The Science and Technology of WWII

Moon Phases and Tides in the Planning the D-Day Invasion
Part I: The Phases of the Moon

Objectives:
1. Students will determine what causes the moon to go through a cycle of phases and the time needed to go from one phase to another.
2. Given some facts about the invasion plan, students will determine which lunar phase would be the 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.

Directions:
1. Introduce or review the names and shapes of the lunar phases (new, waning and waxing crescent, waning and waxing half moon, full, waning and waxing gibbous).
2. Introduce or review the categories of angles (acute, obtuse, right).
3. Allow students to read the introduction to “Phases of the Moon”. Answer any questions and allow them to answer the accompanying questions, complete the data table, and finish labeling the diagram.
4. If time and materials are available, show the laboratory simulation of the phases of the moon.
5. Review the facts about the invasion plan, and critique students’ choices for the best lunar phase during which to invade.
6. Critique students’ choices for the best calendar date during which to invade.

* About the diagram
1. The diagram is not drawn to scale. The orbit of the moon is about 30 earth diameters from the earth. To be drawn to scale, the orbit of the moon would have to be much bigger, or the earth much smaller.

2. The orbits of the moon and the earth are not in the same plane. This usually prevents the moon from blocking the light of sun to the earth or the earth from blocking the sun’s light to the moon when, as shown in the diagram, the three bodies seem to fall on the same line (new moon or full moon).

3. The time required for the moon to go through a complete cycle of stages as seen from earth is about 30 days (one lunar synodic period = 30 days x 12 degrees/day = 360 degrees.) This is longer than the time required for the moon to orbit the earth (about 28 days) because during this time the earth has moved about 30 degrees in its own orbit around the sun.

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

This lesson plan was written for The National WWII Museum by Louis Garcia. Louis teaches science at the New Orleans High School for Math and Science.
The apparent motion of the moon relative to the sun as seen from Earth

- **Moon’s orbit around the Earth**
- **Apparent direction of motion east = 12° per day**
- **Direction of Earth rotation (once in 24 hours)**
- **North Pole**
- **Direction of moon’s apparent motion as seen from Earth (2 days x 12°/day = 24°)**
- **Parallel rays from sun**

**Day 0**
- New moon (not seen)
- Angle SME = 180°

**Day 2**
- Waning crescent moon
- Angle SME = 156° (obtuse)

The angle SME is the angle between the sun, the moon, and the Earth. The moon is located at the vertex of this angle.

Not drawn to scale.
The D-Day Invasion: When, and Why Then?
Part I: The Phases of the Moon

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 by 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.

Questions:

1. Why was the moon important to the Allied invasion plan? Why would the use of artificial lighting, like flashlights, be dangerous for the paratroopers?

2. In order to be useful to the Allies, on the night of the invasion, by what time should the moon be high in the sky?

3. In order to be useful to the Allies, on the night of the invasion, until what time should the moon remain above the horizon?

4. During the times referred to in questions 2 and 3, in order to provide the most possible light to the paratroopers, what phase should the moon be in?

In order to be able to intelligently advise General Eisenhower on these matters, the Allied astronomers had to be familiar with the timing of the phases of the moon. In the exercise that follows, you will play the role of Eisenhower’s astronomer. You will be given a hypothetical first date on which the invasion force is fully ready, and you must inform the general of the first date on which lunar conditions are perfect following the first day of full readiness.

The Phases of the Moon

You probably already know that the moon shines by reflected sunlight. The phases of the moon are caused by changes in the angle between the sun, the moon and the earth (angle SME). The changes in this angle in turn are caused by changes in the position of both the moon and the earth relative to the sun as they move in their orbits. An important basic observation in
determining the timing of the phases of the moon is that as seen from earth, the moon appears to move by 12 degrees per day toward the east relative to the sun. Let us investigate these changes with the use of the accompanying diagram and possibly, a laboratory simulation.

A note about the view of the earth shown in the diagram: the diagram shows a polar view of the earth and the moon’s orbit, as though we were looking down on the earth from far above the North Pole. The view of the earth that you are probably most familiar with is an equatorial view, with the equator horizontal, the northern hemisphere on the top and the southern hemisphere on the bottom. In this different view, any movement in the counterclockwise direction is toward the east, and any movement in the clockwise direction is toward the west. You can simulate this with a globe. Point the North Pole toward you, and spin the globe toward the east; it will appear to be moving counterclockwise.

Laboratory simulation of the phases of the moon: In a darkened room, let a centrally seated observer represent the earth, a small bright ball represent the moon, and a flashlight represent the sun. As the angle between the “sun,” the “moon” and the “earth” changes, the “moon” will go through phases, similar to those of the real moon.

Complete the data table below. Also, using a protractor, show the location and apparent shape (phase) of the moon on the diagram on each of the days indicated.

