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CNES-NASA STUDIES OF THE MARS SAMPLE RETURN ORBITER AEOCAPTURE PHASE

H.FRAYSSE*, R.POWELL**, S.ROUSSEAU*, S.STRIEPE**

* Centre National d'Etudes Spatiales, 18, avenue Edouard Belin, 31401 Toulouse Cedex 4, France

** NASA-Langley Research Center, 8 Langley Boulevard, Hampton, Virginia 23681-0001, USA

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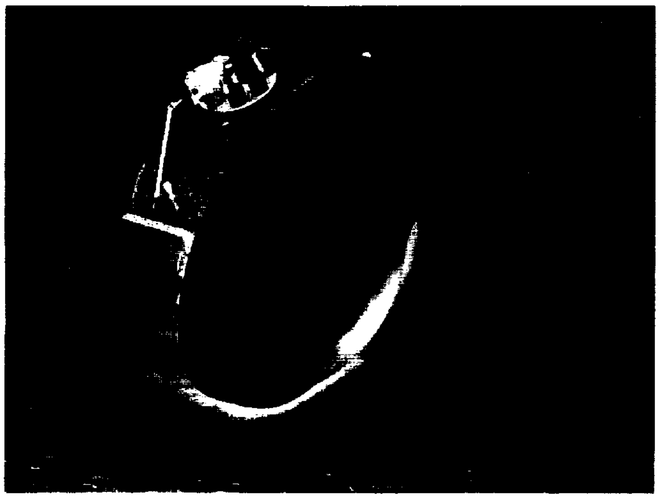


Abstract

A Mars Sample Return (MSR) mission has been proposed as a joint CNES and NASA effort in the ongoing Mars Exploration Program. The MSR mission is designed to return the first samples of Martian soil to Earth. The primary elements of the mission are a lander, rover, ascent vehicle, orbiter, and an Earth entry vehicle. The Orbiter has been allocated only 2700kg on the launch phase to perform its part of the mission. This mass restriction has led to the decision to use an aerocapture maneuver at Mars for the orbiter. Aerocapture replaces the initial propulsive capture maneuver with a single atmospheric pass. This atmospheric pass will result in the proper apoapsis, but a periapsis raise maneuver is required at the first apoapsis. The use of aerocapture reduces the total mass requirement by ~45% for the same payload. This mission will be the first to use the aerocapture technique. Because the spacecraft is flying through the atmosphere, guidance algorithms must be developed that will autonomously provide the proper commands to reach the desired orbit while not violating any of the design parameters (e.g. maximum deceleration, maximum heating rate, etc.). The guidance algorithm must be robust enough to account for uncertainties in delivery states, atmospheric conditions, mass properties, control system performance, and aerodynamics. To study this very critical phase of the mission, a joint CNES-NASA technical working group has been formed. This group is composed of atmospheric trajectory specialists from CNES, NASA-Langley Research Center and NASA-Johnson Space Center. This working group is tasked with developing and testing guidance algorithms, as well as cross-validating CNES and NASA flight simulators for the Mars atmospheric entry phase of this mission. The final result will be a recommendation to CNES on the algorithm to use, and an evaluation of the flight risks associated with the algorithm. This paper will describe the aerocapture phase of the MSR mission, the main principles of the guidance algorithms that are under development, the atmospheric entry simulators developed for the evaluations, the process for the evaluations, and preliminary results from the evaluations.

Acronyms

AFE: Aeroassist Flight Experiment
CNES: Centre National d'Etudes Spatiales
EMCD: European Martian Climate Database
FPA: Flight Path Angle
$\dot{h}$: Altitude rate
IMU: Inertial Measurement Unit
JPL: Jet Propulsion Laboratory
L/D: Lift-to-drag-Ratio
MarsGRAM: Mars Global Reference Atmosphere Model
MCI: Mars Centered Inertial
MCMF: Mars Centered Mars Fixed
MSR: Mars Sample Return
NASA: National Aeronautics and Space Administration
3DOF: Three Degrees Of Freedom
6DOF: Six Degrees Of Freedom

Introduction

The Mars Sample Return (MSR) has been proposed as a French-US mission in the framework of the Mars Exploration Program. Its purpose will be to bring back Martian samples and to deploy a geophysical station network (the Netlander network). The initial timeline had the mission occurring in the 2005 timeframe. The Mars exploration program is currently under review, and the current timeline for the MSR mission is not known. All the comments, results, scenarios, etc. that follow in this paper deal with the originally designed MSR mission.

Two kinds of vehicles were to be used. The US would launch one or two landers to Mars in order to collect samples and put them into a Martian orbit. The Ariane 5 would launch a French orbiter. Its mission consists of delivering the Netlander then collecting the samples and bringing them back to Earth. During the Mars approach phase, Netlanders would be targeted to their atmospheric entry points and released, and then the orbiter would prepare for the Mars insertion phase.

