MISSION ANALYSIS FOR ROSETTA DESCENDING PHASE

J. BERNARD
CNES
18,Avenue E. Belin
☎ : 33 (0) 5 61 28 25 00
Fax : (0) 5 61 27 35 40
Email : jacques.bernard@cnes.fr

F.X. CHAFFAUT
CNES
18,Avenue E. Belin
☎ : 33 (0) 5 61 27 43 00
Fax : (0) 5 61 28 29 95
Email : francois-xavier.chaffaut@cnes.fr

S. ROUSSEAU
CISI-Groupe Compagnie des signaux
13,Rue Villet - ZI du Palays
☎ : 33 (0) 5 61 17 66 66
Fax : (0) 5 61 17 66 96
Email : stephane.rousseau@cisi.fr

Abstract

The ROSETTA mission is scheduled for launch on ARIANE 5 in January 2003, and a Lander will be released from the Orbiter in October 2012 to land on the WIRTANEN comet surface.

Ten French laboratories are contributing to the Orbiter and Lander payloads. Moreover, CNES is associated with DLR and several other European institutions and agencies to design the Lander.

This paper deals with the mission analysis concerning the descent trajectory to land a Surface Science Package (SSP) on the comet.

Several scenarii have been studied to define the separation mechanism (Lander/Orbiter) and the Active Descent System (ADS) and to take into account the wide range of comet parameters.

We processed in two studies :

- *Sensivity study of different parameters such as candidate landing sites or comet parameters ;*
- *Dispersion study at the impact due to error sources concerning ROSETTA Position/Velocity, manoeuvre realisations and comet parameters uncertainty.*

The purpose of the software ANDROMAC (ANalysis and Design of ROsetta Manoeuvres Around the Comet), developed by CNES, is to help the design of the manoeuvres (separation and other manoeuvres) in order to guarantee the success of the landing in all cases and to be an operational tool to plan the manoeuvres.

Keywords : Dispersion, Landing, Manoeuvre, Monte Carlo analysis, Selection, Sensitivity.

Introduction

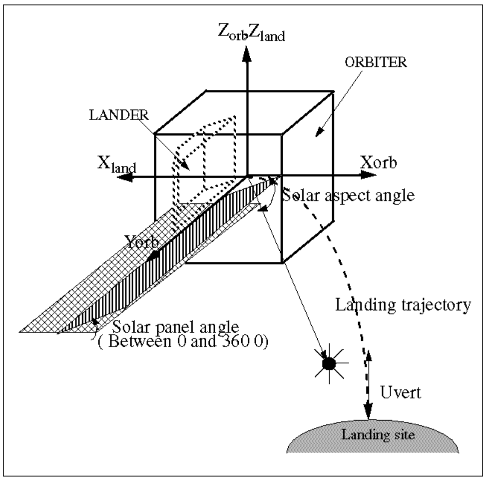


Figure 1 : Configuration Lander/Orbiter

The Orbiter and the Lander are in orbit around the comet (in this paper, this orbit will be called "ROSETTA" or "DELIVERY" orbit) and the Lander delivery will occur in October 2012 at about 3 UA from the sun.

A first manoeuvre will be made to separate the Lander from the Orbiter and to put the Lander on a descent trajectory to reach a candidate landing site. The Lander attitude is such that the Lander Z axis is normal to local surface of landing site.

The separation manoeuvre ΔV is provided by mechanical impulsion adjustable from 0.05 to 0.5 m/s and is uploaded before separation when the comet model parameters are improved and the site selected. In the actual configuration, the Lander is mounted on the $-X_{orb}$ Side of the Orbiter (See fig. 1).

And the direction of the manoeuvre, which is along the X_{orb} axis, is also perpendicular to the Orbiter mounting plane and to the solar generator panels (Y_{orb} axis).

It's planned that the lander will realise a second manoeuvre provided by the Active Descent System (ADS). The function of the ADS is to deliver an impulsion in the Lander –Z Direction by mean of a Cold Gas Propulsion System (CGPS). Its capability is 1 m/s for that purpose. We will see in this paper that the effect of this manoeuvre is to reduce the flight time and the dispersions at landing. Another option for this manoeuvre is to use a PYRO thruster.

Furthermore, we want to land with an impact velocity relative to the comet along the local vertical and limited to 2 m/s.

