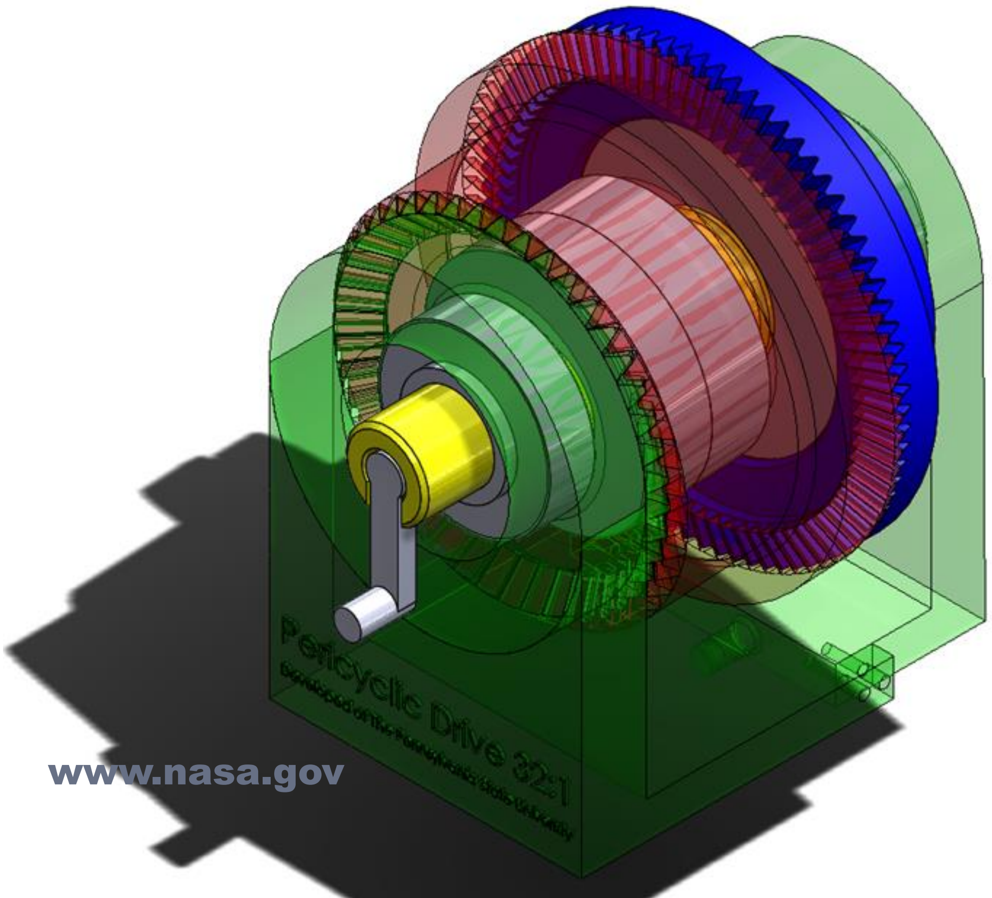
# Design Space Exploration of Pericyclic Transmission with Counterbalance and Bearing Load Analysis

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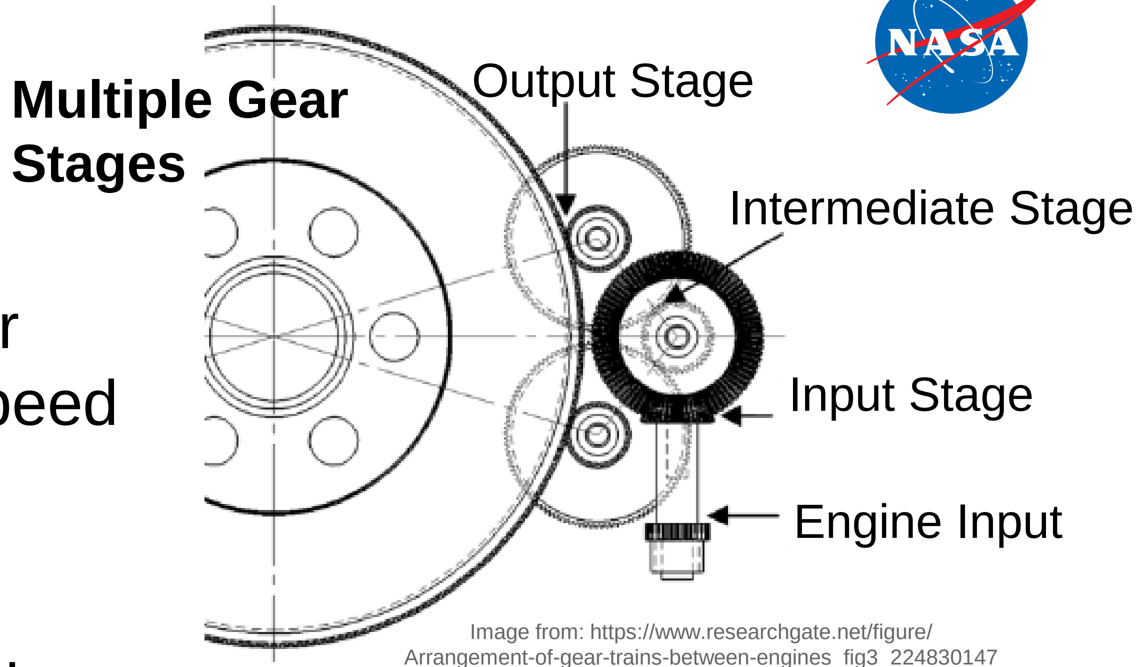
Prepared for AHS Forum 74, May 2018 Phoenix, AZ

# Motivation

- Rotorcraft transmission require multiple gear stages to decrease turbine speed to rotor speed
- Pericyclic transmission can replace multiple gear stages through its ability to achieve high reduction ratios (40:1 or greater)
- Additional benefits shown by Mathur were fewer total components, reduced weight, and decreased noise due to many teeth in contact

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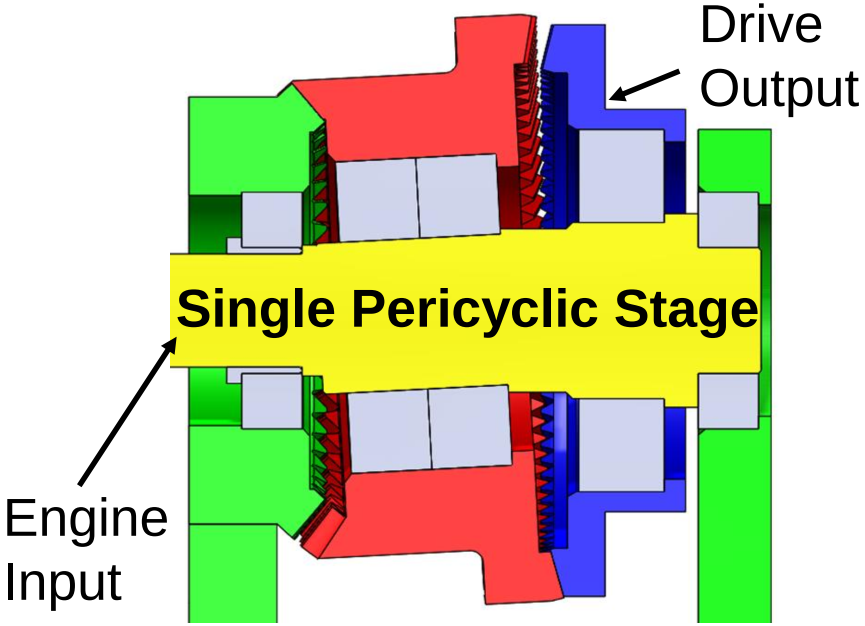
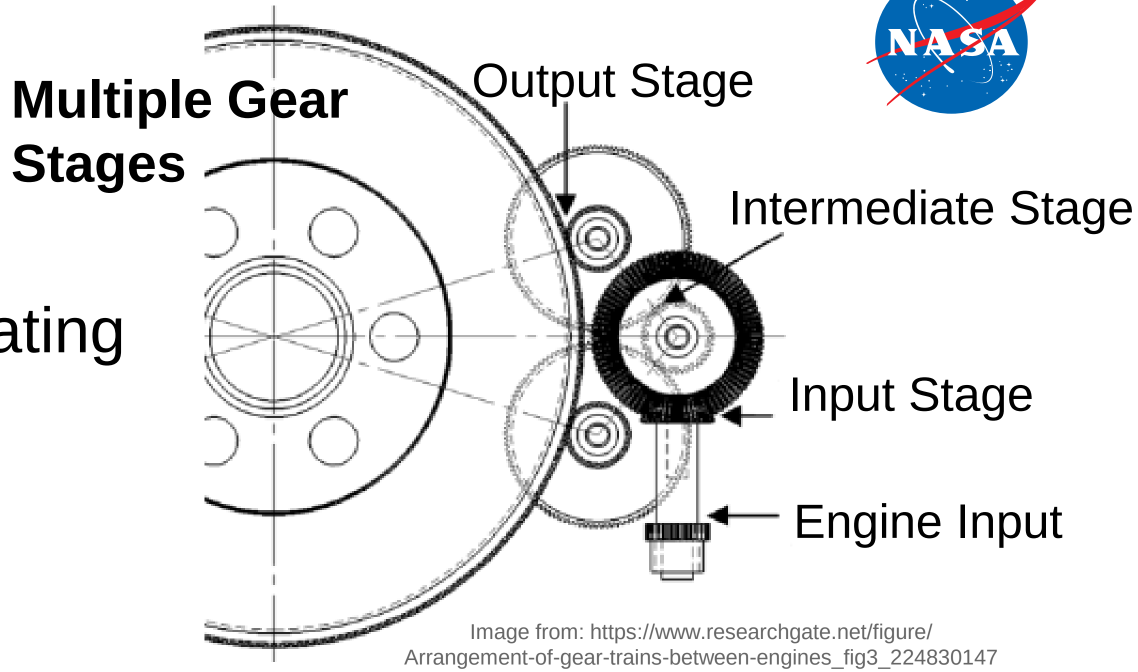


