# PULSE

## Payload Uplift, Lateral Separation and Extraction

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Technical Review for Johnson Space Center

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# Background

Potential usage,  state-of-the-art solutions, requirements

# Potential Usage

# Lunar Habitation

Artemis program, plans annual mission to the moon, which will require heavy on-site infrastructure

Potential Usage of PULSE for Artemis Program:

- Deploying Permanent Lunar Habitat
- Deploying Lunar Terrain Vehicle
- Deploying Nuclear Fission Surface Power Unit

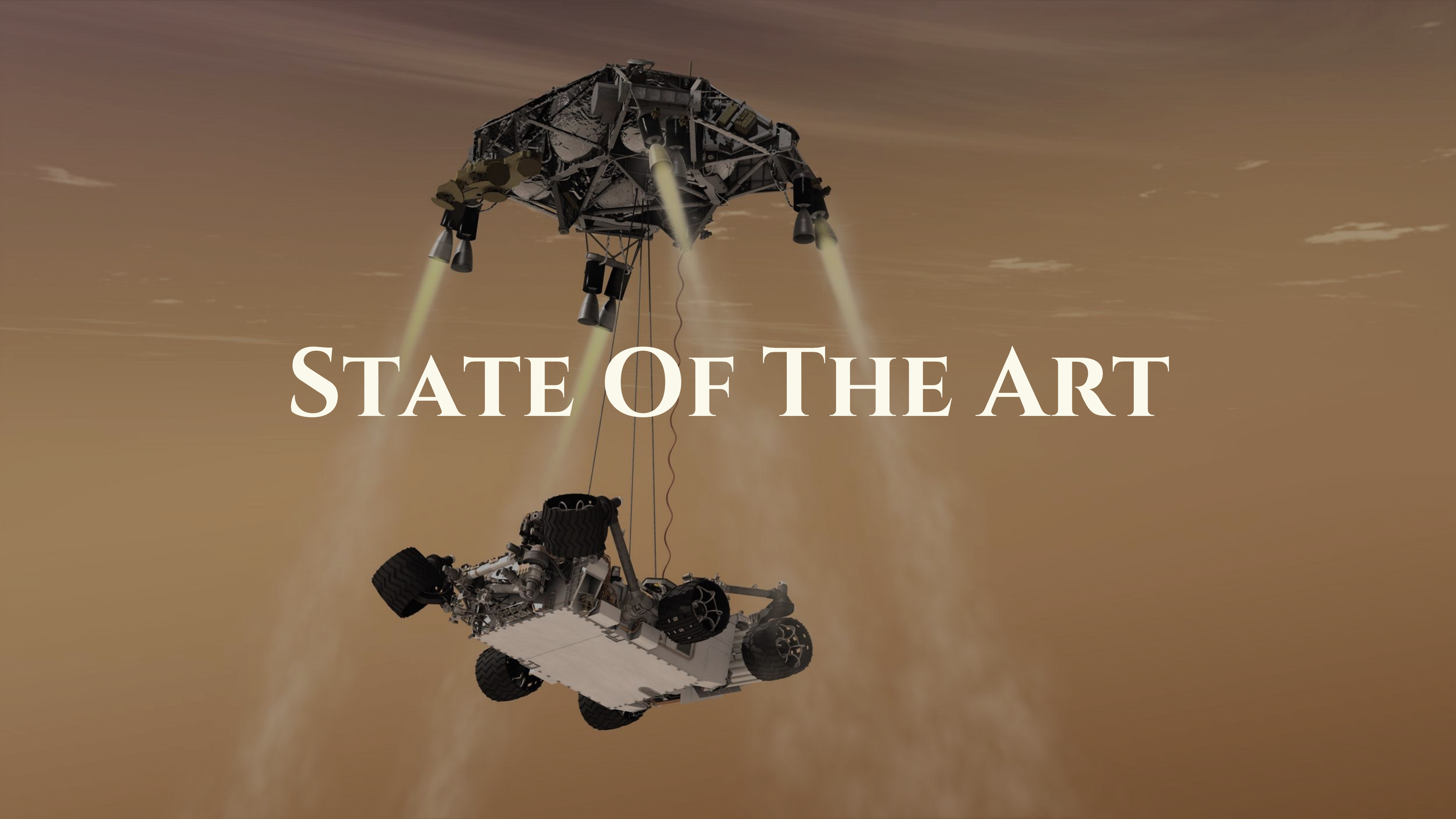
# Mars Habitation

NASA's first manned mission is planned for late 30s, and early 40s

Long distance from the earth will require placing heavy infrastructure before astronauts arrival