It's also planned to achieve a manoeuvre to reach the "RELAY" Orbit from the "DELIVERY" Orbit.

In the case of a MSS failure, it's planned to use an emergency scenario with the help of a spring.

Two themes are developed in this paper :

- sensitivity study of different parameters (candidate landing sites, density and comet shape, sideral rotation time, gravitational potential of the comets, outgassing effects) on the separation parameters and descent characteristics ;
- dispersion study at the impact due to error sources concerning the "DELIVERY" orbit Position / Velocity, realisation of the manoeuvres, planetary environment parameters.

Presentation of the ANDROMAC Software

For this study the software ANDROMAC has been developed by CNES and CISI.

The main goal of this software is :

- to define the planning and the magnitude of the manoeuvres ;
- to specify the reachable sites.

By taking into account the constraints concerning Orbiter and Lander and after covering the comet parameters, this software is in charge to deliver a range of descent characteristics (ΔV Separation & ΔV_Z delivered by the "Active Descent System", "Delivery" orbit elements, Time flight). In a first step we have to solve an optimisation problem for each model parameter set.

The command parameters are the following :

- magnitude of the impact velocity ;
- dates of both manoeuvres ;
- magnitude and direction (around the Z axis) of the separation manoeuvre ;
- magnitude of the vertical manoeuvre ;
- date of the landing (defined by the landing site position w.r.t Sun).

In this preliminary version, we solve the optimisation problem in the following form :

- selection of trajectories satisfying the constraints for a discrete set of command parameters ;
- selection of a final trajectory after taking into account criteria such as minimisation of the flight time.

And the last step consists in a dispersion study of the error sources by using "Monte Carlo" analysis (1000 draw).

Moreover, the algorithm of computation for the descending phase is the following :

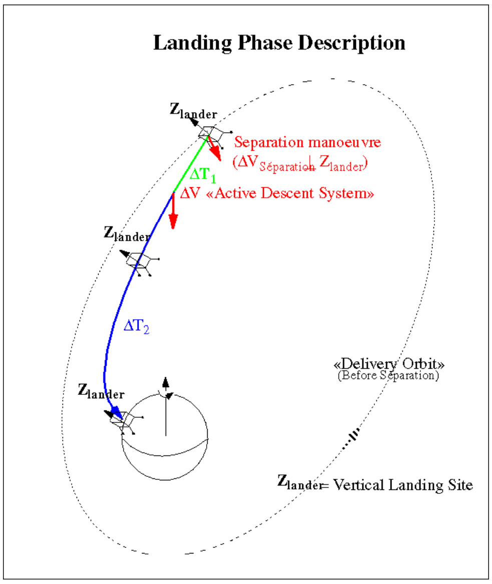


Figure 2 : Landing phase description

From touchdown to the separation, the algorithm is based on a backward propagation (See fig. 2).

The initial conditions of this propagation are the position of the landing site and the impact velocity (supposed to be along the local vertical).

The descent is divided in 2 arcs :

- first arc from landing until just after the vertical manoeuvre ;
- second arc from just before the vertical manoeuvre until the separation.

After adding the separation manoeuvre it's also possible to compute the "Delivery" orbit elements.

Sensitivity Study

For this analysis, we assumed :

- keplerian movement,
- no comet outgassing ,

- no spin nutation,
- only ellipsoid shape.

(For the two first themes a sensitivity study is presented at the end of this paper).

The main criterion used for the selection of the trajectories is minimisation of the descent duration in order to reduce the dispersions at landing.

Constraints

We present in this chapter the constraints concerning different components of the spatial system, that is to say :

- “DELIVERY” Orbit (before the separation manoeuvre) ;
- “ROSETTA” Spacecraft (after the separation manoeuvre) ;
- “ROSETTA” Lander.

“Delivery” Orbit

The delivery orbit shall be safe (no impact with the comet), with an orbit radius below 15 times the comet equivalent radius R_{eq}, 16 hours before and after the separation and greater than MAX (1 Km, R_{eq}).

The Orbiter shall never be in Sun eclipse and the Earth visibility shall be possible during the major part of the orbit.

To increase the range of solutions we have supposed the possibility to select hyperbola orbits.