Any insertion around Mars requires a significant decrease of the spacecraft arrival energy. For this mission, the required velocity change is generally greater than 1.5 km/s to reach the desired apoapsis. Traditionally, the insertion is achieved by a propulsive maneuver at the periapsis of the hyperbolic arrival orbit to put the spacecraft in an elliptic orbit around the planet. Other maneuvers are then performed to correct the orbital elements to attain the desired mission orbit. This second part of the insertion has been done two ways. The first, as employed by Viking, is to use the propulsion system. The second, as used by Mars Global Surveyor, and will be used by the Mars Surveyor 2001 Orbiter, is aerobraking. For aerobraking, the spacecraft uses multiple passes through the upper atmosphere to gradually reduce the apoapsis to that required for the mission. Using this methodology, a significant amount of propellant is saved, however a long (weeks) and complex operational sequence is needed before reaching the final orbit.

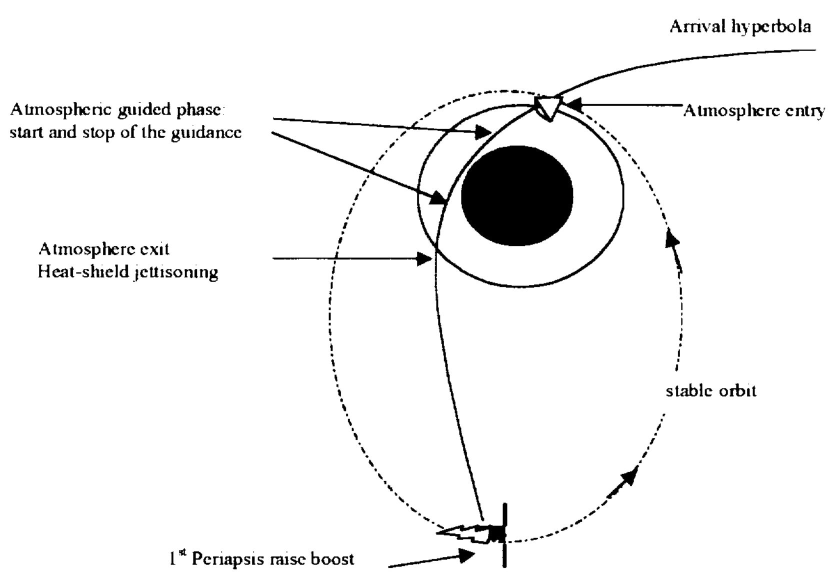
Another solution is to use the aerocapture technique. Aerocapture replaces the initial propulsive capture maneuver with an atmospheric pass; in general, its captured orbit is closer to the desired orbit than the captured orbit resulting from the use of propulsive capture followed by aerobraking. In addition, aerocapture requires less fuel than aerobraking. Up to now, this insertion method has never been used for space missions. For the MSR orbiter, aerocapture was chosen because this provided the best solution for the launch mass constraint.

Initial feasibility studies were performed by CNES during the development phase A. These studies indicated that the technologies required for aerocapture were sufficiently mature to baseline for this mission. To further the study of this very critical phase of the mission, a joint CNES-NASA technical working group (led by CNES) has been formed. This group is composed of atmospheric trajectory specialists from CNES, NASA-Langley Research Center and NASA-Johnson Space Center. This working group is tasked to review the aerocapture study hypotheses, to develop and test guidance algorithms, as well as cross-validate CNES and NASA aerocapture flight simulators for this mission. The final result will be a recommendation on the guidance algorithm to use and an evaluation of the flight risks associated with that algorithm.

In parallel to this effort, another working group involving CNES, ONERA and NASA-Langley Research Center aerodynamicists and aerothermal specialists has been formed to study the aerothermodynamic issues related to the atmospheric transit of the spacecraft during aerocapture (simulations, wind-tunnel tests...). This paper does not address these very important issues.

Aerocapture description

Main phases



The MSR orbiter will arrive at Mars with an excess velocity of about 3.2 km/s. The objective of the MSR Mars Orbit Insertion maneuvers (aerocapture followed by a periapsis raise maneuver) is to reach the following Martian orbit:

- Apoapsis: 1400 km ± 100 km
- Periapsis: 250 km
- Inclination: 45 deg ± 0.5 deg.

Until Mars Orbit Insertion minus 12 (MOI-12) days, the major activity of the Mars approach phase is the Netlanders release. From MOI-12 days until insertion, the activity is dedicated solely to the MOI of the Orbiter. The last maneuver prior to aerocapture is planned at MOI-6 hours in order to achieve good precision at the atmosphere entry point. This maneuver will nominally be designed with a minus 12 hours Orbit Determination (OD) solution. This solution will also be used to initialize the on-board navigation instruments.

