# Moon Phases and Tides in the Planning the D-Day Invasion
# Part II: The Moon and the Tides

**Objectives:**

1. The student will determine the nature of tides, and their relation to the moon.

2. Given some facts about the invasion plan, students will determine when the tides would be best for determining D-Day.

3. After being given a hypothetical first day of readiness, students will determine a hypothetical calendar date for the beginning of the actual invasion based on both the phases of the moon and the tides.

**Directions:**

1. Allow students to read the introduction to "The Moon and the Tides." Answer any questions and allow them to answer the accompanying questions, and to complete the data table.

2. Review the facts about the invasion plan, and critique students' choices for the best set of tidal conditions during which to invade.

3. Critique students' choices for the best calendar date during which to invade.

**Assessment:**

Components for assessment include the answers to questions, completion of the data table and participation in class discussions.

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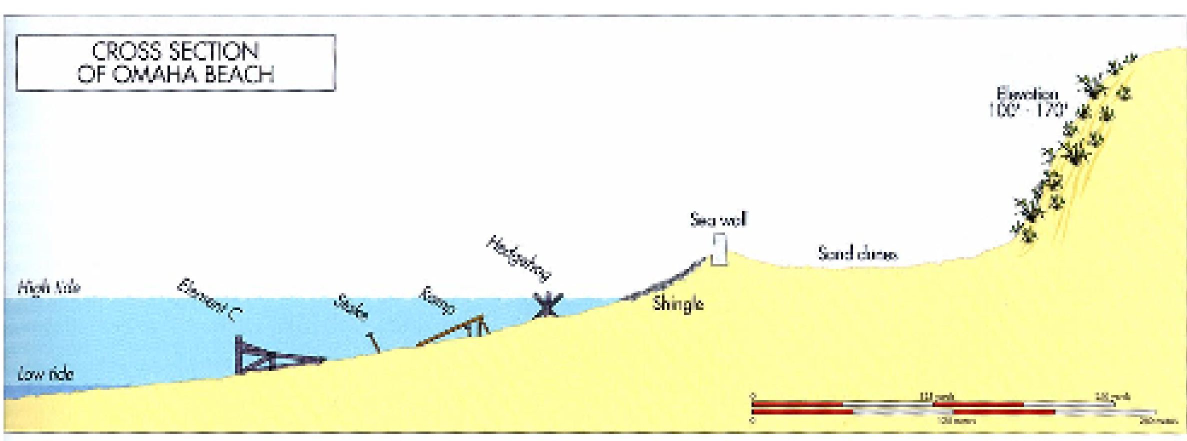
## Part II: The Moon and the Tides

**Introduction:** The D-Day invasion of June 6, 1944 has been called the climatic battle of World War II. It was probably the most carefully planned and executed military operation in history. It consisted of a combined amphibious and aerial assault across the English Channel against the beaches of France, which had been occupied be the German Nazis since 1940. The Supreme Commander of Allied forces was American general (and later president) Dwight D. Eisenhower.

In addition to numerous political and military advisers, Eisenhower was guided in his choice of an invasion time and date by a team of astronomers and meteorologists. Why was their advice important? The Allied invasion was scheduled to begin by an aerial attack by paratroopers and glider-borne troops whose job it would be to land to the rear of the beaches, disrupt German communications and to seize roads and bridges to prevent a German counter attack. This air attack was scheduled to begin at about midnight on the night before the beach landings, which were scheduled to begin at the first light of dawn.

Part I of this exercise dealt with the timing of the invasion and the phases of the moon. If you worked through that exercise you probably concluded that the invasion would best be accompanied by a full moon, which, in fact, it was. There was another factor, however, perhaps more important that the phases of the moon, namely, the tides.

