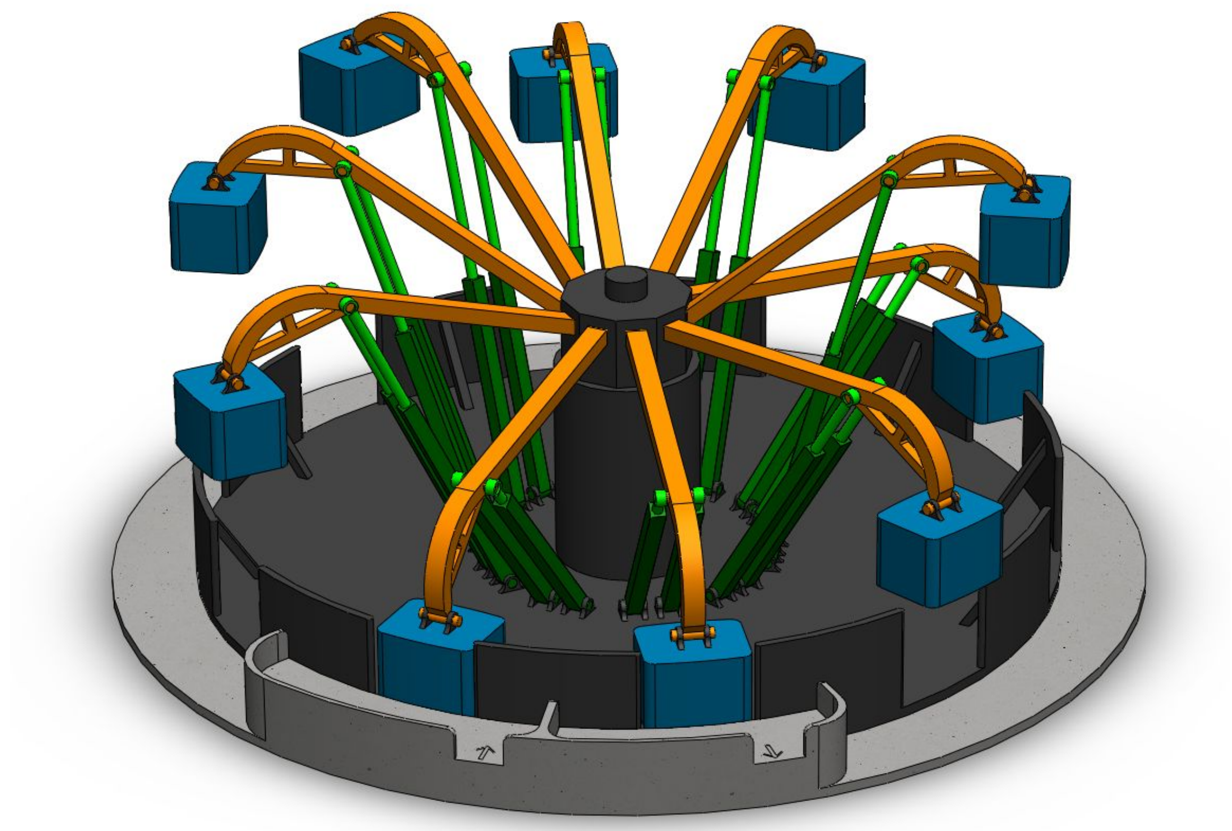
WORLD OF WATER

Team 10

Technical Analysis

Floating Theater Ride Concept



Ride Design Concept

Throughout *World of Water*, guests are encouraged to explore their environment, and we wanted to make sure that didn't stop in its headlining attraction, *Expedition Eco*. To accomplish this, we developed the Floating Theater, an entirely new kind of ride experience where guests can roam freely inside an enclosed but comfortable gondola, and even control its movement at certain points in the ride. Despite this innovation, the components of the ride system are standard in the industry to ensure the highest reliability and ease of construction.

The main thrill of the Floating Theater ride system comes from the vertical movement of the gondolas. Each gondola maintains an upright position as it hangs from an arm supported by two hydraulic cylinders which control the gondola's movement. For increased capacity and ease in loading, the entire system also continually rotates at a slow speed. Guests enter and exit the gondolas as they slowly move along the loading platforms.

Watch the accompanying video with filename "TEAM_10_VIDEO" to understand how our ride system works and what guests will experience!

Size & Capacity

The whole ride sits in a 30 x 40 m box, which includes the loading platforms, scenery, and maintenance bay. The gondolas are contained in a 13 m diameter circle. They also travel up to a vertical distance of 10.4 m, taking all of the vertical space in the ride's section of the building.

There are 10 gondolas which are suggested to each hold 8 people, which provides each family or group with an intimate and personalized experience. With a ride time of 5 minutes and 60 seconds of load and unload time, a gondola dispatches every 36 seconds. This results in a theoretical hourly capacity of 800 people per hour. With no seatbelts to check, loading is a quick and easy process.

The outer door of the gondola moves at just 0.22 m/s, which is in the acceptable range for moving platforms. The ride can also safely stop and start for any accessibility needs. In this case, the expedition is lengthened (but not paused) for the other riders in their respective locations, and once the ride starts moving again, it transitions seamlessly as it normally would.

