Human HET: *Challenge 3 Mirror Alignment*

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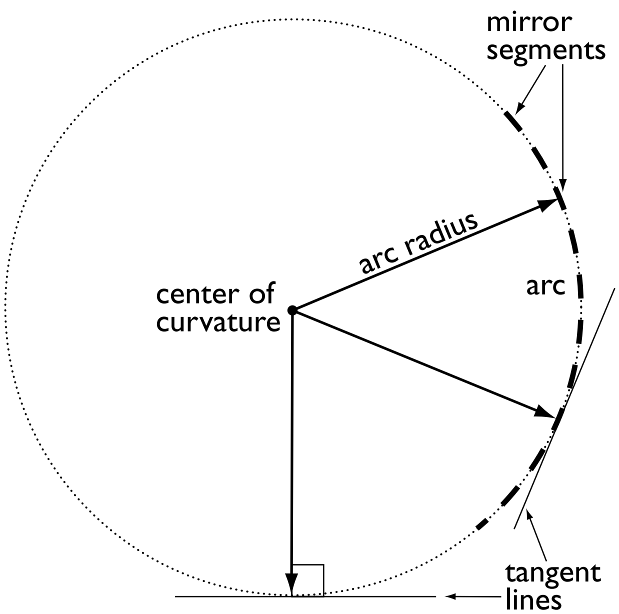
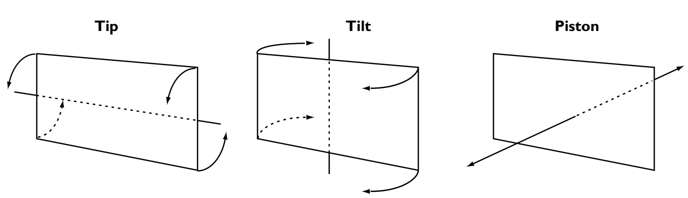
Introduction

Following Challenges 1 and 2, in which all the mirrors were set in the array, the next step is to align them so that they act as a team of mirrors focusing light to the same place. This alignment takes advantage of the geometry of a circle: at any point on the circle, the tangent line is perpendicular to the radius. In this case, the tangent line is the small flat mirror, and the radius is a light beam shining from the center of curvature. A mirror is aligned once it reflects the beam back to the center, or the source of the beam.



Each mirror segment on the HET primary mirror array can move in three ways:



Tip — top or bottom edge moves toward or away from the center of curvature.
Tilt — left or right edge moves toward or away from the center of curvature.
Piston — mirror moves toward and away from the center of curvature.

The HET aligns all of its mirrors in just a few minutes. A laser at CCAS (center of curvature alignment system) is fired at all the mirrors; the mirrors reflect the light back to a detector inside CCAS. A control computer instructs each mirror to tip, tilt, and/or piston into position until the reflected beam, at the center of curvature, is within a target area the size of George Washington's eye on a U.S. quarter. Once all the reflected beams lie within the target area, the mirror array is aligned and ready for astronomical observations.

The students will move their hand-held mirrors in just the same manner. Their hands and wrists act like the actuators on the back of each mirror, while their arms and bodies act like the truss. In fact, with their free arm, they may interlock with their neighbor, to form a more rigid model truss.

While students hold their mirrors, their arms and hands might jiggle, or slightly wander about. In a few minutes, the model mirror will significantly drift out of alignment. Similarly, over the course of a few hours, the HET's mirrors slowly drift out of alignment. Temperature changes in the telescope structure warp the truss and change the directions at which the mirrors point. During astronomical observing, the temperature changes because the dome and telescope are open to the sky and night air. HET staff has several solutions for this problem that maximize the time the mirrors remain aligned. First, the dome is cooled during the day to the temperature expected for nighttime observations. Second, several fans circulate air beneath the mirrors to keep the temperatures constant throughout the structure. Third, HET staff has programmed the control computer to adjust the mirrors at a given temperature. The computer can tip, tilt, and piston mirrors to compensate for the anticipated truss deformation. All three of these methods extend usable observing time and increase the observing efficiency of the telescope.

Goal

Devise a method to align the mirrors of the model HET mirror array to the center of curvature.

Materials

1. One flashlight per class.
2. One manila folder per class.
3. One small flat mirror per member of the array.
4. Arc and CCAS location that are marked on the floor from Challenge 2.
5. Graph paper (one piece for each alignment trial) and pencil.

Texas Essential Knowledge and Skills

Science TEKS Process Skills

- plan and implement investigative procedures (6.2, 7.2, 8.2, IPC, Physics, Astronomy)
- relationships between science and technology (8.5)

Science TEKS Concepts

- Systems (6.5, 7.5)

Math TEKS

- Geometry and spatial reasoning (6.6, 6.7, 7.8)
- Underlying processes and mathematical tools (6.11, 7.13, 8.14)

Preparation

The students' model mirror array should be on the arc and ready for alignment, after completing Challenge 2. The student at the center of curvature acting as CCAS will need a flashlight and reflective card. This may work best if the card hangs on a string around the student's shoulders. Explain the problem to the students.

Problem

Tell the students to align the mirrors using "tip, tilt, piston" while they are all held at the same distance from CCAS. When the CCAS student shines a flashlight at the mirrors (individually), each student should try to position the reflection as close as possible to the center of the reflective card. Let the students decide the measure of success (i.e., how big is the target area.). They may wish to record the size of the desired target by drawing a circle on the graph paper and comparing it with the actual result when the light beams are reflected there.

Solution

Elect a student to stand at the center of curvature to act as CCAS. The student should systematically aim the flashlight beam at each mirror in succession. The student holding the mirror should move the mirror until the reflected light hits the target area of alignment. CCAS and the student holding the mirror may talk to each other to establish alignment just as the mechanisms and computers do for HET.

Tips

This challenge follows directly where Challenge 2 left off. After completing Challenge 2, the model is set up for running a solution for Challenge 3.

This is an excellent application of the concepts of precision and accuracy. The precision is the size of the target space in which all the reflected beams must fit in order for the array to be considered aligned. The accuracy is the distance between the reflected beam and the center of the target space. You may wish to have a contest to see how small an area each group can achieve.

Extension

Set up an experiment to determine the average duration that the mirror array remains aligned.

Tips

Establish the alignment precision — how far to allow the mirrors to drift before declaring them out of alignment. Ask the members of the mirror array to close their eyes during this experiment. With their eyes open, the students can "cheat" — each segment can adjust tip, tilt, and piston while receiving visual feedback from CCAS to stay on target. With their eyes closed, that feedback loop is closed, just like with the real HET. Some new telescopes operate as if the students' eyes were open using a technology called adaptive optics. In this case, the mirror array is always in alignment.

Ask for suggestions for methods to extend the "align time."