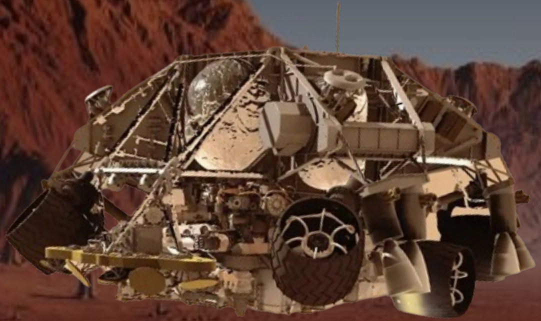
Potential use of PULSE:

- Deployment of Common Habitat
- Deployment of Heavy Rovers


State Of The Art

# Lunar Landers

# Sky Crane

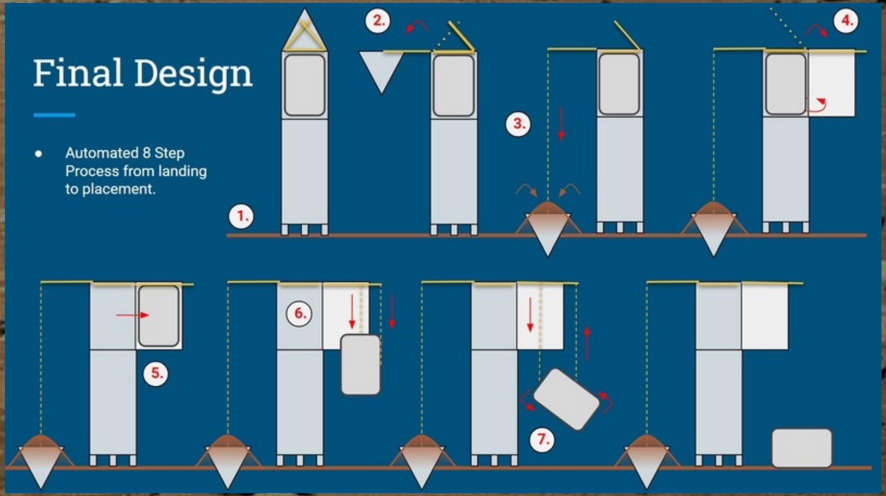


Cargo: 1t

## Issues:

- Unable to lift heavy cargo
- Designed to work from high altitudes
- Not compatible with the lander

# Mars Crane




## Issues:

- Requires on-site infrastructure
- Places habitat near starship, not allowing for future lunches

# Requirements

Requirements for the PULSE system:

- Fits into the Starship lander
- Total mass does not exceed 100t
- Is capable of deploying 90t common habitat
- Moves the habitat to a safe distance
- Rotates the habitat into a horizontal position
- Safely lands the habitat with a final velocity close 0 m/s