The orbiter will then enter the Mars atmosphere after having separated from its cruise stage. The next steps are the following:

- Orbiter attitude control is commanded to the inertial attitude corresponding to the desired aerodynamic attitude at the beginning of the guided atmospheric trajectory.
- Start Angle of Attack (AoA) limits (-4deg.<AoA<+4deg.) and "rate damping mode" (maximum pitch and yaw angular velocity limitation). Start of the guidance algorithm (drag deceleration criteria of about 0.05 m/s^2).
- Guided phase: during this phase, the guidance computes at each guidance step the bank angle that leads to the desired apoapsis and inclination (1400 km and 45 deg. for the MSR mission). Navigation data are computed from angular rate and deceleration measurements provided by an Inertial Measurement Unit (IMU). The minimum altitude reached during this phase is about 35 km.
- End of guidance (drag deceleration criteria) and transition to inertial attitude control mode.
- Heat shield jettisoning.
- Periapsis raise maneuver at the end of the atmospheric pass. The periapsis altitude must be above -50 km (system requirement) after the aerocapture phase. A first periapsis raise maneuver will be performed near the apoapsis to increase the periapsis value to at least +165 km.
- Solar panels deployment, Earth acquisition, system health check of the orbiter and orbit determination.
- At the next apoapsis, a second periapsis raise maneuver will be performed to achieve the +250 km altitude.

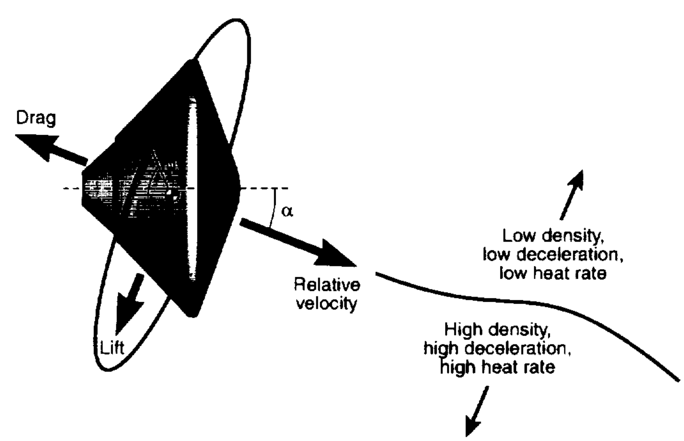
Aerocapture principle

The aerocapture technique is based on the use of the aerodynamic force to slow and to control the vehicle. The principle is the same as for a reentry vehicle such as the Atmospheric Reentry Demonstrator or the Space Shuttle except the target parameter is not a landing point but orbit parameters (apoapsis and inclination). All of these vehicles use the lift direction to tune the vertical velocity and then the drag deceleration level to control the reduction of velocity. The angle that defines the lift direction is the bank angle (rotation angle around the aerodynamic velocity vector). As the bank angle magnitude increases, the Lift vector will force the vehicle into the higher density portions of the atmosphere than would be achieved with no bank angle change. Conversely, a decrease in the bank angle magnitude will direct the vehicle to a lower density portion of the atmosphere. (See figure below and note that zero bank angle is Lift up.) The effect of bank angle on the vertical acceleration is shown through the following relation (assuming a small flight path angle):

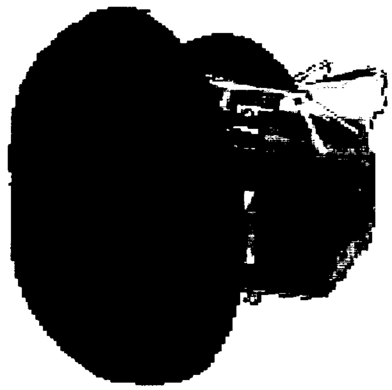
$$\ddot{h} = \frac{V^2}{R} - g + \frac{L\cos(\Phi)}{m} \qquad (1)$$

where Φ is the bank angle.

At this time, there are two solutions to obtain the same deceleration level: $\pm\Phi$. The orbit inclination control will be performed based on the sign of the bank angle. Indeed, the lift force generates a component out of the orbit plane that affects the orbital inclination. It is important to note that there is a natural drift of the inclination, even if $\Phi = 0$ or $\Phi = 180$, due to the out of plane drag force component.



The aerocapture vehicle



The aerocapture phase leads to specific design requirements for the orbiter. These requirements include:

- To provide a sufficient Lift capability in the Mars atmosphere to provide the required vertical acceleration. This requirement necessitates adding a heatshield to the spacecraft, which is shaped to provide Lift. The shape chosen is based on the NASA Aeroassist Flight Experiment (AFE) that was extensively designed and studied in the nineties by the NASA.

- To withstand the loads due to high velocity into the atmosphere, i.e.:
  - Maximum deceleration: 3.5 g's
  - Maximum heat flux: 500 kw/m^2
  - Maximum total heat load: 70 MJ/m^2
  - Maximum dynamic pressure: 4.8 kPa

  This requirement leads to a heatshield design that protects the orbiter from thermal loads and dynamic pressure. This heatshield should be jettisoned after aerocapture to minimize the propellant use during on-orbit maneuvers, and must give a sufficient Lift-to-Drag ratio capability to the orbiter, as well as dissipate the thermal energy imparted to the spacecraft.

