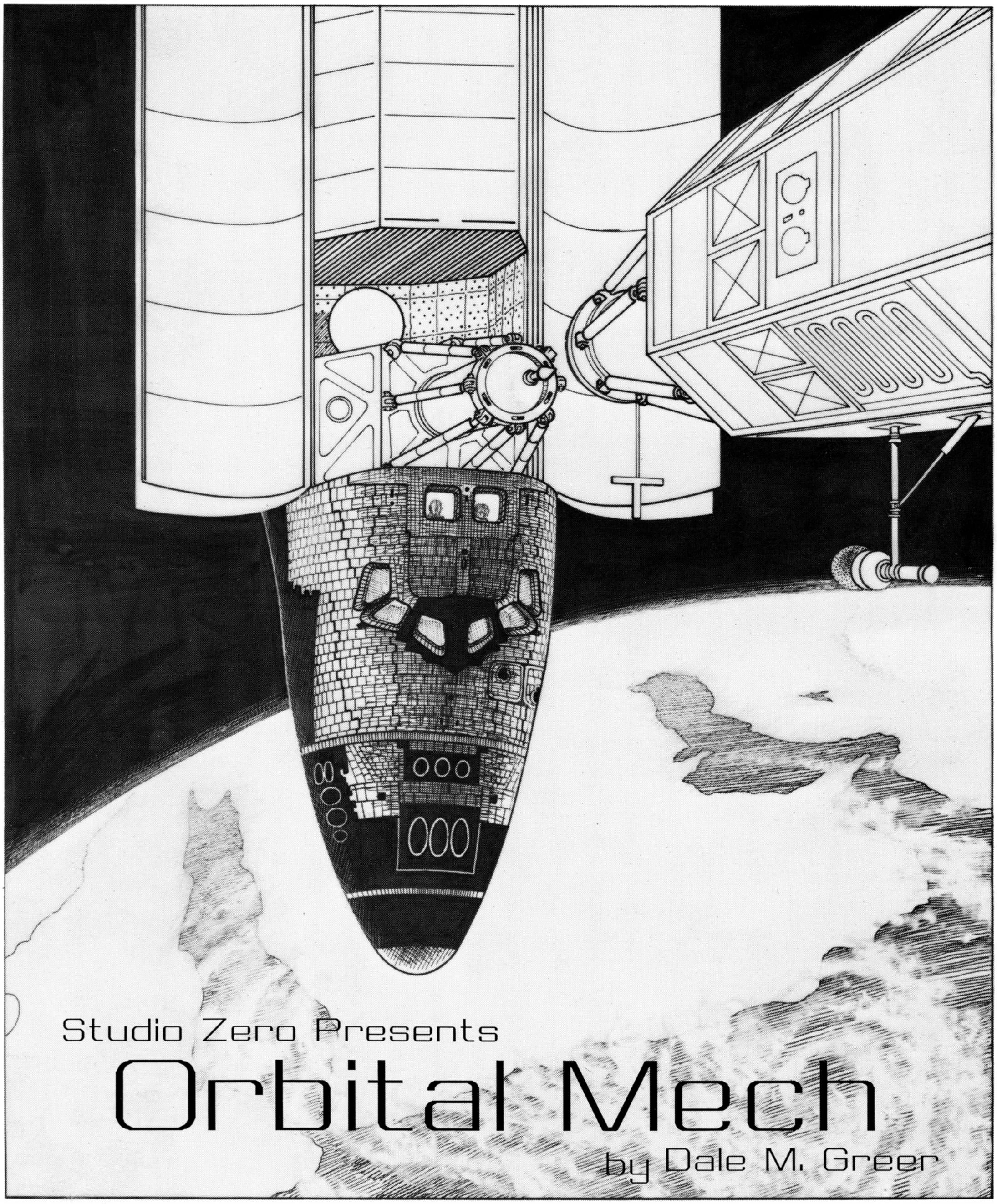
Studio Zero Presents
Orbital Mech
by Dale M. Greer

Orbital Mech

Manual of Operation

Orbital Mech™

Designed and developed by Dale M. Greer
at Studio Zero

Many thanks to Ward McFarland,
David Sibley, Fred Weiss,
and the rest of the MacFORTH User's Group

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For Clare

Preface

" At the Insitute, they taught me that everything has an explanation. I thought that if there really were magic, things would be, well..., different."

Alpha, in The Lost Angel

But things really *are* different, and there *is* magic.

Scientists find it curious that anyone should feel that an explanation of something should take away the wonder of it. Scientists find wonder in the explanation itself, and their imaginations are excited by the possibilities exposed by knowledge. This is why they always seem to be writing books intended to explain the World to the layperson. When one feels as profound a sense of wonder at something as most scientists do, one is compelled to share this feeling with others.

I hope that **Orbital Mech** will convey to scientists and laypersons alike, the sense of wonder that I feel towards the relatively simple phenomenon of Gravity.

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Acknowledgments

Many thanks to all those who contributed to the MacForth User's Group programming library. Without all those tips and routines, I don't think **Orbital Mech** would have gotten this far. If you own a computer, and especially if you program one, **Join Your User's Group** and **Contribute!**

Special thanks to Ward McFarland of the MacForth User's Group. His encouraging review of a preliminary version of **Orbital Mech** really spurred me on.

And of course, my wife Clare deserves much credit for the production of this work, if only for putting up with my working long nights on it. But aside from that, she listened when I just needed to talk through a problem I was having with the program, she advised me on the layout of the program and of the manual whenever I was at a point of indecision, she helped me to proofread the manual, and she lent her support to my efforts in many other ways as well.

Dallas, Texas
December, 1986

Dale M. Greer

Introduction

"...Look how the floor of Heaven
is thick inlaid with patines of bright gold.
There's not the smallest orb which thou behold'st
But in his motion like an angel sings,..."
William Shakespeare, The Merchant of Venice, V.i.47

Characterization

A playground is a place for the enjoyment of motion. **Orbital Mech** is designed to simulate a celestial playground, where you may play with the motions of objects in orbit. **Orbital Mech** gives you complete control over the motions of a spacecraft, as well as some control over the environment in which you will pilot it.

This environment consists of a gravitational system which may be either unary (single body) or binary (dual body), and may include a space station with which you may attempt to rendezvous and dock. The unary system offers you the challenge of mastering basic orbital maneuvers and enables you to learn intuitively the basic concepts of orbital mechanics. The binary system more than doubles the fun, challenge, and fascination, as intricate orbits may be achieved about the two bodies. The binary system also gives you an intuitive insight into that complex topic known in the trade as the restricted three body problem.

Both of the systems are user definable, that is, you may alter the mass of the body in the unary system and you may alter the masses of both bodies in the binary system as well as the separation between them. Furthermore, you may elect to view motion in the binary system in any of four coordinate systems, each of which gives a unique insight into the nature of motion within the system. You may elect to attempt rendezvous and docking with the space station, or you may simply putter about in space, experimenting with the effects which gravity and thrusting have on the motion of your ship.

A Quick Walk-Through

When you first start **Orbital Mech**, the ship is in a near-circular orbit with a period of around 10 seconds (real time) about a single attractive body. From this point, there are a number of options open to you. At first, you may want to just get acquainted with the controls. Although the ship may be controlled from either the keyboard or the mouse (refer to the *Controls* section of this manual for more information) you may find it easiest to use the keyboard only for rotation (using the z, x, c, & v keys), and the mouse only for thruster activation. *Note that there are five levels of power for the thrusters, with highest power to the right, lowest to the left.*

Now select "**Space Station**" from the **Station** menu and the space station will appear in a near-circular orbit with an altitude somewhat higher than that of the initial orbit of the ship. You may find rendezvous, the process of getting close enough to the station to dock with it, to be a bit difficult until you are well acquainted with the vagaries of orbital maneuvering (see the section, *Orbital Maneuvering Technique*). Therefore, "**Near Station**" under the **Station** menu is provided to allow you to practice docking before you are able to rendezvous on your own. "**Near Station**" cannot be selected unless the station is in orbit. Also, to be able to dock with the station, the item "**Enable Docking**" under the **Station** menu must checked. See more about docking in the section, *Rendezvous and Docking*.

Now select "**Binary System**" from the **Environs** menu, and the single attractive body is replaced by two, orbiting about their common center of gravity, with the smaller one being a third the mass of the larger. Strange and fascinating orbits are possible about a binary system. More on this is explained in the section *Binary Systems*. Also explained in that section is the Binary System Definition screen, selectable via "**Define System**" under the **Environs** menu, as well as the various coordinate systems from which the binary system may be viewed.

The **Orbital Mech** window automatically adjusts to fill large screens, unless there isn't enough memory available to hold the bitmaps. In that case, the window is downsized so as not to overflow available memory. The maximum window size at start-up is adjustable through the "**Display**" menu.

Controls, Menus, & Dials

"For 'Is' and 'Is-Not' though with Rule and Line,
And 'Up-and-down' by Logic I define, ..."
Omar Khayyam

Controls

Controls for the ship are in the lower right-hand corner of the screen and appear as three banks of ten pushbuttons. Each bank is arranged as two rows of five pushbuttons. The more powerful pushbuttons are on the left, and their power gradually decreases to the right.

The top bank is for rotation of the ship. The top row rotates the ship clockwise, the bottom, counter clockwise. Rotation may also be accomplished via the **Z, X, C,** and **V** keys on the keyboard.

The second bank of pushbuttons controls the fore and aft thrusters. The top row activates the aft thrusters, giving a forward accele- ration. The bottom row gives a rearward acceleration.

The third bank controls the top and bottom thrusters. The top row gives an upward acceleration, relative to the *rest position* of the ship that is. The bottom row gives the ship a downward acceleration.

The thrusters may also be activated via the keyboard and are mapped thusly:

Highest				Lowest	Thrusting Direction
8	9	0	-	=	forward
I	O	P	[	]	rearward
J	K	L	;	'	upward
N	M	,	.	/	downward

See the annotated diagram of the control panel on page 10.

File Menu

"**Restart**" puts the ship back into its initial orbit and sets the clock and fuel meter back to zero. Useful when the ship gets into an uncontrollable state.

"**Page Setup...**" brings up the familiar page setup dialog box. On an ImageWriter, be sure to use "Tall Adjusted" or "Wide" so the image won't be distorted.

"**Print**" sends the contents of the **Orbital Mech** window to your printer. Print images too large for one page on your printer are printed in sections.

"**Print Inverse**" is the same as "**Print**" except that the white and black of the screen are inverted to black and white for the printer. This allows faster printing from the "celestial" screen, saves wear and tear on your print head, and doesn't use up your printer ribbon as quickly.

"**Save to File**" allows you to save the state of the simulation to a file for later recall via "**Restore from File**". *The screen image is <u>not</u> saved.*

"**Save to Memory**" saves the state of the simulation temporarily to memory for recall via "**Restore from Memory**" or "**Restart from Memory**", the difference being that *restore* resets the clock and fuel meter to their previous readings, while *restart* sets the clock and fuel meter to zero.

"**Save Memory to File**" is provided in case you previously saved a state only to memory, but now want to save it to a file.

Note: When you do a "**Save to File**" or a "**Restore from File**", whatever state is currently saved in memory will be overwritten. If you want to be able to retrieve what is currently saved in memory, you should do a "**Save Memory to File**" before selecting "**Save to File**" or "**Restore from File**".

"**Launch...**" allows you to launch another application without returning to the Finder.

"**Quit**" exits to the Finder after asking you if you want to save anything.

Simulation Menu

Select "**Slower**" to decrease the speed of simulation. Each time it is selected, the speed will be halved, so you can make things come to a virtual standstill. "**Faster**" is used in the same manner to double the speed of simulation. Note that when the speed is increased, the orbital calculations get less accurate, whilst slowing down the simulation makes these calculations more accurate. The reason for this is explained in Appendix A.

Select "**Initial**" to revert to the initial speed of simulation.

"**Free Rotation**" means that once you start the ship rotating, it will continue to do so until you supply the appropriate counter-rotation. This is realistic but is very difficult to work with, so "**Controlled Rotation**", where the ship stops rotating as soon as you lift off the control, is the initially selected option. Use the **S** key to stop a free rotation.

"**Suspend**" stops everything and disables most menu items until "**Continue**" is selected. This allows you to answer the phone or whatever.

Display Menu

Select "**Trail**" to leave a trail of dots wherever the ship goes. Subsequent reselection will cancel any new trail but will not remove present trails from the screen.