“Rosetta ” Spacecraft

The Orbiter will be “3 Axis” stabilised. At the separation the Solar Aspect angle between sun direction and solar panel axis will be greater than 60 degrees. There is no constraint on the Solar panel angle.

No Orbiter thruster operation shall be performed short before, during and short after separation, in order to reduce contamination and limit attitude and orbit perturbations.

This shall apply within a minimum distance of 30 m between Orbiter and Lander after the separation in case of an ADS Manoeuvre or 150 m if we use a solid thruster.

It’s planned to realise manoeuvres to reach the “RELAY” Orbit from the “DELIVERY” Orbit.

“Rosetta” Lander

The main constraints are the following :

- minimisation of the descent duration (upper limit fixed to 6 hours and Goal below 3 hours) ;
- alignment of the Lander Z Axis and of impact velocity at landing with the vertical of the selected site ;
- magnitude of the impact velocity limited to 2 m/s ;
- magnitude of the separation manoeuvre limited to 50 cm/s.

Comet models

Several comet models have been studied. At the present time, we have limited our studies to ellipsoids defined by parameters a, b, c said “normalised” and an equivalent radius R_{eq} which are connected by the equation :

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = R_{eq}^2 \qquad \textbf{(1)}$$

Three main comet models (*Nominal Cases* for this study) have been studied :

Small	R_{eq} = 0.5 km	ρ_c (Density)	= 0.2 g/cm3
Wirtanen	R_{eq} = 0.6km	ρ_c	= 0.75 g/cm3
Big	R_{eq} =1.5 km	ρ_c	= 1.5 g/cm3

For each comet model, we have studied the following ellipsoids :

G2	a = 1.25	b = 1.00	c = 0.80
G3	a = 1.25	b = 1.25	c = 0.64 (*Reference geometry*)
G4	a = 1.60	b = 1.25	c = 0.50

Concerning the rotation period, we have considered two options :

Short period : T_c = 7 hours (10 hours for Small) *(Reference Period)*

Long period : Tc = 10 days

To take into account different configurations of the Sun w.r.t the comet equatorial plane, we have considered 3 Spin directions (α_s, δ_s) in the local orbital plane (that is to say defined by direction Sun-Comet and comet kinetic momentum).

P1 *(Reference Spin)*	α_s = undet	δ_s = 90 deg ($\delta_{equatorial}$ = 0 deg)
P2	α_s = 135 deg	δ_s = 45 deg ($\delta_{equatorial}$ = 30 deg)
P3	α_s = 180 deg	δ_s = 30 deg ($\delta_{equatorial}$ = 60 deg)

where $\delta_{equatorial}$ is the sun declination w.r.t comet equatorial plane.

Landing sites

The 12 studies Landing sites correspond to the following latitudes φ and longitudes λ :

- φ = 5,30 (reference site) and 45 deg,
- λ = 0,45 (reference site), 90 and 135 deg,

in order to cover a wide range of configurations.

Results for the nominal cases

This paragraph presents a synthesis of the trajectories obtained for all the 12 landing sites and all model parameter values.

We present the results mainly in term of descent duration and velocity increments, that is to say :

- dt (mn) Descent duration
- V_{imp} Impact velocity at the landing
- ΔV_S Separation increment velocity module
- ΔV_Z Axial (ADS) increment velocity module

In all the presented tables, the term “Passive Mode” concerns a descent without Axial (ADS) manoeuvre.

The results are :

Table 1 : For Passive mode

	dt (mn)	V_{imp} (cm/s)	ΔV_S (cm/s)	ΔV_Z (cm/s)
Small Comet	60 to 270	10 to 20	5 to 25	0
Wirtanen	75 to 165	20 to 42	17.5 to 40	0
Big Comet	75 to 135	75 to 155	37.5 to 50	0

Table 2 : For ADS

	dt (mn)	V_{imp} (cm/s)	ΔV_S (cm/s)	ΔV_Z (cm/s)
Small Comet	24 to 48	20 to 55	5 to 27.5	30 to 50
Wirtanen	32 to 47	45 to 70	22 to 45	30 to 50
Big Comet	18 to 76	60 to 160	42 to 50	30 to 50

We can observe that :

- The descent duration never exceeds 3 hours, except in the small comet passive case. To obtain a short flight time, a $\Delta V_{separation}$ up to 50 cm/s is needed in case of Big Comet.
- The use of ADS manoeuvre induces a decrease of the descent duration and an increase of the impact velocity, which is favourable in case of a strong outgassing activity.
- The impact velocity is raising up to 1.6 m/s in case of the big comet.
- In case of small comet and a passive descent, the impact velocity is not sufficient to avoid the outgassing effects in case of a strong activity.