- The spacecraft center of gravity (CoG) must provide a trim AoA in the range [-2deg, +2deg].

- To have an on-board navigation system that provides the guidance algorithm and attitude control system the current attitude, position and velocity of the orbiter. This information is computed by the integration of gyroscope and accelerometer measurements.

- To have an on-board guidance algorithm that leads the orbiter to the desired orbit upon exiting the atmosphere. The system specification for this orbit is
  - Apoapsis altitude: 1400 km ±100km
  - Periapsis altitude: >-50 km
  - Inclination: 45 deg ±0.5deg

- To have an on-board attitude control system that uses thrusters to control the spacecraft:
  - Attitude "rate damping" mode for pitch and yaw,
  - Pitch angle control in the range [-4deg., +4deg.],
  - Bank angle control sufficient to follow the commanded value provided by the guidance algorithm.

The MSR Orbiter vehicle has been allotted a mass of 2200 kg for the insertion phase (Netlander and cruise stage jettisonned).

CNES-NASA aerocapture study joint group mission

Because the aerocapture phase of the MSR is critical and because it would be the first aerocapture space mission, it was decided to form a dedicated joint CNES-NASA project team.

The main technical points to be jointly investigated are:

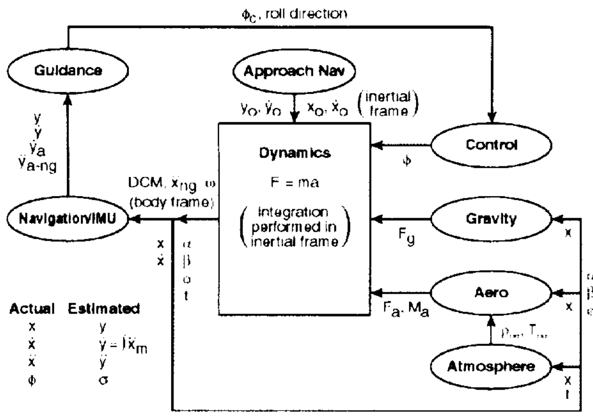
- The aerocapture phase validation methodology
- The flight simulation cross-validations (3DOF and 6 DOF),
- The flight simulation hypotheses and assumptions review,
- The guidance algorithm development,
- The atmospheric models comparisons,
- The stress cases development and simulation,
- The guidance algorithms comparison and selection (criteria, recommendation).

These points are described in the following paragraphs.

Trajectory simulations

The NASA-LaRC 3DOF/6DOF simulation software is based on simulations developed for the Mars 2001 aerocapture and entry studies, as well as Mars Pathfinder and Mars Polar Lander. (Note the Mars 2001 orbiter mission has been modified to use aerobraking and not aerocapture.) The CNES simulation software was derived from the Atmospheric Reentry Demonstrator trajectory software that was developed from earlier Hermes project studies.

These simulators include Guidance, on-Board Navigation and Control functions and allow Monte-Carlo statistic analyses. The 3DOF simulator principle is presented below:



As a first task, cross-validation of the NASA and CNES 3DOF trajectory simulation software for the MSR aerocapture was done. Test cases including guidance, control and navigation functions were jointly defined and performed independently on each simulation. Except for tests including the navigation function that are not yet completed, all the cross-tests give very good results.

As the atmospheric model for the MSR studies, CNES use the European Martian Climate Database (EMCD) developed for ESA by the Laboratoire de Météorologie Dynamique (Paris) and the Oxford University. For the Martian studies, NASA uses the Mars-Gram Model. For these common work and comparisons, CNES has implemented the Mars-Gram model in its simulator and NASA has implemented the EMCD model in its simulator. Then, CNES and NASA use both models to perform all the MSR aerocapture simulations. The currently implemented versions are the 3.8 for Mars-Gram and 2.3 for EMCD.

Guidance algorithms

For the MSR mission CNES has decided to develop the orbiter aerocapture guidance algorithms until the end of phase B of the orbiter development. At that time, the principal guidance algorithm will be specified to the orbiter contractor. That is, CNES will choose, develop and validate the guidance algorithm during phases A and B of the orbiter development. About ten years ago NASA extensively studied an aerocapture demonstration around the Earth: the Aeroassist Flight Experiment. At this time, multiple guidance algorithms were developed by the NASA teams.

Three years ago, an important NASA effort was done to develop aerocapture guidance algorithms for the early 2001 orbiter mission. Some of them were derived from the AFE studies. Three algorithms developed for the early 2001 orbiter were proposed by NASA for the MSR aerocapture algorithm:

- An analytical predictor-corrector (NASA-JSC),
- A terminal control algorithm ("Apollo derived", NASA-JSC and NASA-LaRC),
- A numerical predictor-corrector (NASA-LaRC).

On the CNES side, based on the ARD experience and on the American and Russian work on the aerocapture guidance, two algorithms were developed:

- An analytical predictor-corrector,
- A numerical predictor-corrector.

