The flowfield contributions at each point in the mesh are calculated for each individual point source, and the results are summed to get the total influence of the sources on the flow properties at each mesh point.

The model developed by Woronowicz uses free-molecule theory to describe the flowfield. Assuming that the flow expands radially from each point source, properties at each mesh point can be calculated using the conservation equations. Although the free-molecular description of the flow is not valid in the continuum core of the plume, it has been found that the radial expansion assumption gives a reasonably accurate approximation of the spatial variations in plume flow properties at sufficiently large distances from the exit. Furthermore, the free-molecular conservation formulation has been shown to capture much of the functional dependence of these properties on nozzle-exit conditions.[4] Empirically derived corrections can then be made to account for nonlinear behaviors caused by phenomena such as plume shocks and boundary-layer expansion.[6]

The boundary between continuum and transitional flow that is used for DSMC simulation is often determined based on the Bird breakdown parameter,[7] which relates the collision length scale to the gradient length scale for density expansion. This approach was used in the work of Glass,[8] which used a full Navier–Stokes CFD computation for the continuum portion of the RCS plume for MGS. However, with the current simple source-flow model such an approach is neither practical nor accurate. The source-flow theory does not accurately capture the detailed density gradients in the continuum portion of the plume, and computation of the Bird breakdown parameter from the flowfield is likely to produce significant errors. Because the objective of the current work is to capture the first-order plume impingement and flow interaction effects, an alternate scheme was chosen that is expected to satisfy these objectives.

To create a surface for the DAC simulations, an isodensity surface was chosen based on the momentum ratio of the plume to the freestream flow. A momentum ratio of 100 was chosen. Because the plume surface was modeled as an outgassing surface in DAC, that is, particles can only flow out of the surface and not into it, the momentum ratio has to be high enough that only a negligible amount of atmosphere particles can penetrate the plume. If the ratio is too low, the amount of particles penetrating the plume will no longer be negligible, and error will be introduced into the calculations.

Results

Plume Flowfield

The nozzle-exit properties are given along a line from the centerline of the nozzle to the nozzle wall. With the assumption that the flow at the exit is symmetric, the solution along a radial line is propagated 360 deg about the centerline to form a two-dimensional exit plane solution. This solution was input into the source-flow model.

The plume number density contour predicted by the source-flow model for an Odyssey thruster is shown in Fig. 3. Inaccuracies occur near the nozzle exit, but the plume contour lines show the behavior typically expected for a radially expanding flow farther away from the exit. Based on the momentum ratio described earlier, a number density of 6.1×10^{20} molecules/m^3 was used to extract an isodensity surface of the plume. The plume surface corresponding to this density is shown in Fig. 4.

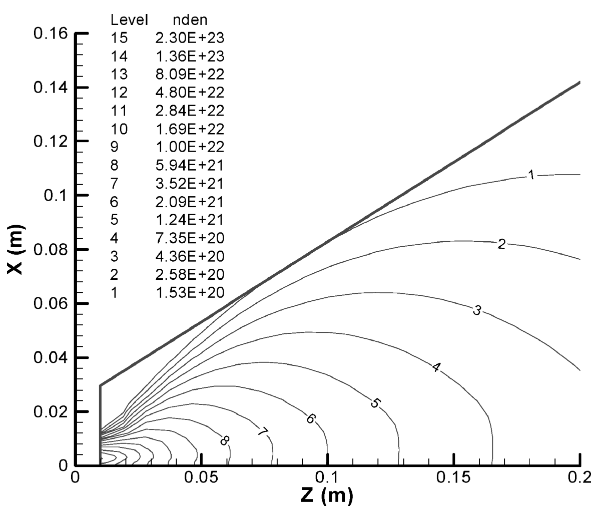

Fig. 3 Plume number density contours for an Odyssey thruster.