Select "**Clean**" to clean excessive trails from the screen.

The **Orbital Mech** celestial screen shows the view from high above the orbital plane. "**Zoom Out**" shows the view from twice as far away as in the initial setting and so quadruples the maneuvering area available. "**Zoom In**" just gets you back to the initial scale.

"**Show Time & Fuel**" shows the elapsed time and fuel consumed in **Orbital Mech** units. When selected, it changes to "**Hide Time & Fuel**", in case you didn't want the pressure of metered performance.

"**Reset Time & Fuel**" zeroes the elapsed time and consumed fuel.

When checked, "**Starfield**" causes the background starfield to be created each time the screen is cleaned. When not checked, the background will be completely black when the screen is cleaned.

When "**Sound**" has a checkmark in front of it, thruster activation will produce a modest *shhh...* sound, and there will be sound during the reward sequence after docking with the space station. Otherwise, **Orbital Mech** will be completely silent. When the sound is off, **Orbital Mech** will run about 20% faster than when it is on.

"**Max Window**" allows you to change the maximum startup size of the **Orbital Mech** window. We chose this unorthodox method of changing window size for a number of very good reasons which shall not be discussed here. Use the buttons in the dialog box to change the window size. The new dimensions will stay in effect from session to session. The window may not be smaller than the original Macintosh screen, so on Macintoshes of that variety, this item is disabled.

Coordinates Menu

When "**Celestial Coordinates**" is selected, the action is displayed relative to a fixed point in space so that each member of the binary system appears to orbit about the center of mass of the system. This is in fact the true case, unless you consider that the entire universe revolves around just one of the members of the system.

With the other three items, "**Primary Relative Coordinates**", "**Companion Relative Coordinates**", and "**L5 Relative Coordinates**", the center of the display coordinate system is attached to the primary body, the companion body, or the L_5 libration point respectively. This is explained more fully in the section, *Binary Systems*.

Environs Menu

Select "**Unary System**" to orbit about a single attractive body.

Select "**Binary System**" to orbit about two mutually orbiting attractive bodies.

Select "**Define System**" if you want to change the gravitational system through which you will maneuver. If the current system is a unary system, you may change only the mass of the body. If the current system is a binary system, you may change the masses of either or both bodies as well as the distance by which they are separated. See more about this in the section *Binary Systems*.

"**Reset System**" reverts the current system to its initial setting.

Station Menu

Select "**Space Station**" to get the station into orbit.

"**Near Station**" is the quick way to get near enough to the station and at a low enough relative velocity to begin docking maneuvers.

When "**Enable Docking**" has a check mark in front of it, **Orbital Mech** will automatically switch to the docking screens whenever the ship is within a certain distance, about one ship's length, from the station. See more about the docking screens in the section *Rendezvous and Docking*.

"**Disable Docking**" turns off the automatic switch-to-docking-screens feature, and will also throw you back into the celestial screen if selected from within the docking screens.

"**Put Station at L5**" puts the station at the L_5 point of a binary system. The station will then be in a stable orbit about this point under certain circumstances (see the section, *Binary Systems*).

Help Menu

"**Panic Button**" is the same as "**Restart**" under the File menu.

Select "**Control Panel**" to see the diagram of the ship's controls shown below.

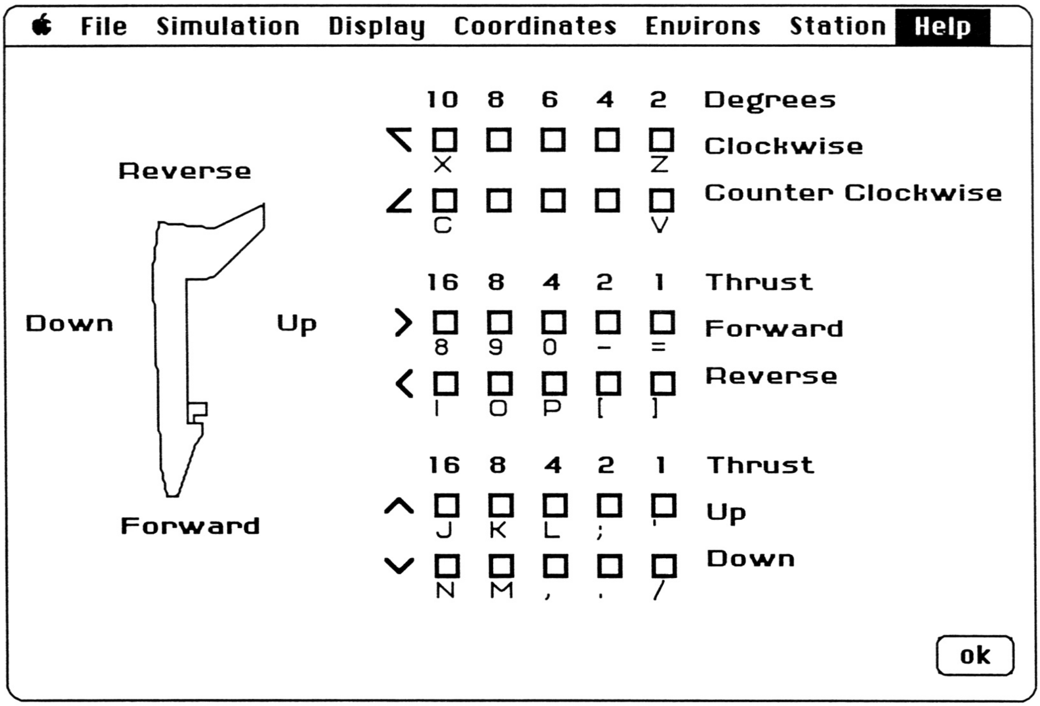


Fig. 1 Enlarged & Annotated Control Panel

Dials

When the space station is activated, two dials appear in the lower left of the screen.

The leftmost dial, labeled Δ**V**, is called the Relative Velocity Indicator, or RVI. It shows the velocity of the ship relative to the station. The number below the dial is the absolute value of the relative speed, and the pointer shows the direction of motion of the ship relative to the station.

The other dial, labeled Δ**R**, is called the Relative Position Indicator, or RPI. It shows the position of the ship relative to the station. The number below the dial is the distance from the docking port of the ship to that of the station, and the pointer shows the direction from same.

The use of these dials is explained more fully in the section *Rendezvous & Docking*.

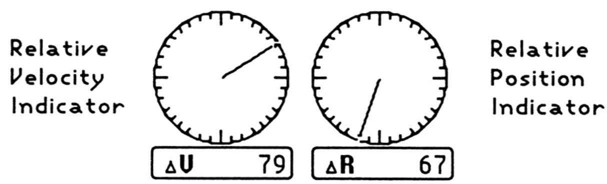


Fig. 2 Indicators

Orbital Maneuvering Technique

"When I had learned the name and position of every visible feature of the river, when I had so mastered its shape that I could shut my eyes and trace it from St. Louis to New Orleans, when I had learned to read the face of the water as one would cull the news from the morning paper, and finally when I had trained my dull memory to treasure up an endless array of soundings and crossing-marks, and keep fast hold of them, I judged that my education was complete..."

Mark Twain, Old Times on the Mississippi

In our everyday lives we understand many things intuitively without necessarily understanding them analytically. For example, we all know how to catch a ball. When we try to catch a ball, we don't think about the process of ball catching; we just do it. Through years of experience, we have learned to intuitively calculate the trajectory of a ball in flight so we can predict where it will be when it becomes catchable. We also know how to maneuver our body to be at that place at the right time, and we know how to maneuver our hand into position so it will be ready to

Fig. 3 The Process of Catching a Ball

grasp the ball as soon as it gets to that place. Some people can even do this while running and looking over their shoulder with their head tilted backward. Such people are called Wide Receivers, but that's a different story.

The technique of orbital maneuvering is quite a bit different than any other maneuvering technique to which most of us have been exposed. In orbital maneuvering, we are concerned not really with getting to a certain place at a certain time, but with being in a certain orbital state. Sometimes this means just being in a particular orbit. For example, an information gathering satellite needs to be in an orbit with a particular altitude profile, but it doesn't really matter where it is at any particular time; it just gathers data throughout its orbit. To dock with a space station however, it's not enough just to be in the same orbit with the station, since we could be on opposite sides of the same orbit. We also need to have the same orbital longitude as the station. But before we begin to discuss such details, let's cover the basics of orbital mechanics.

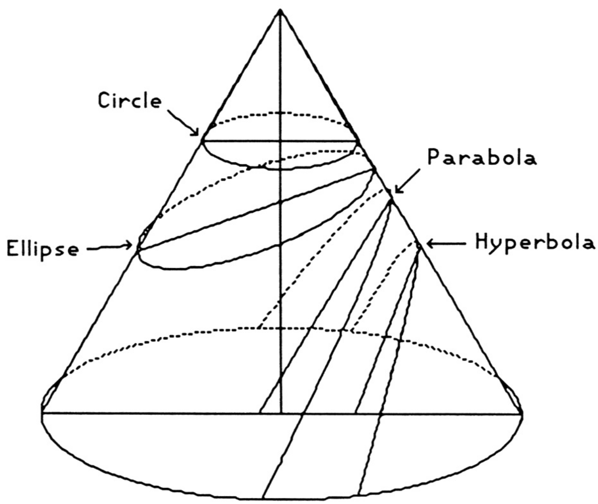


Fig. 4 Conic Sections

Basic Orbital Mechanics

The trajectory of an object in free space is a straight line, but the warpage of space-time in the vicinity of mass will cause this line to appear to be curved. The apparent curvature of a line in the vicinity of a spherical mass will follow the form of a section of a cone. There are four classes of conic section: the hyperbola, the parabola, the ellipse, and the circle (see Fig. 4). The parabola and the circle are special cases of hyperbola and ellipse respectively, so all unbounded orbits will be referred to as hyperbolic, and all bounded ones as elliptical or near-circular.

There are a few points of interest on an ellipse that are helpful in a discussion of orbital mechanics. Every ellipse has two foci with the property that any ray emanating from one focus will impinge on the other focus after one reflection off the perimeter of the ellipse. Moreover, the distance the ray travels from one focus to the next will be the same regardless of the initial direction of the ray, and this distance will be equal to the length of the major axis of the ellipse (see Fig. 5).

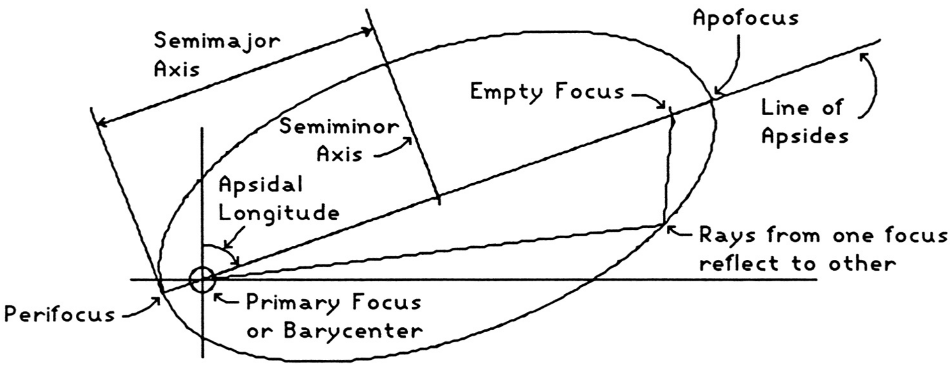


Fig. 5 Elements of the Orbital Ellipse

In orbital mechanics, the attractive body is at one of these foci, which is called primary focus or barycenter (from the Greek word for heavy). The other focus is the known as the empty focus. You may have heard the term *perigee* or *apogee* in reference to the closest and furthest approach, respectively, of a satellite to the Earth, but in general, the point on the orbital ellipse closest to the barycenter is called the perifocus, while the point furthest from the barycenter is called the apofocus. The line which runs through the apofocus, the perifocus, and the two foci is called the line of apsides. For the purposes of this discussion, the angle between the line of apsides and a vertical line (on the Mac's screen) through the barycenter will be called the apsidal longitude, and the angle between a line from the barycenter to the orbiting object and the aforementioned vertical line will be called the orbital longitude, with both angles being measured clockwise.

