AAS 07-255

RE-AIMING CASSINI'S IAPETUS FLYBY

Frederic J. Pelletier*, Brent B. Buffington*, Nathan Strange* Tilmann Denk†

Cassini's only targeted Iapetus flyby is scheduled for September 10, 2007. In 2006, inquireries were made to investigate the possibility to improve the flyby geometry. After numerous discussions and design variations, modifications to the trajectory were adopted by the Project in early 2007. The goal of the designers was to achieve a flyby geometry that maximized the science results for a reasonable propellant cost. This involved (as a major driver) the reassessment of a star occultation that took away observation time from remote sensing of the surface. Ground-tracks were also studied to ensure the observation of very interesting features near the satellite's equatorial line.

INTRODUCTION

The first and only targeted flyby of Saturn's moon Iapetus (Iapetus-1, I1 or 049Ia) by the Cassini spacecraft will take place on September 10, 2007. This encounter is scheduled on the 51th revolution‡ of Cassini about Saturn, approximately 3 years into its 4-year prime mission. The orbit of Iapetus has a long period of 79.33 days and is inclined by 15.42 degrees with respect to Saturn's mean equator. This geometry makes it particularity difficult for Cassini to encounter Iapetus, mainly because Cassini's orbit is coupled with Titan's and the inclination of Titan's orbit is nearly zero (0.3^o). As a result, the Iapetus encounter is the only targeted close encounter currently planned.

During its first year at Saturn, Cassini had a close non-targeted encounter with Iapetus on December 31, 2004 at a range of 124,000 km, where numerous discoveries were made.[1,2,3] This includes: The equatorial ridge on the leading and anti-Saturn side, a latitude dependence of the dark terrain characteristics, an unusually high number of giant impact basins, the significant role of these basins for the overall shape of Iapetus, or the latitudinal dependence of bright and dark crater rims. In addition, earlier discoveries from Voyager data such as the irregular boundary between the bright and the dark hemispheres, the giant bright mountains on the anti-Saturn side ("Voyager" mountains) and the ellipsoidal shape of the whole moon have been confirmed. However, besides many unanswered questions, a major missing piece is a very close-up view on the surface. This is planned for the targeted flyby on Sept. 10, 2007.

As this flyby is the only opportunity for Cassini to study Iapetus up close, efforts have been put into optimizing the trajectory for the science return. This paper presents the design work that led to the release of a new reference trajectory. These changes were officially adopted in early 2007 by the Cassini project.

*Jet Propulsion Laboratory, Guidance Navigation and Control Section, Pasadena, CA

†Freie Universität, Berlin, Germany

‡For various reasons, the Project refers to this part of the Cassini Tour as Orbit 49, hence the denomination 049Ia

GEOMETRY OF THE IAPETUS-1 ENCOUNTER

Figure 1 shows Cassini's orbit leg between Titan-35 (T35; August 31, 2007; 3302 km) and Iapetus-1 (I1; September 10, 2007; 1644 km[*]). Also shown is a close encounter with Rhea (non-targeted, 5737 km) a day before T35. The I1 encounter is targeted by the Titan-35 encounter together with the Orbit Trim Maneuvers (OTM) 125 and 126. OTM-127 is a statistical maneuver meant to correct navigation errors and is not used in the design of the orbit. Following I1 is the Titan-36 encounter (T36; October 2, 2007; 975 km), targeted by OTM-128 and 129. T36 is not shown on the plot but occurs after Saturn periapsis at the same location as T35. All these events are interconnected to optimize the propellant use and at the same time satisfy the encounter constraints. The original reference trajectory had a periapsis altitude constraint of 1500 km[*] for I1 and 975 for T36.[†] The T35 altitude was not constrained (More details can be found in the Cassini Navigation Plan[5] and the Cassini Mission Plan[6]).

Because of the geometry imposed by the Titan encounters, the incoming and outgoing asymptotes at Iapetus are locked. That means that the set of possible ground-tracks on Iapetus are limited between the asymptotic points on the body. Therefore, only the flyby B-Plane angle, the closest approach altitude and the flyby epoch can be modified. This nevertheless allows a wide range of ground tracks that cover different parts of Iapetus. The B-Plane angle was however optimized at 156.7 degrees to minimize the propellant use between T35 and T36.

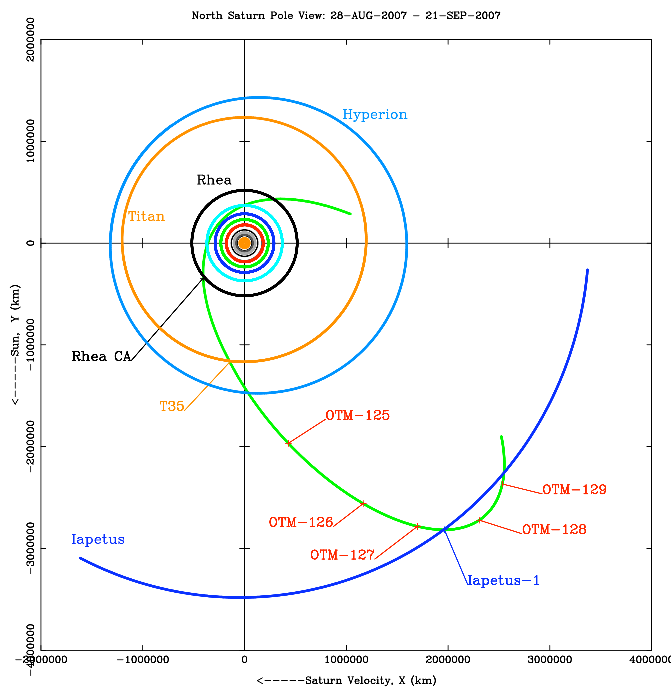


Figure 1 Iapetus-1 Encounter

The possible ground tracks are shown on the map of Iapetus in Figure 2.[‡] Each track corresponds to variations in the B-plane in increments of 10 degrees. It starts at the incoming asymptote (60^{o}W, 10^{o}N) and goes to the outgoing (240^{o}W, 10^{o}S) asymptote. The original ground-track corresponding to the 156.7 degree B-plane angle is shown in red. The theory used to generate these curves can be found in Buffington and Strange,[7] where they present results for a similar trajectory update study done for flybys of Enceladus. It

