Gear Windage Modeling Progress –Experimental Validation Status

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In the Subsonics Rotary Wing (SRW) Project being funded for propulsion work at NASA Glenn Research Center, performance of the propulsion system is of high importance. In current rotorcraft drive systems many gearing components operate at high rotational speed (pitch line velocity > 24000 ft/ min). In our testing of high speed helical gear trains at NASA Glenn we have found that the work done on the air - oil mist within the gearbox can become a significant part of the power loss of the system. This loss mechanism is referred to as windage. The effort described in this presentation is to try to understand the variables that affect windage, develop a good experimental data base to validate, the analytical project being conducted at Penn State University by Dr. Rob Kunz under a NASA SRW NRA. The presentation provides an update to the status of these efforts.

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Topics

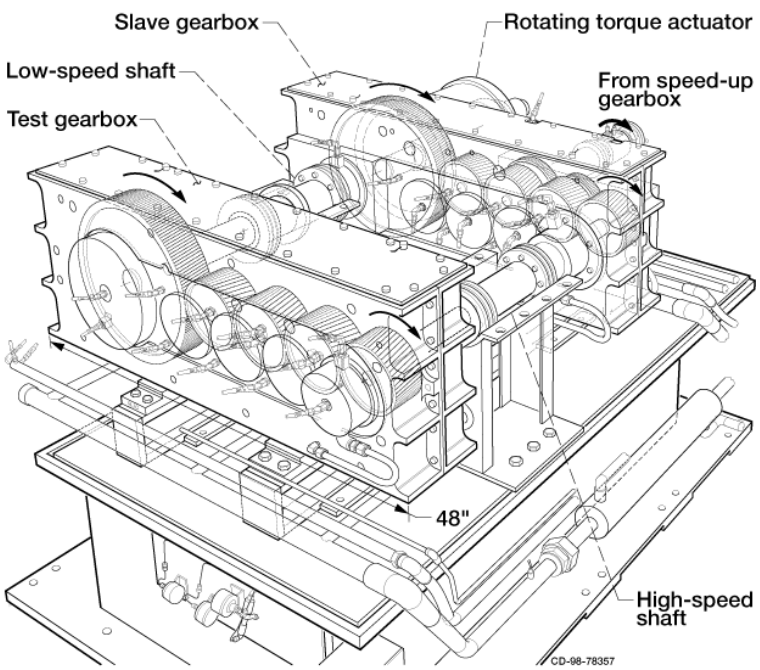
- Background
- CFD modeling of high speed gearing
- Current analytical validation results
- Experimental testing build-up
- Status & plans

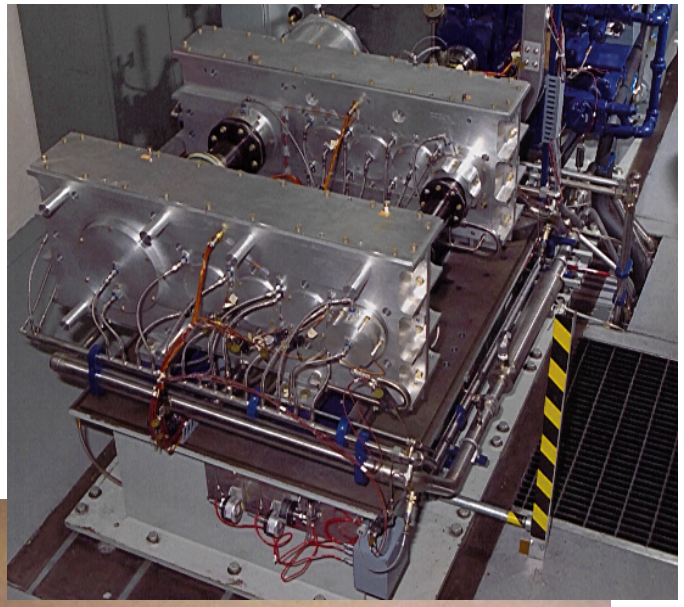
Background

- High speed gearing tests at GRC have shown the importance of windage losses
- This topic has received very little attention in the open literature
- Analytical and experimental efforts are focusing on developing a proper aerospace database and a full 3-D modeling capability