Initially in **Orbital Mech**, the ship is in a near circular orbit about a single attractive body. In this case the perifocal length is essentially equal to the apofocal length. A short, medium power thruster burst with the velocity vector (that is, in the direction of motion of the ship) will put the ship into a new, more elliptical orbit with a perifocus at the point where thrusting was ended. Once per orbit, the ship will return to this point with the same velocity, assuming there was no thrusting in the intervening period. The speed at the apofocus will be lower than that at the perifocus, and it will be lower than the speed at any point in the initial near-circular orbit. Moreover, the period of the new orbit will be longer than that of the initial orbit.

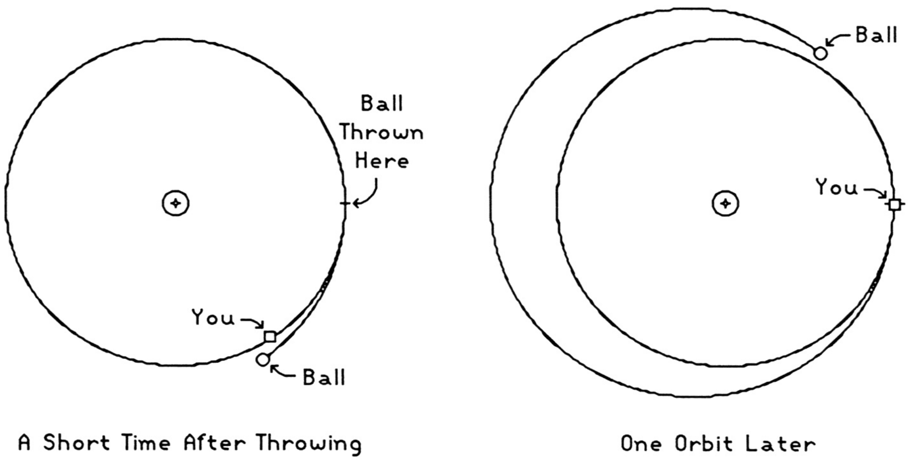


Fig. 6 A Ball Thrown from Orbit Slows Down

This illustrates something of the peculiarity of life in orbit as compared with life on the ground. Imagine that you are in orbit about the Earth in a spacesuit, facing your direction of motion with your feet pointing toward the Earth. You throw a ball exactly in your direction of motion. For a time, the ball will advance away from you,as you might expect. But remember that the ball's orbit has an apofocus higher than your own, which means that the period of its orbit must be longer than yours so that before you have completed a full orbit it will be behind you. Many orbits later it will hit you in the back, unless you turn around to catch it.

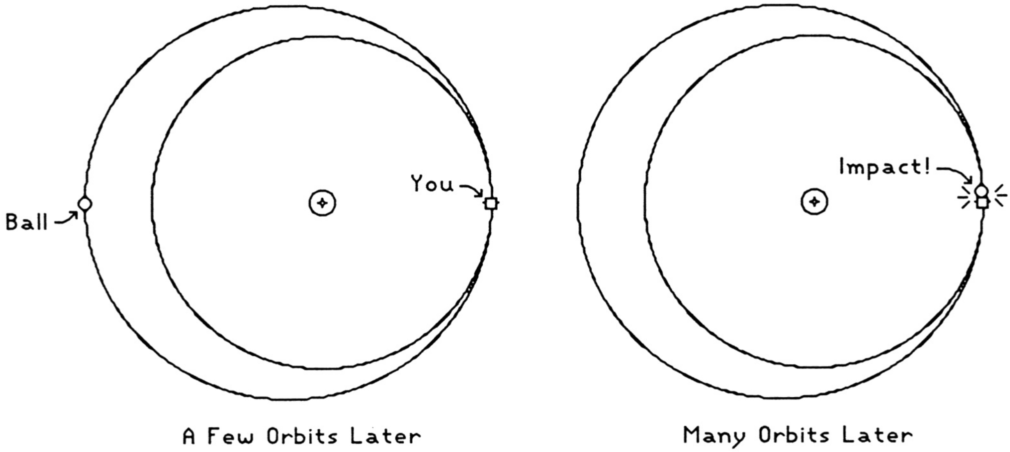


Fig. 7 Ball Thrown from Orbit, Part II

You can use **Orbital Mech** to see this effect first hand, or nearly so. To set it up, select "**Unary System**" from the **Environs** menu, select "**Disable Docking**" from the **Station** menu, select "**Space Station**" from the **Station** menu, then select "**Near Station**" from the **Station** menu. The ship should now be very near to the station with a slightly different velocity. Now rotate the ship, if necessary, to point it in its direction of motion and give it a short, medium power burst of thrust. The ship in this case, is the ball, which you, being the station, have just "thrown" by means of the ship's thrusters.

You may wonder why the ship should slow down after you have given it extra speed. When the ship is in a circular orbit, no matter where it is, its velocity will be perpendicular to the force of gravity. Therefore there is no force to pull with or against its direction of motion, so there is nothing to change its speed (see Fig. 8). On the upside (the journey from perifocus to apofocus) of an elliptical orbit however, the direction of motion is slightly away from the center of attraction so that gravity will pull against the velocity vector, and the speed of the ship will decrease. Conversely, on the downside, the direction of motion is toward the center of attraction, so that the speed increases.

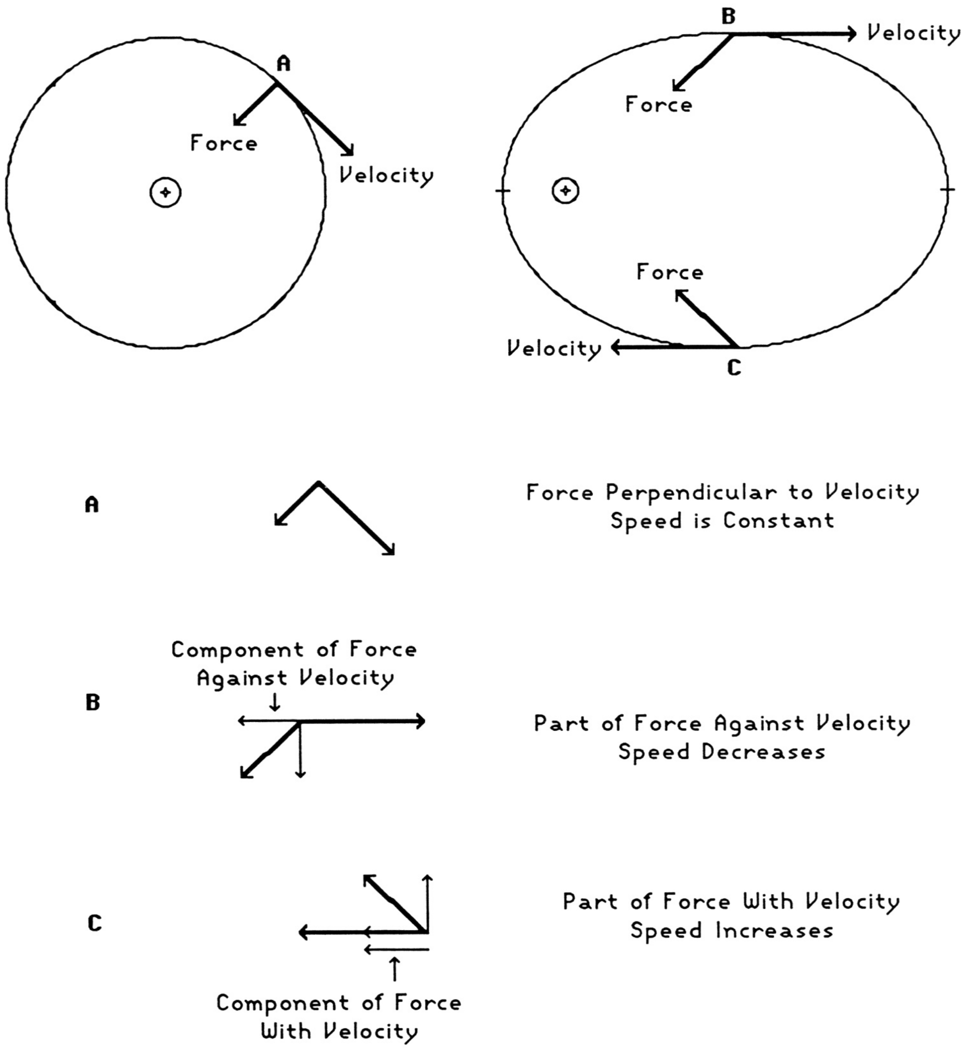


Fig. 8 Forces: Pro & Con

The mathematical relations for this behavior are given in Appendix A in the back of this manual, but you may come to an intuitive understanding of it by experimenting within **Orbital Mech**. In fact, you can probably get a better understanding of it in this way than if you were commanding a real spaceship. In the real thing, you wouldn't have unlimited fuel, and a low Earth orbit would take at least 90 minutes so you'd have to wait a fairly long time to see the effects of your actions. A low Lunar orbit would be better at 20 minutes, but in **Orbital Mech** you may see the fruits of your actions in seconds, which gives you a much better feel for the principles involved.

Incidentally, figures 6 and 7 make it appear as though you should hit the ball from its back since it's going around more slowly than you. Why then, does it hit *you* in *your* back?

Well, here's the situation. Each time you pass through the point where you threw the ball, the ball will be further behind you in orbital angle because of its longer orbital period. Eventually then, the ball will be more than 180° behind you, so since you are going around in a circle, you will then be progressing towards it in orbital angle, and that is why it seems that you should hit the ball in the back.

But whenever the *ball* passes through the point where you threw it, it will have the velocity it had when it left your hand, which is greater then your velocity at that point. Therefore, whenever you both get around to being at the same point again, the ball *must* hit you in the back, since it would be impossible for you to hit it in the back if you are going slower than it is.

Apsidal Thrust Maneuvers

In the course of your experimentation, you will find that there are four maneuvers which give the most easily classifiable, and therefore most predictable, results, viz:

(1) Thrusting with the velocity vector at the apofocus increases the perifocal distance, making the orbit more circular and increasing the orbital period.

(2) Thrusting against the velocity vector at the apofocus decreases the perifocal distance, making the orbit more eccentric and decreasing the orbital period.

(3) Thrusting with the velocity vector at the perifocus increases the apofocal distance, making the orbit more eccentric and increasing the orbital period.

(4) Thrusting against the velocity vector at the perifocus decreases the apofocal distance, making the orbit more circular and decreasing the orbital period.

This class of maneuver shall be called an *apsidal thrust maneuver*, since thrusting takes place only on the line of apsides. Figure 9 shows the effects of the four types of this maneuver for *clockwise* orbits.

Note that for a near-circular orbit, the distinction between apofocus and perifocus is negligible.

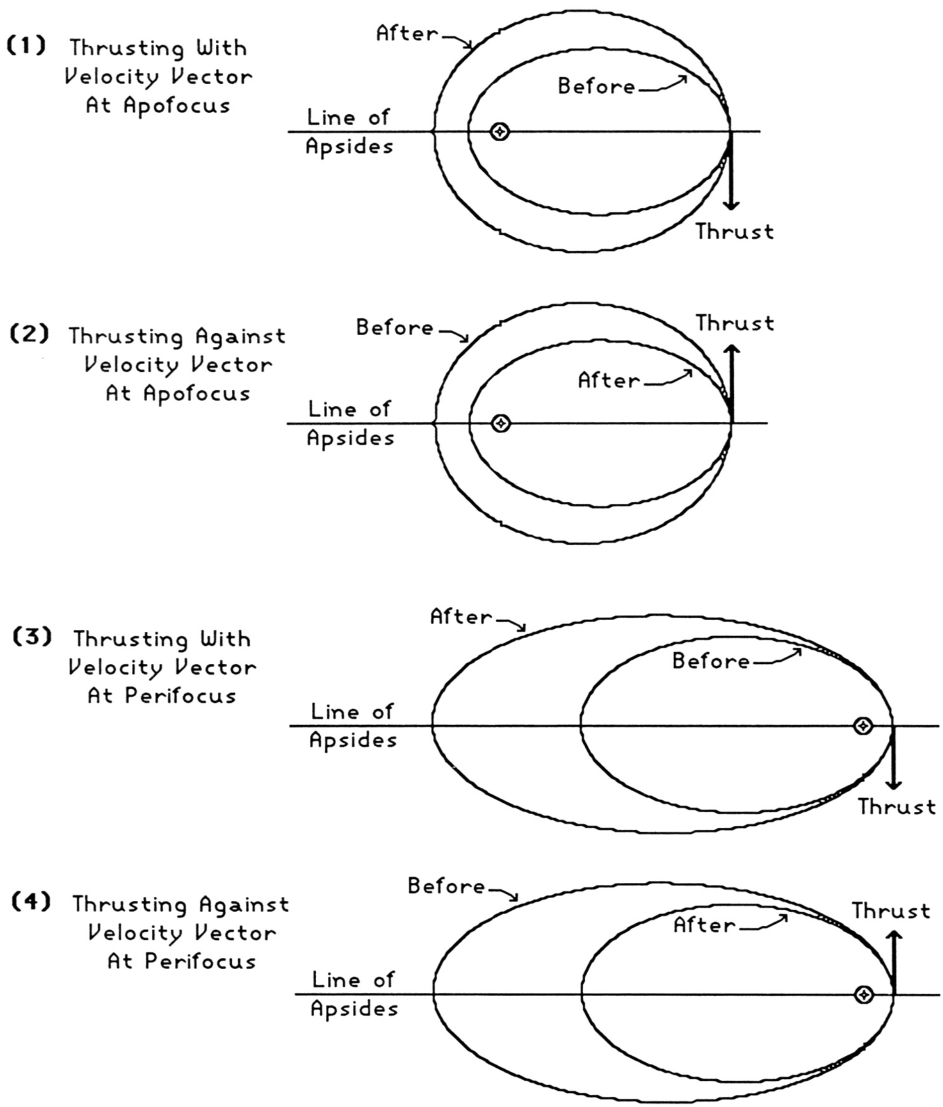


Fig. 9 Apsidal Thrust Maneuvers

Note: All orbits are clockwise in this figure.