# 02

# Our Design

CAD designs, ConOps, Calculations, and Justifications

# High Level Overview

## 1. System Deployment

Removing the fairing, and unfolding the arms

## 2. Decoupling

Using pressurized methane to decouple the system from the Starship

## 3. Releasing Tethers

Releasing the habitat on Tethers

## 4. Engine Firing

Firing the engine to first accelerate, and then slow down

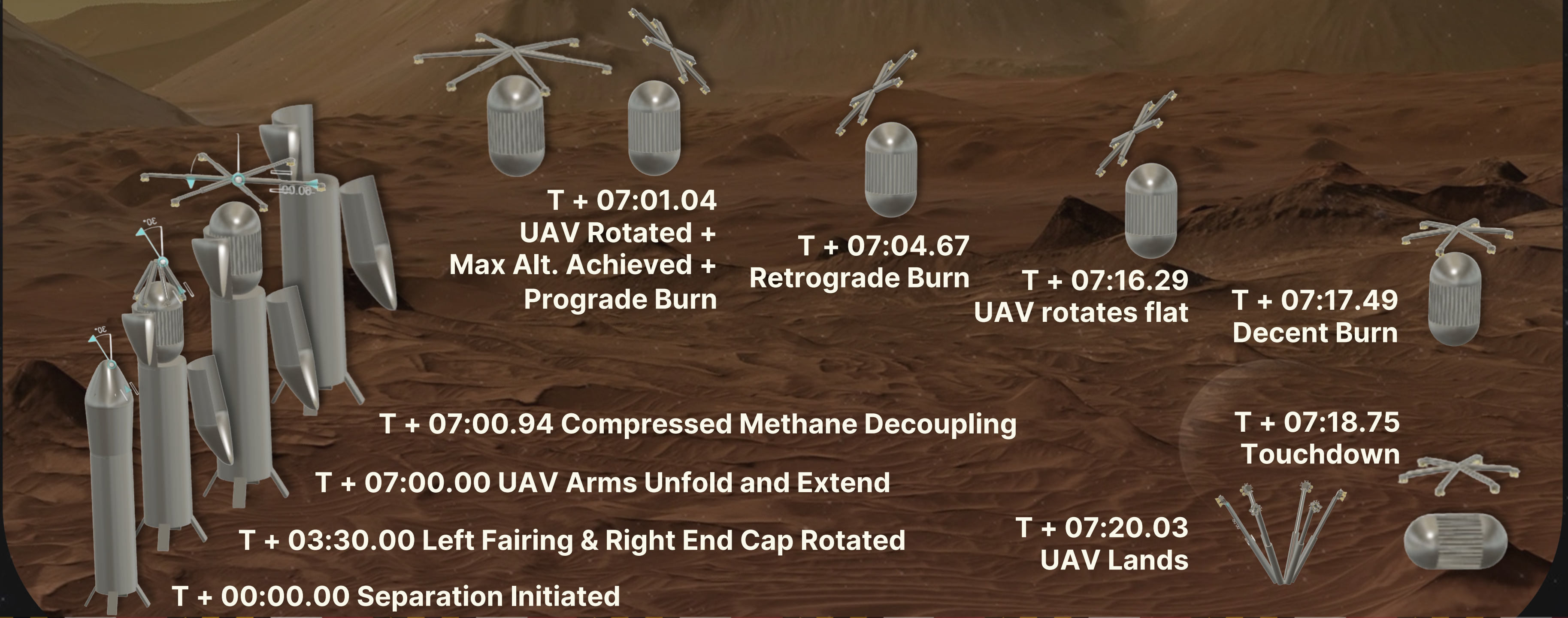
## 5. Rotating Habitat

Rotating the habitat with tethers

## 6. Habitat Landing

Performing the final burn with maximum thrust to safely land the habitat

# CONCEPT OF OPERATIONS



# Compressed Methane Decoupling

## Raise system up 2 meters

### Find Required PULSE Velocity

$$v^2 = 2ad_v$$

a = 3.71 m/s^2 ; acceleration due to Martian gravity

d = 2m ; distance

v = 3.85 m/s ; initial velocity of UAV/Habitat

### Find Required Compressed Methane Velocity

$$v_a = \sqrt{\frac{2 \times (\frac{P_1}{\rho_1} - \frac{P_2}{\rho_2})}{R_S(\gamma - 1)}}$$

P_1 = 30,000,000 Pa = 300 bar ; initial pressure (max is 400bar)

rho_1 = 65 kg/m^3; initial density at 300bar, 150K

P_2 = 700 Pa = 7 mbar ; final pressure (mars atmosphere)

rho_2 = 0.02 kg/m^3; final density (mars atmosphere)

gamma = 1.4 ; specific heat ratio of air at 300bar, 150K

R_S = 0.518 J/(T*K) ; specific gas constant

v_a = 1434 m/s; velocity of air (calculated above)