# Motivation

- Previous work examining dynamics of nutating plate transmission by Anderson showed dynamic moment as a speed limiter to the drive

- Further work by Saribay also made note of this dynamic moment or “overturning moment”

- Neither works explored a method to manage the dynamic moment in high speed operation or reduce resulting bearing loads

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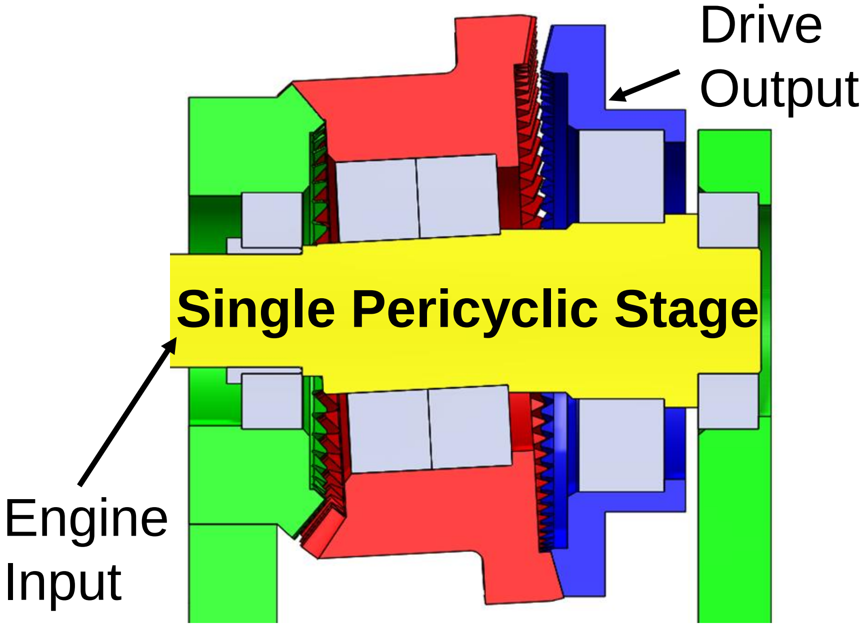


# Objectives

- Determine design aspects that impact transmission loading
- Gain firm grasp on dynamics of the transmission and magnitudes of moments for operating speeds relative to rotorcraft
- Explore methods to reduce generation of high dynamic loads
- Resolve bearing loads for entire transmission, while utilizing strategies to limit dynamic loads generated

# Outline

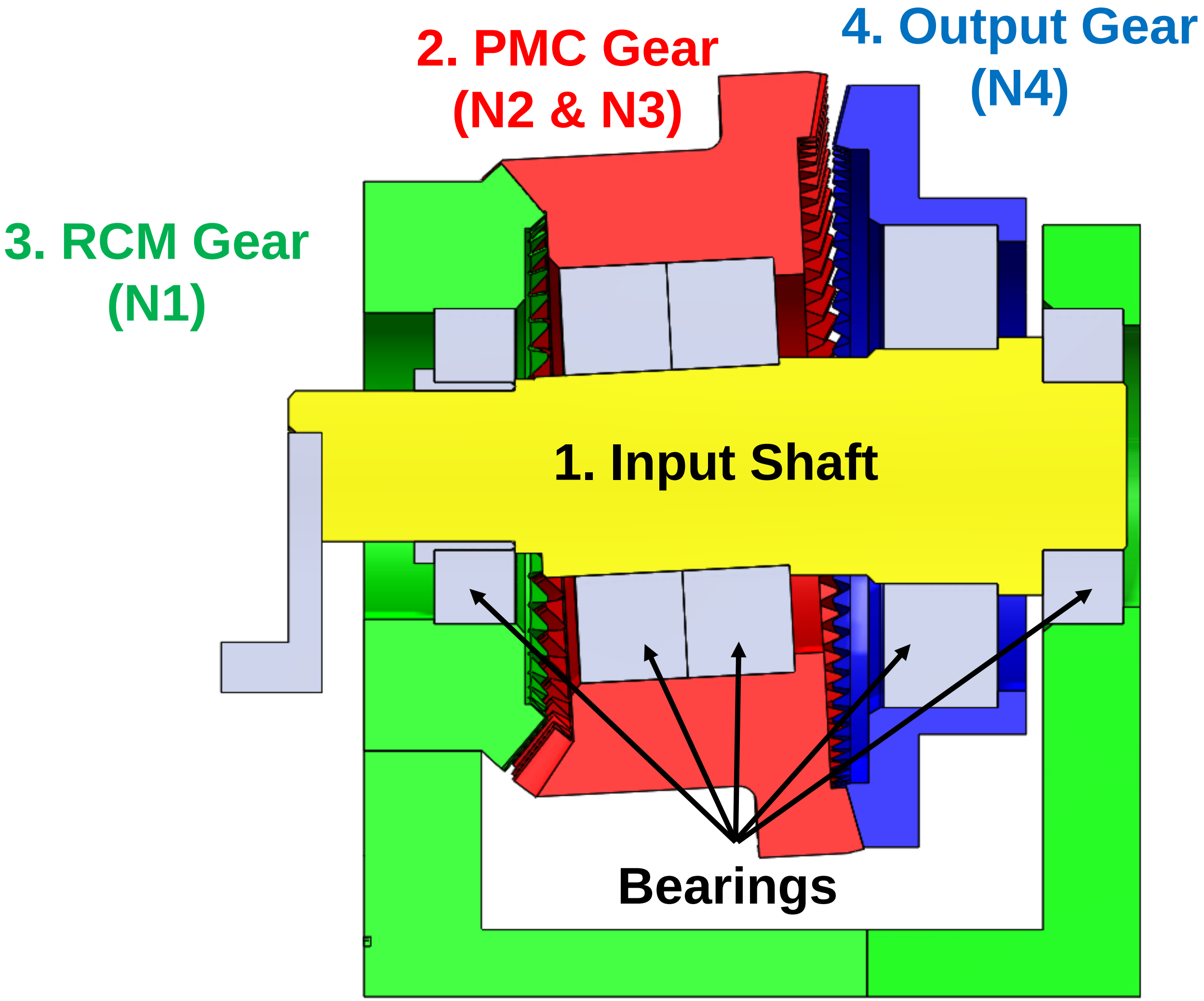
1. Pericyclic Transmission Geometry, Kinematics, and Power Flow
2. Pericyclic Dynamics & Methods to Limit Dynamic Loads
3. Static Model of Dual Pericyclic Motion Converter Drive
4. Conclusions

# Pericyclic Transmission Geometry, Kinematics, and Power Flow

# Components of Pericyclic Transmission

**Four Major Components:**

1. Input Shaft
2. Pericyclic Motion Converter (PMC) Gear
3. Reaction Control Member (RCM) Gear
4. Output Gear



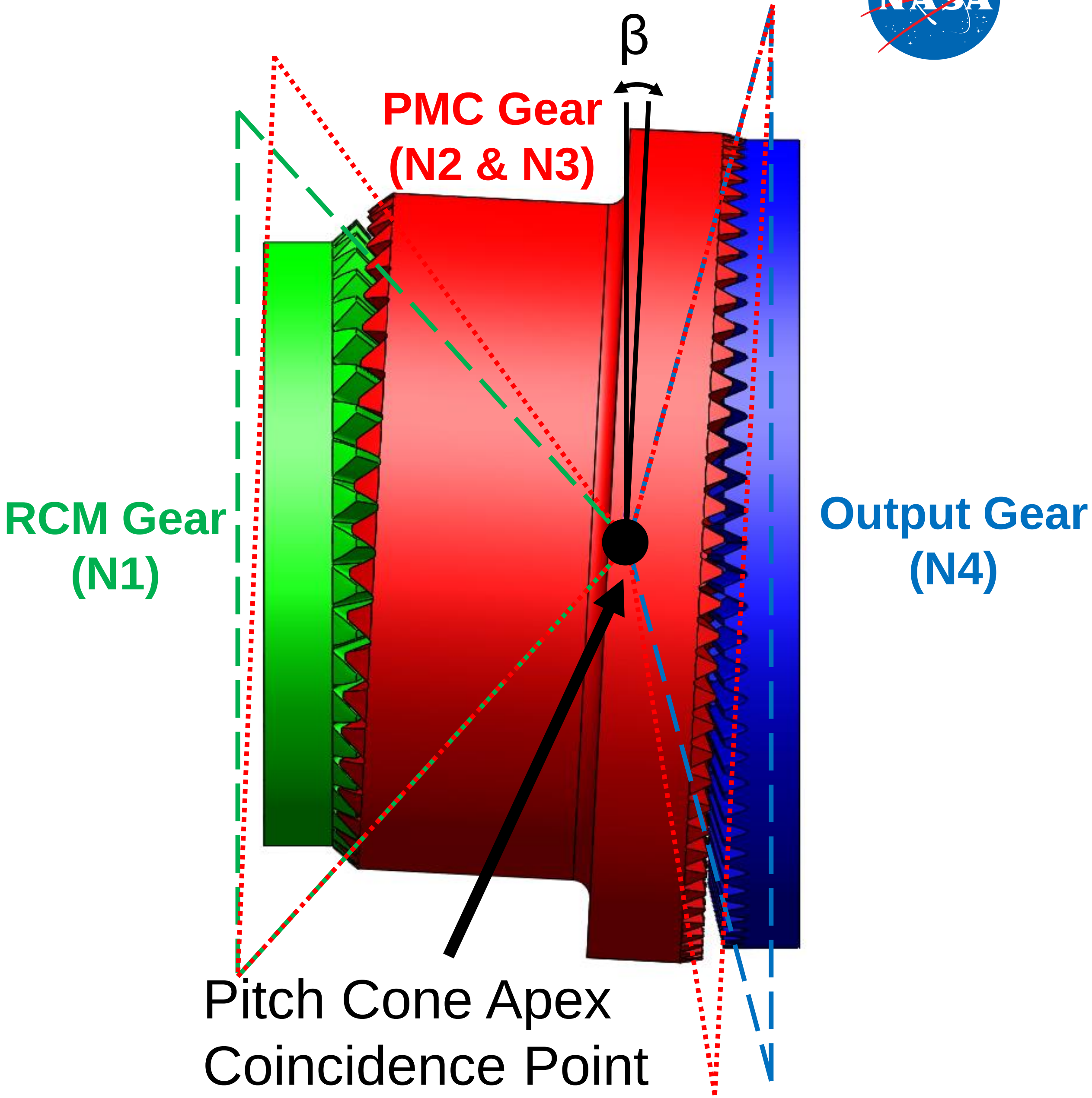
# PMC Gears in Motion

Pericyclic transmission makes use of rotational and nutational motion to achieve high reduction ratios