All of these guidance principles use the absolute value of the bank angle to control the "in-plane trajectory" (orbit apoapsis) and the sign of the bank angle to control the "out-of-plane trajectory" (orbit inclination). A bank reversal occurs whenever the commanded bank angle changes sign for inclination control.

The CNES analytical predictor-corrector is very close to the NASA-JSC version because both are based on the AFE studies. The principle of these algorithms is for in-plane guidance (apoapsis control) to focus on the vertical velocity and the drag deceleration of the vehicle during the atmospheric trajectory (in-plane guidance to control the apoapsis). The trajectory falls into two parts. The purpose of the first part of the trajectory (referred to as capture phase, or inbound trajectory) is to control the vehicle deceleration until aerodynamic equilibrium is achieved (when aerodynamic lift force balances the inertial and gravitational forces). The desired aerodynamic equilibrium is designed to maximize control margins. After the vehicle slows to a certain velocity, the second phase is initiated. The purpose of this phase is to benefit from the equilibrium glide condition to target the desired orbit (outbound trajectory). The atmosphere exit conditions (target orbit) are predicted analytically and corrected assuming a constant vertical velocity from the current altitude to the altitude at the exit of the atmosphere. This vertical velocity is used by the guidance to determine the magnitude of the bank angle. This algorithm does not need any pre-loaded on-board trajectory and has shown good performance during testing. As CNES and NASA principles as well as results were very close with this algorithm, it was decided to jointly work on this principle to develop the best possible version for MSR (cf Ref 1).

The principle of the numerical predictor-corrector is to determine at each guidance step the constant bank angle value to be applied to reach the target apoapsis. The prediction of the trajectory with this constant bank angle is performed on-board by a numerical integration of the equations of motion until the exit of the atmosphere.

This kind of method allows the coupling of the "in-plane" and "out of plane" guidance due to the on-board integration of the trajectory. This methodology was done in CNES version using Russian work on that method (Keldysh Institute of Applied Mathematics). For the NASA numerical predictor-corrector algorithm, the bank-reversal time was determined based on when the inclination limits were exceeded, and then the reversal was commanded when that time was reached. All the other algorithms perform a bank-reversal the instant inclination limits are violated.

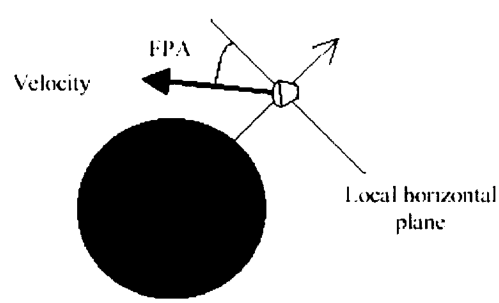
The Terminal Point guidance algorithm uses the calculus of variations optimal control approach with influence coefficients to control a vehicle about a nominal trajectory. Influence coefficients are solved from a set of differential equations adjoint to the linearized perturbations of the equations of motion about a nominal trajectory. Conceptually, the influence functions provide a means to calculate a new trajectory "on-the-fly" when dispersions relative to the nominal trajectory are encountered. This new trajectory will theoretically have the same in-plane terminal conditions as the nominal trajectory; hence, this type of guidance scheme is referred to as a terminal point control algorithm. As indicated above, out-of-plane (inclination) control is achieved by monitoring inclination and commanding a reversal when limits are exceeded.

As a common subroutine interface for all the guidance subroutines, the following parameters are used as INPUT/OUTPUT:

INPUTS			
Name	*Description*	*Unit*	*Type*
time	time since simulation start	s	real*8 time
bank	current estimate of vehicle bank angle	rad	real*8 bank
pos_abs	current estimated vehicle position in MCI coordinates	m	real*8 pos_abs(3)
vit_abs	current estimated vehicle inertial velocity in MCI coordinates	m/s	real*8 vit_abs(3)
pos_rel	current estimated vehicle position in MCMF coordinates	m	real*8 pos_rel(3)
vit_rel	current estimated vehicle relative velocity in MCMF coordinates	m/s	real*8 vit_rel(3)
acc	current sensed acceleration in body coordinates frame	m/s^2	real*8 acc(3)
mci2body	MCI to body coordinate system transformation matrix	-	real*8 mci2body(3,3)
mci2mcmf	MCI to MCMF coordinate system transformation matrix	-	real*8 mci2mcmf(3,3)
OUTPUTS			
Name	*Description*	*Unit*	*Type*
bank_com	commanded bank angle	rad	real*8 bank_com
idir	rotation option flag that specifies the way of achieving the commanded bank angle : ❑ 0 to roll through the smallest angle to reach commanded angle (shortest path), ❑ 1 to roll in a positive sense, ❑ -1 to roll in a negative sense		Integer idir

Aerocapture simulation hypotheses

For the aerocapture simulations, the insertion conditions of a nominal 2005 mission have been used. The excess velocity of the arrival hyperbola is about 3.2-km/s; the targeted inclination is 45 deg. The nominal targeted Flight Path Angle (FPA) has been defined as the middle of the theoretical entry corridor (about 1.2 deg width). This corresponds to a targeted FPA of -10.5 deg. This value may be optimized in the future, depending, for example, on the exact arrival day.



