OUR RESTLESS TIDES

A BRIEF EXPLANATION OF THE BASIC ASTRONOMICAL FACTORS WHICH PRODUCE TIDES AND TIDAL CURRENTS

Chapter 1 - Introduction

The word "tides" is a generic term used to define the alternating rise and fall in sea level with respect to the land, produced by the gravitational attraction of the moon and the sun. To a much smaller extent, tides also occur in large lakes, the atmosphere, and within the solid crust of the earth, acted upon by these same gravitational forces of the moon and sun. Additional nonastronomical factors such as configuration of the coastline, local depth of the water, ocean-floor topography, and other hydrographic and meteorological influences may play an important role in altering the range, interval between high and low water, an times of arrival of the tides.

The most familiar evidence of the tides along our seashores is the observed recurrence of high and low water - usually, but not always, twice daily. The term tide correctly refers only to such a relatively short-period, astronomically induced vertical change in the height of the sea surface (exclusive of wind-actuated waves and swell); the expression tidal current relates to accompanying periodic horizontal movement of the ocean water, both near the coast and offshore (but as distinct from the continuous, stream-flow type of ocean current).

Knowledge of the times, heights, and extent of inflow and outflow of tidal waters is of importance in a wide range of practical applications such as the following: Navigation through intracoastal waterways, and within estuaries, bays, and harbors; work on harbor engineering projects, such as the construction of bridges, docks, breakwaters, and deep-water channels; the establishment of standard chart datums for hydrography and for demarcation of a base line or "legal coastline" for fixing offshore territorial limits both on the sea surface and on the submerged lands of the Continental Shelf; provision of information necessary for underwater demolition activities and other military engineering uses; and the furnishing of data indispensable to fishing, boating, surfing, and a considerable variety of related water sport activities.

Chapter 2 - The Astronomical Tide-Producing Forces: General Considerations

At the surface of the earth, the earth's force of gravitational attraction acts in a direction inward toward its center of mass, and thus holds the ocean water confined to this surface. However, the gravitational forces of the moon and sun also act externally upon the earth's ocean waters. These external forces are exerted as tide-producing, or so-called "tractive" forces. Their effects are superimposed upon the earth's gravitational force and act to draw the ocean waters to positions on the earth's surface directly beneath these respective celestial bodies (i.e., towards the "sublunar" and "subsolar" points).

High tides are produced in the ocean waters by the "heaping" action resulting from the horizontal flow of water toward two regions of the earth representing positions of maximum attraction of combined lunar and solar gravitational forces. Low tides are created by a compensating maximum withdrawal of water from regions around the earth midway between these two humps. The alternation of high and low tides is caused by the daily (or diurnal) rotation of the earth with respect to these two tidal humps and two tidal depressions. The changing arrival time of any two successive high or low tides at any one location is the result of numerous factors later to be discussed.

Origin of the Tide-Raising Forces

To all outward appearances, the moon revolves around the earth, but in actuality, the moon and earth revolve together around their common center of mass, or gravity. The two astronomical bodies are held together by gravitational attraction, but are simultaneously kept apart by an equal and opposite centrifugal force produced by their individual revolutions around the center-of-mass of the earth-moon system. This balance of forces in orbital revolution applies to the center-of-mass of the individual bodies only. At the earth's surface, an imbalance between these two forces results in the fact that there exists, on the hemisphere of the earth turned toward the moon, a net (or differential) tide-producing force which acts in the direction of the moon's gravitational attraction, or toward the center of the moon. On the side of the earth directly opposite the moon, the net tide-producing force is in the direction of the greater centrifugal force, or away from the moon.

Similar differential forces exist as the result of the revolution of the center-of-mass of the earth around the center-of-mass of the earth-sun system.

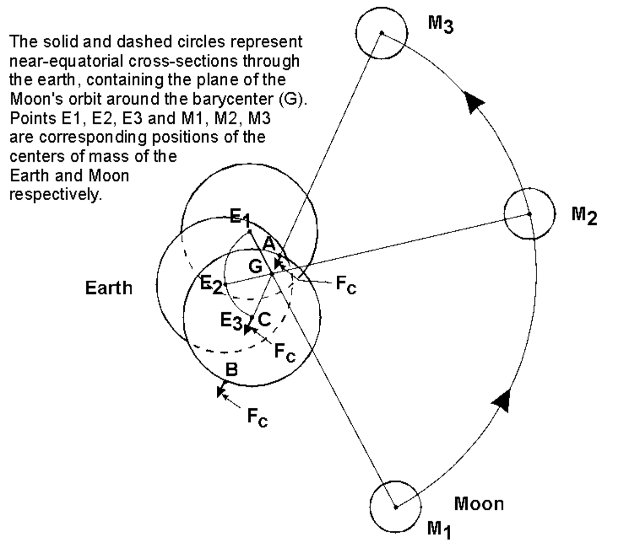

FIGURE 1
The Monthly Revolution of the Earth and Moon Around the Barycenter of the Earth-Moon System
This revolution is responsible for a centrifugal force component (Fc) necessary to the production of the tides. (Note that the earth revolves around G, but does not rotate around G. There is no monthly rotation of the earth as it revolves around the barycenter such that the same point on the earth's surface always faces the moon.)