See figures 1 and 2 for additional measurements and comments.

See page 9 for a summary of the ride statistics, including conversions to imperial units.

Fig 1 - Floating Theater Full Assembly

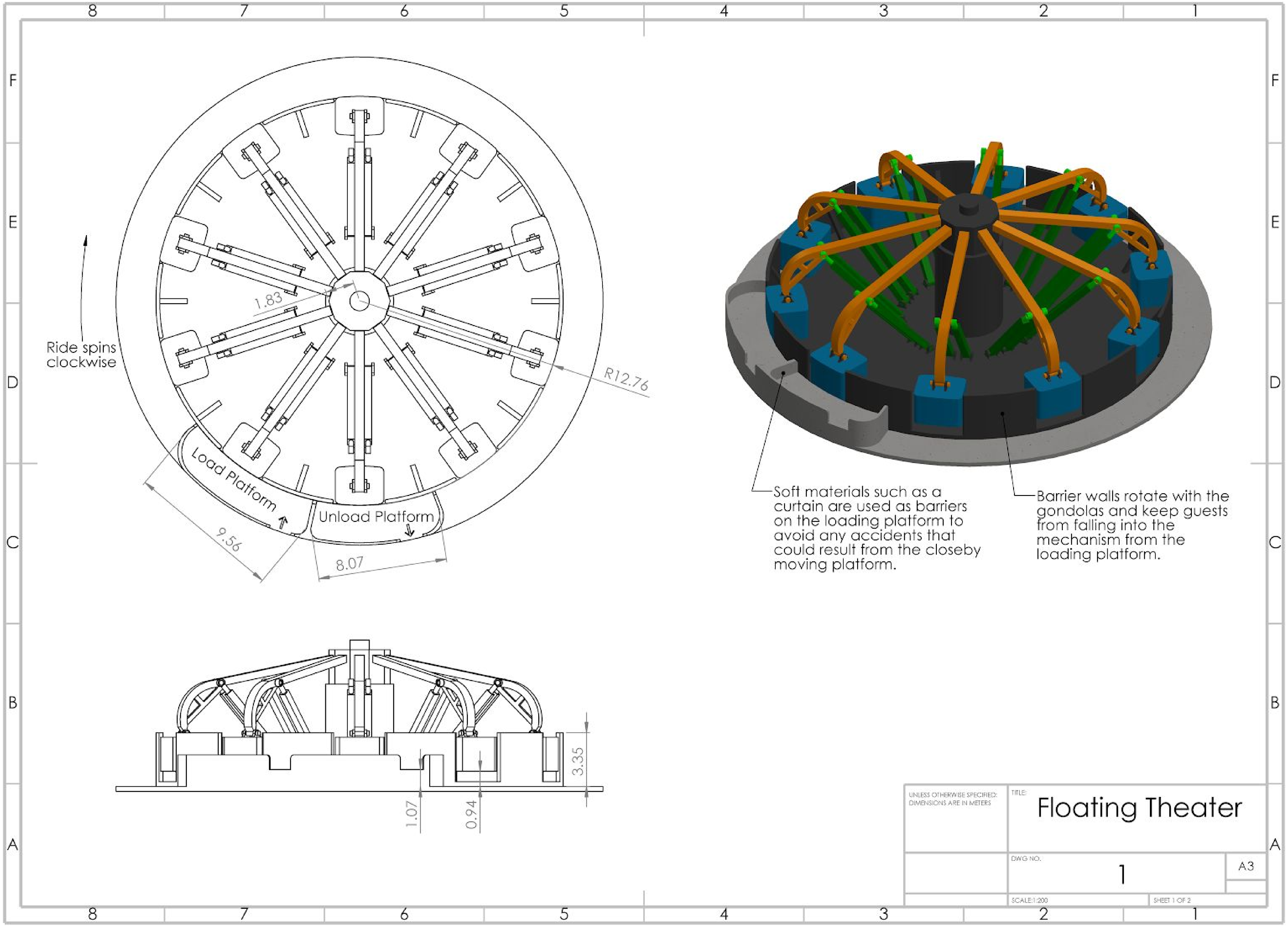
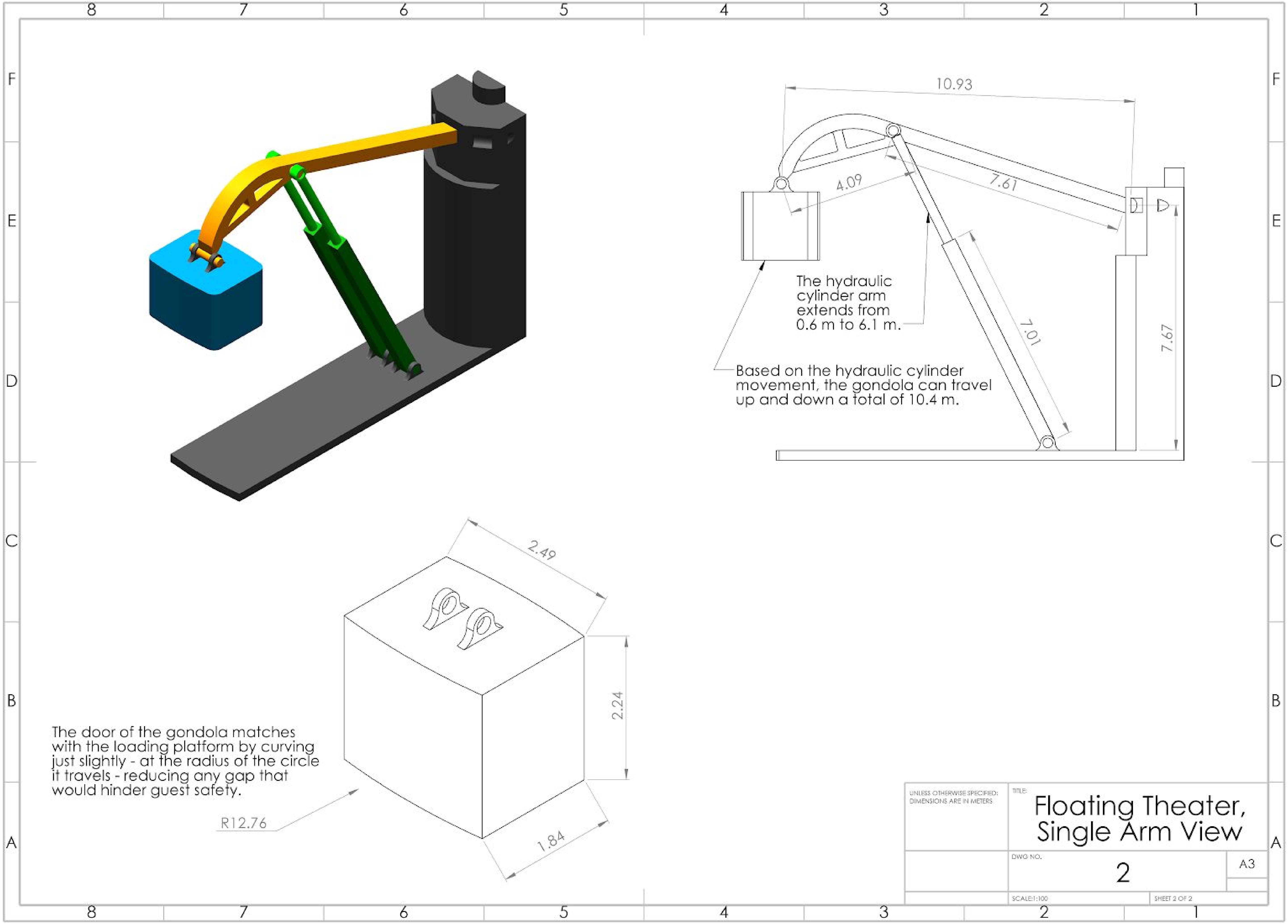