### Find Required Compressed Methane Mass

$$m_h v_h = m_a v_a$$

m_h = 100 T ; mass of habitat & hexarocket

v_h = 3.85/1.7 m/s ; velocity of habitat & hexarocket (calculated above)... dividing by 1.7 due to multiplier effect from surface

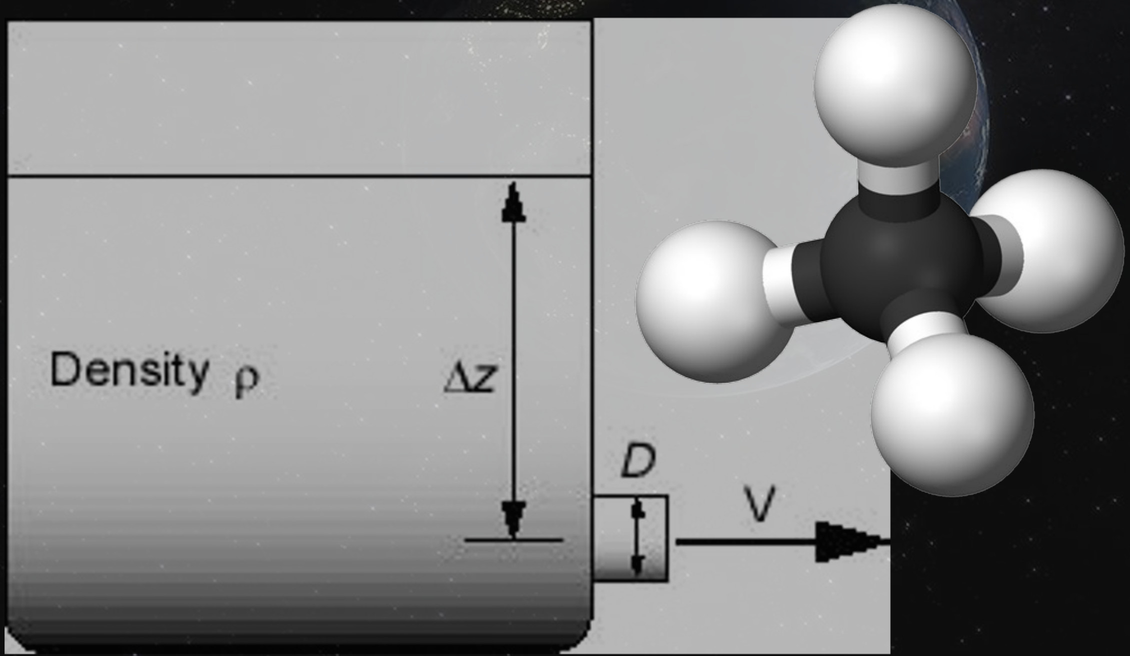
v_a = 1434 m/s; velocity of methane (calculated above)

