Concepts for Multi-Speed Rotorcraft Drive System - Status of Design and Testing at NASA GRC

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Objective

Overview the Status of Three Drive Designs from an earlier concept study:

1. Design/testing of two *multi-speed drives*.
   Highlight some positive/negative aspects and future development areas.

2. Update to the design of *third concept*.
   Variable-speed gear drive based on a dual-input planetary differential.

Background

Future advances in rotorcraft propulsion systems require increased efficiency, power, and enhanced capabilities

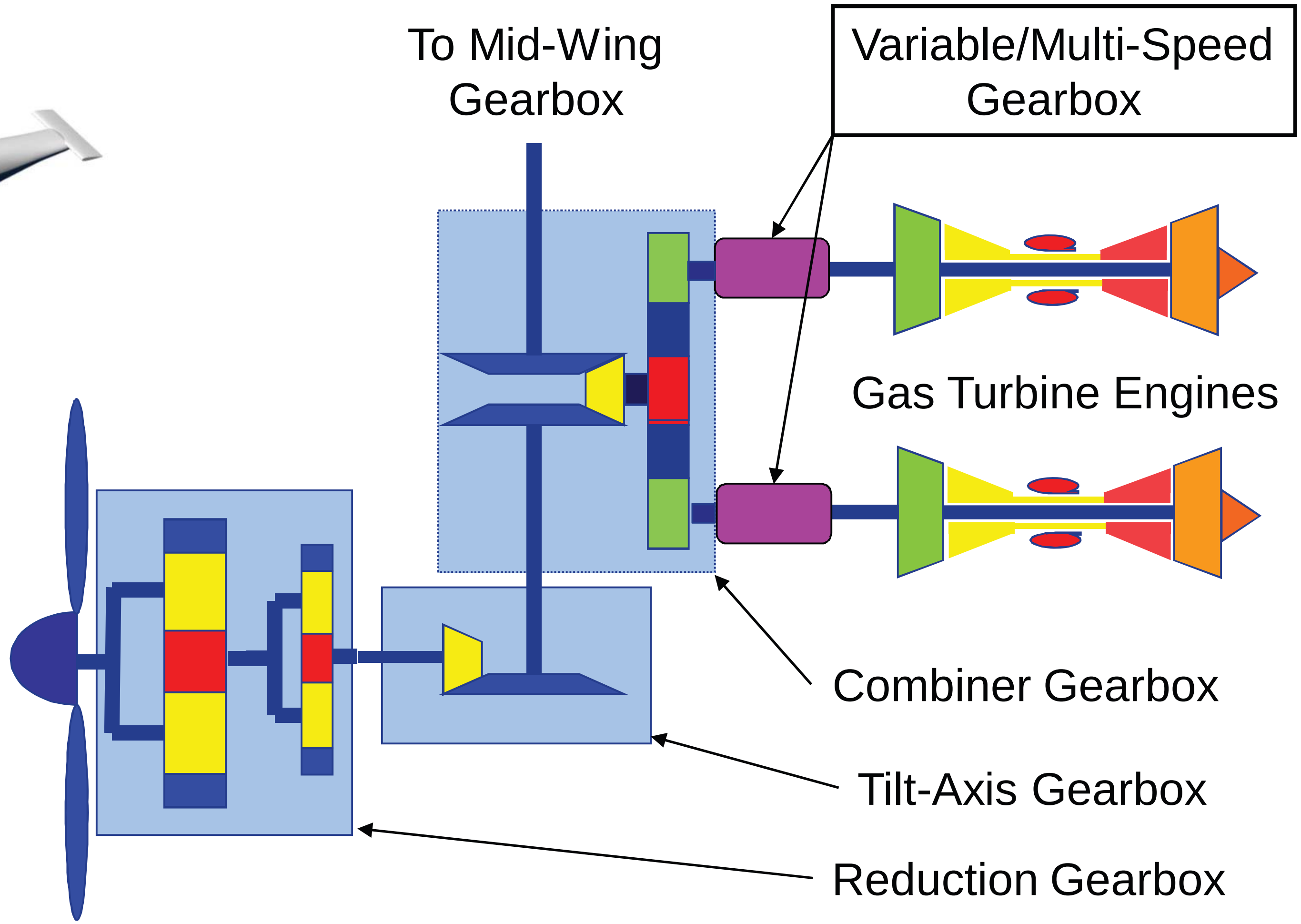
Studies show that ***variable rotor speed*** is required for:

- Reduction in noise
- Increased performance
- Enhanced capabilities (speed - capacity - range)

Advances are contingent upon ***varying rotor speeds 50%.***

Present Limitations ~15% (via engine control).

Future Rotorcraft Propulsion System Configuration
V/M-S Gearbox Application



Hover Ratio 131.4 : 1   Forward Flight Ratio 243.6 : 1

Test Article Design Requirements

- 250 HP nominal (200 HP facility capacity)
- Inline configuration (input-output shafts)
- Input Speed 15,000 rpm
- Output Speeds 15,000 rpm (hover), 7,500 rpm (cruise)
- Employ straight spur gear geometry (budget consideration)
- Drive should fail safe to the high-speed (hover) mode
- Lubricant: DOD-PRF-85734A, synthetic ester-based oil
  - 40C 104F 23.0 cSt
  - 100C 212F 4.90-5.40 cSt
  - -54C -65F pour point
- [a] Provide high-speed positive drive element
- [b] Light-weight rotating components (flight like)
- [c] Housing design (modular, possibility of windage shrouds)

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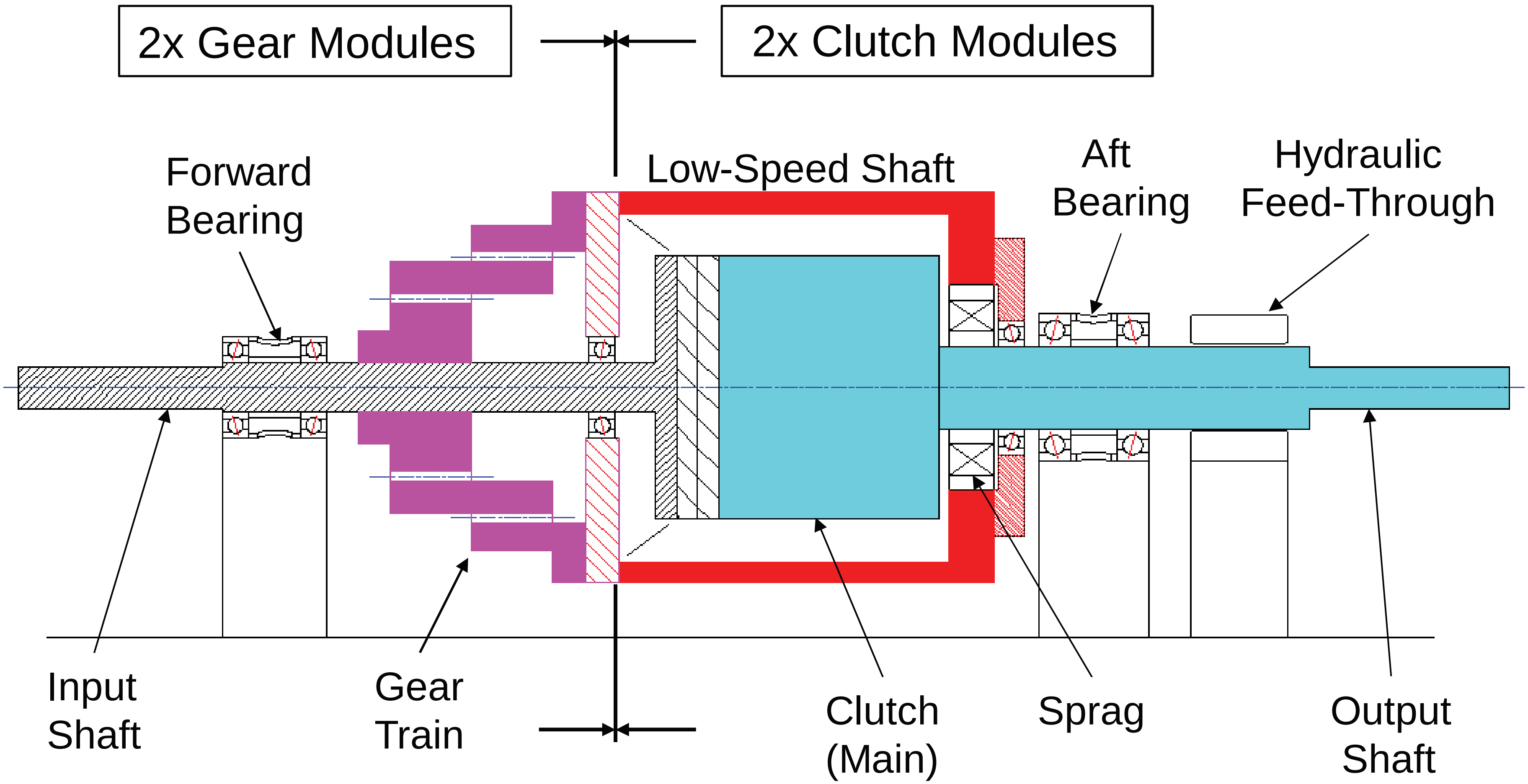
[a] *requirement dropped due to complexity and budget*