Data table:

<table>
<thead>
<tr>
<th>Day of cycle</th>
<th>Motion of moon on orbit (degrees toward east)</th>
<th>Angle SME</th>
<th>Category of angle</th>
<th>Phase of moon</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>180</td>
<td>open</td>
<td>new (not seen)</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>156</td>
<td>obtuse</td>
<td>waxing crescent</td>
</tr>
<tr>
<td>7.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>15</td>
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<td></td>
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</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>22.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>360</td>
<td>180</td>
<td></td>
<td>new (not seen)</td>
</tr>
</tbody>
</table>

Answer the following questions with reference to the diagram and/or the simulation. Fill in the accompanying data table as you go.

5. What time is it for the observer on earth shown in the diagram (Hint: where is the sun?)

6. Why is the moon not seen on the night of a new moon?
7. Would the night of a new moon be a good night to begin the invasion? Why or why not?

8. On the night of a waxing half moon, where is the moon seen at sunset? (Hint: Analyze the diagram.)

9. On the night of a waxing half moon, at what time does the moon set? (Hint: The moon and the entire sky appear to move from east to west by 15 degrees/hour due to the rotation of the earth in the opposite direction.)

10. Would the night of a waxing half moon be a good time for the invasion? Why or why not?

11. On the night of a full moon, where is the moon at sunset? (Hint: Analyze the diagram.)

12. On the night of a full moon, where is the moon at midnight? (Hint: The moon and the entire sky appear to move from east to west by 15 degrees/hour due to the rotation of the earth in the opposite direction.)

13. Would the night of a full moon be a good night to start the invasion? Why or why not? (Hint: Check your answers to questions 1 through 4.)

Determining the best night for the invasion

By now you are an expert on lunar phases and their timing. 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. Carefully consult your data table 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 begin at midnight, on ____________, followed by beach
landings at dawn at _____________.

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

Part I

1. Why was the moon important to the Allied invasion plan? Why would the use of artificial lighting, like flashlights, be dangerous for the paratroopers? Since the aerial assault would be beginning slightly after midnight, the paratroopers would need light to see by. The use of flashlights or any other artificial light would attract the attention of the Germans and reveal their location.

2. In order to be useful to the Allies, on the night of the invasion, by what time should the moon be high in the sky? It should be high in the sky by midnight, when the aerial assault was scheduled to begin.

3. In order to be useful to the Allies, on the night of the invasion, until what time should the moon remain above the horizon? The moon should remain above the horizon until the first light of dawn.

4. During the times referred to in questions 3 and 4, in order to provide the most possible light to the paratroopers, what phase should the moon be in? Ideally, the moon should be full, or nearly so.

5. What time is it for the observer on earth shown in the diagram (Hint: where is the sun?) Since the sun is on the western horizon, it is sunset.

6. Why is the moon not seen on the night of a new moon? Because since it lies in the same direction as the sun, it sets when the sun sets, and does not rise until sunrise.

7. Would the night of a new moon be a good night to begin the invasion? Why or why not? No, because there would be no moonlight at all.

8. On the night of a waxing half moon, where is the moon seen at sunset? (Hint: Analyze the diagram.) Moving to the east at 12 degrees per day, in the 7.5 days since new moon it will have separated from the sun by 90 degrees. Therefore when the sun sets in the west, the moon will be at its highest point in the sky.

9. On the night of a waxing half moon, at what time does the moon set? (Hint: The moon and the entire sky appear to move from east to west by 15 degrees/hour due to the rotation of the earth in the opposite direction.) As seen in question 8, at sunset, the moon would be separated from the sun by 90 degrees. Due to the apparent rotation of the sky by 15 degrees per hour toward the west, it will set by approximately midnight (six hours after sunset). (15 degrees/hour × 6 hours = 90 degrees)

10. Would the night of a waxing half moon be a good time for the invasion? Why or why not? No, because by the time the aerial assault would have begun at about midnight, the moon would have set.
11. On the night of a full moon, where is the moon at sunset? (Hint: Analyze the diagram.) Moving to the east at 12 degrees per day, in the 15 days since new moon it will have separated from the sun by 180 degrees. Therefore when the sun sets in the west, the moon will rise in the east.

12. On the night of a full moon, where is the moon at midnight? (Hint: The moon and the entire sky appear to move from east to west by 15 degrees/hour due to the rotation of the earth in the opposite direction.) As seen in question 11, at sunset, the moon would be separated from the sun by 180 degrees. Due to the apparent rotation of the sky by 15 degrees per hour toward the west, it will be 90 degrees above the eastern horizon at midnight (six hours after sunset). Therefore, it will be at its highest point in the sky.

13. Would the night of a full moon be a good night to start the invasion? Why or why not? (Hint: Check your answers to questions 1 through 4.) The night of a full moon would be a good night to start the invasion because by the time the aerial assault begins at midnight the moon will be at its highest point in the sky, with maximum brightness, and will not set until dawn.

Determining the best night for the invasion

By now you are an expert on lunar phases and their timing. 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. Carefully consult your data table 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 Monday, August 9, followed by beach landings at dawn 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.