RENDEZVOUS FLIGHT MANUAL

EW037:AP2:M1

by

Wesley Huntress, Ph.D.

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EDU-WARE®
INTERACTIVE SIMULATIONS

RENDEZVOUS was developed by Wesley Huntress in cooperation with EDU-WARE Services, Inc., a California software development company dedicated to the production of instructionally valid Computer Aided Instruction and intellectually challenging games.

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THE MISSION PROFILE

You are the flight Commander for an Enterprise Class Space Shuttle. Your mission is to deliver needed supplies to a space station orbiting at an altitude of 1.5Ø earth radii. The mission has four phases:

Earth Lift-Off (1) starts at the launch pad. Select this option to experience the entire mission from beginning to end.

Orbital Rendezvous (2) starts with the shuttle in Earth orbit. From this initial point, you need to intercept and match orbits with the space station.

Approach (3) starts in the same orbit as the space station but out of visual range. You adjust the shuttle's three directional velocities to bring you within visual range of the space station.

Alignment and Docking (4) starts in visual range of the space station. You need to maneuver your spacecraft into the docking port.

PRE-MISSION TRAINING

To become familiar with the best tactics to employ during each part of the mission, we suggest that you select each phase of the mission individually from the main mission menu rather than flying a complete mission from beginning to end.

In the detailed phase descriptions which follow, you are provided with practice problems of varying difficulty for each phase. Use the data in these problems to sharpen your skills.

MAIN MISSION MENU

The main mission menu appears immediately after booting the disk. It can be accessed from the options menu during the running of phases 2, 3 and 4. Use the main mission menu to choose one of the four mission phases in which to start.

After choosing a mission phase, you will be given two choices: you may set up your flight parameters for the phase, or you may load a position which you have previously saved in a disk file. Simply respond to the menu's prompts. RENDEZVOUS will do the rest. If you decide to set up flight parameters, you may store them in a disk file for future use.

PHASE OPTION MENUS

During the running of phases 2, 3 and 4 you may interrupt the action at any time to access the options menu. The menu provides options to save your present position to a disk file, load a new position from a disk file, go back to your original starting point in the phase, return to your present position, return to the main mission menu, or quit. Access the options menu in phase 2 by pressing the **[2]** key and in phases 3 and 4 by pressing the **[ESC]** key.

DISK FILES

You may store up to 1Ø positions each for phases 2, 3 and 4 on your RENDEZVOUS disk. The same file names may be used in different phases. If 1Ø file names in a given phase have already been used and you wish to save a new position, you will be asked which of the 1Ø existing files you wish to replace.

To retrieve a saved file, select the number of the file next to the name on the menu. If you decide not to load any of the position files displayed, press the **[Ø]** key and you will be returned to your previous position.

The second part of this manual gives you the information necessary for accomplishing each of the four mission phases. Flight Operations will acquaint you with the objectives of each phase, provide a detailed description of the mission in each phase, outline the method for achieving the objective with an operational summary on maneuvering, and give a set of practice problems.

FLIGHT OPERATIONS

Phase One: EARTH LIFT-OFF

OBJECTIVE: Launch your spacecraft and achieve orbit. Minimum altitude is 191 kilometers (ALT: 191 KM) and minimum horizontal velocity 7,8ØØ meters per second (VELX: 78ØØ M/S). A perfect orbit requires a near zero vertical velocity (VELZ).

DESCRIPTION: You are about to set out on a journey into space, flying your space shuttle to rendezvous with an earth-orbiting space station. Your vehicle is an advanced version of the original NASA shuttle. Your craft has been upgraded and modified to serve an invigorated space program. The legacy of Mercury, Gemini, and Apollo is with you.

Your mission begins at the Earth launch site with an external view of your shuttle's multi-stage rocket standing ready for lift-off. Pressing the **[RETURN]** key will ignite the booster rockets.

You can pitch the rocket toward a horizontal heading after it has cleared the launch tower by pressing the [←] key. The [→] key will pitch the rocket back toward a vertical heading. The instrument panel at the bottom of the screen gives you data on position and velocity, while the graph at the left of the screen shows your trajectory.

Your goal is to reach a minimum orbital altitude (ALT) of 191 KM. with a minimum horizontal velocity (VELX) of 78ØØ M/S. The altitude requirement is somewhat arbitrary, but below this altitude the atmosphere is dense enough to drag the shuttle down after only a few orbits. The velocity is necessary to overcome the Earth's gravitational pull. Given the sophisticated capabilities of your space craft and basic piloting skills, this is easily accomplished. Your ultimate success in docking with the space station hinges on reaching an initial advantageous orbit with minimum fuel consumption.

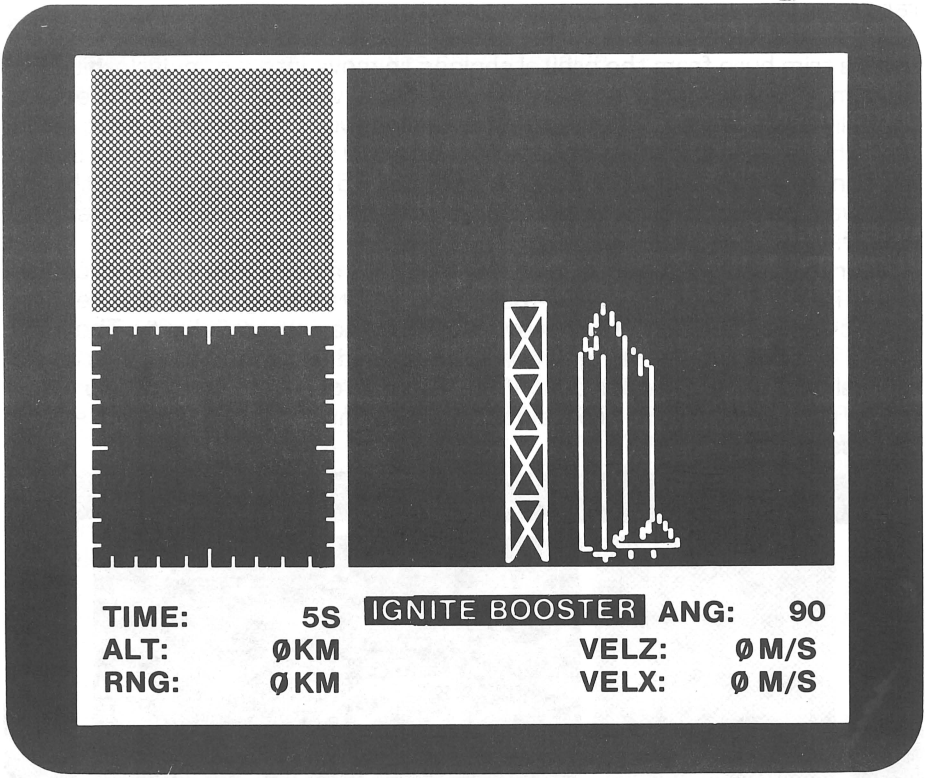


Figure 1

The original NASA shuttle (the prototype for your craft) uses solid-fueled boosters and a large expendable external tank to power the sustainer engines on the shuttle body. Smaller engines in the tail pods next to the sustainer engines are used for orbital maneuvers. Your RENDEZVOUS shuttle is boosted in two stages, but the burn times are shorter and the sustainer engines are part of the external tank. The booster burns for 9Ø seconds and propels you through the dense layers of the atmosphere with enough power so that the sustainer engines can carry you into orbit. The sustainers burn for 2ØØ seconds and should easily carry you to orbital altitude and speed.

The booster and sustainer burn and stage automatically. The only control you have during this phase of flight involves the pitch or attitude of the craft. The [→] and [←] keys control pitch. If you fail to reach a sufficient altitude or velocity during the sustainer stage, you can ignite the shuttle's orbital engine by pressing the **[RETURN]** key. Turn off the shuttle engine by pressing the **[RETURN]** key a second time. Conserve your shuttle's energy supply. You will need a significant quantity of fuel for orbital and docking maneuvers.

The booster and sustainer engines can effect the pitch of the craft only during engine burn. The shuttle has an attitude control system that is separate from the main engine. You can pitch the shuttle at any time.

A perfect initial orbit is rarely achieved. Even the NASA space shuttle uses a trim burn from the orbital engines to move into a circular orbit. You will almost always incur some residual vertical velocity which will create a partially eliptical orbit. This is acceptable, since you can trim your orbit in the next phase while taking advantage of the gained altitude to reach the space station. It is orbiting at 1.5 earth radii (3185 KM above the earth). To achieve a perfect orbit your vertical velocity should be near zero at engine cutoff.

Your trajectory is ballistic in this phase. This means that the vertical velocity is determined by three factors: the force of gravity, the vertical thrust applied to counteract gravity, and the horizontal velocity. The horizontal velocity, which changes only with applied horizontal acceleration, is critical because it provides centrifugal force to overcome gravity. No vertical thrust is required in orbit since the horizontal velocity is sufficient to balance gravity.

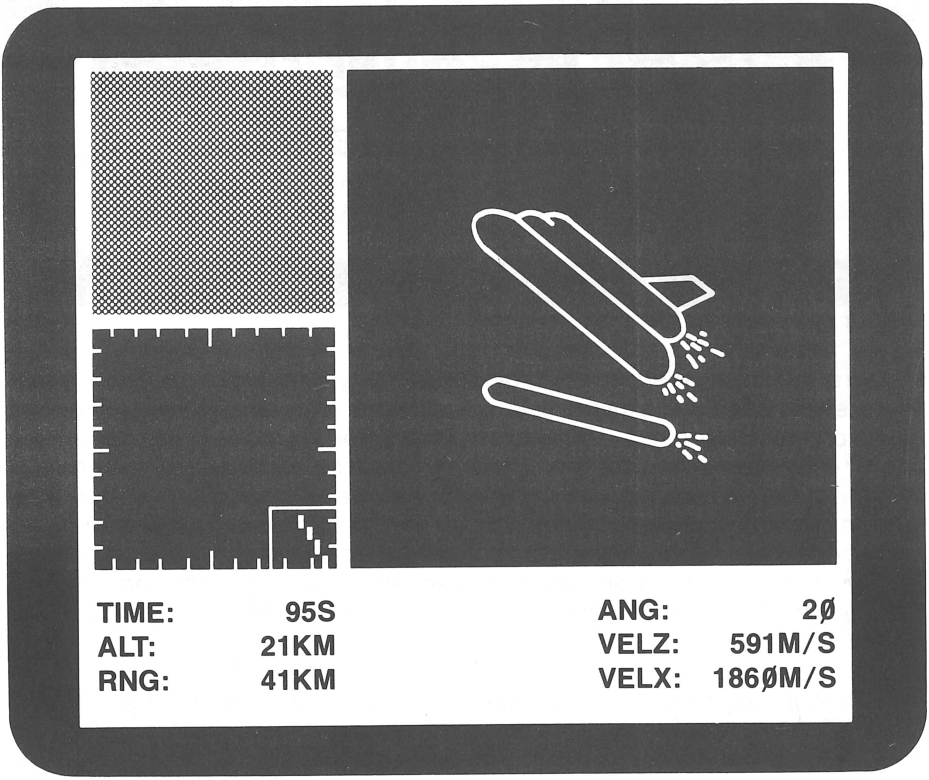


Figure 2

METHOD: Ignite rockets and control pitch of spacecraft to gain both vertical and horizontal velocity, starting initially in the vertical position and ending with all horizontal motion at orbital altitude.

OPERATIONAL SUMMARY:

[RETURN] ignites booster, toggles shuttle engine
[←] pitches rocket down
[→] pitches rocket up

PRACTICE PROBLEMS:

Many of us assume that a rocket need only travel directly upwards in order to achieve orbit around the Earth.