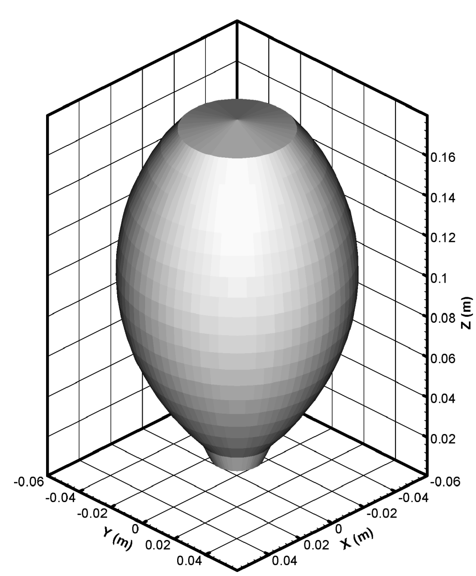

Fig. 4 Isodensity plume surface for an Odyssey thruster: momentum ratio = 100; $n = 6.1 \times 10^{20}$/m^3.

MGS Plume Comparison

Because CFD results were already available for an MGS thruster,[8] which has similar characteristics to the Odyssey thruster, the MGS plume was selected to validate the current source-flow model. Again, VNAP was used to calculate the internal nozzle flow, and then the source-flow program was used to determine the plume flowfield. Figure 5 compares the number density along the plume centerline for the CFD results and for the source-flow program results. The results match up well except in the proximity of the nozzle exit, where the source-flow program is not considered accurate. An individual number density contour line ($n$den = 2.0946E+22 molecules/m^3) from the CFD results is compared to the same number density contour line from the source-flow program results in Fig. 6. The CFD results show a flowfield that is slightly more elongated than the source flow plume flowfield, but overall the two show good correlation.

Baseline Aerodynamics

DAC simulations were first made with the spacecraft at nominal attitude (zero pitch and yaw) with respect to the freestream velocity for the varying densities with no RCS plumes present. The aerodynamic coefficients predicted by these simulations are included in Table 3. The moments were shifted to be about the spacecraft center of mass during the midpoint of aerobraking. The center of mass used was $x = -0.0629$ m, $y = -0.0172$ m, and $z = 1.11$ m in the body coordinate system.

One of the first things that can be observed from Table 3 is that the vehicle in the nominal attitude is not at the trim angle. This is evident from the fact that there are nonzero aerodynamic moments on the spacecraft, whereas a vehicle at trim angle would have virtually no moments. The coefficient of force in the Y direction is much larger

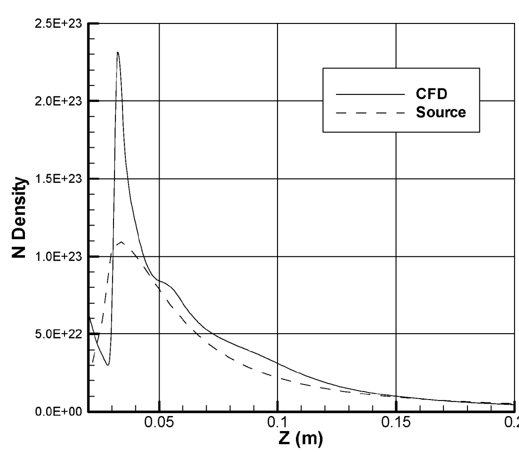

Fig. 5 Comparison of plume centerline number density between the source-flow code and CFD for MGS plume.

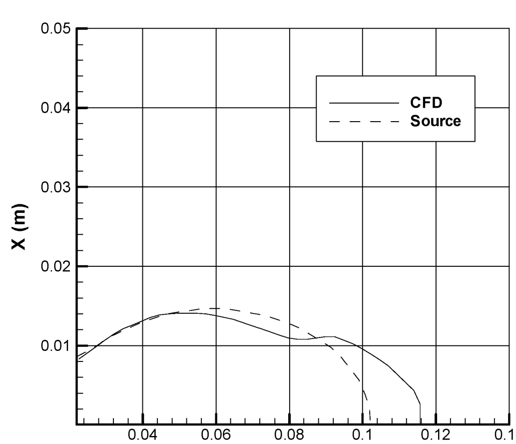

Fig. 6 Plume contour comparison between the source flow code and CFD for MGS: number density: $n$den = 2.0946E+22 molecules/m^3.