Chapter 3 - Detailed Explanation of the Differential Tide Producing Forces

The tide-raising forces at the earth's surface thus result from a combination of basic forces: (1) the force of gravitation exerted by the moon (and sun) upon the earth; and (2) centrifugal forces produced by the revolutions of the earth and moon (and earth and sun) around their common center-of-gravity (mass) or barycenter. The effects of those forces acting in the earth-moon system will here be discussed, with the recognition that a similar force complex exists in the earth-sun system.

With respect to the center of mass of the earth or the center of mass of the moon, the above two forces always remain in balance (i.e., equal and opposite). In consequence, the moon revolves in a closed orbit around the earth, without either escaping from, or falling into the earth - and the earth likewise does not collide with the moon. However, at local points on, above, or within the earth, these two forces are not in equilibrium, and oceanic, atmospheric, and earth tides are the result.

The center of revolution of this motion of the earth and moon around their common center-of-mass lies at a point approximately 1,068 miles beneath the earth's surface, on the side toward the moon, and along a line connecting the individual centers-of-mass of the earth and moon. (see G, Fig. 1) The center-of-mass of the earth describes an orbit (E1, E2, E3..) around the center-of-mass of the earth-moon system (G) just as the center-of-mass of the moon describes its own monthly orbit (M1, M2, M3..) around this same point.

1. The Effect of Centrifugal Force. It is this little known aspect of the moon's orbital motion which is responsible for one of the two force components creating the tides. As the earth and moon whirl around this common center-of-mass, the centrifugal force produced is always directed away from the center of revolution. All points in or on the surface of the earth acting as a coherent body acquire this component of centrifugal force. And, since the center-of-mass of the earth is always on the opposite side of this common center of revolution from the position of the moon, the centrifugal force produced at any point in or on the earth will always be directed away from the moon. This fact is indicated by the common direction of the arrows (representing the centrifugal force Fc) at points A, C, and B in Fig. 1, and the thin arrows at these same points in Fig. 2.

It is important to note that the centrifugal force produced by the daily rotation of the earth on it axis must be completely disregarded in tidal theory. This element plays no part in the establishment of the differential tide-producing forces.

While space does not permit here, it may be graphically demonstrated that, for such a case of revolution without rotation as above enumerated, any point on the earth will describe a circle which will have the same radius as the radius of revolution of the center-of-mass of the earth around the barycenter. Thus, in Fig. 1, the magnitude of the centrifugal force produced by the revolution of the earth and moon around their common center of mass (G) is the same at point A or B or any other point on or beneath the earth's surface. Any of these values is also equal to the centrifugal force produced at the center-of-mass (C) by its revolution around the barycenter. This fact is indicated in Fig. 2 by the equal lengths of the thin arrows (representing the centrifugal force Fc) at points A, C, and B, respectively.

2. The Effect of Gravitational Force. While the effect of this centrifugal force is constant for all positions on the earth, the effect of the external gravitational force produced by another astronomical body may be different at different positions on the earth because the magnitude of the gravitational force exerted varies with the distance of the attracting body. According to Newton's Universal Law of Gravity, gravitational force varies inversely as the second power of the distance from the attracting body. Thus, in the theory of the tides, a variable influence is introduced based upon the different distances of various positions on the earth's surface from the moon's center-of-mass. The relative gravitational attraction (Fg) exerted by the moon at various positions on the earth is indicated in Fig. 2 by arrows heavier than those representing the centrifugal force components.

3. The Net or Differential Tide-Raising Forces: Direct and Opposite Tides. It has been emphasized above that the centrifugal force under consideration results from the revolution of the center-of-mass of the earth around the center-of-mass of the earth-moon system, and that this centrifugal force is the same anywhere on the earth. Since the individual centers-of-mass of the earth and moon remain in equilibrium at constant distances from the barycenter, the centrifugal force acting upon the center of the earth (C) as the result of their common revolutions must be equal and opposite to the gravitational force exerted by the moon on the center of the earth. This fact is indicated at point C in Fig. 2 by the thin and heavy arrows of equal length, pointing in opposite directions. The net result of this circumstance is that the tide-producing force (Ft) at the earth's center is zero.

At point A in Fig. 2, approximately 4,000 miles nearer to the moon than is point C, the force produced by the moon's gravitational pull is considerably larger than the gravitational force at C due to the moon. The smaller lunar gravitational force at C just balances the centrifugal force at C. Since the centrifugal force at A is equal to that at C, the greater gravitational force at A must also be larger than the centrifugal force there. The net tide-producing force at A obtained by taking the difference between the gravitational and centrifugal forces is in favor of the gravitational component - or outward toward the moon. The tide-raising force at point A is indicated in Fig. 2 by the double arrow extending vertically from the earth's surface toward the moon. The resulting tide produced on the side of the earth toward the moon is know as the direct tide.

