DESIGN SPACE EXPLORATION OF PERICYCLIC TRANSMISSION

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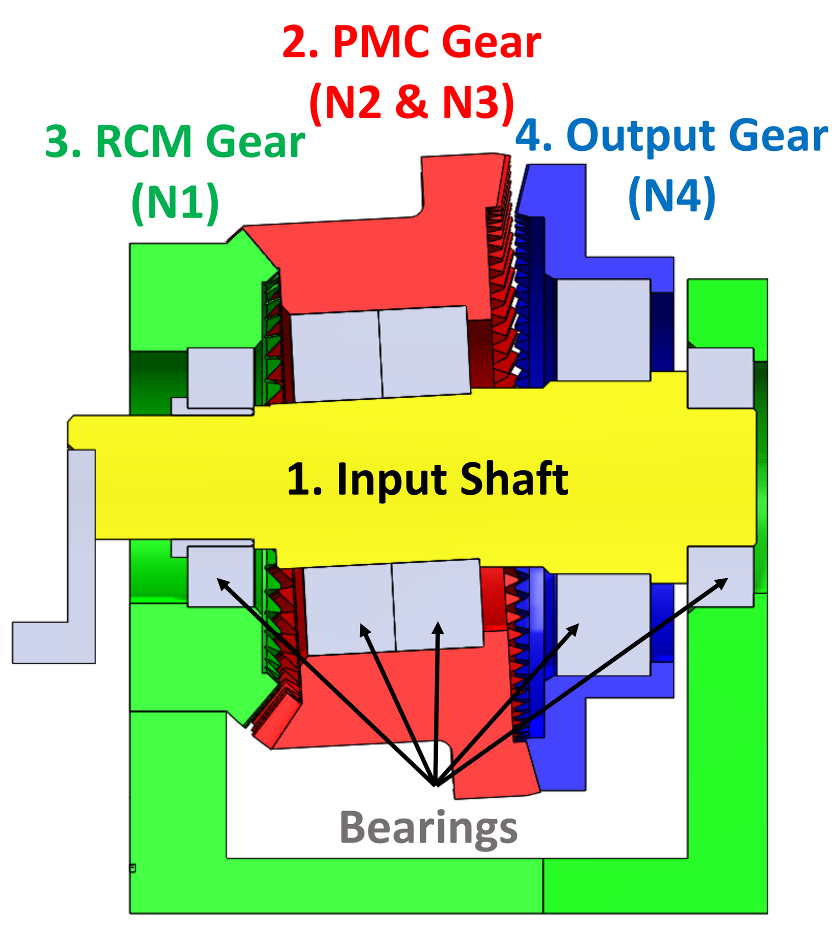
Pericyclic Transmission Design