Intersection Thrust Maneuvers

Another usefull class of maneuver, known in this manual as an *intersection thrust maneuver* , is generally more costly of fuel but more efficient in time than apsidal thrust maneuvering. It is also somewhat more difficult to accomplish with repeatable results in the seat-of-the-pants environment of **Orbital Mech**, as opposed to the computer controlled navigation of real spaceflight. Consider the following figure.

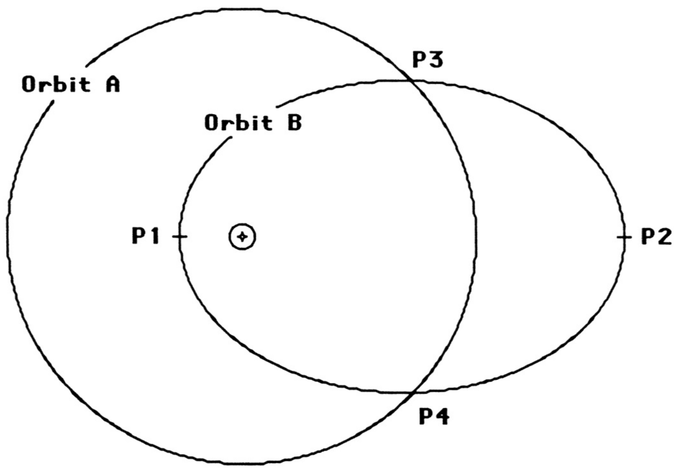


Fig. 10 Intersecting Orbits

To transfer from orbit **B** to orbit **A** using apsidal thrusting, you would apply thrust at $\mathbf{P}_1$ against the velocity vector to bring down the apofocus to coincide with orbit **A**. Then you would apply thrust with the velocity vector at the new apofocus to bring up the perifocus.

Using *intersection thrusting*, on the other hand, you would apply a single thrust at $\mathbf{P}_3$ or $\mathbf{P}_4$ to get into orbit **A**. The velocity at $\mathbf{P}_3$ in orbit **B** is represented by the arrow $\mathbf{V}_{B3}$ in the diagram below. Arrow $\mathbf{V}_{A3}$ represents the desired velocity, that of orbit **A** at $\mathbf{P}_3$. Arrow $\mathbf{V}_{C3}$ shows the direction and amount of velocity change required for the transfer. The situation is similar for $\mathbf{P}_4$.

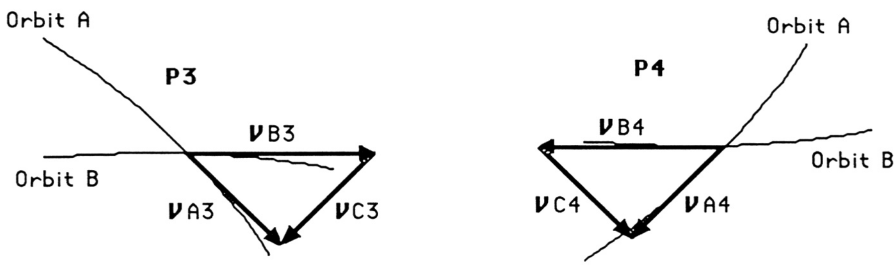


Fig. 11 Intersection Thrust Maneuver

Note that in either case you have to burn off some of the velocity in your direction of motion.

A technique of less general utility but well suited for rendezvous, the *spiral thrust maneuver*, will be discussed in the next section.

Rendezvous and Docking

"...and near approaches the subject of our watch."

William Shakespeare, **Macbeth**, III.iii.9

The Hohmann Transfer Maneuver

This section assumes you are already well acquainted with the basic concepts and nomenclature of orbital maneuvering. From the initial setting, the simplest way to rendezvous with the station is to execute what is called a Hohmann Transfer Maneuver, after the German engineer Walter Hohmann, who showed in 1925 that it is the most economical, though not the shortest or fastest way to get from one orbit to another. A Hohmann transfer orbit is an elliptical orbit tangent to both the initial and target orbits, which in this case are the initial spacecraft and station orbits respectively. This maneuver will allow rendezvous with the station with just two short thruster bursts: one with the velocity vector at a well timed point in the initial orbit, and the second with the velocity vector at the apofocus of the transfer orbit, at which point the ship will be very close to the station if the first thrust was of the proper magnitude and was indeed well timed.

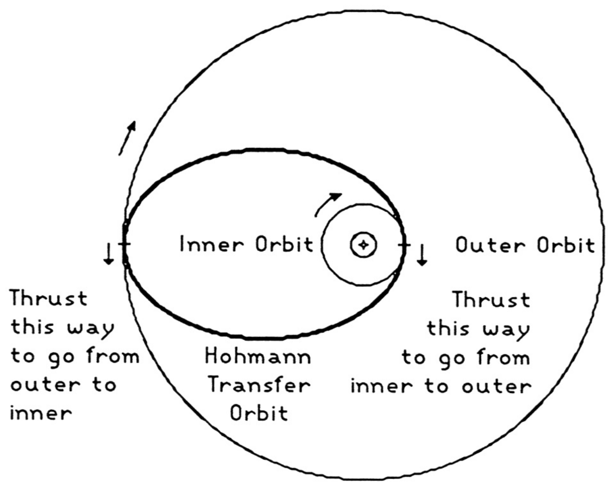


Fig. 12 Hohmann Transfer Ellipse

On your first attempt at Hohmann transfer rendezvous, you may not achieve this perfection: you might overshoot or undershoot the apofocus of the transfer orbit, or you might get the apofocus right but be off on your orbital longitude. In the former case, you'll need to adjust your orbit using the techniques described previously, until the ship's orbit is similar to the station's.

From there, you only need to make minor adjustments to bring the ship closer to the station. Just remember that when the ship is at a *higher* altitude than the station it will move *more slowly* than the station, and when it is at a *lower* altitude than the station, it will move *more quickly* than the station. Thus, contrary to earthbound intuitions, if the station is ahead of the ship, thrusting away from it will cause the ship to close in on the station, or if the station is behind the ship thrusting away from it will cause the station to overtake the ship!

The Spiral Thrust Maneuver

The Hohmann maneuver is simple in theory, but the spiral thrust maneuver mentioned earlier may be a bit easier in practice. It is accomplished by applying a continuous, or frequent intermittent, *low power* thrust always in the direction of motion to increase orbital altitude, or against the direction of motion to decrease altitude. It is more tolerant of error than other methods and it has the advantage that the final orbit is never very far from circular.

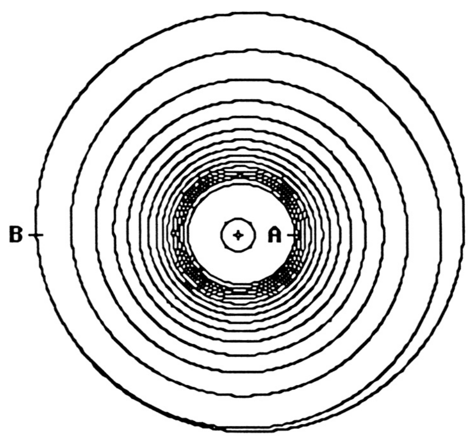


Fig. 13 Spiral Thrusting from Point A to Point B

Docking

If docking is enabled, the docking screens will be activated upon close approach to the station. The left screen shows a 3-D view of the station from the docking port which is on top of the ship. The right screen shows a side view of the ship and station in station relative coordinates, so that the station appears not to be moving.

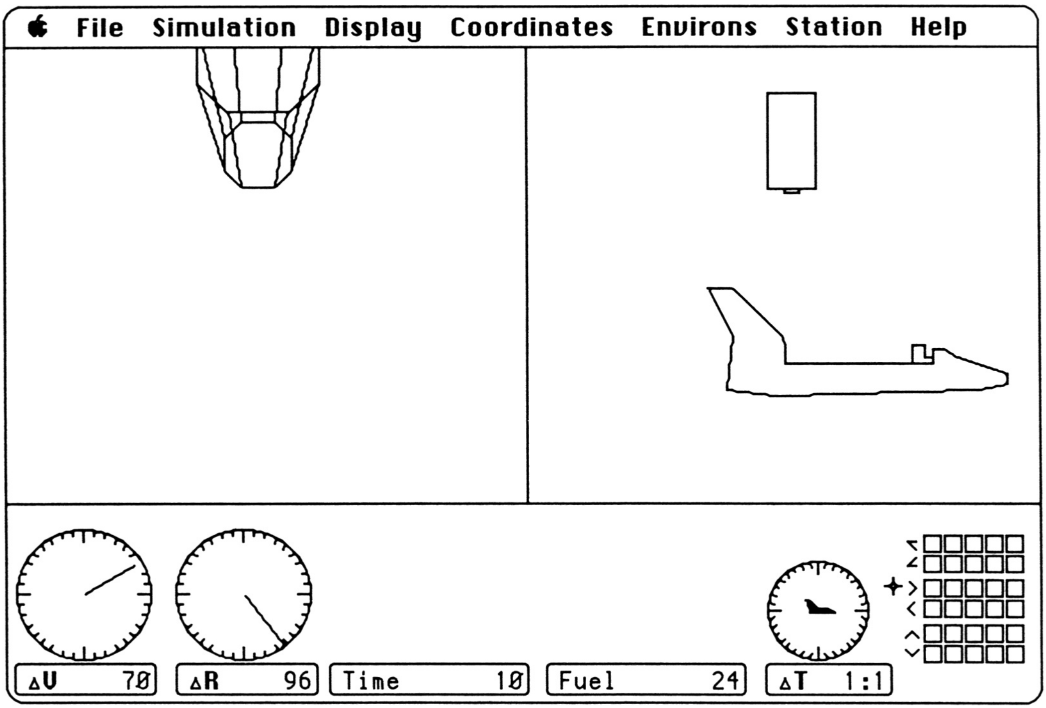


Fig. 14 Docking Screens

From this view, docking with the station will be more like the point A to point B maneuver we earthlings are used to, but there will still be relative motion between the ship and the station even if they are in the same orbit. The ship, if left to its own devices, will appear to orbit about a point in the vicinity of the station. The location of this point depends on how well the ship's orbit matches that of the station. If the orbits match exactly, save for orbital longitude, this point will be in the center of the station.