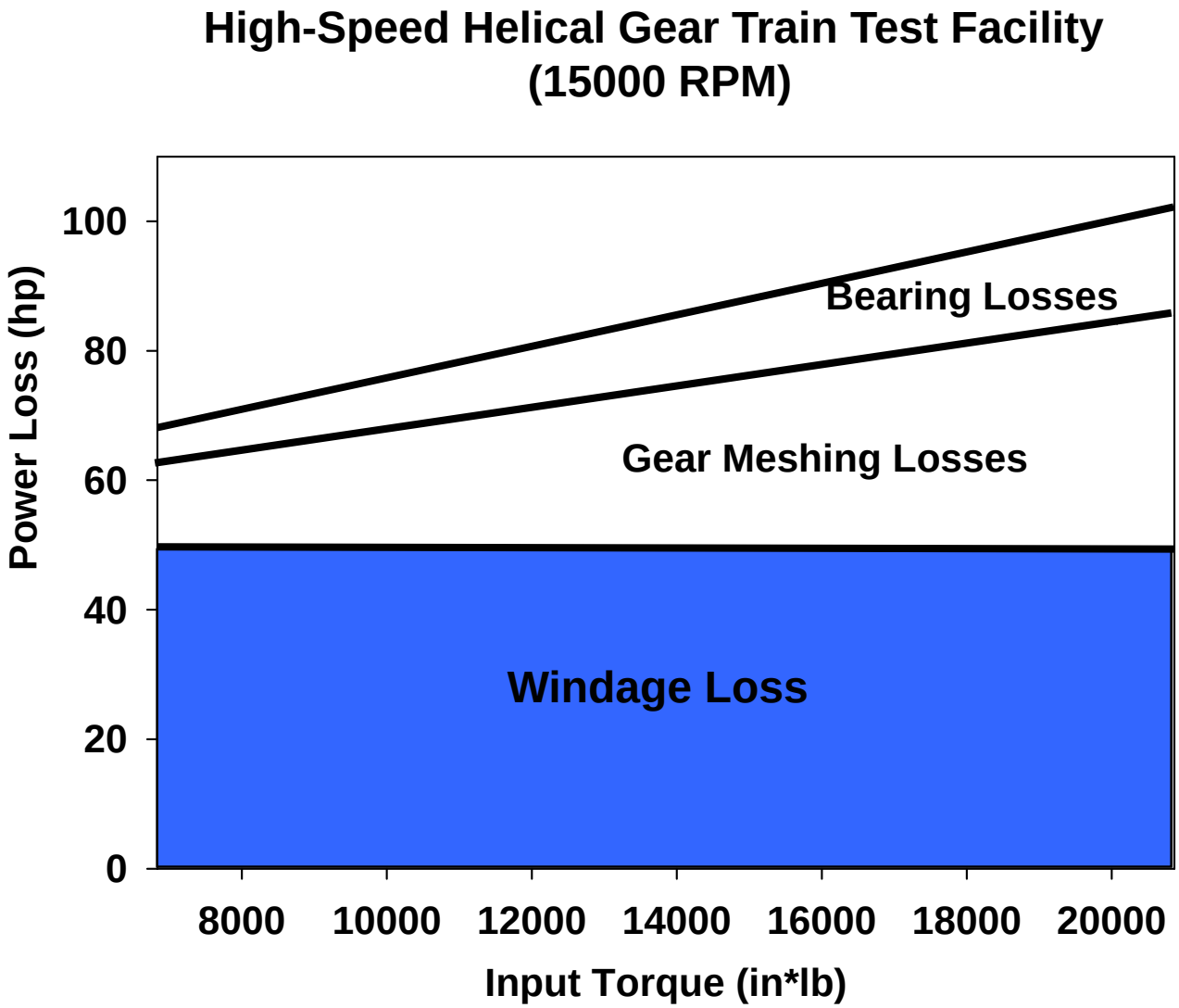
Background

High-Speed Helical Gear Train Test Facility (NASA – GRC)