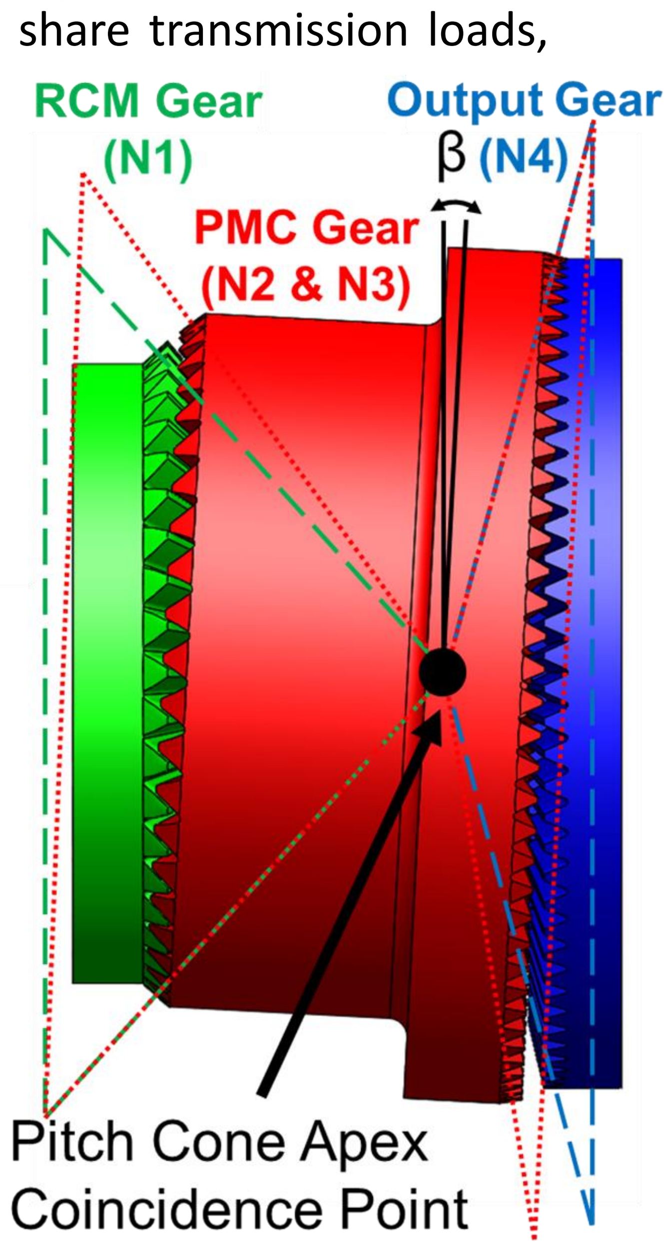
A pericyclic transmission is comprised of four major components: the input shaft which drives power into the pericyclic motion converter (PMC) gear, and meshes with the stationary reaction control member (RCM) gear and drives power out of the system through the output gear. The transmission is capable of providing very high reduction ratios in compact forms with small differences in tooth number via:

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



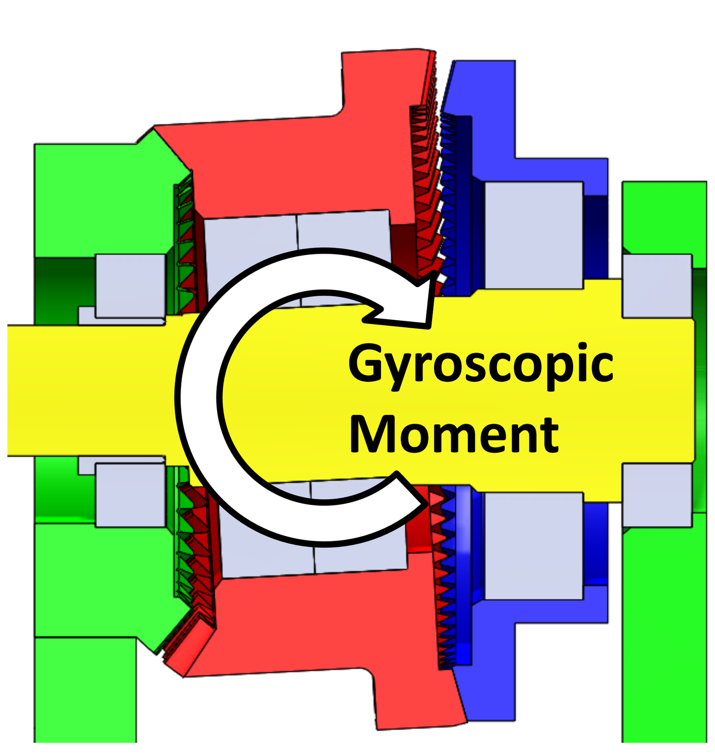
A benefit of this gear type is highly conformal pitch cones which have many teeth in contact simultaneously which share transmission loads, and lower transmission noise levels.

Some basic tradeoffs associated with the pericyclic transmission are tied directly to the nutation angle β that the PMC sits offset from the input rotation axis. The first tradeoff is increased nutation angle increases static tooth loads and decreases static bearing loads. This is due to fewer teeth being in contact at high nutation angles and the effective lever arm the bearing loads act at becoming more effective. Increased nutation angle also flattens out PMC gear pitch cones. This leads to reduced size and weight of the PMC and overall transmission. An additional design aspect of the pericyclic transmission is its components can be mirrored to form a dual PMC pericyclic. This leads to some loads on the input shaft and output body to be balanced, decreasing peak loading and improving transmission life.