Below is a flight transcript of a mission designed to test that assumption. The flight transcript lists the major events of a mission and the time at which they occur. All events under the heading T-MINUS time are listed in seconds before launch and are not re-enacted in your RENDEZVOUS simulation. Those under T-PLUS time occur after launch, the time values matching the clock on your RENDEZVOUS flight simulator control panel at the bottom of the screen. Actions appearing after the word **OPERATOR** are keystrokes that you would have to make on your simulator to achieve the same results.

Duplicate this mission with your RENDEZVOUS flight simulator. Begin from the menu at Earth Liftoff. As soon as the launch site appears on the screen, press the **[RETURN]** and **[REPT]** keys simultaneously. Release them only after the shuttle rises from the launchpad.

AUTOCLOCK TRANSCRIPT
PROJECT: **ADVANCED SHUTTLE VERTICAL FLIGHT**
LAUNCHDATE: **16 MAY 82**
ABRIDGED VERSION

T-MINUS TIME (SEC)	**PROCEDURE**
7265	Kennedy Launchpad Block 8, Mission Control, reports systems check on schedule
18ØØ	Gantry removed
144Ø	Final craft systems check
114Ø	Final shuttle systems check
76Ø	Final systems check read as negative
452	Cable decoupling

67	Stat-link decoupling
5	Ignition **OPERATOR: Press [RETURN] and [REPT] keys**
4	Launchpad Block 8 clears all systems
Ø	Core clamps released. Launch

T-PLUS TIME (SEC)

3	First motion **OPERATOR: Release keys**
9	Vehicle clears launch tower Tracking reported
11	Tracking confirmed
92	First stage booster engines released Computer reports flight parameters as:

		ANG:	9Ø
ALTITUDE:	4Ø KM	VELZ:	1669 M/S
RANGE:	Ø KM	VELX:	Ø M/S

102	Second stage sustainer engines ignite
174	Minimum altitude for orbit attained Orbital check negative as reported by Houston Computer reports flight parameters as:

		ANG:	9Ø
ALTITUDE:	192 KM	VELZ:	2278 M/S
RANGE:	Ø KM	VELX:	Ø M/S

1723	Maximum altitude achieved Vehicle begins descent back to ground Computer reports flight parameters as:

		ANG:	9Ø
ALTITUDE:	4513 KM	VELZ:	Ø M/S
RANGE:	Ø KM	VELX:	Ø M/S

3221	Vandenberg reports vehicle has broken up in atmosphere Computer reports flight parameters as:

		ANG: 9Ø
	ALTITUDE: 131 KM	VELZ: -7Ø12 M/S
	RANGE: Ø KM	VELX: Ø M/S
3251	Breakup confirmed	

END TRANSCRIPT

FLIGHT ANALYSIS: When an object is in a perfect orbit around a planet, it continuously travels parallel to that planet's surface. Therefore, it needs to have horizontal motion relative to that surface. The minimum horizontal velocity to attain orbit around the Earth is 78ØØ meters/second. However, throughout the mission, all of the shuttle's thrust was directed downward to produce vertical acceleration only. The RANGE and VELX remained at Ø.

Notice that even after the shuttle's fuel supply was exhausted, it continued to travel upwards. An object in motion will stay in motion as long as no other forces are acting upon it. It was not until the shuttle had reached an altitude of 4513 kilometers at the 1723 second mark that gravity's acceleration cancelled out the vertical motion and pulled the shuttle back down. It continued to accelerate back towards the Earth until it reached a dense enough point in the atmosphere for the shuttle's speed to produce enough energy to destroy the craft.

Now try a mission that emphasizes horizontal motion. Begin the simulation again from liftoff, pressing the **[RETURN]** and **[REPT]** keys as soon as the launchpad appears, ensuring that liftoff will begin at time Ø. As soon as the vehicle begins to lift, place your finger on the **[←]** and **[REPT]** keys. This will pitch the craft towards a horizontal position. Release the keys only when the craft reaches an angle of 2 degrees. The shuttle will stop its pitch downward two seconds later, at Ø degrees, and devote all of its thrust towards horizontal motion.

Here is the flight transcript of such a mission:

AUTOCLOCK TRANSCRIPT
PROJECT: **ADVANCED SHUTTLE HORIZONTAL FLIGHT**
LAUNCHDATE: **1 JULY 82**
ABRIDGED VERSION

T-MINUS TIME (SEC)	**PROCEDURE**
695Ø	Kennedy Launchpad Block 3, Mission Control, reports systems check on schedule
2877	Ground Control reports clog in fuel line Mission Control holds
STOP CLOCK	STOP CLOCK. REALTIME LOSS 18Ø6 SECONDS

2877	Count resumed. Clock Corrected
18ØØ	Gantry removed
144Ø	Final craft systems check
114Ø	Final shuttle systems check
76Ø	Final systems check read as negative
451	Cable decoupling
68	Stat-link decoupling
5	Ignition **OPERATOR: Press [RETURN] and [REPT] keys**
4	Launchpad Block 3 clears all systems
Ø	Core clamps released. Launch

T-PLUS TIME (SEC)

3	First motion **OPERATOR: Press [←] and [REPT] keys**
9	Vehicle clears launch tower Vehicle begins pitching downward at rate of 1 degree/second Tracking reported
12	Tracking confirmed
92	First stage booster engines released Computer reports flight parameters as:

		ANG:	6
ALTITUDE:	2Ø KM	VELZ:	473 M/S
RANGE:	42 KM	VELX:	189Ø M/S

1Ø2	Second stage sustainer engines ignite
1Ø7	**OPERATOR: Release all keys**
1Ø9	Vehicle stops downward pitch at Ø degrees Computer reports flight parameters as:

		ANG:	Ø
ALTITUDE:	27 KM	VELZ:	323 M/S
RANGE:	74 KM	VELX:	2ØØ6 M/S

186 Grand Bahama reports flight instability

198 Sydney reports vehicle has broken up in atmosphere
Computer reports flight parameters as:

		ANG:	Ø
ALTITUDE:	2Ø KM	VELZ:	-424 M/S
RANGE:	331 KM	VELX:	3865 M/S

213 Breakup confirmed

END TRANSCRIPT

FLIGHT ANALYSIS: Automatic safeguards prevent the vehicle from pitching downward until after it has cleared the launchpad. Once it has cleared, it will pitch down at a rate of one degree/second so long as the **[←]** and **[REPT]** keys are depressed. As the craft is pitched down, thrust is removed from vertical acceleration and applied to horizontal acceleration.

Sometime after the second stage ignited, the vertical acceleration had been so depleted that gravity began to reduce the craft's altitude. However, the horizontal velocity still increased. At 198 seconds the vehicle's horizontal velocity was fast enough and the atmosphere at that altitude was dense enough to destroy the shuttle.

Now that we have destroyed two very expensive spacecraft, let's create a flight plan that will allow the shuttle to achieve orbit. The vertical and horizontal components of thrust must be balanced in such a way that the shuttle will gain an altitude of 192 kilometers and a horizontal velocity of 78ØØ meters/second. Here is one approach for achieving a partial orbit.

Begin the simulation from Earth Lift-off. As soon as the launchpad appears on the screen, press the **[RETURN]** and **[REPT]** keys. When the vehicle lifts off, press the **[←]** and **[REPT]** keys. Do so until the vehicle pitches down to 22 degrees, at which point you should release the keys. The vehicle will stop its pitch at 2Ø degrees.

Here is the transcript of such a mission:

AUTOCLOCK TRANSCRIPT
PROJECT: **ADVANCED SHUTTLE HORIZONTAL FLIGHT**
LAUNCHDATE: **15 OCTOBER 82**
ABRIDGED VERSION

T-MINUS TIME (SEC)	**PROCEDURE**
6982	Kennedy Launchpad Block 2, Mission Control, reports systems check on schedule

18ØØ	Gantry removed
144Ø	Final craft systems check
114Ø	Final shuttle systems check
76Ø	Final systems check read as negative
452	Cable decoupling
66	Stat-link decoupling
5	Ignition **OPERATOR: Press [RETURN] and [REPT] keys**
4	Launchpad Block 2 clears all systems
Ø	Core clamps released. Launch

T-PLUS TIME (SEC)

3	First motion **OPERATOR: Press [←] and [REPT] keys**
9	Vehicle clears launch tower Vehicle begins pitching downward at a rate of 1 degree/second Tracking reported
12	Tracking confirmed
15	Kennedy radar reports unidentified objects approaching spacecraft
28	Fighter jet accompaniment identifies objects as flock of geese
76	**OPERATOR: Release all keys**
78	Vehicle stops downward pitch at 2Ø degrees Computer reports flight parameters as:

		ANG:	2Ø
ALTITUDE:	14 KM	VELZ:	417 M/S
RANGE:	22 KM	VELX:	1Ø24 M/S

92 First stage booster engines released
Computer reports flight parameters as:

		ANG:	20
ALTITUDE:	21 KM	VELZ:	591 M/S
RANGE:	41 KM	VELX:	1860 M/S

102 Second stage sustainer engines ignite
Vertical velocity begins to drop

182 Vehicle begins gaining vertical velocity
Computer reports flight parameters as:

		ANG:	20
ALTITUDE:	58 KM	VELZ:	349 M/S
RANGE:	269 KM	VELX:	3341 M/S

303 Second stage sustainer engines released
Computer reports flight parameters as:

		ANG:	20
ALTITUDE:	138 KM	VELZ:	1443 M/S
RANGE:	904 KM	VELX:	8013 M/S

340 Orbit achieved
Computer reports flight parameters as:

		ANG:	20
ALTITUDE:	192 KM	VELZ:	1462 M/S
RANGE:	1200 KM	VELX:	8013 M/S

358 Orbit check indicates that craft will re-enter atmosphere without proper adjustment as reported by Vandenberg

END TRANSCRIPT

FLIGHT ANALYSIS: The shuttle was pitched downward to 20 degrees to balance the thrust between horizontal and vertical motion so as to reach the velocity and altitude requirements for orbit. You might try pitching the vehicle to 19 or 21 degrees to see how the trajectory will be affected.

After the first stage dropped away and the less powerful sustainer engine took over, the vehicle began to lose vertical velocity. However, at the 182 second mark, the horizontal velocity was great enough to provide lift for the shuttle, increasing its vertical velocity.

When the second stage burnt out, the craft had attained the necessary horizontal velocity of more than 7800 meters/second to achieve orbit. Although its altitude was too low, the shuttle had enough residual velocity to send it up to the required 192 kilometer altitude. If either value was too low, the orbiter's engine would need to have been toggled on (by pressing the **[RETURN]** key) to make up the difference.

Note that this is only one way to achieve orbit and that the orbit was not perfect. In order to attain a perfect orbit, the vertical velocity must be close to Ø when orbit is achieved.

PHASE TWO: ORBITAL RENDEZVOUS

OBJECTIVE: Change the shuttle's orbit to intercept and match orbits with the space station in circular orbit at 1.5Ø earth radii.

DESCRIPTION: Once you have achieved orbital velocity and altitude, RENDEZVOUS will generate a plot of the orbits of both the space station and your shuttle. Each will proceed on the plotted orbit until you halt progress by pressing any key on the keyboard. You may now elect to change the orbit, access the options menu, or return to orbital cruise.

If you elect to change the orbit, the RENDEZVOUS system will freeze your present position and display another image of the spacecraft one position ahead of your present position in orbit. This enables you to plan for orbital maneuvers in advance. Always halt orbital cruise and set up your next maneuver at least one orbital position before the maneuver is to take place.