Sensitivity to comet density

Three new comet models with the same radius than the nominal case but with different density have been studied.

They are :

- $Wirtanen^+$ with ρ_c = 2.0 g/cm^3 (instead of 0.75)
- Big^- with ρ_c = 0.2 g/cm^3 (instead of 1.5)
- Big^+ with ρ_c = 2 g/cm^3 (instead of 1.5)

For the 12 landing sites and only for the “reference” model parameters than the previous paragraph, the results obtained are :

Table 3 : For Passive mode

	dt (mn)	V_{imp} (cm/s)	ΔV_S (cm/s)	ΔV_Z (cm/s)
$Wirtanen^+$	75 to 75	45 to 60	30 to 40	0
Big^-	90 to 105	32.5 to 45	42 to 45	0
Big	72 to 105	115 to 160	45 to 47.5	0

Table 4 : For ADS

	dt (mn)	V_{imp} (cm/s)	ΔV_S (cm/s)	ΔV_Z (cm/s)
$Wirtanen^+$	30 to 30	65 to 75	32 to 40	50 to 50
Big^-	48 to 48	55 to 62.5	50 to 50	40 to 50
Big	48 to48	105 to 155	50 to 50	30 to 50

Compared to the nominal comet results, the increase of density induces an increase of the impact velocity and the flight time.

The range of the different parameters are smaller than for the nominal study because of limited numbers of analysed cases.

Dispersion studies

Error sources

Comet and delivery orbit knowledge

The error sources, have been given by ESA and correspond to the expected accuracy at the end of the Close Observation Phase (last phase before Lander delivery).

Table 5 : Errors sources values

Errors (at 1 sigma)	Small	Wirtanen	Big
Spacecraft position (m)	10	10	15
Spacecraft velocity (mm/s)	0.5	1	2
Euler angles (deg.)	0.2	0.15	0.10
Gravitational constant (%)	0.2	0.15	0.10

Orbiter-Lander separation manoeuvre

The following values have been assumed for the global separation errors including all contributions (Orbiter attitude, mass properties, propellant quantity and distribution, propellant sloshing and MSS contribution) :

- $\delta\Delta V$ (Error in magnitude) = 1.3 % (at 1 σ),
- $\delta dir\Delta V$ (Error in direction) = 0.3 deg (at 1 σ).

ADS manoeuvre

We indicate in this paragraph a global profile which has been determined by taking into account different error sources due to attitude before manoeuvre, uncertainty on the Lander Gravity Centre, misalignment of the thruster and realisation of the manoeuvre.

Table 6 : ADS manoeuvre errors

ADS Manoeuvre	$\delta\Delta V$ (at 1 σ)	$\delta dir\Delta V$ (at 1 σ)
ΔV = 0.1 m/s	1 %	0.33 deg.
ΔV = 0.5 m/s	1 %	0.6 deg.
ΔV = 1.0 m/s	1 %	1.0 deg.

Typical dispersion

We present in this section the order of magnitude of the dispersions for the three nominal comet models (Small, Wirtanen and Big). This study has been limited to the reference landing site and to the reference model parameters.

To evaluate the dispersions in meters on the lander position at landing, the Monte Carlo process has been realised on the deviations ΔX and ΔY between the real landing site and the nominal landing site (without error source) evaluated in the local reference frame.

The standard deviations at 1σ have the following meaning :

- σ_x(m),σ_y(m) = standard deviations along the first and second eigen direction of the covariance matrix,
- σ_α(deg) = attack angle (attitude standard deviation) (w.r.t mean surface normal frame),
- $\sigma_{\gamma c}$ (deg) = impact angle (velocity) standard deviation (w.r.t mean surface normal frame),
- $\sigma_{\gamma\lambda}$ (deg) = Impact angle (velocity) standard deviation (w.r.t lander Z-axis).

where :

- α is the angle between the lander Z axis and the mean surface normal which has been effectively obtained ;
- γ_c is the angle between the impact velocity and the mean surface normal which has been effectively obtained ;
- and γ_λ is the angle between the impact velocity and the lander Z axis.

