Voyager

The 32nd Anniversary Edition

Operations Manual

June, 2009
by
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WARNING

This add-on is not for Orbiter beginners. TransX MFD is difficult, and the realistic low thrust and small fuel supply modeled for Voyager makes reaching Neptune *really* difficult!

Background
Section 1

YOU CAN'T GET THERE FROM HERE

In 1925 Walter Hohmann, the head civil engineer for the city of Essen, Germany, published a little book entitled *Die Erreichbarkeit der Himmelskörper (The Attainability of Heavenly Bodies)* in which he demonstrated the most economical trajectory, in terms of energy required, to get from the Earth to the Moon, or from one planet to another. The Hohmann transfer orbit is a fat ellipse, just tangent to the orbits of both the departure and target planets.

Figure 1-1 Cover from <u>Attainability of Heavenly Bodies</u> by Walter Hohmann, 1925.

It seems rather eccentric that Walter Hohmann worked out a solution for a problem that would have no practical application for another 30 years. But Hohmann was a respected civil engineer. His reputation lent respectability to space ponderings. As an inescapable matter of orbital mechanics, the Hohmann transfer remains the cheapest way to get from Earth to anywhere else in a single hop.

So, as the space age dawned in the late 1950s, American and Russian engineers busied themselves plotting Hohmann rendezvous orbits between spacecraft in low Earth orbit, and Hohmann transfers from Earth to the other planets. They immediately ran into a couple of problems. First, the gravitational influence of the other planets, and especially the target planet itself, perturbed the perfection of the Hohmann orbits, requiring careful corrections to account for unwanted acceleration and orbital deflection. Second, and much more daunting, was the vastness of the solar system. Even by taking the lowest-thrust Hohmann route, the largest conceivable rockets could not propel a useful payload much past the orbit of Jupiter. And even if immensely more powerful rockets were built, a Hohmann transfer to Neptune would be a 30-year flight! Not enough thrust and too much time — it appeared that exploring the outer planets would never be practical.

The solution to the second problem, of course, lay with exploiting the first problem.

In 1960 the Jet Propulsion Laboratory hired Michael A. Minovitch, a 25 year old mathematics graduate student, as a summer intern. He was assigned the task of confirming previously proposed Hohmann transfers to Venus, such that the target planet's gravity would perturb the spacecraft's orbit so as to send it on a new transfer back to Earth. (Why this was considered important is a bit of a mystery. Perhaps there was some practical plan behind this idea, perhaps it was just considered a cool thing to do. The literature doesn't say.) After solving the assigned problems, Minovitch, acting on his own initiative, found that with a gravity-assist from Venus he could sling a spacecraft to all of the inner planet. Using Jupiter's gravity, Minovitch could throw a spacecraft to any outer planet, or out of the solar system altogether! Minovitch found a way to reach *any* planet, using only enough thrust to get from Earth to Jupiter. "Not enough thrust" was no longer a problem. But even with accelerations from gravity-assist, it could still take decades to send a spacecraft from outer planet to outer planet, back and forth across the solar system.

In 1965 another JPL summer intern, Gary A. Flandro, was assigned the task of finding possible unmanned trajectories to the outer planets. Flandro began by studying Minovitch's work, then plotting missions to Saturn via Jupiter. He found the best launch times would occur in the late 70s. Then he found something more. In the early 80s all of the outer planets would be on one side of the Sun and reasonably lined up for a "grand tour" — a planetary arrangement that occurs only once every 176 years.

The following year, 1966, Flandro published a technical paper in the journal *Acta Astronautica* describing, in full mathematical detail, several grand tour trajectories taking in all four gas giants, along with Pluto. He identified launch windows, payload masses and delta V requirements, taking great care to demonstrate that the gravity-assist maneuvers would not violate Newton's laws of energy conservation. (When Voyager 1 swung by Jupiter in 1979 the spacecraft 's velocity relative to the Sun increased 13 km/sec while the planet's velocity decreased 0.3 meters/trillion years, shaving nearly a nanosecond off of its orbital period.)

In December 1966, Homer Joe Stewart, director of JPL's Advanced Studies Office, wrote a summary article for *Astronautics and Aeronautics*. Stewart took care to credit Minovitch and Flandro, writing in an accessible, math and jargon free style. His article caught the attention of the national press, Congress and the general public. Space flight was still exciting and new in the mid 60s, and the prospect of seizing an opportunity that comes up once every 176 years was especially appealing.

But things changed over the next ten years. By the mid 70s, when it came time to secure funding for the Grand Tour spacecraft design and construction, NASA's budgets and public interest in space flight reached their nadir. With estimated costs approaching $1 billion, the Grand Tour mission was cancelled and replaced with a much less ambitious plan designated Mariner Jupiter-Saturn. The twin MJS spacecraft were sold to Congress as simple Mariner-class vessels, with radioisotope generators in place of solar panels; the Sun being too distant from the outer planets to be a practical source of energy. Even in this diminished form, the Jupiter-Saturn mission treaded a fine line between continuation and cancellation, almost until its launch day.

The precarious balancing act played out even within JPL. Upper management consistently squelched any public talk of extending the Mariner Jupiter-Saturn mission into something like a grand tour, but at the same time they allowed MJS program managers to slant every possible option and design choice toward building a hardy vehicle capable of enduring an extended mission. When John Casani took over management of Mariner Jupiter-Saturn he went so far as to change the program's phone number to 864-6578 — that is, 86***4-MJSU*** — For Mariner Jupiter-Saturn-Uranus. Upper management at JPL reluctantly approved the change.

It was not until February, 1977, six months before launch, that NASA officially approved a Uranus option for the second MJS spacecraft. If the first spacecraft fulfilled its observational goals for Saturn and its moons, then the second craft could be targeted for Uranus, extending the mission four more years. (Prospects for adding Neptune to the itinerary were regarded as very slim.) NASA also approved a name change for the project, acknowledging the open secret that this would be much more than another Mariner mission.

Voyager was born and the Grand Tour was very tentatively underway.