[b] *requirement dropped due to scope and budget*

[c] *not an original requirement*

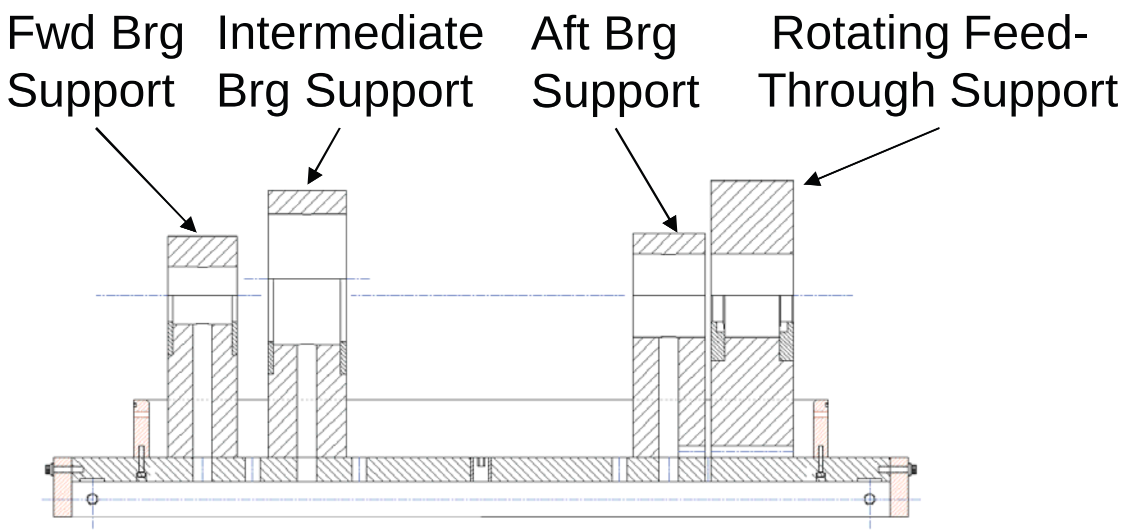
Modules: Gear & Clutch

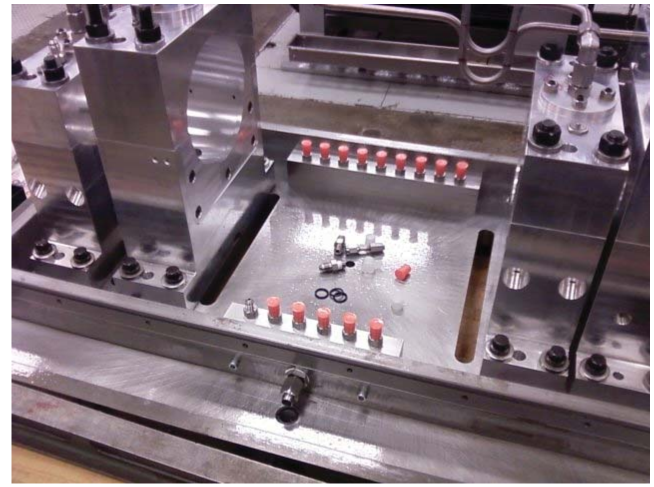


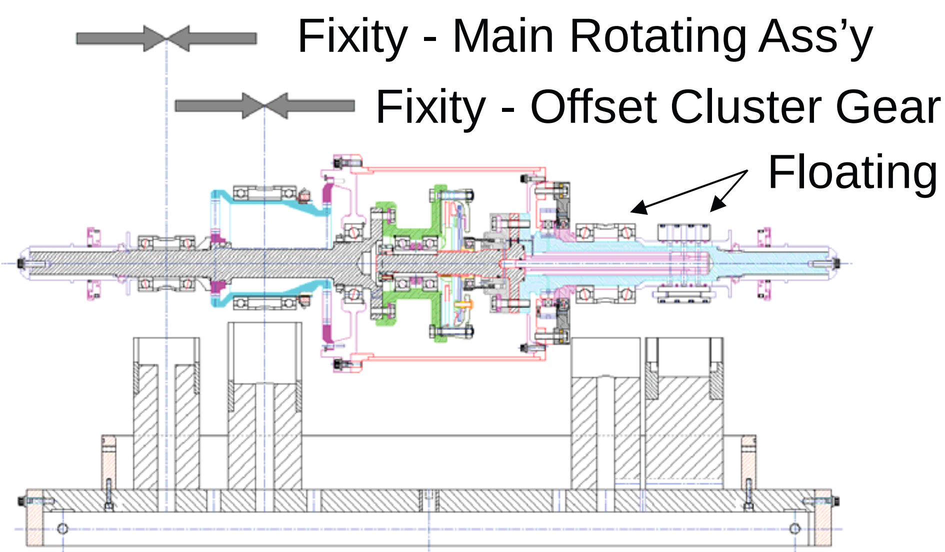
1:1 Direct Drive (Vertical Flight)
Main Clutch Engaged

2:1 Reduction Drive (Cruise)
Main Clutch Disengaged

Baseplate/Supports/Housing

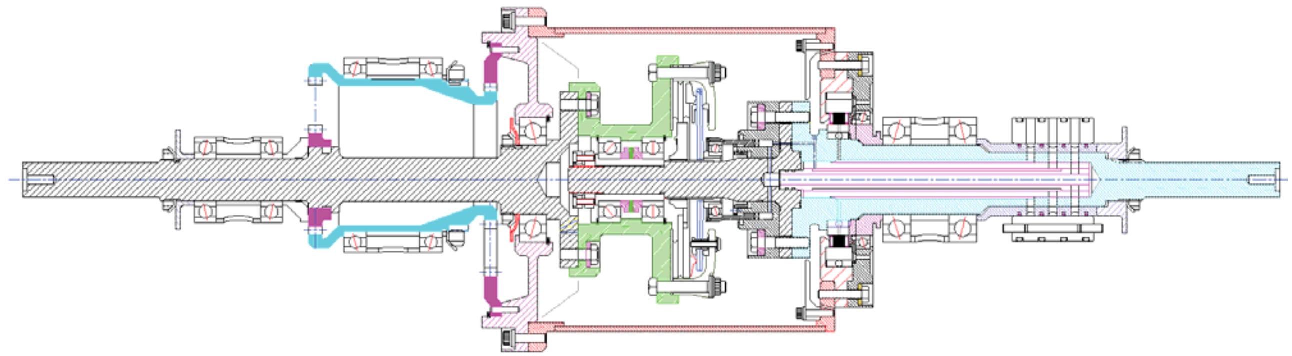




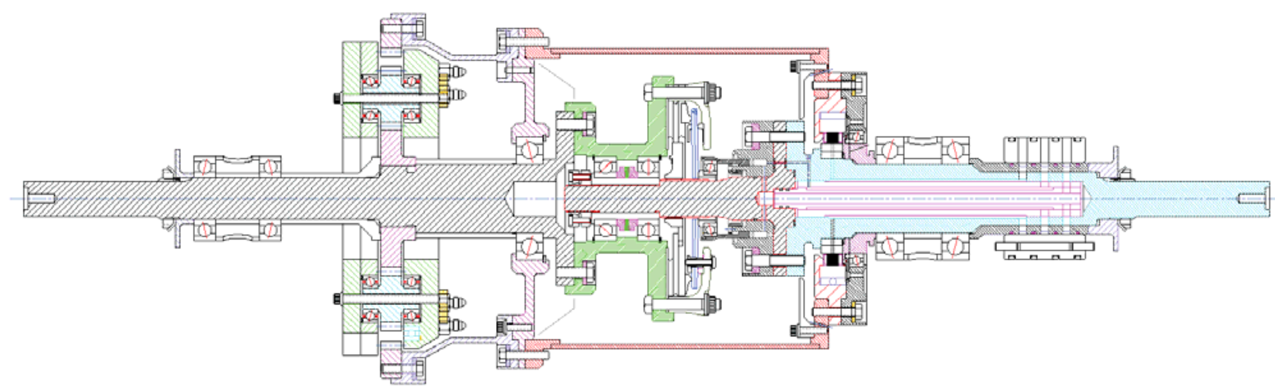


Two-Speed Drive Test Configurations

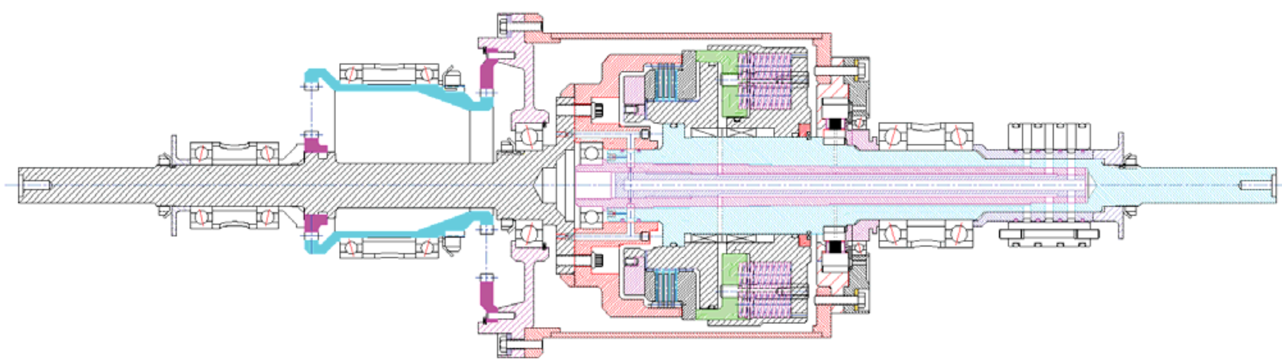
Configuration 1:
OCG / Dry-Clutch
(Tested)