Corridor definitions:

1 - Theoretical corridor: FPA range defined by the steepest and shallowest FPA that reach the desired apoapsis. The steepest value corresponds to a full lift-up trajectory. The shallowest value corresponds to a full lift-down trajectory. This corridor is linked to the Lift-to-Drag ratio capability of the vehicle (that is, the corridor is linked to the orbiter's performance). This corridor depends slightly on the atmospheric model that is used to compute the trajectories. It also depends slightly on the arrival date (due to the excess velocity value). It is computed with nominal aerodynamic characteristics and nominal atmosphere (both scenarios when EMCD is used).

2 - Corridor with guidance limitation: due to the guidance response to the FPA dispersions, the previous corridor may be decreased somewhat (that is, the guidance may not be able to use the whole theoretical range). This reduction depends on the guidance algorithm principles and tuning.

3 - Survivability corridor: this FPA range in which the mission is not lost (survivability criteria to be defined). For example, apoapsis between 250 km and 2000 km, as well as maximum loads up to orbiter design values with no margin would be considered acceptable.

The other computation assumptions are:

- Maximum bank rate of 20 deg/s
- On-board navigation initial position corresponding to the nominal entry point determined at 12 hours prior to atmospheric entry
- Perfect initial attitude

MSR Orbiter Atmospheric Mission Dispersions

Quantity	3 DOF	6 DOF	Nominal Value	Distribution Type	3-σ or min/max
Mission Uncertainty					
Initial Bank, deg	•	•	-90 or +90	Gaussian	5.0
Close window Initial inertial FPA, deg	•	•	-10.5	Gaussian	0.4
Close window Initial inertial FPA, deg	•	•	-10.5	Gaussian	0.5
Close window Initial inertial FPA, deg	•	•	-10.5	Gaussian	0.6
Close window Initial inertial FPA, deg	•	•	-10.5	Gaussian	0.8
Open window Initial inertial FPA, deg	•	•	-10.5	Gaussian	0.4
Aerodynamic Uncertainty					
Trim Angle of Attack Incr, deg	•		Nat. trim*	Uniform	2.0
Axial Force Coeff Increment	•	•	nominal	Uniform Correlated	10 %
Normal Force Coeff Increment	•	•			
Mass Property Uncertainty					
Mass, kg	•	•	2200.0	Gaussian	20.0
X CG position, m	•	•	-1.24432 m	Gaussian	5E-03
Y CG position, m		•	0	Gaussian	5E-03
Z CG position, m	•	•	0.74335 m	Gaussian	5E-03
Atmospheric Uncertainty					
Initial Seed Value	•	•	0	Uniform	1/29999
Scenario for EMCD	•	•	"clear"&"Viking"	Small and large scale	
Tau value for Mars-Gram	•	•	TBD	Uniform	TBD
Control System Uncertainty					
Bank Acceleration, deg/sec^2	•	•	5.6	Uniform	3%
IMU Uncertainty					
Initial angular misalignment, μrad	•	•	0	Gaussian	200
gyro bias drift, μrad/hr	•	•	0	Gaussian	500
gyro scale factor, ppm	•	•	0	Gaussian	60
gyro nonorthogonality, ppm	•	•	0	Uniform	20
gyro random walk (PSD), deg/rt-hr	•	•	0	Gaussian	0.07
accelerometer bias, milligees	•	•	0	Gaussian	180
accelerometer scale factor, ppm	•	•	0	Uniform	100
accelero scale factor asymmetry, ppm	•	•	0	Uniform	50
Accelerometer nonlinearity, μg/g^2	•	•	0	Uniform	10
accelerometer random noise ,fps/√h	•	•	0	Gaussian	TBD
accelero input axis nonorthogo., arc-s	•	•	0	Uniform	20

* -4 to +4 deg absolute limit

Stress cases

To test robustness of the guidance algorithms, some "stress cases" have been defined and will be simulated:

1 •6 sigma IMU gyro initialization error,

2 •Extreme-density shear/wave,

3 • 10 %-uncorrelated variation of CA and CN in addition to the 10% correlated variation,

4 • Accelerometer signal degradation,

5 • Gyroscope signal degradation,

6 •Single roll-thruster failure,

7 •Computer swaps during aeropass.

Other stress cases may be added in the near future considering the results of a Failure Mode Analysis relative to the aerocapture phase of the MSR mission.