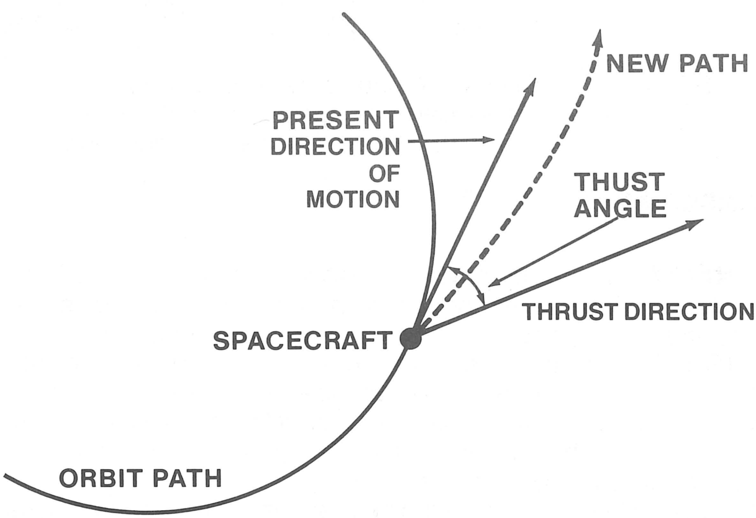


Figure 3

You can project an orbit forward (or backward) by using the **[→]** and **[←]** keys to choose the spot at which you want the maneuver to occur. The station orbit is projected forward simultaneously so that you can judge the effect of the maneuver on the relative positions of the spacecraft and the space station. Once you have projected the orbit to the desired position, press the **[RETURN]** key. You may press the **[ESC]** key to cancel these functions and return to orbital cruise.

To set up a trial maneuver at the orbital position selected, answer **[Y]** to the query **CALCULATE NEW ORBIT?** Any other key will send you back to the orbit projection routine. You can now circularize the orbit or set up a custom maneuver. If you select auto-circularization, the direction and velocity will be calculated for you. If you select a custom maneuver RENDEZVOUS will ask you to enter the thrust angle (the direction in which the impulse is applied measured in degrees from your present direction). Then RENDEZVOUS will ask you for DELTA-V (the change in velocity you wish to apply in the direction selected). A non-numeric response to any of these queries will cancel the trial maneuver. Figure 3 illustrates these parameters.

The parameters of your new trial orbit will be calculated and displayed. Fuel reserves remaining after the trial maneuver will also be displayed. Avail-

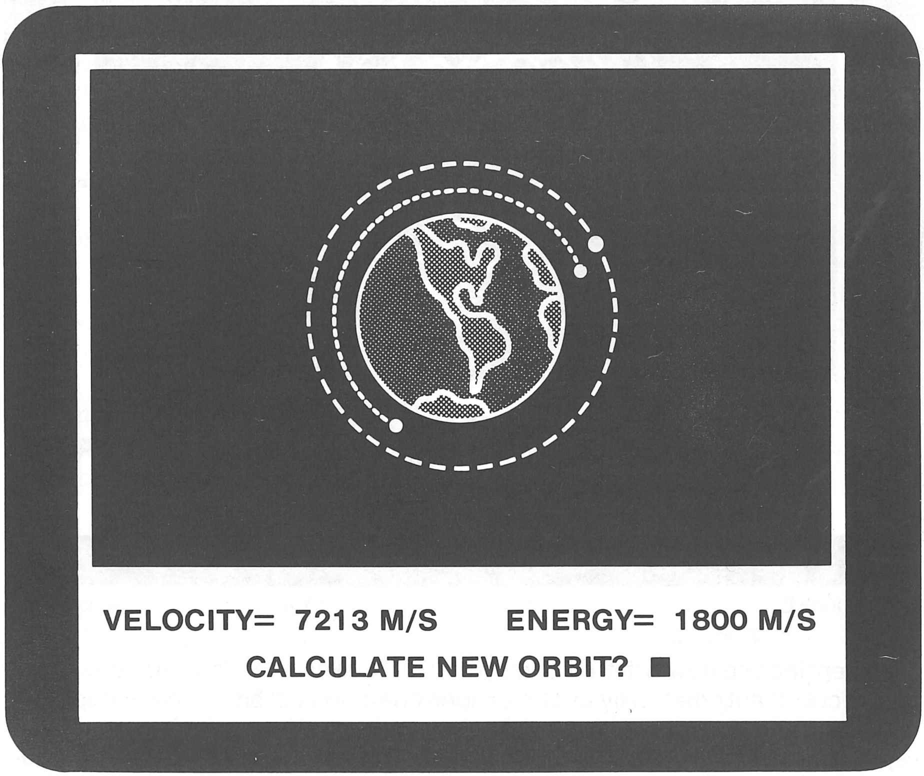


Figure 4

able energy is always given in terms of the amount of velocity change which can be accomplished. Indicate that these parameters are acceptable, and the new trial orbit will be plotted.

Do not worry if your trial orbit enters the atmosphere. You may readjust it before reaching the atmosphere re-entry point.

Now RENDEZVOUS will ask whether you want to project the spacecraft forward along this trial orbit. If you do, the system will move the spacecraft and the station forward (or backward) in their orbits with the shuttle moving on the new trial orbit. This allows you to judge the effect of the maneuver on the relative positions of the spacecraft and space station. During this orbit projection routine, the computer will plot a + at the point where the orbits intersect if the spacecraft and the station are close enough to achieve rendezvous. Press the **[ESC]** key to cancel the trial orbit projection routine and return to the trial orbit start.

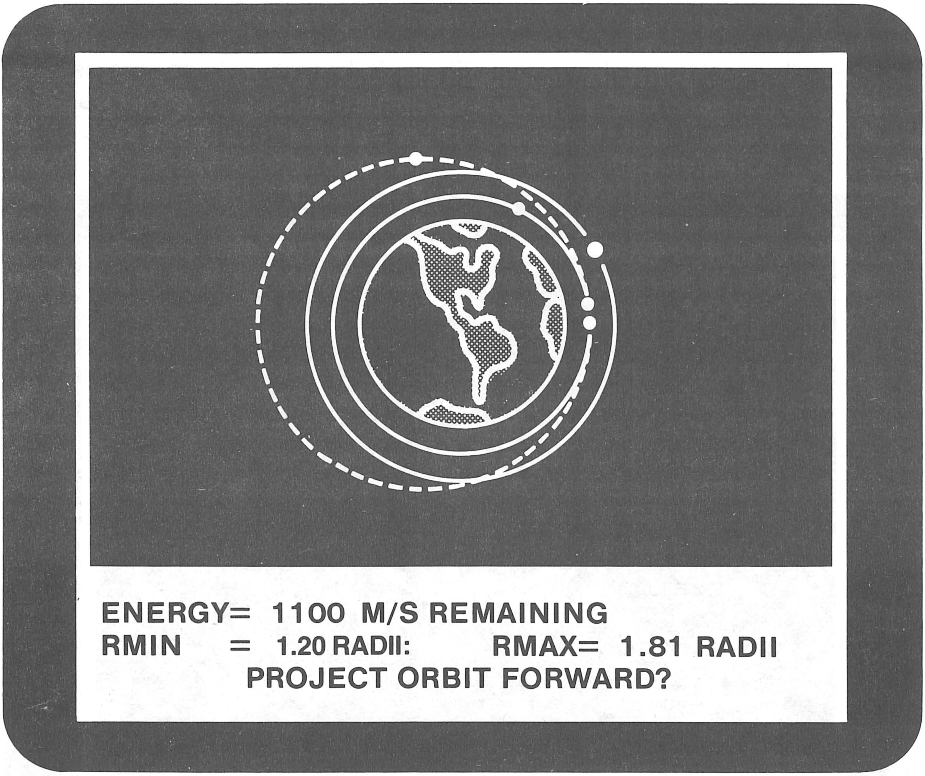


Figure 5

Accepting the new orbit returns you to orbital cruise. Your maneuver will be executed automatically at the proper position in orbit. If you accept the new orbit and later want to cancel it, hit any key during orbital cruise. If you reject the trial orbit, the plot will be erased and you will be given the opportunity to select another trial orbit.

Use these procedures to manipulate your orbit so that your spacecraft intersects the orbit of the space station at the same moment that the station arrives at the rendezvous point. Once you have achieved an orbit with a rendezvous crossing, you must circularize your orbit at the rendezvous point or you will fly past the station. Set up this maneuver before reaching the rendezvous crossing.

HINT: This portion of the simulation is set up so that you can play with thrust angle and velocity to see the effect that each has on orbital motion. Rendezvous is most readily accomplished if you first establish a circular orbit well above or below the space station. Above the station, your shuttle will be moving slower than the station, and it will out-pace you. Below the station, your craft will be moving faster than the station and you will out-pace it. Wait until the distance between you and the space station has closed to within 1Ø orbit plot points before starting trial maneuvers.

When in circular orbit below the station, always use a thrust angle of Ø degrees and vary both DELTA-V and maneuver position to find a transfer orbit with a rendezvous crossing. The procedure is the same, with the exception of the thrust angle (18Ø degrees), if you are above the space station. The maneuver position is most important, and should be varied after having found the DELTA-V which results in an orbit crossing. If you allow the distance between the shuttle and station to become too small, the opportunity to rendezvous will be lost.

METHOD: Make orbit corrections to rendezvous with the space station. You move faster than the station in orbits closer to the Earth, and slower in orbits farther from the Earth. Once near the station, adjust your orbit to one which will cross the orbit of the station. When you reach the point where your transfer orbit crosses the orbit of the space station, circularize your orbit. The difficulty is in ensuring that you are in the immediate vicinity of the station after you have matched orbit with it.

OPERATIONAL SUMMARY:

STEP #1: Interrupt orbital motion. Any key will halt orbital motion and display the menu:

- **[1]** key: set up orbit change
- **[2]** key: Options Menu
- **[3]** key: return to orbit cruise

STEP #2: Press the **[1]** key to set up an orbit change. Use the [←] [→] keys to project the orbit forward in time. Press the **[RETURN]** key when you have reached the maneuver position from which to plan a new orbit:

- [→] key: project forward along orbit
- [←] key: project backward along orbit
- **[RETURN]** key: maneuver position selected

STEP #3: Set up a new trial orbit. Answer **[Y]** to the query **AUTOCIRCULARIZE?** to obtain a circular orbit. To reject circular orbit, answer **[N].** You will then be asked to enter the thrust angle and velocity.

THRUST ANGLE: direction of engine burn
Ø degrees: increase speed and move to a higher orbit
18Ø degrees: reduce speed and move to a lower orbit
DELTA-V: velocity of change in meters per second

STEP #4: Decide if the trial orbit is satisfactory. The trial orbit radii will be calculated and if you accept them the trial orbit will be plotted. Project the spacecraft along the new trial orbit to determine if the new orbit achieves your objective.

If at any time during the projection the spacecraft is close enough to the station to achieve rendezvous, a + will be plotted over that point.

Accept or reject the trial orbit. If accepted, the orbit change maneuver will be accomplished automatically at the selected point along the orbit.

STEP #5: Once you have entered an orbit which has a rendezvous crossing, set up a final orbit change maneuver to circularize the orbit at the rendezvous point. Do this before you reach the rendezvous point. If this maneuver is successful, you will transition automatically to the approach phase.

PRACTICE PROBLEMS:

The second phase of the RENDEZVOUS mission requires you to intercept with the space station and move into its orbit. This maneuver requires that you:

- Find by trial and error the correct DELTA-V and thrust angle that will transition the shuttle from its present orbit to one that crosses the station's orbit of 1.5Ø radii.
- Project your present orbit to a position from which the shuttle and the station will intercept after the orbit maneuver is made. The position from which the maneuver is made is the "maneuver position," and the point at which the two objects intercept is called the "rendezvous point."
- Execute the orbit maneuver using the DELTA-V and thrust angle from step one.
- Before the two objects intercept, project your orbit to the rendezvous point and autocircularize.
- Execute the maneuver.

Three sample problems are provided for this phase: easy, medium, and hard. Along with each is the voice transcript from a shuttle mission executing the same maneuvers. The actual shuttle operations have been edited out and replaced with the corresponding commands for your RENDEZVOUS flight simulator.