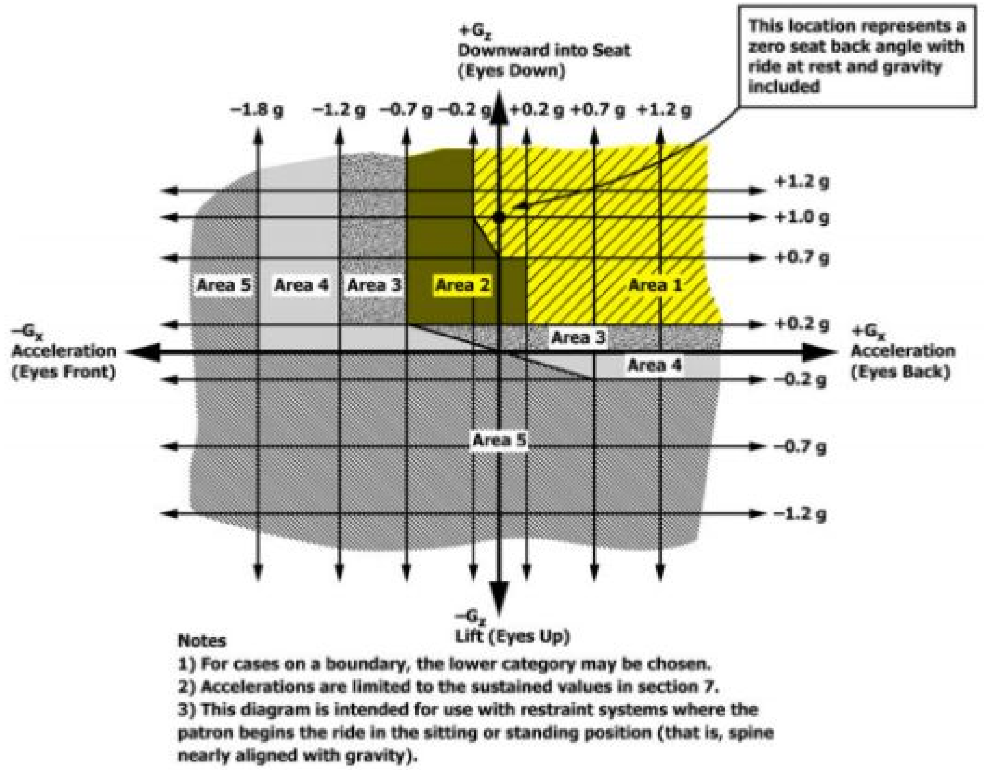
Fig 2 - Single Arm Section View



Accelerations

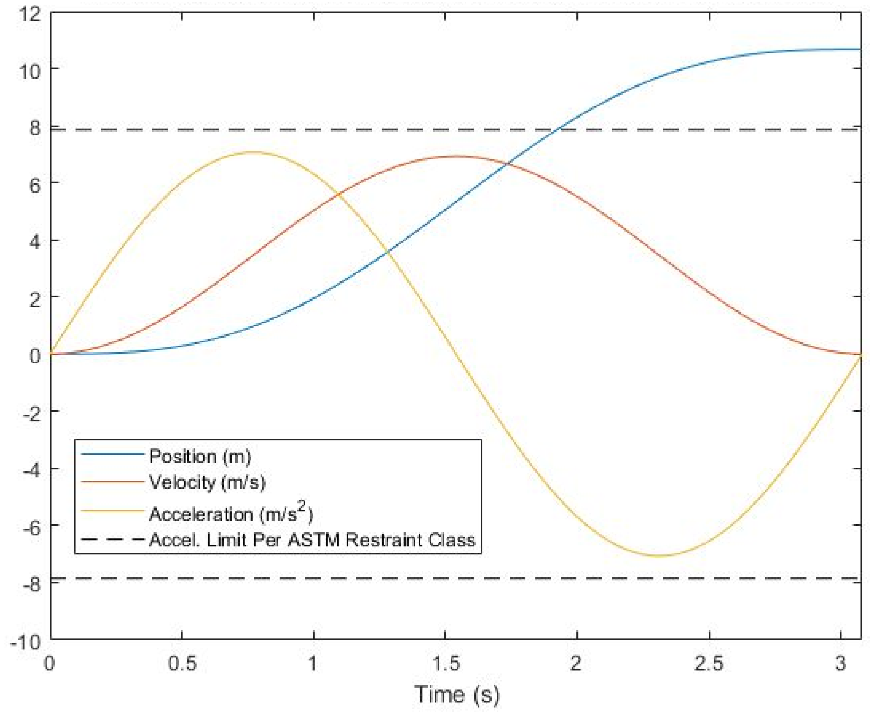
The lack of restraints in the gondolas adheres to the Class-2 restraint as described in ASTM F2291-18.6.4.3.5, where “patrons are provided sufficient support and the means to react to the forces, for example, handrails, footrest, or other devices.” Plenty of seating is provided for the 8 guests and handrails surround the cabin. ASTM F2291-18 outlines the limits of forces the guests can experience. Our riders experience up to +1.8 g and weightlessness up to +0.2 g, as seen highlighted in figure 3.

Fig 3 - Restrain Determination and Accelerations (Fig 2 from ASTM F2291)



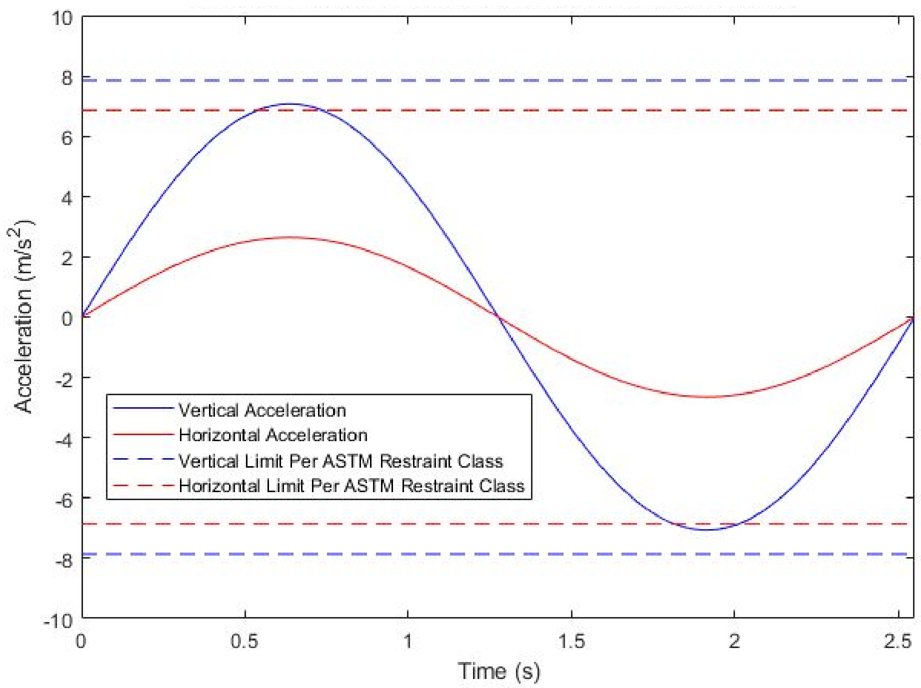
Using those limits, the maximum ride velocity and acceleration can be found. For this calculation we used a cycloidal position path to negate any discontinuities in velocity or acceleration. To traverse the entire vertical distance of 10.4 m, it must take at least 3.08 seconds. As seen in figure 4, the maximum velocity is 6.93 m/s and maximum acceleration 7.07 m/s^2, which stays under the acceleration limits including room for error.