m_a = 0.168 T; mass of methane required

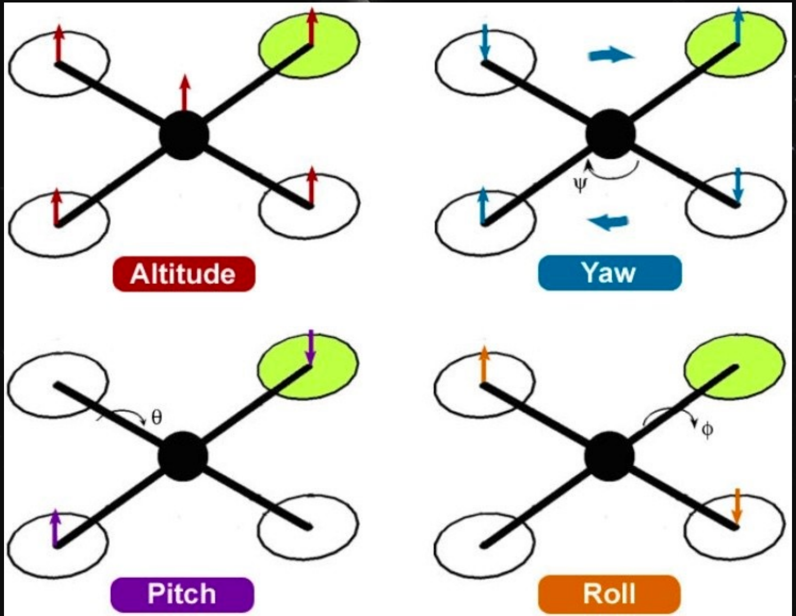
### Apply Relevant Safety Factors

Carry 120% the required methane in case of error or damage

**0.2T compressed methane**



# Decoupling Part 2




## Turning to 45 deg

### Calculate Mass Moment of Inertia

$$\int_a^b r \cdot dm$$

Assume fuel is a 3m radius circle, mass 7T;
Each of 6 arms is a 16m long cylinder, mass 150kg;
Each of 30 thrusters are at a distance of 14.5m, mass 35kg.

I ~ 31.98 Tm^2

### Calculate Angular Acceleration due to Gravity

$$\alpha_a = \theta'' = mgd\sin\theta$$

m = 10T ; mass of UAV

g = 3.71 m/s^2 ; acceleration due to Martian gravity

d = distance between C_m and C_t

$\theta$ is variable ; angular position (pitch)

### Approximate Angular Impulse

This is probably an unsolvable problem

$$\omega_f^2 = \omega_i^2 + 2\alpha_g\Delta\theta$$

Large (well over 2x) overestimation to assume a constant $\alpha$ from $\theta = \pi/8$. Thus for $\alpha_g = mgd\sin\theta = -42.6$ rad/s^2

$\omega_f$ = 0 rad/s; angular velocity when in flight ready position

$\Delta\theta = \pi/4$ ; change in angular position (0 deg to 45 deg)

$\omega_i$ = 8.18 rad/s; angular velocity when horizontal

### Calculate Angular Acceleration due to Gravity

$$\tau = Fr = I\alpha$$

r = 14.5 sin(60deg) m ; distance of thruster to center of thrust

I = 31.98 Tm^2; acceleration due to Martian gravity

$\alpha_a$ = 8.18/0.1 = 81.8 rad/s^2

F = 208.3 kN

### Fuel Needed for Rotation Maneuver

$$\Delta m_p = \frac{F \cdot t_r}{I_{sp} g}$$

F = 208.3 kN ; required force of thruster

t_r = 0.1 s ; thruster burn time aka rotation time

**16.3 kg propellent required**

## Move system laterally to safe distance

### Determine Arc Time

$$v_{fy} = v_{iy} + a \times t_x$$

v_fy = 0 ; final upwards velocity at top of parabola

v_iy = 3.85 ; initial upwards velocity at top of rocket

a = -3.71 m/s^2 ; acceleration due to Martian gravity

t_x = 1.0377s ; time between compressed methane fire and top of parabola

### Determine Safe Distance

$$d = F_S \times (l_a \cos\theta + l_p \sin\theta)$$

l_a = 14.5m ; distance of center to engine / effective arm length

l_p = 20m ; length of plume

$\theta = \pi/4$ rad ; pitch of UAV

F_S = 1.1 ; Safety factor on distance

Note that even if the thrusters are fired directly over Starship, the plume theoretically wouldn't hit starship, due to the extension of each arm. However, these measures are for additional safety in case there is unwanted yaw.

d = 32.27 m

### Determine Velocity Required

$$d = v_x \times t_x$$

d = 32.27m ; lateral distance required

t_x = 1.0377 s; time to vertex

v_x = 46.96 m/s; velocity

### Find Required Compressed Methane Mass

$$m_h v_h = m_a v_a$$

m_h = 100 T ; mass of habitat & hexarocket

v_h = 31.10/1.7 m/s ; velocity of habitat & hexarocket (calculated above)... dividing by 1.7 due to multiplier effect from surface

v_a = 1434 m/s; velocity of methane (calculated above)

**1.28 T compressed methane required**

## Find Remaining Mass Budget for Fuel

**6.54 T mass available for propellent**

# Fuel And Distance Calculations

$$\Delta m_p = m(\frac{\sqrt{2} \cdot t_3}{I_{sp}} + \frac{v_t}{(1 - \frac{mg}{T_{max}})I_{sp} * g})$$

$$d = x_0 + \frac{a_x t_a}{2} + v_{x0} t_a + (v_{x0} + a_x t_a)t_b - \frac{a_x t_b}{2}$$