Pitch Cones Diagram Showing Conformity and Nutation Angle β

PMC Dynamics and Impact on Loading

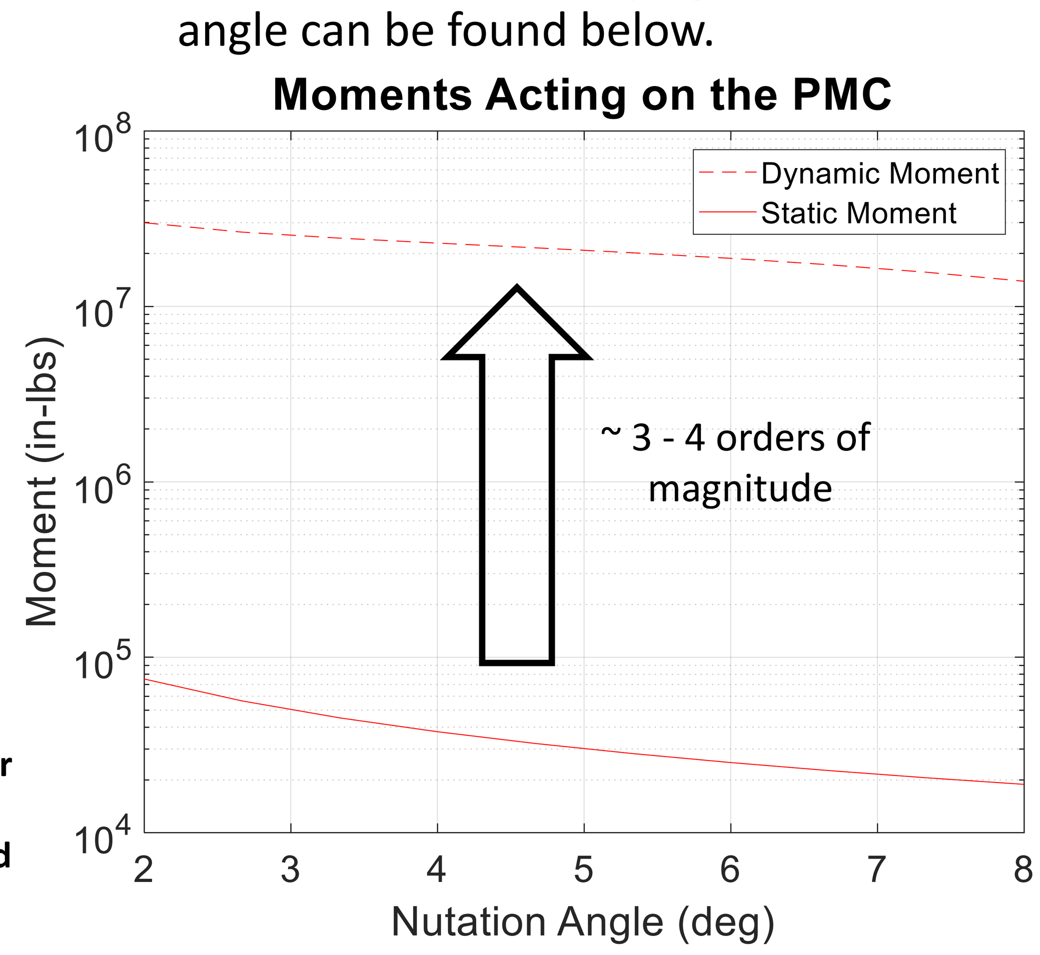


Direction of Gyroscopic Moment Generated by PMC

Due to the PMC gear's rotational and nutational motion a gyroscopic moment is generated. This gyroscopic moment is translated to radial loads on the PMC bearings, and at high input speeds can be much greater than static radial loads. In rotorcraft applications, the pericyclic would have input speeds in the 1000's of RPM making the gyroscopic moment the primary driver of bearing loads. This forces bearings to be larger and increases transmission weight. Design case details and resultant dynamic and static moments varying nutation angle can be found below.