The German commanding general, Erwin Rommel, assumed that the invasion would come at the time of a high tide. This was because then the distance from the shore to the first available cover, which the invading troops would have to cross under German fire, would be minimal. Actually, as it turned out, the conditions that the Allies wanted were just the opposite: low tide at dawn. This requirement had to do with the nature of the German defenses along the beaches of Western Europe. The Germans had built an extensive line of fortifications along the beaches that included bunkers, barbed wire, mine fields, and anti-tank ditches. Their defenses also included tens of thousands of beach obstacles meant to stop Allied landing craft. At low tide, these obstacles were fully exposed on dry beaches, posing no threat to approaching landing craft. But at high tides, these obstacles would be partially or fully submerged, posing a great danger to approaching landing craft. [See schematic below]



Allied commanders planned to flood the invasion zone with 150,000 soldiers, who would arrive on the beaches on specially-designed landing craft. These boats—called LCVPs, for Landing Craft Vehicle Personnel—were made to run directly onto the beaches, drop a ramp in the front of the boat onto the shore, and discharge the troops. Ideally, once this was done, the ramp could be lifted, and the landing craft could back out, and return to larger ships well offshore and load up for a second run. [See images 1 and 2] If these boats came in at high tide, many would be destroyed by the underwater obstacles.

*Image 1: LCVP with ramp up, approaching beach, showing sea bottom*

*Image 2: Beached LCVP with ramp down and troops exiting*

## The Moon and the Tides

### What causes tides?

Imagine that you are on a camping trip to the beach. You are from Kansas and this is your first trip to the ocean. You spend a full day swimming, fishing and sunbathing. It is now sunset and you are tired. You decide to sleep on the beach until 12:00am, when you plan to get up for a midnight hike. You spread a beach blanket, set an alarm clock, and lie down with only your feet in the water. Before falling asleep, you notice that there is no wind or waves. You see a full moon rising in the east as the sun sets in the west. On a nearby rock you see oysters and mussels exposed to the air. Well before midnight you are awakened, but not by your alarm clock. You are now wet from the chest down. What has happened? There is still no wind or waves. The oysters and mussels are now covered by water. The full moon, now well above the horizon, seems to be smiling at you. Like Dorothy in the *Wizard of Oz,* you may say to yourself *"We're not in Kansas anymore, Toto!"* What has happened? Why does the moon seem amused? You have just had your first real life experience with **tides.**

**Tides are mainly due to a gravitational attraction between the moon and every molecule of water in the Earth's oceans.**

**Gravity** is an attractive force between any two objects in the universe. The force of gravity is directly proportional to the product of the masses of the two objects. It is inversely proportional to the distance between the two objects squared.

Tidal forces are a special case of gravitational forces. **Lunar tidal forces** are due to differences between the gravitational pull caused by the moon on every molecule of water in the oceans on the side of Earth closest to the moon, as compared to those same forces on the opposite side of Earth. Since water is free to flow in response to these forces, it causes the Earth's oceans to form two bulges, one in the direction of the moon, and the other in the direction opposite it. (See figure 1) These bulges average about 6 feet in height.

*Figure 1: A North Polar view of the Earth, the moon and its orbit, and the lunar tidal bulges.*

These bulges are not stationary; they follow the moon in its orbit around the sun, moving, as the moon does, about 12 degrees per day toward the east. In the meantime, the much more rapid rotation of the Earth in the same direction causes the continents to move through these bulges. When this happens, the oceans' waters seem to mysteriously rise, even in the absence of wind, waves or currents. As the continents move past these bulges, the level of water is seen to drop.

1. **If the model presented above is correct, on the average, how many high tides and how many low tides should there be in each 24 hour period?**

**The Sun, the Moon, and the Tides**

You may ask, "What is the influence of the sun on the tides?" The answer is that the sun does have an influence, although only about half as strong as that of the moon. This is because even though the sun is more than a million times more massive than the moon, it is so much farther away (over three hundred times more distant than the moon) that the difference between the sun's force on the water nearest the sun compared to the sun's force the water away from the sun (**solar tidal force)** is only half as strong as the lunar tidal forces.