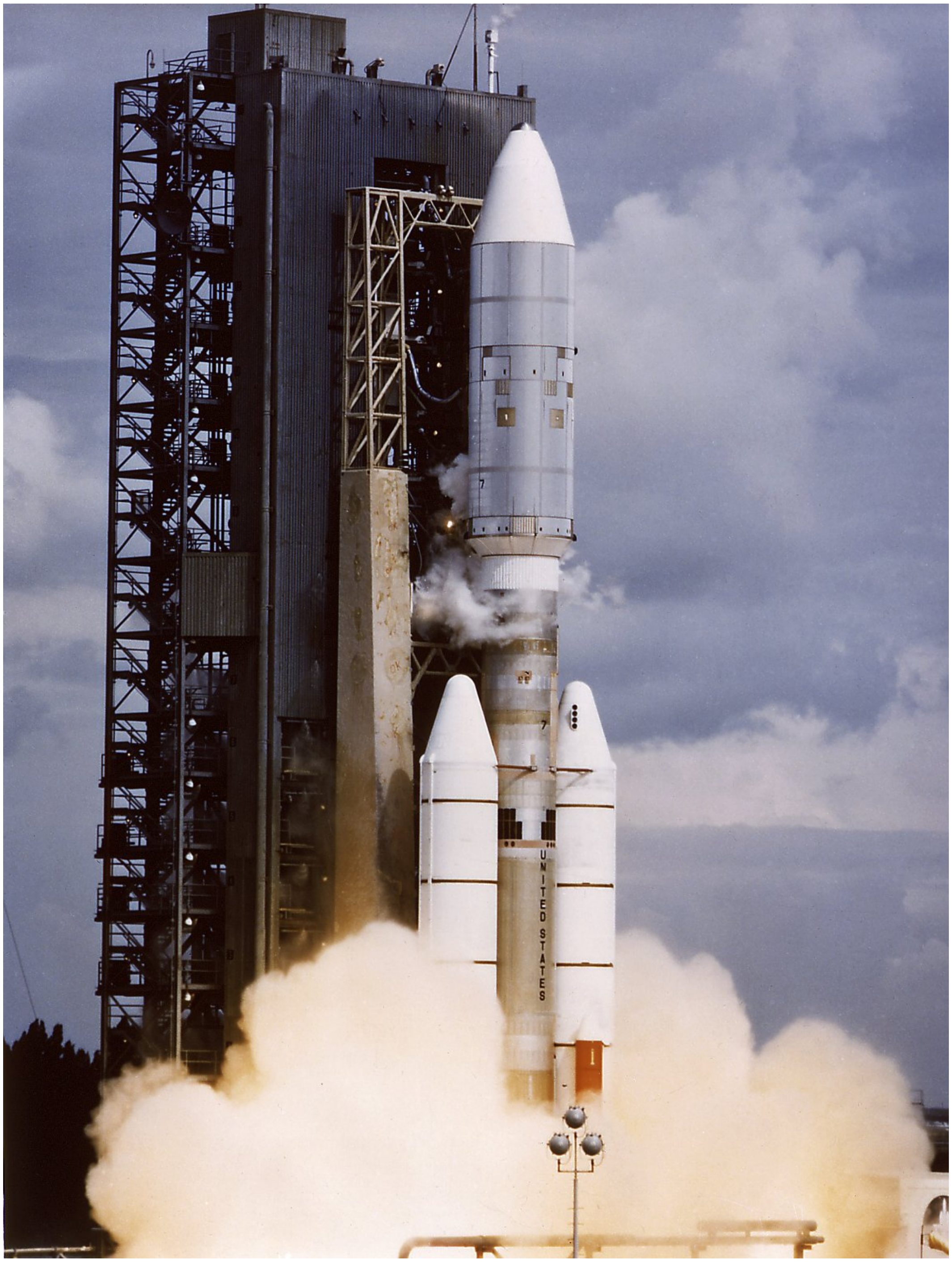

Figure 1-2 Launch of Voyager 2, August 20, 1977.

SPACECRAFT DESCRIPTION

The basic structure of the Voyager spacecraft is a ten-sided box, or Bus, with each side forming a compartment housing various electronic components. The Bus surrounds a single spherical fuel tank, and provides structural support for 16 attitude control thrusters, two folding booms, and several antenna arrays. Power is provided by three Radioisotope Thermal Generators (RTG) in which heat generated from decaying Plutonium-238 is converted into electricity. The RTGs are mounted on a boom that swings out along the –Y axis. Most of the instruments are mounted on the opposing +Y Science Boom to distance them from interfering or damaging radiation generated by the RTGs.

The Bus, fuel tank and most of the instruments are covered in multiple layers of black insulating blankets. Unlike spacecraft plying the warm inner solar system, wrapped in heat reflective foil, the Voyagers are designed to absorb and retain heat. The final fabric layer has hand sewn seams giving the dark spacecraft a distinctive look with edges highlighted by white stitching.

The spacecraft determines its orientation by means of a sun sensor, looking through an opening in the high-gain antenna, and a star tracker trained on one of several bright stars, most often Canopus. Attitude control is maintained by gyroscopes and sixteen 0.9 Newton thrusters. Four of these thrusters point in the Z minus direction, providing a maximum main thrust of only 3.6 Newtons. Mid-course correction burns of one to two hours duration were not uncommon.