Table 3 Aerodynamic coefficients with varying densities about c.m. for Mars Odyssey

Coefficient	1 kg/km^3	3 kg/km^3	10 kg/km^3	32 kg/km^3	100 kg/km^3
Qinf	0.0116	0.0366	0.1157	0.3659	1.1569
Cx	−0.0002	0.0001	0.0005	0.0021	0.0059
Cy	2.1322	2.1046	2.0588	2.0203	1.9457
Cz	−0.0041	−0.0061	−0.0106	−0.0182	−0.0286
Cmx	0.0048	0.0047	0.0044	0.0043	0.0043
Cmy	−0.0005	−0.0008	−0.0013	−0.0012	−0.0014
Cmz	0.0301	0.0300	0.0284	0.0277	0.0255

Table 4 Aerodynamic coefficients about c.m. for Mars Odyssey with plumes, density = 100 kg/km^3

Coefficient	s/c[a]	s/c and RCS-1	s/c and RCS-2
Cx	0.0059	0.0054	0.0070
Cy	1.9457	1.9161	1.9577
Cz	−0.0286	−0.0163	−0.0199
Cmx	0.0043	0.0017	0.0044
Cmy	−0.0014	−0.0093	−0.0071
Cmz	0.0255	0.0160	0.0326

[a]s/c = Spacecraft.

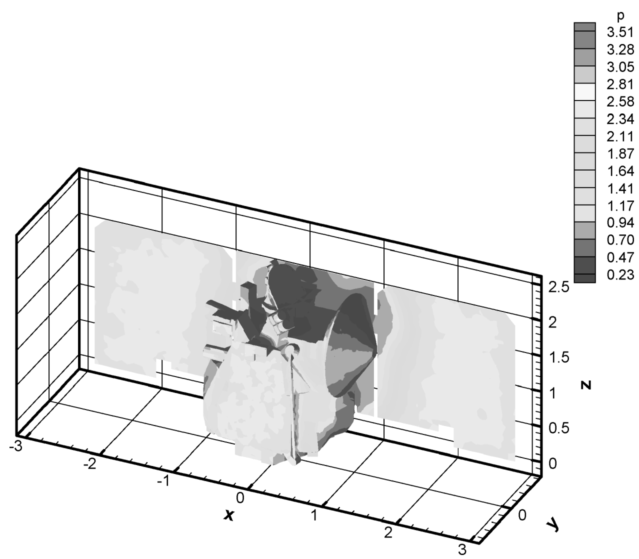

Fig. 7 Odyssey pressure contour, no plumes: $\rho_\infty = 100$.

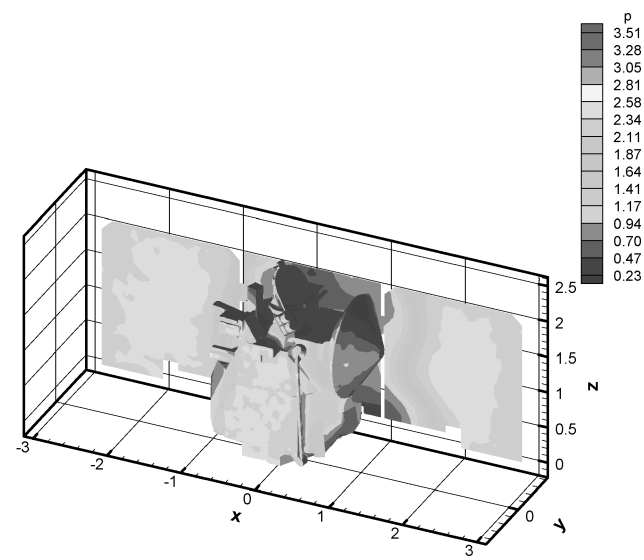

Fig. 8 Odyssey pressure contour, RCS-1 plume: $\rho_\infty = 100$ kg/km^3.

than the other coefficients because the freestream velocity is in the Y direction. The surface pressure contours on the Odyssey with a freestream density of 100 kg/km^3 are shown in Fig. 7. The values from these DSMC simulations will serve as comparisons for later simulations with the plumes added.