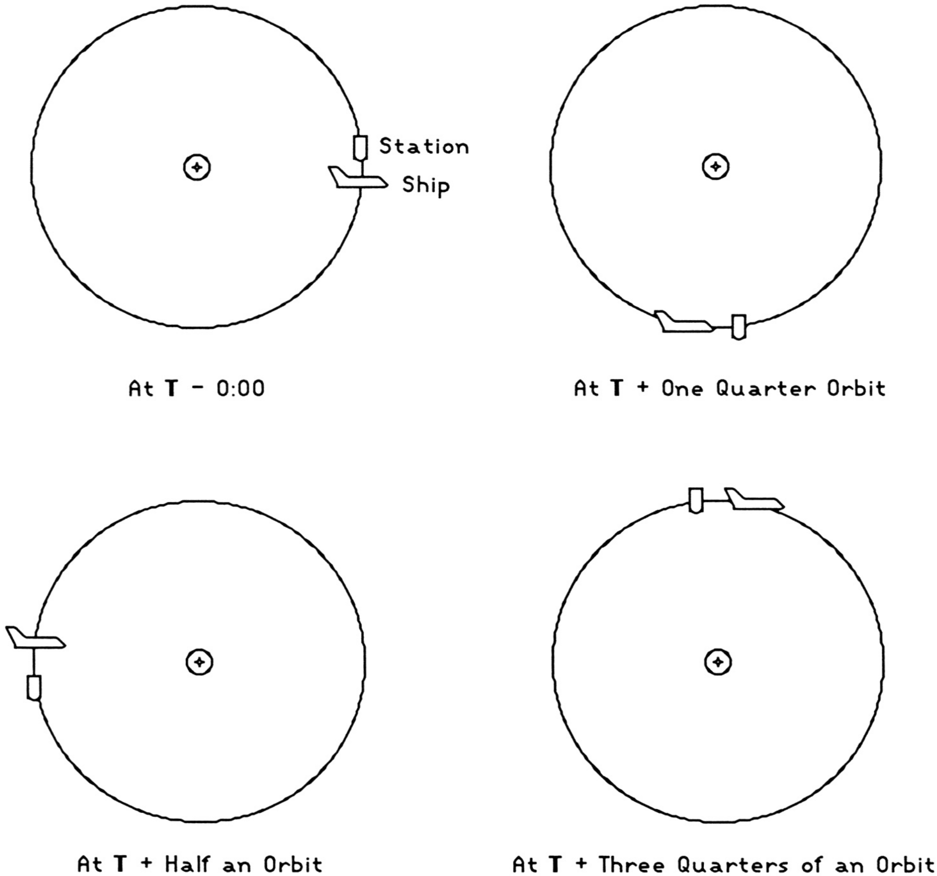


Fig. 15 Relative Circular Motion

Figure 15 shows this case. The ship is always ahead of the station in orbital longitude, but in celestial coordinates the ship and the station rotate about a point in between the two, in addition to their movement through the orbit. This effect can make it very difficult to dock with the station if the mass of the attractive body is much greater than its initial value. Conversely, docking becomes easier if the mass of the attractive body is reduced.

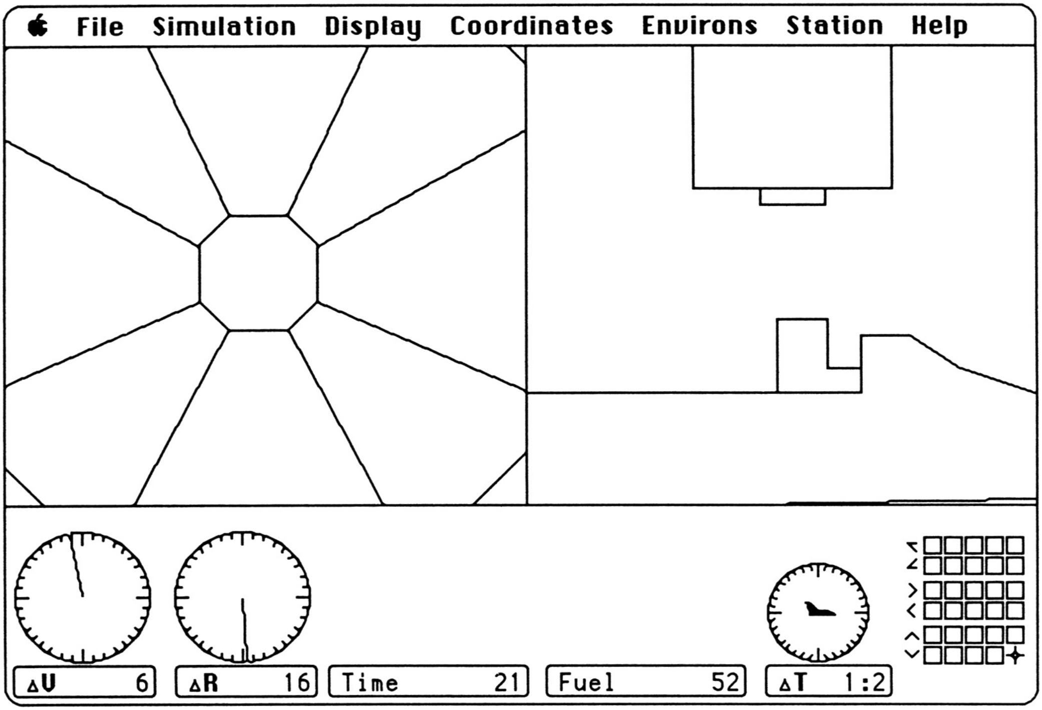


Fig. 16 Docking Screens Just Prior to Docking

In order to dock with the station, the relative velocity of the ship to the station, here called **ΔV** *, must be within 10 OMvels horizontal and 20 vertical at the moment of contact. Observe the Relative Velocity Indicator (RVI) while docking to ensure that the ship's **ΔV** is within this limit. The RVI also gives useful maneuvering information. For example, in Figure 14 the ship is below and to the right of the station, while the pointer on the RVI dial is pointing up and to the right. This indicates the need for a leftward thrust correction. The Relative Position Indicator (RPI) is somewhat redundant here, since this information is already given by the images of the ship and station, but it is included for completeness. Figure 16 shows a scene just prior to docking.

* Pronounced "delta vee". Not to be confused with the rocketry term of the same name which refers to the maximum change in velocity producible by a set configuration of rocket motor, fuel mass, and vehicle mass. The greek letter Δ is most often used in physics to denote a *difference*. Here ΔV is the difference between the station's velocity and the ship's velocity.

Performance Evaluation

The flexibility of **Orbital Mech** makes computer evaluation of performance in terms of time and fuel used very difficult. When, for example, the mass of the body in the unary system is increased, the periods of the ship and station become shorter while the gravity well through which the ship must travel becomes deeper. This means that the rendezvous will take less time (assuming a perfect rendezvous trajectory) but more fuel than in the standard configuration. The shorter orbital period will also affect the rotation of the ship and station about one another, making docking more difficult.

On the other hand, when the mass of the body is made as small as possible, the gravity will be so slight that rendezvous can be accomplished by simple straight line maneuvering and docking becomes a piece of cake. Somewhere between the standard and lowest mass configurations, rendezvous will be more time consuming, but docking will still be somewhat easier.

Similar statements can be made concerning the binary system, but here the mass of the companion and its distance from the primary also come into play complicating matters considerably. When the companion is small and far away, the binary system resembles the unary, but when it is large and/or close in it causes significant perturbations in the orbits of the ship and station. Also, in the binary system there is the possibility of docking at the L_5 point, which is a horse of a different color altogether.

So, after you dock with the space station, and after the concomittent "fireworks" display indicating job accomplished, you are shown the elapsed time, fuel consumed, lateral and vertical velocities, and lateral displacement on impact, as well as the configuration of the gravitational system in which you accomplished your feat. Since the **Orbital Mech** world is a bit removed from reality, all measured quantities are given in OM units, e.g., OMsecs for time, OMvels for velocity, etc. You can print out this information to compare with previous or later achievements, or with the achievements of others who own **Orbital Mech**.

Binary Systems

"Was it the Earth, I wonder?—Or is this another World? "
Edmond Rostand, Cyrano de Bergerac, Act III

When you select "**Binary System**" from the Environs menu, two attractive bodies appear. The larger body, called the primary, is initially three times as massive as the smaller one, called the companion. The two are in circular orbits about their mutual center of mass with an orbital period of about 34 **Orbital Mech** time units. You may alter the parameters of the system after selecting "**Define System**" from the **Environs** menu.

The Binary System Definition Screen

In the binary system definition screen, there are scroll bars for changing the mass of

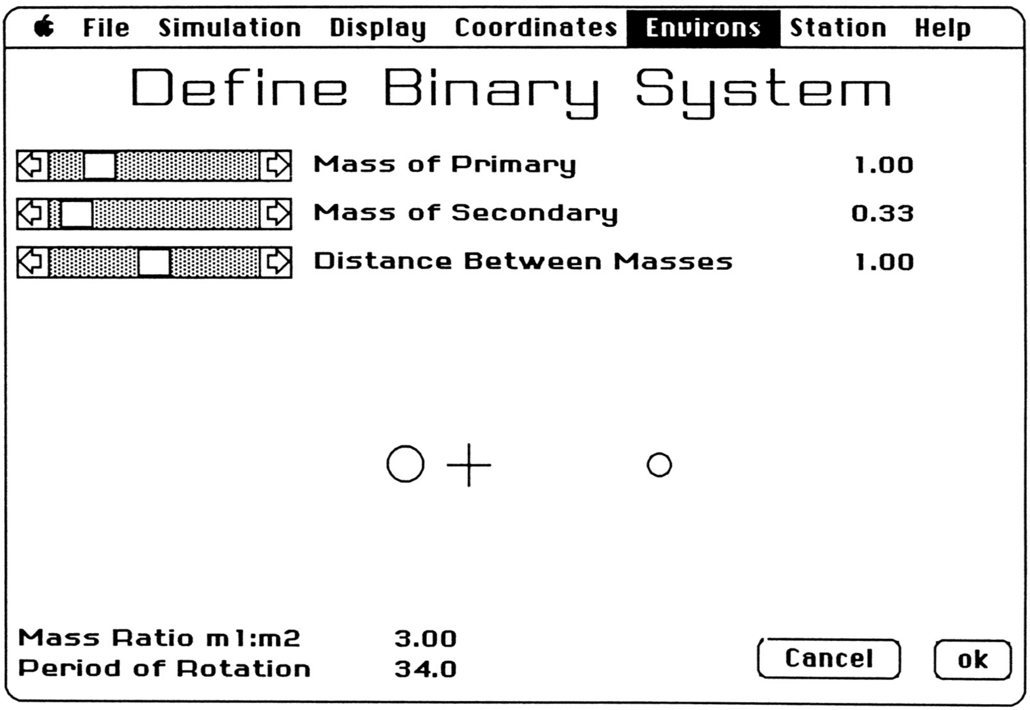


Fig. 17 Binary System Definition Screen

the primary, the mass of the secondary, and the distance of separation between the two. At present, you may not change the eccentricity of the system, so the two bodies always follow circular orbits. Immediately below the scroll bars is a graphic depiction of the system which changes as the parameters are changed. The cross mark between the two bodies locates the center of mass of the system, and the size of the circle representing a body is proportional to the cube root of its mass. The masses of the two bodies are shown quantitatively as ratios to the initial mass of the primary. The mass ratio of the primary to the companion is also shown, as well as the separation distance as a ratio to the initial setting, and the period of rotation of the system in **Orbital Mech** time units. *Note that alteration of any of the parameters of the system changes its period.*

Alternate Coordinate Systems

In the celestial screen, you may view the action from one of four coordinate systems. The celestial coordinate system is the absolute from which all else is relative. In the real world of course, there is no truly absolute coordinate system, but the apparent motion between us and the stars is so small that takes many years of measurement with precise instruments to notice, so our celestial coordinate system is relatively absolute.

You may also view the action relative to the primary or companion. In this case, the body chosen appears to be stationary because all distances are measured relative to it. In the celestial coodinate system, an orbit about either of the bodies will leave a curlycued trail because the focus of the orbit is moving with the body. This makes it difficult to see the true nature of the orbit about the orbited body. In a coordinate system relative to the orbited body, a close in orbit will be seen to be approximately elliptical but with perturbations caused by the other body. Orbits farther out will be less elliptical as the gravity of the other body has more influence on the trajectory.

Libration Points

Finally there are L_5 relative coordinates, which require an extra bit of explanation. In any binary system there are five libration points. These are so called because the gravitational forces and the Coriolis forces are at equilibrium at these points. The three collinear points L_1, L_2, and L_3 are unstable for any binary system. The equilateral points L_4 and L_5 are stable if the ratio of the mass of the primary to that of the companion is greater than about 24:1. In **Orbital Mech**, discretization in the orbital calculations leads to artificial perturbations at these points, so the mass ratio must be better than around 45:1 for an object to remain in a stable orbit about one of them.

