Space Station Drum Considerations

Feburary 28, 2021

Zachary Bochanski

This notebook provides documentation exploring the design of a trash-can-style space colony. The key features outlined in this design are the size and rotation rate of this colony to practically simulate a feeling of gravity (normal force) acting on a human living in the colony.

This foray may or may not have been inspired by watching the expanse then spending way too much time on Wikipedia reading about O'Neill cylinders.

Let's get started!

Dependencies

- `numpy` math library contains tools for computations and analysis.
- `matplotlib` plotting library is used to create the visual aids.

In [2]:

```
import numpy as np
import matplotlib.pyplot as plt
from numpy.polynomial import polynomial as ply
```

Tools

Circular motion:

.

$$\sum_{all} F_{radial} = m\frac{v^2}{r}$$

Station Requirements

- > To provide a framework for the the design process... create some restrictions, bounds, etc...

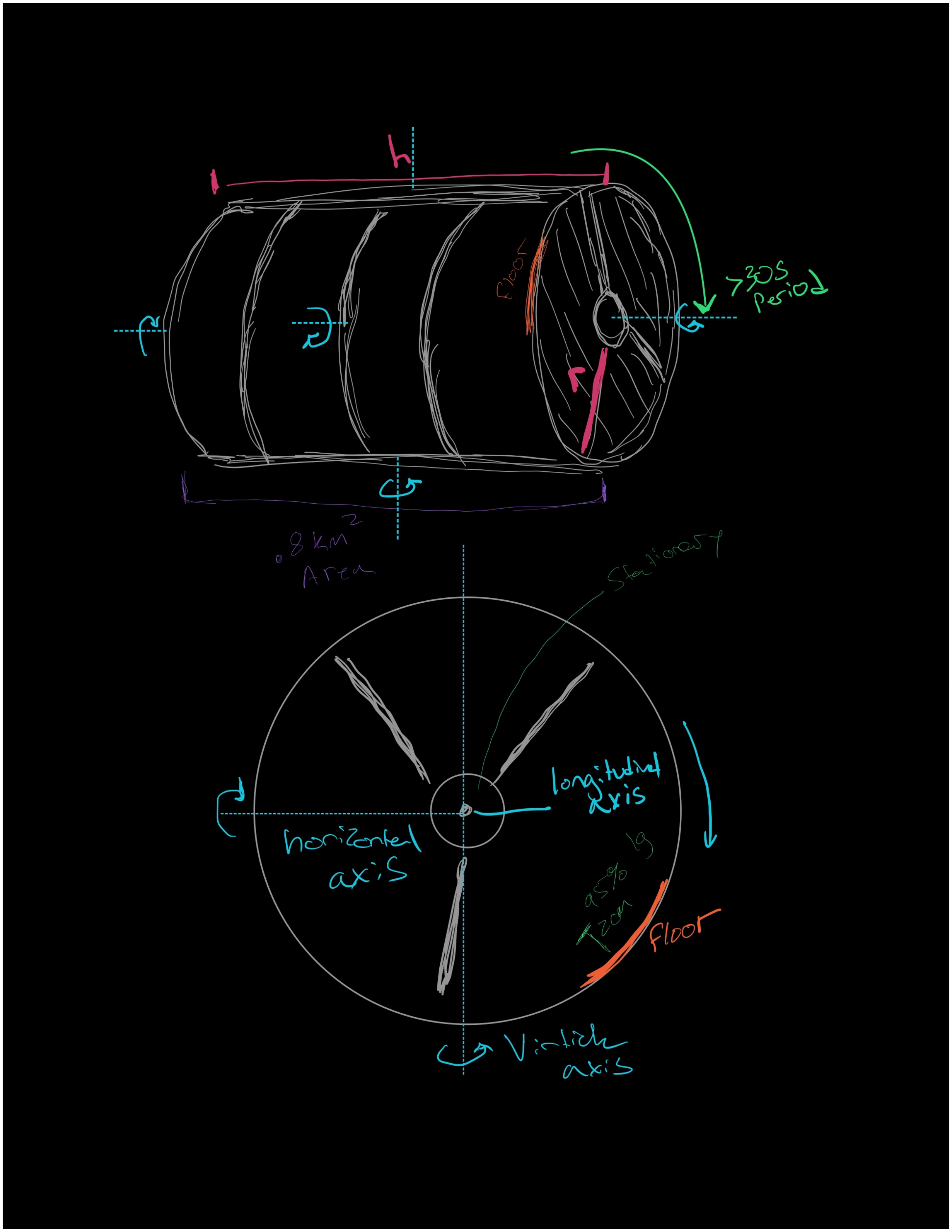
1. 1 g acceleration felt
2. 20m above the floor acceleration how about 95% of 1 g
3. $.8km^2$ area (going for less than a square kilometer.. it must cost a lot to send material into space)
4. period of rotation > 30s
5. location at L4 or L5 (Lagrange points) in earth - moon system