[*]For the purpose of this study, a mean radius of 718 km for Iapetus is used (IAU-adopted values from Voyager data). Cassini scientists are now using a more recent and accurate model from P. Thomas (747 × 747 × 712 km radius)[4]

[†]The T36 encounter is dedicated to a Synthetic Aperture Radar measurement and the 975 km altitude has to be preserved

[‡]Map taken from Steve Albers' web site (http://laps.fsl.noaa.gov/albers/sos/sos.html)

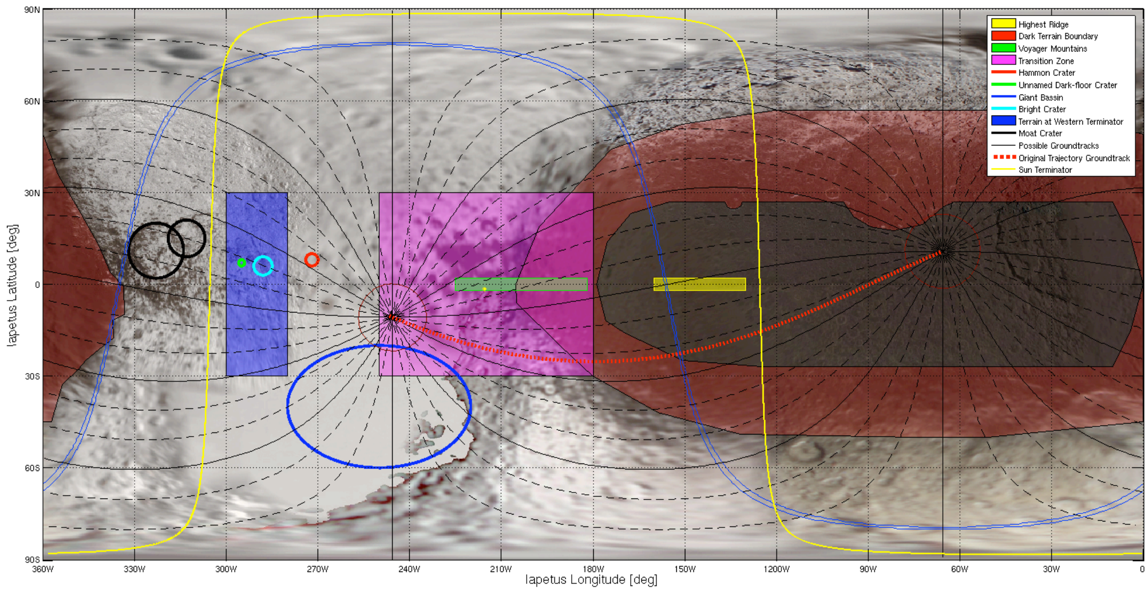


Figure 2 Iapetus Landmarks and Ground Tracks

is important to note that while these ground-tracks are possible, any deviation from the nominal plan will most likely increase the propellant cost.

SCIENCE OBJECTIVES

In light of the 2005 discoveries, the Cassini navigation team has been approached by the Cassini Imaging Team to see if the encounter could be modified to maximize the science return for all the instrument teams of Cassini.

Star Occultation

An important science objective of the encounter is the observation of a star occultation with Iapetus. In this measurement, a star passes behind (or near) the satellite's rim as seen from Cassini and is picked up by the Ultraviolet Imaging Spectrograph (UVIS). This serves to detect the presence or absence of an atmosphere. The original plan for UVIS was to use the star ζ Ophiuchi, which was one of very few stars occulted by Iapetus during the flyby. This observation had to be preserved and has already been negotiated and approved by the Project.

However, the observation would take place when Cassini is at its closest distance with Iapetus. Therefore, a valuable portion of the observation time around closest approach could not be used for surface observations. A potential shift of the UVIS stellar occultation by about 1 hour on the inbound leg (Iapetus crescent view) would add the option to observe the surface well before closest approach, including new observations of parts of the newly detected equatorial ridge at $\sim$30 m/pxl spatial resolution. In the original plan, the ridge would be close to, or behind, the eastern horizon at C/A+5 min, the time when the tracking for surface observations was intended to begin over high southern latitudes.

Thus, one of the main scientific rationales for this trajectory tweak was the hope that the occultation might be shifted backwards in time without compromising its goals at all. In addition, the occultation with ζ Ophiuchi was not ideal since it was only grazing the surface.[§] With navigation errors, this could potentially have led to only partially fulfilling the objective. Efforts have therefore been put to search for alternative trajectories with acceptable star occultations as far from closest approach as possible.