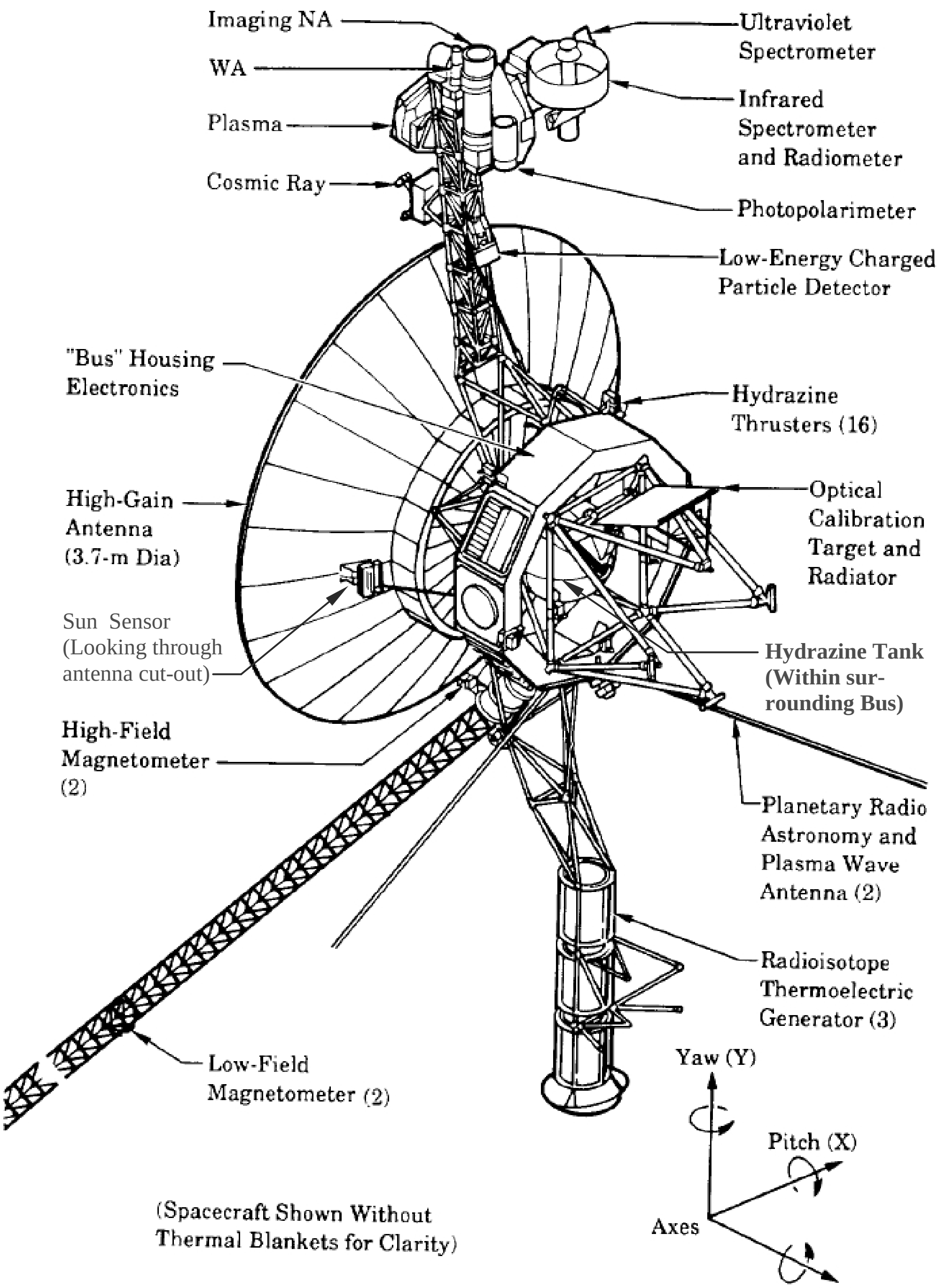

Figure 1-3 Voyager spacecraft structure.

Several instruments (wide and narrow angle cameras, spectrometers and photopolarimeter) are mounted at the end of the Science Boom on a Scan Platform that can be rotated during long exposures to prevent image "smearing" . Low field magnetometers are mounted on a 13 meter long expanding fiberglass truss to separate them from the spacecraft's own magnetic field. The JPL Voyager mission web page provides detailed information on the 10 science instruments supporting 11 different experiments. (See Section 3 for sources.)

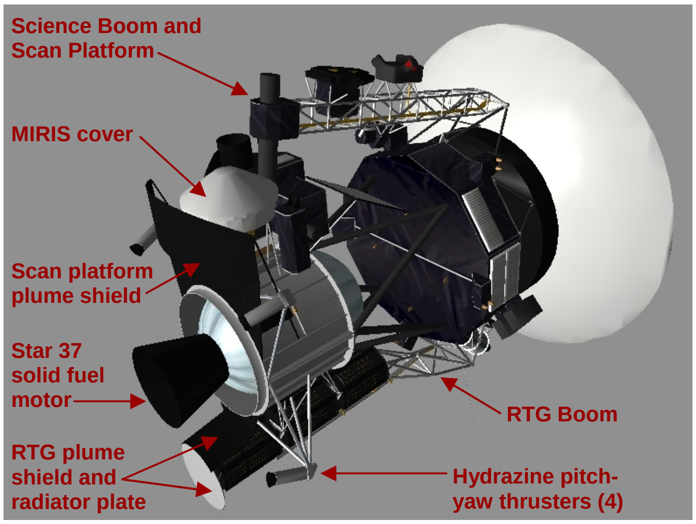

Figure 1-4 Voyager in launch configuration showing Propulsion Module and plume shields.

Each Voyager was launched by a Titan IIIE-Centaur rocket. The spacecraft also included a Propulsion Module using a Thiokol STAR-37E solid fuel motor. This type of "apogee kick motor" is often spin-stabilized, but the Voyager Propulsion Module had three-axis stabilization using hydrazine thrusters fueled from the Voyager's tank. In launch mode, the RTG and Science booms were folded down and braced against the Propulsion Module. This placed the RTGs and Scan Platform so close to the STAR-37 engine bell that plume shields were added to prevent exhaust heat, gases and particulates from damaging the instruments and generators. The large gold reflector of the Modified Infrared Interferometer Spectrometer (MIRIS) was further protected by a jettisonable aperture cover.

Altogether, it was an awkward arrangement that NASA and JPL have never duplicated.

A more successful and widely celebrated feature of the Voyager spacecraft is the Golden Record. During construction of the spacecraft a standard Concern/Action memo circulated through JPL observing that there was "no plan for sending a message to our extra-solar system neighbors." John Casani's succinct response: "Send a message!" NASA consulted famed astronomer Carl Sagan, who put together a committee of scientists, musicians and artists. They devised a collection of representative images, sounds, music and verbal greetings in 55 languages, all digitally encoded on a gold plated aluminum phonograph record. The record (along with a cartridge and stylus) was bolted to the Bus under a gold plated cover with engraved graphic instructions for playback. The cover engraving also includes a "map" showing the location of our Solar System relative to several pulsars.

It is highly unlikely that any spacefaring civilization will find and appreciate the Golden Record, but it was a hit on Earth and a publicity bonanza for NASA and Voyager.