Station Mock-up

A sketch of the proposed space can to visualize what needs to happen

Note:

- axes of rotation
- powered rotation (intended rotation axis)
- area requirements
- height and radius
- intended floor



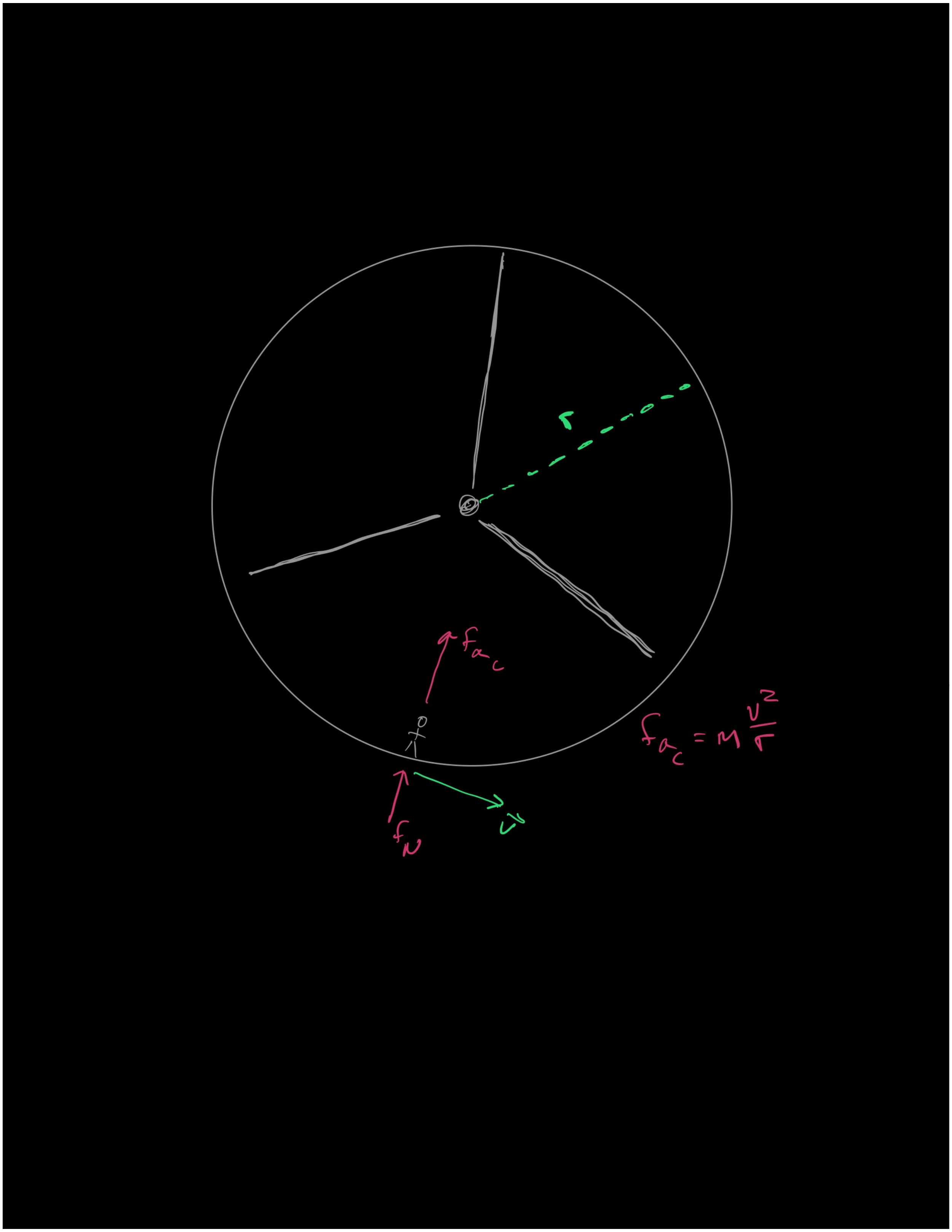
Free Body Diagram

A sketch of the forces important to meeting the design requirements

Note:

- direction of acceleration and force
- velocity vector

- normal force
- axis of rotation at center of circle, radius



Radius vs. Apparent Gravity Model

Calculating the intended gravity "felt" at various radii by controlling the period.

Constants:

- `GRAVITY` desired simulated, "felt" gravity in the drum
- `PERIOD` seconds (s) to complete on rotation of the drum

Speed of edge:

- The drum rotates at a constant speed, the edge's speed is circumference (distance traveled), divided by period (time for one rotation).
- The speed will change depending on the desired period and radius.

  .

$$Speed_r = \frac{2\pi r}{PERIOD}$$

Apparent gravity:

- The apparent gravity is the acceleration towards the center of rotation; the force of acceleration in a circular motion.

  .

$$Apparent_g = \frac{speed_r^2}{r}$$

In [3]:

```
GRAVITY = 9.81 # m/s^2

PERIOD = 41 # in s

# Min and max radii (m)
max_radius = 600
min_radius = 50

# X values generate
num_points = 200
range_radii = np.linspace(min_radius, max_radius, num_points)

# Speed of edge and simulated gravity
speed_r = 2.*np.pi*range_radii/PERIOD
apparent_gravity = speed_r**2/range_radii
```