At point B, on the opposite side of the earth from the moon and about 4,000 miles farther away from the moon than is point C, the moon's gravitational force is considerably less than at point C. At point C, the centrifugal force is in balance with a gravitational force which is greater than at B. The centrifugal force at B is the same as that at C. Since gravitational force is less at B than at C, it follows that the centrifugal force exerted at B must be greater than the gravitational force exerted by the moon at B. The resultant tide-producing force at this point is, therefore, directed away from the earth's center and opposite to the position of the moon. This force is indicated by the double-shafted arrow at point B. The tide produced in this location halfway around the earth from the sublunar point, coincidentally with the direct tide, is know as the opposite tide.

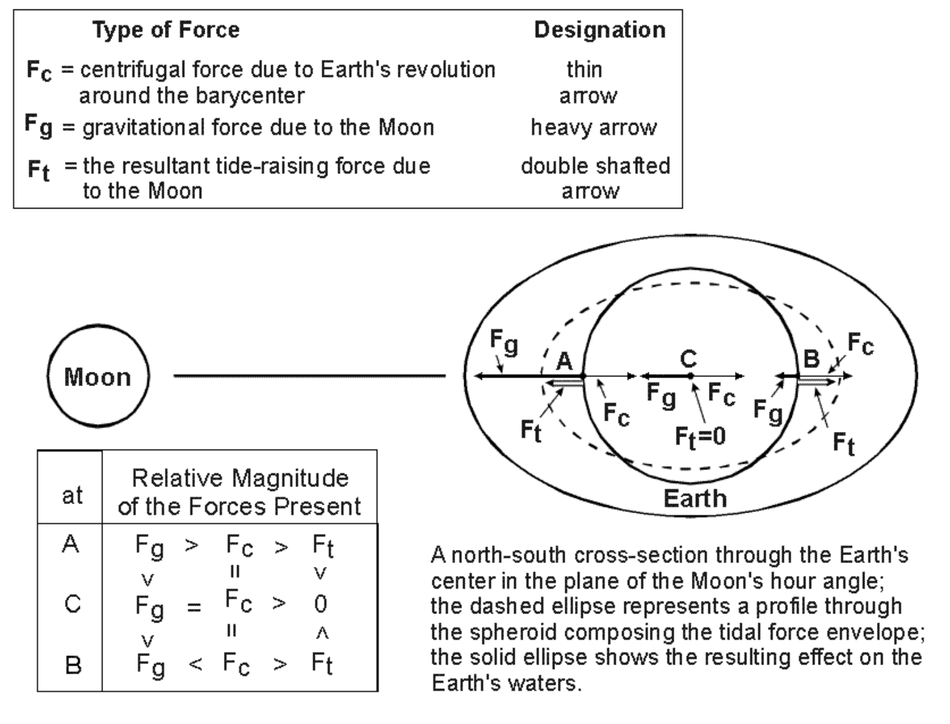

FIGURE 2
The Combination of Forces of Lunar Origin Producing the Tides
(A similar complex of forces exists in the Earth-Sun system)

4. The Tractive Force. It is significant that the influence of the moon's gravitational attraction superimposes its effect upon, but does not overcome, the effect's of the earth's own gravity. Earth-gravity, although always present, plays no direct part in the tide-producing action. The tide-raising force exerted at a point on the earth's surface by the moon at its average distance from the earth (238,855 miles) is only about one 9-millionth part of the force of earth-gravity exerted toward its center (3,963 miles from the surface). The tide raising force of the moon, is, therefore, entirely insufficient to "lift" the waters of the earth physically against this far greater pull of earth's gravity. Instead, the tides are produced by that component of the tide-raising force of the moon which acts to draw the waters of the earth horizontally over its surface toward the sublunar and antipodal points. Since the horizontal component is not opposes in any way to gravity and can, therefore, act to draw particles of water freely over the earth's surface, it becomes the effective force in generating tides.

At any point on the earth's surface, the tidal force produced by the moon's gravitational attraction may be separated or "resolved" into two components of force - one in the vertical, or perpendicular to the earth's surface - the other horizontal or tangent to the earth's surface. This second component, know as the tractive ("drawing") component of force is the actual mechanism for producing the tides. The force is zero at the points on the earth's surface directly beneath and on the opposite side of the earth from the moon (since in these positions, the lunar gravitational force is exerted in the vertical - i.e., opposed to, and in the direction of the earth-gravity, respectively). Any water accumulated in these locations by tractive flow from other points on the earth's surface tends to remain in a stable configuration, or tidal "bulge".