Surface Imaging

Cassini's Imaging Science Subsystem (ISS) consists of a wide angle camera, with angular resolution of 60 microradians per pixel, and a narrow angle camera, with angular resolution of 6.0 micro-radians per pixel. One of ISS's high-level objectives is to map the surfaces of the satellites in order to both study their geological histories, and to determine the nature and composition of the icy satellite surface materials. To answer these questions, the ISS team has identified landmarks of prime interest on Iapetus. These features were first observed in the past by either Voyager or Cassini. They are:

- a complex dark/bright transition zone west of the dark terrain (violet)
- huge mountains observed by Voyager 2 near 0^oN 210^o W (green),
- the highest part of the equatorial ridge near 150^o W longitude (yellow),
- the dark terrain on the leading side (Cassini Regio, brown and dark red),
- several craters to the west, espcially dark-floor craters (blue and circles),
- a huge ~500-km basin at southern latitudes (blue ellipse)

These key landmarks have been portrayed on Figure 2 over the map of Iapetus. As mentioned above, the possible ground-tracks for Cassini are indicated on the map. The sun terminator at the time of the flyby is also indicated by a yellow line. A yellow star near 210^o W longitude represents the sub-solar point.

Other Science Objectives

In addition to ISS and UVIS, there will be many more scientific highlights during the flyby. For instance, the RADAR instrument is planning the only SAR observation of an icy satellite, the Composite Infrared Spectrometer (CIRS) will conduct very high-resolution thermal observations, and the Visual and Infrared Mapping Spectrometer (VIMS) expects to get the best-ever examination of outer-solar system dark material.

While the details of how the time is divided up between the instrument is beyond the scope of this paper, the important aspect is that all instruments will benefit from an improved ground-track with better timing for the UVIS star occultation. More details on the science benefits of the flyby were presented at a workshop by Denk *et al.*[1] as well as in an internal JPL memorandum by Dennis Matson.[8]

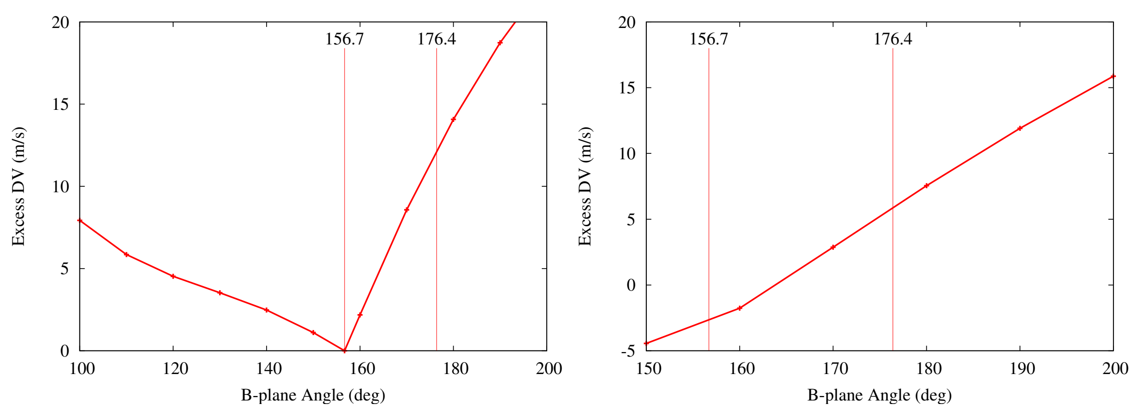
[§]This was not known many years ago during the initial planning process, but only recognized more recently with improved estimation of Iapetus' orbital parameters

ENCOUNTER RE-DESIGN

From Figure 2, one can see that although close, the nominal ground-track misses a nadir-looking geometry for most of the particularly interesting features which are preferentially located near the equator. Discussion with ISS revealed that a B-Plane angle of 180^o would be ideal for this flyby. This trajectory would fly directly above the highest section of the ridge, the dark terrain and the transition zone near closest approach, and would offer a potentially incredible side view of the high mountains observed by Voyager 2 as well. Based on this, the mission designer's goal was to look for alternative trajectories that would significantly improve the science return for ISS (and all optical remote sensing (ORS) instruments in general) while minimizing the interference with the rest of the mission.

In summary, the search for a better trajectory was constrained by the following four factors:

- Having the B-plane angle as close to 180 degrees as possible,
- Finding a star occultation away from closest approach on the inbound leg,
- Minimizing the ΔV cost,
- Minimizing the impact to the rest of the Tour.



(a) 1500 km C/A Altitude

(b) 2000 km C/A Altitude

Figure 3 ΔV Cost of Changes in the B-Plane

Figure 3 shows the ΔV cost associated with varying the I1 B-plane angle. To achieve these, a series of optimized trajectories was generated where, for each case, the Iapetus B-plane angle was constrained to a specific value while the time of closest approach was free to move by a few hours. For the rest of the tour, the general shape of the trajectory was maintained, although some flexibility in the Titan flyby asymptotes was allowed in order to minimize propellant cost.¶ In Figure 3(a), the altitude at closest approach was not allowed to go beyond 1500 km. This study showed that it is more expensive, unfortunately,

¶During this first phase of the study, the trajectory optimizer chose to use OTM-129 to correct the trajectory after Iapetus. This is different from the final design where OTM-128 was chosen instead. This explains some of the discrepancies in DV and timing in the first few tables and the final ones to increase the angle than to lower it. The ΔV cost associated with moving the B-Plane angle to 170^o and 180^o is approximately 8.5 m/s and 14 m/s, respectively. Considering this, the Cassini scientists were willing to trade in C/A altitude for a better B-plane. In Figure 3(b), the same cost analysis is performed with the minimum altitude allowed to reach up to 2000 km. One can see that in this case, keeping the B-plane at 156.7 degrees saves a little ΔV, but the cost quickly goes up close to 8 m/s to reach a 180 degrees B-plane angle.