Plot Radii vs. Apparent Gravity

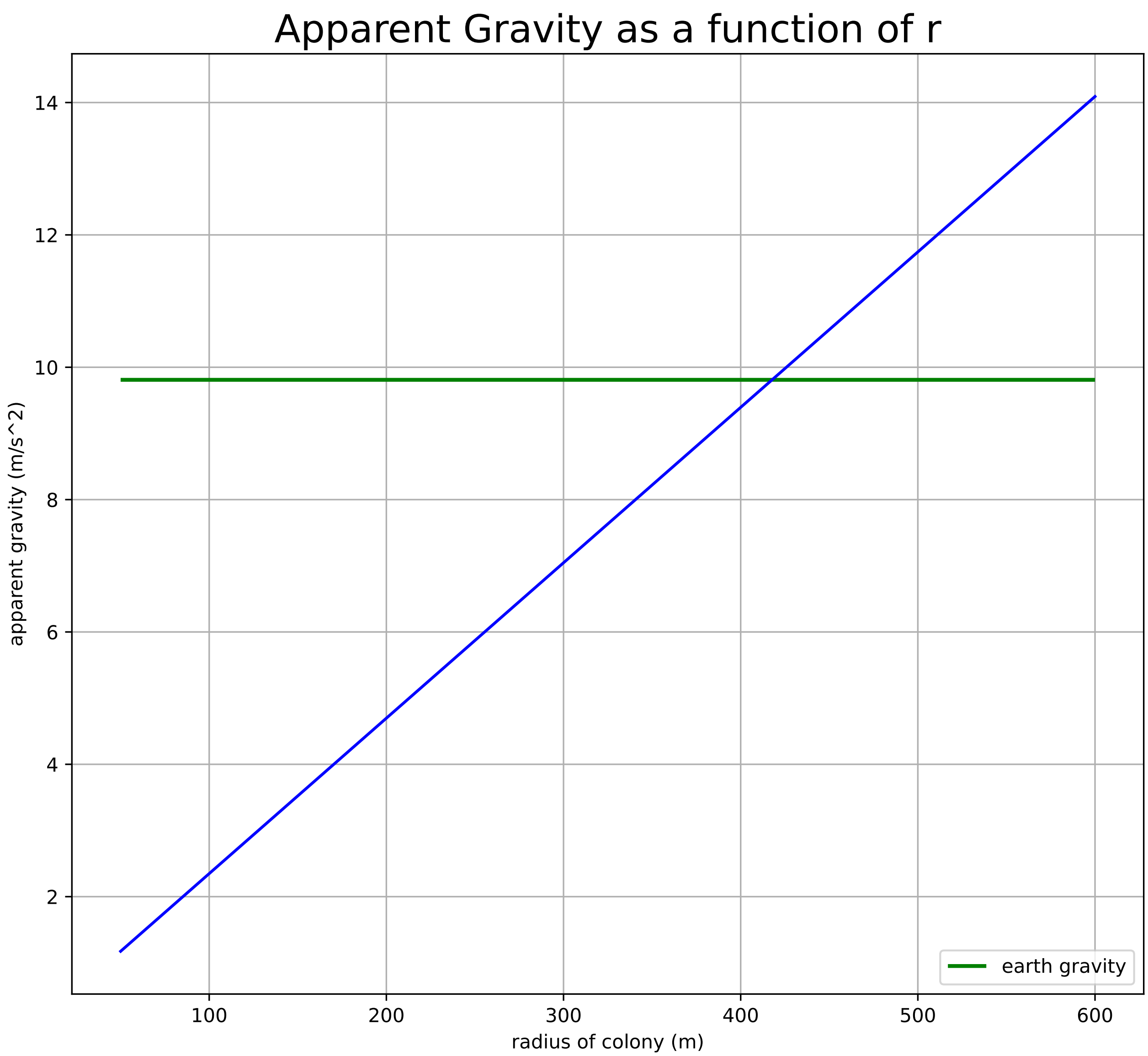
The plot shows the relationship between the radius of the habitat drum and the apparent gravity felt at the edge. The larger the radius the greater the acceleration towards the center of the station at a constant speed.

The intersection point is when the acceleration toward the center of the drum simulates Earth's gravity (1g).

In [4]:

```
fig1, ax1 = plt.subplots()

# Plot velocity model
ax1.plot(range_radii, apparent_gravity, color = 'blue')
```

```
# Draw Earth grav constant
ax1.hlines(9.81, min_radius, max_radius,
           color = 'green', linestyle = '-',
           linewidth = 2., label = "earth gravity")

# Lables
plt.xlabel('radius of colony (m)', fontsize = 10)
plt.ylabel('apparent gravity (m/s^2)', fontsize = 10)
plt.title('Apparent Gravity as a function of r', fontsize = 20)

fig1.set_size_inches(10, 9)
ax1.grid()
plt.legend(loc= 4)

plt.show()
```



Maintain Simulated 1g Requirement

The design requirement specifies that 20 (m) from the edge of the ring must be within 95% of simulated 1g.

Modify the model to visualize an "inner" ring that is 20m closer the the axis of rotation.

In [5]:

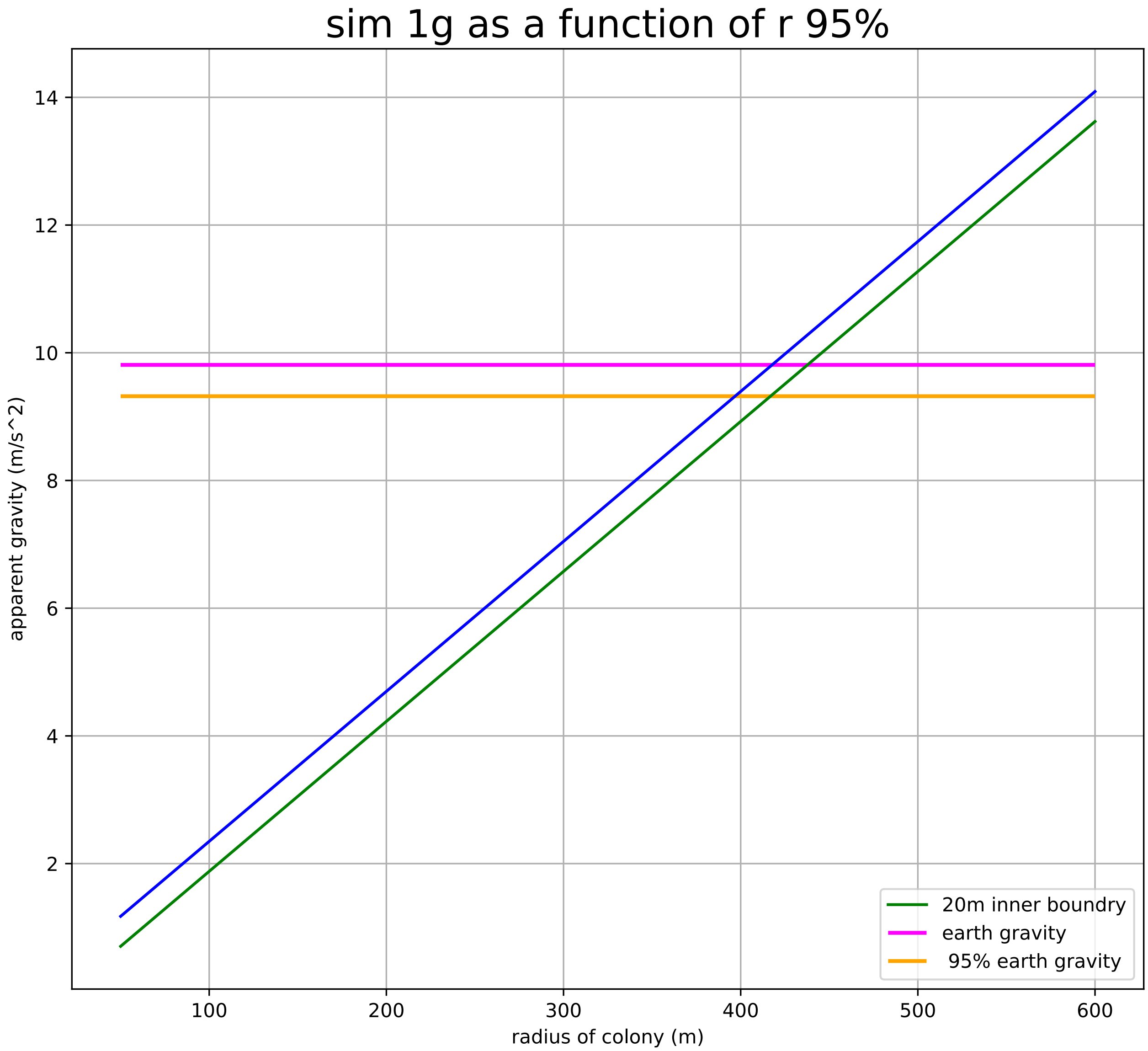
```
# inner_radii = []
# for i in range(len(range_radii)):
#     inner_radii.append(range_radii[i]-20)

inner_radii = range_radii-20

inner_speed = 2*np.pi*inner_radii/PERIOD
apparent_inner_gravity = inner_speed**2/inner_radii
```

Plot Inner Boundry

Adding the modified model to the plot. It shows how at a smaller radius there is less circular acceleration than a larger radius. The horizontal line less than earths gravity is the range that the "inner" ring must be within.