We have obtained (σ in meters for X and Y and in degrees for the angles) :

Table 7 : For Passive Mode

	σ_x	σ_y	σ_α	$\sigma_{\gamma c}$	$\sigma_{\gamma\lambda}$
Small Comet	19.5	9.0	1.2	1.8	1.7
Wirtanen	19.8	8.1	0.8	1.0	0.9
Big Comet	22.5	16.5	0.6	0.6	0.3

Table 8 : For ADS

	σ_x	σ_y	σ_α	$\sigma_{\gamma c}$	$\sigma_{\gamma\lambda}$
Small Comet	14.4	10.1	0.9	1.3	0.9
Wirtanen	14.8	9.8	0.8	1.1	0.8
Big Comet	21.6	13.7	0.4	0.6	0.4

The main conclusions are :

- Improvement of the accuracy for impact and attack angles if gravitational attraction increases (Cases of Big Comet w.r.t Wirtanen and Wirtanen w.r.t Small Comet) ;
- Better results with ADS in all the cases ;
- Bigger position dispersions for big comet compared to small and Wirtanen comets although angle dispersions are smaller.

Sensitivity to landing site

This section presents the variations of dispersions in function of the latitude φ for the reference comet parameters.

Table 9 : For Passive Mode

	φ	σ_X	σ_Y	σ_α	$\sigma_{\gamma c}$	$\sigma_{\gamma\lambda}$
	(deg)	(m)		(deg)		
Small Comet	5	23.0	10.9	2.9	3.5	2.2
	30	19.5	8.9	1.2	1.8	1.7
	45	18.6	8.6	0.8	1.3	1.4
Wirtanen	5	23.0	10.7	2.5	2.6	1.4
	30	19.8	8.1	0.8	1.0.	0.9
	45	19.0	8.3	0.7	0.7	0.7
Big Comet	5	28.0	15.8	2.0	2.0	0.5
	30	22.5	16.5	0.6	0.6	0.3
	45	24.1	14.0	0.4	0.4	0.3

Table 10 : For ADS

	φ	σ_X	σ_Y	σ_α	$\sigma_{\gamma c}$	$\sigma_{\gamma\lambda}$
	(deg)	(m)		(deg)		
Small Comet	5	14.1	11.8	2.8	3.1	1.2
	30	14.4	10.1	0.9	1.3	0.9
	45	14.2	10.7	0.7	1.1	0.8
Wirtanen	5	15.7	11.8	2.4	2.6	1.2
	30	14.7	9.9	0.8	1.2	0.9
	45	13.4	10.2	0.6	0.9	0.7
Big Comet	5	22.0	17.0	1.5	1.7	0.6
	30	21.7	13.7	0.5	0.6	0.5
	45	18.2	13.6	0.3	0.4	0.3

The main conclusions are :

- Worst results for the dispersions concerning velocity and attitude in case of lower latitudes due to the quick variation of the local curvatures radius.
- No significant variations for the dispersions σ_X and σ_Y although the maximum dispersions were found for low latitude landing sites.
- A vertical manoeuvre increases significantly the landing position accuracy.

Other sensibility studies

These studies have consisted in evaluating the impact of each error source independently from the others.

The main error sources are the Orbiter state at the separation and the manoeuvre realisation (3/4 for the both). Moreover, the attack and impact angles are mainly sensitive to the comet shape.

The landing position (σ_X, σ_Y) are not very sensitive to the comet shape.

Emergency scenario study

The purpose of this chapter is to find a fixed $\Delta V_{Separation}$ increment velocity value in a such way that it will be possible to land in all cases with minimal degradation with regard to the nominal situation.

This ΔV will be given by the spring, used in the case of a MSS failure (Emergency scenario).

The value which has been found is 15 cm/s.

The results of this study are :

Table 11 : For Passive Mode

	Flight Time	V_{impact}	ΔV_Z	ΔV_{Sep}
	(minutes)	(m)		
Small Comet	160 to 300	10 to 20	0	15
Wirtanen	135 to 210	18 to 45	0	15
Big Comet	230 to 500	110 to 170	0	15

Table 12 : For ADS

	Flight Time	V_{impact}	ΔV_Z	ΔV_{Sep}
	(minutes)	(m/s)		
Small Comet	33 to78	25 to50	20 to 50	15
Wirtanen	33 to 43	50 to 70	50	15
Big Comet	48 to 213	90 to 180	75 to 100	15

It appears that all landing sites are reachable with a $\Delta V_{separation}$ of 15 cm/s for Wirtanen and Small Comet.