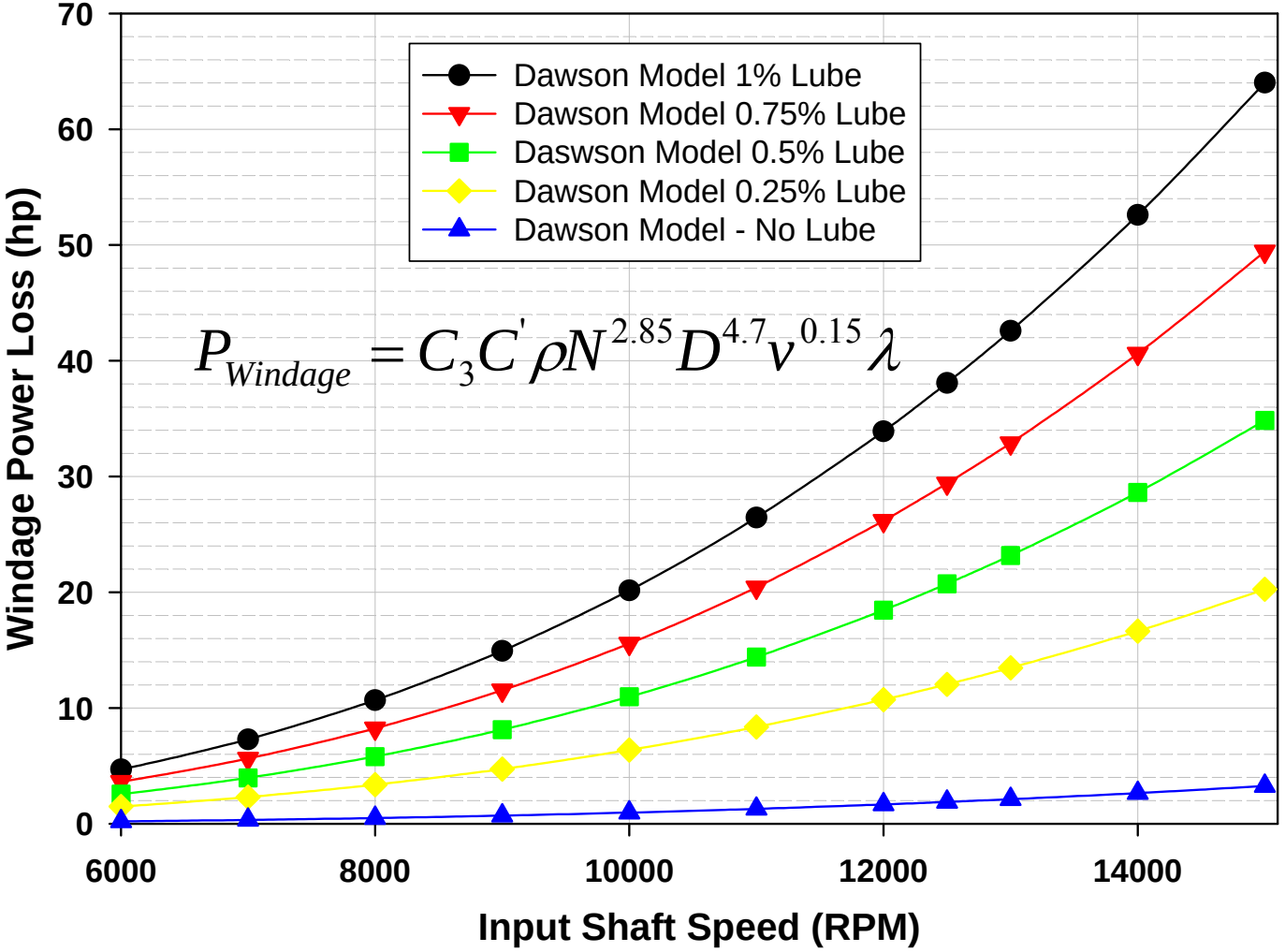


Background


High-Speed Helical Gear Train Test Facility
(15000 RPM)
Power Loss (hp)
100
80
60
40
20
0
Bearing Losses
Gear Meshing Losses
Windage Loss
8000
10000
12000
14000
16000
18000
20000
Input Torque (in*lb)

Background

Gear Windage Results
High-Speed Helical Gear Train Prediction



Technical Challenges

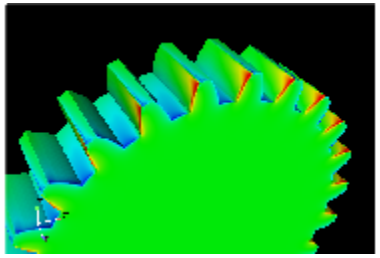
- Complex physics for CFD:
  - Geometries
  - High M_{tip}
  - High Re
  - Contact + relative motion
  - Multiphase flow (disperse [droplets], continuous [films])
  - Turbulence
  - Heat transfer
  - Viscous dissipation
- Little validation data
- Unknown relative importance of 1-phase and 2-phase physics
- Oil-out condition

- Deploy five, modern components of CFD technology:
  1. unstructured, overset, moving meshes
  2. Multi-phase, multi-flow-regime (droplet+film)
  3. Thermal analysis
  4. Modern turbulence modeling
  5. Immersed Boundary Methods for gears.