The influence of the sun means that the difference between the high tide mark and the low tide mark changes significantly during the course of a month (a **lunar synodic period;** the time required for the moon to go through a complete cycle of phases). [See figure 1]

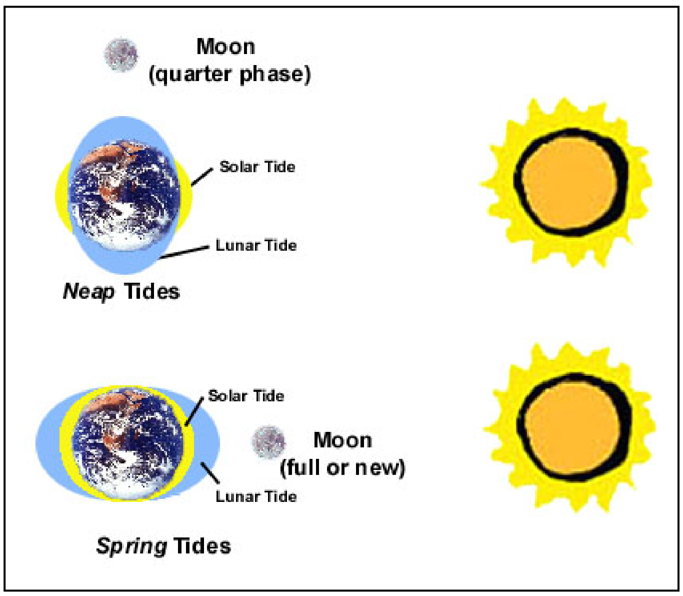



*Figure 1: A diagram showing a view of the Earth, the moon and its orbit the sun, and the lunar and solar tidal bulges during neap tide and spring tide.*

2. **During which phase(s) of the moon is the solar tidal bulge added to the lunar tidal bulge, resulting in spring tides?**

3. **During which phase(s) of the moon is the solar tidal bulge subtracted from the lunar tidal bulge, resulting in neap tides?**

4. **Review the introduction to this exercise and determine which kind of tide would be best for the date of the invasion, spring, or neap, and why**

**Daily Changes in the Times of the Tides**

If your answer to **Question 3** was two high tides and two low tides, you were right. However, these high and low tides do not occur at the same times on successive days.

5. **If there is a high tide today at noon, will there be another high tide tomorrow at noon? Why or why not?**

6. **By how many degrees and in which direction will the moon have moved in its orbit in 24 hours?**

7. **In order for some point on Earth to "catch up" to the moon after 24 hours, by how many additional degrees must the Earth rotate?**

8. **The rotation of the Earth causes any point on its surface to move through a complete circle (360 degrees) in 24 hours. By how many degrees per hour does the Earth rotate?**

9. **Refer back to question 8. How much time does this "catching up" require? (Round your answer off to the nearest whole ten minutes.)**

*Use the information you have learned thus far (both Part I and Part II) to complete the following data table*

| Calendar date | Lunar phase | Time of first low tide past midnight |
|---|---|---|
| August 1 | Waxing half moon | 0010 (12:10am) |
| August 2 | Waxing gibbous | 0100 (1:00am) |
| August 3 | Waxing gibbous | 0150 (1:50am) |
| August 4 | | |
| August 5 | | |
| August 6 | | |
| August 7 | | |
| August 8 | | |
| August 9 | | |
| August 10 | | |
| August 11 | | |
| August 12 | | |

## Determining the best date for the invasion

By now you are an expert on the timing of both lunar phases and tides. You are ready to advise General Eisenhower of the best night to launch the aerial attack that will precede the landings at dawn on the beaches. General Eisenhower has advised you that the soonest date of complete readiness of the invasion force is Sunday, August 1.* You know that on that night, there will be a waxing half moon, with sunrise at about 0700 (7:00am). The time of sunrise will not change significantly during the span of time under consideration. Carefully consult your data tables and diagram, and determine what advice you will give to the general.

** You probably know that the D-Day invasion was actually on June 6, 1944, not in August.*

**Your advice to the general:**

The aerial attack should be at midnight, on ____________________, followed by
(date)
beach landings at dawn at _______________.
(time)

Your reasons for giving the general this advice are as follows:

**Answers to Part II**

1. **If the model presented above is correct, on the average, how many high tides and how many low tides should there be in each 24 hour period?** Two high tides and two low tides

*2.* **During which phase(s) of the moon is the solar tidal bulge added to the lunar tidal bulge, resulting in spring tides?** At either new moon or full moon, when the sun the moon and the Earth lie on nearly a straight line.

3. **During which phase(s) of the moon is the solar tidal bulge subtracted from the lunar tidal bulge, resulting in neap tides?** At half moon, either waxing or waning, when the sun, moon and Earth are separated from each other by 90 degrees.