In case of Big Comet the use of the spring will not allow to reach all the landing sites in the case of passive descent (without ADS manoeuvre).

Now it is interesting to compare the associated dispersions in case of nominal (MSS) and emergency release (with hypothesis concerning the error sources previously defined) excepted the spring accuracy which is –3.3 % to 0 % in magnitude at 1 σ and 0.3° in direction at 1 σ.

In the following table, we present the maximum values for the angles.

Table 13 : Dispersions for emergency scenario

		σ_X	σ_Y	α_{Maxi}	γ_{cMaxi}
		(m)		(deg.)	
Small Comet	MSS	11 to 14	7 to 11	1.3 to 17.4	2.0 to 17.4
	Spring	11 to 18	7 to 11	1.4 to 17.0	2.9 to 17.7
Wirtanen	MSS	10 to 12	7 to 11	1.0 to 16.1	1.3 to 16.2
	Spring	10 to 14	7 to 11	1.1 to 21.4	1.7 to 21.9
Big Comet	MSS	17 to 54	14 to 50	0.9 to 21.3	0.6 to 21.2
	Spring	17 to 60	14 to 50	1.09 to 31.9	0.7 to 32.0

In the case of the Big comet, it is necessary to increase the value of ΔVZ up to 1 m/s.

In conclusion, there is a degradation of the performances in the case of Big Comet.

Other sensibility studies

Effect of outgassing on trajectory

The study concerning the outgassing has been realised for Wirtanen in both following cases :

- Wirtanen Comet with a density of 0.75g/cm^3 (nominal case) ;
- Wirtanen low density with a density of 0.115 g/cm^3.

The computation has been made for :

- G3 Geometry ;
- 3 Spin axis directions (P1,P2 et P3) ;
- 3 Landing sites (1 longitude & 3 latitudes respectively equal to 0,30 and 45 degrees) ;
- 2 Comet periods (10 days & 7 hours).

We used the "CRIFO" model (See Ref. 2) available for 3 AU in the worst case, that is to say :

- Q_0 = 8E^{26} CO molecules/s (maximum outgassing rate),
- a_0 = 0.1 (Anisotropic model).

This model provides a gas density ρ and a gas velocity V.

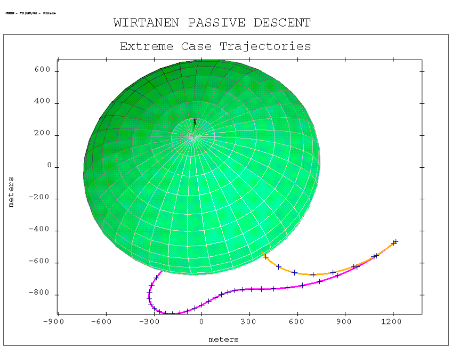
The magnitude of the perturbation due to the outgassing can be the same order of magnitude of the gravitational force in the vicinity of the comet and in the area near the subsolar point (See Ref. 2). It's possible to obtain situations where the lander seems to float because of outgassing effect (See Fig 3).

The force which has been simulated corresponds to the classical formula :

$$F = \tfrac{1}{2}\rho C_X V^2 \frac{S}{m} \qquad \textbf{(2)}$$

with : $C_X = 2$
$S = 0.72\ m^2$
$m = 75$ kg
and V = relative velocity w.r.t the gas

Figure 3 : Wirtanen passive descent trajectories (without and with outgassing)



The main conclusions of this study are the following :

- big variation due to the outgassing effect in the case of passive mode;
- necessity to use a vertical manoeuvre ΔV_Z to increase the velocity in order to reduce the outgassing effect ;
- for values of ΔV_Z corresponding to 30 or 50 cm/s, the characteristics of the landing with outgassing (differences with a nominal "keplerian" trajectory) are given in the following tables :

Table 14 : Maximal variations compared to the not outgassing case

ΔV_Z (m/s)	Descent time (mn)	Landing Position (m)	Attack angle (deg.)	Impact angle (deg.)
30	5	15	10	2.6
50	2.5	6	0.8	1.3

in the case of a density of 0.75 g/cm$^{3.}$

Table 15 : Maximal variations compared to the not outgassing case

ΔVZ (m/s)	Descent time (mn)	Landing Position (m)	Attack angle (deg.)	Impact angle (deg.)
30	40	30	3	15.
50	10	23	1.7	4.4

in the case of a density of 0.115 g/cm^3 (in order to simulate the behaviour of the small comet).

