



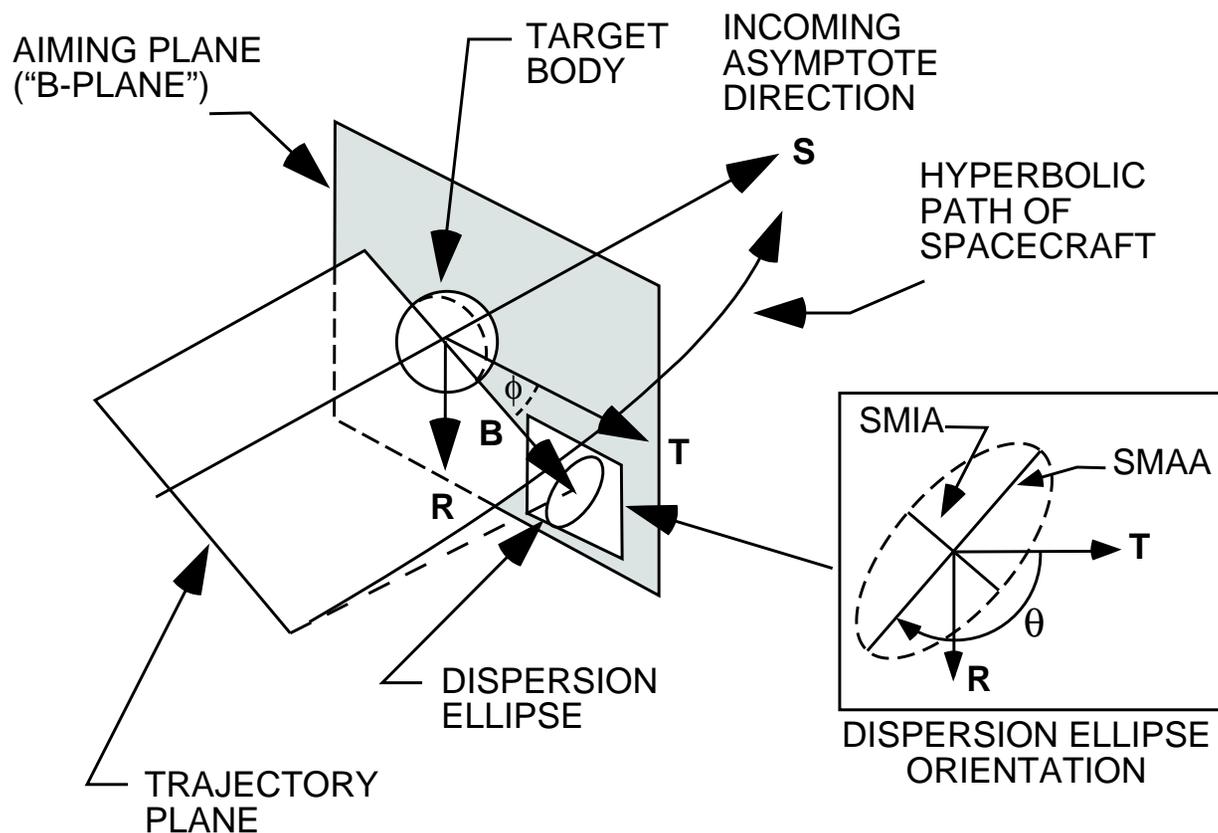
MANEUVER-TARGETING STRATEGIES AND RESULTS FOR THE CASSINI-HUYGENS MISSION

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Overview

- B-plane
- Mission Timeline / Navigation Strategy
- Requirements / Maneuver Targeting
- Operations
- Results

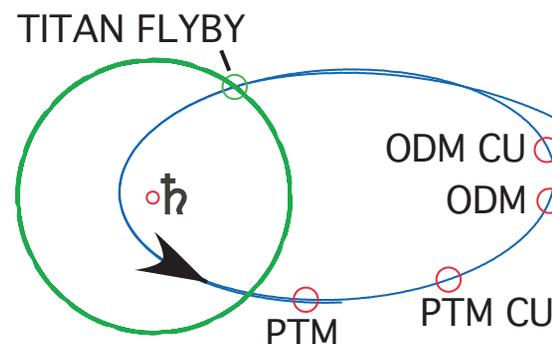
B-plane Coordinate System



ANGULAR MOMENTUM, $h = \mathbf{r} \times \mathbf{v} = \mathbf{B} \times \mathbf{V}_\infty = BV_\infty$

Mission Timeline / Navigation Strategy

- Two navigation phases: probe delivery & relay pointing
- Maneuvers scheduled mostly to meet requirements and desire to reduce risk to schedule (robustness)
- OD DCO was 2 days before maneuver, 1 day for ODM-CU (reliability)