- NPHASE-PSU Code:
  - Developed at Penn State ARL (Kunz).
  - Overset+unstructured+moving meshes
  - All modes of heat transfer
  - Full-n-fluid multiphase flow with deposition, atomization drag, dispersion and other relevant models
  - Parallel (MPI, matrix level)
  - Modern turbulence modeling (2, 4, 7-equation, DES)
  - High order discretization
  - Relevant application/validation basis

Enablers in this research

- Scalar transport equation:
  - Moving grid in context of finite volume



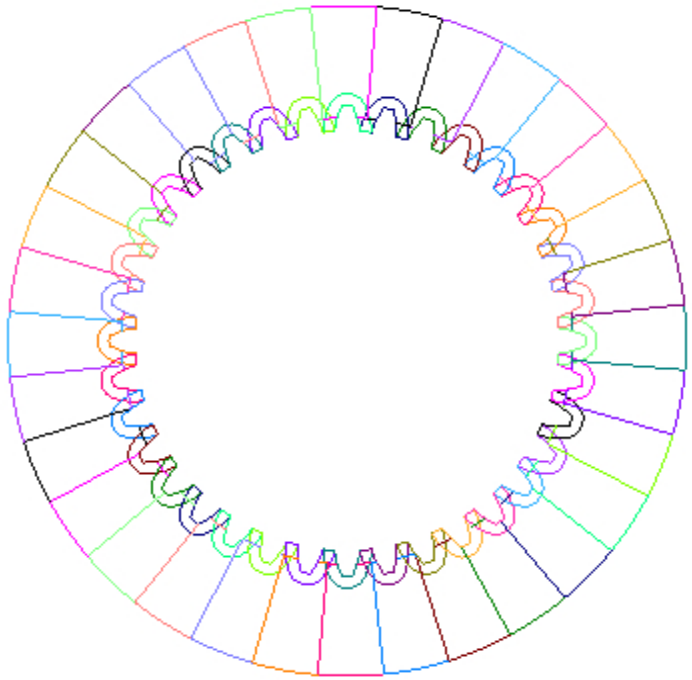
$$\frac{\partial}{\partial t}\int_{\forall}\rho\varphi d\forall+\int_{\underline{S}}\rho\varphi\left(\underline{V}-\underline{W}\right)\bullet d\underline{S}=\text{sources of }\varphi$$

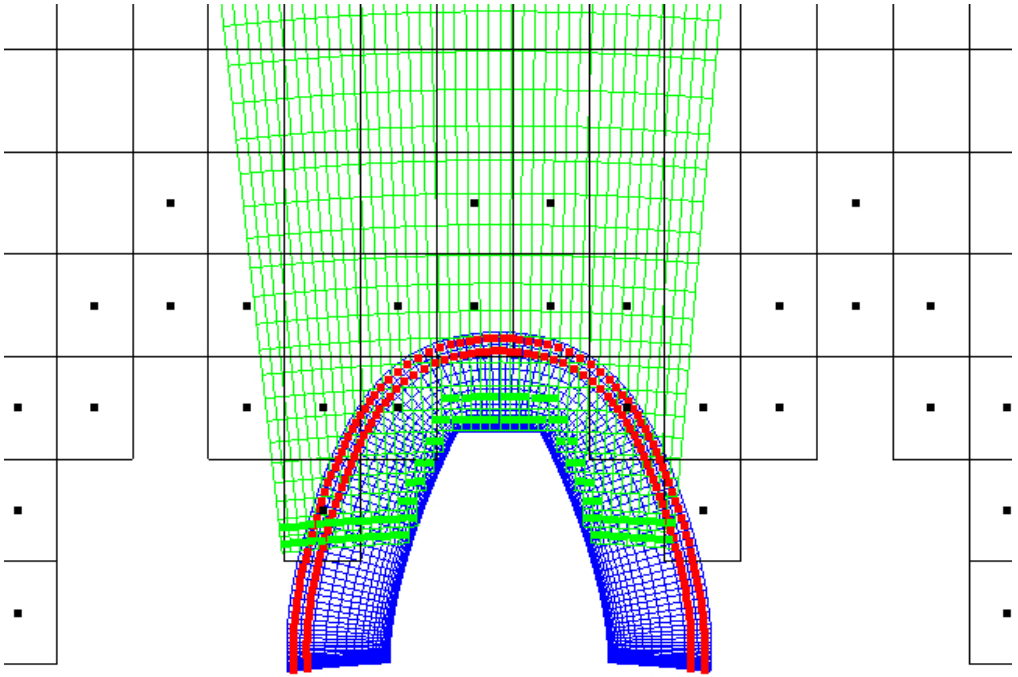
Absolute frame of reference velocity at control volume face