# Gear Pitch Cones

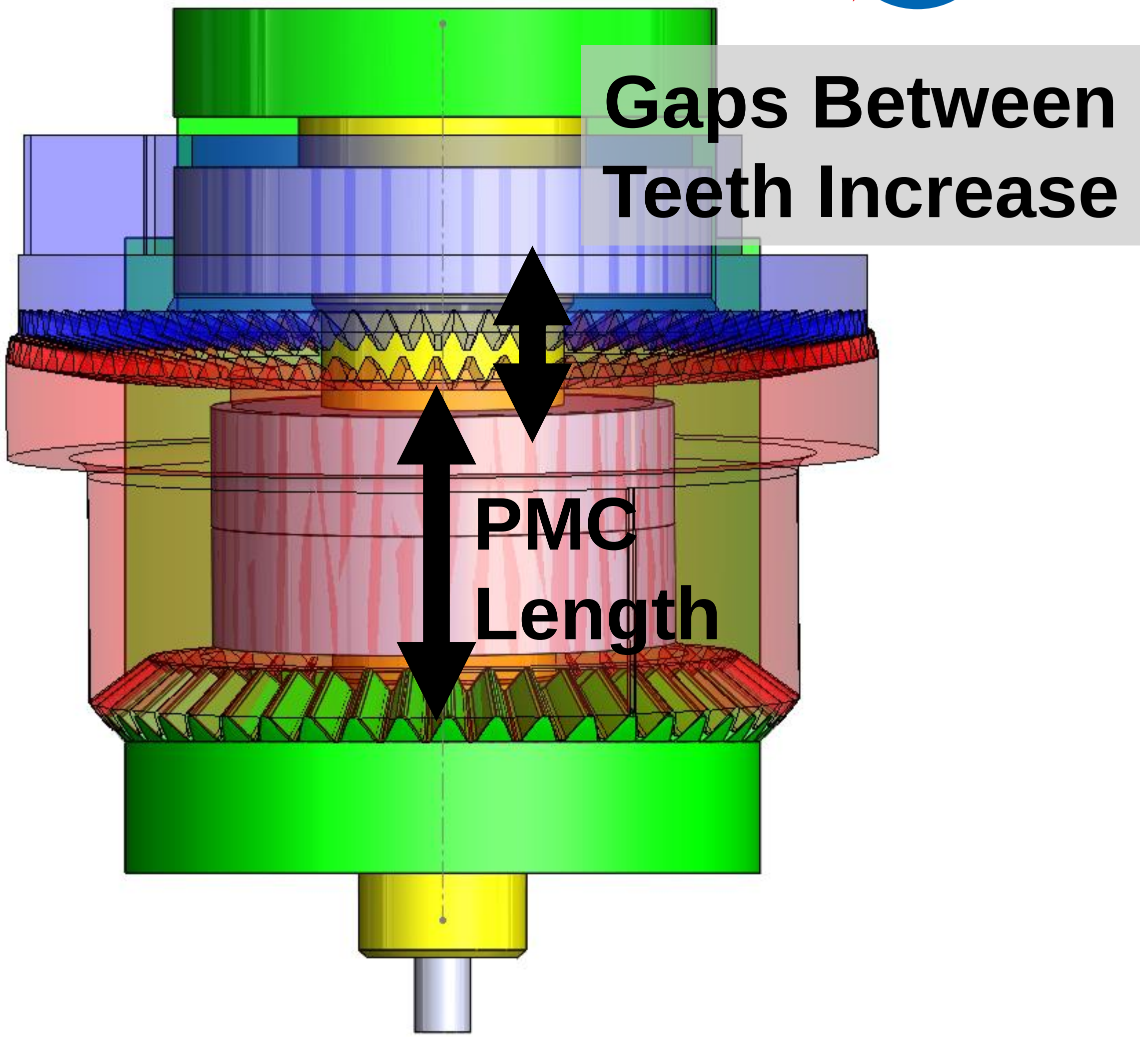
- All pitch cone apexes must be coincident for gears to mesh
- Results in reduction ratio that is independent of nutation angle

$$\frac{\omega_{in}}{\omega_{out}} = \frac{1}{\left(1 - \frac{N1}{N2} * \frac{N3}{N4}\right)}$$



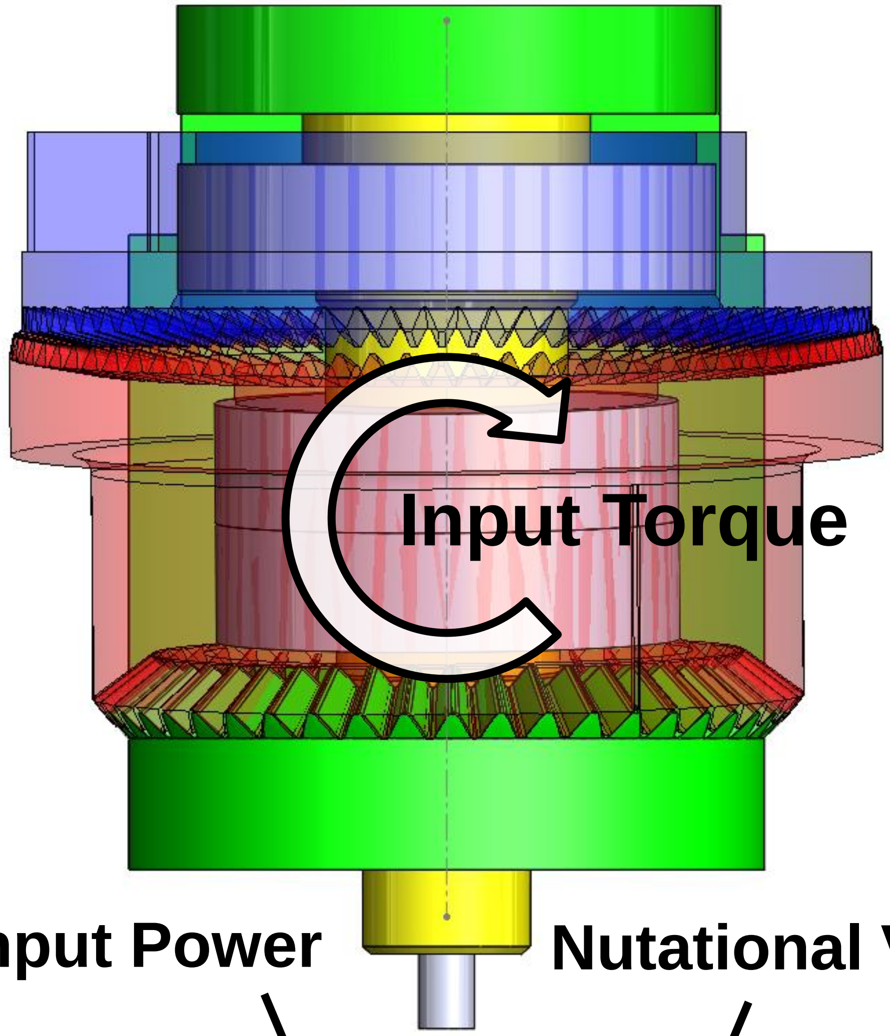
# Increasing Nutation Angle

- Less conformal pitch cones increase gear loads
- Transmission shortens axially; decreases mass but removes available space for bearings



# Increasing Nutation Angle

- Less conformal pitch cones increase gear loads
- Transmission shortens axially; decreases mass but removes available space for bearings
- Increased nutational velocity decreases static input torque and bearing loads