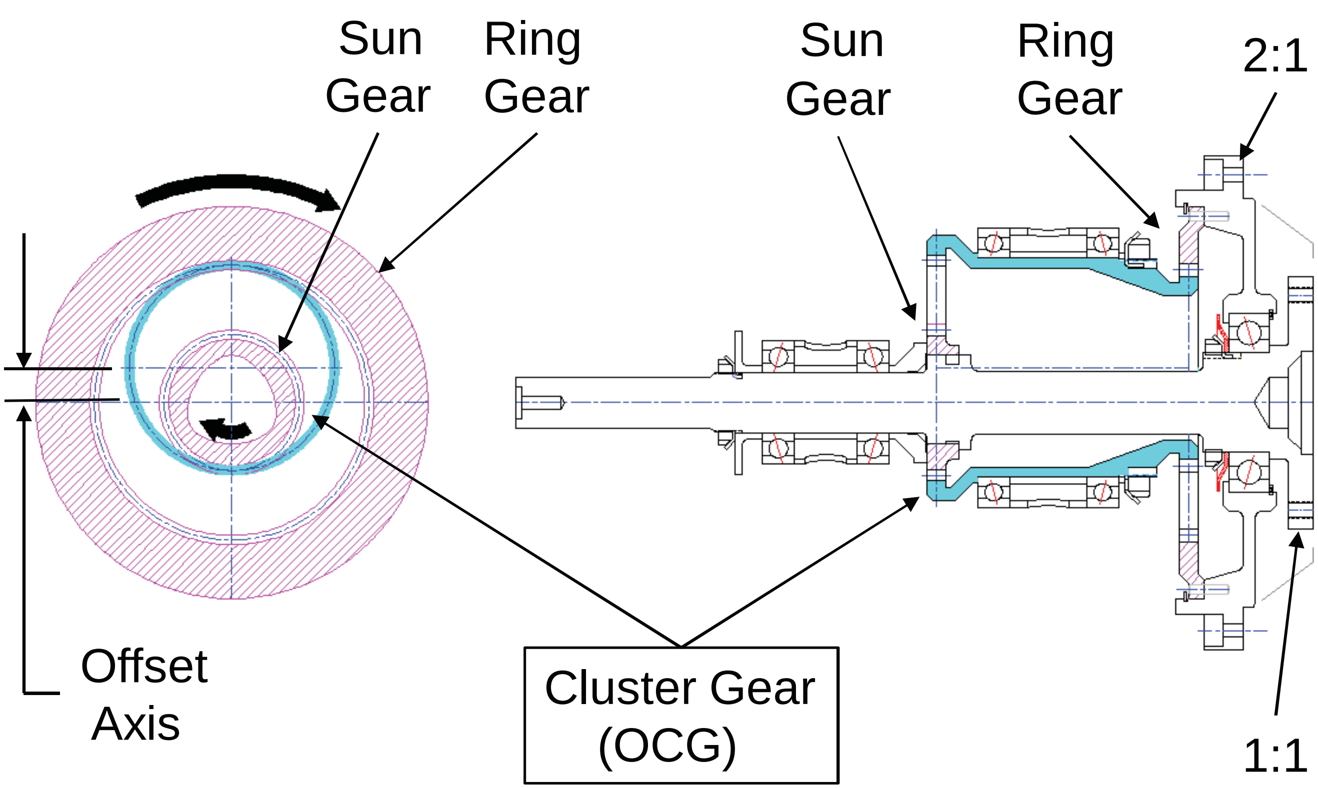
Configuration 2:
DSI / Dry-Clutch
(Tested)

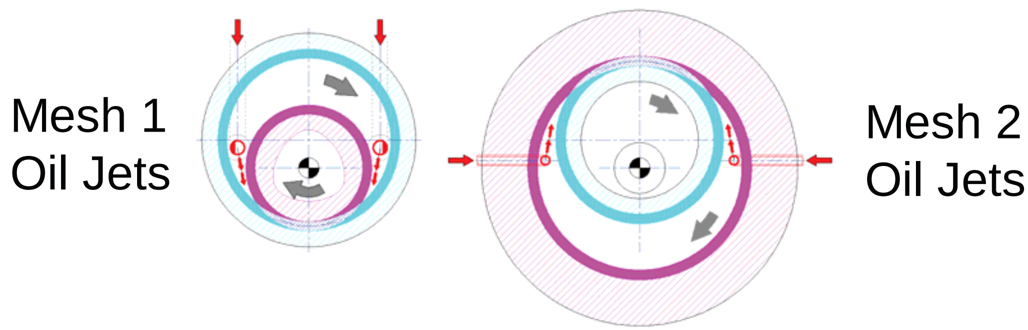


Configuration 3:
OCG / Wet-Clutch
(In assembly)

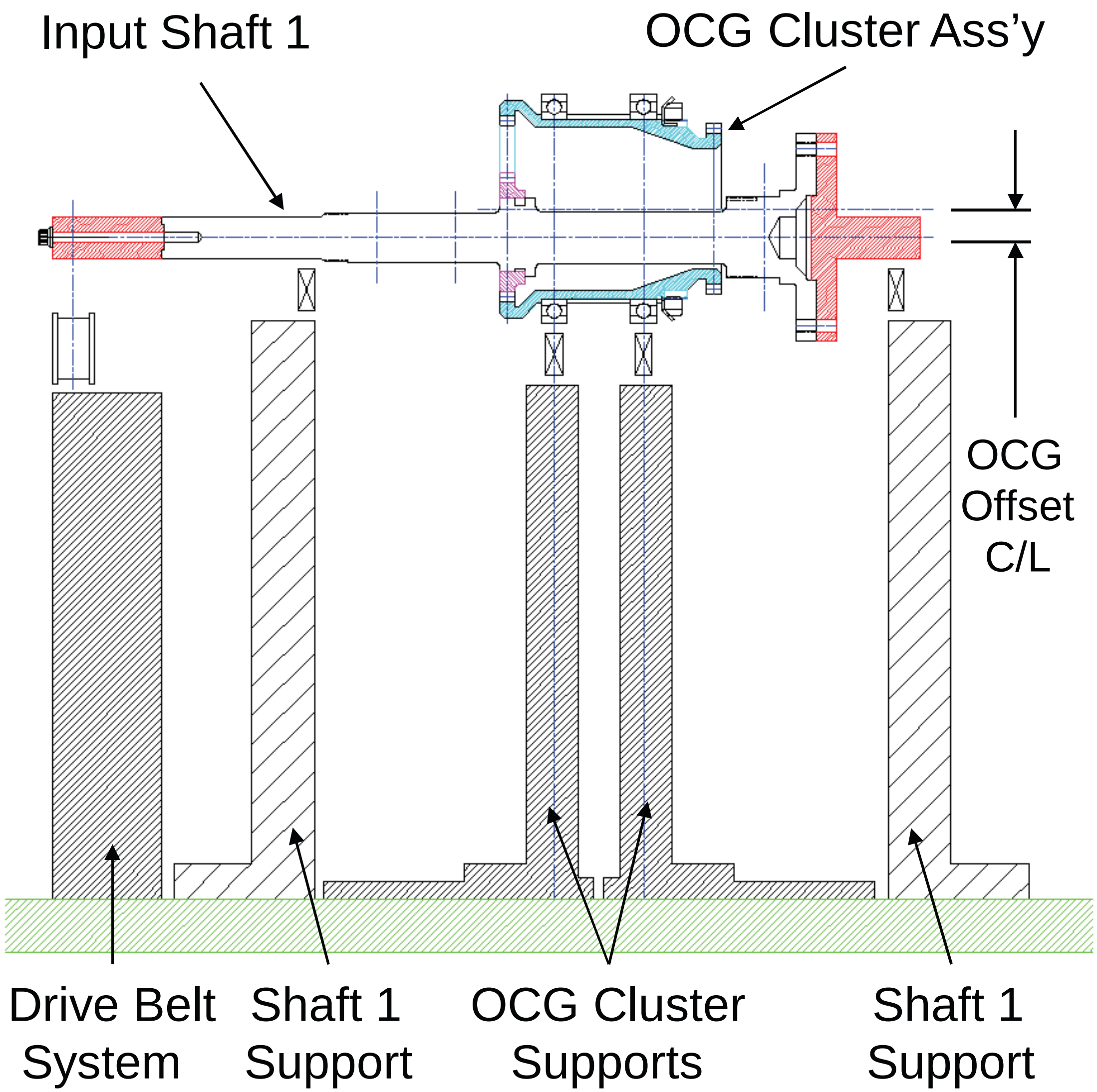


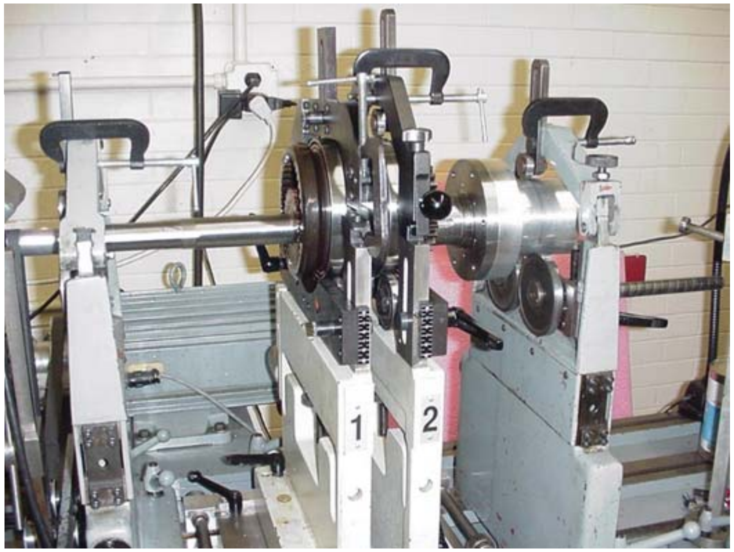
Gear Module 1: (OCG) - Offset-Compound Gear