Gravitational potential modelling

In addition to the classical keplerian model, gravitational "models" have been processed and compared.

- Spherical harmonic expansion,
- Cartesian coordinate expansion,
- IVORY model (First ellipsoidal harmonics).

For all this cases, we have supposed an homogeneous density.

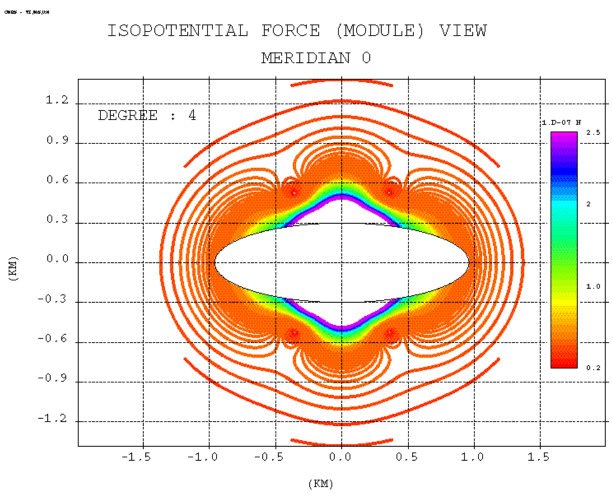
Spherical harmonic expansion

The gravitational potential is developed on the basis of spherical harmonic functions. In the case of an ellipsoid with homogeneous density, it is possible to prove that the even coefficients are equal to zero and that the odd coefficients can be expressed in function of the three semi axis a, b, c (where a > b > c) and the density.

In reference, it is also indicated that the expansion diverges if the satellite (or the Lander) is at a distance of the centre lower than a in the case where $a > c\sqrt{2}$.

We have represented on figure 4 the forces isolevels for the case of Spherical harmonic expansion limited to the order 4. We can observe the irregular behaviour near the comet and at high latitudes.

Figure 4 : ISO/forces isolevels



Cartesian coordinate expansion

In this case, the gravitational potential corresponds to a limited expansion of the gravitational potential integral. This expansion is well adapted to take into account holes and hills, because the coefficients can be easily expressed as function of the inertial integrals. But its behaviour is identical to the Spherical harmonic expansion in term of divergence.

IVORY Model

This model gives the exact potential for any ellipsoidal shape and is based on an analytical approach which consists in evaluating the potential by using elliptical integrals. This is the first ellipsoidal harmonic.

Results of comparative studies

From initial conditions of a keplerian trajectory (worst case of polar orbit with a landing point at a latitude of 45 degrees on the most elongated ellipsoid (G4), we have computed 4 trajectories with the following gravitational models :

- spherical harmonic expansion limited to order 2, 4 and 6 (respectively POT2x2, POT4x4 and POT6x6) ;
- ivory model (IVORY).

Table 16 : Deviations to Keplerian trajectory

		POT 2X2	POT 4X4	POT 6X6	IVORY
SITES (deg)	Longitude	-0.4	-0.4		-0.35
	Latitude	-	-		-07.8
IMPACT VELOCITY	Module (m/s)	15	18.7		0.34
	Angle in the Lander (deg)	13.8	50.		10.6
	Angle in the local frame (deg)	17.	53.		12
ATTITUDE DEVIATION (deg)		3	3	No Intersection	1.7

Conclusions

This mission analysis has been showed a good concordance between CNES and ESA results.

The main conclusion is that an MSS, range between 5 and 50 cm/s, is adequate whatever the comet parameters are. In addition the use of vertical manoeuvre, up to 1 m/s, is necessary to guaranty the success of the descent.

The future works will consist in :

- improving the modelling specially concerning the gravitational potential (Effect of hills and holes), the outgassing, comet nutation ;
- solving a robust control problem based on landing site position/velocity and attitude dispersion minimisation.

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