# Mass overview

## Structure Mass

2 tons

## Methane Mass

1.5 tons

## Fuel Mass

6.5 tons

# 03

# Considerations

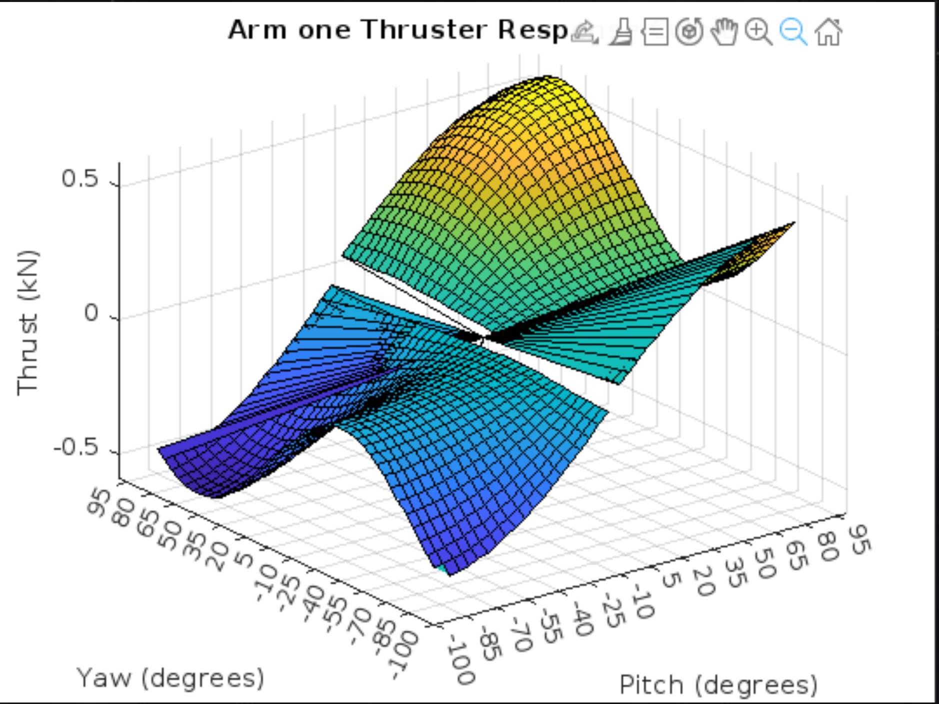
# Considerations

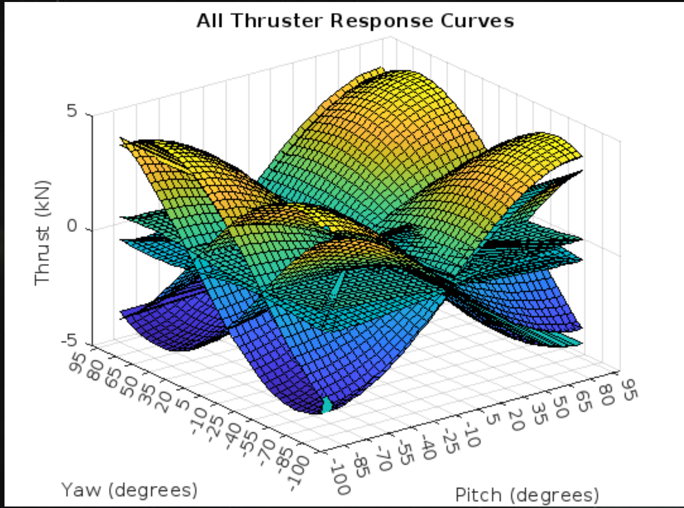
1. Decoupling before landing
2. Early UAV Separation
3. Decoupling System Alternatives
    1. Mechanical/Magnetic
    2. Explosives
4. Degrees of Human Control
5. Actual Capacity of Starship (reusable configuration)
    1. Relatively certain it can be pushed beyond 100 T