New Star Occultations

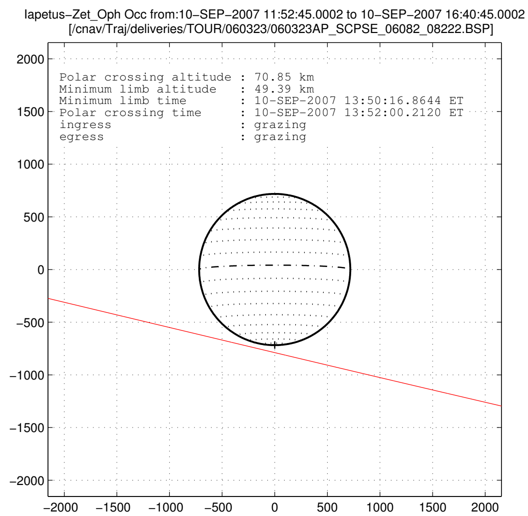
Some of the cases studied above also had the advantage to offer an alternate star occultation. While the original ζ Ophiuchi occultation was preserved in all cases, a more suitable occultation with the star σ Sagittarii was found with a B-plane angle of at least 175 degrees and a closest approach altitude of at least 1800 km. The advantage with σ Sagittarii is that it occurs near the incoming asymptote, about an hour from closest approach over the unlit side of Iapetus. A summary of the occultations found for various cases in the range of B-plane angles and C/A altitude is presented in Table 1. Also shown in the table is the time at the start of the occultation (ingress) and at the end (egress). The original plan with the 156.7-degree B-plane is also included for reference. One thing to note is that for a C/A altitude of 2000 km, lowering the B-plane angle would mean losing the σ Sagittarii occultation.

Table 1 Star Occultation Options

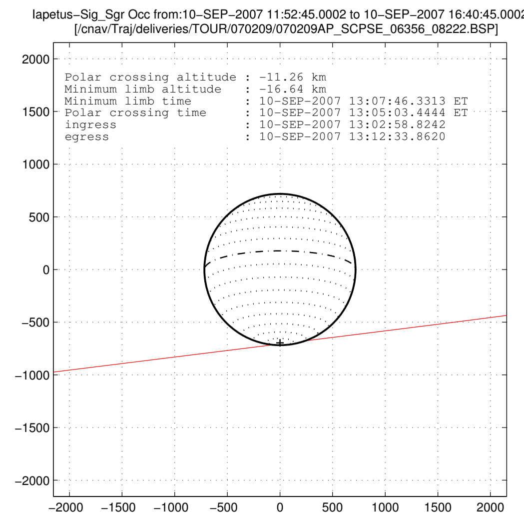
BPlane Angle (^{o})	C/A Altitude† (km)	ΔV Cost (m/s)	Time at C/A	Star	ingress Time	ingress ΔT to C/A	egress Time	egress ΔT to C/A
156.7‡	1500	0.00	14:03:23	ζ Oph	13:49	0:14	13:49	0:14
170	1500	8.53	14:04:00	ζ Oph	13:43	0:21	13:56	0:08
170	1800	4.43	14:47:03	ζ Oph	14:23	0:24	14:36	0:11
170	2000	2.87	15:11:16	ζ Oph	14:46	0:25	14:59	0:12
175	1500	11.4	14:16:17	σ Sgr	13:06	1:10	13:16	1:00
				ζ Oph	13:54	0:22	14:08	0:08
175	1800	7.02	14:50:24	σ Sgr	13:36	1:14	13:36	1:14
				ζ Oph	14:26	0:24	14:40	0:10
175	2000	5.24	15:13:47	ζ Oph	14:48	0:25	15:02	0:11
180	1500	14.1	14:20:56	σ Sgr	12:57	1:23	13:29	0:51
				ζ Oph	13:59	0:21	14:12	0:08
				α Vir	14:18	0:02	14:21	0:00
180	1800	9.48	14:55:28	σ Sgr	13:25	1:30	13:51	1:04
				ζ Oph	14:31	0:24	14:45	0:10
180	2000	7.55	15:17:56	σ **Sgr**	**13:45**	**1:32**	**14:05**	**1:12**
				ζ Oph	14:52	0:25	15:06	0:11

† From IAU Model, Iapetus radius = 718 km
‡ Original Trajectory

Because the 180^o-2000 km case offered the lowest ΔV cost option with a σ Sagittarii occultation more than an hour from closest approach, this case was selected for further consideration by the project. Figure 4 compares the geometry of the ζ Ophiuchi occultation in the original reference trajectory (Figure 4(a)) and the σ Sagittarii occultation for the proposed case (Figure 4(b)). Note that the σ Sagittarii occultation shown corresponds to the final design, which will be discussed shortly. The geometry between the cases presented so far is nevertheless similar.