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

Design Criteria of Pericyclic Drive for Use in Rotorcraft with Resulting Static and Dynamic Moment Plotted



Counterbalance Method

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

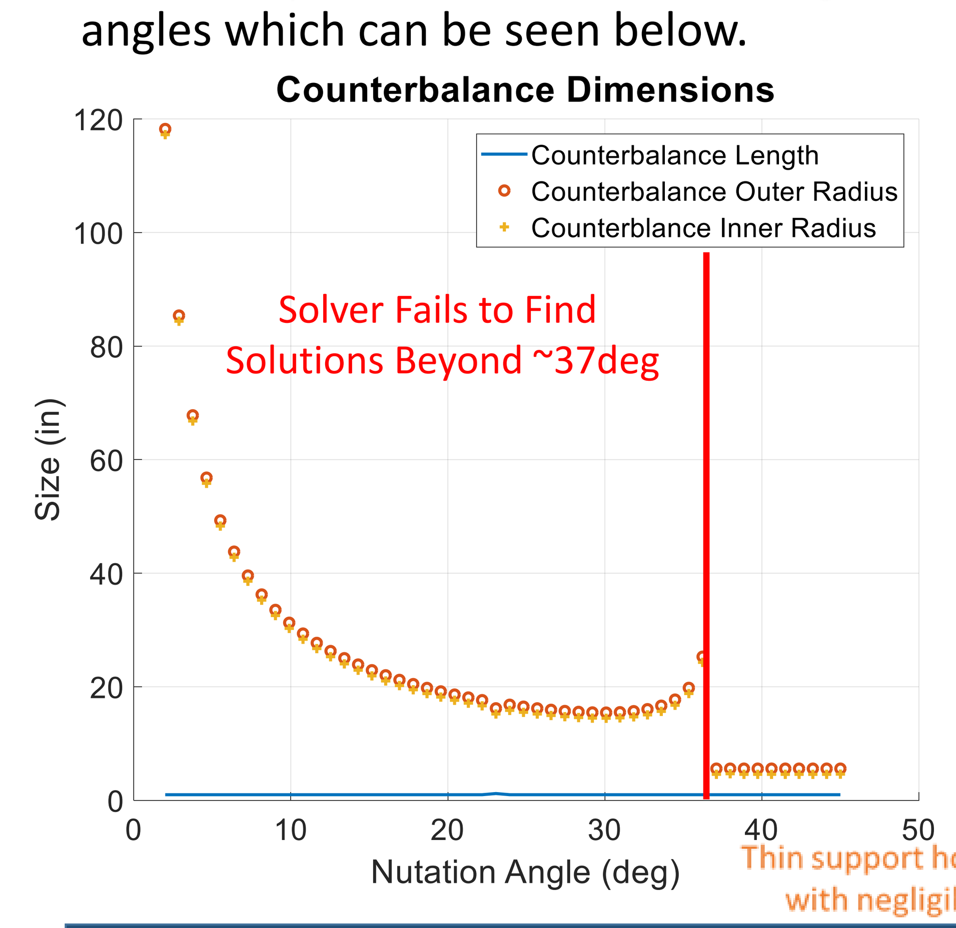
In an effort to reduce the dynamic moment's impact on design of the pericyclic transmission, counterbalancing the PMC was investigated as a means of eliminating it. When the equation defining the dynamic moment was set to zero (above) and inertial equations for a hollow cylinder were inserted, certain requirements were found (right). An additional cylinder body was added to the PMC to alter its mass moment of inertia sufficiently to negate the dynamic moment. This was possible for a select range of nutation angles which can be seen below.