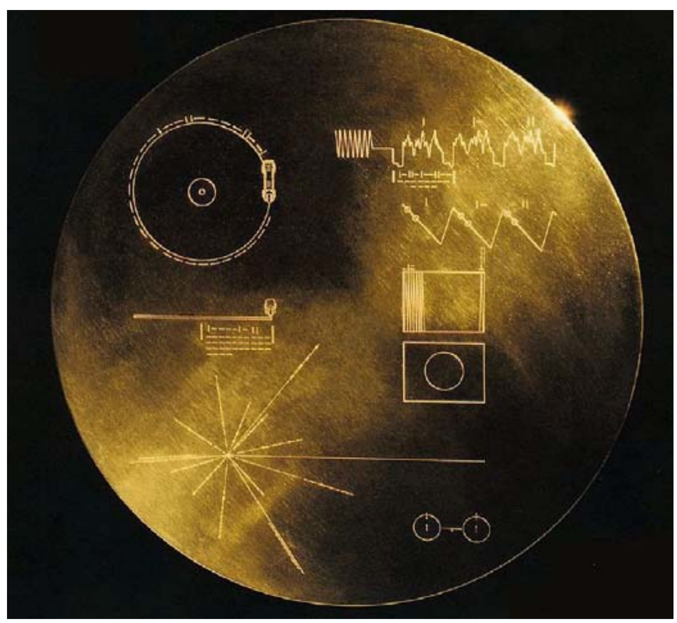

Figure 1-5 Golden Record's engraved cover.

Flight Operations
Section 2

CUSTOM KEY COMMANDS

Keyboard key presses are shown in square brackets [THUS]. On-screen MFD button clicks are shown italicized and in rounded brackets (*Thus*).

[J] means press the "J" key. [CTRL]+[/]numpad means press and hold the control key, then press the slash key on the number pad.

Titan IIIE - Centaur (Velcro commands)

[U] Enter a new launch azimuth.

[O] Ignites engines for liftoff with autopilot ON, and after ignition toggles autopilot ON/OFF.

[J] Jettisons the next payload.

Voyager (Spacecraft3 commands)

[J] Jettison the MIRIS aperture cover (prior to boom deployment, F3 focus on Voyager).

[G] Deploy RTG and Science booms (prior to jettison of the Propulsion Module).

[J] Jettison the Propulsion Module (after boom deployment, F3 to focus on Prop. Module)

[K] Extend Radio Astronomy antennae

[LShift]+[0]numpad
Extend Magnetometer boom.

[LShift]+[1]numpad
Start/Stop Scan Platform elevation axis positive rotation

[LShift]+[CTRL]+[1]numpad
Start/Stop Scan Platform elevation axis negative rotation

[LShift]+[2]numpad
Start/Stop Scan Platform azimuth axis positive rotation

[LShift]+[CTRL]+[2]numpad
Start/Stop Scan Platform azimuth axis negative rotation

ORBITER CONFIGURATION

The Voyager probe is configured with Spacecraft3. Separate configs for Voyager 1 and 2 are furnished so the two spacecraft can fly together in one scenario. The entire Titan IIIE-Centaur launch vehicle, Propulsion Module, and MIRS cover are configured with Velcro Rockets (requires a separate download). These Velcro vessels are automatically deleted from a scenario at about 2¾ hours after launch.

SCENARIOS

Voyager 2 launched on August 20, 1978 from Cape Canaveral Launch Complex 41. Voyager 1 followed from the same launch complex on September 5, but took a shorter flight path to Jupiter, arriving four months ahead of Voyager 2. Voyager 1 encountered Saturn at a high inclination, to provide the best possible view of the ring system, and was slung out of the ecliptic plane. After Voyager 1's successful close encounter with Saturn, Voyager 2's course was set for a lower inclination that would slingshot the spacecraft to Uranus, and ultimately to Neptune.

The Voyager installation includes launch scenarios for both Voyager 1 and Voyager 2, each starting 2 hours before their historic launch times. You must create your own TransX flight plan from scratch with these scenarios.

For Voyager 2, two sets of scenarios are provided with a TransX flight plan pre-loaded. One set is configured with TransX v3.10 (the version included with Orbiter) and the other set is configured with the latest version 3.13 (see Sources, Section 3). Each of these two sets contains four scenarios:

1 - Ready for Launch
2 - Parking Orbit
3 - Ready for Ejection Burn
4 - Ejection Burn Complete

VELCRO ROCKETS

Titan IIIE Centaur

The Titan III E launch vehicle and Voyager Propulsion Module are configured with Velcro Rockets, which works by making each stage of the launch vehicle a fully initiated vessel. Velcro attaches these separate vessels into a stack that operates as a coordinated launch system.

> NOTE
> TransX organizes a flight plan into "Stages." To minimize confusion, from here forward this manual will capitalize Stage when referring to a TransX flight plan Stage, and use the term stage/vessel when referring to a Velcro launch vehicle stage.

During flight, Velcro performs staging, ignites the next stage/vessel in the stack, and changes Orbiter's focus to the next stage/vessel. Velcro also includes an autopilot that can control heading and pitch of all the stage/vessels in the stack to achieve orbit. Unfortunately, Velcro will not automatically transfer a TransX flight plan up the stack, from one vessel to the next during staging. The flight plan must be loaded separately into each stage/vessel prior to launch.

At liftoff and during the flight, a Velcro launcher is controlled by the lowest stage/vessel in the stack. The Voyager launch scenarios begin with focus properly set to the Titan's first stage/vessel, named Titan3A-1. Next up the stack is Titan3A-2, followed by CentaurD-1T, PropulsionModule, and finally Voyager. (There are also Booster1 and Booster2, the Titan's solid fuel strap-ons, but they are guided by the 3A-1. See Figure 2-2)

TransX MULTI-FUNCTINAL DISPLAY

TransX Tutorials

TransX is the only available tool for planning multiple slingshot flights. It is also fair to say that TransX is one of the most difficult MFDs to learn and master. Fortunately, there is a wonderful series of TransX tutorials by Rob McKenzie (Fly-tandem) available at:

http://flytandem.com/orbiter/tutorials/

Two of the Flytandem tutorials specifically address the Voyager flight plan. If you are not acquainted with TransX you should first take the Flytandem tutorials. Work through the tutorials in the order in which they are listed on the web site. They build up from one to the next, allowing the basic instructions to be progressively more abbreviated as successive tutorials add new information. You will likely find it difficult to follow the Voyager tutorials if you jump straight to them without first mastering the basics presented in the earlier tutorials.