Thus there exists an active tendency for water to be drawn from other points on the earth's surface toward the sublunar point (A, in Fig. 2) and its antipodal point (B, in Fig. 2) and to be heaped at these points in two tidal bulges. Within a band around the earth at all points 90^{o} from the sublunar point, the horizontal or tractive force of the moon's gravitation is also zero, since the entire tide-producing force is directed vertically inward. There is, therefore, a tendency for the formation of a stable depression here. The words "tend to" and "tendency for" employed in several usages above in connection with tide-producing forces are deliberately chosen since, as will be seen below, the actual representation of the tidal forces is that of an idealized "force envelope" with which the rise and fall of the tides are influenced by many factors.

5. The Tidal Force Envelope. If the ocean waters were completely to respond to the directions and magnitudes of these tractive forces at various points on the surface of the earth, a mathematical figure would be formed having the shape of a prolate spheroid. The longest (major) axis of the spheroid extended towards and directly away from the moon, and the shortest (minor) axis is center along, at right angle to, the major axis. The two tidal humps and two tidal depressions are represented in this force envelope by the directions of the major axis and rotated minor axis of the spheroid, respectively. From a purely theoretical point of view, the daily rotation of the solid earth with respect to these two tidal humps and two depressions may be conceived to be the cause of the tides.

As the earth rotates once in each 24 hours, one would ideally expect to find a high tide followed by a low tide at the same place 6 hours later; then a second high tide after 12 hours, a second low tide 18 hours later, and finally a return to high water at the expiration of 24 hours. Such would nearly be the case if a smooth, continent-free earth were covered to a uniform depth with water, if the tidal envelope of the moon alone were being considered, if the positions of the moon and sun were fixed and invariable in distance and relative orientation with respect to the earth, and if there were no other accelerating or retarding influences affecting the motions of the waters of the earth. Such, in actuality, is far from the situation which exists.

First, the tidal force envelope produced by the moon's gravitational attraction is accompanied by a tidal force envelope of considerably smaller amplitude produced by the sun. The tidal force exerted by the sun is a composite of the sun's gravitational attraction and a centrifugal force component created by the revolution of the earth's center-of-mass around the center-of-mass of the earth-sun system, in an exactly analogous manner to the earth-moon relationship. The position of this force envelope shifts with the relative orbital position of the earth in respect to the sun. Because of the great differences between the average distances of the moon (238,855 miles) and sun (92,900,000 miles) from the earth, the tide producing force of the moon is approximately 2.5 times that of the sun.

Second, there exists a wide range of astronomical variables in the production of the tides caused by the changing distances of the moon from the earth, the earth from the sun, the angle which the moon in its orbit makes with the earth's equator, the superposition of the sun's tidal envelope of forces upon that caused by the moon, the variable phase relationships of the moon, etc. Some of the principle types of tides resulting from these purely astronomical influences are describe below.

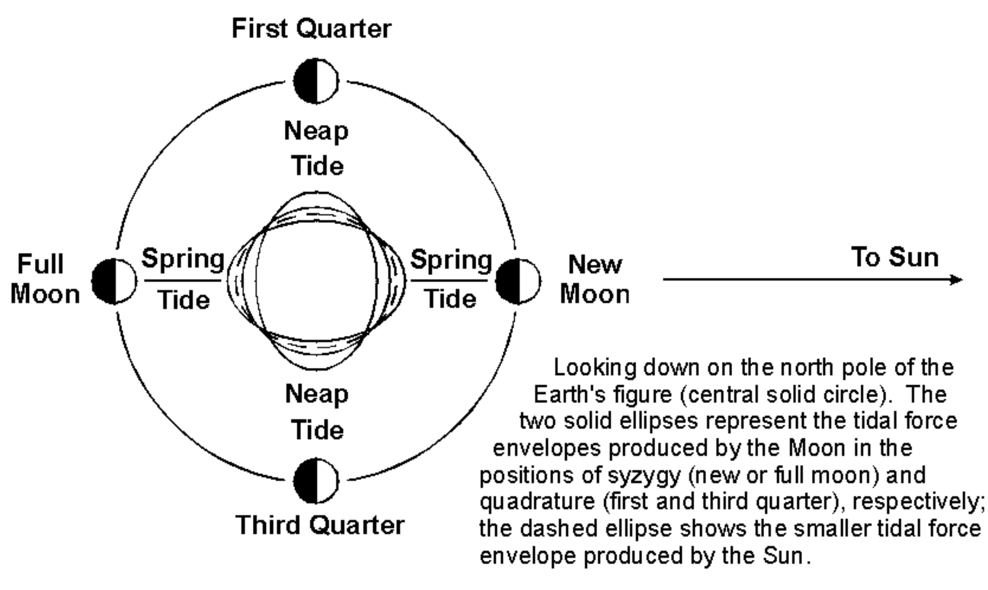

FIGURE 3
The Phase Inequality: Spring and Neap Tides
The gravitational attractions (and resultant tidal force envelopes) produced by the Moon and Sun reinforce each other at times of new and full moon to increase the range of the tides, and counteract each other at the first and third quarters to reduce the tidal range.