(a) ζ Ophuichi (old ref. trajectory)



(b) σ Sagittarii (new ref. trajectory)

Figure 4 Star Occultations with Iapetus (as seen from Cassini)

Final Revision

A careful review by the the Project found that the disruptions to the timing schedules downstream were significant enough to reject the proposed trajectory. As stated previously, the rest of the tour events (up to July 1, 2008) were allowed to move slightly when optimizing the Iapetus flyby in the study. Although all the flybys were preserved and the general orbits were similar, the tweak caused trajectory deviations up to 15,000 km near Saturn apoapsis. The main drawback, however, was with the timing shifts that were also introduced. Such changes would have required a tedious effort of re-sequencing of observations from all science teams. For example, Saturn periapsis shifts were in the order of 20 minutes for a few revolutions after Iapetus-1 and up to 4 minutes afterwards. For these reasons, it became apparent that the downstream deviations were not acceptable and it was requested to correct this issue before the Iapetus tweak could be reconsidered. Although doing so was certainly possible, trajectory analysts were afraid it would drive the ΔV cost up from an already high value of 8 m/s. Not only did the project management have to ensure that the impact on all other science was minimized, but also had to be convinced that the benefits at Iapetus were worth the extra cost in propellant.

Based on these recommendations, the new trajectory was re-designed to eliminate all downstream variations after the Iapetus flyby. The additional constraints started at Titan-37, although the Titan-36 altitude of 975 km had to be maintained as well. The biggest (and very well received) surprise of doing so was that the Iapetus C/A altitude was re-optimized around 1660 km instead of reaching the 2000 km cap.

This sudden drop can be explained the following way: Because of the new constraints at Titan-36 (imposed by fixing T37), the optimizer chose to lump all the ΔV used to re-target T36 after Iapetus-1 in OTM-128, rather than OTM-129 as was previously the case. Since OTM-128 is 4 days earlier and closer to Iapetus, this did not require Cassini to fly so high from Iapetus. More details on this will be provided in the next section when the differences in the trajectory are discussed.

Unfortunately, these additional constraints drove the ΔV cost up to approximately 17 m/s! On the other hand, thanks to the lower Iapetus flyby altitude, lowering the B-plane angle by a few degrees to save propellant was now possible because the σ Sagittarii occultation is preserved with the 1660 km altitude. Table 2 shows the ΔV cost and the duration of the σ Sagittarii occultation for B-plane angles from 175 to 180^o. Note that the altitude shown has been optimized for each case.

Table 2 Iapetus Options for Fixed Dowstream Flybys

Case	B-plane Angle (deg)	C/A Altitude (km)	ΔV Cost (m/s)	OCC Min Altitude (km)	OCC Duration (min)
1	180	1663	17	-150	28
2	179	1654	16	-107	24
3	178	1645	15	-74	20
4	177	1636	14.5	-37	15
5	176	1626	14	-1	6
6	175	1618	13	36	N/A

NEW TRAJECTORY

The final trajectory that was selected is essentially a compromise between case 4 and 5 in Table 2. To ensure that navigation uncertainties would not undermine the occultation, a B-plane of 176.4^o was selected, with a final altitude at C/A of 1644 km.[‖] The corresponding altitude for the occultation for this case is about 13 km below the limb of Iapetus. Currently, the navigation team is expecting an error in Iapetus ephemeris of about 3 km cross-track and 8 km down-track. Because the flyby is only about 10 degrees off Iapetus' cross-track motion, only a fraction of the 8 km will affect the altitude of the occultation.[**] This translates into a 3.3 km 1-sigma polar error from Iapetus. Combined with a 2 km spacecraft uncertainty and a 2 km uncertainty in the polar radii of Iapetus, a 1-sigma (RSS) error of about 5 km in the direction of Iapetus' pole is expected. Thus, a 1-sigma trajectory error either way

‖The altitude quoted is higher than those in Table 2 due to a subsequent tweak made to preserve a star occultation with Enceladus in October 2007. This tweak caused the Iapetus closest approach altitude to go up slightly.

**The other portion will affect accuracy in the timing. A successful observation of the occultation can be ensured by allocating enough time to cover the down-track uncertainty.

would not compromise the occultation. The final cost for the Iapetus re-aiming is 13.7 m/s over the original plan, where most of it is used to re-target Titan-36 with OTM-128, the Iapetus clean-up maneuver.

While the ΔV cost for OTM-128 is significant, it was deemed reasonable considering the scientific gain at Iapetus. Furthermore, due to its peculiar orbit, this might very well be the only close-Iapetus flyby in the Cassini mission.