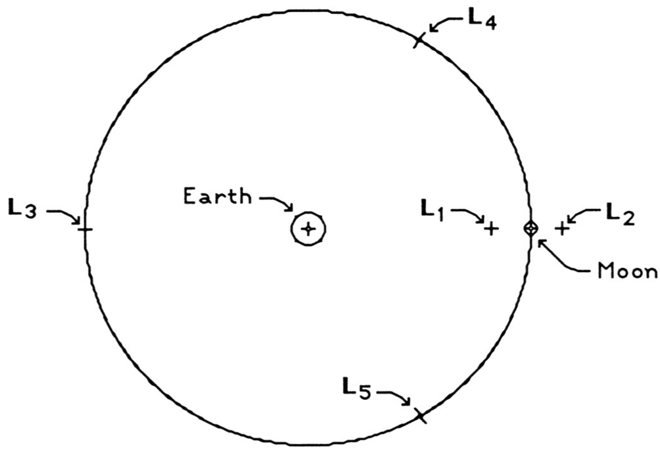


Fig. 18 Earth-Moon Libration Points

To better understand the nature of these points of equilibrium, consider a marble, a basketball, a shallow plate, and a wok. It's fairly easy to throw the marble into the wok, but if you throw it too hard it may go in only to shoot right back out again. The wok then represents the space around a attractive body. To keep the marble in the plate, you must throw it very softly, but once it's in, it'll most likely stay. The plate is a place of stable equilibrium similar to the equilateral libration points. As for the basketball, if you are careful, you may be able to balance the marble on top of it, but even the slightest disturbance will cause it to fall off so that to keep it there requires constant attention. Of course, the basketball represents the collinear libration points.

Figure 19 shows the energy wells and hills in the rotating Earth-Moon system. The large well is the Earth and the smaller one the Moon. In front, you can see the L_5 "plateau". Somewhere within this plateau is the actual L_5 point, but as you can see, it's really a rather large area of stability. The L_4 plateau is obscured in the background, but L_3 is on the ridge opposite the Moon, L_1 on the ridge between the Earth and Moon, and L_2 is on the next ridge to the right. The contours defined, rather incidentally, by the digitization of computer graphics, delineate the boundaries of equal potential. Note that these potentials only apply for objects rotating with the system.

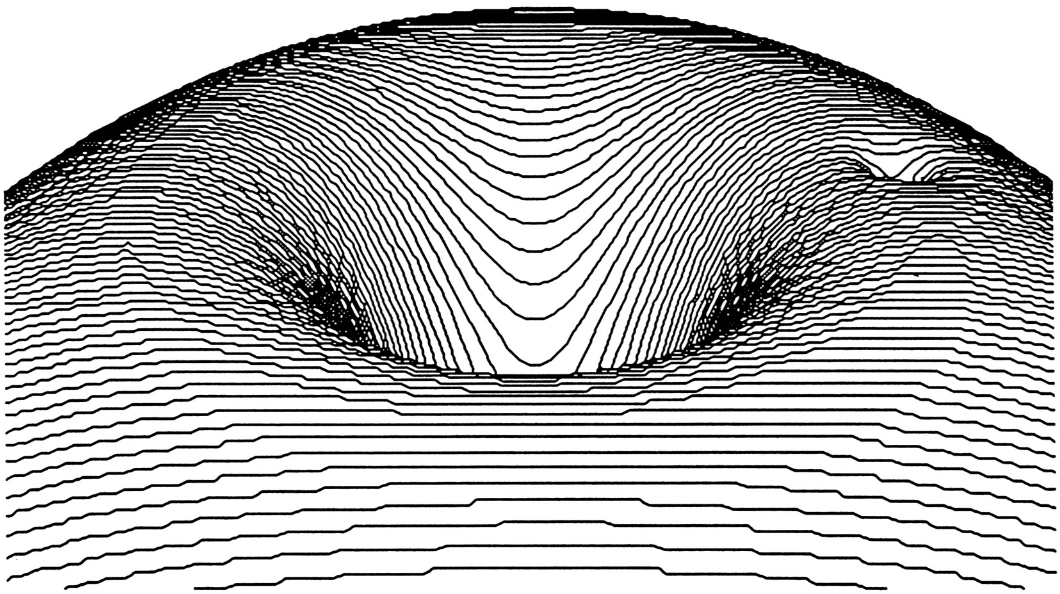


Fig. 19 Potential in the Rotating Earth-Moon System

These libration points are interesting and useful places. The Trojan Asteroids for example, inhabit the L_4 and L_5 points of the Sun-Jupiter system while the L_4 and L_5 points of the Earth-Moon system have been proposed as locations for large Lunar material processing stations with L_2 as a transfer point for material launched from the Moon. The L_1 point between the Sun and the Earth was, until 1982, inhabited by the spacecraft ISEE-C (the third **I**nternational **S**un-**E**arth **E**xplorer) since at that location it could gather data on the solar wind before its interaction with the Earth's magnetic field. It was held there by periodic impulses from its hydrazine jet thrusters. The rest of the story of ISEE-C is related in Appendix B of this manual.

Appendix A

Basic Equations of Orbital Mechanics

"That one body may act upon another at a distance through a vacuum, without the mediation of any thing else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity, that I believe no man, who has in philosophical matters a competent faculty of thinking, can ever fall into it."

Sir Isaac Newton

Truth, in the philosopy of nature, comes in stages. Newton did not believe that a force could act at a distance, but he had to accept this assumption as a part of a theory that works. Einstein on the other hand, grew up in a time when there was no denying that force could act at a distance, owing to the success of Newton's theory. But Einstein discovered that what we perceive as force can be explained as an effect of the curvature of the geometry of space-time by matter, so that forces really don't act at a distance, since there aren't any forces to begin with!

And yet, we do perceive forces, and Newton's theory does work, most of the time. In fact, we can derive Newton's Theory of Universal Gravitation from Einstein's General Theory of Relativity by choosing the proper space-time frame of reference, and making certain approximations. For most of the problems of orbital mechanics, Newton's theory is more useful than Einstein's because of its relative simplicity, and because it only begins to break down in extreme circumstances.

The orbit of Mercury for example, being very close to a large mass (the Sun) and having a high eccentricity (for a planet), is the most likely candidate in this Solar System for observation of relativistic effects. Newton's theory can account for all of the motions of Mercury except for about 43 arc seconds per century in the precession of the perihelion of its orbit. An arc second is one sixtieth of an arc minute which is in turn one sixtieth of a degree. In a hundred years Mercury will orbit the Sun about 415 times which means it will travel through about 1494 degrees so the error of Newton's theory is around 8 millionths of a percent in this case, but it is much, much less for most other cases.

Newton's Universal Law of Gravitation, stated in words, is:

> Each particle of matter attracts every other particle with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

In mathematical terms,

$$F = -G\, m_1\, m_2 / r^2$$

where F is the force on each of the particles, G is the gravitational constant, m_1 and m_2 are the masses of the first and second particle, and r is the distance separating them. To get the acceleration of a particle, we divide the force acting upon it by its mass so that,

$$a_1 = F/m_1 = -G\, m_2 / r^2,$$
$$a_2 = F/m_2 = -G\, m_1 / r^2.$$

The magnitude of G is such that the gravitational acceleration on two people embracing is of the order of 10^{-8} m/s^2, the acceleration of the Earth by a human on its surface is around 10^{-23} m/s^2, and the acceleration of any object on the surface of the Earth is about 10 m/s^2. Normally, orbited bodies are many orders of magnitude more massive than any manmade object that might be orbiting them, so in orbital mechanics the acceleration of the orbited body by a ship or station is disregarded. A very large space station, however, would have a nondisregardable effect on nearby objects, and upon its own structure, but still no measurable effect on the Earth or Moon.

At any rate, the general equations of motion for a particle over some time interval Δt are,

$$x = x_0 + v_x \Delta t + a_x \Delta t^2 \qquad (1.1)$$

$$y = y_0 + v_y \Delta t + a_y \Delta t^2 \qquad (1.2)$$

where in orbital mechanics, if r is the distance from the center of attraction, that is, $r = \sqrt{(x^2+y^2)}$, then the velocity is,

$$v_x = v_{x0} + a_x \Delta t \; x/r \qquad (2.1)$$

$$v_y = v_{y0} + a_y \Delta t \; y/r \qquad (2.2)$$

and the acceleration is,

$$a_x = -Gm_1 x/r + T_x/m_2 \qquad (3.1)$$

$$a_y = -Gm_1 y/r + T_y/m_2 \qquad (3.2)$$

where m_1 is the mass of the orbited body, m_2 is the mass of the ship, and Tx,Ty is the thrust decomposed into its Cartesian coordinate components. Actually, we ought to include a term in the acceleration equations to take into account the loss of mass due to thrusting, but this is disregarded in **Orbital Mech** to simplify matters.

Now, if we start out at some position X_0,Y_0 with an initial velocity Vx_0,Vy_0 and we find the acceleration by equations 3, and then if we crank through equations 1 for some noninfinitesimal Δt, we find X_1,Y_1, the position after Δt. When we now calculate the acceleration at X_1,Y_1, we find that it is different than it was at X_0,Y_0, which means that it must have been different at any point between the two points, since it must have changed gradually, and this means that our equations were only valid at X_0,Y_0, which means that they are only valid for an infinitesimal Δt.

So, with an infinitesimal Δt, the equations will work, since the acceleration is constant over that time period, but it wil take us Forever to trace the position over any noninfinitesimal time period! It was for just such problems that Newton invented the Calculus, by which means it is possible to tame the infinite and infinitesimal. But solution by means of analytical integration here would be exceedingly complicated since we desire to have interactive rocket thrusting, and we would have to resort to iterative solutions anyway to simulate a binary system, so we invoke a form of Occam's Razor,

"Never complicate matters beyond necessity."

Since our purpose is simply to illuminate the nature of orbital motions rather than to plan a trip to Pluto, we will solve our problem with a good approximation, iterating with our simple equations, instead of attempting an exact solution.

Figure 20 shows the results of approximating with a rather large Δt. The calculated orbit is shown with a bold line and the points between succesive Δt's are marked with short horizontal lines. As you can see, the approximation is not very good for large Δt, but the trajectory does curve a little, so it appears we are on the right track.

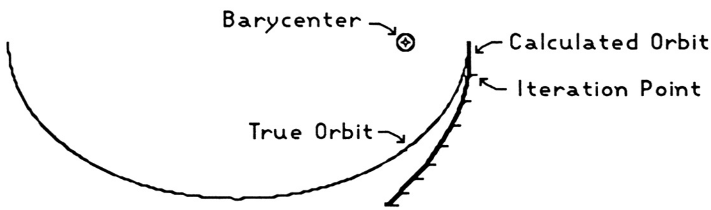


Fig. 20 Iterative Approximation with Large Δt

In figure 21, Δt is half as large, so there are twice as many points to calulate, and the approximation shows signs of improvement.

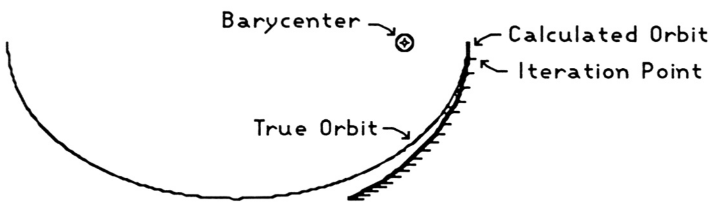


Fig. 21 Iterative Approximation with Smaller Δt

Clearly then, as Δt gets smaller the approximation will come closer to the real, and our task now is to find a Δt small enough to give a good enough approximation while large enough to allow for smooth animation, which depends to a large extent on the speed of the computer on which the program will be run. Fortunately, the Mac is fast enough to allow this to happen.

Speaking of approximations, we have also been approximate in our analysis thus far, leaving out some important details to make others stand out more clearly. It so happens, that halving the mass of the attractive body, or increasing the distance from it by a factor of the square root of 2, will have exactly the same effect on the sort of error we have been discussing, as halving the interval Δt does. Likewise, increasing the mass or getting closer to it will have deleterious effects on the accuracy of our calculations.

Therefore, a close in orbit about a very massive body at a "fast" speed setting will hardly be accurate at all, so you may want to avoid this except for laughs. One thing you will notice about a very eccentric orbit with a moderately large Δt and a moderately sized body, is that the perifocus of the orbit precesses, but otherwise the orbit seems well behaved. If you like, you may imagine this to be a relativistic effect as mentioned previously in connection with the orbit of Mercury, though it's really just an artifact of the chosen method of orbital calculation.