Duplicate each of the three missions by following each of the transcripts exactly. The keyboard responses that you should make are printed after the word **OPERATOR.**

For the first problem, begin the simulation from the Orbital Rendezvous phase. Set up a new problem and enter 1.3Ø for the radius and -23 degrees for the angle. Determine if you entered the values correctly and save the information to disk if you wish.

Here is the mission that these initial values will simulate:

TRANSCRIPT OF VOICE COMMUNICATIONS
ADVANCED SHUTTLE MISSION CONTROL
HOUSTON SPACE FLIGHT CENTER
EDITED VERSION

SHUTTLE: Houston, our scope is now displaying two orbit paths. The blip in the outer orbit is the station, and our orbit path is plotted three-fifths of the way between Earth and the station's orbit.

HOUSTON: Roger, shuttle. That agrees with our scope. Your orbit is at 1.3Ø radii and you are 23 degrees behind the station. You are proceeding on orbit.

SHUTTLE: Houston, we are going to attempt to set up an orbit change now.

HOUSTON: Okay, shuttle. Our computers agree with your timing.

SHUTTLE: We are now halting orbit . . .

OPERATOR: press [ESC] key as soon as the words PROCEEDING ON ORBIT appear on the screen.

. . . and are now engaging our navigation computer to set up an orbit change.

OPERATOR: press [1] key to set up an orbit change when the menu appears at the bottom of the screen.

We are going to see what happens if we make the orbit change from our present position. We are not going to project our orbit forward from here just yet.

OPERATOR: press [RETURN] key to choose maneuver position.

HOUSTON: Shuttle, we suggest that you don't try any fancy maneuvers. Since the station is in a higher orbit, just try an engine angle of Ø degrees.

SHUTTLE: Roger, Houston. We are running the orbit calculation program . . .

OPERATOR: answer [Y] to CALCULATE A NEW TRIAL ORBIT?

and are setting up a custom maneuver . . .

OPERATOR: answer [N] to AUTO-CIRCULARIZATION?

We are trying a thrust angle of Ø as per your suggestion . . .

OPERATOR: enter Ø for thrust angle

and are trying values for the DELTA-V.

OPERATOR: try entering various values for the thrust angle. Do not answer [Y] to TRIAL ORBIT PARAMETERS OKAY? unless RMAX equals 1.5Ø.

I am trying a DELTA-V of 3ØØ meters per second . . . No, that gives me too great of an RMAX. Let's see if 2ØØ works better. Nope, that gives too low an orbit. How about 24Ø? Bingo! 24Ø meters per second gives us an RMAX of 1.5Ø radii, the same altitude as the station.

HOUSTON: Roger, shuttle, our JCN 3ØØØ computers agree with that value. Project your orbit forward to see if you and the station cross paths at the same time.

SHUTTLE: Roger, Houston.

OPERATOR: enter 24Ø for the DELTA-V.
Answer [Y] to TRIAL ORBIT PARAMETERS OKAY?
Answer [Y] to PROJECT ORBIT FORWARD?
Press [→] and [REPT] keys to project the trial orbit forward in time.

It looks like we are going to intercept. Yup, the plotter gives us 2, 5, 8, 13 crosshairs.

HOUSTON: Acknowledged, shuttle, 13 rendezvous points. Accept Ø degrees at 24Ø meters/second as your orbit change maneuver.

SHUTTLE: Roger, Houston.

OPERATOR: press [ESC] to abort the projection.
Press [Y] to accept the new orbit.

SHUTTLE: Houston, our engines are now igniting, thrust angle Ø, DELTA-V 24Ø. Our navigation plotter is now displaying our new orbit path and we are proceeding on orbit. We are heading towards the target!

HOUSTON: Shuttle, instead of celebrating, we suggest that you take advantage of the time and prepare for your final maneuver now. Interrupt orbit and project to the center of your rendezvous window, say the seventh crosshair that appears on your navigation plotter. That should give you the closest rendezvous distance.

SHUTTLE: Okay, Houston. Interrupting orbit and projecting forward to the seventh crosshair.

OPERATOR: press any key to interrupt orbit.
Press [1] key to set up Orbit change.
Press [→] key until the shuttle's blip moves to the seventh crosshair position.

We have projected forward to the rendezvous point and are autocircularizing our orbit to match that of the station.

OPERATOR: press [RETURN] key to choose maneuver position
Answer [Y] to CALCULATE A NEW TRIAL ORBIT?
Answer [Y] to AUTO-CIRCULARIZATION?

Houston, the computer predicts that we will have an RMAX and RMIN of 1.5Ø, right on target.

HOUSTON: Go with it, shuttle.

SHUTTLE: Roger, Houston.

OPERATOR: answer [Y] TRIAL ORBIT PARAMETERS OKAY?

Answer [N] PROJECT ORBIT FORWARD?
Answer [Y] ACCEPT NEW ORBIT.

Engines coming on . . Manuever successful, Houston. We are now 2Ø kilometers from the station.

END TRANSCRIPT

If you have followed all of the steps included in the above transcript, you should have entered the Approach Phase at a distance of 2Ø kilometers from the station.

The next orbital mission requires more maneuvering as it begins at the initial altitude the shuttle attains after completing the Launch Phase.

Return to the RENDEZVOUS menu and set up an orbit problem with an orbit of 1.Ø3 radii and an angle of -9Ø degrees. Then re-enact the following transcript by duplicating the OPERATOR maneuvers.

TRANSCRIPT OF VOICE COMMUNICATIONS
ADVANCED SHUTTLE MISSION CONTROL
HOUSTON SPACE FLIGHT CENTER
EDITED VERSION

HOUSTON: Shuttle, you are presently one-quarter orbit distant from the station. We want you to interrupt your orbit and project forward to approximately 3Ø degrees behind the station.

SHUTTLE: Isn't it a little soon for that, Houston?

HOUSTON: Negative. We want to take advantage of the leeway to avoid making irreparable maneuvering mistakes.

SHUTTLE: We are inspired by your confidence, Houston. Complying. Now projecting forward by sight to about 3Ø degrees behind target destination.

OPERATOR: press any key to interrupt orbit.
Press [1] key to set up orbit change.
Press [←] key until you estimate that you are 3Ø degrees (ONE-TWELFTH OF A CIRCLE) behind the station.

Houston, we've arrived at our maneuver position. We're now setting up a trial orbit by using a thrust angle of Ø degrees and a DELTA-V of, oh, let's try 7ØØ meters/second.

OPERATOR: press [RETURN] to choose maneuver position.
Answer [Y] to CALCULATE NEW ORBIT?
Answer [N] to AUTOCIRCULARIZE?
Enter Ø for the thrust angle.
Enter 7ØØ for the DELTA-V.

That gives us an RMAX of 1.51 radii. Close, but no cigar. We're going to try using a little less thrust. DELTA-V is now set for 69Ø meters/second.

OPERATOR: answer [N] to TRIAL ORBIT PARAMETERS OKAY?
Answer [Y] to CALCULATE A NEW TRIAL ORBIT?
Answer [N] to AUTO-CIRCULARIZATION?
Enter Ø for the thrust angle.
Enter 69Ø for the DELTA-V.

Houston, we have an RMAX of 1.5Ø.

HOUSTON: Good going, shuttle. Project the orbit forward.

SHUTTLE: Roger.

OPERATOR: answer [Y] to TRIAL ORBIT PARAMETERS OKAY?
Answer [Y] to PROJECT ORBIT FORWARD?
Press the [→] key until you are satisfied that the shuttle and station do or do not intercept.

We're advancing towards the station on the projection . . . No, our low orbit is making us a little too fast. We'd arrive at the rendezvous point well ahead of the station. Look's like you were right Houston. We're going to have to try this maneuver again from a little further back.

HOUSTON: I won't say 'I told you so,' shuttle.

SHUTTLE: How kind you are to us flyboys, Houston. We're trying the maneuver again.

OPERATOR: if your projected orbit does not intercept with the station:
Press [ESC] to abort the projection.
Answer [N] to ACCEPT NEW ORBIT?
Answer [N] to CALCULATE A NEW TRIAL ORBIT?

Use the [←] and [→] to project your path forward or back.
Press [RETURN] to choose maneuver position.
Answer [Y] to CALCULATE A NEW TRIAL ORBIT?
Answer [N] to AUTO-CIRCULARIZATION?
Enter Ø for the thrust angle.
Enter 69Ø for the DELTA-V.
Answer [Y] to TRIAL ORBIT PARAMETERS OKAY?
Answer [Y] to PROJECT ORBIT FORWARD.
Press [←] until you determine if you will intercept from this new position. If not, try the above procedure again.

Houston, we've set up the orbit change maneuver from our new position . . . and it looks like, yes, it intercepts with the station at 5 points. How does that look to you mathematicians?

HOUSTON: Looks good to us from here, shuttle.

SHUTTLE: We'll program the automatic maneuvering system to accept the orbit change then, and notify you when it is completed.

OPERATOR: after finding the position from which an angle of Ø and DELTA-V of 69Ø gives an orbit that produces 5 interception crosshairs when projected forward:
Answer [Y] to ACCEPT NEW ORBIT?

Maneuver complete, Houston. Engines have come on at Ø degrees and 69Ø meters/second and we have moved into the new orbit.

HOUSTON: Our ground computers predict that the first rendezvous point will bring you closest to the station, shuttle. Have your onboard navigation system verify that for us.

SHUTTLE: Will do, Houston.

OPERATOR: press any key to interrupt orbit.
Press [1] to set up orbit change.
Press [→] until you reach the first crosshair.
Press [RETURN] to choose maneuver position.
Answer [Y] to CALCULATE A NEW TRIAL ORBIT?
Answer [Y] to AUTO-CIRCULARIZATION?

Sorry, Houston. That position will give us an RMAX of 1.49 radii. Too low. Let's forget the fancy mathematics you guys tried and go by the book. I'm going to try the center rendezvous point, number 3.

HOUSTON: Touché, shuttle. Go ahead.

SHUTTLE: Projecting to number 3 and autocircularizing.

OPERATOR: Answer [N] to TRIAL ORBIT PARAMETERS OKAY?
Answer [N] to CALCULATE A NEW TRIAL ORBIT?
Use the [←] key to project to the third interception crosshair.
Press [RETURN] to choose maneuver position.
Answer [Y] to CALCULATE A NEW TRIAL ORBIT?
Answer [Y] to AUTO-CIRCULARIZATION?

That did it, Houston. We're getting an RMAX and RMIN of 1.5Ø. Programming it into the engines now.

OPERATOR: Answer [N] to PROJECT ORBIT FORWARD?
Answer [Y] to ACCEPT NEW ORBIT?

We've achieved orbital rendezvous, Houston, at a distance of 46 kilometers.

END TRANSCRIPT

The final orbit problem starts the shuttle at a higher orbit than that of the space station. Start again from the Orbit Phase with a radius of 1.7Ø and a start angle of Ø degrees.

The flight transcript below contains no **OPERATOR** instructions. From the transcript dialogue alone try to duplicate the maneuvers for this mission.

TRANSCRIPT OF VOICE COMMUNICATIONS
ADVANCED SHUTTLE MISSION CONTROL
HOUSTON SPACE FLIGHT CENTER
EDITED VERSION

SHUTTLE: Houston, our navigation systems report that we are orbiting at 1.7Ø radii and are currently directly above the station. What is our next maneuver?

HOUSTON: Shuttle, we want you to determine the thrust angle and DELTA-V necessary to bring your ship down into the station's orbit.

SHUTTLE: Roger, Houston. We are interrupting our orbit and preparing to set up a new orbit maneuver. From this position we are calculating a new orbit. Since the station is below us, we are entering a thrust angle of 18Ø degrees and trying a DELTA-V of 19Ø meters per second. That gives us an RMAX of 1.7Ø radii.