Ground Track

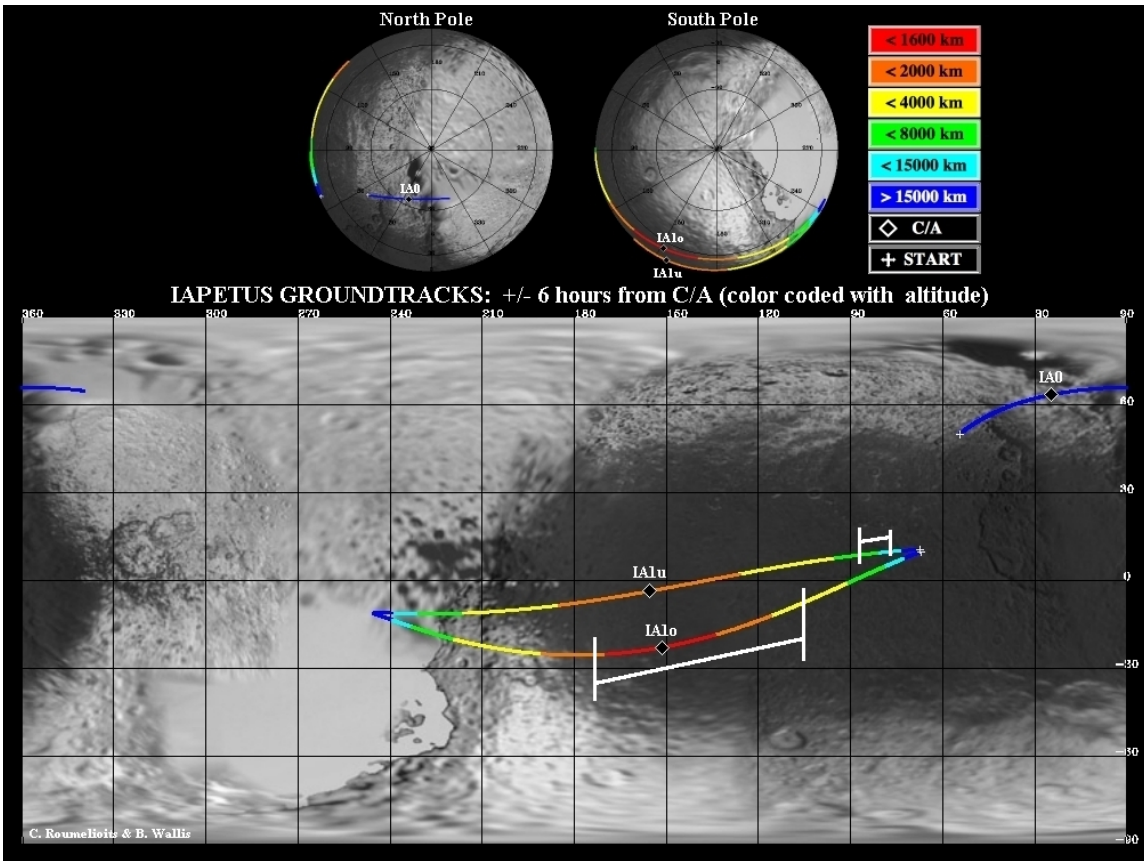
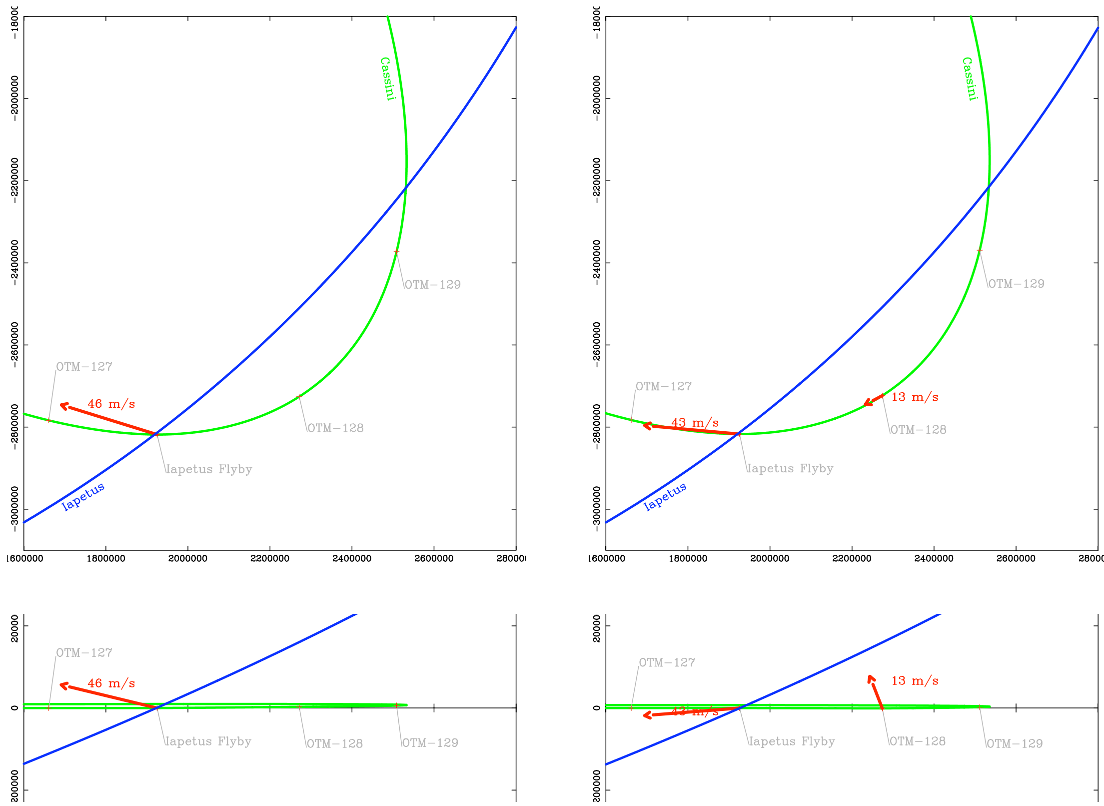


Figure 5 Iapetus Ground Track Comparisons

The new trajectory, while somewhat expensive in terms of ΔV, offers many advantages. Figure 5 shows the ground tracks for the New-Year's Eve 2004/05 flyby over high northern latitudes (IA0) as well as for the upcoming 2007 encounter. The IA0 flyby allowed surface imaging down to 730 m/pxl spatial resolution and gave important new insights into the nature of the dark terrain on the leading hemisphere, and of the "moat" crater and bright terrain on the sub-Saturn side.[1,2,3] The upcoming 2007-updated encounter (IA1u) is shown against the original track (IA1o). While both designs offer a never-before-seen view of Iapetus, the updated encounter is undoubtedly more optimal to observe the equatorial region. One of the main advantages of the new track is the shifted time taken to observe the star occultation. The used parts of the trajectory are depicted by the white lines adjacent to the ground tracks. Because of the more rapid motion of Cassini relative to Iapetus at closest approach, the time allocated to the stellar occultation in the original plan covered a significant portion of the ground track. The new trajectory instead allows surface observations during this very important part of the flyby, with the occultation positioned at a part where the spacecraft moves only very slowly as seen from Iapetus.

