Interplanetary Navigation

Examples from the Cassini/Huygens Mission

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Agenda

- Overview
    - Objectives
    - Functions
- Trajectory Design
    - Direct versus Indirect Trajectories
    - Flybys versus orbiters
- Estimation
    - General Techniques
    - Measurements
    - Models
    - Typical Results
- Control
    - General Techniques
    - Propulsion/Control Systems
    - Navigation Simulation
    - Typical Results

Overview

- Navigation Objective: Delivery instrument fields of view to the desired location subject to the constraints of the spacecraft and ground system design.
  - Support the design of the reference trajectory
    - The reference trajectory provides a “road map” for the execution of the mission
  - Estimate the “state” at all times during the mission
    - “State” may include:
      - spacecraft state,
      - satellite ephemerides,
      - satellite masses,
      - model parameters
  - Control the mission trajectory

Task Phases

- Planning and Prediction
  - Planning the trajectory
  - Defining the navigation strategy
  - Prediction of the capabilities (Accuracy, propellant,…)
- Execution
  - Collecting the measurements
  - Processing the measurements and estimating the model parameters
  - Correcting the trajectory
- Reconstruction
  - After the fact estimating where the spacecraft has been and the associated model parameters

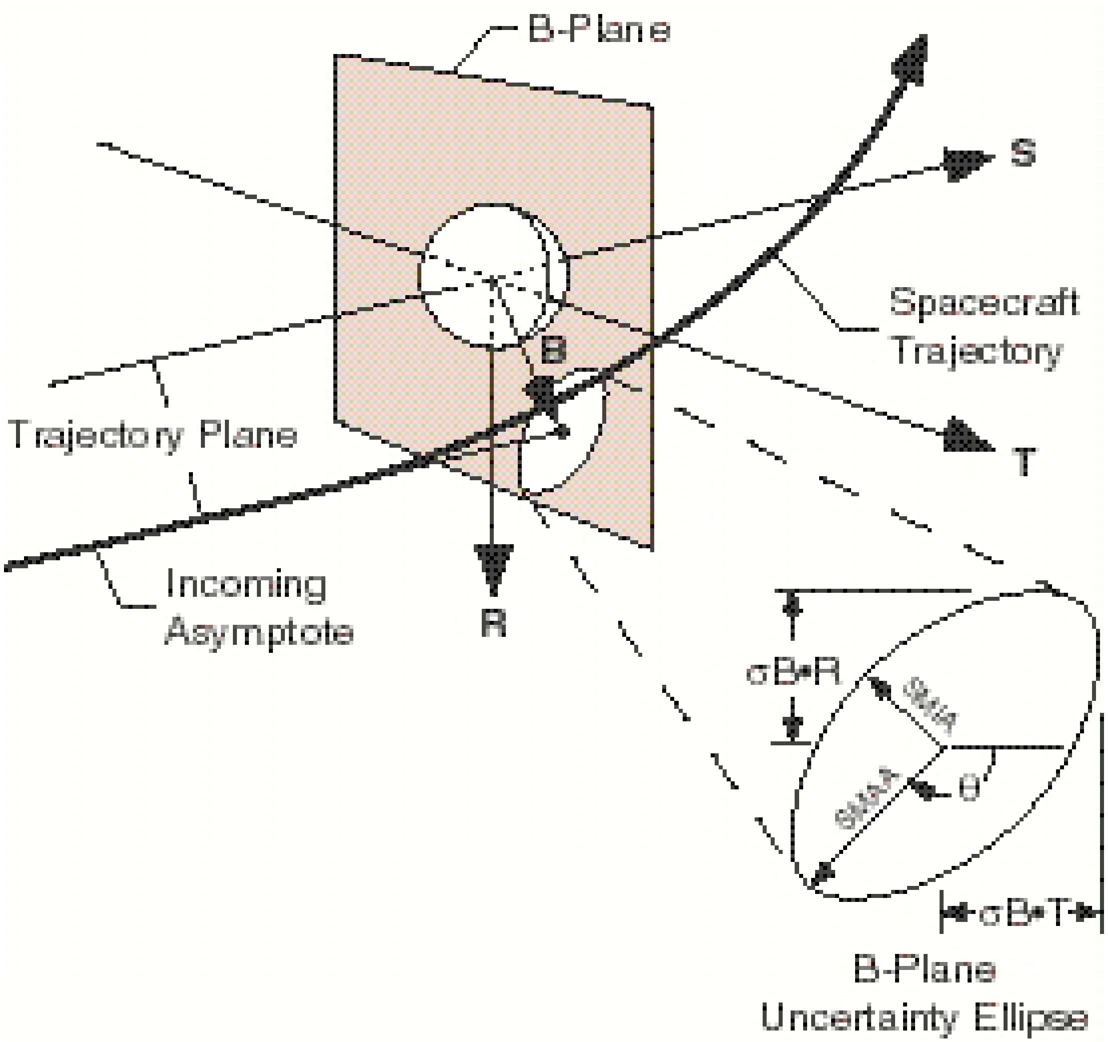
Trajectory Design

- Objective: Find a trajectory which meets the scientific objectives within the capability of the launch vehicle and the spacecraft.
  - Considerations:
    - Launch Window - The duration of the time interval that launch can occur
      - Can vary from instaneous to hours
        - Cassini's daily launch window varied from 5 minutes to 140 minutes
    - Launch Period - The number of days during which a launch can occur
      - Cassini's launch period for the primary mission was about 1 month.
    - Launch Opportunities - The number of available launch periods
      - Cassini identified 3 separate launch periods. Significant variations in the fundamental trajectory for different launch opportunities

Trajectory Design (Continued)

- Direct versus Gravity Assist Trajectories
  - Direct trajectories proceed from launch to their target with only propulsive maneuvers to modify the flight path
    - Minimizes the transfer time (cost) from launch to the target.
  - Gravity assist trajectories use the “sling shot” effect to change (increase or decrease) the orbital energy and inclination.
    - Maximizes the payload capability at the expense of time.
      - Cassini used two Venus flybys, one Earth flyby and one Saturn flyby to increase the orbital energy by 21 km^2/sec^2 ,but took 6.7 years to reach Saturn
      - Voyagers 1 & 2 used a direct trajectory that took about 4.1 to reach Jupiter
- Low Thrust Trajectories
  - Use low thrust - high impulse to decrease transfer time and/or increase payload

B-Plane


B-Plane
S
Spacecraft Trajectory
B
T
Trajectory Plane
Incoming Asymptote
R
σB•R
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θ
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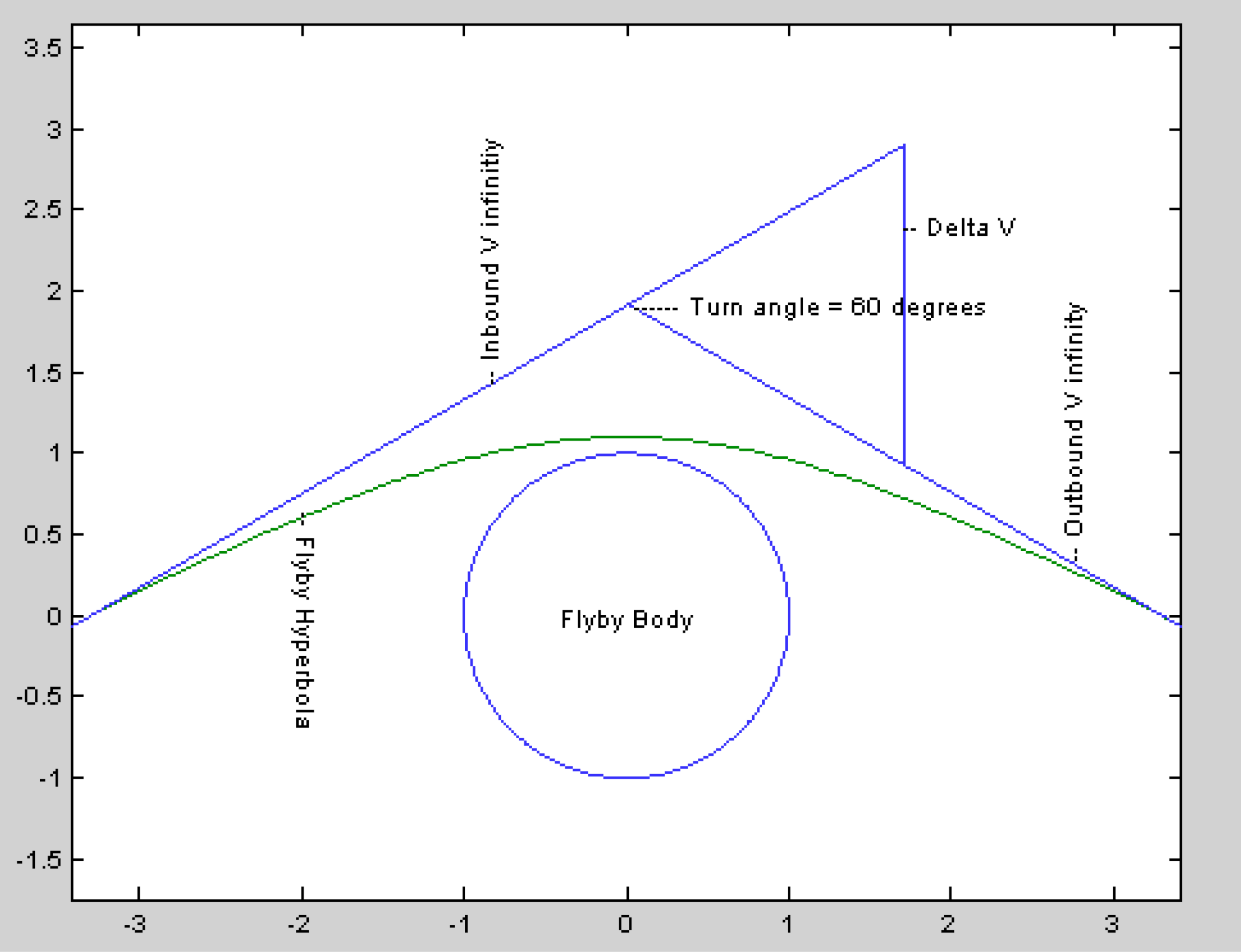
B-Plane Uncertainty Ellipse