# 04

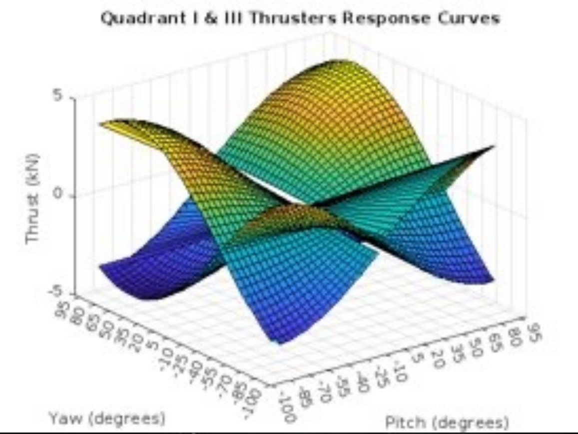
# FUTURE PLANS

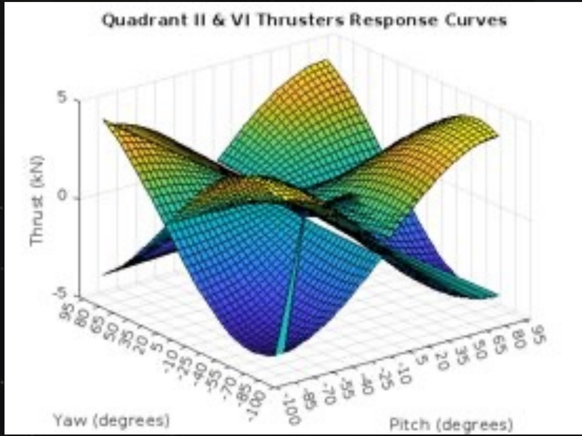
# Thruster Response Curves (Testing)