Trajectory Deviations



(a) Original Trajectory (b) New Trajectory

Figure 6 Iapetus Gravity Assist Geometry

The main drawback of the new trajectory is obviously the propellant cost. Because of the new B-plane angle, OTM-128 grew from ∼0 to about 13 m/s. This maneuver essentially corrects the error introduced by the new Iapetus swing-by and retargets Cassini to the Titan-36 encounter. 13 m/s is equivalent to a burn time of 80 seconds and a fuel consumption of 11.5 kg of Cassini's main engine bi-propellant fuel.

Though Iapetus' gravitational parameter is small ($\mu = 120.5$ km^3/s^2), the gravitational pull of Iapetus still gives Cassini a quite sizable ΔV. The change in velocity for a 1500 km altitude flyby is about 46 m/s and about 37 m/s at a 2000 km altitude.[††] Figure 6 shows the gravity assist ΔV vector from Iapetus together with the OTM-128 vector. The original flyby at 1500 km altitude and 156.7^o B-plane angle are shown in Figure 6(a) and the new

[††]Cassini's hyperbolic excess velocity at Iapetus is about 2.34 km/s

flyby at 1644 km altitude and 176.4^o B-plane angle is shown in Figure 6(b). The top views are looking down from the orbit's normal and the bottom views are looking edge-on at the orbit plane. From the plots, it is clear that the original flyby B-plane angle was optimized in order to achieve the out-of plane impulse that is required to reach T36, as shown in the bottom view of Figure 6(a). Raising the B-plane angle towards 180 degrees had the effect of bending the trajectory towards Iapetus' orbital plane, which caused an inclination change ΔV in the opposite direction, as shown in the bottom view of Fig. 6(b). This necessitated a large OTM-128 maneuver to compensate for the inclination-change.

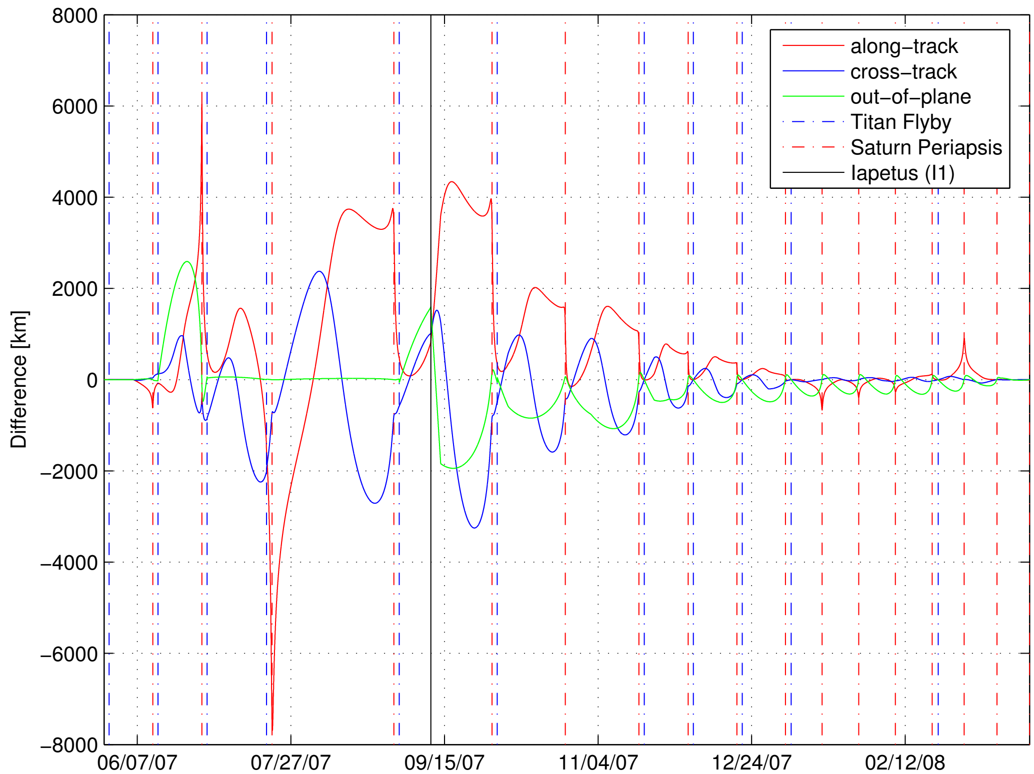


Figure 7 Trajectory Deviations

The geometry also explains why the Iapetus closest approach was optimized at 1644 km rather than 2000 km when OTM-128 is favored over OTM-129 to achieve the inclination change. OTM-128 being closer to Iapetus, it can afford a bigger out-of-plane component from the swing-by since the OTM takes effect sooner.

As mentioned, the trajectory deviations are localized between orbit 46 and orbit 50 of Cassini's prime tour (from T32 to T36). The deviations in the down-track, cross-track and normal directions are shown in Figure 7. The red spikes on the right side of the plot correspond to differences in Saturn periapsis timing, translated into large down-track differences on account of the spacecraft higher velocity at periapsis. The non-targeted Rhea closest approach is raised from 5109 km to 5737 km. A summary of the Titan-35, Iapetus-1 and Titan-36 B-plane parameters can be found in Table 3. Table 4 summarizes the differences in the maneuvers near the I1 flyby.