> NOTE
> There appears to be a conflict between TransX (both versions) and the Velcro Rocket auto-delete feature, causing intermittent and unpredictable crashes to desktop. To prevent these CTD all vessel deletions are set to occur after the last Velcro stage/vessel is jettisoned, about 2¾ hours after launch. This allows time for a maximum parking orbit of 1½ revs. The historically correct short parking orbit is also permitted.

TransX v3.10

Using TransX v3.10, you can create a complete flight plan in the first stage/vessel of the Titan III, then use the TransX "Inherit" feature to copy the plan into each stage/vessel up the stack:

- With focus on Titan3A-1, start up TransX MFD and create a complete flight plan. The Voyager 2 plan to Neptune will have 9 Stages.
- Change focus to the Titan3A-2 [F3].
- TransX in the Titan3A-2 will be displaying a typical startup plan with one Stage. From this Stage 1:1, click the "Back" button *(BCK)* to bring up a screen called General Setup. On-screen note will read "Inherit from Titan3A-1"
- Click the Execute button *(EXE)* to "Inherit" (i.e. copy or transfer) the TransX flight plan you created for the Titan3A-1 vessel/stage.
- Click the Forward button *(FWD)* and you will now see the 9 Stages of the flight plan with all the settings accurately copied.
- Change focus to the next stage/vessel up the stack and repeat the Inherit process for the Centaur, and then the Voyager.

Note again, you do not need to Inherit the flight plan into the Booster1 and Booster2 vessels. Velcro boosters are controlled by the stage/vessel to which they are attached.

TransX v3.13

TransX v3.13 has some valuable added features, including finer adjustments of the flight variables and a very accurate indication of when to begin an ejection burn from a parking orbit. But, as of this writing, *the Inherit feature is broken*. Using TransX v3.13, if you click Back into the General Setup screen, and then click Execute, you will copy all of the Stages from your previously created TransX flight plan, but none of the actual flight data gets copied. In each copied flight plan Stage, all the parameters will be set to zero!

The workaround is to create a complete flight plan in the Titan3A-1 stage/vessel, then exit Orbiter, open the scenario file with a text editor, and manually copy the flight plan data from Titan3A-1 to all the other stage/vessels. This is quite easy, once you know what you are doing.

TransX writes the flight plan under the MFD heading of the Scenario file. The ship's name is followed by a complete list of parameters for each Stage of the plan. When multiple ships are programmed with flight plans, TransX simply continues the list under the same MFD heading, writing the next ship's name followed by its list flight parameters for each flight plan Stage. Here is the procedure for loading the flight plan into multiple stage/vessels:

— With focus on Titan3A-1, start up TransX MFD and create a complete flight plan. The Voyager 2 plan to Neptune will have 9 Stages.

— Change focus [F3] progressively up the stack: to the Titan3A-2, then CentaurD1-T, then Propulsion Module, then Voyager. This creates a one Stage flight plan in each of these stage/vessels, and also writes the unique orbital position of each stage/vessel as it currently sits on the launch pad. This data will be retained in your finished flight plan. Do not click the *(BCK)*. There is no need to create nine-Stage flight plans in each of these vessels (all the flight parameters would be set to zero).

— Exit Orbiter, save the scenario, and open the saved scenario file with a text editor. Under the MFD heading, find the Titan3A-1 flight plan. Copy the portion indicated in ***Figure 2-1*** and paste it over the 1-Stage flight plans for each of the other stage/vessels.

```
BEGIN_MFD Left
  TYPE User
  MODE TransX
  Ship  Voyager\Voyager-2
  FNumber 1
  Int 0
  Orbit True
  Vector  1505588.30212 651330.607949 6156245.71478
  Vector  -392.939206217 -43.6901172284 100.720662864
  Double  3.98600439969e+014
  Double  43375.5173129
  Handle Earth
  Handle NULL
  Handle NULL
Select Target
 0 None
    ......
 Finvars
  Finish BaseFunction
  Ship  PropulsionModule
  FNumber 1
  Int 0
  Orbit True
  Vector  1506721.56613 651456.554883 6155953.62958
  Vector  -392.916100522 -43.7230129177 100.796498679
  Double  3.98600439969e+014
  Double  43375.5172795
  Handle Earth
  Handle NULL
  Handle NULL
    ......
Finvars
  Finish BaseFunction
  Ship  CentaurD-1T
  FNumber 1
  Int 0
  Orbit True
  Vector  1507358.47812 651526.941372 6155783.38361
  Vector  -392.903078393 -43.7415408337 100.839211862
  Double  3.98600439969e+014
  Double  43375.5172607
  Handle Earth
  Handle NULL
  Handle NULL
    ......
Finvars
  Finish BaseFunction
  Ship  Titan3A-2
  FNumber 1
  Int 0
  Orbit True
  Vector  1508014.91747 651599.378924 6155605.93318
  Vector  -392.889641789 -43.7606495978 100.883264099
  Double  3.98600439969e+014
  Double  43375.5172413
  Handle Earth
  Handle NULL
  Handle NULL
    ......
Finvars
  Finish BaseFunction
  Ship  Titan3A-1
  FNumber 9
  Int 1
  Orbit True
  Vector  1509421.47253 651754.629369 6155224.38513
  Vector  -392.860824721 -43.8016012624 100.977671692
  Double  3.98600439969e+014
  Double  43375.5171997
  Handle Earth
  Handle NULL
  Handle NULL
Select Target
 0 Escape
......
Finvars
  Finish BaseFunction
END_MFD
```

Change these to: FNumber 9 and Int 1
Retain Voyager orbital data
Overwrite this portion of the Voyager flight plan
Change these to: FNumber 9 and Int 1
Retain PropMod orbital data
Overwrite this portion of the PowerMudule flight plan
Change these to: FNumber 9 and Int 1
Retain Centaur orbital data
Overwrite this portion of the CentaurD-1T flight plan
Change these to: FNumber 9 and Int 1
Retain Titan3A-2 orbital data
Overwrite this portion of the Titan3A-2 flight plan
Titan3A-1 flight plan begins here
Copy this portion of the Titan3A-1 flight plan. For a nine-Stage Voyager 2 flight plan this will contain about 450 lines of text.