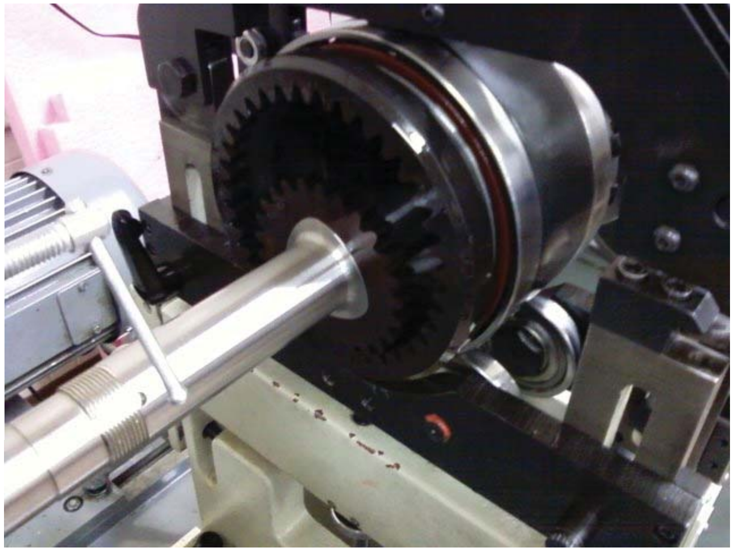




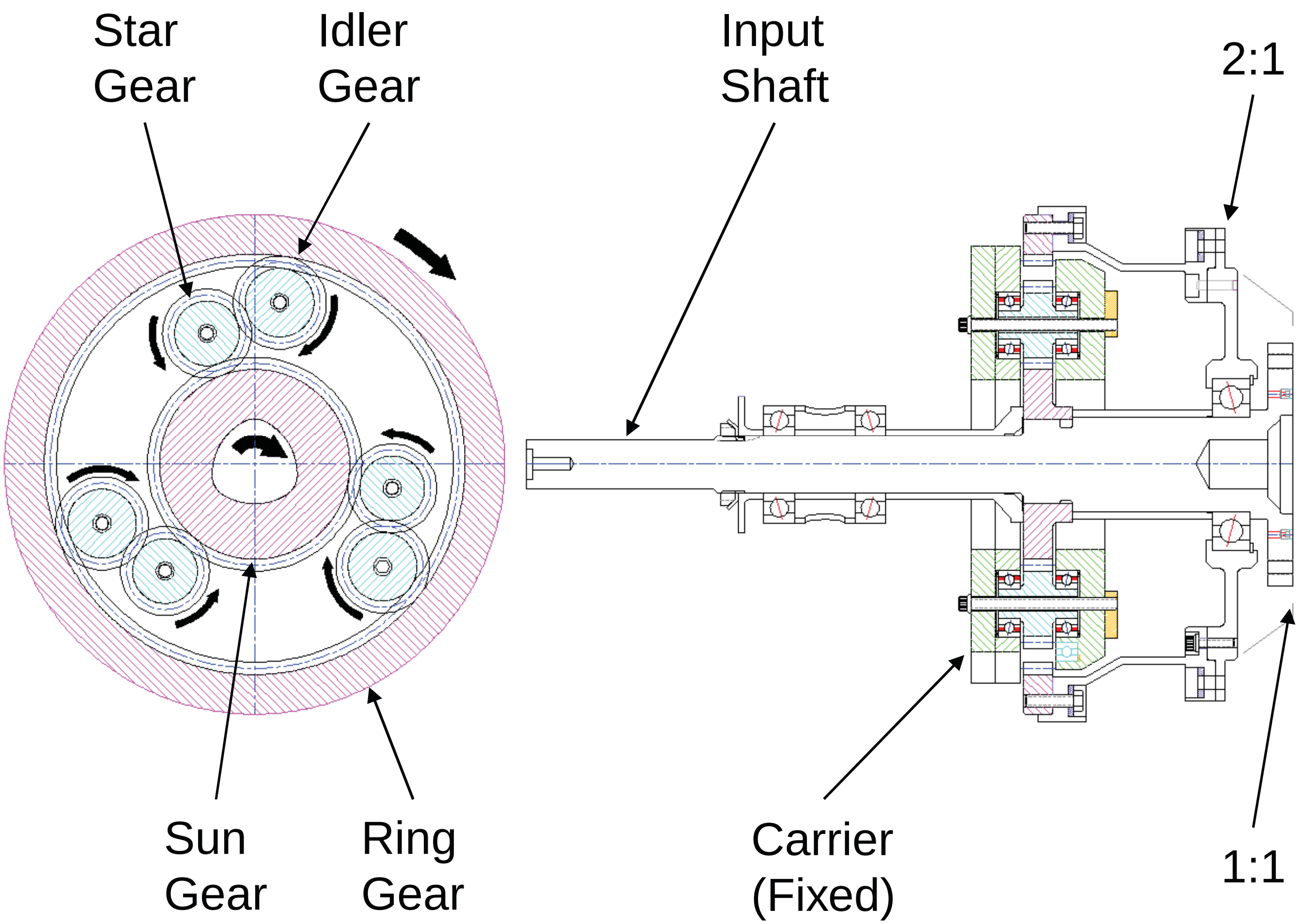
Balancing the OCG Cluster Assembly

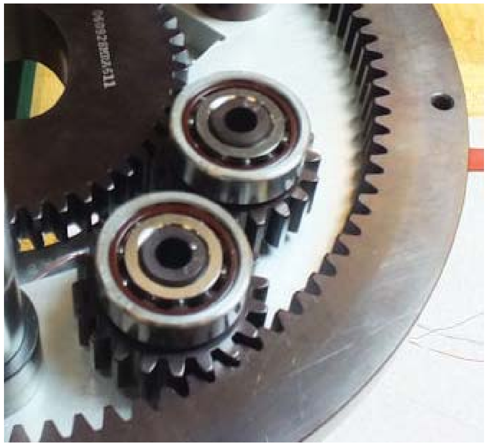




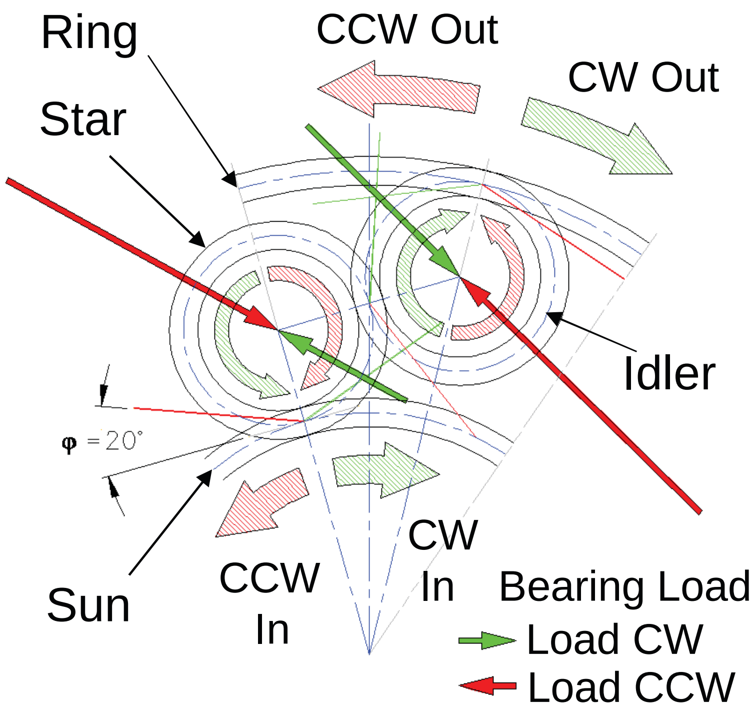


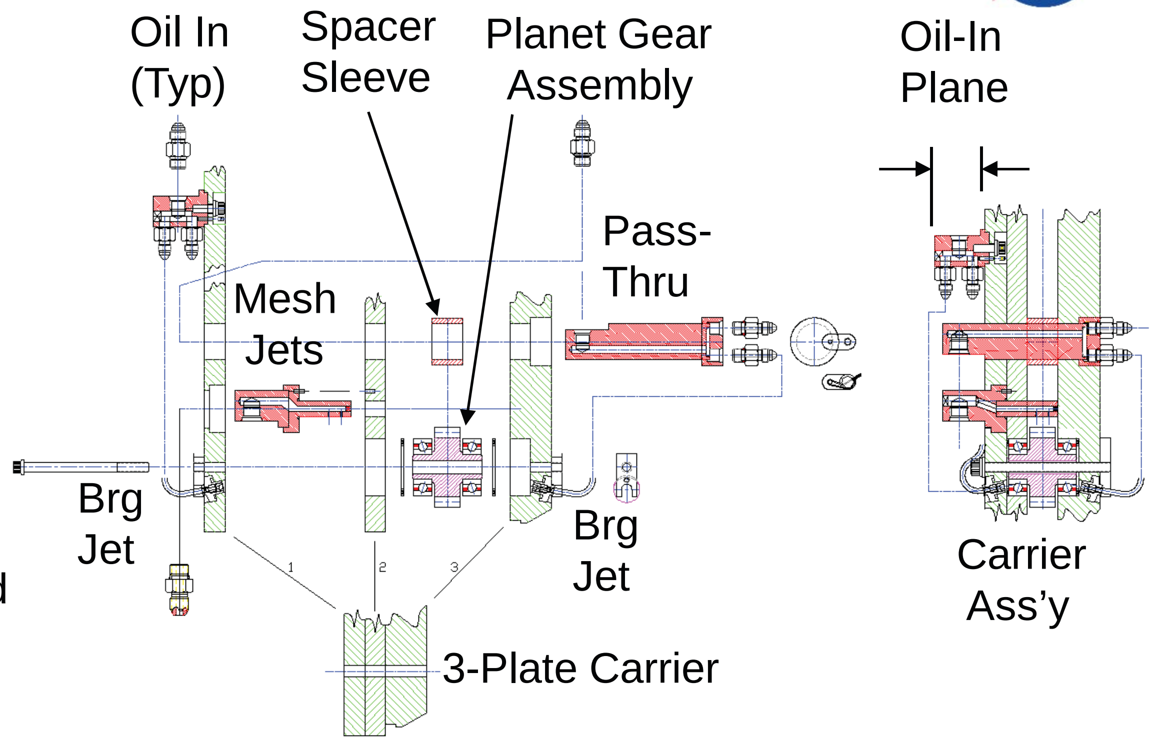
Gear Module 2: (DSI) - Dual Star-Idler Planetary



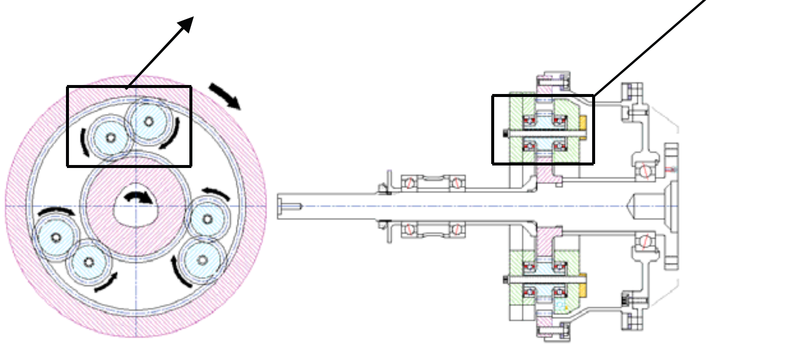


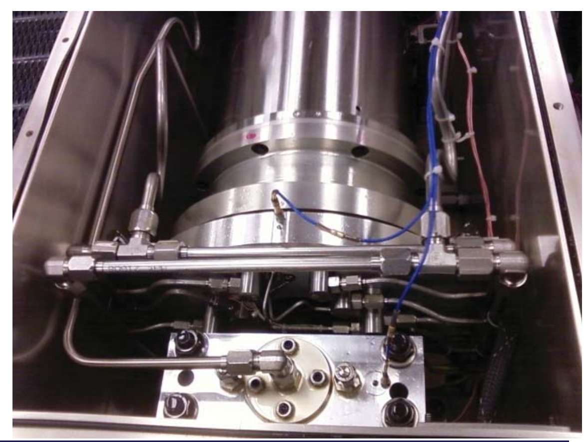
DSI Planetary Gear Design





Bearing Loads vs. Rotational Direction





Gear Parameters - OCG vs. DSI

OCG Gear Train

Material: 9310, Backlash: 0.006-0.011 inch,
Width: 0.375 inch, Contact Angle 20º

Gear	Pitch	Pitch Dia (inch)	N_{teeth}	Rpm
Input	8.727	2.865	25	15,000
2	8.727	4.240	37	10,135
3	8.0	3.875	31	10,135
Ring	8.0	5.250	42	7,481

DSI Gear Train

Material: 9310, Backlash: 0.010-0.015 inch,
Width: 0.600 inch, Contact Angle 20º

Gear	Pitch	Pitch Dia (inch)	N_{teeth}	Rpm
Sun	12	4.1667	50	15,000
Star	12	1.5833	19	39,474
Idler	12	1.6667	20	37,500
Ring	12	8.4167	101	7,426

Observations: DSI planet gears spin at 4x the speed of the OCG cluster gear.