Chapter 4 - Variations in the Range of the Tides: Tidal Inequalities

As will be shown in Fig. 6, the difference in the height, in feet, between consecutive height and low tides occurring at a given place is known as the range. The range of the tides at any location is subject to many variable factors. Those influences of astronomical origin will first be described.

1. Lunar Phase Effect: Spring and Neap Tides. It has been noted above that the gravitational forces of both the moon and sun act upon the waters of the earth. It is obvious that, because of the moon's changing position with respect to the earth and sun (Fig. 3) during the monthly cycle of phases (29.53 days) the gravitational attraction of moon and sun may variously act along a common line or at changing angles relative to each other.

When the moon is at new phase and full phase (both positions being called syzygy) the gravitational attractions of the moon and sun act to reinforce each other. Since the resultant or combined tidal force is also increased, the observed high tides are higher and low tides are lower than average. This means that the tidal range is greater at all locations which display a consecutive high and low water. Such greater-than-average tides resulting at the syzygy positions of the moon are know as spring tides - a term which merely implies a "welling up" of the water and bears no relationship to the season of the year.

At first- and third-quarter phases (quadrature) of the moon, the gravitational attractions of the moon and sun upon the waters of the earth are exerted at right angles to each other. Each force tends in part to counteract the other. In the tidal force envelope representing these combined forces, both maximum and minimum forces are reduced. High tides are lower and low tides are higher than average. Such tides of diminished range are called neap tides, from a Greek word meaning "scanty".

2. Parallax Effects (Moon and Sun). Since the moon follows an elliptical path (Fig. 4), the distance between the earth and moon will vary throughout the month by about 31,000 miles. The moon's tide-producing force acting on the earth's waters will change in inverse proportion to the third power of the distance between the earth and moon, in accordance with the previously mentioned variation of Newton's Law of Gravitation. Once each month, when the moon is closest to the earth (perigee), the tide-generating forces will be higher than usual, thus producing above-average ranges in the tides. Approximately two weeks later, when the moon (at apogee) is farthest from the earth, the lunar tide-raising force will be smaller, and the tidal ranges will be less than average. Similarly, in the earth-sun system, when the earth is closest to the sun (perihelion), about January 2 of each year, the tidal ranges will be enhanced, and when the earth is farthest from the sun (aphelion), around July 2, the tidal ranges will be reduced.

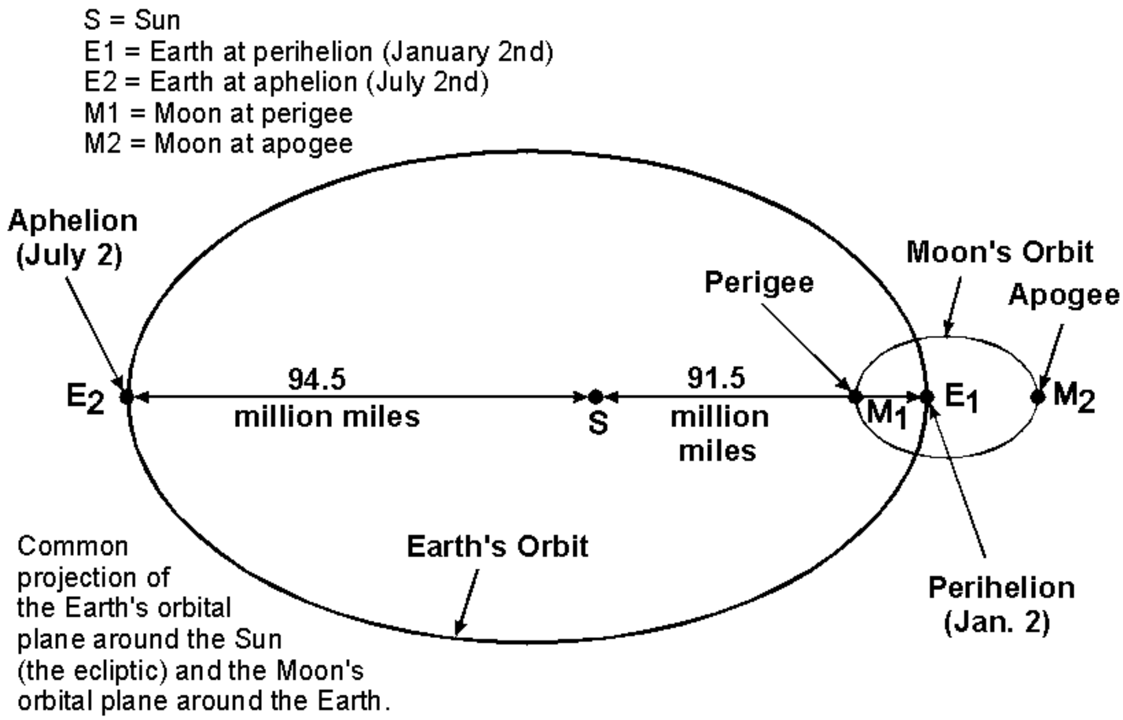

FIGURE 4
The Lunar Parallax and Solar Parallax Inequalities
Both the Moon and the Earth revolve in elliptical orbits and the distances from their centers of attraction vary. Increased gravitational influences and tide-raising forces are produced when the Moon is at position of perigee, its closest approach to the Earth (once each month) or the Earth is at perihelion, its closest approach to the Sun (once each year). This diagram also shows the possible coincidence of perigee with perihelion to produce tides of augmented range.