Appendix B

A Brief History of a Satellite

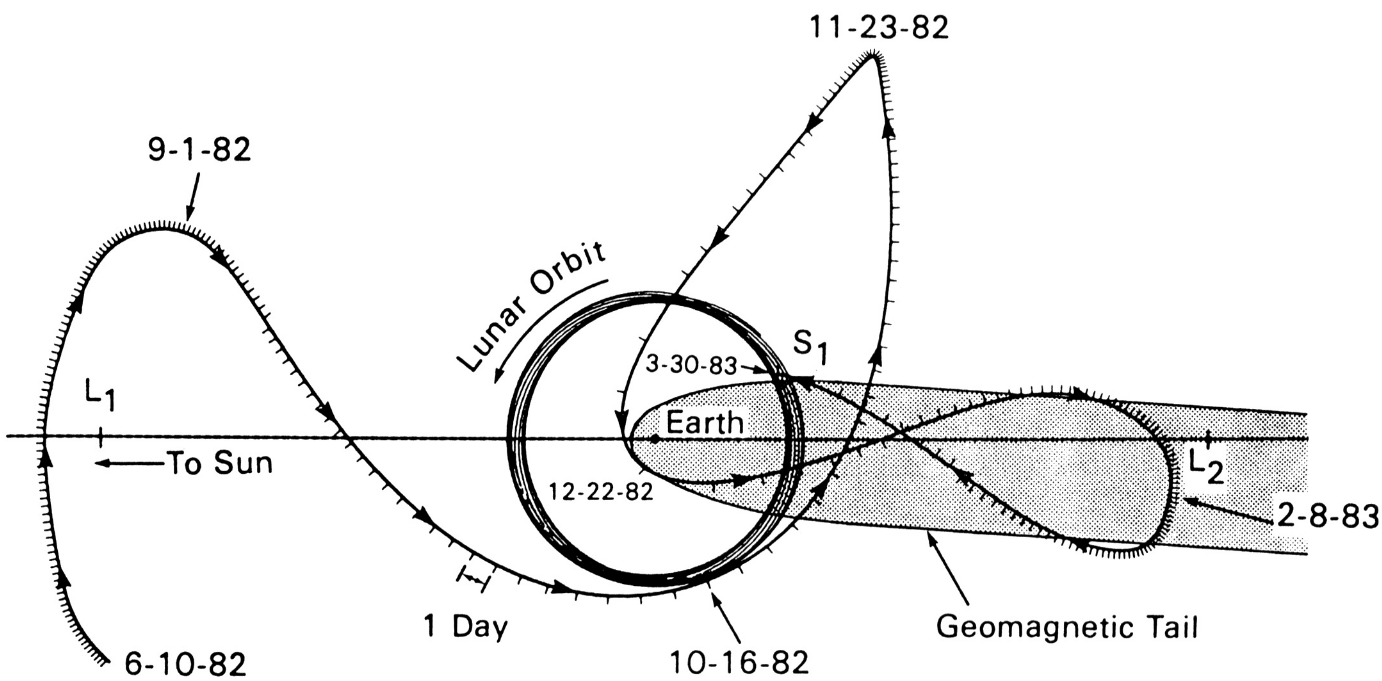
As mentioned in the body of this text, ISEE-C was a spacecraft carrying instruments designed to aid in the study of the solar wind. All of the Comet Halley probes carried similar instruments to gather data on the particles emitted by the comet. When these probes passed through the tail of the comet, there would not be much time to adjust their instruments for maximum accuracy. They were calibrated to measure within the ranges predicted by theory, but as these were to be the first cometary probes, the validity of the theory was not very certain.

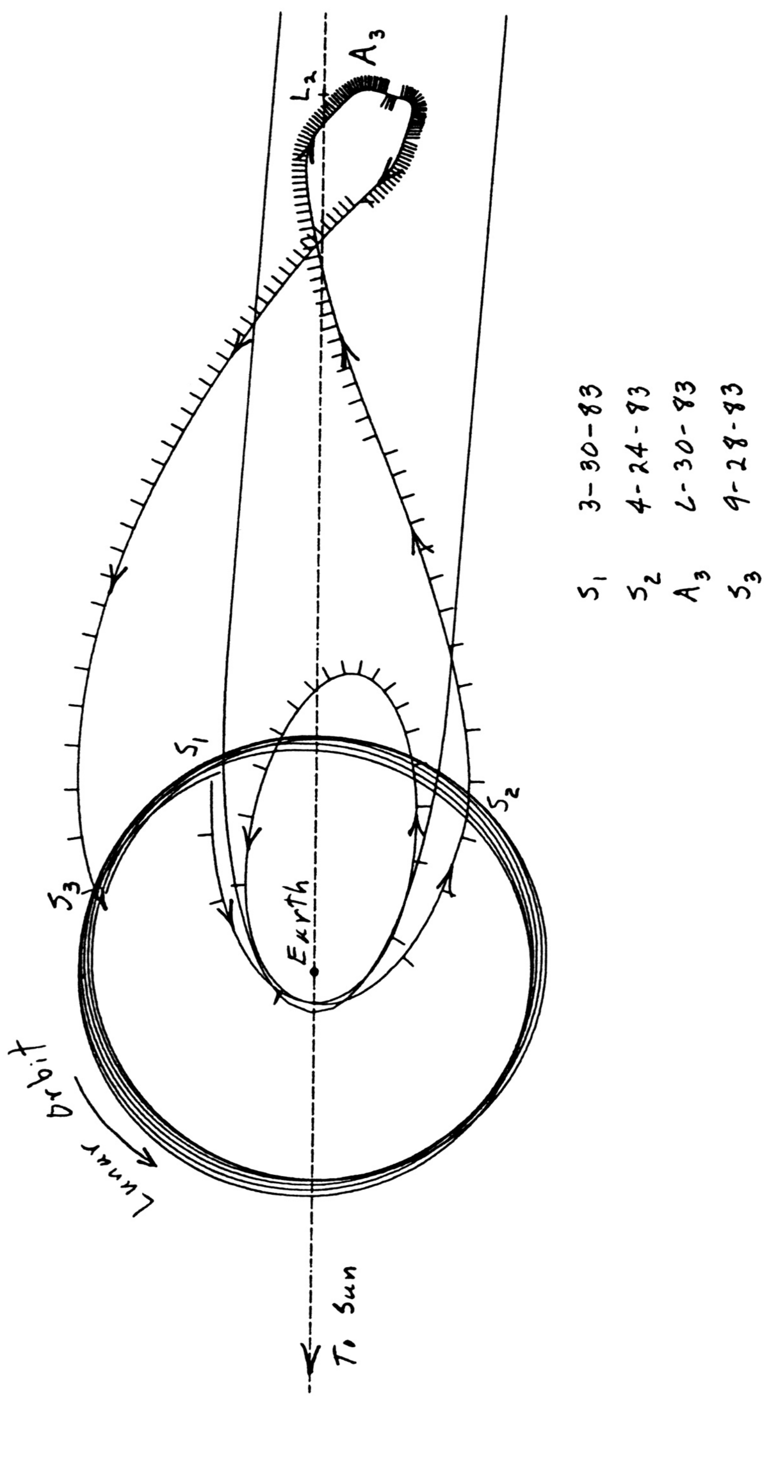
It so happened that the Comet Giacobini-Zinner, a comet smaller than Halley, and with a 13 year period, was to pass this way shortly before Halley was to do so. By 1981, ISEE-C had already completed its mission, it still had plenty of fuel, its instruments were still working, and it was already way out in space. So its thrusters were commanded to boot it onto a path that would take it around the Earth-Moon system five times while it built up enough speed to slingshot out towards rendezvous with Giacobini-Zinner. When it left the Earth-Moon system its name was changed to ICE (International Cometary Explorer) and it became the first spacecraft to pass through the tail of a comet, and to send back information regarding the nature of comets, on the 11th of September, 1985. This information was then used to calibrate the instruments on the Halley probes.

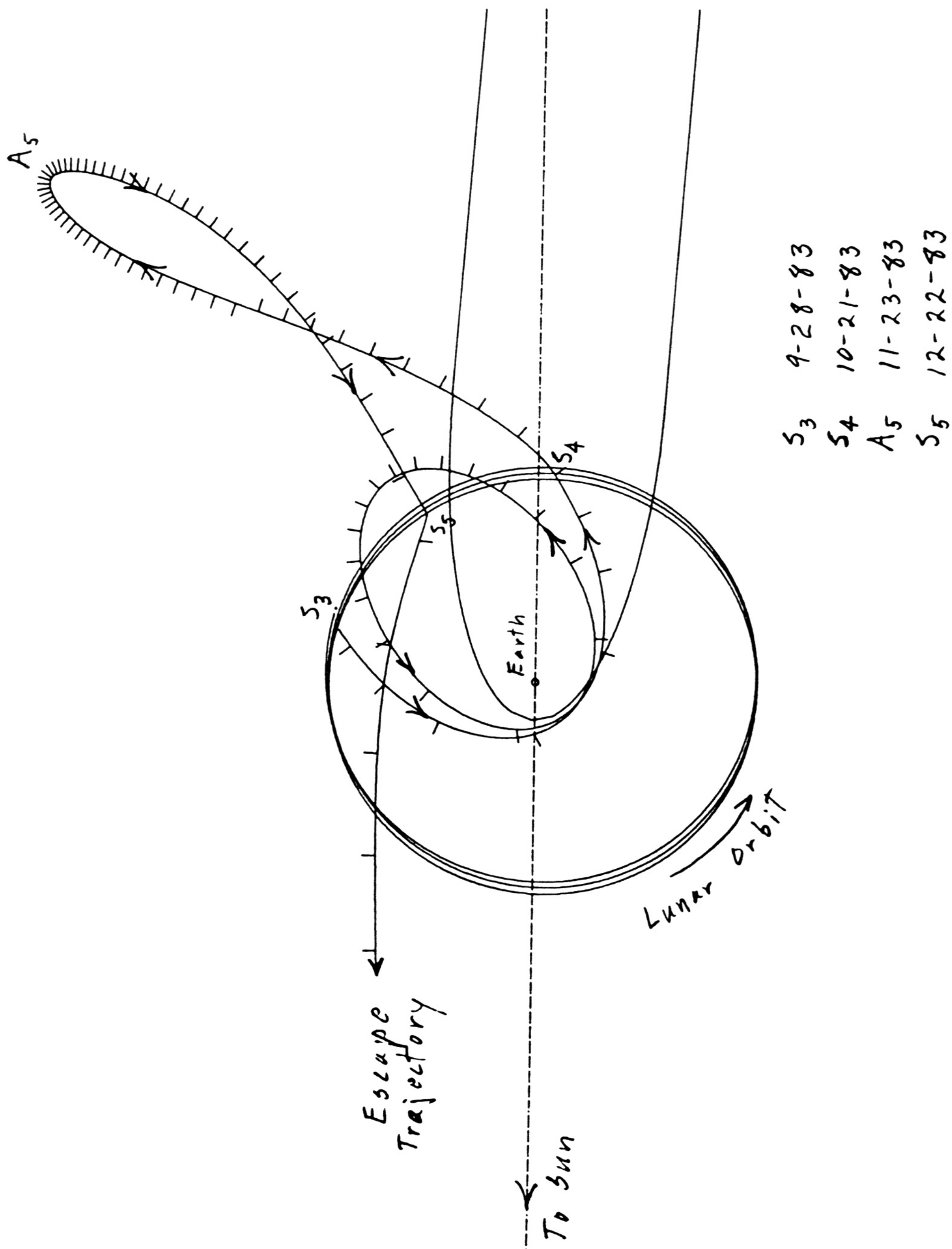
The following figures from the Goddard Spaceflight Center show the trajectory of ISEE-C. The first figure shows the trajectory from the deorbit burn to the first Lunar swing-by, the point labeled S_1. The tickmarks along the path of the spacecraft indicate the distance traversed each day. The second figure picks up at S_1, and shows the flight path through S_3, the third Lunar swing-by. The third figure picks up at S_3, and goes though the escape from the Earth-Moon system at S_5. Note the strong kink at S_5 indicating a very close approach to the Moon.