HOUSTON: Could you repeat that, shuttle? You are moving into a lower orbit. We're interested in the RMIN.

SHUTTLE: Sorry, Houston. The RMIN is 1.5Ø radii. So, it's 18Ø degrees and 19Ø meters/second to bring us into the station's orbit. How would you like us to proceed from here?

HOUSTON: Unfortunately, you missed the orbit change window on your last pass. If you make the orbit transition now you'll wind up behind the station due to your slower speed. You are going to have to make several revolutions around Earth until the station approaches you again from behind.

SHUTTLE: Okay, Houston, we are aborting the orbit change and continuing on our present path. We'll notify you when the station is about 3Ø degrees to our aft.

Hello, Houston. This is advanced shuttle flight 1Ø3. The station is approximately 3Ø degrees behind us according to our navigation systems.

HOUSTON: Roger, shuttle. Halt your orbit and set up the next maneuver. Calculate a trial orbit with the values you sent us.

SHUTTLE: Roger, Houston. Calculating a new orbit using thrust angle 18Ø degrees and DELTA-V 19Ø. We are now projecting the orbit forward . . . and it looks like we'll arrive ahead of the station.

HOUSTON: Advance ahead a few degrees, shuttle, and try it again.

SHUTTLE: Rejecting new orbit and proceeding on present orbit, Houston. Now, we're halting orbit and setting up the new orbit again. We're projecting forward several degrees and selecting that as our maneuver position. Now calculating a new orbit using 18Ø and

190 and projecting forward along that path . . . It looks like we'll get a rendezvous from here, Houston. We're getting 17 rendezvous points.

HOUSTON: Excellent, shuttle. Accept that orbit and autocircularize at the, uh, ninth point.

SHUTTLE: Roger, Houston. Accepting the orbit. We can hear the engines igniting, and we are moving along the new path. Now we are halting our orbit again, and setting up the new maneuver. Projecting forward to the ninth crosshair on our scope and selecting that as our maneuver position. Now calculating a new orbit and autocircularizing. Yes, that's giving us an RMAX and RMIN of 1.50 radii.

HOUSTON: Okay, shuttle, let's accept it.

SHUTTLE: Accepting new orbit. Our engines are igniting . . . and we are now approaching the station from a distance of 55 kilometers.

END TRANSCRIPT

FLIGHT ANALYSIS: The major difference between this flight and the previous one is that you started at a higher orbit than the space station. Instead of travelling faster than the station, you travelled at a slower pace. This means that the station had to be behind you when you executed your orbit change instead of the other way around as in the previous problem. Additionally, you had to use a thrust angle of 180 degrees to send the craft downward to the lower orbit instead of sending it upward.

PHASE THREE: APPROACH

OBJECTIVE: To approach the orbiting space station so that you are no more than 2 KM measured along any axis from the space station.

DESCRIPTION: Techniques for orbital rendezvous and approach to an orbiting platform were perfected during the Gemini series of two-man spacecraft flights in the mid-1960s. The target, in those days was an abandoned orbiting Agena rocket stage. A docking collar was attached to the Agena, enabling astronauts to practice docking with an external port. This same technique was used for the Apollo-Soyuz flights.

You have already emulated the orbital rendezvous accomplished in these missions in Phase Two. Now you must approach the target. Radar and blinking navigational lights guided the approach by the Gemini and Apollo-Soyuz flights. Your RENDEZVOUS shuttle uses similar systems.

You start Phase Three at a distance from the space station that is determined by the results of your orbital rendezvous. From this distance you must maneuver to within 2 KM of the space station in order to begin the Docking Phase. In the Approach Phase, you will be shown a wide angle view

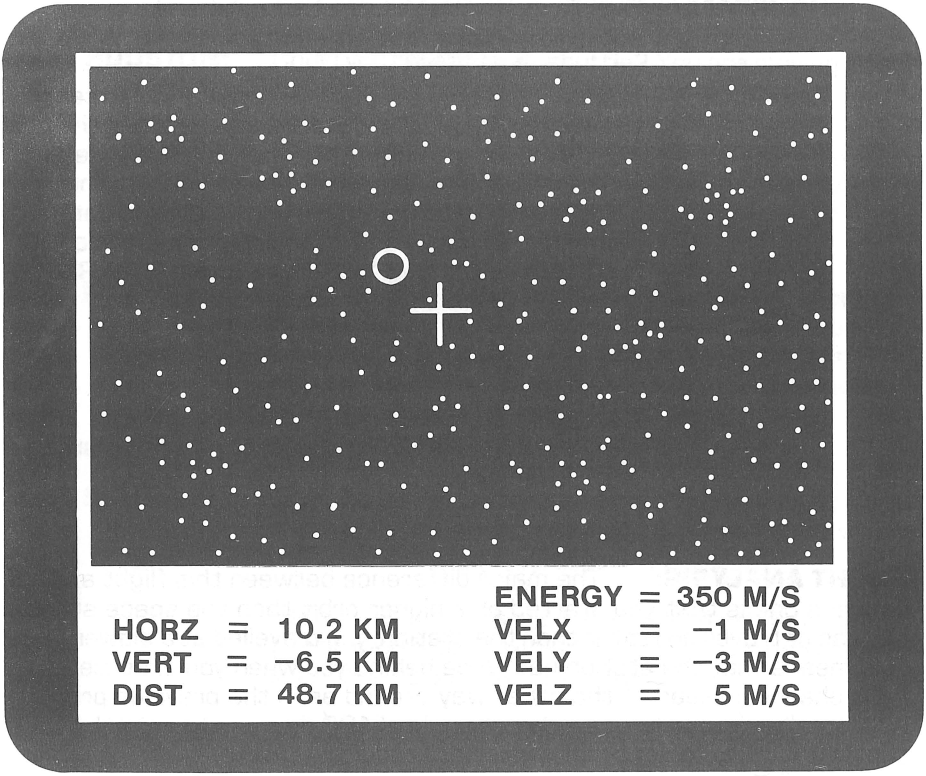


Figure 6

of the space ahead of your shuttle. The blinking dot on the screen represents the space station. Radar data is shown below the screen giving the distance (DIST) from the station along the orbit, the approach velocity (VELZ), the horizontal (HORZ) and vertical (VERT) displacements from the orbit path, and horizontal (VELX) and vertical (VELY) velocities relative to the station's orbital path. The rotation of the shuttle automatically stabilizes to point along the orbital path so that you need adjust your directional velocities alone. This is accomplished by using a joystick or your keyboard as described in the OPERATIONS SUMMARY. Directions and velocities indicated as positive values are forward, up, and to the right of the space station.

To enter the Docking Phase successfully, you must maneuver to within 2 KM of the space station and reduce your velocity in each direction to 2Ø M/S or less. The approach control engines used in the Phase Three burn with 5 M/S increments. You can trim any residual velocity in the Docking Phase using the attitude control thrusters.

If you pass the space station in its orbit, your on-board gyros will turn your spacecraft 18Ø degrees to face the station. Collision with the space station is possible, so be alert. Each pass of the station costs you proficiency points.

METHOD: Use either the keyboard or a joystick to maneuver the spacecraft. In the Approach Phase you control spacecraft rotation only.

OPERATIONAL SUMMARY: Operations in the Approach, Alignment, and Docking Phases are very similar and are covered together here.

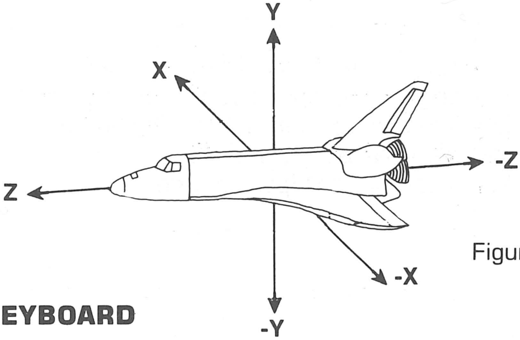


Figure 7

USING THE KEYBOARD

Movement

[M] key: move down (decrease Y)
[I] key: move up (increase Y)
[J] key: move left (decrease X)
[K] key: move right (increase X)
[L] key: move backward (decrease Z)
[;] key: move forward (increase Z)

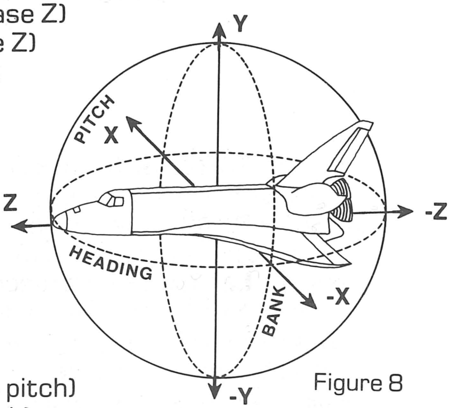
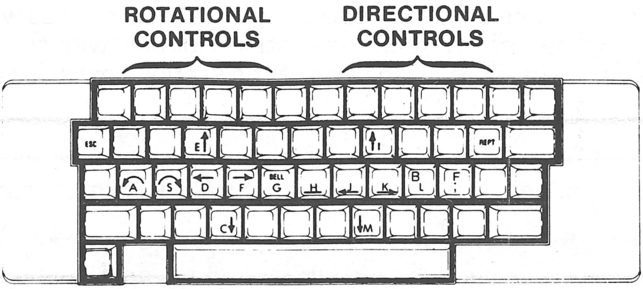


Figure 8

Rotation

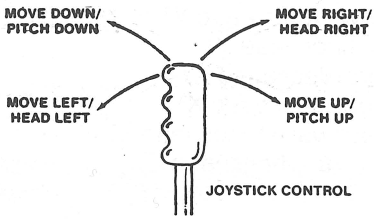
[C] key: rotate down (decrease pitch)
[E] key: rotate up (increase pitch)
[D] key: rotate left (decrease heading)
[F] key: rotate right (increase heading)
[A] key: roll left (decrease bank)
[S] key: roll right (increase bank)

KEYS USED WITH BOTH THE JOYSTICK AND THE KEYBOARD



[G] key: toggle viewfinder (docking only)
[H] key: toggle approach radar (docking only)
[RETURN] key: kill residual motion (docking only)
[SPACE] bar: kill all rotational motion
[ESC] key: interrupt to Options Menu

USING A JOYSTICK



joystick **FORWARD:** move down (decrease Y) or rotate down (decrease pitch)
joystick **BACK:** move up (increase Y) or rotate up (increase pitch)
joystick **LEFT:** move left (decrease X) or rotate left (decrease heading)
joystick **RIGHT:** move right (increase X) or rotate right (decrease heading)
switch **#1:** move backward (decrease Z) or roll left (bank left)
switch **#2:** move forward (increase Z) or roll right (bank right)
switch **#3** or [/] key: toggle joystick between movement control and rotation control

PRACTICE PROBLEMS:

The Approach Phase begins with the shuttle in synchronous orbit with the space station, but at a distance of several kilometers from it. Maneuvering in this stage of the mission requires practice with inertial (the tendency of a moving object to stay in motion in the absence of other forces) motion along the three axial directions (horizontal, vertical, and z-axis.)

The first approach problem is an exercise in motion along the z-axis only. Begin from the RENDEZVOUS menu and set up an Approach problem. Enter 5 kilometers as the distance, Ø kilometers as the off-line distance, 3Ø meters/second as the velocity, and Ø as the off-line velocity. (Off-line refers to being above/below and left/right of the space station).

Try to duplicate the mission outlined below by performing the operations written after the word **OPERATOR** during the events described in the transcript.

TRANSCRIPT OF VOICE COMMUNICATIONS
ADVANCED SHUTTLE MISSION CONTROL
HOUSTON SPACE FLIGHT CENTER
EDITED VERSION

HOUSTON: Shuttle, the space station reports that you are presently 5 kilometers distant. Do you have visual conformation?