Bearing Parameters - OCG vs. DSI

OCG Bearing Parameters.

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Site	Rpm	Size	D_{brg}	d_{brg}	dN factor
Input	15,000	206	62	30	450,000
2	10,135	1822	140	110	1,114,850
3	10,135	1822	140	110	1,114,850
Ring	7,481	210	90	50	374,050

DSI Bearing Parameters.

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Site	Rpm	Size	D_{brg}	d_{brg}	dN factor
Sun	15,000	206	62	30	450,000
Star	39,474	202	35	15	592,110
Idler	37,500	202	35	15	562,500
Ring	7,426	210	90	50	371,300

(Bearing diameters in millimeters)

Observations: Bearing dN are higher for OCG despite high speeds of the DSI planet bearings.

Observations – Gear Trains

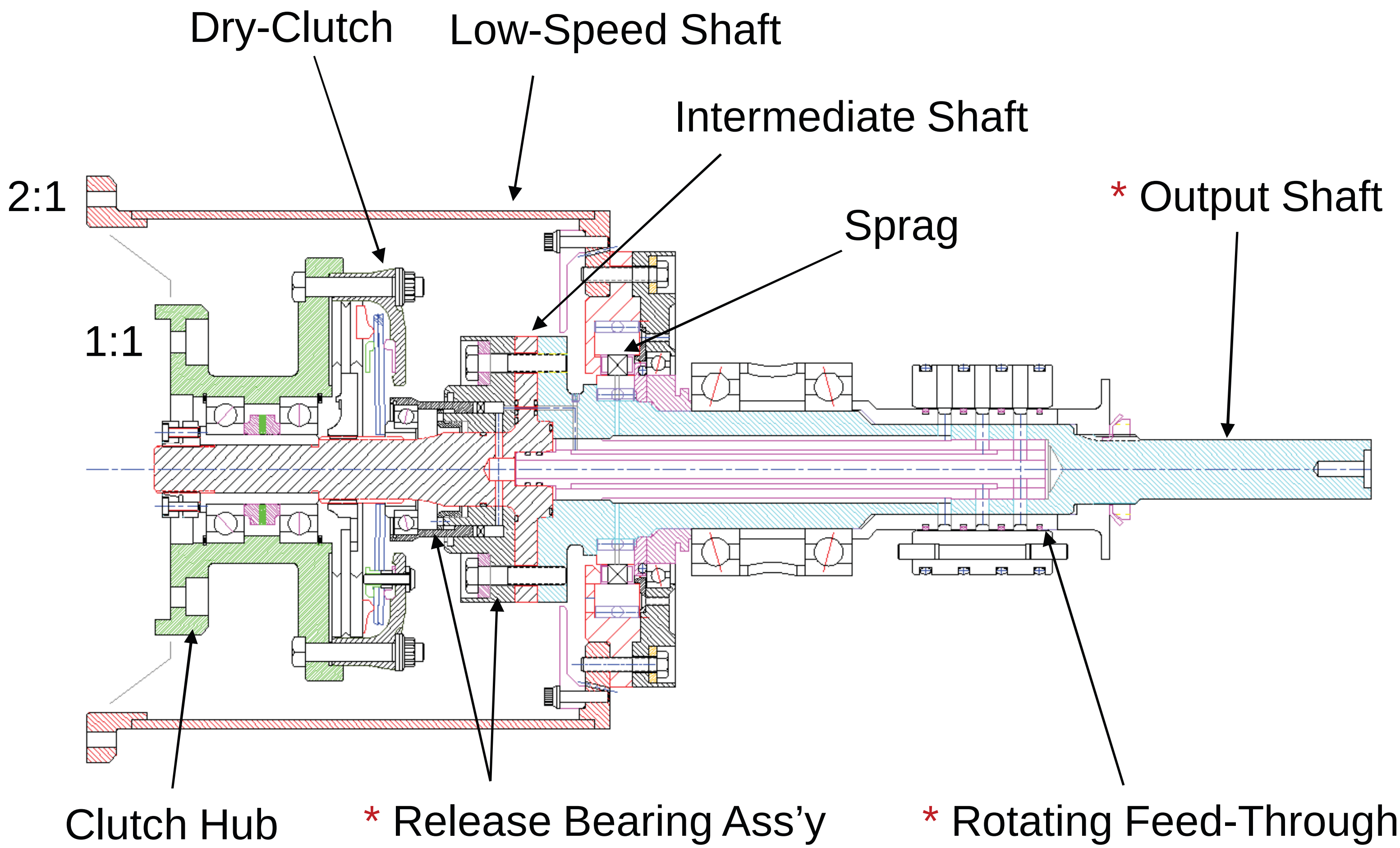
High planet gear speed is an inherent aspect of a single stage planetary gear train with a 2:1 output since the ratio is defined by the ratio of pitch diameters of the ring and sun gears.

For a basic 2:1 Planetary: Ø5.0 sun & Ø10.0 ring yields the following intermediate gear speeds for an input speed of 15,000 rpm

Gear Train	Intermediate Speed (rpm)
Basic Planetary	30,000
DSI (idler addition)	37,500 +25% speed increase due to reduced diameter planets
OCG	10,000

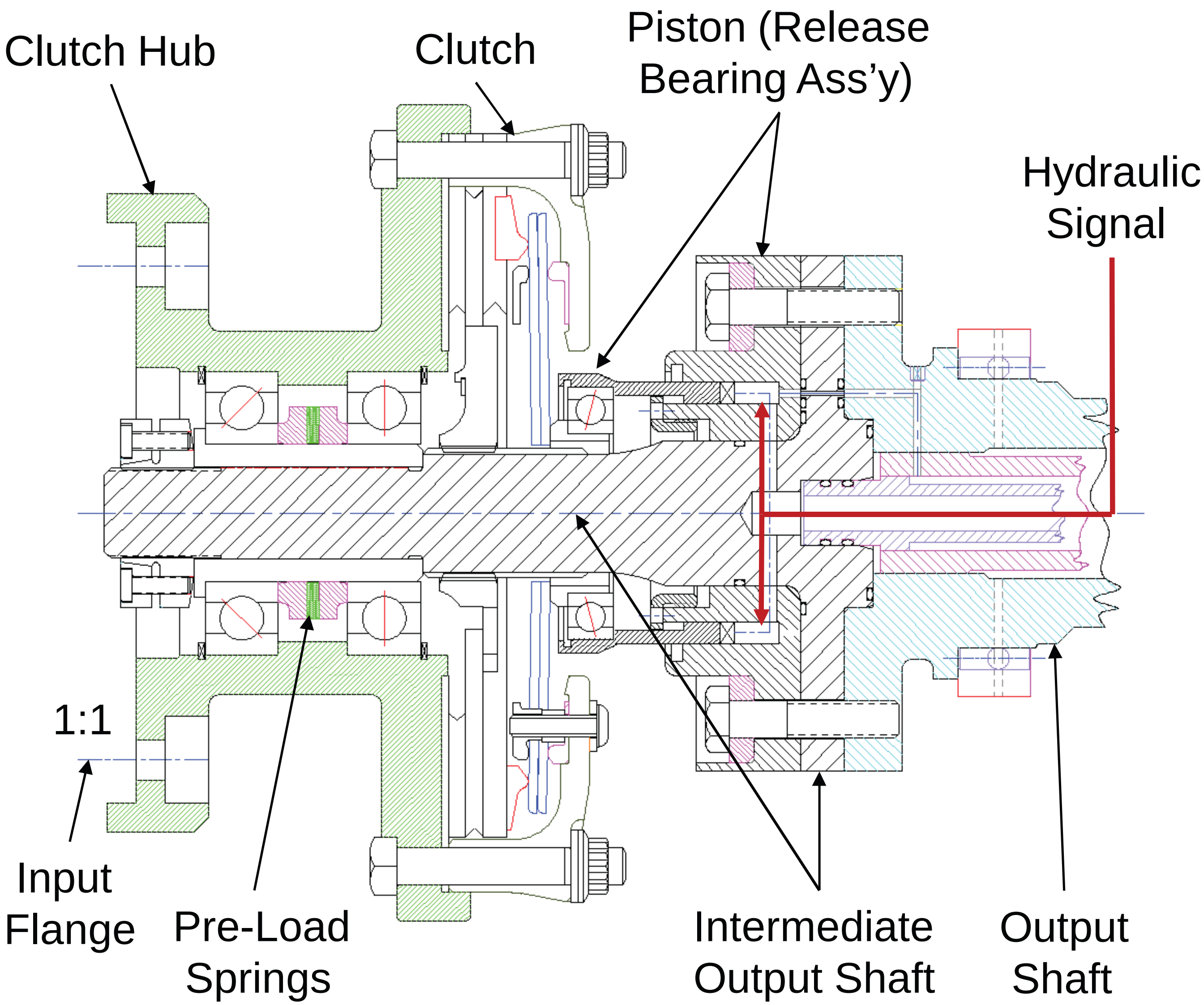
The OCG is simpler to lubricate due to reduced number of gear meshes and bearings.