Figure 2-1 Editing the Scenario file for TransX v3.13

LAUNCH

The Voyager 2 launch scenarios with pre-loaded TransX flight plans also have fully configured Velcro auto pilots. These scenarios begin with focus properly set to the Titan first stage, vessel name Titan3A-1.

Liftoff times are shown in Figure 2-3. Press [O] to ignite engines with the Velcro autopilot. The third stage Centaur will achieve a parking orbit with a reletive inclination error of less than 1°.

PARKING ORBIT

The parking orbits for both Voyagers were short, lasting less than one revolution. During the parking orbit you must correct your TransX flight plan and, most likely, make a plane change burn to achieve a 0.00° relative inclination for the ejection burn. TransX assumes ejection from a circular parking orbit, but you are not likely to achieve this from launch. You can choose to remain in the parking orbit for several revs to correct the orbit so it will match your TransX Pe setting. Although historically inaccurate, this approach would have been possible. The cryogenic Centaur D1-T was designed to handle extended parking orbits (up to ten hours) without significant loss of fuel from boil-off.

As an alternative, once your ejection flight plan is revised, you can compare TransX and Orbit MFD, estimate your altitude at the ejection point, and use that figure for the TransX Pe setting. This works well enough and allows you to perform the historically correct short parking orbit.

EJECTION BURN

If you are using TransX v3.13 you must exit Orbiter after you revise your flight plan and copy the flight plan from the CentaurD-T1 to the Propulsion Module and Voyager, similar to what you did before launch (see procedure on page 2-3). If you are using v3.10 you can use the Inherit function to copy the revised plan into each stage/vessel.

VOYAGER DEPLOYMENTS

After the Propulsion Module shuts down it will remain attached to Voyager. Do the following:

- Shift focus to Voyager [F3]
- Jettison the MIRS cover [J]
- Deploy the RTG and Science booms [G]
- Toggle focus back to the Propulsion Module [CTRL]+[F3]
- Jettison the Propulsion Module [J] Focus will shift automatically to Voyager
- Complete the Voyager deployments:
    - Radio Astronomy antennae [K]
    - Magnetometer boom [LShift]+[0]numpad
- See Key Commands on page 2-1 for rotating the Scan Platform.

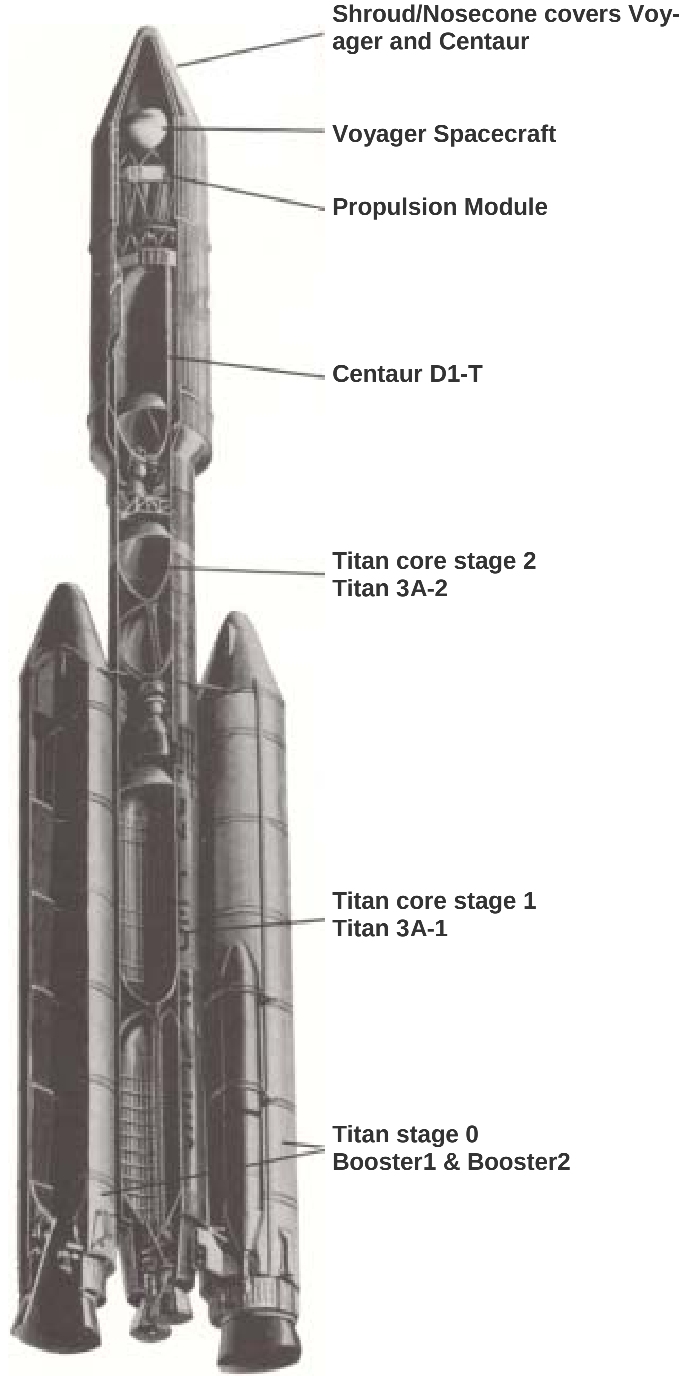

Figure 2-2 Titan IIIE cutaway drawing.

TRAJECTORY CORRECTION MANEUVERS - TCM

In project Voyager, mid-course corrections were called Trajectory Correction Maneuvers (TCM). The Voyager spacecraft have sixteen 0.9 Newton thrusters. Four of these thrusters pointed in the Z minus direction, providing a maximum main thrust of only 3.6 Newtons. Given this very low thrust, TCM burns can last anywhere from one to two hours. Voyager for Orbiter is configured with a historically accurate main thrust so you will find it necessary to go to 10X or 100X time warp when making course correction burns or attitude changes. The 103 kg fuel supply provides a total of 16.76 hours burn time at maximum thrust. The total available Dv is 281 meters per second.