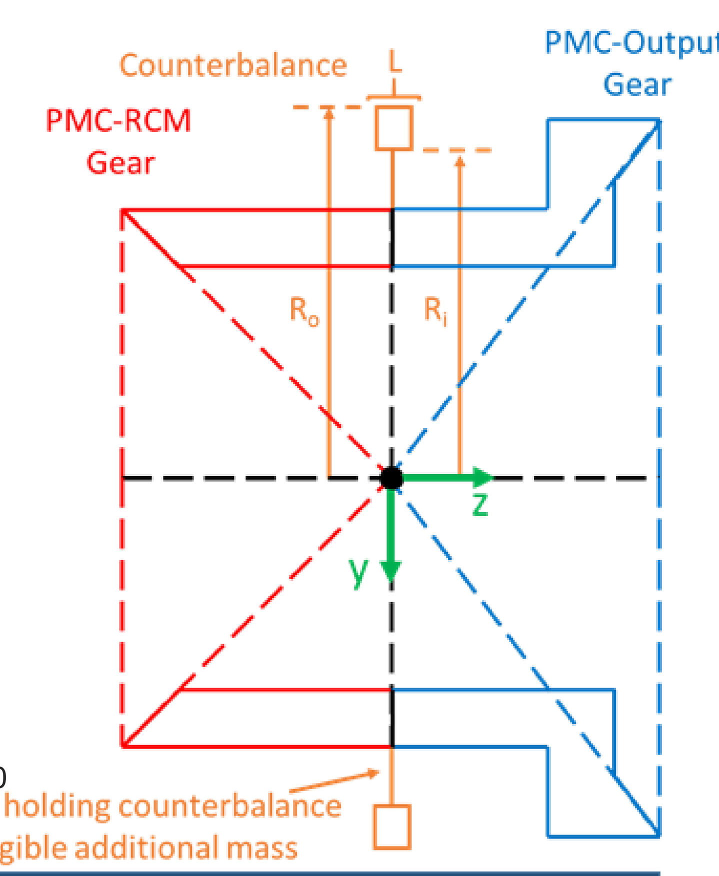
Requirements

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

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

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

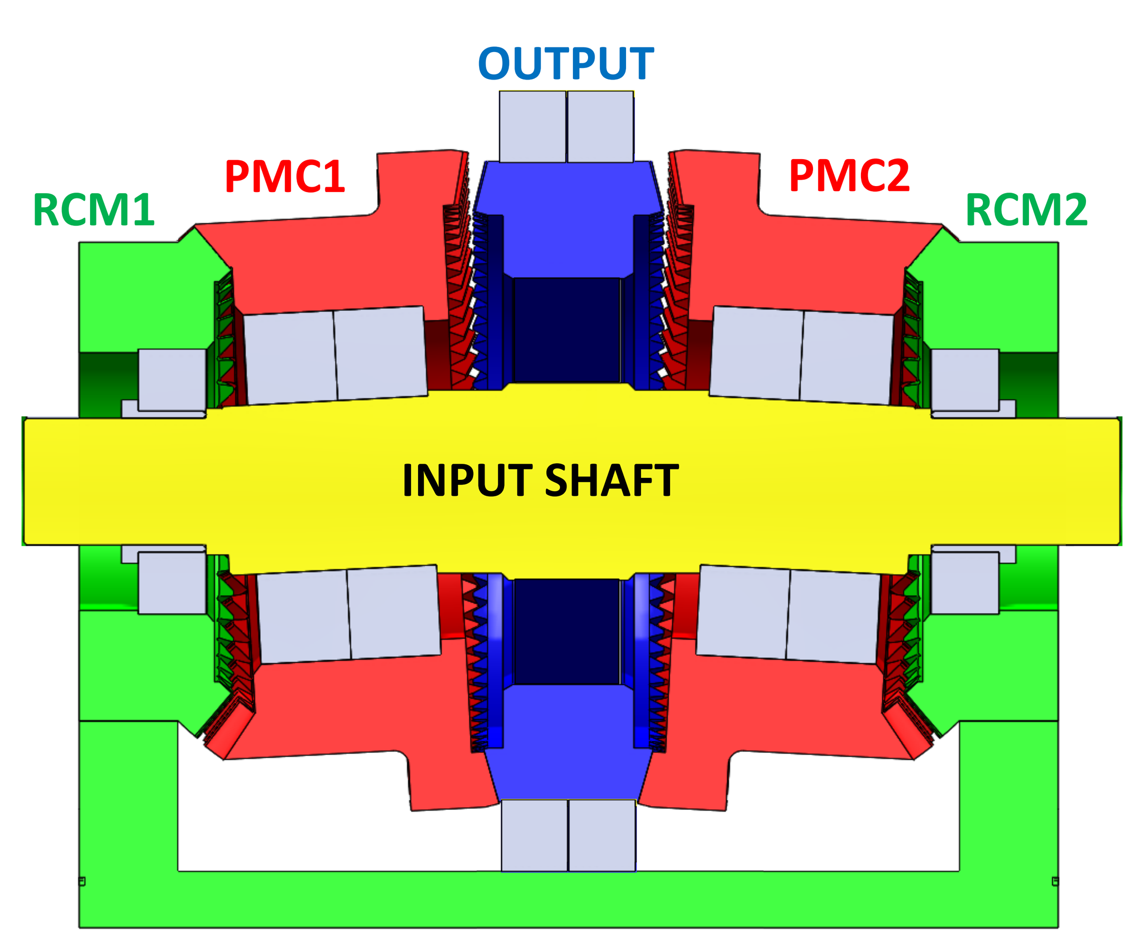




Bearing Load Analysis

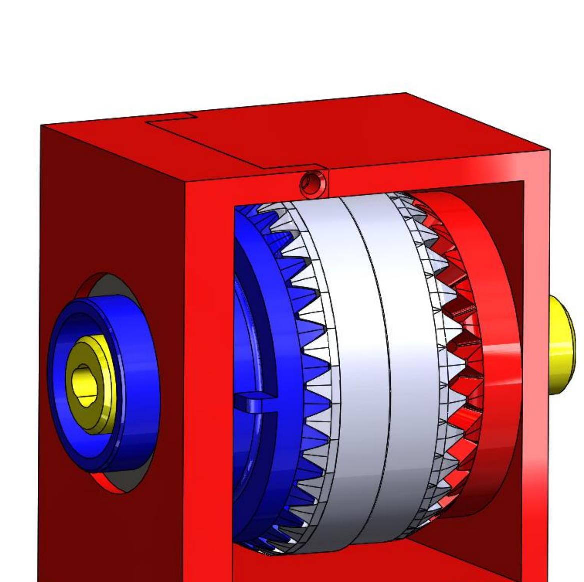
A dual PMC pericyclic drive static model was developed that took into account gyroscopic moments to evaluate bearing loads across the entire transmission. The model included 8 bearings reacting to radial and axial loads who's spacing and approximate sizing were adjusted as nutation angle varied. Then the counterbalance tool was added to the solver to alter the mass moment of inertia of the PMCs and diminish the dynamic moment. Bearing loads were then recalculated with the new PMC mass and respective loads. With operating loads and speeds known, bearings were selected to provide a total transmission mass estimate.

Design Variable	
Reduction Ratio	40:1
N1	30
N2	75
N3	78
N4	32
Input Power	1,000 HP
Input Speed	12,000 RPM



Conclusions and Future Work

This work showed that when dynamic moments generated by the PMC are of grave concern to a particular pericyclic design, it is possible to use a counterbalance to negate the dynamic moment for a weight penalty. Future efforts are focused on aiding a team at The Pennsylvania State University in design and fabrication of a 50 horsepower pericyclic drive. It will eventually be tested at NASA Glenn research center on the variable speed drives test stand to examine contact patterns under load, kinematics, vibrations, and performance. Additional efforts are examining the capability of the drive at very high reduction ratios exceeding 500:1 for aerospace applications.



900:1 Speed-Ratio Pericyclic