When perigee, perihelion, and either the new or full moon occur at approximately the same time, considerably increased tidal ranges result. When apogee, aphelion, and the first- or third-quarter moon coincide at approximately the same time, considerably reduced tidal ranges will normally occur.

3. Lunar Declination Effects: The Diurnal Inequality. The plane of the moon's orbit is inclined only about 5^o to the plane of the earth's orbit (the ecliptic) and thus the moon monthly revolution around the earth remains very close to the ecliptic. The ecliptic is inclined 23.5^o to the earth's equator, north and south of which the sun moves once each half year to produce the seasons. In similar fashion, the moon, in making a revolution around the earth once each month, passes from a position of maximum angular distance north of the equator to a position of maximum angular distance south of the equator during each half month. (Angular distance perpendicularly north and south of the celestial equator is termed declination.) twice each month, the moon crosses the equator. In Fig. 5, this condition is shown by the dashed position of the moon. The corresponding tidal force envelope due to the moon is depicted, in profile, by the dashed ellipse.

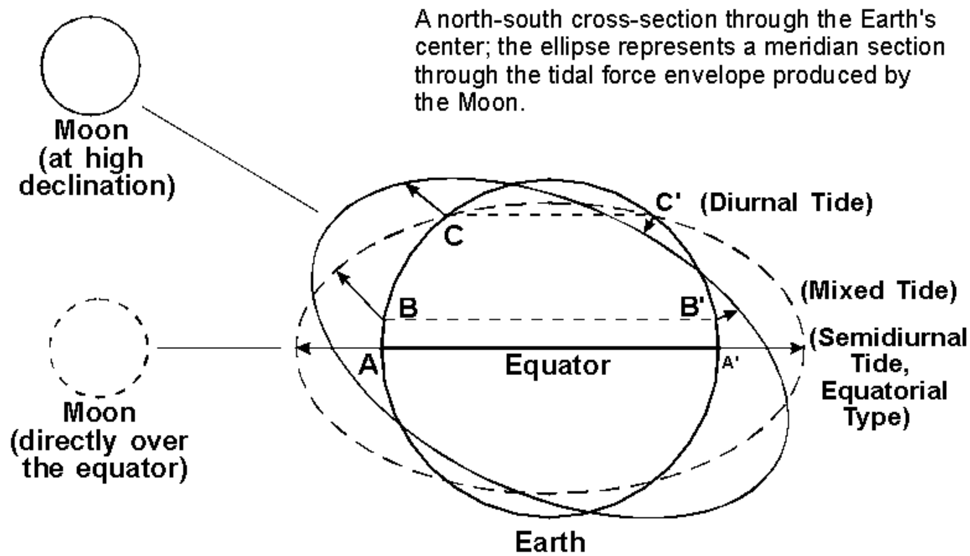

FIGURE 5
The Moon's Declination Effect (Change in Angle With Respect to the Equator) and the Diurnal Inequality; Semidiurnal, Mixed, and Diurnal Tides
A north-south cross-section through the Earth's center; the ellipse represents a meridian section through the tidal force envelope produced by the Moon.

Since the points A and A' lie along the major axis of this ellipse, the height of the high tide represented at A is the same as that which occurs as this point rotates to position A' some 12 hours later. When the moon is over the equator - or at certain other force-equalizing declinations - the two high tides and two low tides on a give day are at similar height at any location. Successive high and low tides are then also nearly equally spaced in time, and occur twice daily. (See top diagram in Fig. 6.) This is known as semidiurnal type of tides.
However, with he changing angular distance of the moon above or below the equator (represented by the position of the small solid circle in Fig. 5) the tidal force envelope produced by the moon is canted, and difference between the heights of two daily tides of the same phase begin to occur. variations in the heights of the tides resulting from the changes in the declination angle of the moon an in the corresponding lines of gravitational force action give rise to a phenomenon known as the diurnal inequality.

In Fig. 5, point B is beneath a bulge in the tidal envelope. One-half day later, at point B' it is again beneath the bulge, but the height of the tide is obviously not as great as at B. This situation gives rise to a twice-daily tide displaying unequal heights in successive high or low waters, or in both pairs of tides. This type of tide, exhibiting a strong diurnal inequality, is known as a mixed tide. (See the middle diagram in Fig. 6.)