Table 3 Orbit 49 and 50 Close Encounters (≤ 300,000 km)

Encounter		Epoch (UTC	Altitude (km)
Orbit 49	Saturn	29-AUG-2007 13:02:32	262,596
	Rhea	30-AUG-2007 01:18:55	5,737
T35	Titan	31-AUG-2007 06:32:34	3,326
I1	Iapetus	10-SEP-2007 14:15:40	1,644
	Dione	30-SEP-2007 05:47:56	43,444
	Tethys	30-SEP-2007 07:43:41	139,407
	Enceladus	30-SEP-2007 10:51:26	101,506
Orbit 50	Saturn	30-SEP-2007 11:28:40	223,410
	Rhea	30-SEP-2007 23:25:15	186,689
T36	Titan	02-OCT-2007 04:42:43	975
	Hyperion	21-OCT-2007 15:00:55	121,643
Orbit 51	Saturn	24-OCT-2007 07:56:22	169,371

Table 4 Orbit 49 Maneuver Summary

Maneuver	Epoch (UTC)	Target	ΔV (m/s)	ΔV differences (m/s) from Original Trajectory
OTM125	02-SEP-2007 11:35:00	OTM126-XYZ	0.002	−0.011
OTM126	05-SEP-2007 18:50:00	I1-B-plane	0.002	−0.009
OTM128	13-SEP-2007 18:20:00	OTM129-XYZ	13.429	13.426
OTM129	17-SEP-2007 18:21:00	T36-Bplane	0.001	−0.001

SUMMARY

The Cassini project released a new reference trajectory on February 2007 to modify the geometry of the Iapetus-1 flyby. This change was approved in order to maximize the science return for an acceptable ΔV cost. The trajectory deviations were localized between the Titan-32 and the Titan-36 flybys.

A detailed analysis was performed to come up with the best scenario, some of which is discussed in Pelletier.[9] The modification adopted raises the B-Plane angle from 156.7 degrees to 176.4 degrees, has an occultation with the star σ Sagittarii near Iapetus' incoming asymptote and costs a little less than 14 m/s. Note that the flyby periapsis altitude is raised from 1500 km to 1664 km to save propellant. Although the propellant cost is relatively high, the project has deemed the cost acceptable for the greatly increased science. A trade-off discussion on the science benefits versus ΔV cost of the trajectory update is discussed in Matson.[8]

ACKNOWLEDGMENTS

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

The authors would like to thank in particular Candice Hansen, Chris Roumeliotis, Jeremy Jones and Peter Antreasian for their support to this paper.

REFERENCES

[1] Denk, T., Neukum, G. , Roatsch, Th., Hendrix, A.R., Pelletier, F.J. and Strange, N.J., "The Cassini Targeted Iapetus Flyby Will Take Place in September, 2007," *Workshop on Ices, Oceans, and Fire: Satellites of the Outer Solar System, Boulder, CO*, August 2007.

[2] Porco, C.C., E. Baker, J. Barbara, K. Beurle, A. Brahic, J.A. Burns, S. Charnoz, N. Cooper, D.D. Dawson, A.D. DelGenio, T. Denk, L. Dones, U. Dyudina, M.W. Evans, B. Giese, K. Grazier, P. Helfenstein, A.P. Ingersoll, R.A. Jacobson, T.V. Johnson, A.S. McEwen, C.D. Murray, G. Neukum, W.M. Owen, J. Perry, T. Roatsch, J. Spitale, S.W. Squyres, P.C. Thomas, M. Tiscareno, E.P. Turtle, A.R. Vasavada, J. Veverka, R. Wagner, and R. West, "Cassini Imaging Science: Initial Results on Phoebe and Iapetus," *Science 307 1237-1242*, February 2005.

[3] Denk, T., G. Neukum, T. Roatsch, A.S. McEwen, E.P. Turtle, P.C. Thomas, P. Helfenstein, R.J. Wagner, C.C. Porco, J.E. Perry, B. Giese, T.V. Johnson, J. Veverka, and the Cassini ISS Team, "First Imaging Results From the Iapetus B/C Flyby of the Cassini Spacecraft," *36th Lunar and Planetary Science Conference*, abstract 2268, 2005.

[4] Thomas, P.C., Burns, J.A., Helfenstein, P., Squyres, S.W., Veverka, J., Porco, C.C., Turtle, E.P., McEwen, A.S., Denk, T., Giese, B., Roatsch, Th., Johnson, T.V., "Shapes of the Saturnian Icy Satellites and their Significance," *Icarus, doi:10.1016/j.icarus.2007.03.012*, 2007.

[5] "Cassini Navigation Plan," *699-101 Update, JPL D-11621*, August 2003.

[6] "Cassini Mission Plan," *Revision 0, JPL D-5564*, October 2003.

[7] Buffington, B., Strange, N., "Science-driven Design of Enceladus Flyby Geometry," *57th International Astronautical Congress, Paper IAC-06-C1.6.05*, Valencia, Spain, October 2-6 2006.

[8] Matson, D., "Recommendation to implement Iapetus tweak," *JPL Interoffice Memorandum*, January 10 2007.

[9] Pelletier, F., "Cassini Iapetus-1 Flyby Variations," *JPL IOM 343J-06-049*, November 2006.