The fourth figure in this series shows the orbit of ISEE-C over the four and a half years following its escape from the Earth-Moon system. The orbit is elliptical with a somewhat greater eccentricity than the Earth's orbit, and with a period of 354 days. In the figure the orbit looks curlycued because it is shown relative to a fixed Earth-Sun line. Since its period is a bit shorter than the Earth's, it advances relative to this line through most of its orbit, but near to its aphelion the spacecraft's angular velocity is lower than the Earth's, so its motion near aphelion is retrograde relative to the fixed Earth-Sun line. Over the four year span, the aphelion of the orbit is in September while the perihelion is in March.

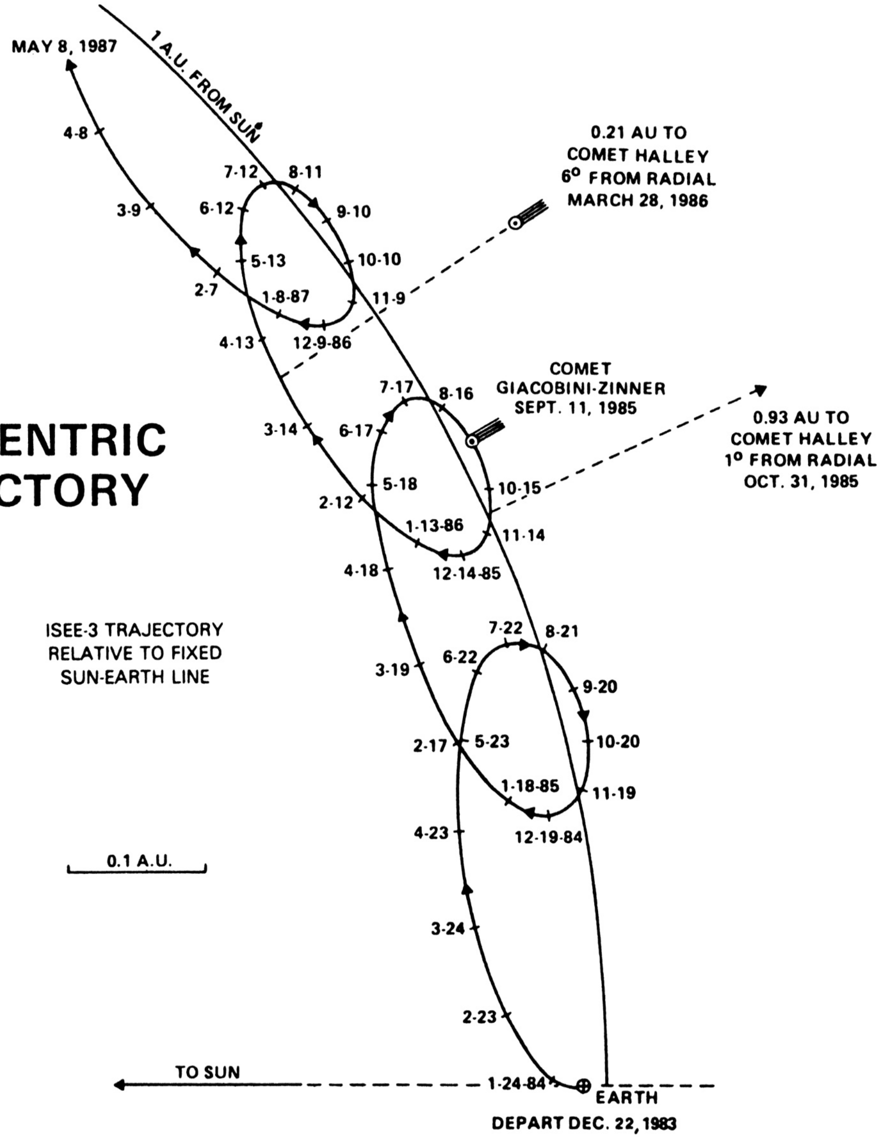
TRANSFER FROM L1 HALO ORBIT TO GEOMAGNETIC TAIL




A3
L2
S1
S2
S3
Earth
Lunar Orbit
To Sun
S1 3-30-83
S2 4-24-83
A3 6-30-83
S3 9-28-83


A5
S3 9-28-83
S4 10-21-83
A5 11-23-83
S5 12-22-83
S3
S4
S5
Earth
Lunar Orbit
Escape Trajectory
To Sun

HELIOCENTRIC TRAJECTORY



Appendix C

Units

When work on **Orbital Mech** first began, we had the notion that it would be a space *craft* simulator which would go into great detail about manned or man-in-the-loop spacecraft, present and proposed. We realized during development however, that instead we were really interested in orbital space flight rather than spacecraft per se, and that the minutiae of the craft impeded our enjoyment of the flight. We then set out to make an orbital space *flight* simulator, with minimal reference to the technological aspects of such flight, and which would convey our message in a more abstract than concrete way.

As the technology of the craft was abstracted, so also was the scale of the craft to its environment, and the scaling was chosen so as to optimize the educational and entertainment value of the program. The **Orbital Mech** world is therefore a world unto itself, with an abstract relationship to the real world, and this is why we have invented the **Orbital Mech** world units mentioned briefly on page 29 of this manual.

Again, **Orbital Mech** units are:

OMsecs - Units of time. The real time taken by these units varies depending on the ΔT setting (refer to Simulation Menu), and on the compute burden, which becomes greater as objects are added to the environment and is much larger during docking maneuvers.

OMmeters - Units of distance.

OMvels - Units of velocity.

Appendix D

Copyright

Software piracy – the illegal copying of software for use by people who have not purchased the sofware – is theft of intellectual property. We recently read an editorial which stated that some people don't know that software piracy is wrong. We can only conclude that such people cannot or do not read, since so much has been written on the subject, and if this is so, they probably will not read this appendix to find out why it is wrong.

Nevetheless, we have it in our mind that most people do read, that most people are honest, and that most would welcome a few words of moral support to help them muster the courage of their convictions in times of dire temptation. We have ourself been tempted on occaision, even by respected friends, and so understand the delicacy of such matters, and the uneasiness engendered by such situations.

Difficult problems in politeness and polemics beset us whether we are tempted by a an unenlightened friend or a seasoned pirate. "How can I say no without implying I think this person a sleazy, thieving scumbag? If I say no, will this person label me a 'dupe of the running-dog capitalists', or worse yet, an old fuddy-duddy? etc., etc." We could exhort you to "Just say no" as the recent anti-drug campaign puts it, but the dangers of drug abuse are all too apparent, while the dangers of illicit software copying do not seem so clear to everyone that they will accept 'no' without argument. So we shall provide you with some ammunition with which to gird your defense.

At the heart of the argument against software piracy lies the fact that every illegal copy cheats the author of the software out of rightful remuneration for a job well done (if it were not done well, nobody would copy it). This ought to be enough for most people, but some software pirates are particularly persistent and may not be convinced that intellectual property is at least as valuable as physical property, so we must elaborate further. We do so by means of analogy to physical property in the following list which was part of a letter written by Brian Dougherty and is reprinted here by permission of the editors of the magazine **IEEE Spectrum**.

- *Rationalization:* I only pirate software I wouldn't otherwise purchase.
  Analogy: The next time I'm in a grocery store, I will feel free to steal a bag of chocolate chip cookies since I was not planning to buy any.
- *Rationalization:* Software costs too much. Software vendors make too much profit per package. It's all right to steal a few.
  Analogy: Chocolate chip cookies cost too much. Their vendors make too much money on each bag. It's all right to steal a bag.
- *Rationalization:* There are a lot of software packages that don't live up to my expectations. Before purchasing a product, I should be able to get a copy to try out.
  Analogy: There are new chocolate chip cookies coming on the market constantly. Some may not live up to my expectations. I should feel free to steal a package to see if I like the product.
- *Rationalization:* I only pirate software that I don't use very often. Since I'm not getting the full value of the software, I don't feel I should pay for it.
  Analogy: I really don't eat chocolate chip cookies very often. I should feel free to steal a package since I may not get "full value" from it.

Most people who pirate software wouldn't steal a bag of chocolate chips from a grocery store even if they knew they wouldn't be caught. They understand and respect a person's right to own tangible property, but have not yet extended that understanding or that respect to include intellectual property. Perhaps the chocolate chip analogy will help them to understand.

If the pirate is still not deterred, try the following paragraph.

If authors of software cannot be assured of just compensation for their work, they will not produce even mediocre software, but will simply seek another line of business. Conversely, the more authors believe they might be richly rewarded for their work, the more likely they will be to make the effort to create excellent or even truly great software. Thus software piracy which cheats the author out of compensation, eventually cheats society out of great, then excellent, then good software so that soon there is no software worth copying. Software piracy then, is a crime against the whole of society, including you and the software pirate to boot.

If that's still not enough, then you'll just have to get downright legalistic with them. The fact is that software piracy is illegal. Every nation in the world has laws to deal with copyright infringement and software piracy is just that.

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Bibliography

The following is a list of a few books and publications on space, gravity, and other related topics.

Space

1. Office of Technology Assessment, *Civilian Space Stations and the U.S. Future in Space*. Washington, D.C.: U.S. Congress, OTA-STI-241, November 1984.
   Well written and more thoughtful than similar texts of the past. Covers the main technical issues surrounding the selection and acquisition of infrastructure in space and delves into the philosophical and moral questions regarding the direction of U.S. efforts in that area.

2. R.D. Johnson, ed.: *Space Settlements: A Design Study*. Washington, D.C.: Scientific and Technical Information Office, NASA SP–413, 1977.
   A detailed study of medium scale space habitation, written in a more exuberant time than the above, mostly by Gerard K. O'Neill.

N.B.: The U.S. Government Bookstore is fun place to shop.

Gravity

3. C.W. Misner, K.S. Thorne, J.A. Wheeler, *Gravitation*. San Francisco: W.H. Freeman and Company, 1973.
   An appropiately hefty work weighing in at about 6 lbs, this book contains everything you'd ever want to know about gravity from the point of view of General Relativity. There are enough mathematical equations here to frighten Albert Einstien himself, but a large part of it is devoted to excellent verbal and pictorial explanations of its mind-bending subject, as well as to short biographies of many of the great personages of physics.

4. Victor Szebehely, *Theory of Orbits: The Restricted Problem of Three Bodies*. New York: Academic Press, 1967.
   Dry and abstruse but a definitive text on the three body problem, with lots of neat pictures and diagrams.

5. Arthur I. Berman, *The Physical Principles of Astronautics.* New York: John Wiley & Sons, Inc., 1961.
An engineerring textbook on astronautics, somewhat old but still full of practical information on the subject. After all, the laws of physics never change, do they? Begins with a quote by Alfred North Whitehead: "Without Adventure, Civilisation is in full decay."

Physics

6. J.S. Trefil, *The Unexpected Vista: A Physicist's View of Nature.* New York: MacMillan, 1985.
Many people feel that knowledge of the physical world dissolves the mystery of life and hence the wonder to be found therein. But a profound sense of the mystery and wonder of the cosmos is part and parcel of a physicist's life. This book is yet another attempt to share this feeling with the layman, and it's a good one at that.

7. J. Walker, *The Flying Circus of Physics.* New York: John Wiley and Sons, 1977.
A sometimes maddening book, rather like having a four year old child around incessantly asking questions to which you think you ought to know the answers, especially if you're trained in physics! The latest edition has answers in the back, if you get <u>really</u> frustrated.

Glossary

apofocus The point in an orbit farthest from the barycenter.

apsidal longitude The angle from a vertical line (on the screen) to the line of apsides.

attractive body A body which attracts things to itself by virtue of relatively great mass. Actually, all physical entities exert attractive forces upon each other due to gravitation, but gravity is so weak that we usually only notice the force exerted by extremely large, nearby objects.

barycenter The focus of an orbital ellipse containing the attractive mass.

empty focus The focus of an orbital ellipse which does not contain the attractive mass.

line of apsides The line which runs through the perifocus, the barycenter, the empty focus, and the apofocus.

orbital longitude The angle from a vertical line (on the screen) to the object in orbit, with vertex at the barycenter.

perifocus The point in an orbit nearest to the barycenter.

primary focus See barycenter.

semimajor axis Half the length of the long axis of an ellipse.

semiminor axis Half the length of the short axis of an ellipse.

speed Scalar time rate of change of position. A body in a circular orbit has a constant speed, but its velocity changes constantly, e.g, on opposite sides of its orbit, it has equal speed but opposite velocity.

velocity Vector time rate of change of position: speed with direction. For example, two cars going in opposite directions may have the same speeds, but if so, the velocity of one is opposite the velocity of the other.

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