Finally, as depicted in Fig. 5, the point C is seen to lie beneath a portion of the tidal force envelope. One-half day later, however, as this point rotates to position C', it is seen to lie above the force envelope. At this location, therefore, the tidal forces present produce only one high water and one low water each day. The resultant diurnal type of tide is shown in the bottom diagram of Fig. 6.

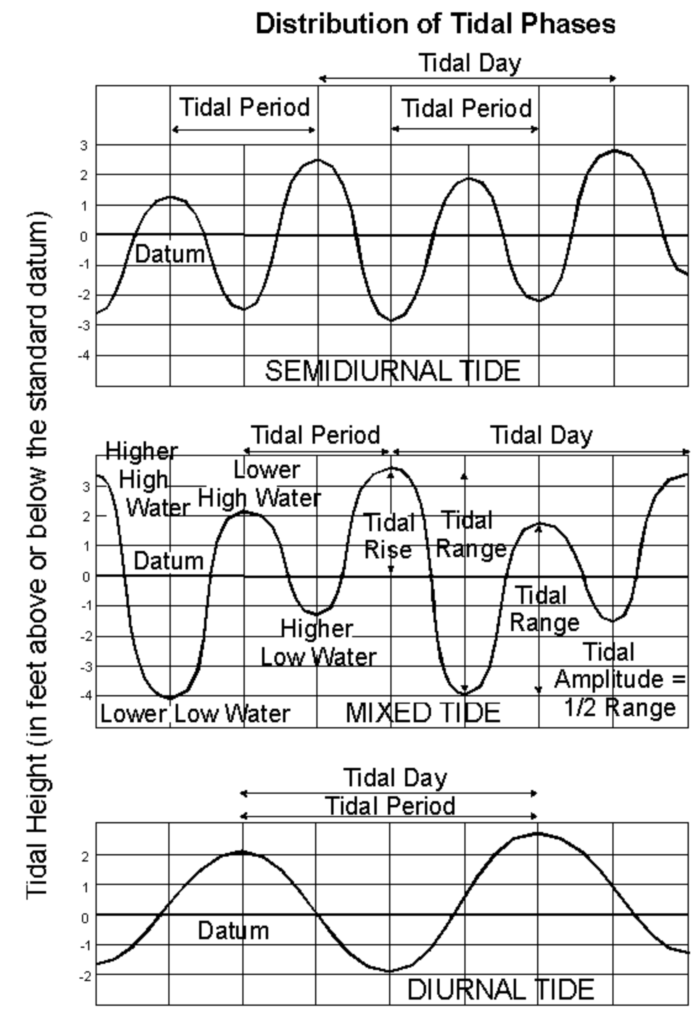

FIGURE 6
Principal Types of Tides
Showing the Moon's declinational effect in production of semidiurnal, mixed, and diurnal tides.

Chapter 5 - Factors Influencing the Local Heights and Times of Arrival of the Tides

It is noteworthy in Fig. 6 that any one cycle of the tides is characterized by a definite time regularity as well as the recurrence of the cyclical pattern. However, continuing observations at coastal stations will reveal - in addition to the previously explained variations in the heights of successive tides of the same phase - noticeable differences in their successive time of occurrence. The aspects of regularity in the tidal curves are introduced by harmonic motions of the earth and moon. The variations noted both in observed heights of the tides and in their times of occurrence are the result of many factors, some of which have been discussed in the preceding section. Other influences will now be considered.

The earth rotates on its axis (from one meridian transit of the "mean" sun until the next) in 24 hours. But as the earth rotates beneath the envelope of tidal forces produced by the moon, another astronomical factor causes the time between two successive upper transits of the moon across the local meridian of the place (a period known as the lunar or "tidal" day) to exceed the 24 hours of the earth's rotation period - the mean solar day.

The moon revolves in its orbit around the earth with an angular velocity of approximately 12.2° per day, in the same direction in which the earth is rotating on its axis with an angular velocity of 360° per day. In each day, therefore, a point on the rotating earth must complete a rotation of 360° plus 12.2°, or 372.2°, in order to "catch up" with the moon. Since 15° is equal to one hour of time, this extra amount of rotation equal to 12.2° each day would require a period of time equal to 12.2°/15° x 60 min/hr., or 48.8 minutes - if the moon revolved in a circular orbit, and its speed of revolution did not vary. On the average it requires about 50 minutes longer each day for a sublunar point on the rotating earth to regain this position directly along the major axis of the moon's tidal force envelope, where the tide-raising influence is a maximum. In consequence, the recurrence of a tide of the same phase and similar rise (see middle diagram of Fig. 6) would take place at an interval of 24 hours 50 minutes after the preceding occurrence, if this single astronomical factor known as lunar retardation were considered. This period of 24 hours 50 minutes has been established as the tidal day.