RCS Study

The RCS thrusters for Odyssey can be fired individually or in combinations of two thrusters. However, it was decided to consider just one plume initially, so that the influence of the plume impingement and atmosphere interaction effects could be determined without having to consider possible plume-plume interaction effects. Based on the symmetry of the spacecraft and the RCS thrusters, two cases were chosen, one with the RCS-1 thruster firing and one with the RCS-2 thruster firing. To obtain the maximum possible plume-flowfield interaction effects, these cases were performed at the atmospheric density of 100 kg/km^3. The aerodynamic results of these DSMC simulations are shown in Table 4. These results represent only aerodynamic and impingement forces and do not include the thrust from the firing. The aerodynamic coefficients from the preceding simulations with no plumes at the same atmospheric density are included in the table for comparison. It can be seen that both RCS-1 and RCS-2 plumes have a small but observable impact on the coefficients of forces and moments on the spacecraft. The surface-pressure contours with RCS-1 firing and RCS-2 firing are shown in Figs. 8 and 9, respectively. The direct impingement of the plume onto the solar panel is evident for RCS-2. This direct impingement occurs because the RCS-2 nozzle is canted toward the panel.

It is now important to determine how these moment coefficients compare to those caused by the RCS thrust. The forces are not included in this comparison because the attitude is the primary concern of this study. Tables 5–7 show the moment coefficients caused by aerodynamics only, thrust only, and the combination of the two. From Tables 5–7, it can be seen that the plume impingement and aerodynamic moments are smaller than the thrust moments, but are of a comparable magnitude. Because the plumes induce moments that sometimes oppose the thrust moments, it is important that RCS effects be considered in any six-DOF simulations of the spacecraft attitude and attitude rates with RCS firings.

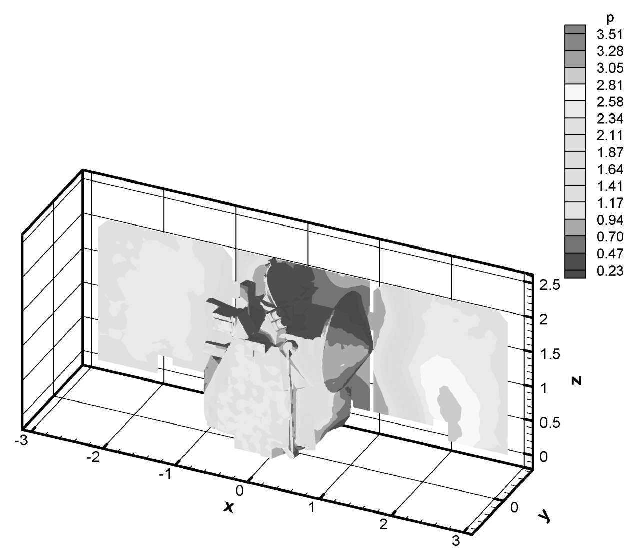

Fig. 9 Odyssey pressure contour, RCS-2 plume: $\rho_\infty = 100$ kg/km^3.

RCS interactions during aerobraking are composed of two components: impingement and atmosphere interaction. It is possible to look at the effect of each of these components separately by analyzing the same cases with a zero-density atmosphere. With no atmosphere, all of the forces and moments on the spacecraft will be a result of plume impingement only. With the assumption that the plume impingement forces do not change even with the addition of an atmosphere, then the plume-flowfield interaction forces and moments can be calculated as the difference between the forces and moments caused by the RCS firing with and without an atmosphere. The assumption that the impingement forces do not change is probably a reasonable assumption because the spacecraft is in the low-density rarefied flow regime for all densities of interest. The breakdown between moments caused by plume impingement and plume-flowfield interaction for RCS-2 is shown in Table 8. The table also includes the moments caused by thrust only to serve as a comparison of magnitudes. The plume impingement moments are larger in magnitude than the plume-flowfield interaction moments but in opposite directions for the x and z components. The combined moments caused by the RCS-2 firing are all in the opposite direction of the thrust. The thrust has the larger magnitude, but because of the RCS-2 aerodynamic effects the thrusters effectiveness could be reduced.