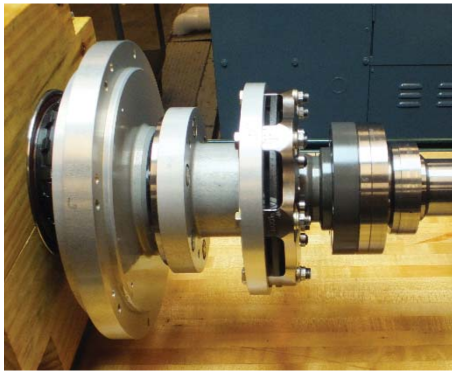
Clutch Module: (DC) DRY-CLUTCH



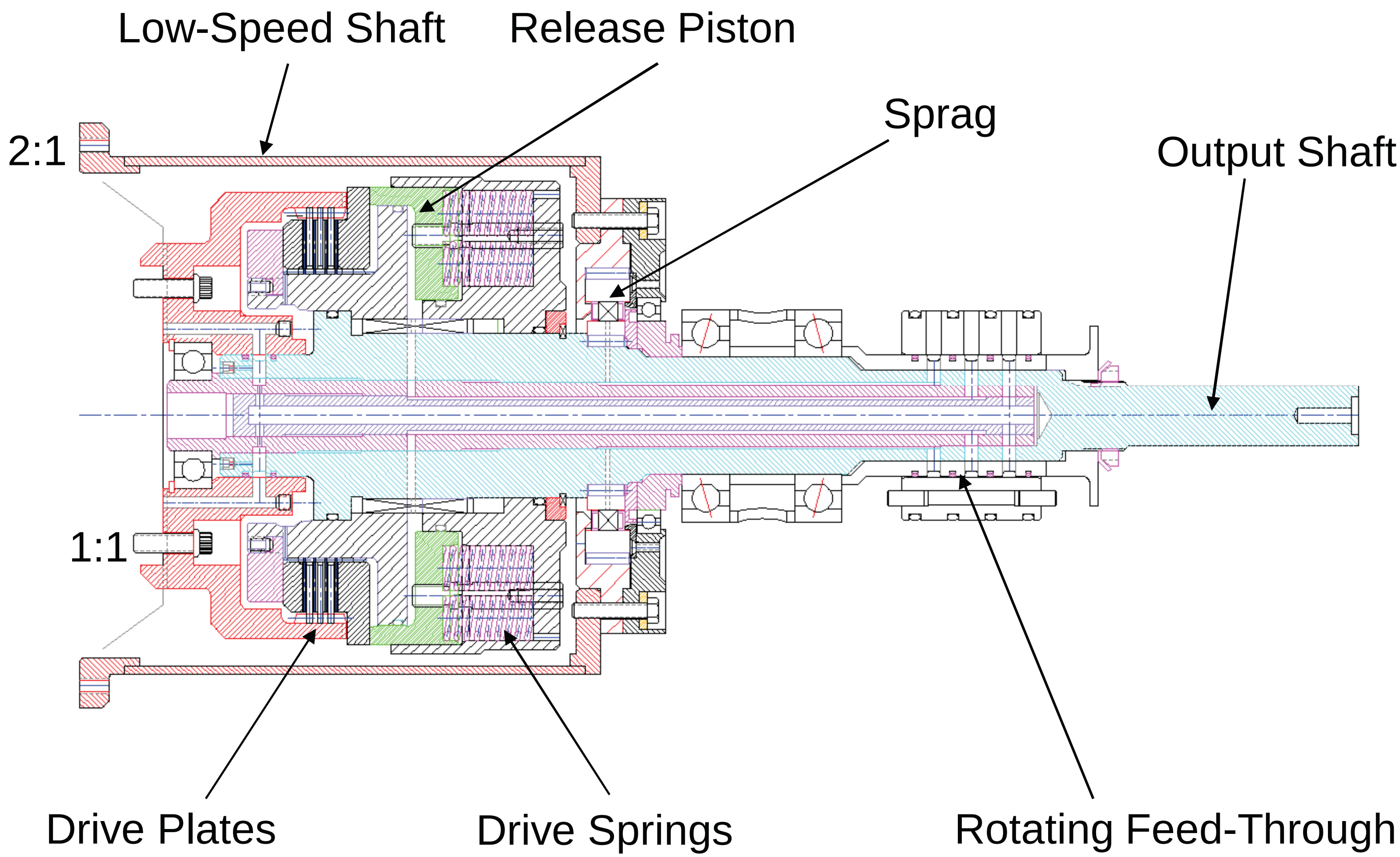
* Unique hardware necessary to meet the inline design requirement