SHUTTLE: Roger, Houston. We can see the station through our foward window. It's smack dab in the middle of the crosshairs at the window's center.

HOUSTON: Your vertical and horizontal distances are Ø.Ø kilometers, then?

SHUTTLE: That's right, Houston. Our approach radar is working fine. We are now 3.5 kilometers distant and closing at 3Ø meters per second.

HOUSTON: Slow down your VELZ immediately, shuttle! The automatic defense laser system will shoot you down, repeat shoot you down, if you continue to approach at that velocity!

SHUTTLE: Looks like you're right, Houston. We are getting a collision warning at 3.Ø kilometers distance. Slowing down our VELZ to 5 meters per second immediately.

OPERATOR: Press [L] key 5 TIMES

Houston, we've slowed down to 5 meters/second. We're no longer getting the collision warning.

HOUSTON: Shuttle, we have a request that you keep your foot light on the gas.

SHUTTLE: Sorry about that, Houston. We are now 2.Ø kilometers distant, vertical and horizontal distances are Ø. We're entering the final phase of the mission right on target.

END TRANSCRIPT

As the distances from the station along the three axes close down to a few kilometers, it is advisable to keep your velocities low as well. This not only prevents the necessity of the station having to activate its defense systems, but also prevents your spacecraft from overshooting the target. The ideal situation is to have vertical and horizontal distances come to Ø kilometers, the horizontal and vertical velocities set to Ø meters/second, and the z velocity set to 5 meters/second, when the distance approaches 2.Ø kilometers.

The second exercise makes this task more difficult. Set up an Approach problem with a distance set to 1Ø kilometers, the off-line distance set to 5 kilometers, the velocity set to 2Ø meters/second, and the off-line velocity set to 5 meters/second.

Follow the transcript below. In this phase, however, the values that will show up on your approach radar may not necessarily match with those in this transcript.

TRANSCRIPT OF VOICE COMMUNICATIONS
ADVANCED SHUTTLE MISSION CONTROL
HOUSTON SPACE FLIGHT CENTER
EDITED VERSION

HOUSTON: Shuttle, our radar tracking reports that you are 1Ø kilometers distant from your destination, and that your VERT is -4.Ø kilometers and HORZ is 3.6 kilometers.

SHUTTLE: Correct, Houston, the station is showing up above and to the left of the crosshairs at the center of the screen.

HOUSTON: Okay, Shuttle, slow down your VELZ to 1Ø meters per second. We want you to have time to bring your off-line distances to Ø.

SHUTTLE: Roger, Houston, slowing down our approach velocity to 1Ø.

OPERATOR: Press [L] until VELZ reaches 1Ø meters per second.

Now approaching at 1Ø meters per second from a distance of 8.6 kilometers, Houston, We are going to bring our off-line distances to Ø.

OPERATOR:

If the station appears above the crosshairs. VERT will be a negative value. Press [I] to raise VELY to a positive value that will bring VERT to Ø by the time the distances reach 2.Ø.

If the station appears below the crosshairs. VERT will be a positive value. Press [M] to raise VELY to a negative value that will bring VERT to Ø by the time the distances reach 2.Ø.

If the station appears left of the crosshairs. HORZ will be a positive value. Press [K] to raise VELY to a negative value that will bring VERT to Ø by the time the distances reach 2.Ø.

If the station appears right of the crosshairs. VERT will be a negative value. Press [J] to raise VELY to a positive value that will bring VERT to Ø by the time the distances reach 2.Ø.

Houston, we've got our horizontal and vertical distances approaching Ø. HORZ is Ø.3 kilometers with VELX at -6 meters/second, and VERT is -1.2 kilometers with VELY at 9 meters per second. Distance from the station is 8 kilometers.

HOUSTON: Roger, Shuttle, This is how we would like you to proceed from here. Your off-line distances are acceptable. They could be as high as 2.Ø kilometers, and we could still reach the final phase. But we would like you to get them as close to Ø as possible so that you will maintain visual contact with the station. Are your thrusters firing at 5 meter per second increments?

SHUTTLE: Correct, Houston.

HOUSTON: Then bring your VELX down to -1 and your VELY up to 3 meters per second. Then bring your VELZ up to 3Ø meters per second.

SHUTTLE: I see your plan, Houston. We'll be bringing our vertical and horizontal distances to Ø slowly compared with our line of sight distance. That way we won't overshoot our VERT and HORZ by the time we close in on the station. Okay, we'll make the adjustments.

OPERATOR: Make the necessary adjustments to your VELX, VELY, and VELZ that you estimate will bring HORZ and VERT to Ø by about the same time distance reaches 2.Ø kilometers.

Houston, we're now 2.4 kilometers from the station, and our vertical and horizontal distances are -.3 and Ø.Ø respectively.

HOUSTON: Prepare for entering the station's proximity, Shuttle. Bring your VELZ down to 5 meters per second.

SHUTTLE: Slowing down line of sight velocity, Houston, and the station is appearing pretty darn close to the center of our crosshairs.

OPERATOR: Press [L] to lower VELZ

At 2.Ø kilometers distance, we are switching to our narrow angle screen. There it is! 2ØØØ meters distant with the docking port situated on top of the station, pointing downward. We are now in the final stage of the mission.

END TRANSCRIPT

Your vertical and horizontal distances may be as great as 2.Ø kilometers for you to transition to the final phase of the mission when the line of sight distance (along the z axis) reaches 2.Ø kilometers. However, it is best to keep VERT and HORZ as low as possible so that you will maintain visual contact with the shuttle when you enter the docking phase.

Remember that when VELY is positive, VERT will decrease; when VELY is negative, VERT will increase. The same holds true for VELX and HORZ. Also remember that as DISTANCE approaches 2.Ø kilometers to bring VELZ down to about 5 meters/second and avoid crashing into the space station.

Now that you have had practice in adjusting the off-line velocities, try a harder problem: set the distance to 5Ø, the off-line distance to 2Ø, the velocity to 9Ø, and the off-line velocity to 2Ø. Use your fuel sparingly and try to adjust your changes in the VELX, VELY, and VELZ so that VERT and HORZ reach Ø and DISTANCE reaches 2.Ø at about the same time.

PHASE FOUR: ALIGNMENT & DOCKING

OBJECTIVE: To approach and dock with the space station, by entering the docking tunnel without causing damage to either the shuttle or the space station.

DESCRIPTION: At this writing the NASA space shuttle has yet to rendezvous and dock with an orbiting vehicle. Space stations which the actual shuttle might visit exist only on the drawing boards in NASA dream factories. In RENDEZVOUS's Docking Phase, you are pioneering spacecraft navigation techniques, piloting a realistic simulation of how NASA's objectives might someday be accomplished.

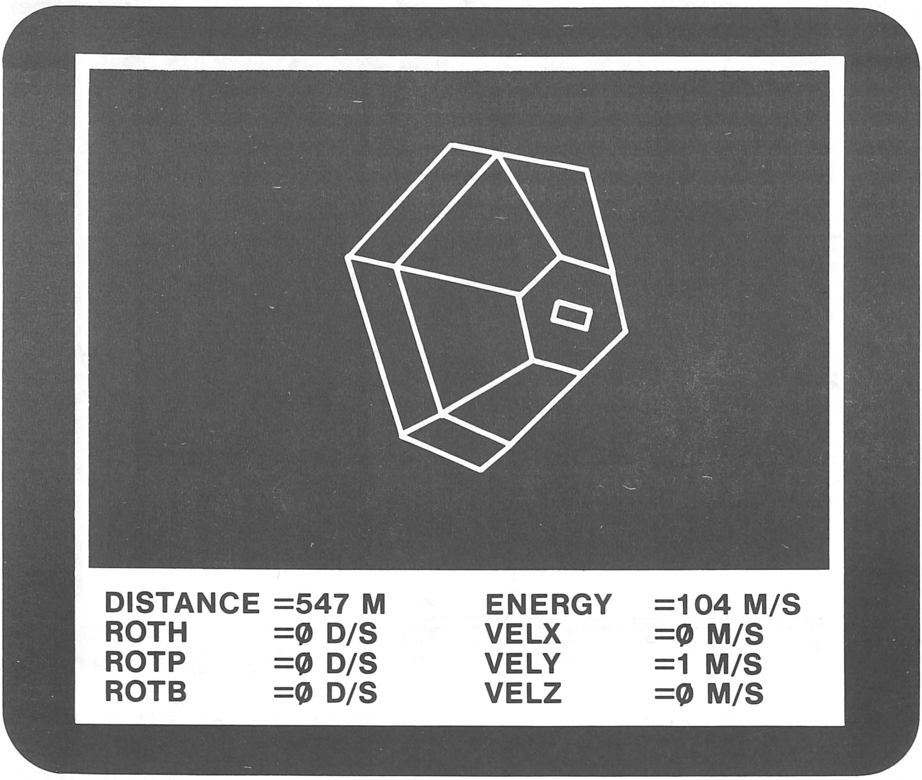


Figure 11

On first entering Phase Four, you have radar data to assist you. You are provided only with the distance from the center of the station and the amount of fuel remaining. The **[H]** key will toggle the radar on and off. You lose proficiency points for toggling the radar and continue to lose points while the radar remains on. The on-board radar gives you rate information. Rates in degrees/seconds are given for rotation around each axis of the space craft (ROTH for right or left heading, ROTP for up or down pitch, ROTB for left or right bank). Rates are given in meters/seconds for directional motion along each axis of the spacecraft (VELX for left or right, VELY for up or down, VELZ for forward or backward). The directions expressed in positive values are FORWARD, UP and RIGHT.

Instead of simple porthole parking (as NASA's shuttle is likely to use) this huge space station sports a hangar-sized docking port. The docking bay will become visible when the face of the space station containing it is visible. A vertical strut above the door indicates the top of the port for correct rotational alignment.

If you lose sight of the station at any time and are uncertain as to its location, use the **[G]** key to toggle the direction finder. A figure will appear at the lower left of the screen to show you where the space station is located relative to your shuttle. The figure below illustrates the relationship between the viewfinder figure and your position relative to the space station.

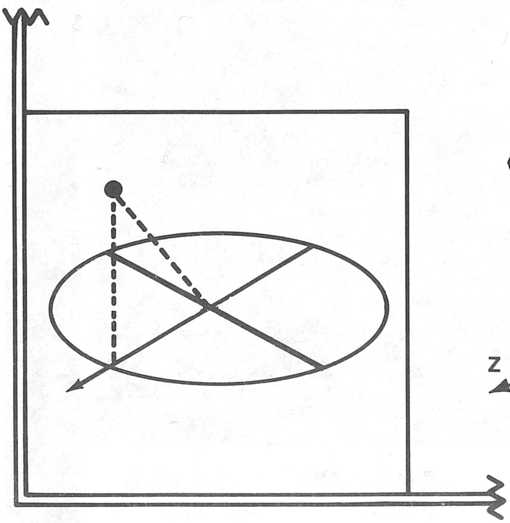


Figure 12A

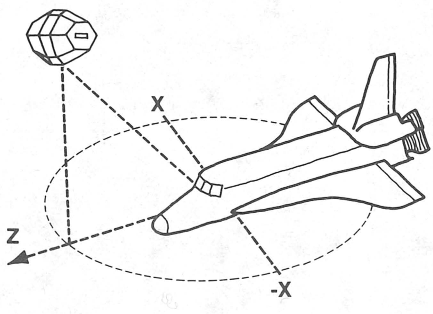


Figure 12B

The circle represents the "floor" of the spacecraft. Imagine that you are standing at the center of the circle and facing outward in the direction of the arrow. The arrow points forward, in the +Z direction. The other axis in the circle is the horizontal, or X axis. The example on this page shows the station above and to the right of the forward window. The spacecraft must be rotated (headed) right and rotated (pitched) up in order to face the station. You lose proficiency points whenever you toggle the viewfinder on, and continue to lose points as long as it remains on.