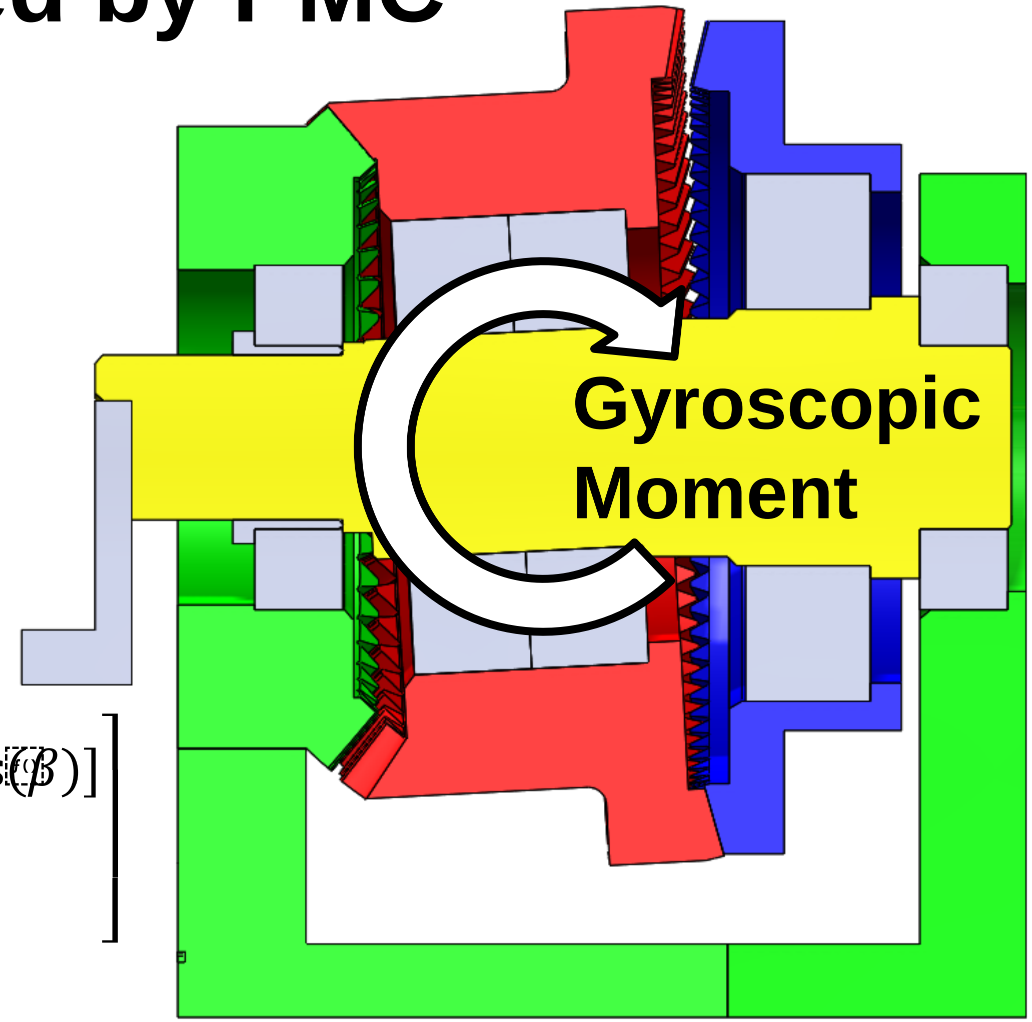

$$\vec{T}_{PMC} = -P_{in} / (-\omega_{in} * \sin(\beta))$$

# PMC Dynamics & Methods to Limit Dynamic Loads

# Dynamic Moment Generated by PMC

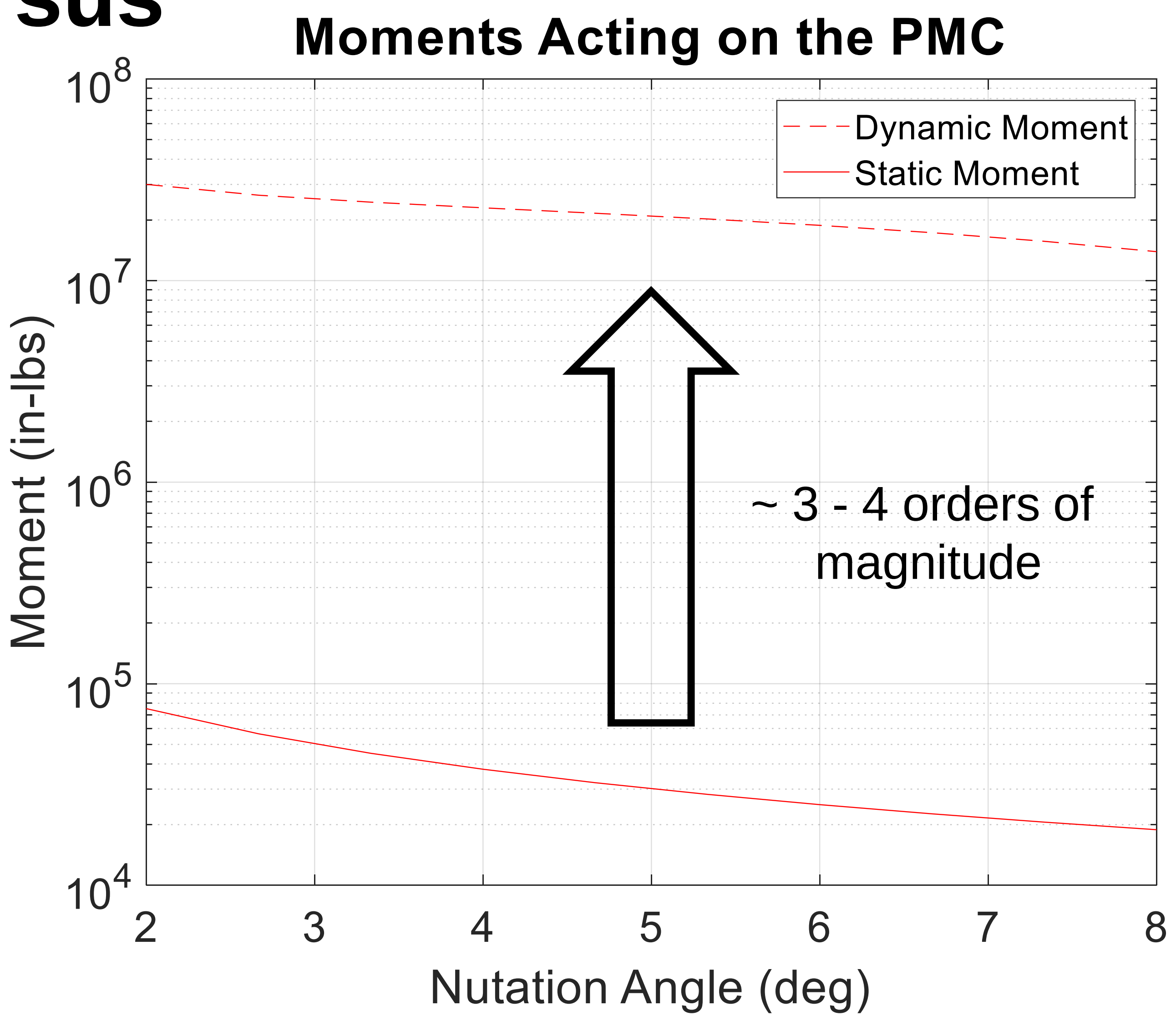
- Gyroscopic moment from combination of rotation and nutational velocities acting about x axis (out of page) provides additional PMC bearing load

$$\frac{D\vec{H}_{PMC}}{Dt} = \begin{bmatrix} -{\omega_{in}}^2 * \sin(\beta) * [I_{pzz} * \left(\cos(\beta) - \left(\frac{N1}{N2}\right)\right) - I_{pyy} * \cos(\beta)] \\ 0 \\ 0 \end{bmatrix}$$



# Dynamic Moment Versus Static Moment

| Design Variable | |
|---|---|
| Reduction Ratio | 40:1 |
| N1 | 52 |
| N2 | 54 |
| N3 | 81 |
| N4 | 80 |
| Input Power | 1,000 HP |
| Input Speed | 12,000 RPM |