Fig 4 - Position Profile for Gondola Movement with Maximum Acceleration



Because of the arm and pivot mechanism, any vertical movement also results in slight horizontal movement. To ensure that this horizontal acceleration is still within the ASTM defined limits, we can find a relationship between the vertical and horizontal distance covered over the same gondola movement using the arm's radius. To simplify the analysis, a linear relationship of the distances was found based on the arm's circular movement. The relationship between the horizontal and vertical accelerations can be seen in figure 5. The horizontal accelerations come nowhere near the limits for a Class-2 restraint, and are usually found within the Class-1 restraint limits, which ensures our system is safe for all guests.

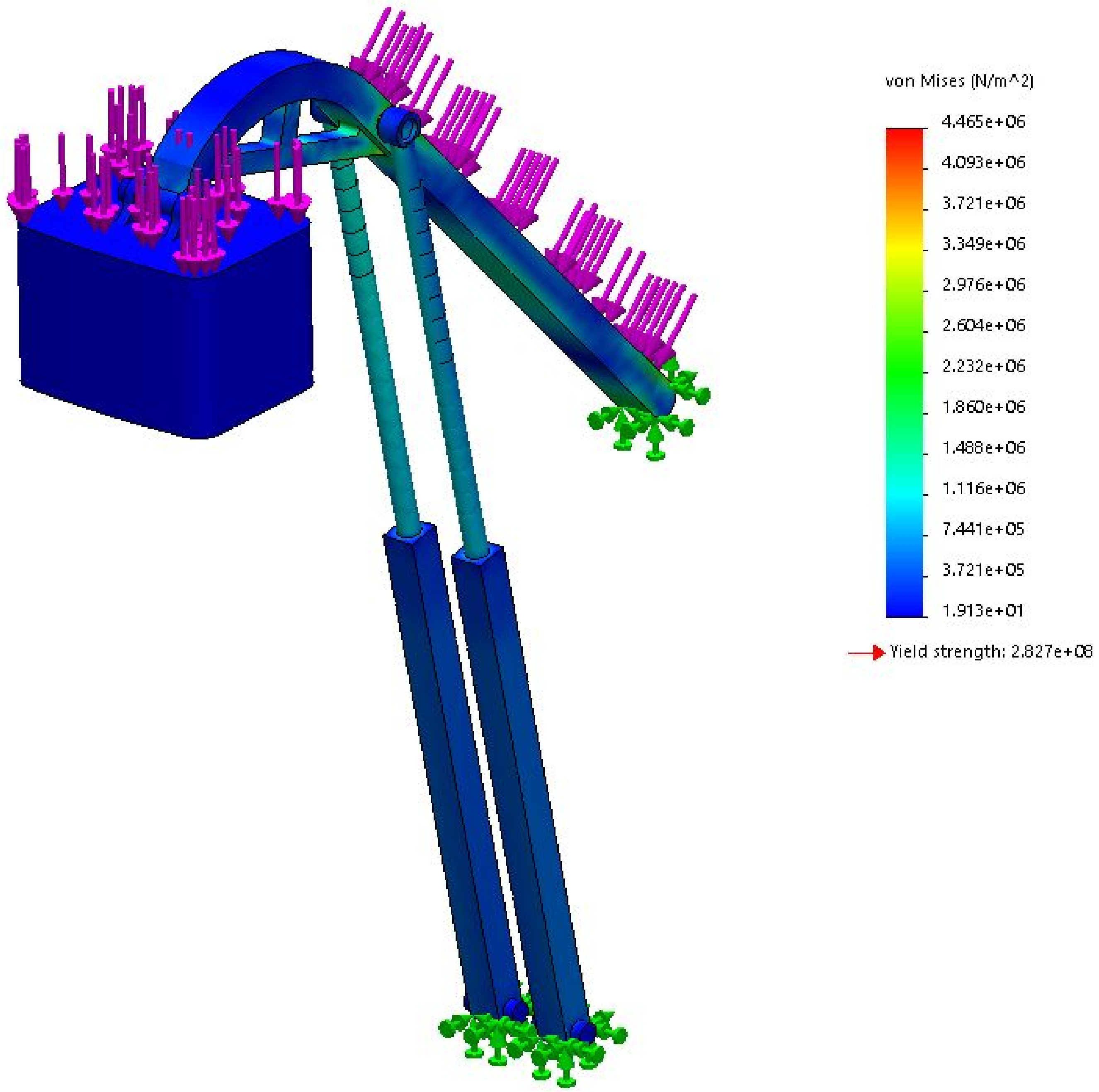
Fig 5 - Maximum Vertical and Horizontal Accelerations



Forces & Weight

While the suggested capacity is 8 people per gondola, it is rated for over 12 people at an average of 75 kg per guest. Based on aerial tramway and elevator safety code EN-81, the base weight (mass) of the gondola is around 1500 kg. With 4 projectors at 73 kg each, the total car mass equals 1792 kg. When multiplied by a gravity force, each gondola plus the arm results in 115.6 kN of downward force. This weight was included in an Finite Element Analysis of the gondola and arm, as seen in figure 6. This arm design only reaches 4.465 MPa, well under the yield strength for a common steel.