The moment you maneuver into the vicinity of the docking port you will find yourself facing the docking corridor. This corridor is a cylindrical imaginary space 32 meters in diameter and 42 meters long directly in front of the docking port. Once you are inside the corridor, the docking port doors will open. There are crossbars inside the far end of the docking port to assist you in aligning your craft. Your monitor will provide radar data from the station radar link (without penalty). The station radar provides position data (the on-board radar supplies rate data). Docking is extremely difficult without this data.

Rotational position is given as heading from the line of the docking port (HEAD), pitch above or below the approach line (PTCH), and bank angle relative to the port (BANK). Distance from the nose of your shuttle to the docking collar at the far end of the port is given as (DIST).

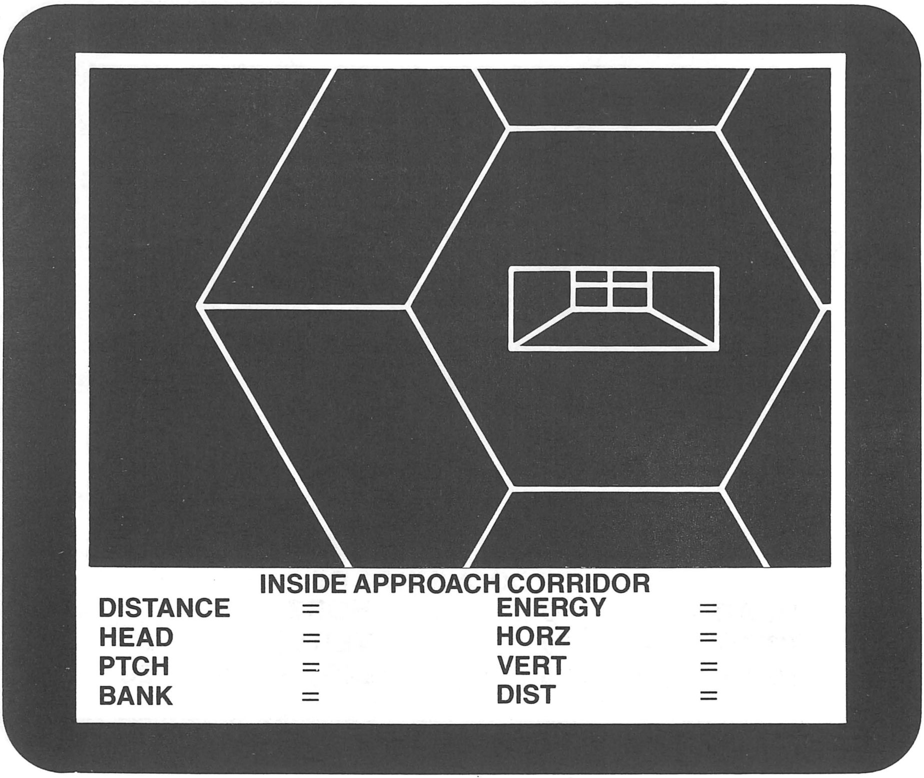


Figure 13

During your approach to the station, you may have acquired some residual velocity along any or all of the directional axes as a result of velocity increments applied in arbitrary rotational positions. These cannot be removed by the fixed velocity increments used in manual flying without rotational acrobatics. At this point, any motion can cause difficulty in the final docking procedure where a good deal of thrusting is required to offset it. The **RENDEZVOUS** flight system can eliminate this residual velocity. Press the **[RETURN]** key to remove incremental velocities along the directional axes. This will cost you proficiency points. This command works only within the docking corridor since the system requires station radar data to kill residual velocities relative to the space station. You can stop all rotational motion by pressing **[SPACE]** bar at any time. This will cost you proficiency points as well.

After entering the docking port, continue until the spacecraft is entirely within the dock hangar (DIST=Ø). Once inside the port, the spacecraft must be kept under rigid control. Heading, pitch, and bank must not exceed 2 degrees. The horizontal and vertical distances away from the approach line should not exceed 2 meters. If this is not the case, the shuttle will crash into the walls of the docking port.

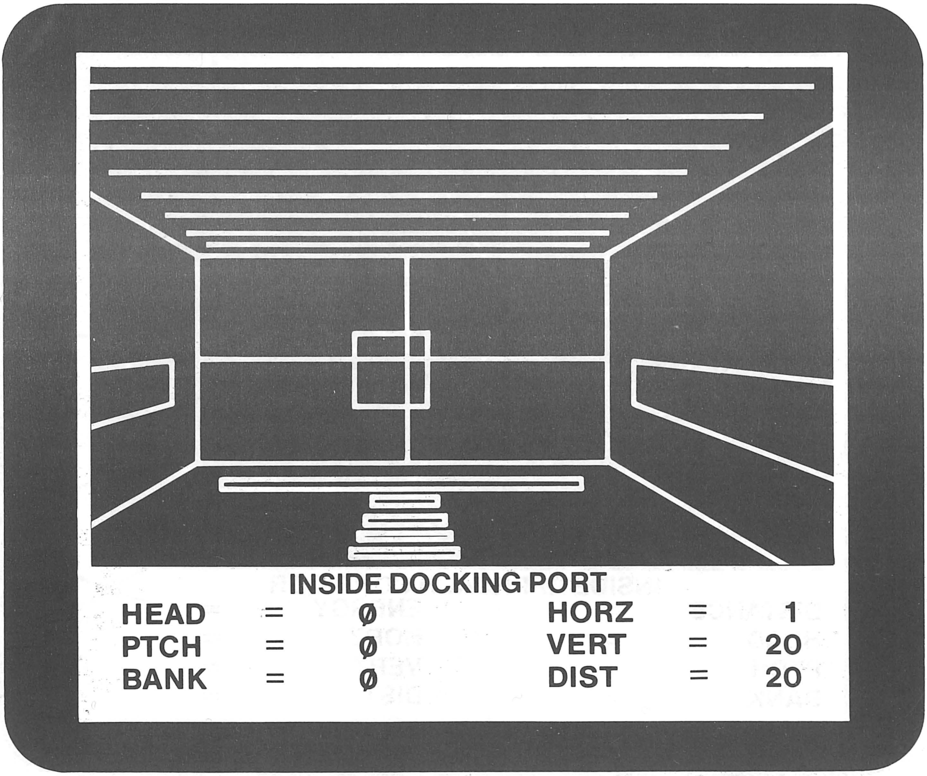


Figure 14

METHOD AND OPERATIONAL SUMMARY: See Approach (Phase 3)

PRACTICE PROBLEMS:

The Docking Phase begins with the shuttle within 2ØØØ meters of the space station. In addition to translational motion along the three directional axes that you accomplished in the Approach Phase, you must perform rotational maneuvers as well.

The first docking problem, however, is designed to give you experience in docking with the space station while using very few maneuvers. From the RENDEZVOUS menu, set up a docking problem with the axial distance set to 4ØØ meters, and the horizontal and vertical distances set at Ø meters. Set the bank to "easy."

Try to duplicate the mission outlined in the flight transcript below. As before, your equivalent keyboard operations are listed after the word **OPERATOR.**

TRANSCRIPT OF VOICE COMMUNICATIONS
ADVANCED SHUTTLE MISSION CONTROL
HOUSTON SPACE FLIGHT CENTER
EDITED VERSION

HOUSTON: Shuttle, please report your present position.

SHUTTLE: Right now, Houston, we're sitting motionless at a distance of 4ØØ meters from the station. Our horizontal and vertical off-line distances are all Ø, as are our pitch, heading, and bank.

HOUSTON: How is the station oriented with respect to you?

SHUTTLE: We're looking right down its maw. The docking port is directly in front of us. We just need your go ahead to bring this baby in.

HOUSTON: Clearance given for docking shuttle. Accelerate your velocity to 3 meters/second, and let us know when you reach the approach corridor.

SHUTTLE: Right-o, Houston, setting VELZ to 3 meters per second.
OPERATOR Press [;] key 3 times.

Houston, we're heading in. Heading, pitch, bank all Ø degrees rotation per second. Horizontal and vertical both Ø meters per second.

HOUSTON: Can you see the strut marking the top of the docking entrance?

SHUTTLE: Yup, it's right on top of the bay doors right where it should be. We're not going to bring this baby in upside down. Everything's going Jim dandy. Whoa there, our radar display just changed over. We're getting the actual distances in meters instead of the relative velocities in meters per second. It looks like we've entered the docking corridor.

HOUSTON: Halt your motion and double check your values.

SHUTTLE: Roger, Houston.

OPERATOR: Press [L] key 3 times.

Motion stopped. Pitch, heading, bank, horizontal, and vertical all Ø. Distance from station, 16Ø meters.

HOUSTON: Okay, shuttle, you're clear for docking. Accelerate to 1 meter per second, but keep your eye on those off-line distances. You may have slight residual motion. Don't let them get above 2 meters.

SHUTTLE: Understood, Houston. We're going in.

Operator: Press [;] key 1 time.

All systems green. We've entered the docking doors. Off-line distances all Ø, rotation Ø. I don't think we'll crash into any walls today. Almost there. There! Docking completed. I hope you guys have some beer in the 'fridge.

END TRANSCRIPT

FLIGHT ANALYSIS: In this problem, the only motion you had to worry about was that along the axis towards the docking port. However, several important points were brought up in this example. For most of the phase, your onboard radar systems report your heading, pitch, and bank in terms of degrees of rotation per second. Vertical and horizontal values are given in terms of velocity: meters per second.

Once inside the imaginary approach corridor 16Ø meters out from the station, the radar reports the actual deviations from the station. Heading, pitch, and bank are relayed back in degrees difference from the orientation of the station, and the vertical and horizontal values are in meters distant from the docking port. Also, there are two ways to enter the docking port: upside down and rightside up. To enter rightside up and successfully dock, the vertical strut above the docking doors must be on top of the opening relative to you.

While in the docking bay itself, the heading, pitch, bank, and horizontal and vertical distances should all be set at Ø. If they get above 2, your shuttle will crash into the walls of the docking port.

For the next problem, set both the axial and horizontal distance to 4ØØ meters. Set for a random bank, but leave the vertical distance at Ø. Then follow the transcript given below for docking strategy. Because of the random bank, the orientation of the station may be slightly different from that experienced by the pilot of the described mission, but the principles remain the same.

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SHUTTLE: We're situated 4ØØ meters from the station. The side housing the docking port is pointing down and to our port side.

HOUSTON: Please toggle on your viewfinder for confirmation, Shuttle. It should indicate that the station is vertically in line with you, but several degrees to your left.

SHUTTLE: Toggling on viewfinder, Houston.

OPERATOR: Press [G] key.

Verification affirmative, Houston. Toggling viewfinder off. Going to rely on visual data from this distance.

OPERATOR: Press [G] key.

HOUSTON: Very well, Shuttle. Proceed as you think best.

SHUTTLE: Roger, Houston. We're going to fire our starboard thruster to bring our VELX to 1 meter per second.

OPERATOR: Press [J] key.

Now heading left at 1 meter per second. The right edge of the docking port is approaching the right edge of our forward window. When they align we'll halt our movement to adjust our heading. Now halting movement. The edge of the port has met the edge of our window.

OPERATOR: Press [K] key.

VELX down to Ø meters per second. Now adjusting our heading to 1 degree per second.

OPERATOR: Press [F] key.

We are rotating right at a rate of 1 degree per second. The docking bay is coming back to the center of the screen. Now it is at the center, and we are halting rotation and toggling on the viewfinder.

OPERATOR: Press [D] key.
Press [G] key.

Rotation stopped, Houston. The line on the viewfinder indicating the position of the station is closer to the arrow indicating our line of sight. From visual inspection, the docking port appears to be in greater alignment with us.