Table 5 Breakdown of RCS aerodynamic forces, density = 100 kg/km^3: moment coefficients about c.m., aerodynamic forces only

Coefficient	s/c	s/c and RCS-1	s/c and RCS-2
Cmx	0.0043	0.0017	0.0044
Cmy	−0.0014	−0.0093	−0.0071
Cmz	0.0255	0.0160	0.0326

Table 6 Breakdown of RCS aerodynamic forces, density = 100 kg/km^3: moment coefficients about c.m., thrust forces only

Coefficient	s/c	s/c and RCS-1	s/c and RCS-2
Cmx	0.0000	0.0037	−0.0037
Cmy	0.0000	0.0132	0.0132
Cmz	0.0000	0.0128	−0.0123

Table 7 Breakdown of RCS aerodynamic forces, density = 100 kg/km^3: moment coefficients about c.m., thrust and aerodynamic forces

Coefficient	s/c	s/c and RCS-1	s/c and RCS-2
Cmx	0.0043	0.0053	0.0007
Cmy	0.0014	0.0039	0.0062
Cmz	0.0255	0.0288	0.0203

Table 8 RCS-2 plume impingement and flowfield interaction effects about c.m., density = 100 km/kg^3

Coefficient	A[a]	B[b]	C[c]	D[d]	E[e]	F[f]
Cmx	0.0043	0.0044	0.0001	0.0033	−0.0032	−0.0037
Cmy	−0.0014	−0.0071	−0.0057	−0.0032	−0.0025	0.0132
Cmz	0.0255	0.0326	0.0071	0.0101	−0.0030	−0.0123

[a]A = aerodynamic moments on Odyssey, no RCS.
[b]B = aerodynamic moments on Odyssey, with RCS-2.
[c]C = total RCS-2 interaction (B-A).
[d]D = RCS-2 impingement.
[e]E = RCS-2 flowfield interaction (C-D).
[f]F = RCS-2 thrust only.

RCS Database Construction

The task shifts to incorporating the plume effects into a POST six-DOF simulation of Odyssey during aerobraking. For the simulation, specific combinations of RCS thrusters fire when the Odyssey attitude or attitude rates exceed certain critical values. A database had already been constructed for the POST six-DOF simulations to give the aerodynamic coefficients for the Odyssey as a function of attitude and density in the absence of RCS firings. A new database was constructed that compliments the original database and includes the change in aerodynamic coefficients as a result of the RCS firings over a range of attitudes and atmospheric densities.

A procedure was developed that incorporates the RCS aerodynamic effects for POST simulations. The procedure requires the attitude, in POST coordinate frame, density, and thruster on/off as input. The database is then called to determine the change in aerodynamic coefficients. Linear interpolation is used to interpolate coefficients as a function of attitude and density.

To complete the database in the timeframe needed, some simplifying assumptions were made. The first major assumption was that superposition holds. To test this assumption, three situations were examined: superposition with RCS-2 and RCS-3, with RCS-1 and RCS-3, and with RCS-1 and RCS-2. Refer to Tables 9–11 for the results (in dimensional form). For example purposes, the focus will be on the superposition using RCS-2 and RCS-3. At nominal attitude and a density of 100 kg/km^3, four simulations were performed. The first simulation was with no plumes. Then two simulations were performed, one with only RCS-2 firing and another with only RCS-3 firing. With these three simulations, the change in coefficients caused by RCS-2 and RCS-3 was determined separately. Based on the assumption of superposition, a simulation with both RCS-2 and RCS-3 firings should give the same change in coefficients as just adding the two separate changes in coefficients. The two separate sets of delta coefficients were then added and compared to the increments obtained from a DSMC simulation with both RCS-2 and RCS-3 firings simultaneously. The difference between the actual values and the superposition-approximated values are shown in column 8 of Table 9. The superposition assumption for this case appears to be reasonably good, with errors less than 10% of the total

Table 9 Superposition of RCS effects for multiple thruster firings about the c.m., density = 100 km/kg^3: RSC-2 and RCS-3

Moment	(1) s/c alone	(2) s/c and RCS-2	(3) s/c and RCS-3	(4) = (2)−(1) RCS-2 alone	(5) = (3)−(1) RCS-3 alone	(6) Thrust alone	(6) = (1) + (4) + (5) Superposition	(7) s/c and RCS-2 and RSC-3	(8) = (7) − (6) Error
Mx	0.2606	0.2659	0.2445	0.0053	−0.0160	−0.4571	0.2499	0.2787	0.0288
My	−0.0826	−0.4289	0.2192	−0.3463	0.3019	0.0194	−0.1271	−0.1265	0.0006
Mz	1.5443	1.9722	1.1573	0.4279	−0.3870	−0.0466	1.5852	1.5048	−0.0804

Table 10 Superposition of RCS effects for multiple thruster firings about the c.m., density = 100 km/kg^3: RSC-1 and RCS-3