Event	T-rel.	Date (SCET-UTC)	TA	Comments
Titan-b flyby	T _c -32	13-Dec-2004 11:38	-126°	1,200 km altitude
Pericrone	T _c -30	15-Dec-2004 05:51	0°	
PTM	T _c -28	17-Dec-2004 01:22	131°	Target to Probe entry
DCO for SEP	T _c -23	22-Dec-2004 03:30	161°	
PTM-CU	T _c -22	23-Dec-2004 00:52	163°	Target to Probe entry
SEP	T _c -20	25-Dec-2004 02:00	169°	
ODM	T _c -17	28-Dec-2004 00:37	174°	target Orbiter, ODT
Apocrone	T _c -14	31-Dec-2004 04:35	180°	
ODM-CU	T _c -10	3-Jan-2005 23:38	-174°	pointing profile, ODT
Probe entry	T _c	14-Jan-2005 09:07 ET	-133°	1,270 km altitude
Orbiter TCA	T _c	14-Jan-2005 11:13 ET	-133°	60,000 km altitude

Requirements / Maneuver Targeting

- PTM, PTM-CU targeted, at interface time:
 - interface alt. 1270 km
 - entry angle
 - B-plane angle
- ODM, ODM-CU targets, at periapsis:
 - B magnitude
 - B-plane angle
 - TCA
- SEP designed before Titan-b
- PTM, ODM mostly deterministic

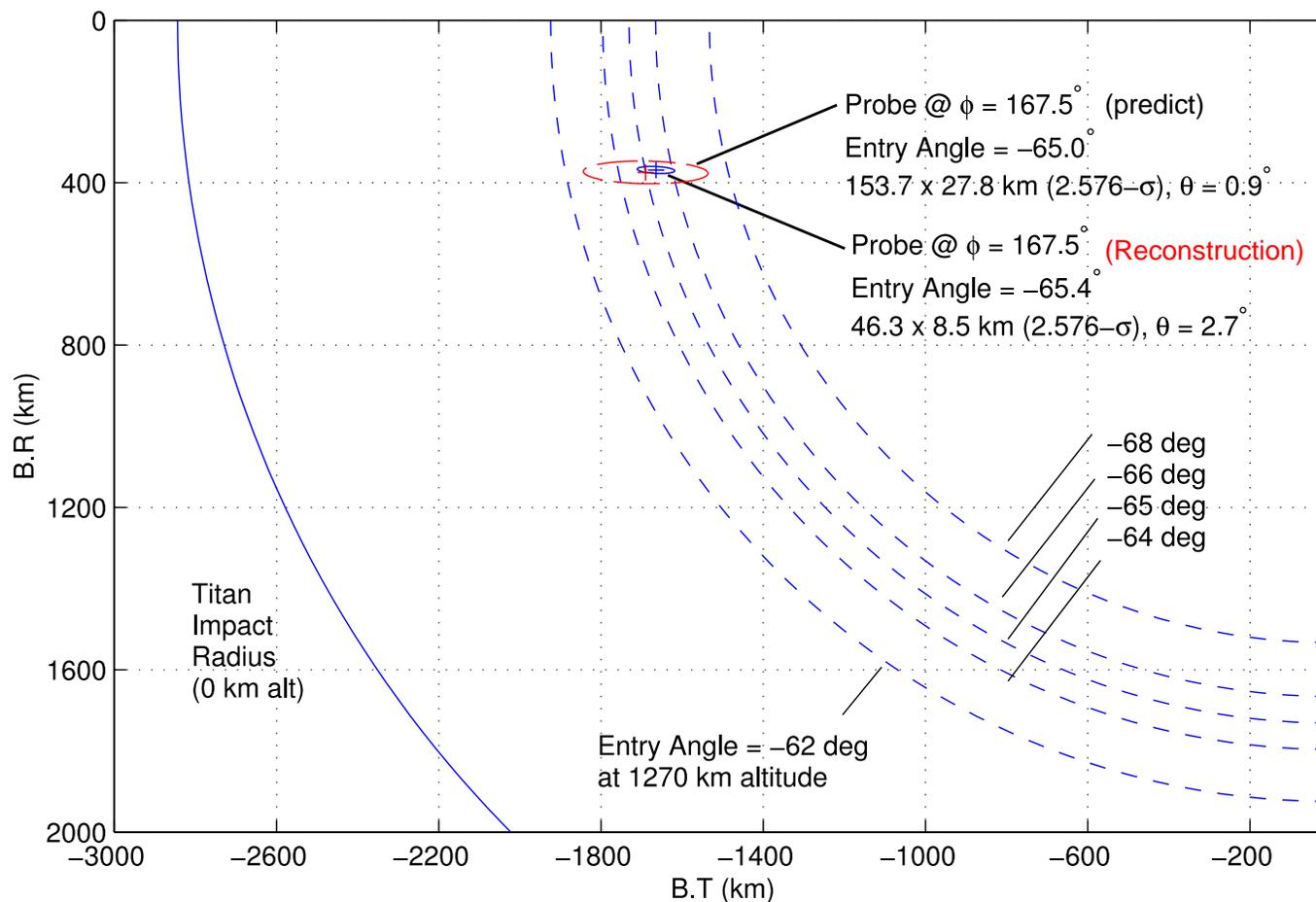
	Target	Reconstructed Error
interface time (ET)	09:07	-3.29 s
Probe V_{∞} , km/s	5.63	0.8 m/s
Probe B ang, deg	167.5	0.015
entry ang, deg	-65	-0.4
AOA, α , deg	0.00	1.4
Orbiter alt., km	60,000	3.3
Orbiter TCA (ET)	11:13	3.0 s
Orbiter B angle, deg	-180	0.03