Velocity of control volume face

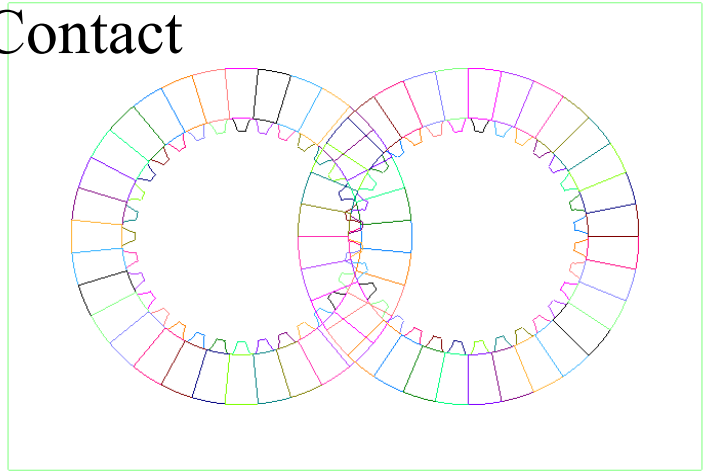
  - Exact satisfaction of Geometric Conservation law (GCL)

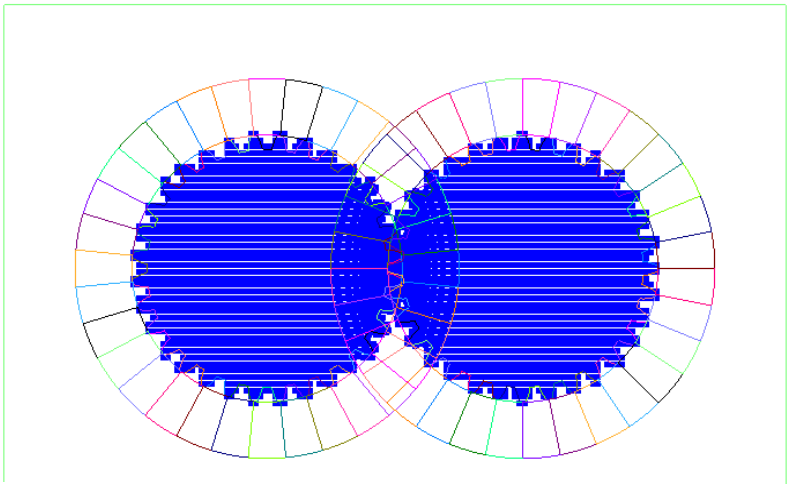
- Critical enabler for multiple gear systems.
  - Quality meshes for gears required for accurate aero modeling
  - Each gear has its “own” high quality mesh
  - Efficient use of elements/computer resources