In [6]:

```
fig2, ax2 = plt.subplots()

# Plot model
ax2.plot(range_radii, apparent_gravity, color = 'blue')
ax2.plot(range_radii, apparent_inner_gravity, color = 'green', label = "20m inne

# Draw target accelerations
ax2.hlines(9.81, min_radius, max_radius,
         color = 'magenta', linestyle = '-',
         linewidth = 2., label = "earth gravity")
ax2.hlines(0.95*9.81, min_radius, max_radius,
         color = 'orange', linestyle = '-',
         linewidth = 2., label = " 95% earth gravity")

# Labels
plt.xlabel('radius of colony (m)', fontsize = 10)
plt.ylabel('apparent gravity (m/s^2)', fontsize = 10)
plt.title('sim 1g as a function of r 95%', fontsize = 20)

fig2.set_size_inches(10, 9)
ax2.grid()
plt.legend(loc= 4)

plt.show()
```

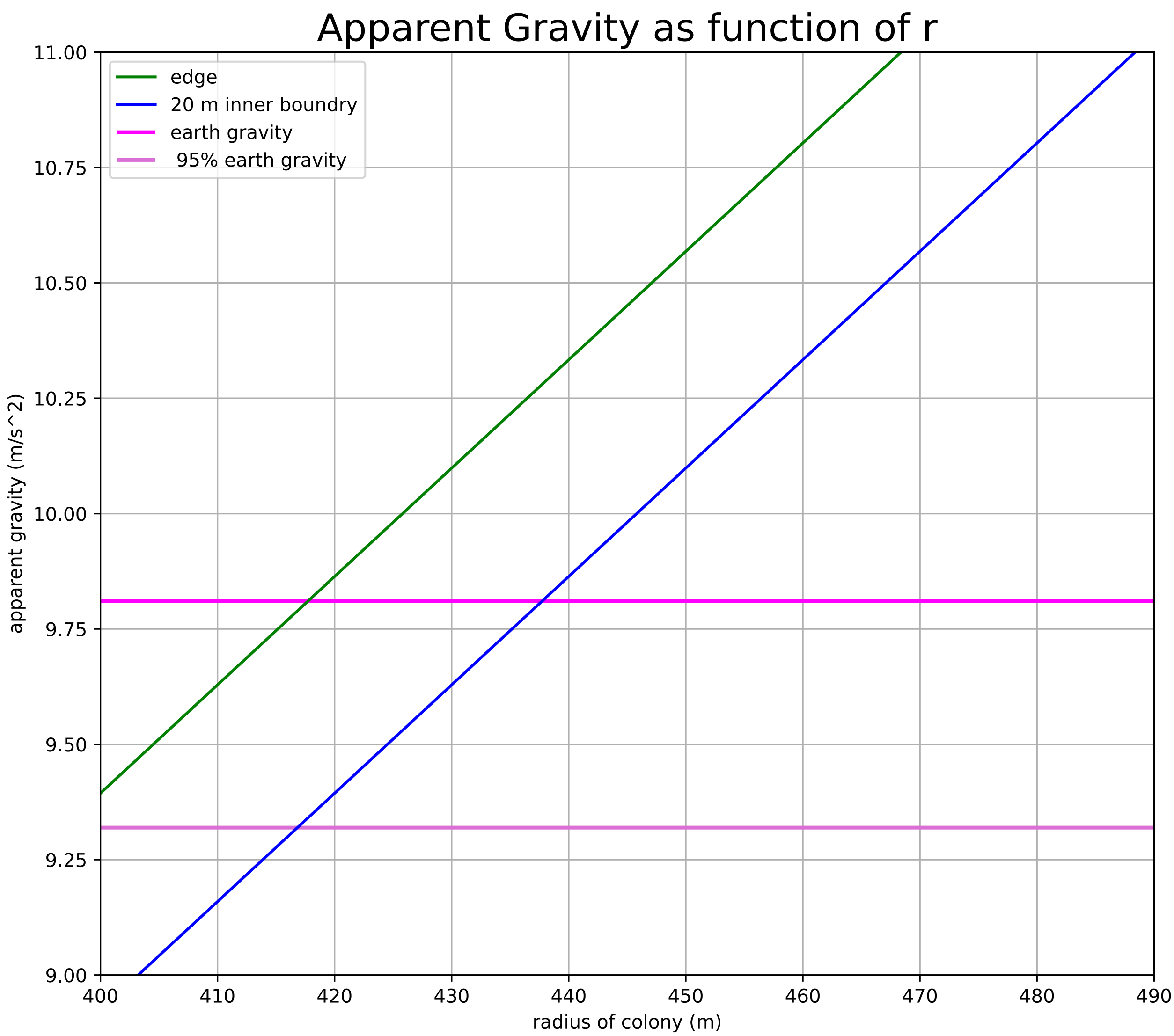


Zoom in on that action!