Fig 6 - FEA of Gondola, Arm, and Hydraulic Cylinders



Power & Daily Cost

According to the FEA, this results in a 103 kN force on the pair of pistons. We can find the power the system requires using

$$\text{Power} = \frac{\text{Work}}{\text{Time}} = \frac{\text{Force} \cdot \text{Displacement}}{\text{Time}}$$

When the gondola moves its maximum distance of 10.4 m, the piston rod moves 5.49 m. For one full stroke up, the power the piston requires is 91.5 kW. If we assume that an average 5 minute ride cycle goes up and down fully 12 times, the power required for the whole ride system (all 10 gondolas) to do one full ride cycle is 28.5 kW. It should be noted that this value assumes that the hydraulic cylinders have no power consumption when they are not moving, so this value will probably be higher in a real setting.

Given that the ride runs for 8 hours on a given day without stopping, the power needed for one day is 228 kWh. With the average commercial electricity rate in Vancouver, the cost for one day of ride operation is 12.92 CAD. In an effort to practice what we preach, the power for the ride system can be covered completely by solar panels placed on the roof of the building. If we assume 50% of the roof is solar, then it can cover over 400% of the ride's daily electricity usage on an average day. The excess electrical power generated helps to cover other areas of the attraction, like the preshow room and overall lighting.