Dry-Clutch Design

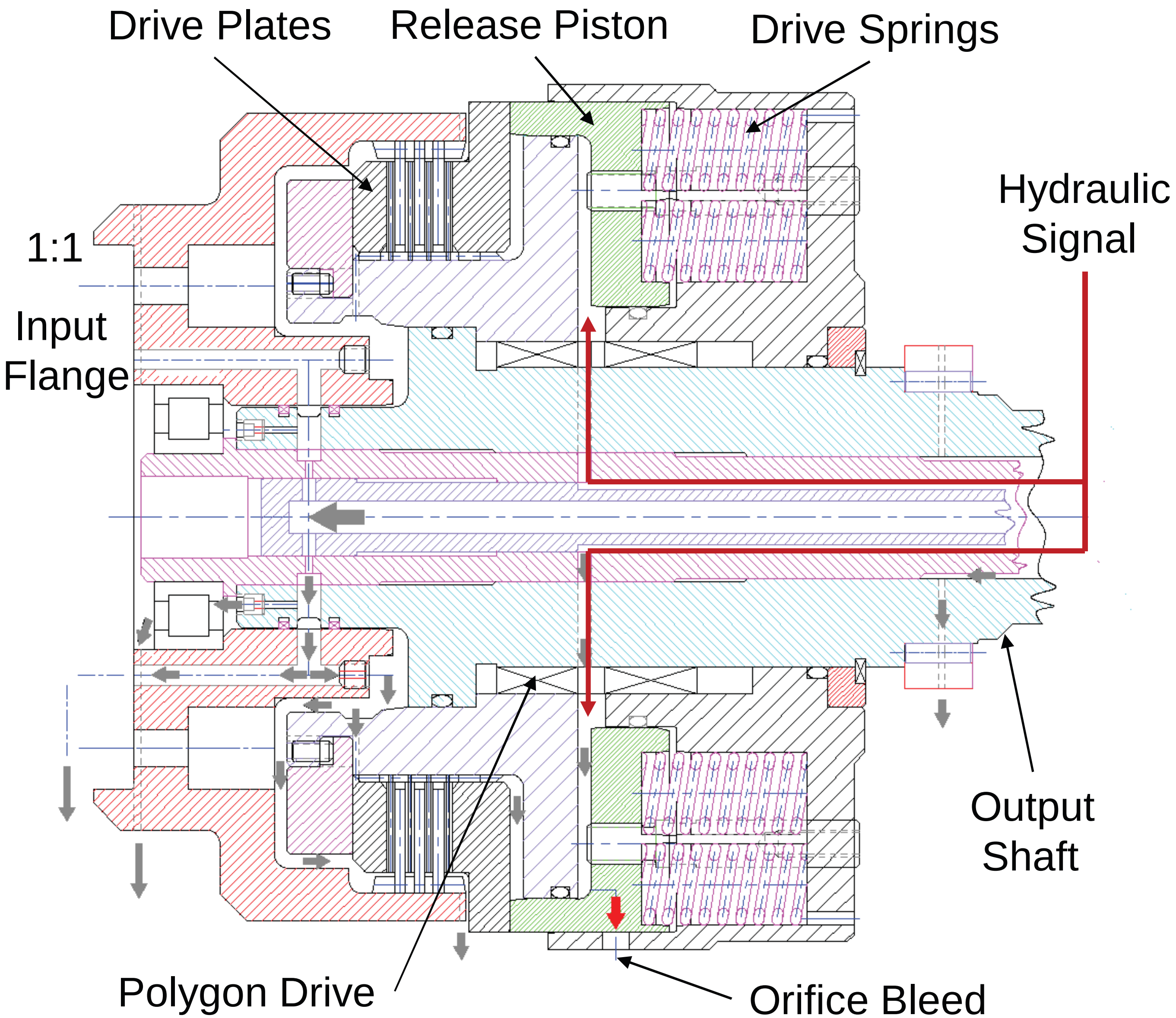




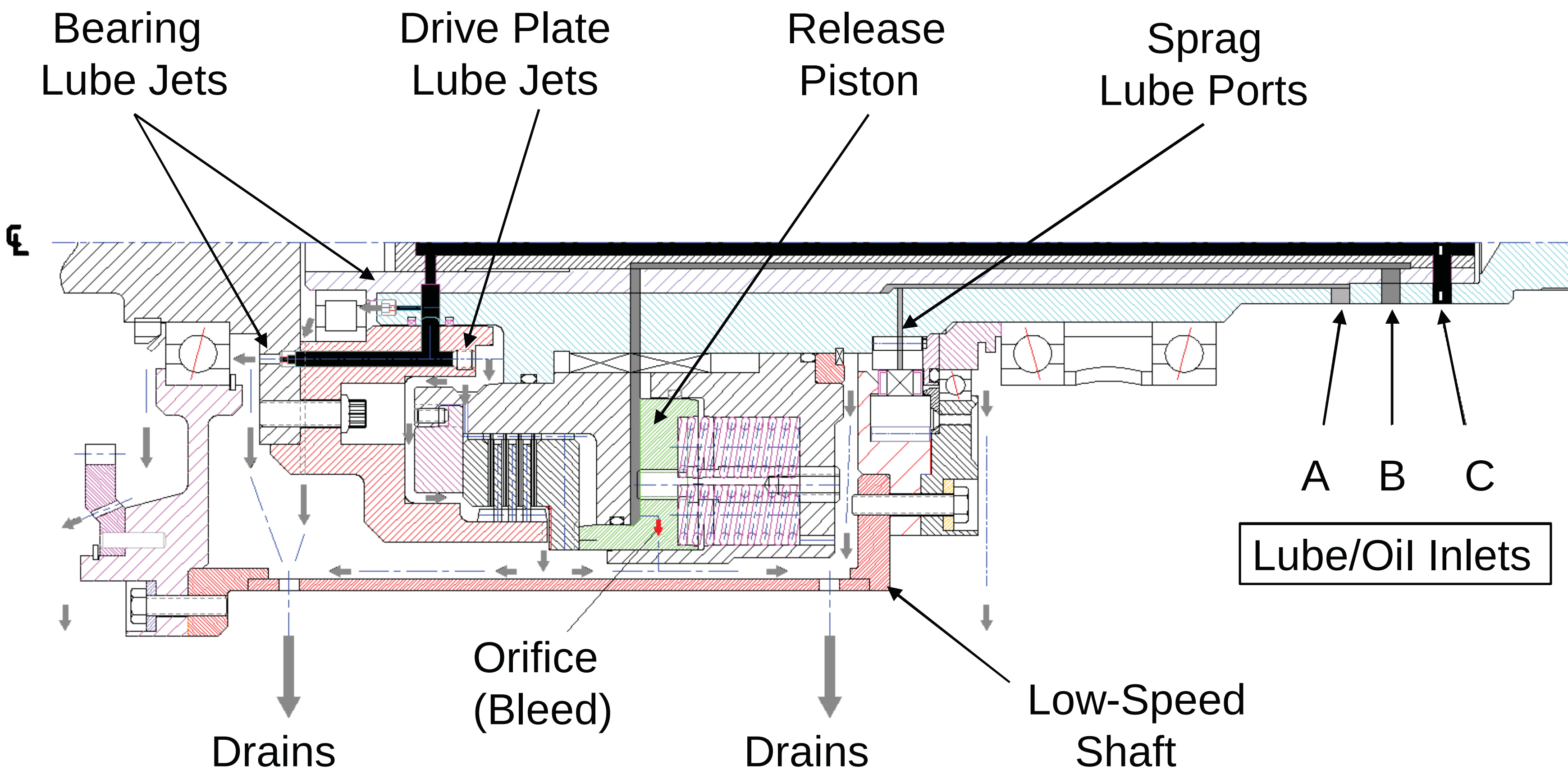
Clutch Module: (WC) Wet-Clutch



Wet-Clutch Design

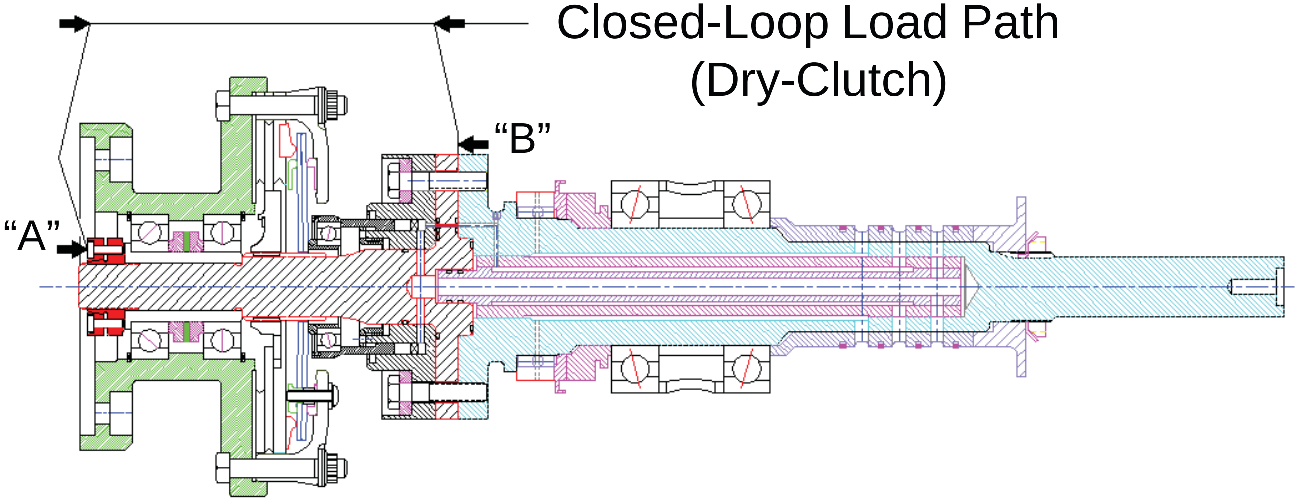


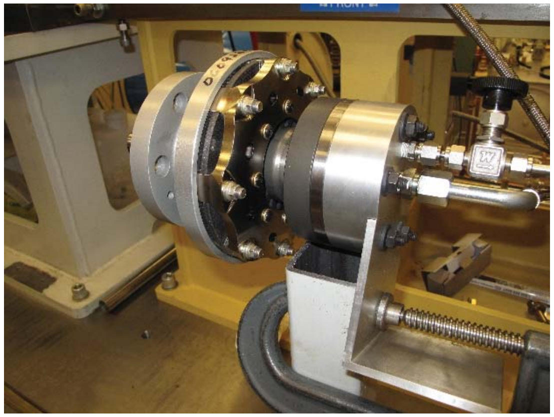
Output Shaft Hydraulic / Lubrication Passages (Wet-Clutch)



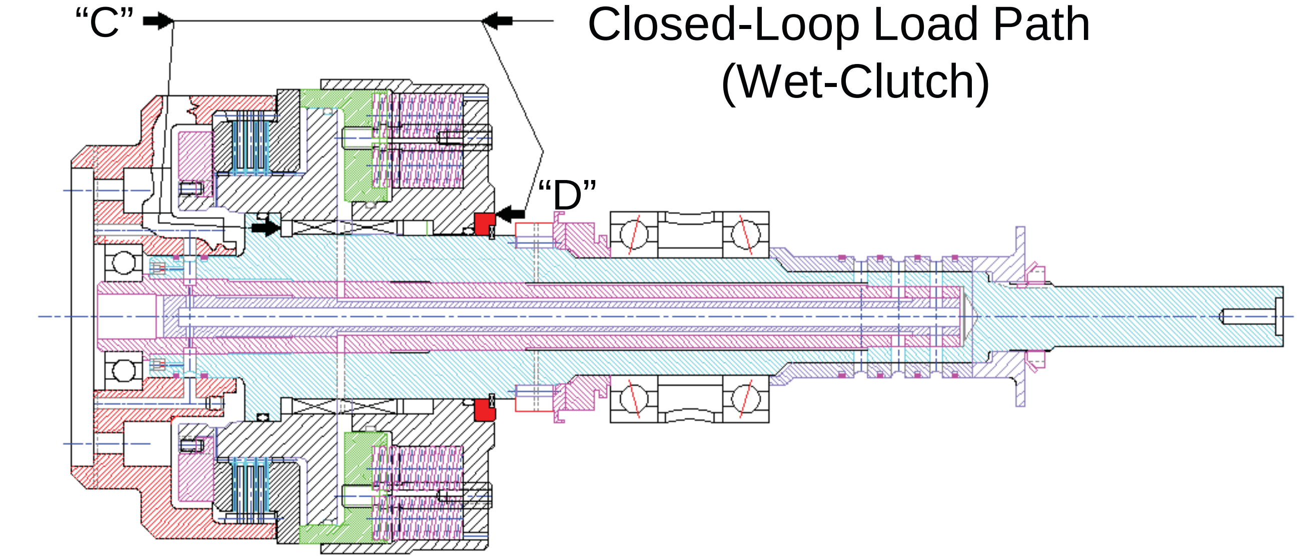
Clutch Release Closed-Loop Load Path

Closed-Loop Load Path
(Dry-Clutch)



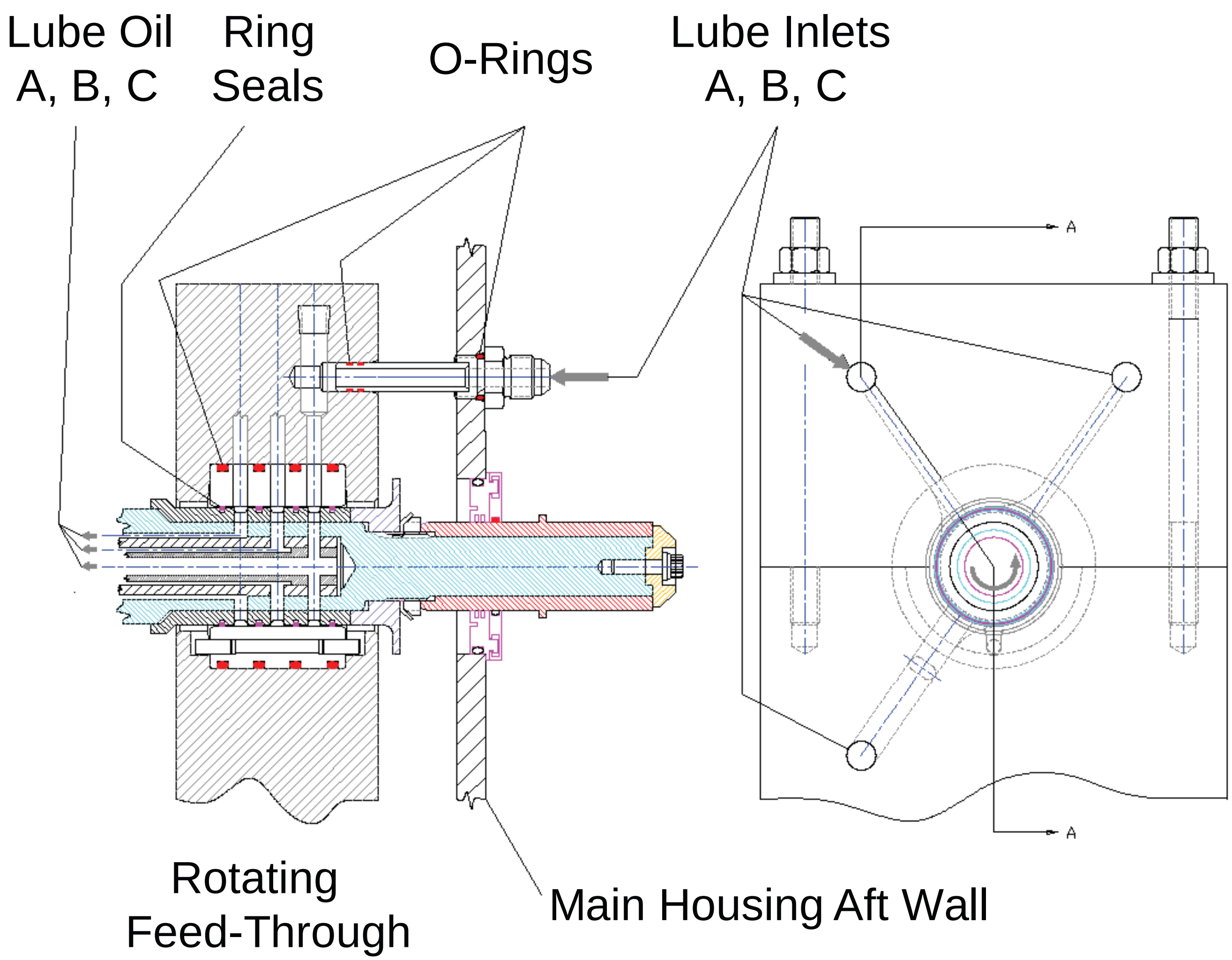


Closed-Loop Load Path
(Wet-Clutch)