Maneuver	Predicted Mean	Design	Reconstructed Error
PTM	11.9	11.9	-0.009
PTM-CU	0.14	0.0176	0.003
ODM	23.7	23.8	-0.008
ODM-CU	0.20	0.14	0.004

Operations

- There were many tasks for Navigation to complete on a daily basis—used software for automation
 - probe_entry_tool - entry angle and AOA statistics
 - landing_predict tool - rough landing-site sanity check
 - probe_relay_pointing_tool - relay-pointing statistics
 - probe_relay_ivp_check tool - to predict pointing error
- ran analyses nearly every day, whenever OD was updated
- kept track of extra PTM/PTM-CU design case: redesign of SEP to targ AOA
- plots and presentation packages were automatically generated and showed items such as the predicted delivery in the B-plane vs the entry-angle corridor

post-PTM-CU B-plane Delivery



1- σ delivery ellipses. Shows both predict and reconstruction. Predict met requirement; reconstruction shows high accuracy of predict. (Titan Equator of Date)

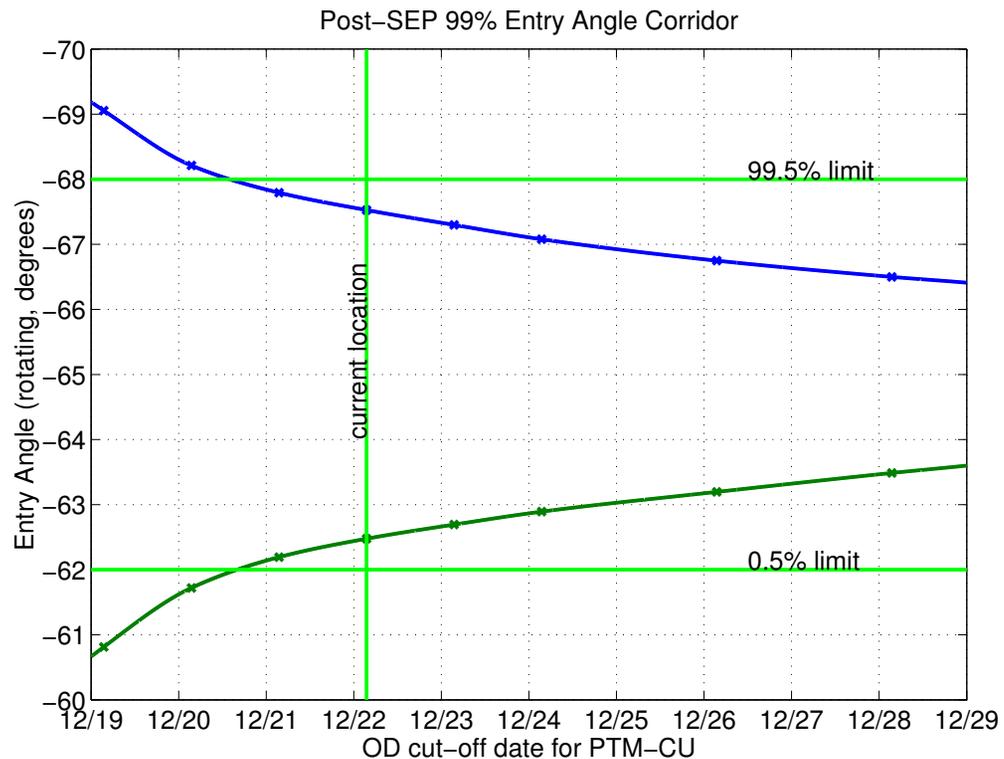
Results

- Based on the data in the reconstruction, the navigation strategy was a complete success. All of the Huygens mission requirements were met with a comfortable margin
- OD performed as predicted.
- Maneuver execution errors relatively small. OD reconstruction confirms this.
- Navigation analysis statistics held up very well.
- Probe delivery at interface altitude was less than $0.5\text{-}\sigma$ away from target.
- Error in entry angle was only about 0.4° .