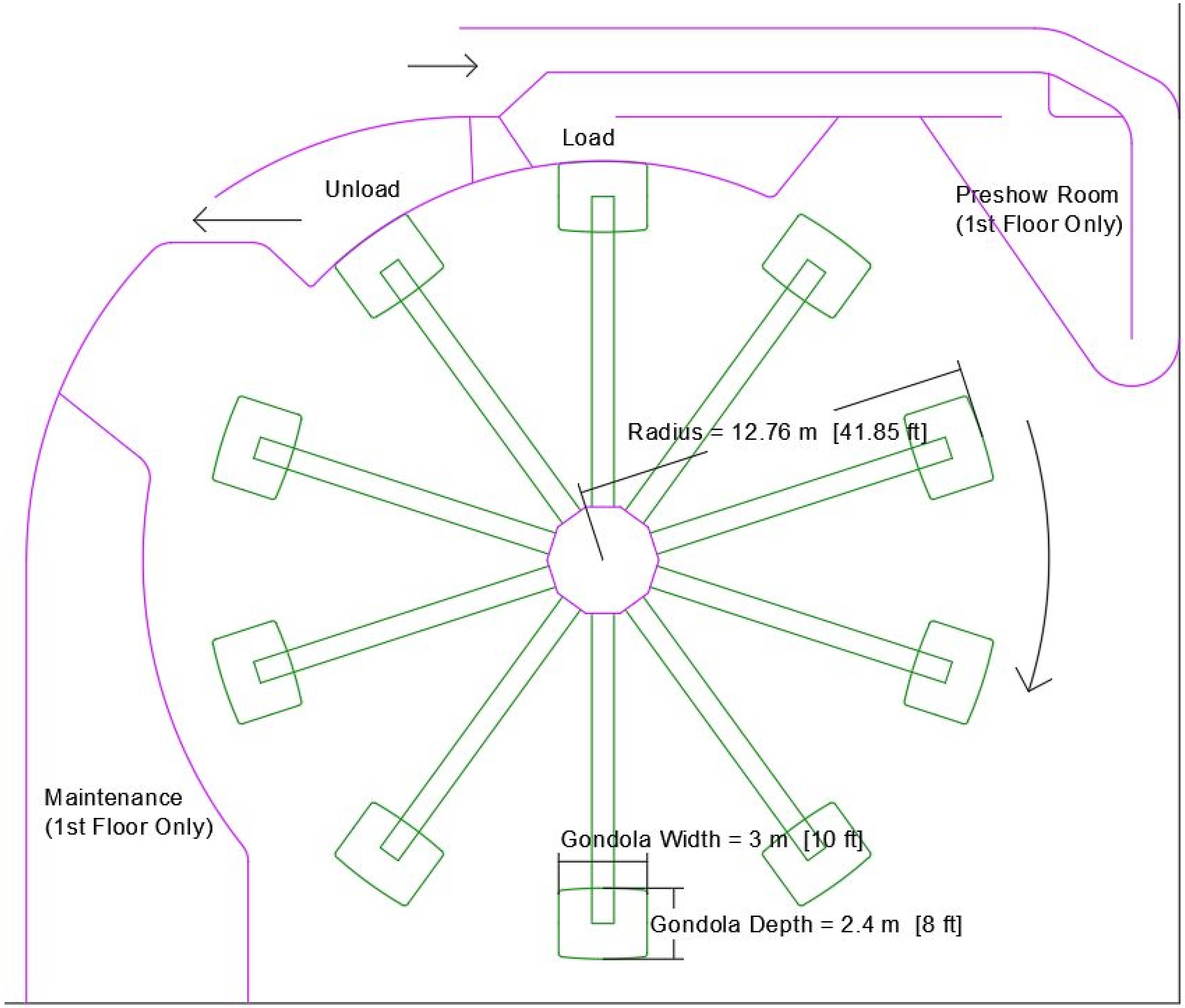
Summary of Ride Statistics

Parameter	Value	Reasoning or Formula
Time		
Ride Time	5 min	Appropriate for full experience with acceptable capacity. Can be adjusted by *Seas of Imagination* based on preference and even daily attendance.
Load + Unload Time	60 s	35s load, 25s unload. No seatbelts means quick load time.
Capacity		
Number of Cars	10	Chosen based on ride area and spacing between cars.
Capacity per Car	8	Optimal capacity for best personalized experience and throughput. Each car is rated to hold up to 12 adults.
Theoretical Hourly Capacity	800 pph	8 people per car / Dispatch every 36s.
Size		
Radius (To Car Door)	12.76 m [41.85 ft]	See diagram.
Rotation Speed (At Car Door)	0.22 m/s [0.5 mph]	2π * ride radius / (ride time + load and unload time).
Weight & Force		
Car Rated Mass Capacity	1250 kg [2755 lbs]	Rated for 12+ people, with average 75 kg mass.
Car Mass	1792 kg [3951 lbs]	1500 kg gondola + 292 kg technology.
Weight Force Per Car	17.6 kN [3948 lbf]	Car Mass * 9.8 m/s^2.
Mass of Arm	10000 kg [11 ton]	Based on volume of the arm modeled in Solidworks, the density of an average steel alloy, and assuming a lighter, truss structure than the simple Solidworks model.
Weight Force of Arm + Car	115.6 kN [25853 lbf]	This weight force is put into Solidworks to find the forces acting on each hydraulic cylinder.
Power		
Power for 1 Full Ride Rotation	15.7 kW	Based on power used for hydraulic cylinders for up and down motion, drive tires for the ride body rotation, and technology systems in each gondola.
Daily Ride Power Usage	228 kWh	Assumes the ride runs without stopping for an 8 hour day.
Daily Ride Electricity Cost	12.92 CAD [9.18 USD]	Based on 0.0567 CAD per kWh, the commercial rate for electricity in Vancouver. Assumes 8 hour day.
Solar Panel Power Output	400% Ride Power Use	Assumes 50% of roof is solar panels at average solar power output.

See the matlab code index for more statistics and detailed analysis.

Index - Ride Layout Including Preshow and Maintenance Building

Note: Above the preshow and maintenance rooms, on levels 2 and 3, is additional ride scenery.