Taking a more detailed look at what the models present.

In [7]:
```
fig3, ax3 = plt.subplots()

# Plot
ax3.plot(range_radii, apparent_gravity,
            color = 'green',label = "edge")
ax3.plot(range_radii, apparent_inner_gravity,
            color = 'blue',label = "20 m inner boundry")

# Constants
ax3.hlines(9.81, min_radius,max_radius,
         color = 'magenta', linestyle = '-',
         linewidth = 2., label = "earth gravity")
ax3.hlines(0.95*9.81, min_radius,max_radius,
         color = 'orchid', linestyle = '-',
         linewidth = 2., label = " 95% earth gravity")

# Lables
plt.xlabel('radius of colony (m)', fontsize = 10)
```

```
plt.ylabel('apparent gravity (m/s^2)', fontsize = 10)
plt.title('Apparent Gravity as function of r', fontsize = 20)

# Zoom
ax3.set_xlim([400,490])
ax3.set_ylim([9,11])

fig3.set_size_inches(10, 9)
ax3.grid()
plt.legend(loc= 2)

plt.show()
```



Dimension Calculations

Finding a radius that is within 1g and 95% of 1g requires finding the minimum radius that fits both models. According to the models above it appears that a station needs a radius of:

- 417 m

Height (longitudinal axis)

To build a practical station that is restricted to the required $.8km^2$ we need to maximize the dimension (h) of the drum. The final dimensions of a drum can be found with $A = 2\pi rh + 2\pi r^2$. Solving for h, h = 542m.

.

$$A = 2\pi rh + 2\pi r^2$$

.

$$2\pi rh = A - 2\pi r^2$$

.

$$h = \frac{A - 2r^2}{2r}$$

.

$$m^2 = .8km^2 \cdot 1 \cdot 10^6$$

.

$$800000m^2 = .8km^2 \cdot 1 \cdot 10^6$$

.

$$h = \frac{A - 2r^2}{2r}$$

.