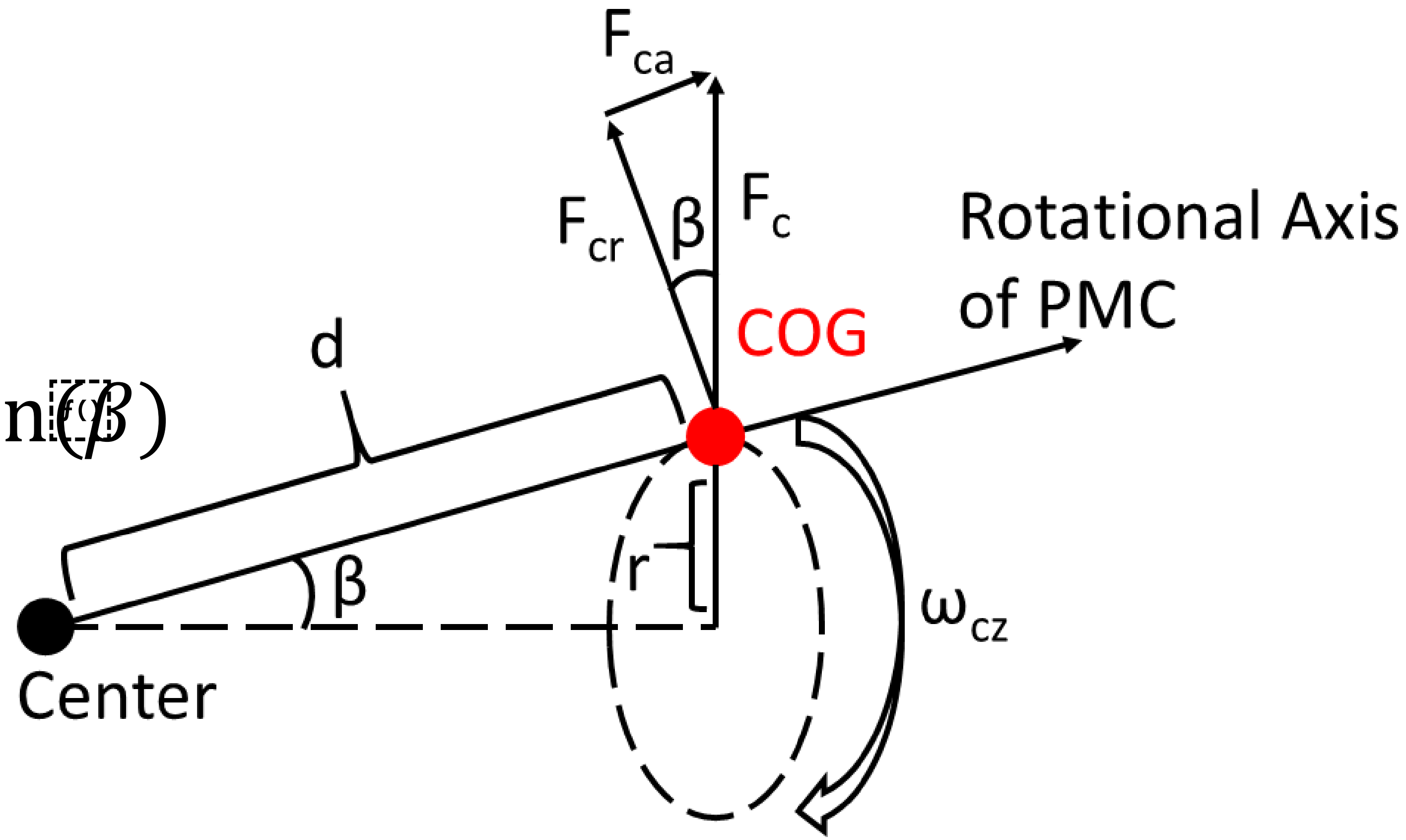



At high input speeds dynamic moment is unreasonable

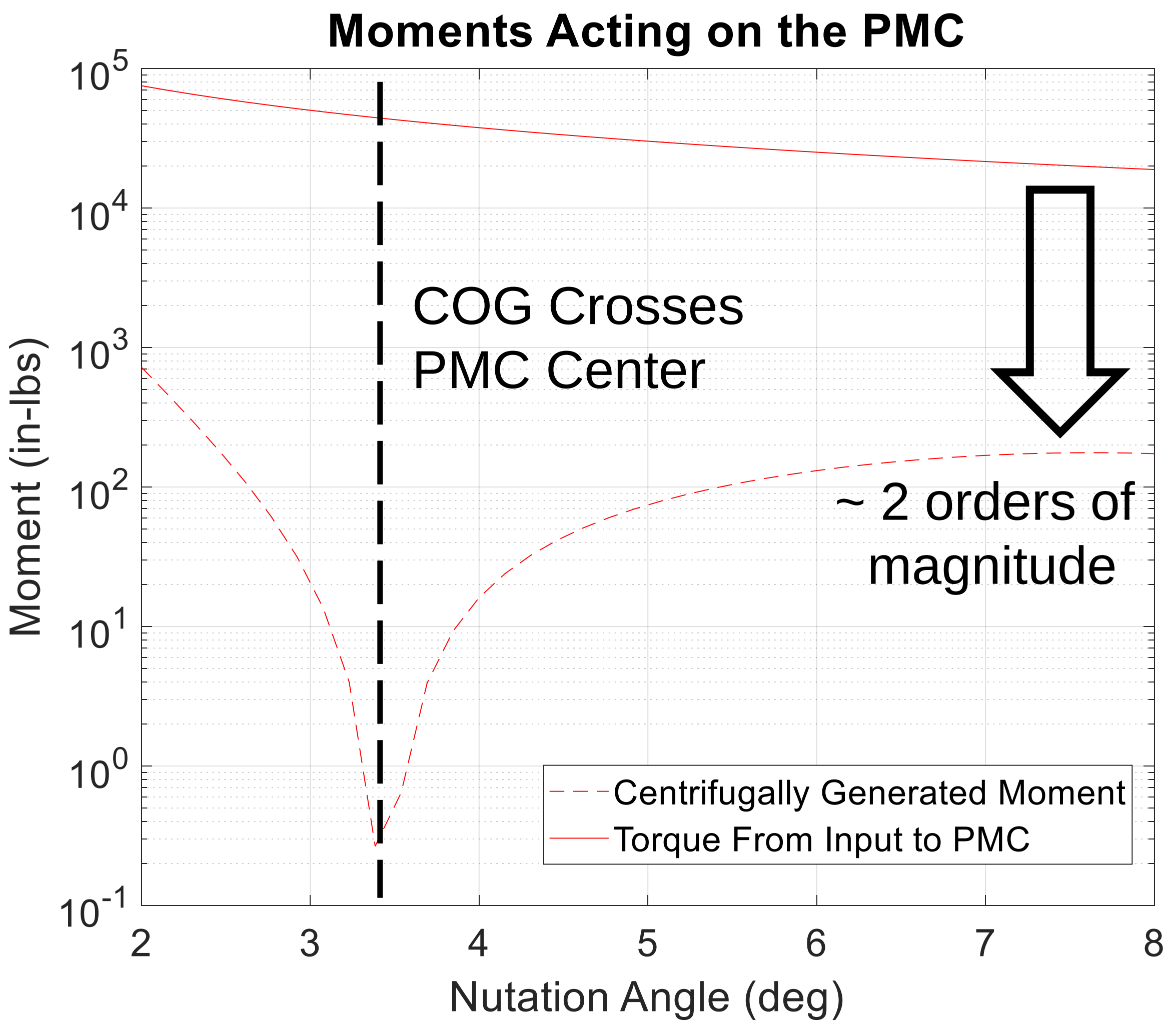
# Centrifugal Force and Resulting Loads

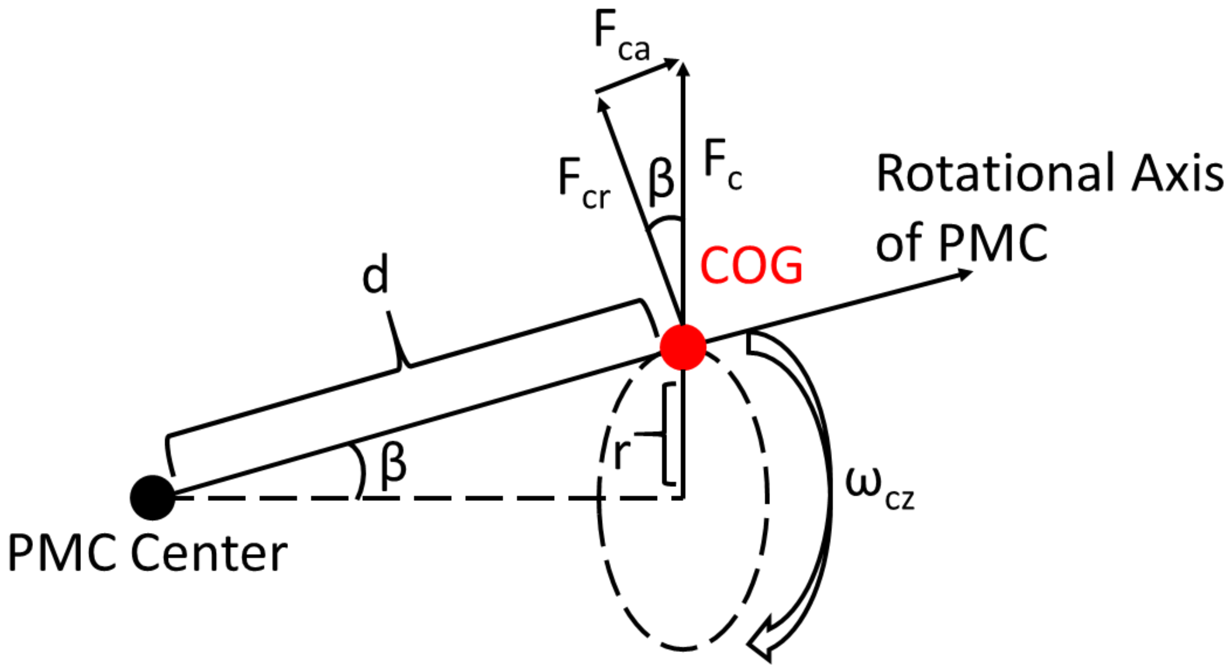
Center of gravity offset from PMC center has orbital motion generating centrifugal force