Moment	(1) s/c alone	(2) s/c and RCS-1	(3) s/c and RCS-3	(4) = (2) − (1) RCS-1 alone	(5) = (3) − (1) RCS-3 alone	(6) Thrust	(6) = (1) + (4) + (5) Superposition	(7) s/c and RCS-1 and RCS-3	(8) = (7) − (6) Error
Mx	0.2606	0.1002	0.2445	−0.1603	−0.0160	−0.0053	0.0842	0.1104	0.0262
My	−0.0826	−0.4939	0.2192	−0.4113	0.3019	0.0194	−0.1921	−0.2273	− 0.0353
Mz	1.5443	0.9685	1.1573	−0.5758	−0.3870	1.4734	0.5816	0.5757	−0.0059

Table 11 Superposition of RCS effects for multiple thruster firings about the c.m., density = 100 km/kg^3: RSC-1 and RCS-2

Moment	(1) s/c alone	(2) s/c and RCS-1	(3) s/c and RCS-2	(4) = (2) − (1) RCS-1 alone	(5) = (3) − (1) RCS-2 alone	(6) Thrust	(6) = (1) + (4) + (5) Superposition	(7) s/c and RCS-1 and RCS-2	(8) = (7) − (6) Error
Mx	0.2606	0.1002	0.2659	−0.1603	0.0053	−0.0053	0.1056	0.0660	−0.0396
My	−0.0826	−0.4939	−0.4289	−0.4113	−0.3463	1.6026	−0.8402	−0.6931	0.1472
Mz	1.5443	0.9685	1.9722	−0.5758	0.4279	0.0273	1.3965	1.5190	0.1225

moment. It is also shown to be a good assumption for the other two cases as well. Superposition eliminates the need to perform DSMC simulations for combinations of thruster firings, including thruster firings that result in plume-plume interactions.

The next major assumption is that the change in coefficients caused by RCS-3 and RCS-4 firings can be determined from the change in coefficients caused by RCS-2 and RCS-1 firings, respectively. This assumption is made possible by the symmetry of the spacecraft.

Additional DSMC simulations were performed to develop a database for the nominal attitude at each density. Then an interpolation scheme was developed to interpolate values between densities. It is assumed that the RCS increments for different attitudes will vary with density in a similar manner. Additional DSMC simulations were then performed at attitudes of ± 15 deg in pitch and yaw to provide sufficient data to define variations in the RCS increments with attitude. The database was enhanced utilizing a curve-fitting technique. This technique was used to expand the database into coefficients at 5- deg increments with respect to pitch and yaw from -20 to 20 deg for the full range of densities.

Six-DOF Simulations

A POST six-DOF simulation was compared to flight data for typical densities experienced during an aerobraking pass. Orbit 24 was chosen to represent the average pass. Two six-DOF simulations were performed for this orbit, one with the RCS plume effects subroutine active and one with it inactive. The attitude rates for this pass are shown in Fig. 10. For the roll rate, there are significant differences between simulation and flight data, and including the RCS plume effects subroutine improves the prediction by about a factor of two. For the pitch rate and the yaw rate, there is more reasonable agreement between simulation and flight data, and RCS firings have little effect until the end of the pass.

The attitude for the pass is shown in Fig. 11. Here, there is a noticeable effect on the simulation results caused by the inclusion of the RCS plume effects model. The model greatly improves the predictions after periapsis in roll, pitch, and yaw. Overall the RCS model allows the POST six-DOF simulations to match more closely with the actual Odyssey flight data. Orbit 24 represents the typical aerobraking pass, and a similar conclusion can be drawn for most other passes.