A second astronomical factor influencing the time of arrival of tides of a given phase at any location results from the interaction between the tidal force envelopes of the moon and sun. Between new moon and first-quarter phase, and between full moon and third-quarter phase, this phenomenon can cause a displacement of force components and an acceleration in tidal arrival times (known as priming the tides) resulting in the occurrence of high tides before the moon itself reaches the local meridian of the place. Between first-quarter phase and full moon, and between third-quarter phase and new moon, an opposite displacement of force components and a delaying action (known as lagging of the tides) can occur, as the result of which the arrival of high tides may take place several hours after the moon has reached the meridian.

These are the two principle astronomical causes for variation in the times of arrival of the tides. In addition to these astronomically induced variations, the tides are subject to other accelerating or retarding influences of hydraulic, hydrodynamic, hydrographic, and topographic origin - and may further be modified by meteorological conditions.

The first factor of consequence in this regard arises from the fact that the crests and troughs of the large-scale gravity-type traveling wave system comprising the tides strive to sweep continuously around the earth, following the position of the moon (and sun).
In the open ocean, the actual rise (see middle diagram, Fig. 6) of the tidally induced wave crest is only one to a few feet. It is only when the tidal crests and troughs move into shallow water, against land masses, and into confining channels, that noticeable variations in the height of sea level can be detected.

Possessing the physical properties of a fluid, the ocean waters follow all of the hydraulic laws of fluids. This means that since the ocean waters possess a definite, although small internal viscosity, this property prevents their absolute free flow, and somewhat retards the overall movement of the tides.

Secondly, the ocean waters follow the principle of traveling waves in a fluid. As the depth of the water shallows, the speed of forward movement of a traveling wave is retarded, as deducted from dynamic considerations. In shoaling situations, therefore, the advance of tidal waters is slowed.

Thirdly, a certain relatively small amount of friction exists between the water and the ocean floor over which it moves - again slightly slowing the movement of the tides, particularly as they move inshore. Further internal friction (or viscosity) exists between tidally induced currents and contiguous current in the oceans - especially where they are flowing in opposite directions.

The presence of land masses imposes a barrier to progress of the tidal waters. Where continents interpose, tidal movements are confined to separate, nearly closed oceanic basins and the sweeps of the tides around the world is not continuous.

Topography on the ocean floor can also provide a restraint to the forward movement of tidal waters - or create sources of local-basin response to the tides. Restrictions to the advance of tidal waters imposed both by shoaling depths and the sidewalls of the channel as these waters enter confined bays, estuaries, and harbors can further considerably alter the speed of their onshore passage.

In such particularly confined bodies of water, so-called "resonance effects" between the free-period of oscillation of the traveling, tidally induced wave and that of the confining basin may cause a surging rise of the water in a phenomenon basically similar to the action of water caused to "slosh" over the sides of a wash basin by repeatedly tilting the basin and matching wave crests reflected from the opposite side of the basin.

All of the above, and other less important influences, can combine to create a considerable variety in the observed range and phase sequence of the tides - as well as variations in the times of their arrival at any location.

Of a more local and sporadic nature, important meteorological contributions to the tides know as "storm surges", caused by a continuous strong flow of winds either onshore or offshore, may superimpose their effects upon those of tidal action to cause either heightened or diminished tides, respectively. High-pressure atmospheric systems may also depress the tides, and deep low-pressure systems may cause them to increase in height.

Chapter 6 - Prediction of the Tides

In the preceding discussions of the tide-generating forces, the theoretical equilibrium tide produced, and factors causing variations, it has been emphasized that the tides actually observed differ appreciably from the idealized, equilibrium tide. Nevertheless, because the tides are produced essentially by astronomical forces of harmonic nature, a definite relationship exists between the tide-generating forces and the observed tides, and a factor of predictability is possible.

Because of the numerous uncertain and, in some cases, completely unknown factors of local control mentioned above, it is not feasible to predict tides purely from a knowledge of the positions and movements of the moon and sun obtained from astronomical tables. A partially empirical approach based upon actual observations of tides in many areas over an extended period of time is necessary. To achieve maximum accuracy in prediction, a series of tidal observations at one location ranging over at least a full 18.6-year tidal cycle is required. Within this period, all significant astronomical modifications of tides will occur.

Responsibility for computing and tabulating - for any day in the year - the times, heights, and ranges of the tides - as well as the movement of tidal currents - in various parts of the world is vested in appropriate governmental agencies which devote both theoretical and practical effort to this task. The resulting predictions are based in large part upon actual observations of tidal heights made throughout a network of selected observing stations.

The National Ocean Survey, a component of the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce, maintains for this purpose a continuous control network of approximately 140 tide gages which are located along the coasts and within the major embayments of the United States, and it possessions, and the United Nations Trust Territories under its jurisdiction. Temporary secondary stations are also occupied in order to increase the effective coverage of the control network. Predictions of the times and heights of high and low water are prepared by the National Ocean Survey for a large number of stations in the United States and its possessions as well as foreign countries and United Nations Trust Territories.

Source: http://tidesandcurrents.noaa.gov/restles1.html