$$F_c = M_{PMC} * \omega_{cz}{}^2 * d * \sin(\beta)$$



# Centrifugal Force and Resulting Loads

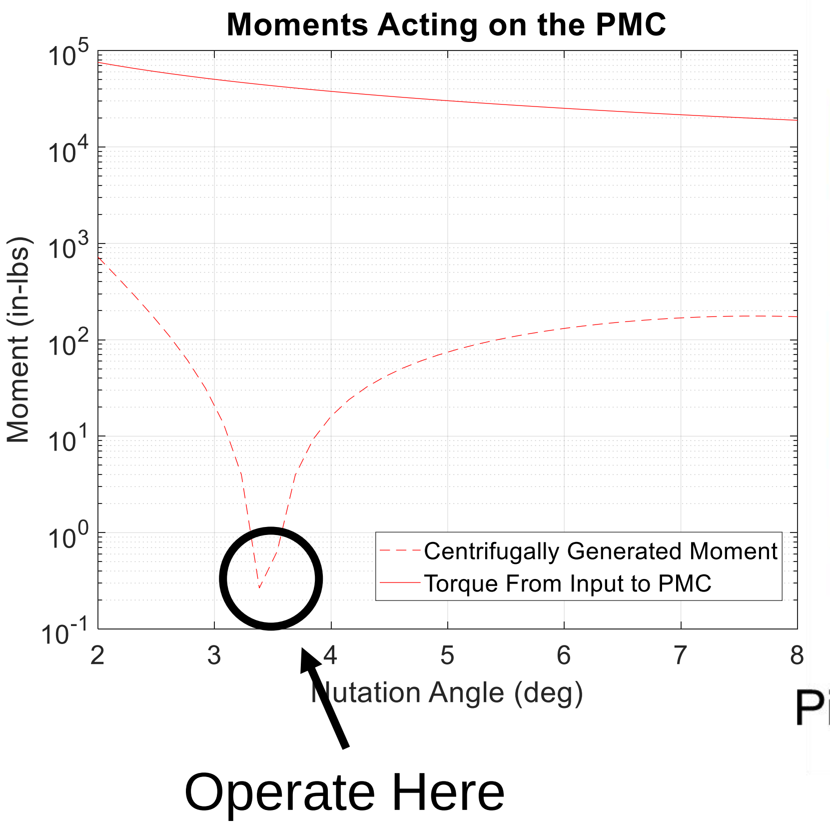


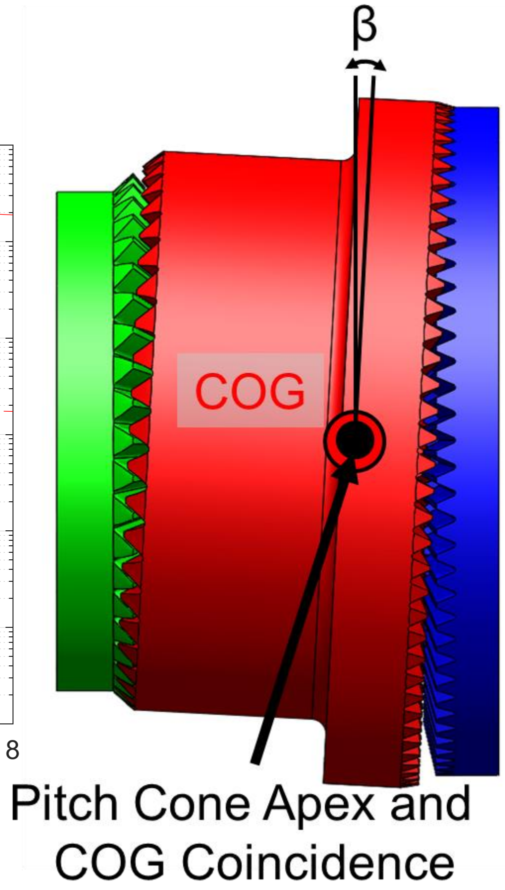




Centrifugal load in this design case is lower but should not be ignored

# Limiting Centrifugal Moment

- Limiting the centrifugal loads developed can be accomplished by making the two sides of the PMC teeth numbers close in value (symmetrical)
- Altering mass of either side to center COG over pitch cone apex center
- Selection of nutation angle where COG crosses from one side of PMC to the other



# Eliminating Gyroscopic Moment

Setting Dynamic Moment to Zero

$$0 = \begin{bmatrix} -\omega_{in}^{2} * \sin(\beta) * [I_{pzz} * \left(\cos(\beta) - \left(\frac{N1}{N2}\right)\right) - I_{pyy} * \cos(\beta)] \\ 0 \\ 0 \end{bmatrix}$$