SOME TIPS

The Chapman Challenge on the Orbiter Forum (see Sources, Section 3) offers many useful tips on TransX and slingshot flight plans. For instance: Use translation thrusters to keep the green crosshairs centered in the TransX Target View. Use rotational thrusters to get the crosshairs close, but perfect the alignment with translation, and use translation throughout the burn.

A Config\Spacecraft\Voyager\AlternateConfigs subfolder contains configurations that increase thrust, making the Voyager spacecraft handling more "conventional" (like the Chapman Probes.) The total burn time is shorter, so total available Dv of 281 m/sec remains the same. A text file in the subfolder contains instructions for using the Alternate Configs.

In addition to TransX you may find Interplanetary MFD (IMFD) useful; especially the Map Program which shows a much more accurate plot of your course. IMFD can be run simultaneously with TransX. Just make sure TransX is active when you exit Orbiter. If it is not, you will lose your TransX flight plan.

Reaching Neptune with the realistically low Dv is difficult. If needed, you can "refuel" by editing the scenario file, setting PRPLEVEL back to 1.0.

Good Luck!

Voyager 1

Launch: September 5, 1977 - 12:56:01 UTC

Jupiter Encounter

Closest Approach: March 5, 1979 - 12:05:26 UTC
(43937.5037 MJD)

Saturn Encounter

Closest Approach: November 12, 1980 - 23:46:30 UTC
(44555.9906 MJD)

Voyager 2

Launch: August 20, 1977 - 14:29:44 UTC

Jupiter Encounter

Closest Approach: July 9, 1979 - 22:29:51 UTC
(44063.9674 MJD)

Saturn Encounter

Closest Approach: August 26, 1981 - 03:24:57 UTC
(44842.1423 MJD)

Uranus Encounter

Closest Approach: January 24, 1986 - 17:59:47 UTC
(46454.2499 MJD)

Neptune Encounter

Closest Approach: August 25, 1989 - 03:56:36 UTC
(47763.1643 MJD)