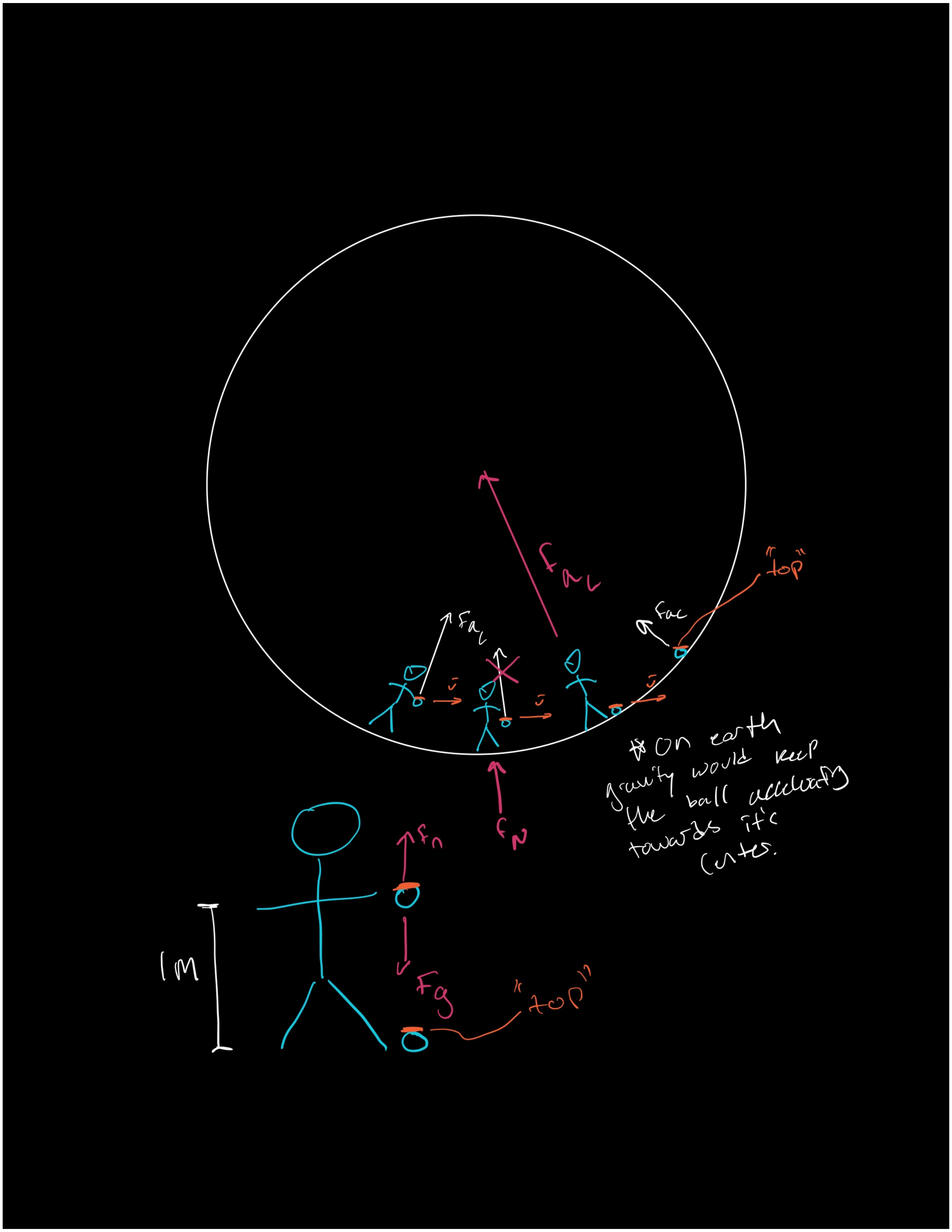
$$h = \frac{800000m^2 - 2 \cdot 417m^2}{2 \cdot 417m}$$

.

$$h = 542m$$

What to do in the can!?

Let's see what earthly activities are available in the cylinder colony...



While standing on the floor of the rotating drum a dropped ball is subjected to circular acceleration. From the perspective of the person dropping the ball, it will appear to drop straight down to the floor because both the person and ball are traveling at the same velocity. There is a slight perspective shift because the person changes direction but the ball does not change direction because it is no longer in contact with the system that is moving in a circle. So the ball would hit the floor on a different area than it would normally on earth. It seems the main reason for this is because gravity can act on objects without touching them, so the ball on earth would constantly accelerate toward the center of the earth, while in the space colony, the ball would continue moving through space how it was last interacted with by the contact forces of the system (the last contact from the system being the person’s hand).

Ball Drop Time

.

$$d = \vec{v_i}t + \frac{1}{2}at^2$$

.

$$t^2 = \frac{2d(m)}{a(\frac{m}{s^2})}$$

.

$$t = .45s$$

The difference between earth and a rotating drum would result in the same times to contacting the "floor" if the drum accelerating matches gravity, but the ball would appear to "rotate" while in space in a drum. This is best visualized in the free body diagram above where the ball continues its path once it's dropped.

Earth vs Space: thoughts on stability

1. Would the human vestibular system get disrupted while the body is constantly spinning leading to dizzyness, illusions etc... or would it only be affected near another gravitational force like the earth. So maybe only rotate the can away from large gravitational influences...?

2. How does the stability of a massive spinning drum behave in space. If there is an imbalence or a suddenly strange mass redistribution, etc... would the drum become unstable, tumble, or rotate wierd and possible break apart or just throw humans and gear around indefinetly. Seems like there would need to be some sort of strict weight and balance protocol. Thinking of this in terms of dynamic and static stbility as is true in aviation, need to look into this further.

Discussion/Final Thoughts etc

Experimenting with documentation via jupy lab. To continue learning take all oppertunities to explore questions or intrigues raised by curiosity. Work towards documenting in an organized manner.

```
In [ ]:
```