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# P4_1 Rendezvous With Rama: An analysis of the physics behind Arthur C. Clarke's science-fiction spaceship

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**Abstract**

This article investigates quantitatively the conditions described by a group of astronauts within a ship in the science-fiction book *Rendezvous with Rama* by Arthur C. Clarke. It was found that the conditions would have allowed the astronauts to walk on the surface and breathing should be possible.

### Introduction

In *Rendezvous with Rama* a team of astronauts are sent to investigate a mysterious ship heading through the solar system. Rama is a gigantic spinning hollow cylinder, allowing the astronauts on the innermost side to experience a grounding centripetal force which acts as artificial gravity. The gravity experienced by the astronauts will be calculated. A second section will deal with internal air pressures within Rama.

### Dimensions

"The internal cavity is fifty kilometres long and sixteen wide, the two ends are bowl shaped with rather complex geometry" [1] (p. 40). From the airlocks the astronauts make their way to the inner chamber bridge situated in the central axis of the cylinder. Due to no effect of centripetal force along the axis of Rama, the astronauts remain tethered.

### Traversing Rama

The equation for centripetal acceleration $a_c$ is given by equation 1. Using the dimensions from the book we can take $R$ as half of Rama's diameter. Equation 2 is used to establish the velocity $v$ of rotation and a quote from the book gives us "whereas a normal 'day' for an asteroid was several hours, Rama's was only four minutes" [1] (p. 14).

$$a_c = v^2/R \tag{1}$$

$$v = 2\pi R/T \tag{2}$$

Taking $T$ as the 4 minute period, $R$ as 8 km, $v$ is established as 209 m/s. Substituting $v$ and $R$ into equation 1 gives $a_c$ as 5.46 m/s$^2$. This surface gravity is a little over 3 times that of the Moon (1.62 m/s$^2$) [2] so it should allow the astronauts to walk on the inner surface of Rama.

### Air Pressure

Rama has its own internal atmosphere containing oxygen. Due to the rotation of Rama, the frictional force of rotation causes the air to move in the direction of rotation. This causes a pressure difference in which high pressure air migrates to the wall with lower pressure along the central axis. "Theres no change in temperature', he reported to Commander Norton. 'Still just below freezing. But the air pressure is up, as we expected around 300 millibars." [1] (p. 55).

The quote tells us the atmosphere inside Rama is approximately *isothermal* and it provides the temperature and pressure at which the astronaut can breathe. We take the temperature $T$ as 263 K and the pressure $P$ at 30 kPa, with a distance to the axis given in the book as 2 km. The pressure gradient in relation to the density gradient is determined using equations 3 and 4:

$$P = c^2\rho, \tag{3}$$

$$\frac{\partial P}{\partial r} = c^2\frac{\partial \rho}{\partial r}, \tag{4}$$

where $c$ is the speed of sound and $\rho$ is the density of air. The pressure gradient and density can be related to the rotational characteristics of Rama from the following derivation:

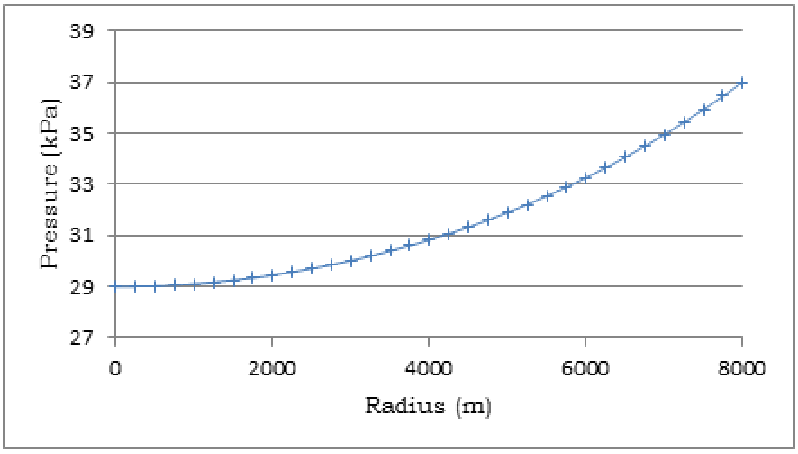

Fig. 1: A plot of pressure against radius in Rama.

$$\frac{1}{\rho}\frac{\partial P}{\partial r} = \omega^2 r, \tag{5}$$

where $\omega$ is the angular velocity. Since $1/\rho = c^2/P$, substituting into equation 5 gives:

$$\frac{c^2}{P}\frac{\partial P}{\partial r} = \omega^2 r. \tag{6}$$

Rearranging and bringing $1/P$ into the differential equation, by recognition we obtain:

$$\frac{\partial \ln P}{\partial r} = \frac{\omega^2}{c^2} r^2. \tag{7}$$

Integrating and taking the exponent of the natural logarithm we obtain an expression for $P$ in terms of it initial pressure $P_0$:

$$P = P_0 \exp\left[\frac{\omega^2}{2c^2} r^2\right]. \tag{8}$$

By using equation 4, the book's numbers for the breathable air height, the assumption that the composition of Rama's atmosphere is identical to that of Earth's, and estimating a mean value for the speed of sound within Rama based on typical Earth values as 300 m/s, we can ascertain the density gradient at a 2 km depth. This comes to +0.333 kg/m$^3$ per 2 km, yet we can expect this gradient to be non-linear [3].

The angular velocity of Rama is $\omega = 2\pi/T = 0.02619$ rad/s. By using equation 8 and assigning a value to $P_0$, which conforms to the detected pressure at the 2 km depth, the pressure gradient can be found. As shown in figure 1, we should expect the astronauts to be able to breathe relatively comfortably at these air pressures assuming the composition of Rama's air to be identical to that of Earth's.

## Conclusion

Astronauts traversing Rama in the book behave correctly within the physical system of Rama. The lack of gravity allows the astronauts to jump up the sides of ship with ease. As it is described in the book, the astronauts can begin to feel and fatigue due to the centripetal force increase. We neglected the effects of pressure, frictional and Coriolis forces on air pressure. The frictional force would oppose the direction of rotation [4]. We found that astronauts should be able to breathe assuming the composition of Rama's air to be identical to that of Earth's yet this is unlikely.

## References

[1] Arthur C. Clarke (1973), *Rendezvous with Rama*, Gollancz.
[2] `http://nssdc.gsfc.nasa.gov/planetary/factsheet/moonfact.html` accessed on October 7, 2014.
[3] `http://en.wikipedia.org/wiki/Speed_of_sound#Equations` accessed on October 14, 2014.
[4] `http://www.aos.wisc.edu/~aalopez/aos101/wk11.html` accessed on October 8, 2014.