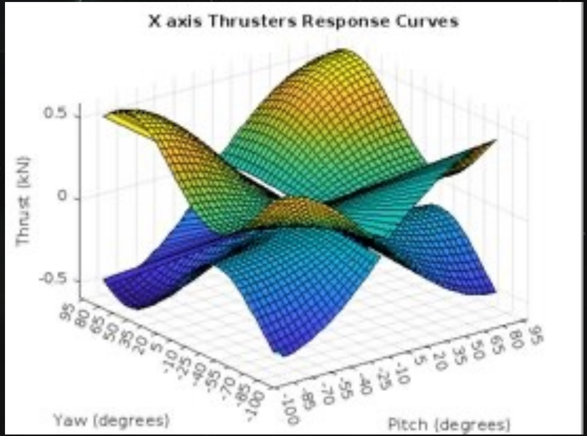


# Stabilization Through Differential Thrust



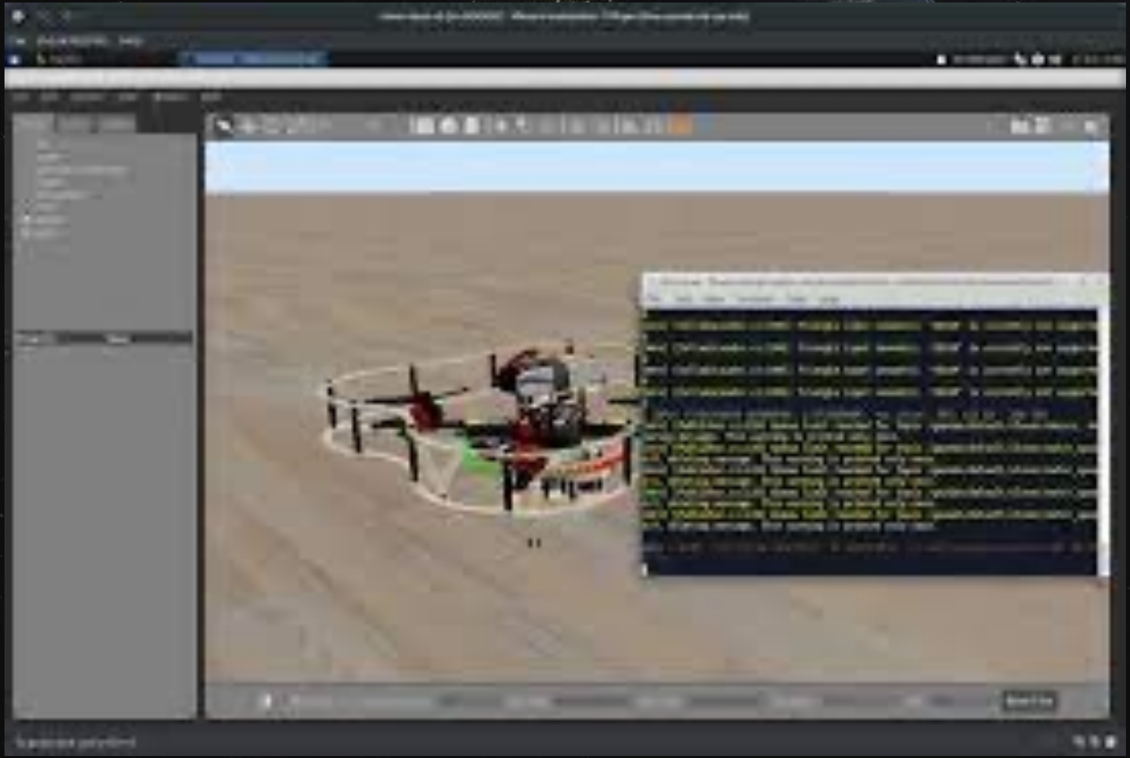



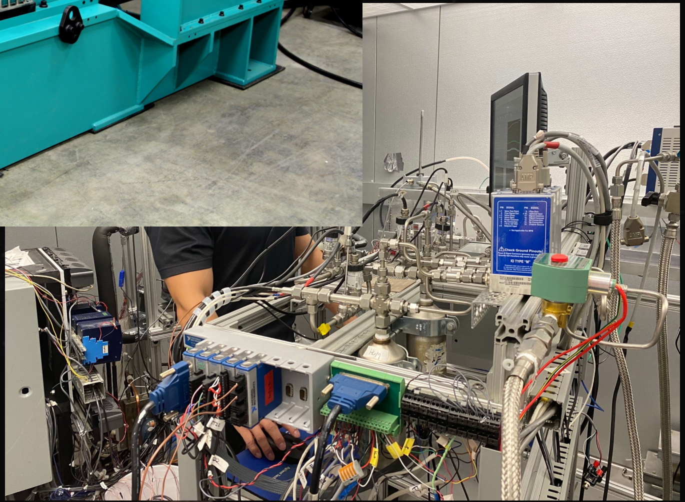

The above graphs show the thrust required from each engine to hold any given pitch while travelling at any given direction.

# Product demo

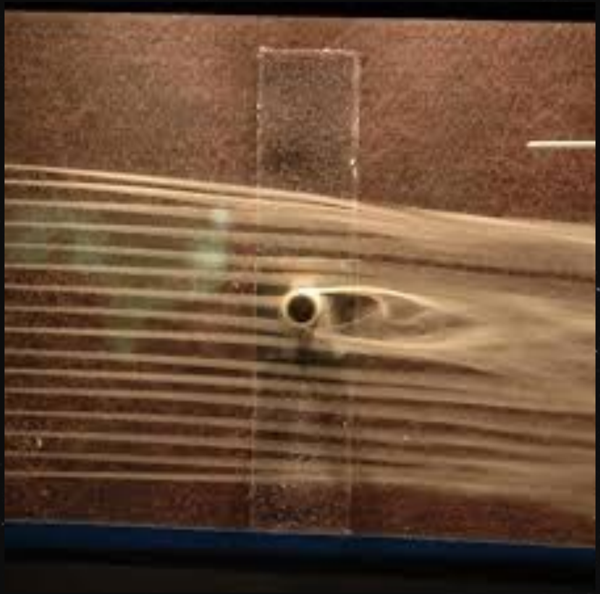
GAZEBO



# Environmental Testing



# Drag Testing



# SCALE TESTING

# Thank You!

Any Questions