Appendix

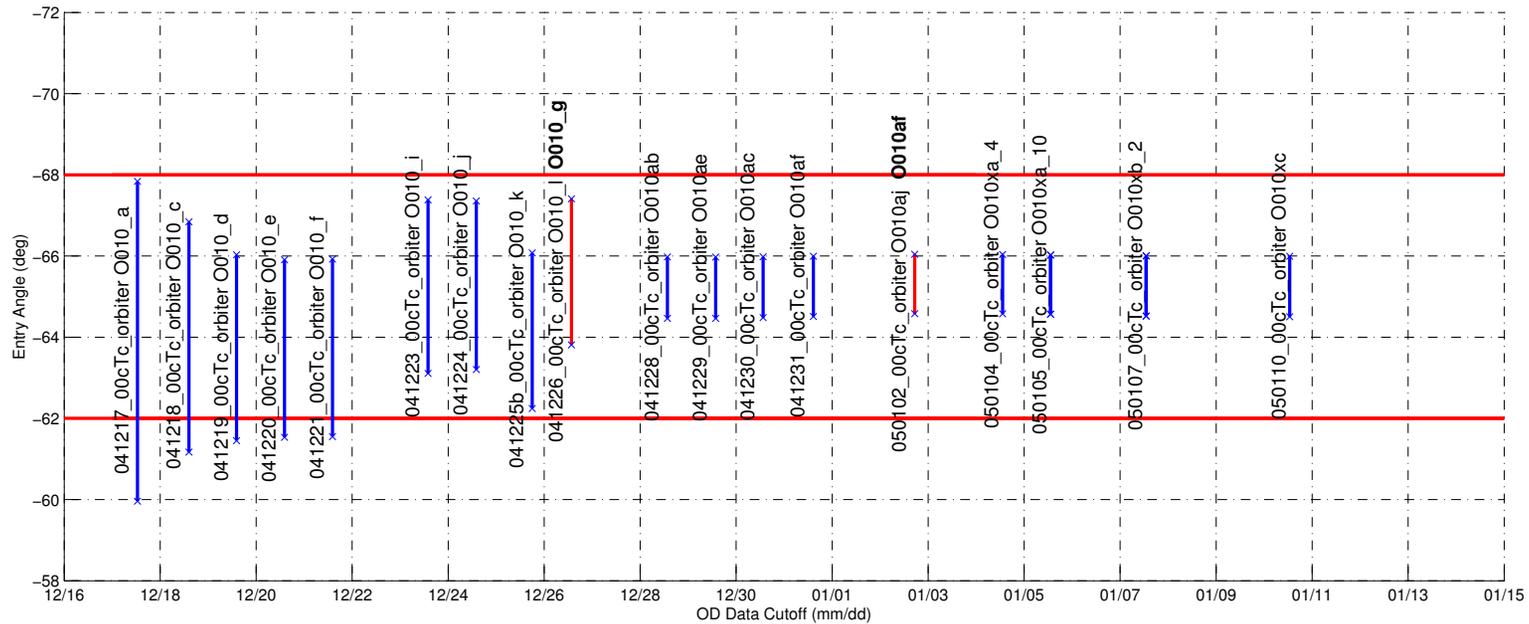
Maneuver Scheduling

- PTM-CU date determined mostly by entry-angle requirement: between -62° and -68° at 99%
- PTM mostly independent but determined by ΔV
- ODM-CU date determined mostly by probe-relay-pointing requirement.
- ODM mostly determined by ΔV



Entry-Angle Corridor vs OD DCO. For varying dates of PTM-CU's OD DCO, the predicted entry-angle corridor is compared to the required corridor, both widths shown at 99%.

History of Estimates for the Entry-Angle Corridor



This is a history of the 99%-level entry-angle corridor, showing

- the need to cleanup PTM—estimates post-PTM fell outside the requirement
- that all OD estimates following PTM-CU were consistent with delivery prediction
- that reconstructed entry-angle value is consistent with OD estimates during mission operations