Flyby Geometry



Gravity Assist

Changing an orbit parameters without propellant

$V_p = \text{"Planet"\_Velocity}$

$V^- = Spacecraft\_velocity\_before\_the\_flyby$

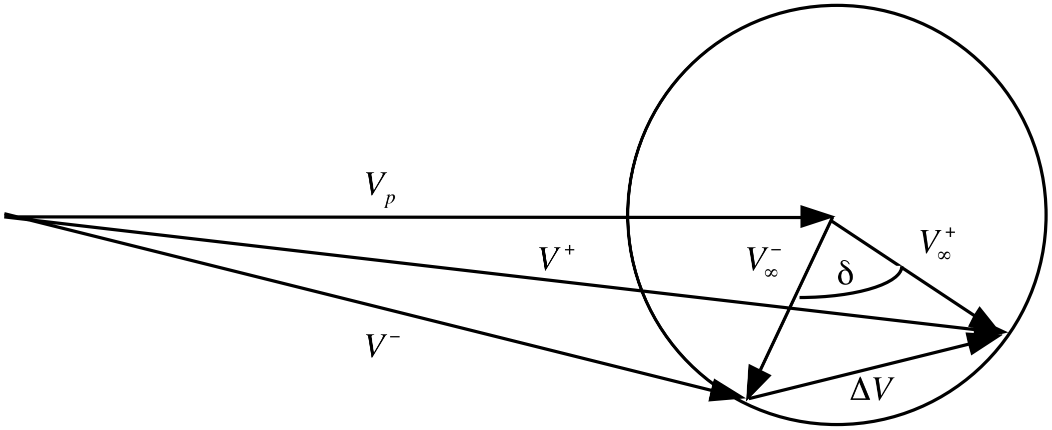
$V_\infty^- = Asymptotic\_velocity\_before\_the\_flyby$

$V_\infty^+ = Asymptotic\_velocity\_after\_the\_flyby$

$\delta = Turn\_angle\_during\_the\_flyby$

$\Delta V = velocity\_change$

$V^+ = Spacecraft\_velocity\_after\_the\_flyby$



$$\Delta V = 2V_\infty Sin(\delta/2)$$

$$Sin(\delta/2) = 1/e$$

$$e = 1 + \frac{r_p V_\infty^2}{\mu}$$

Question: Where did the energy change come from ?

Cassini Interplanetary Trajectory