Index - Matlab Code

```
clear all
clc

%% Given parameters, discussed in document.
cycle_time = 360; %(s) Ride time + load, unload = one cycle
r = 12.76; %(m) from center of ride system to outer gondola door
gondolas = 10;
gondola_capacity = 8;
rated_mass = 1250; %(kg) each gondola is rated for over 12 people, or 1250 kg
gondola_mass_wotech = 1500; %(kg) based on elevator cars and rated mass
projectors = 4;
projector_mass = 73; %(kg) mass of one projector
arm_mass = 10000; %(kg) approx mass of one gondola arm including a truss structure


%% Ride Time, Size, Capacity, Mass, etc.
%Capacity
THRC = gondola_capacity / (cycle_time / gondolas) * 3600;

%Loading platform speed (velocity at car door)
circumference = 2*pi*r; %m
door_speed = circumference / cycle_time; %m/s

%Total gondola mass & weight force
gondola_mass = gondola_mass_wotech + projector_mass*projectors; %kg
gondola_weight = gondola_mass * 9.8; %N

gondola_arm_mass = gondola_mass + arm_mass; %kg
gondola_arm_weight = gondola_arm_mass * 9.8; %N


%% Position, Veloc, Accel Graphs for max accel
% per astm, max negative acceleration for our restraint class is 7.85 m/s^2
max_accel = 7.85;

% We want to find the max acceleration for our max length (resulting in the
% max velocity). Use vertical traversable length of 10.67 m (35 ft).
L = 10.67;

% find time to reach destination, to, based on max acceleration
% using max_accel = 2*pi*L / to^2. We will use our max acceleration to be
% 0.9 the limit value, to maximize comfort for our guests and ensure it
% stays under the limit.
to = sqrt(2*pi*L/(max_accel*0.9));
```

```
% s profile is based on cycloidal motion,
% where s = L(t/to - 1/2*pi * sin(2*pi*t/to)
t = 0:.01:to;
s = L*(t/to - 1/(2*pi)*sin(2*pi*t/to));

% v and a are first and second derivatives of position s
v = (L/to)*(1-cos(2*pi*t/to));
a = (2*pi*L/to^2)*sin(2*pi*t/to);

% plot graphs, including accel limit
l = zeros(1,length(t))+max_accel;

figure(1)
plot(t,s,t,v,t,a)
hold on
plot(t,l,'--k',t,-l,'--k')
title('Position Profile for Gondola Movement with Maximum Acceleration')
legend({'Position (m)', 'Velocity (m/s)', 'Acceleration (m/s^2)', 'Accel. Limit Per ASTM Restraint Class'}, 'Location','southwest')
ylim([-10 12])
xlim([0 to])
xlabel('Time (s)')


%% Vertical vs Horizontal Accelerations
% Analyze top half of movement (bottom half should be similar or same).
% Assume linear correspondence between vertical and horizontal motion.
% For an arm movement radius, on outer gondola door, of 12.76 m (41.85 ft),
% Vertical movement of 7.32m corresponds with horizontal movement of 2.74m.
Lv = 7.32;
Lh = 2.74;

% For our ASTM restraint class, the max forward/backwards accel is -.7g.
max_h_accel = 6.86;%m/s^2

% find time to reach destination, to, based on max acceleration
% using max_accel = 2*pi*L / to^2.
to2 = sqrt(2*pi*Lv/(max_accel*0.9));

% calculate accelerations like done previously based on to.
t2 = 0:.01:to2;
av = (2*pi*Lv/to2^2)*sin(2*pi*t2/to2);
ah = (2*pi*Lh/to2^2)*sin(2*pi*t2/to2);

% plot graphs, including accel limit
l = zeros(1,length(t2))+max_accel;
lh = zeros(1,length(t2))+max_h_accel;
```

```
figure(2)
plot(t2,av,'b',t2,ah,'r')
hold on
plot(t2,l,'--b',  t2,lh,'--r',   t2,-l,'--b',  t2,-lh,'--r')

legend('Vertical Acceleration', 'Horizontal Acceleration', 'Vertical Limit Per ASTM Restraint Class', 'Horizontal Limit Per ASTM Restraint Class',
'Location','southwest')
ylim([-10 10])
xlim([0 to2])
xlabel('Time (s)')
ylabel('Acceleration (m/s^2)')
title('Maximum Vertical and Horizontal Gondola Accelerations')


%% Power Analysis
% For the power analysis, we will start by using the full-height position
% and acceleration information.

% Solidworks was used to find the forces acting on the hydraulic cylinders.
% Each arm has two pistons.

% solidworks calculated force on pair of hydraulic cylinders
cyl_force = 102647; %N

% power = force * distance / elapsed time
cyl_distance = 5.49; %m, Cyl rod extends up to 18 ft or 5.49m.
power_1stroke_pair = cyl_force * cyl_distance / to; %W
power_1stroke_single = power_1stroke_pair/2;
power_1stroke_total = power_1stroke_pair*gondolas;

% Now we're going to apply these numbers to the whole system. We'll assume
% that one ride cycle goes up and down fully 12 times. This will account
% for when it does go up and down fully, as well as when it moves up and
% down only a little to simulate movement.
rideupdown = 12;

power_onesystemcycle = cyl_force * gondolas * cyl_distance / cycle_time;

%other ride technology power consumption
power_rotation = 11000;
power_screens = 450*projectors + 4*gondolas*1/2;
power_total = power_onesystemcycle + power_rotation + power_screens;
```

```
% One day power usage assuming perfect conversion of
% electricity into movement forces. Assuming an 8-hour day,
power_oneday = power_total * 8 /1000; %kWh
cost_electricity = 0.0567; % $CAD/kWh
cost_oneday = power_oneday * cost_electricity;

%Solar option for electricity reduction
solar_onepanelproduce = 0.538; %avg kWh in one day per 1 m^2 of solar panel
roof_size = 3600; %m^2
solar_roof_portion = 0.5; %portion of roof covered by solar panels
solar_daily_output = roof_size * solar_roof_portion * solar_onepanelproduce;
solar_help_fraction = solar_daily_output/power_oneday;
```

Index - Matlab Output

Note: Graphs displayed in figures 4 and 5.

Name	Value	Name	Value
a	1x309 double	power_1stroke_pair	1.83E+05
ah	1x256 double	power_1stroke_single	9.15E+04
arm_mass	10000	power_1stroke_total	1.83E+06
av	1x256 double	power_oneday	2.28E+02
circumference	80.17344452	power_onesystemcycle	1.57E+04
cost_electricity	0.0567	power_rotation	11000
cost_oneday	12.91565558	power_screens	1820
cycle_time	360	power_total	2.85E+04
cyl_distance	5.49	projector_mass	73
cyl_force	102647	projectors	4
door_speed	0.2227040126	r	12.76
gondola_arm_mass	11792	rated_mass	1250
gondola_arm_weight	1.16E+05	ridestrokes	24
gondola_capacity	8	roof_size	3600
gondola_mass	1792	s	1x309 double
gondola_mass_wotech	1500	solar_daily_output	1.94E+03
gondola_weight	1.76E+04	solar_help_fraction	4.251296395
gondolas	10	solar_onepanelproduce	0.538
l	1x256 double	solar_roof_portion	0.5
L	10.67	t	1x309 double
lh	1x256 double	t2	1x256 double
Lh	2.74	THRC	800
Lv	7.32	to	3.080463454
max_accel	7.85	to2	2.551463686
max_h_accel	6.86	v	1x309 double