HOUSTON: Shuttle, continue your alignment procedure until the docking port is pointing as directly towards you as you think you can get it from this distance.

SHUTTLE: Acknowledged, Houston. Repeating procedure as necessary.

OPERATOR: Repeat the procedure for travelling left until the right side of the docking port meets the right edge of the screen and then rotate right to bring the docking door to the center again. Do this until no better alignment seems possible.

Houston, we've performed our alignment procedure 5 times. Request permission to move in closer.

HOUSTON: Shuttle, move in to a distance of 2ØØ meters and begin the second alignment procedure.

SHUTTLE: Roger, Houston, advancing to 2ØØ meters distance.

OPERATOR: Press [;] key.
When the distance reaches 2ØØ meters press the [L] key.

Houston, now at 2ØØ meters. Adjusting our bank to align ourselves with the strut on top of the docking bay.

OPERATOR: Rotate your bank by using [A] and [S] keys until the strut is pointing straight up.

Bank aligned, Houston. Now beginning second stage of alignment.

OPERATOR: There is a cross at the far end of the docking port. Use your vertical and horizontal thrusters to bring that cross to the center of the screen. Then rotate your heading so that the vertical strut at the front of the docking port matches the vertical axis of the cross at the far end.

Houston, we've completed the second stage of alignment as well as we can from this distance.

HOUSTON: Roger, Shuttle. Repeat your alignment procedure every 2Ø meters until you reach the docking corridor.

SHUTTLE: Roger, Houston. Will comply.

OPERATOR: Advance 2Ø meters along the Z axis. Repeat the above procedure, adjusting first the vertical thrusters to bring the horizontal section of the cross at the back of the docking port to the center of the screen, and then do the same with the horizontal thrusters to center the vertical axis of the cross. Then rotate your heading to align the vertical strut with the vertical axis of the cross then advance another 2Ø meters and repeat.

SHUTTLE: Houston, we're in the approach corridor, distance 16Ø meter.

HOUSTON: Shuttle, adjust your heading, pitch, bank, horizontal, and vertical to Ø. Don't get fancy. Adjust only one direction or rotation at a time.

SHUTTLE: Acknowledged, Houston, by the book. Adjusting orientation to Ø relative to station.

OPERATOR: Follow the procedure as described in the first transcript for maneuvering in the approach corridor.

Orientation complete, Houston. Accelerating forward along the Z axis at Ø meter per second to dock with the station.

OPERATOR: Press [;] key to advance the shuttle forward. See the first transcript for maneuvering in the docking bay.

END TRANSCRIPT

FLIGHT ANALYSIS: In this problem, you had to maneuver along several axes or rotational frames. The secret is to adjust only one direction or rotation at a time. Always make your adjustments in small increments and keep your eyes on the display and radar to see the actual effect. When the maneuver you wish to accomplish is made, return the velocity or rotation back to Ø.

At great distances from the station, you should try to center the docking doors with respect to yourself. If the docking doors are to your left, then move left until they come to the right edge of the screen, but stop your movement before you lose sight of them. Then rotate left, bringing the doors back to the center of the screen, so that you will be pointing towards them again. Then repeat again to fine tune the alignment. Use the same process if the docking doors appear to be right of, above, or below your line of sight.

At close distances, you can use the details of the station to further align yourself. Center the rectangle representing the back of the docking port inside of the rectangle representing the opening. Also align the vertical strut at the opening with the cross at the back. Make a change in your horizontal position, and then reorient yourself with a change in your rotational heading. Make a change in your vertical position, and then make up for it with a change in your pitch. Repeat as necessary.

For a more difficult docking problem, set the axial, horizontal, and vertical distances to 2ØØØ meters and allow for a random bank. When you enter the docking phase, the station will be quite distant. Accelerate your VELZ to 9 meters per second so that the bulk of the distance will be quickly travelled.

At a distance of 8ØØ meters, bring the shuttle to a halt. Adjust your horizontal and vertical thruster to bring the docking port to the center of the screen. Now try to imagine a line extending from the back of the docking port to infinity. If the line goes off to the left or right, then rotate the heading in the opposite direction. If the imaginary line goes above or below you, rotate the pitch in the opposite direction until the line is pointing at you as much as possible. Then bring the docking port to the center of the screen again using the motion thrusters.

Repeat the above procedure every 1ØØ meters until you are 4ØØ meters distant. Then repeat every 5Ø meters until you are 2ØØ meters distant. Now adjust your bank so that the strut indicating the top of the docking port is pointing straight up. Then repeat the adjustment procedure every 2Ø meters until you enter the docking corridor. Go on from there as you did in the previous problem.

MANEUVERING

USING THE KEYBOARD

NASA pilots use joysticks to manually fire the shuttle's maneuvering system. They use computer control for automatic maneuvers. You can fly your RENDEZVOUS spacecraft manually with the computer keyboard just as effectively as with a joystick. Keyboard maneuvering will seem quite natural once you've experienced it.

Your right hand controls directional motion and you left hand controls rotational movement. Your middle and index fingers have to do double duty, but if you are accustomed to the Autostart ROM J,K,I,M editing keys it will come quite easily. Just as the **[J], [K], [I], [M]** keys are used to move the cursor left, right, up, and down when editing on the Apple II+, so they are used to move the spacecraft in the same directions. Each key depression adds an incremental 1 M/S pulse in the appropriate direction. This changes to 5 M/S in the Approach Phase. Likewise, the rotational motion of the spacecraft is controlled by the **[D], [F], [E],** and **[C]** keys using the middle and index fingers of the left hand. The fourth and fifth fingers control backward and forward motion on the right hand **[L]** and **[;]** keys, and bank rotation on the left hand **[S]** and **[A]** keys.

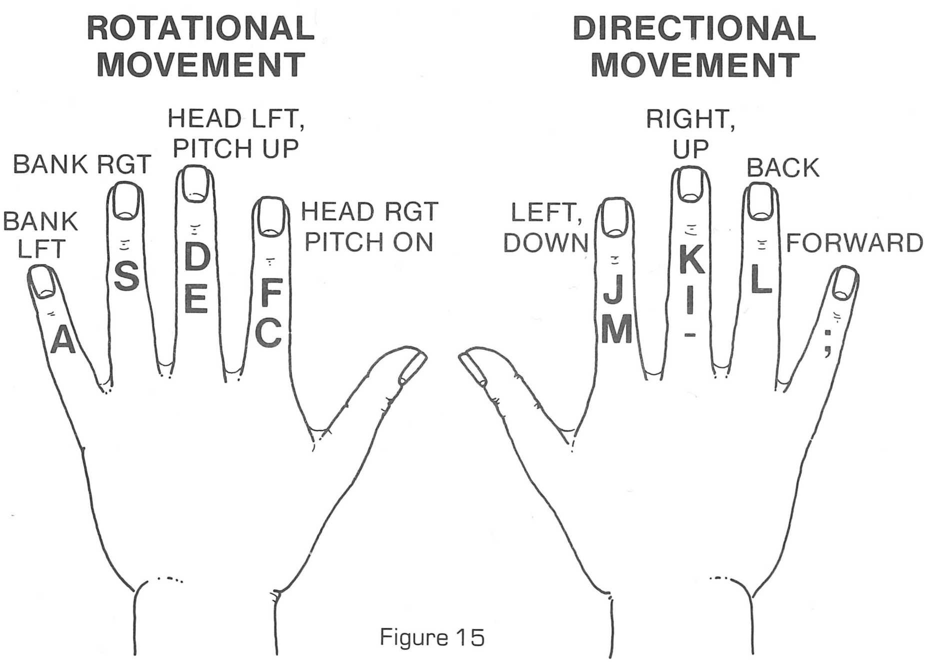

Figure 15

You can determine the placement of your hands on the keyboard by consulting figure #00 and figure #00. The middle and index fingers should rest on the **[D], [F]** and **[J], [K]** keys. You will find it easier to maneuver if your hands remain on the keyboard. It is difficult to hit **[RETURN], [SPACE], [G], [H].** They can be reached with the fingers indicated in figure #00 while your hands remain on the keyboard.

The bail-out key **[ESC]** allows you to halt the mission momentarily in order to assess your status and/or return to the Options Menu. The **[G], [H], [RETURN],** and **[SPACE]** keys are explained in section II.

USING A JOYSTICK

The joystick provides a more realistic control mechanism to fly the spacecraft than the keyboard, although only one stick is available. Therefore, the single joystick must be alternately used for translational and rotational motion. If you have a three-button joystick, use switch **#3** to toggle the joystick between these two controls. If you have a two-button joystick, or if you are using paddles, the **[/]** key on your keyboard will toggle between translational and rotational motion. The RENDEZVOUS instrument panel will show a column of "§" or "†" characters, pointing to the three directional controls presently affected by the joystick. Switches **#1** and **#2** act as throttles to control forward and backward motion. Figure 00 demonstrates how the joystick controls affect spacecraft motion. Five keyboard keys remain operative in the joystick operating mode; **[G], [H], [ESC], [SPACE]** and **[/].**

Warning: Do not hit the **[RESET]** key. The disk will reboot. Do not hit **[CTRL-C].** You may hang the system or break to an unresponsive Applesoft prompt, sometimes with an error message.

SCORING

Three criteria are used to evaluate your skill: time, energy consumption, and piloting. The less time you take, the less energy you use, and the more piloting skill you demonstrate result in a higher score. The elapsed time and energy consumed are reported after docking, or as a status check when the Options Menu is accessed. You evaluate your own score on elapsed time and energy consumed. The computer will score you on piloting skill in the Approach and Docking Phases. The scores below are listed from lowest to highest.

ZERO
SWAB
ENSIGN
LIEUTENANT
COMMANDER
CAPTAIN
ADMIRAL
FLEET ADMIRAL

GLOSSARY

ACCELERATION: increasing or changing velocity.
ALTITUDE: height above the surface.
ATTITUDE: rotational position.
AXIAL: along the main rotation axis, or the axis running forward and backward as perceived from within a rotating body.
AXIS: A line through a body about which it rotates.
BALLISTIC: motion under the influence of gravity but without atmospheric lift or drag.
BANK: rotation around the axial direction either left or right.
BOOSTER: first stage of a multi-stage rocket, usually with high power but short burn duration.
CENTRIFUGAL FORCE: force acting to move a rotating body away from the center of motion.
DELTA-V: velocity change (acceleration).
ELLIPTICAL: non-circular, elongated.
FORCE: work or energy applied to move an object (acceleration applied to mass).
GYROS: gyroscopes, which establish a reference for rotational motion.
HEADING: Yaw or rotation about the vertical axis left or right.
HORIZONTAL: the axis running exactly left and right as perceived from within a rotating body.
IMPULSE: force applied over a short time.
INCREMENT: small change.
INERTIA: the tendency to remain in constant motion in the absence of any applied force.
KILOMETER: 1ØØØ meters, or Ø.621 of a mile.
METER: 39.37 inches.
ORBIT: unpowered motion around a central object or force field.
PARAMETER: a number or variable which characterizes what is being described: i.e. velocity is a parameter describing motion.
PITCH: rotation about the horizontal axis up or down.
PROJECTION: to look ahead in time or space.
RADIUS: distance from the center, size of circle as measured from the center (½ diameter).
RENDEZVOUS: to meet and move together.
RESIDUAL VELOCITY: small remaining velocity usually difficult to remove.
ROTATIONAL MOTION: tumbling motion of an object about some center within it.

SUSTAINER: main engine or rocket stage, usually the longest burning.
TRAJECTORY: flight path.
THRUST: force producing motion.
THRUST ANGLE: the direction in which the impulse is to be applied.
TRANSLATIONAL MOTION: motion in a straight line.
VECTOR: an indicator of direction and magnitude, an arrow drawn in the direction of motion with a length proportional to the magnitude.
VELOCITY: speed vector.
VERTICAL: the axis running up and down as perceived from within a rotating body.