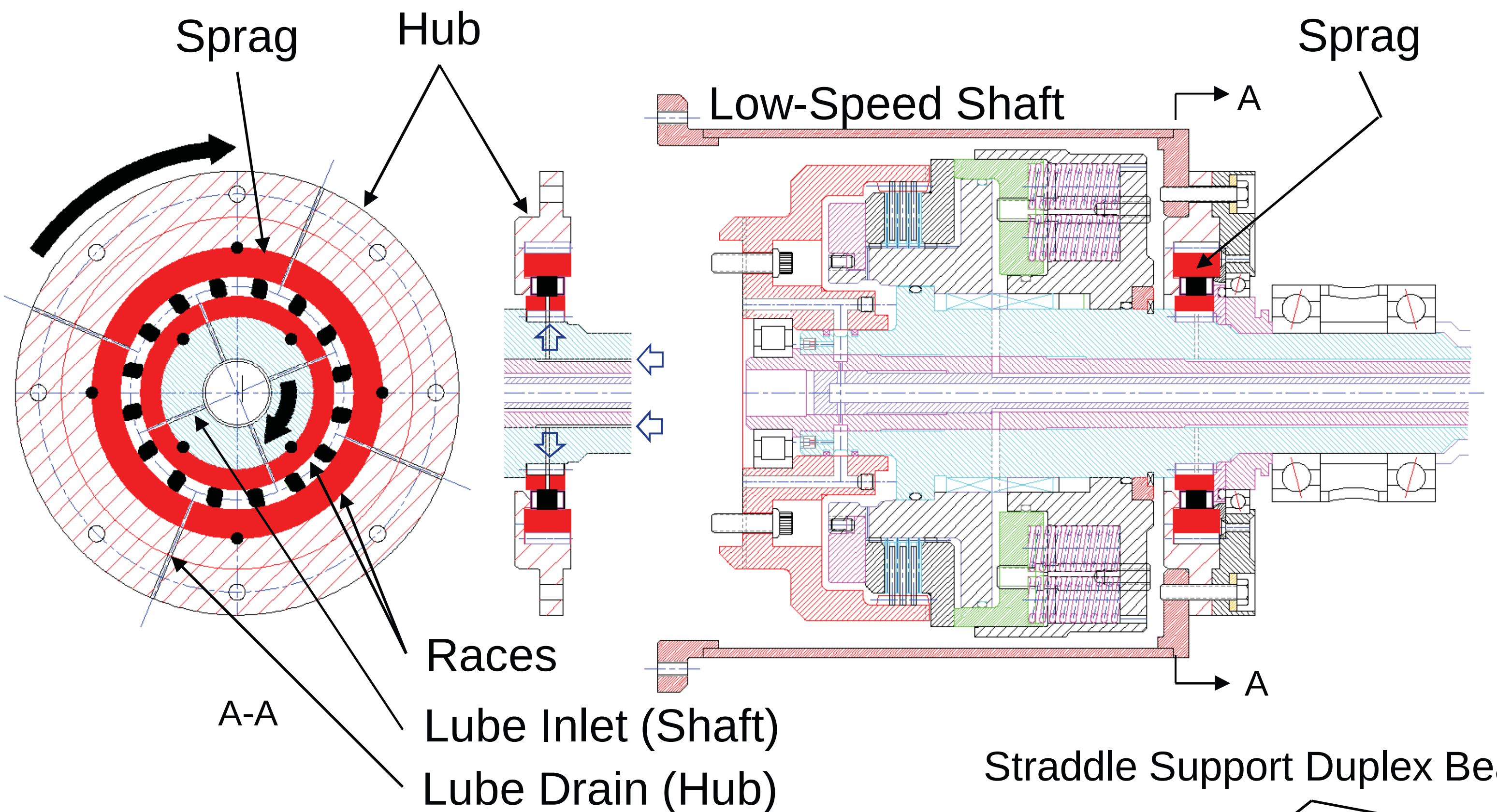


Rotating Hydraulic/Lubricant Feed-Through

- 15,000 rpm
  Ring Seals – DuPont Vespel
  Significant drag



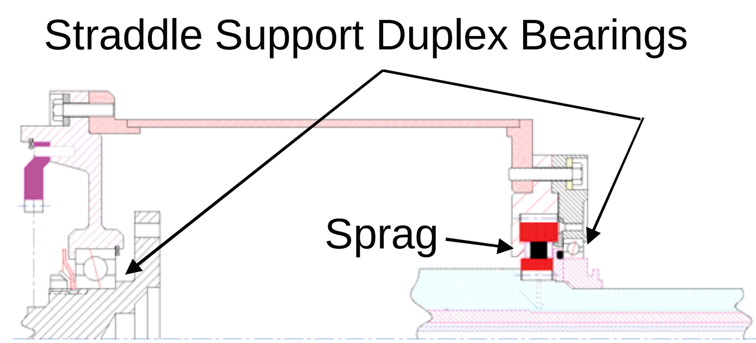
Sprag (Overrunning Clutch)



Sprag
- 16-element
- 4-lube inlets

Races
- 4-drive pins

Revisions
- Addition of aft-sprag bearing forming straddle duplex bearing support



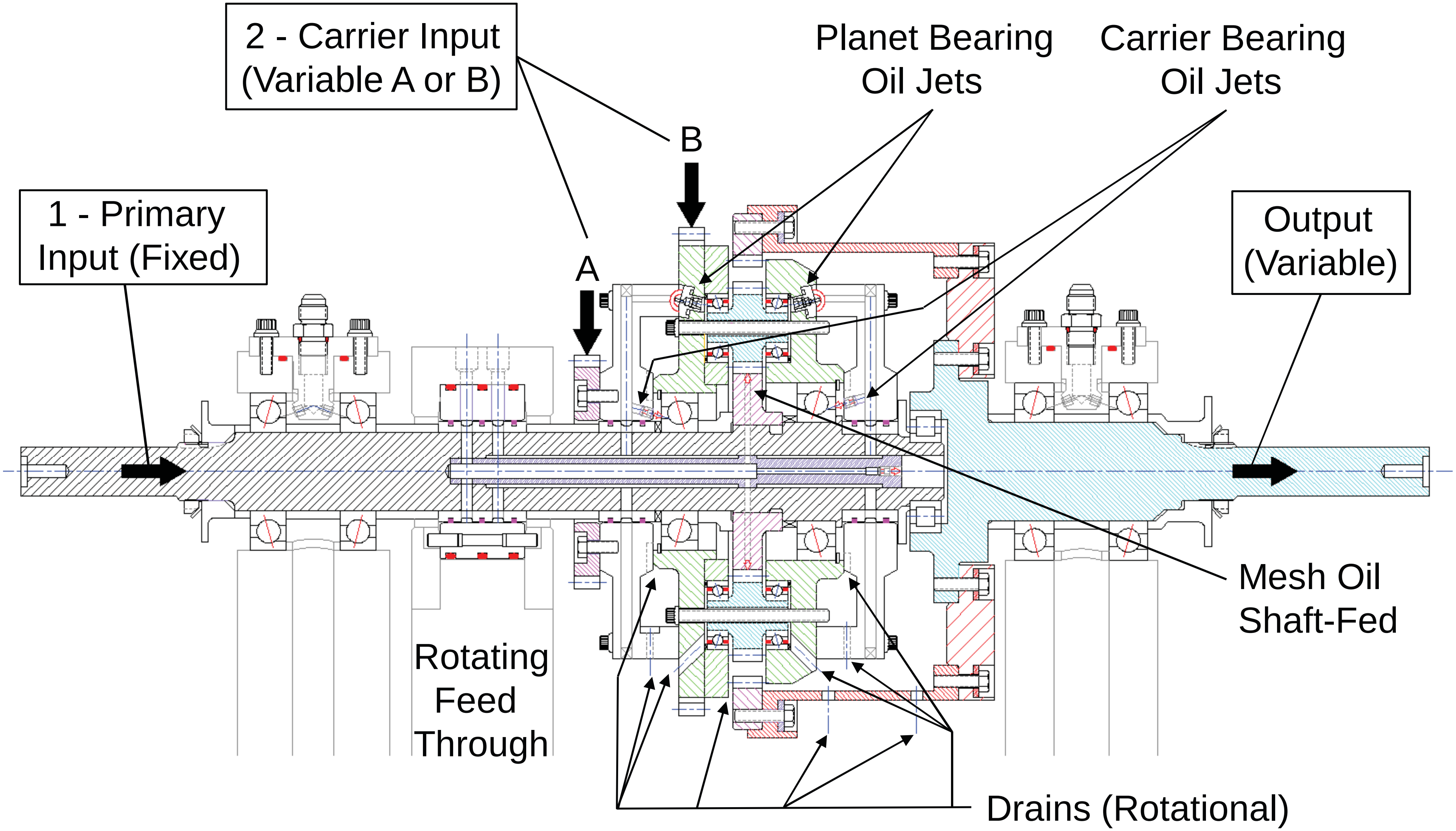
Future Design (Concept 3)

Variable-Speed Drive
Dual-Input Planetary Differential

- Concept Variable-Speed Drive leveraged from the DSI Planetary Gear Train & Lubrication Design
  - Sun Gear - Input
  - Carrier - Control (Second Input)
  - Ring Gear – Output
- Direct Point Bearing and Gear Lubrication

Second Input Is Not Within Current Scope

DUAL-INPUT PLANETARY DIFFERENTIAL



CONCLUDING REMARKS

- Presented an overview of designs and current status of two-speed drive concepts developed at NASA GRC.
- Identified a few areas for future development.

  Many more are discussed in detail in the paper.
- Presented an updated concept for a variable-speed gear drive based on a dual-input planetary differential.

Questions?