4. **Review the introduction to this exercise and determine which kind of tide would be best for the date of the invasion, spring, or neap, and why.** Spring tide would be better than neap tide because then the difference between low tide level and high tide level would be greatest, maximizing the amount of rise of water level during any given amount of time.

5. **If there is a high tide today at noon, will there be another high tide tomorrow at noon? Why or why not?** No, because the high tide bulge will follow the moon, which will have moved on its orbit relative to the sun and Earth

6. **By how many degrees and in which direction will the moon have moved in its orbit in 24 hours?** By 12 degrees toward the east.

7. **In order for some point on Earth to "catch up" to the moon after 24 hours, by how many additional degrees must the Earth rotate?** By 12 additional degrees.

8. **The rotation of the Earth causes any point on its surface to move through a complete circle (360 degrees) in 24 hours. By how many degrees per hour does the Earth rotate?** By 15 degrees. (*360 degrees / 24 hours = 15 degrees per hour)*

9. **Refer back to question 8. How much time does this "catching up" require? (Round your answer off to the nearest whole ten minutes.)** By about 50 minutes. *(12 degrees / 15 degrees/hour = 0.8 hours.) (0.8 hours x 60 minutes /hour = 48 minutes, which rounds to 50 minutes.)* Referring back to question 7, if there is a high tide today at noon, the corresponding high tide tomorrow will not occur until 12:50 **[am or pm????].**

| Calendar date | Lunar phase | Time of first low tide past midnight |
|---|---|---|
| August 1 | Waxing half moon | 0010 (12:10am) |
| August 2 | Waxing gibbous | 0100 (1:00am) |
| August 3 | Waxing gibbous | 0150 (1:50am) |
| August 4 | Waxing gibbous | 0240 (2:40am) |
| August 5 | Waxing gibbous | 0330 (3:30am) |
| August 6 | Waxing gibbous | 0420 (4:20am) |
| August 7 | Waxing gibbous | 0510 (5:10am) |
| August 8 | Full | 0600 (6:00am) |
| August 9 | Waning gibbous | 0650 (6:50am) |
| August 10 | Waning gibbous | 0740 (7:40am) |
| August 11 | Waning gibbous | 0830 (8:30am) |
| August 12 | Waning gibbous | 0920 (9:20am) |

**Determining the best night for the invasion**

Your advice to the general:

The aerial attack should be at midnight, on Monday, August 9, followed by beach landings at dawn on at 6:50am (0650).

Your reasons for giving the general this advice are as follows:

Because on the night of August 8th-9th there will be a full moon, which will already be at its highest point in the sky at midnight when the paratroopers land and will not set until dawn. (As determined in Part I)

Equally important, on the morning of August 9 there will be a low tide at dawn, about 0700, (7:00 a.m.). Additionally, since the moon is full, this will be a spring tide.

**Other questions that may arise:**

**A. Why round off the answer to question 11 to the nearest ten minutes?**
Because during the time that the rotating Earth is "catching up" to the tidal bulge following the moon, the moon is still moving. This requires about two additional minutes for a point on Earth to catch up. The rounding off simplifies the arithmetic.

**B. Why does the size of tidal changes vary so much from place to place on Earth?**
For a variety of reasons, but most importantly having to do with irregularities in the shapes of shorelines. Tidal changes are reduced in bays and gulfs with restricted openings to the oceans, for example, the average tidal range in the Gulf of Mexico is only about two feet. On the other hand, funnel- shaped bays facing large expanses of open oceans, such as Canada's Bay of Fundy, may experience tidal ranges in excess of fifty feet.

**C. Why is there a tidal bulge facing away from the moon?**
It is easy to see why there is a tidal bulge of water facing the moon, since that is the direction toward which the moon's gravity pulls the water. Why there should be a bulge in the opposite direction has to do with the **difference** between the strength of the moon's gravitational pull on the water nearest the moon, and the weaker gravitational pull on the water on the more distant opposite side.

By way of analogy, imagine a motorcycle race in which the field of competing cycles is arranged in a circle with the starting line analogous to the direction of the moon. If the cycles with the more powerful engines are positioned closest to that line, and those with the weakest engines in the rear and those with intermediately powerful engines in the middle, how will the shape of the entire field of racing cycles change once the race starts?