Algorithms comparison criteria

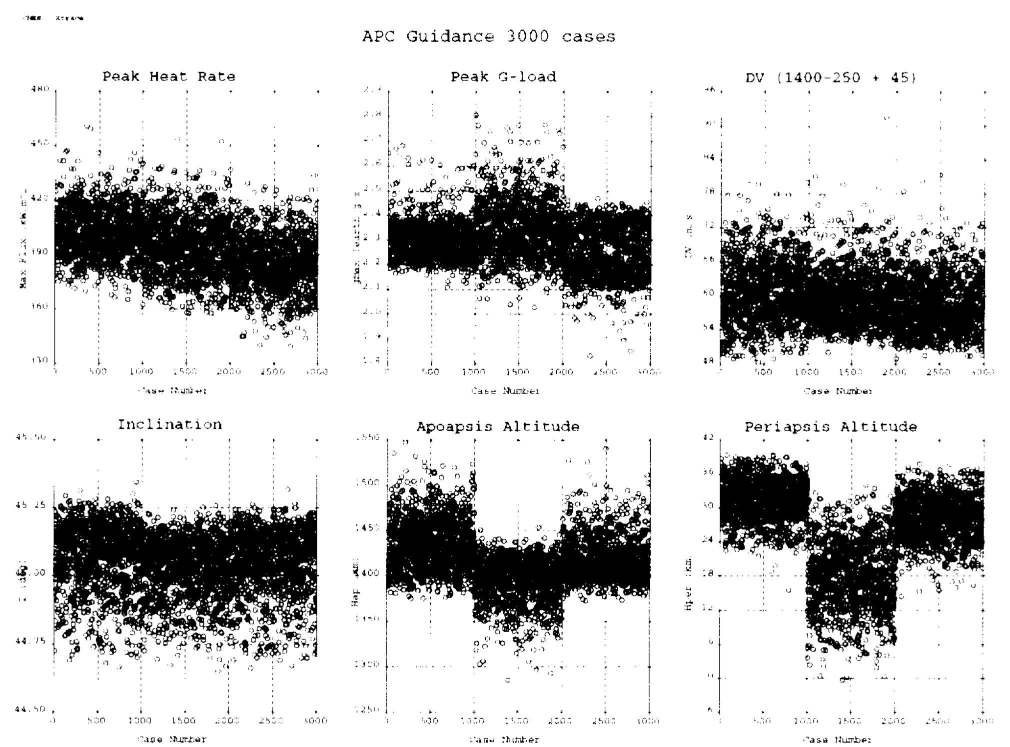
In order to choose the best guidance algorithm for the MSR mission, an initial list of comparison criteria has been defined (other criteria may be added):

- guidance precision and robustness to uncertainties (Monte-Carlo results)
- robustness to stress cases
- delta V cost to correct the insertion orbit (linked mainly to the periapsis altitude after aerocapture)
- number of source lines of code
- number of parameters to be stored on-board
- Complexity of the source codes (numbers of loops, tests, etc.)

First results

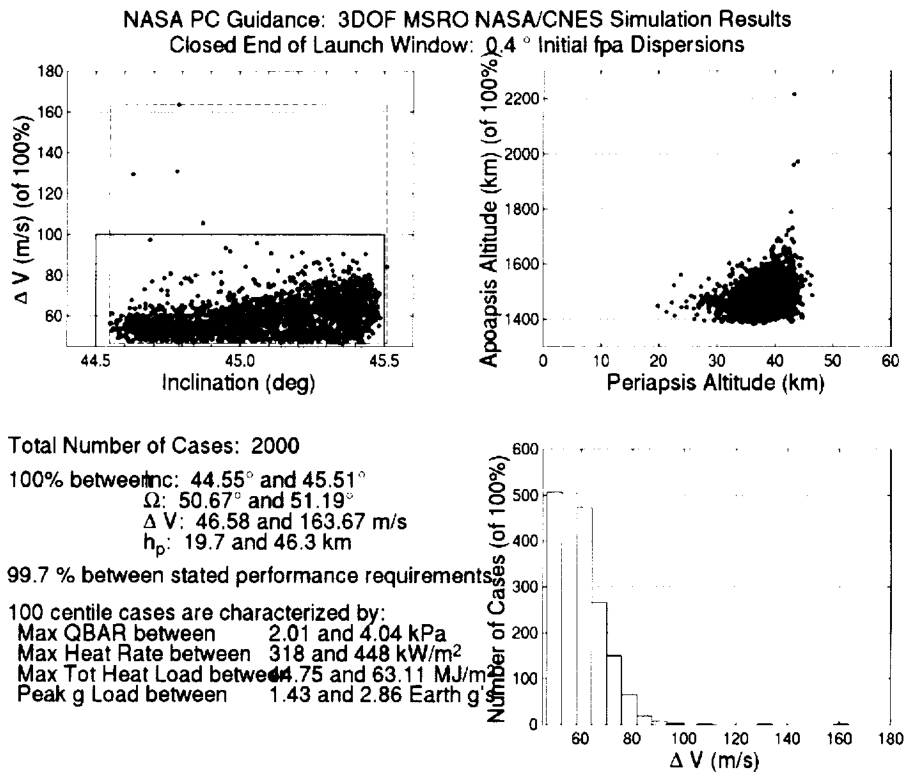
The first round of Monte-Carlo simulations performed with a FPA uncertainty up to ±0.4 deg 3σ has demonstrated that all the proposed algorithms are able to reach the specifications of precision orbital delivery and delta V cost to correct the periapsis at 3 sigma. As typical results, the following figures show Monte-Carlo results obtained with an analytical predictor-corrector guidance algorithm (on-board navigation errors included), and Monte-Carlo results obtained with a numerical predictor-corrector (on-board navigation errors not included).