Figure 2-3 Voyager 1 & 2 Timelines

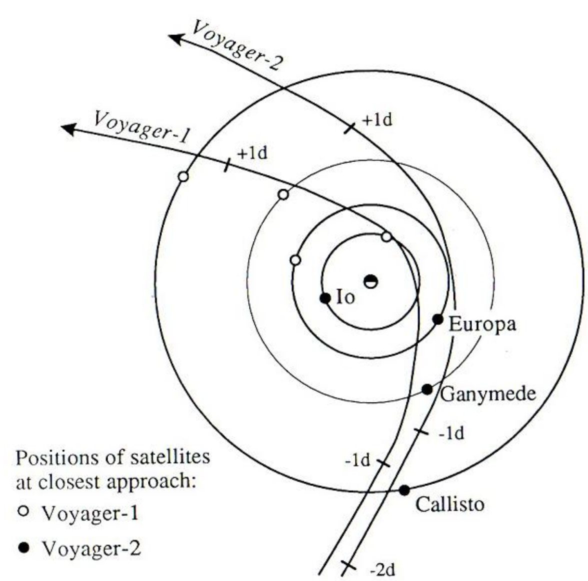

Figure 1-4 Voyager 1 & 2 Jupiter Encounters

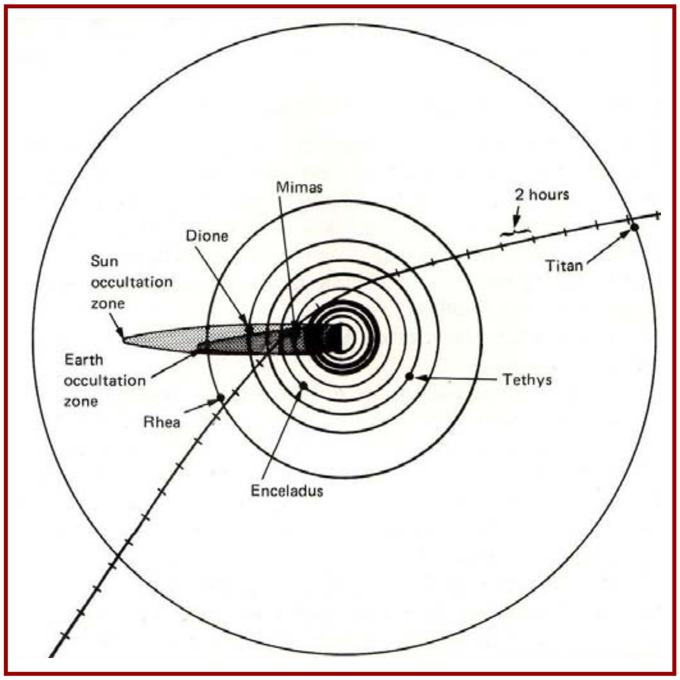

Figure 1-4 Voyager 1 Saturn Encounter

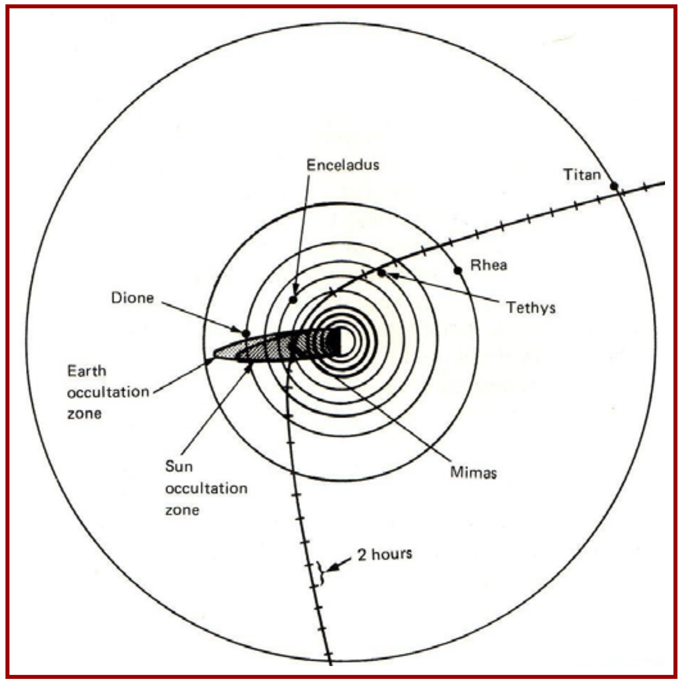

Figure 1-4 Voyager 2 Saturn Encounter

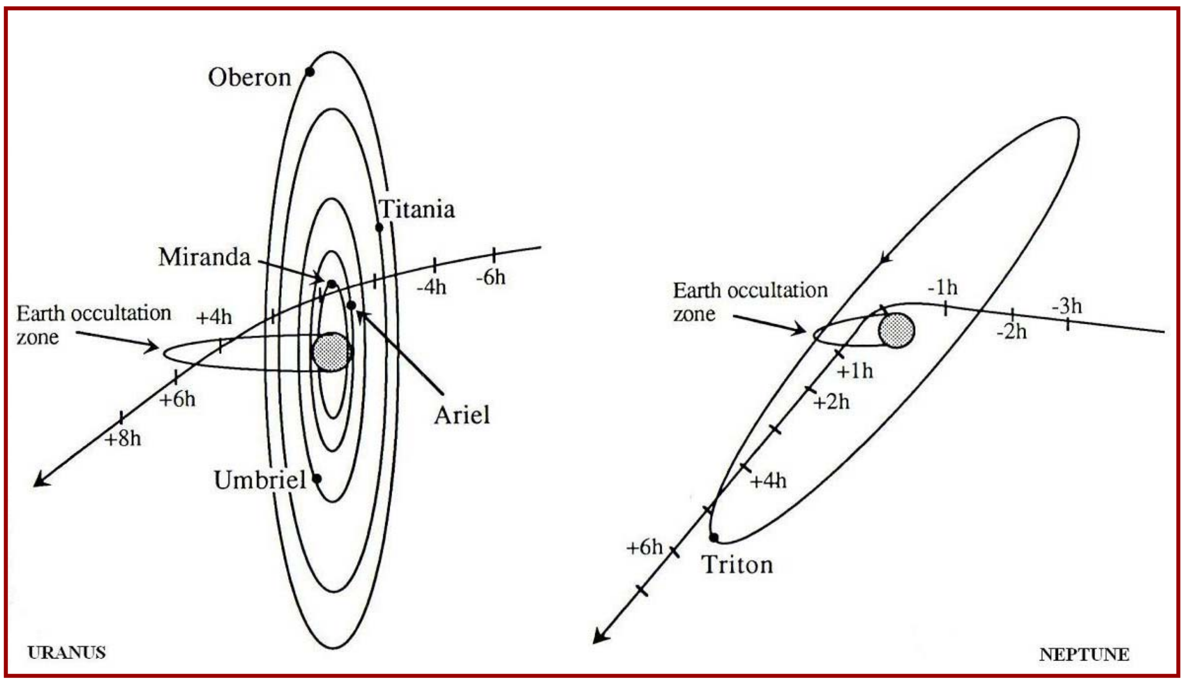

Figure 1-4 Voyager 2 Uranus and Neptune Encounters

Credits & Sources
Section 3

Voyager - The 32nd Anniversary Edition has been tested on "clean" installations of Orbiter, with only the add-ons listed here. All Voyager files are installed to their own sub-folders, so nothing is overwritten and conflicts should not occur. However, as with any Orbiter add-on, there are no guarantees of any kind.

REQUIRED PROGRAMS

Unless noted otherwise, all programs can be found at Orbithanger.com Thank you, Martin and Vinka: *Your programs make mine possible!*

Orbiter Space Flight Simulator 2006-P1 (Base) (available at: www.orbitersim.com) (Orbiter060929) by Martin Schweiger.

Spacecraft3 by Vinka (available at: http://users.swing.be/vinka/) The required files are included with the installation of *Voyager.*

Voyager - The 32nd Anniversary Edition by Scott Conklin (Usonian). Unzip the download file into your Orbiter *Voyager* directory, preserving the directory structure.

Velcro Rockets by Erik Anderson (Sputnik). Unzip the download file into your Orbiter *Voyager* directory, preserving the directory structure.

TUTORIALS AND OTHER HELP

TransX Tutorials (available at: http://flytandem.com/orbiter/tutorials/) by Rob McKenzie (Fly-tandem). A truly great series, including two tutorials aimed specifically at the Voyager flight plan. If you are not very familiar with TransX, work through the tutorials in the order listed - they climb a steep learning curve.

Chapman Probes by Piper. A set of fictional probes with realistic performance using current technology. See also ***Chapman Challenge*** on the Orbiter Forum: http://www.orbiter-forum.com/showthread.php?t=5617

OPTIONAL PROGRAMS

AbsoluteKillrot by enjo. This might better be listed as required software. Completely stops spacecraft roation, even at 10,000x time warp.

TransX v3.13 (available at Orbit Hagar) TransX, originally created by Duncan Sharpe, is now open source software currently managed by Agentgonzo.

Launch Complex 40 and 41 by Kev Shanow (Kev33) (download file name K-LC-40-41.zip) For historically correct launch structures.

SOURCES & CREDITS

Voyager Homepage by Jet Propulsion Laboratory http://voyager.jpl.nasa.gov/

Voyager's Grand Tour: To the Outer Planets and Beyond by Henry C. Dethloff and Ronald A, Schorn, Smithsonian Books, 2003 . A brief history of the Grand Tour and Voyager's development

The Voyager Neptune Travel Guide by Jet Propulsion Laboratory, JPL Publication 89-24, 1989. One of the best "general readership" publications from JPL/NASA; technical enough but readable: http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19900004096_1990004096.pdf

Walter Hohmann's Roads in Space by William I. McLaughlin, 1992, appearing in Fall 2000 issue of Journal of Space Mission Architecture, pp. 1-14. An enjoyable little biographic sketch. Available at: http://www2.jpl.nasa.gov/csmad/journal/issue2/01.pdf

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Thruster Options for Microspacecraft, by Juergan Mueller, Jet Propulsion Laboratory, 1997.

Ninfinger Productions Scale Models by Sven Knudsen at: http://www.ninfinger.org/models/models.html A site devoted to spacecraft model builders with a remarkable repository of information and links - including this set of JPL construction drawings for Voyager: http://www.ninfinger.org/models/vault2007/Voyager%20plans/voyager-stitched-post.jpg