Laser Teaching Center

Creating a Demonstration Liquid Mirror Telescope

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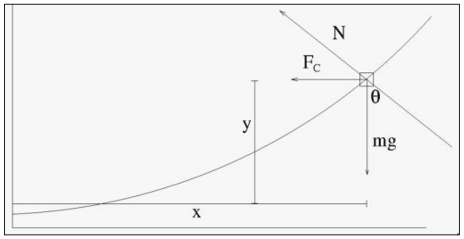
Background

It is a familiar fact that the surface of a rotating liquid assumes a concave shape. Three hundred years ago Sir Isaac Newton proved that this shape is in fact a paraboloid of revolution described by the equation

$$y=\frac{\omega^2}{2g}x^2$$

where ω is the angular velocity in radians per second and *g* is the acceleration of gravity. Ernesto Capocci first proposed using such a parabolic surface as the primary mirror of a telescope around 1850, but it was only about two decades ago that the numerous technical challenges were overcome and a successful full-scale telescope created. Liquid mirror telescopes are much cheaper than comparable glass mirror telescopes. They can only observe objects directly overhead, but in practice this isn't an important limitation.

The goal of our project is to build and test a basic liquid mirror telescope.



$$\tan\theta=\frac{dy}{dx}$$
$$F_c=\frac{mv^2}{r}=m\omega^2 r=m\omega^2 x$$
$$\cos\theta=\frac{mg}{N}$$
$$N\cos\theta=mg$$
$$\sin\theta=m\omega^2\frac{x}{N}$$
$$N\sin\theta=m\omega^2 x$$
$$\frac{\sin\theta}{\cos\theta}=\frac{\omega^2 x}{g}=\tan\theta=\frac{dy}{dx}$$

$$\Rightarrow$$

$$\frac{dy}{dx}=\frac{\omega^2 x}{g}$$
$$\int dy=\int\frac{\omega^2 x}{g}dx$$
$$y=\frac{\omega^2 x^2}{2g}+c$$
$$y=\frac{\omega^2}{2g}x^2$$
$$f_{parabola}=\frac{1}{4a}$$
$$f=\frac{g}{2\omega^2}$$

Proof that a rotating liquid takes on a parabolic shape

Acknowledgements

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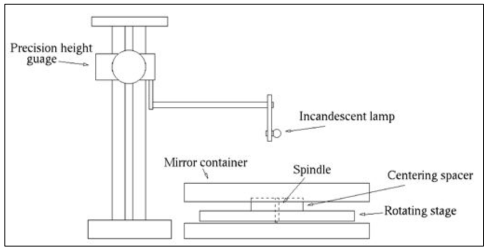
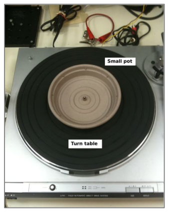
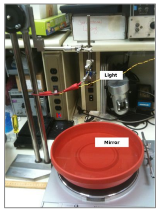
Set up



Our telescope is simply a shallow container of water about 30 cm in diameter placed on a record player. The rotational speed of the record player can be continuously varied from 30 to 36 rpm or 40 to 46 rpm.

An effective container must be:
- Watertight
- Rigid
- Able to be centered on the rotation stage





Our current container is made from two plastic gardening pots, which are about 15 cm and 33 cm in diameter, respectively. A hole that provides a snug fit around the spindle of the record player was drilled in the exact center of the smaller pot. An indent on the bottom of the larger pot keeps it centered on the smaller one, and hence concentric with the axis of the turntable.

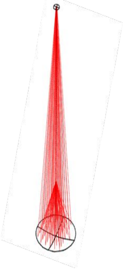
References

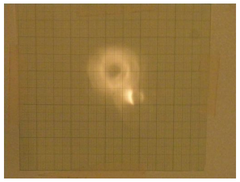
Borra, E.F., Content, R., Drinkwater, M.J., Szapiel, S. A Diffraction-Limited f/2 1.5 Meter Diameter Liquid Mirror. The Astrophysics Journal, 346:41-44 (1989)

Ninane, N.M., Jamar, C. A. "Parabolic liquid mirrors in optical shop testing," Appl. Opt. 35, 6131-6139 (1996)

Measurements

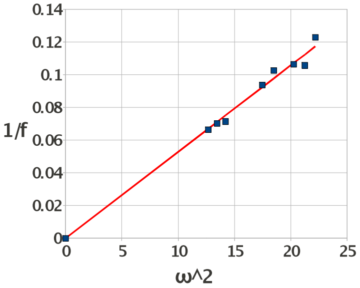
Two related types of measurements were carried out with our prototype device and a precision 0.5 meter height gauge. The first procedure created a map of the parabolic surface by probing its depth at several locations. The second determined the focal length of the mirror by projecting an image of a small filament on the ceiling, which is essentially making a telescope in reverse. Both results can be compared to predictions derived from the formulas seen in the background.





The image of the filament seen here is about 0.9 cm long, while the actual filament is about 0.2 cm long, showing a magnification of about 4.5, exactly what is expected for the distances and speed used.

- Each data point represents 1/f at a different angular velocity.
- The orange line is the theory line of best fit.
- Each point is accurate to about .01" and deviates from the theory by less than 4%.



Imaging

We placed a CCD camera near the focal point of the mirror and were able to image a pinhole light source with the telescope.

Images taken with the mirror at 36 rpm (3.77 radians per second) giving a magnification of about 4.5 times.