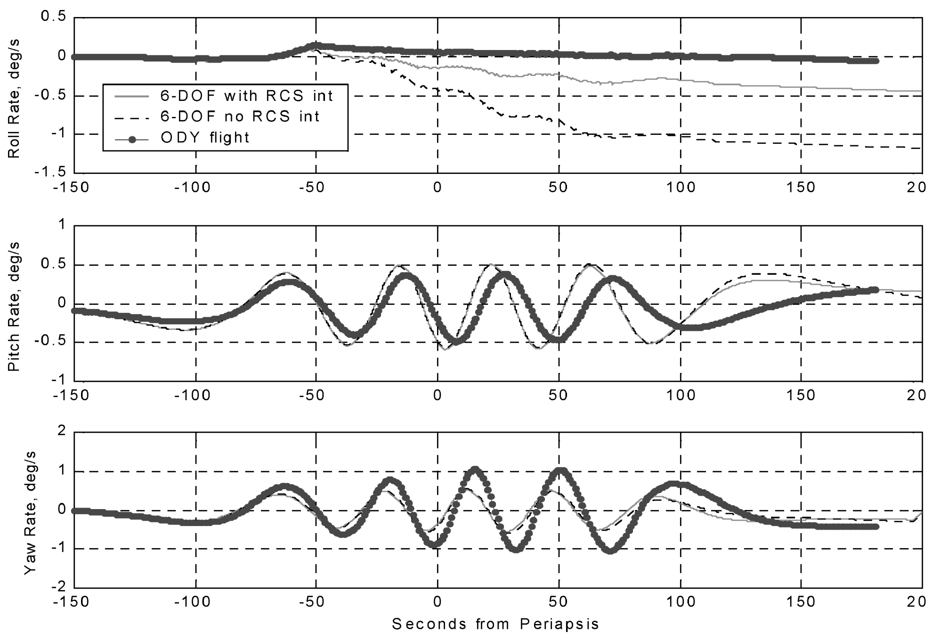

Fig. 10 Attitude rates comparison of six-DOF simulation to Odyssey flight data, orbit 24, RCS model active.

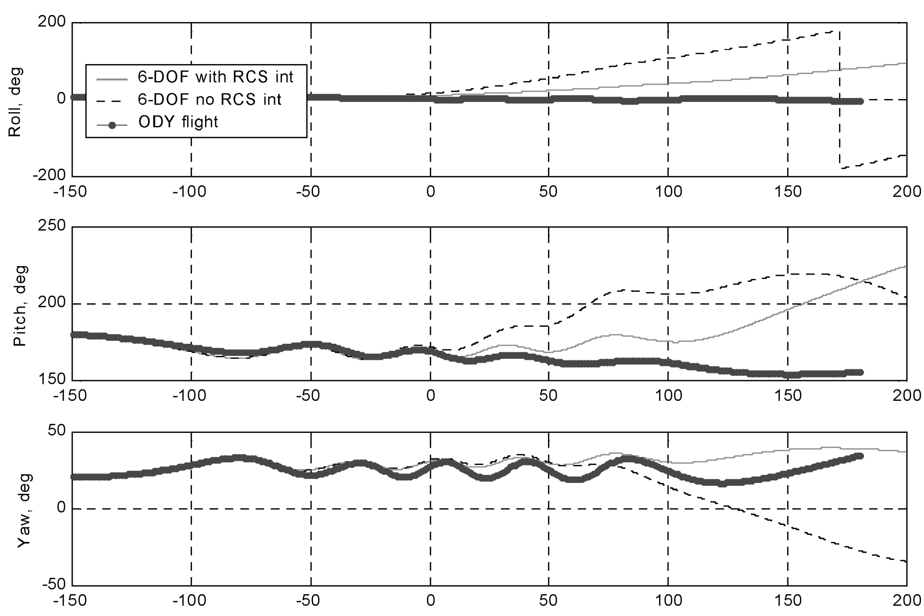

Fig. 11 Attitude comparison of six-DOF simulation to Odyssey flight data, orbit 24, RCS model active.

Conclusions

A source-flow program was used to determine the plume flowfield for the Odyssey RCS thrusters. The program was also used to determine the plume flowfield for an MGS thruster and compared to the results obtained using a detailed CFD analysis. The results compared favorably. The source-flow code gave reasonably accurate results with minimal computational time required.

A study of the RCS effects on the Odyssey aerodynamics was then performed. Assumptions were made based on the symmetry of the spacecraft and superposition that reduced the number of DSMC simulations necessary. The assumptions proved to be reasonable. An RCS database of the change in aerodynamic coefficients caused by the plumes was constructed through a series of DSMC simulations coupled with a curve-fitting technique. Inclusion of the RCS plume effects in POST six-DOF simulations proved to significantly increase the accuracy of the predictions in roll rate and the spacecraft attitude.

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Guest Editor