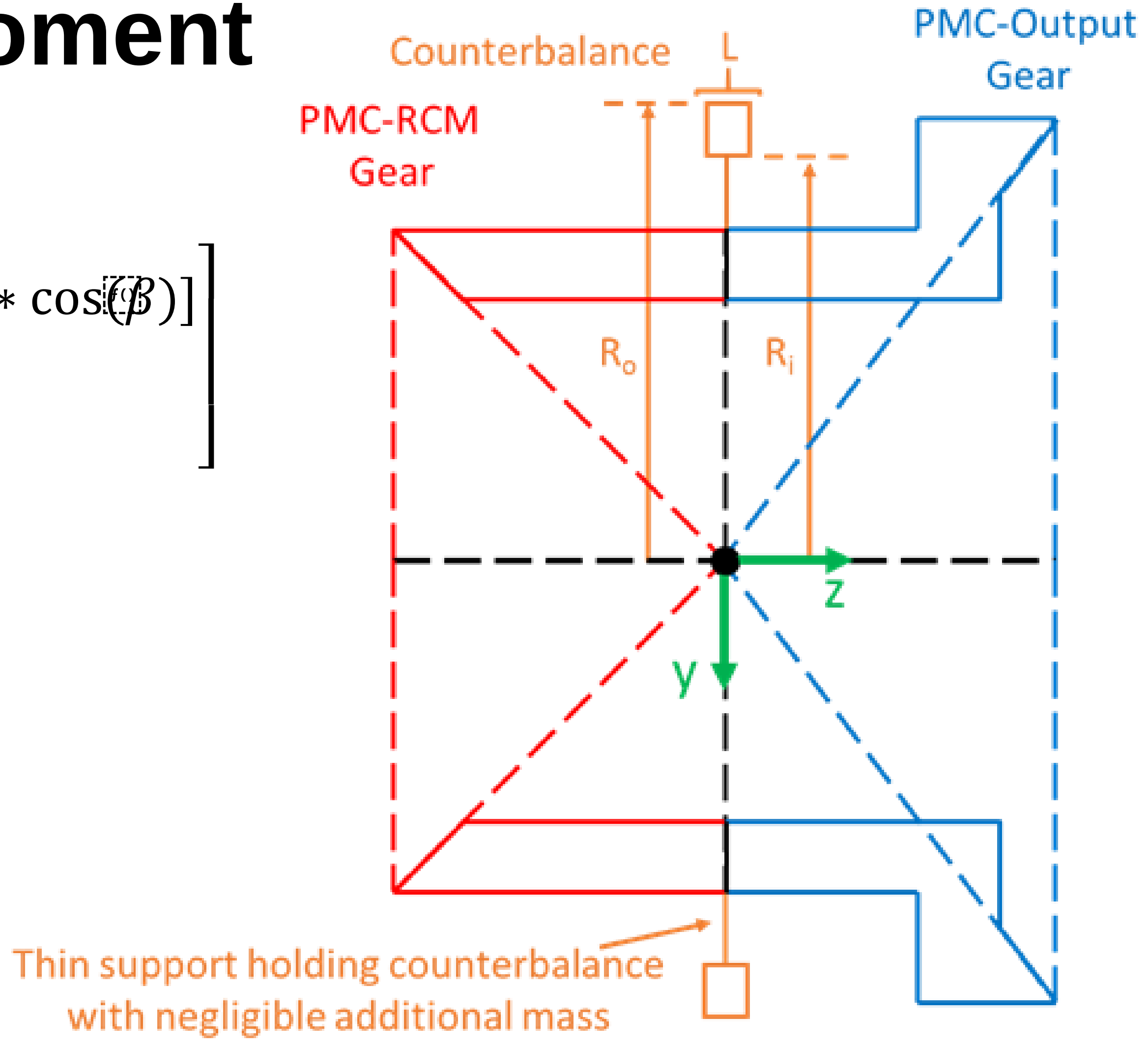
## Requirements

$$(R_O^2 + R_i^2) \gg L^2$$

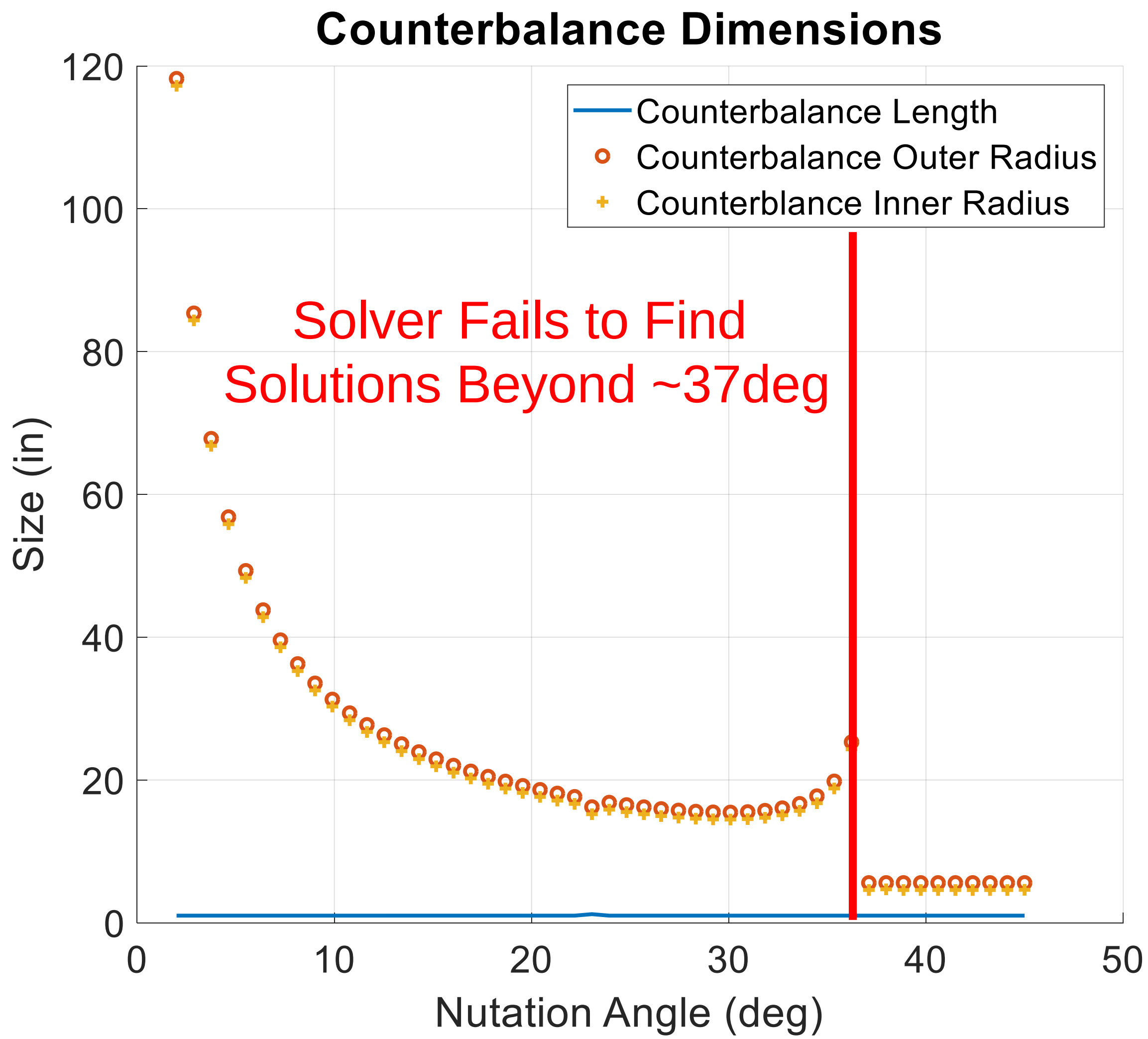
$$\cos(\beta) \geq \frac{1}{2}$$

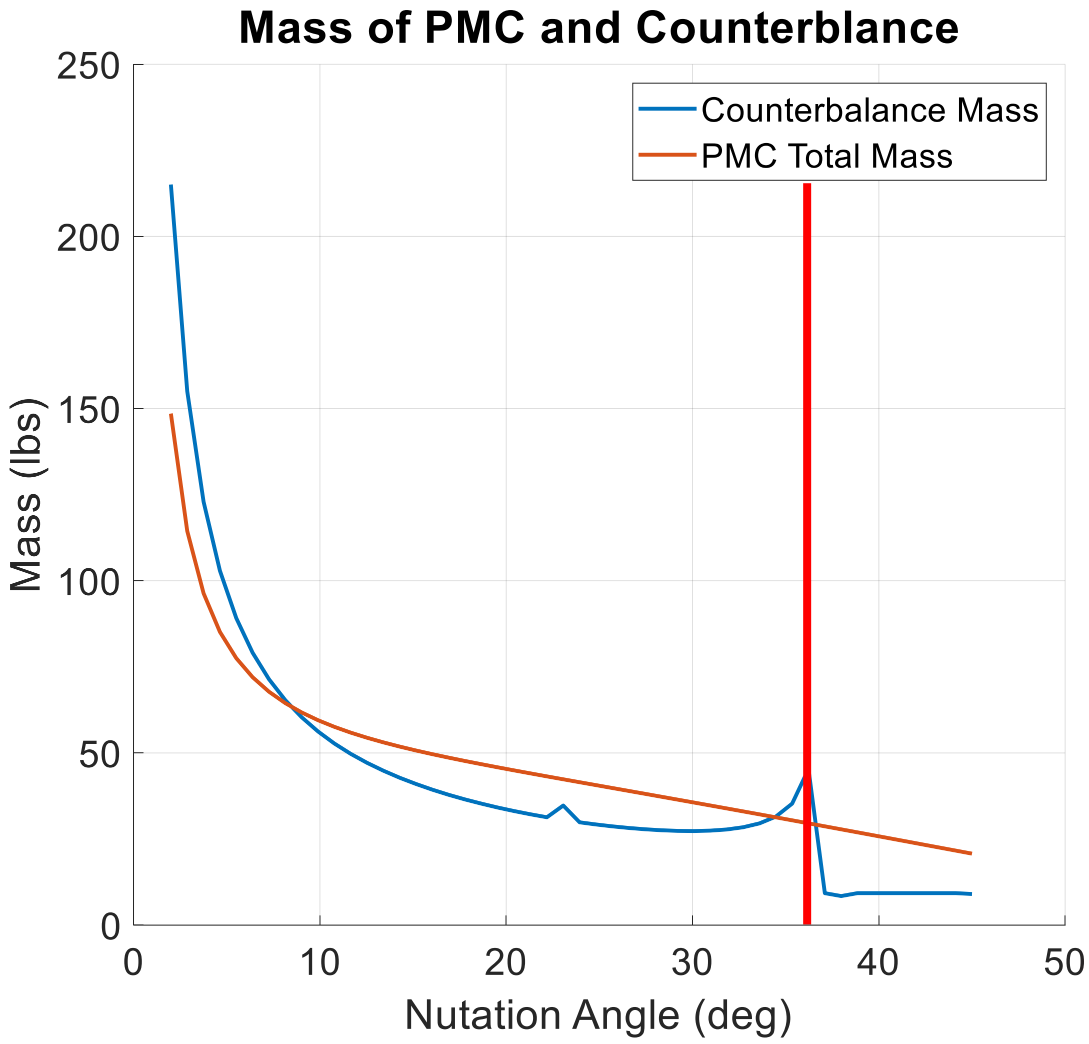
$$\frac{N1}{N2} \leq \frac{1}{2}$$

| Design Variable | |
|---|---|
| Reduction Ratio | 40:1 |
| N1 | 30 |
| N2 | 75 |
| N3 | 78 |
| N4 | 32 |
| N1 / N2 | 0.40 |



# Eliminating Gyroscopic Moment

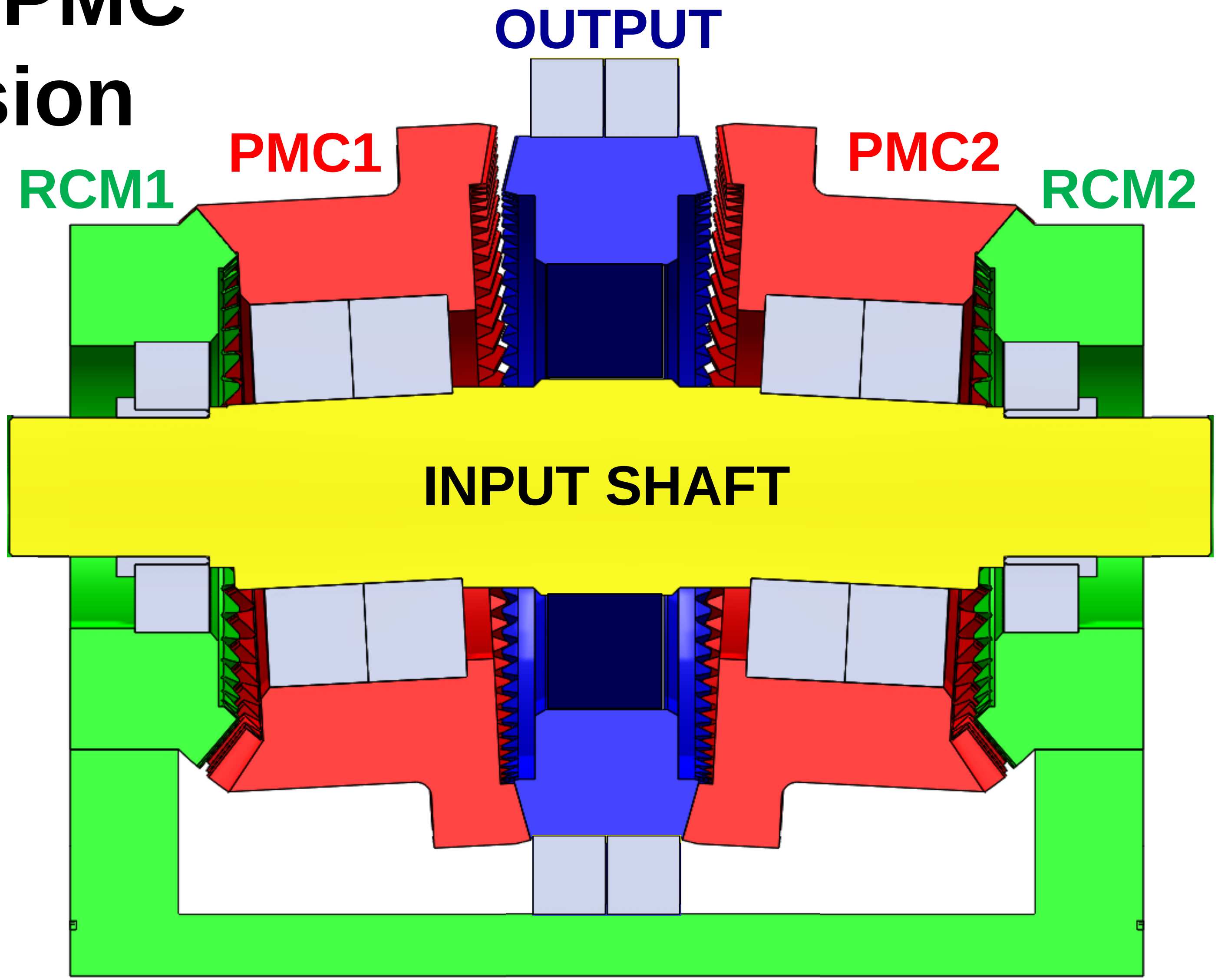


# Static Model of Dual Pericyclic Motion Converter Drive

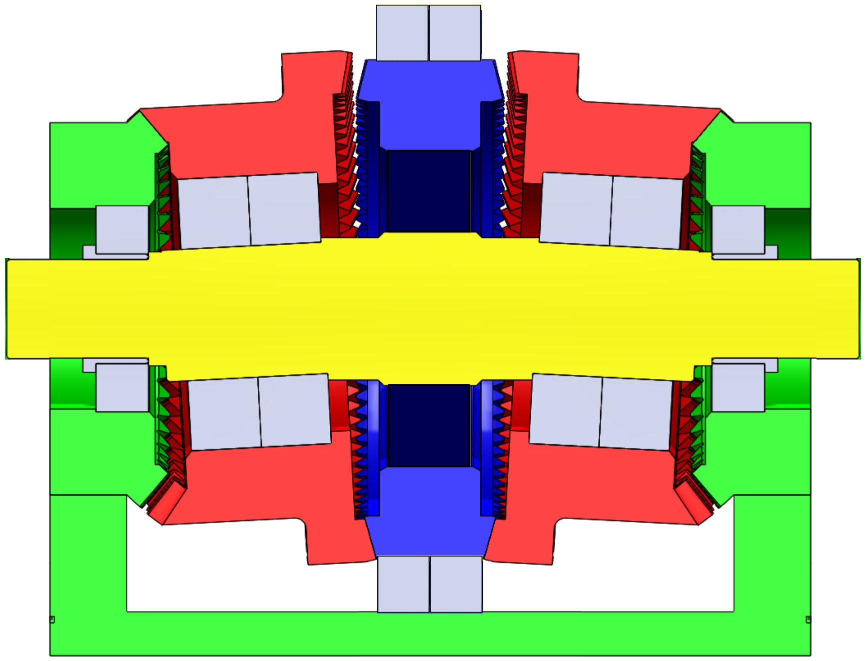
# Static Model of Dual PMC Pericyclic Transmission