Note that the NASA numerical predictor-corrector algorithm was developed using the Mars-GRAM atmosphere model. Further work to tune the algorithm for both the Mars-GRAM and EMCD will reduce the delta V and inclination error.

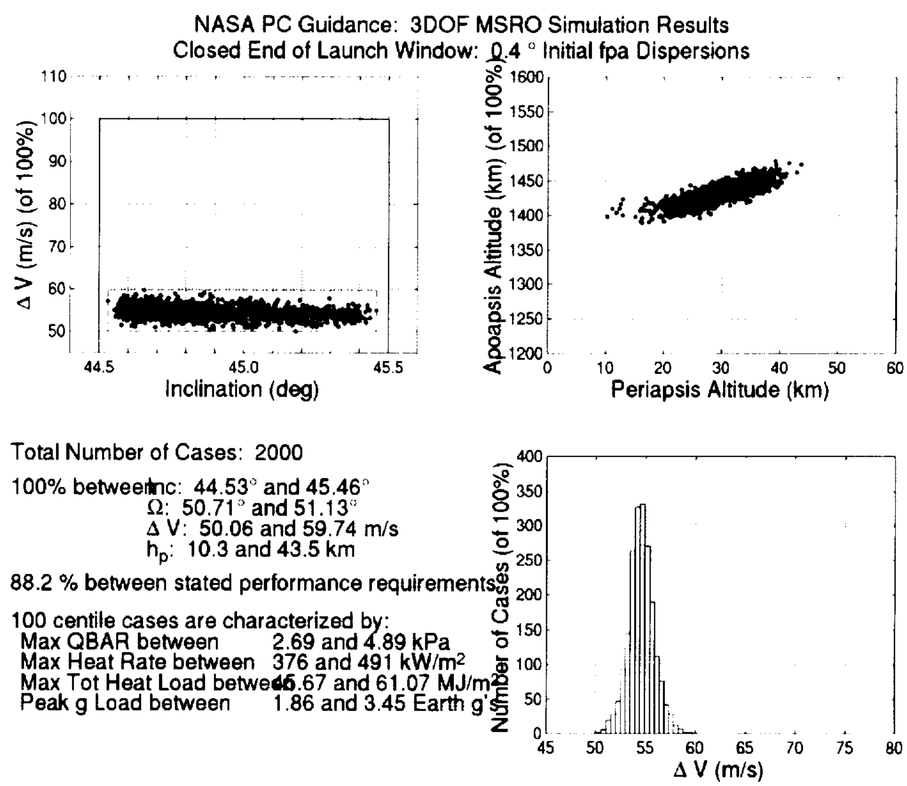


	Inc deg.	Hap km.	Hper km.	Heat Rate kw/m^2	Heat load Mj/m^2	G loads	Pdyn Kpa.	DeltaV (m/s)
Mean	45.04	1416.7	25.9	394.5	50.2	2.30	3.0	59.9
St Dev	0.13	31.74	7.57	16.98	1.84	0.11	0.24	5.40

3000 runs with EMCD and Mars-Gram using analytic predictor-corrector



2000 runs with EMCD for the NASA numerical predictor-corrector



2000 with Mars-GRAM for the NASA numerical predictor-corrector

Conclusion

The aerocapture of the MSR orbiter is a challenging task. Thus, a joint CNES-NASA effort is underway to study this very critical phase of the mission, demonstrate its robustness, and choose the best guidance algorithm to be used for this atmospheric trajectory. The first batch of simulation results, which corresponds to a 2005 mission, has demonstrated the feasibility of aerocapture with respect to the atmospheric entry uncertainties (±0.4 deg. uncertainty on the FPA at 3σ) computed by JPL. Indeed, during the Monte Carlo simulations, all the guidance algorithms result in successful aerocapture. Other studies are underway in order to determine the algorithm limits, by testing extreme cases (FPA uncertainty up to ±0.5, ±0.6 deg) with the objective to demonstrate as much margin as possible. This study will determine the robustness of all the algorithms, and it will enable a choice of the best algorithm in terms of complexity and robustness. In addition, more complex simulations (6 DoF, with actual flight system models) are planned to evaluate the impact of the aerodynamic torque on the orbiter and the control system efficiency. In parallel with these trajectory/guidance studies, a dedicated CNES-ONERA-NASA group is investigating the aerothermodynamics problems for this aerocapture mission. This work will have to take into account the new Mars Exploration Program architecture (mission dates).

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