- Dual pericyclic mirrors components
- Splits power between two PMCs
- Each PMC has counterbalance
- PMCs designed to place COG at center



# Dual PMC Model

| Bearing Name | Loads Reacted | Unknowns |
|---|---|---|
| Input 1 | Radial | 2 |
| Input 2 | Radial & Axial | 3 |
| PMC 1-A | Radial | 2 |
| PMC 1-B | Radial & Axial | 3 |
| PMC 2-A | Radial | 2 |
| PMC 2-B | Radial & Axial | 3 |
| Output 1 | Radial | 2 |
| Output 2 | Radial | 2 |
| | **TOTAL** | **19** |



| Design Variable | |
|---|---|
| Reduction Ratio | 40:1 |
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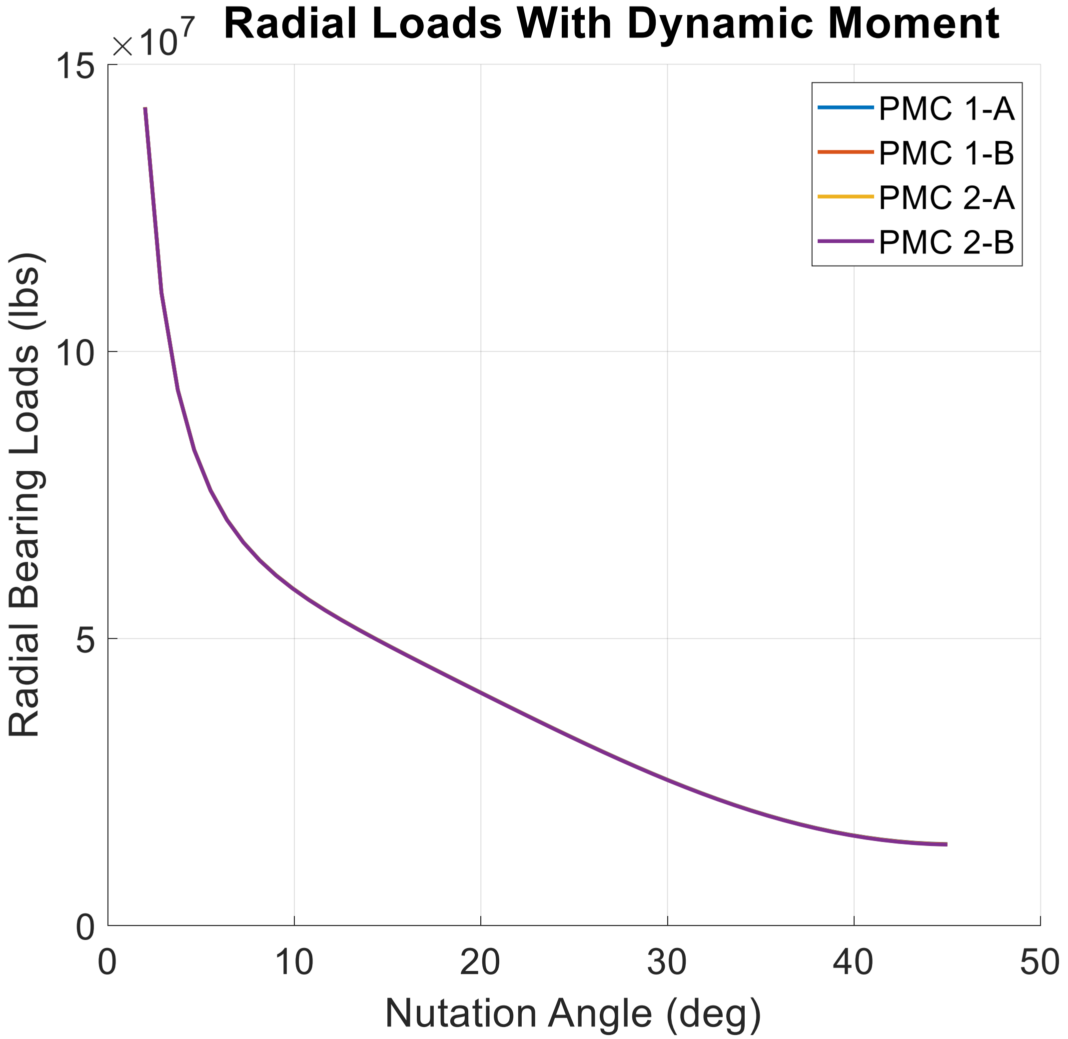
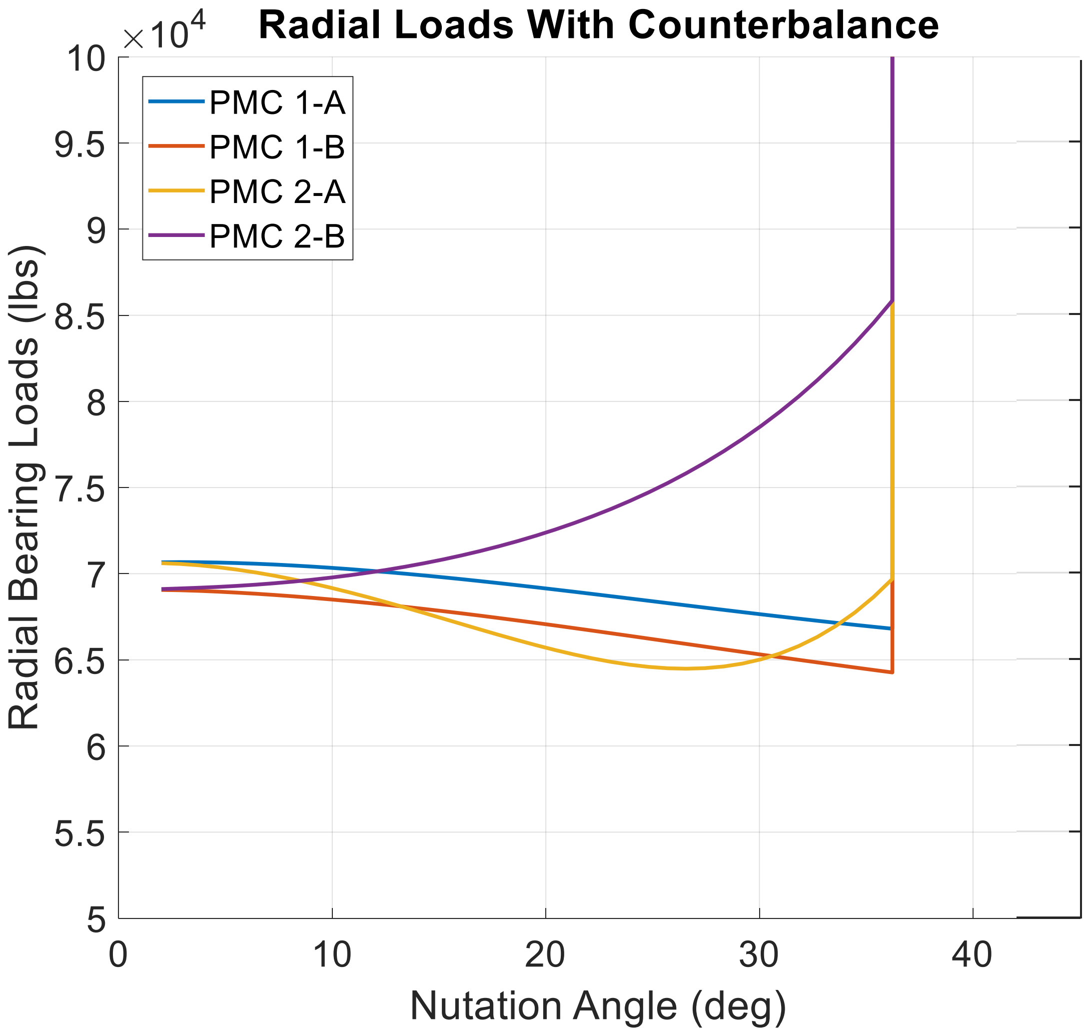
| N2 | 75 |
| N3 | 78 |
| N4 | 32 |
| Input Power | 1,000 HP |
| Input Speed | 12,000 RPM |

# Sample Output From Static Model



# Conclusions

# Conclusions

- Tradeoff with increased nutation angle is decreased PMC bearing static loads for increased gear tooth loads
- Intelligent PMC design can effectively negate the PMC centrifugal loads
- The high gyroscopic moment, given **certain tooth numbers and nutation angles,** can be counterbalanced, in the case sown for as little as 60% additional mass to the PMC
- Static model of dual pericyclic developed to find loads across entire transmission and showed drop of radial loads of three orders of magnitude in the PMC bearings when counterbalanced

# Questions