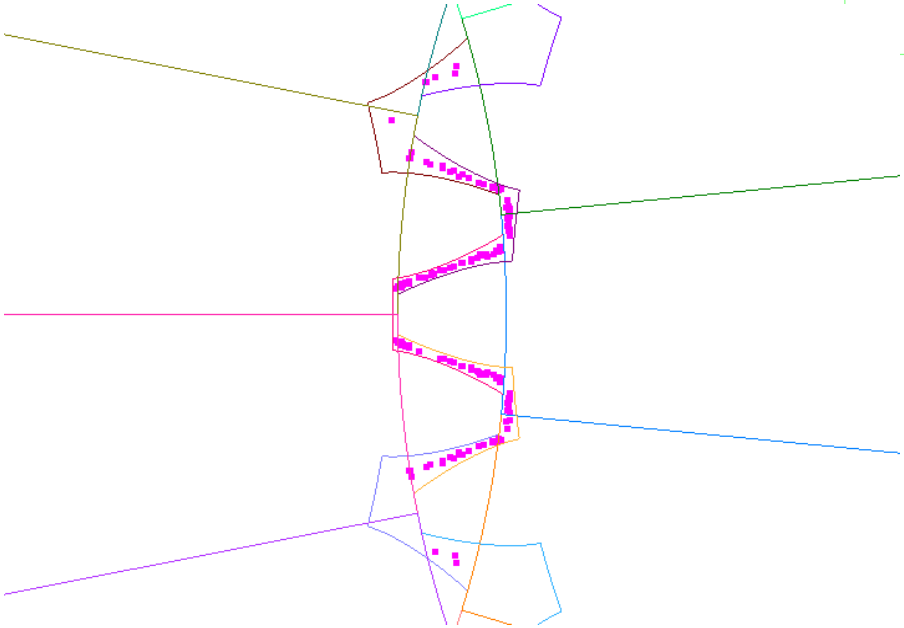


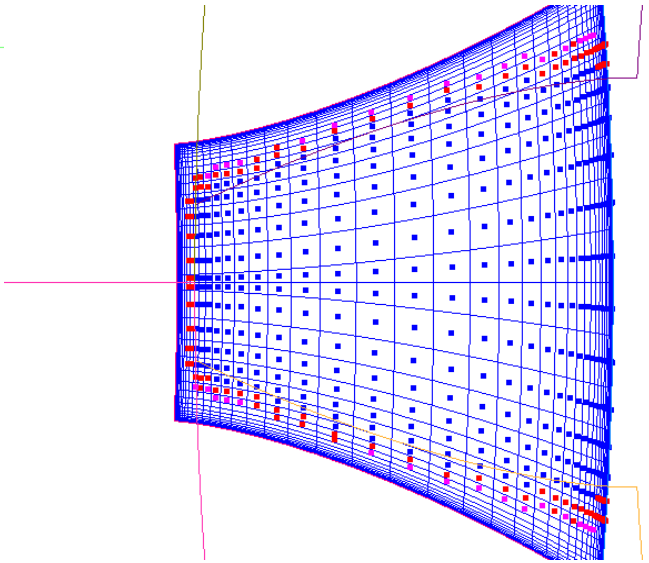


- Contact

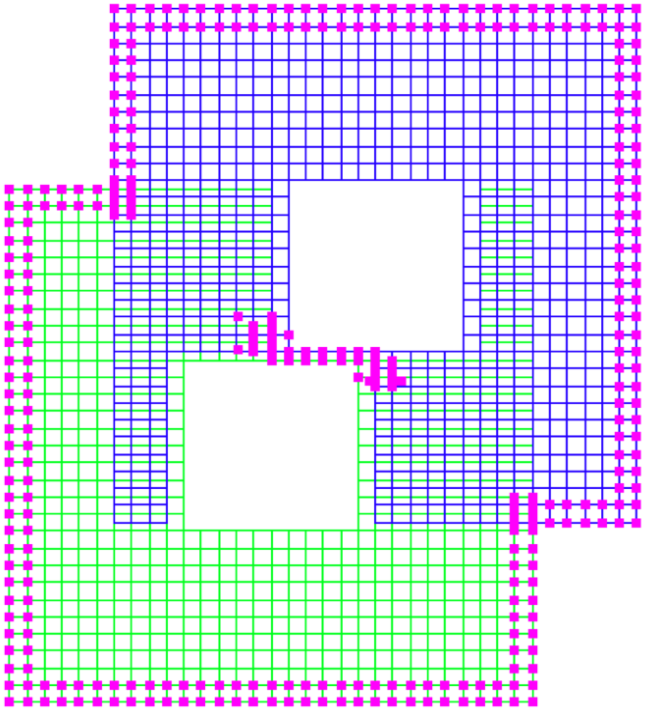


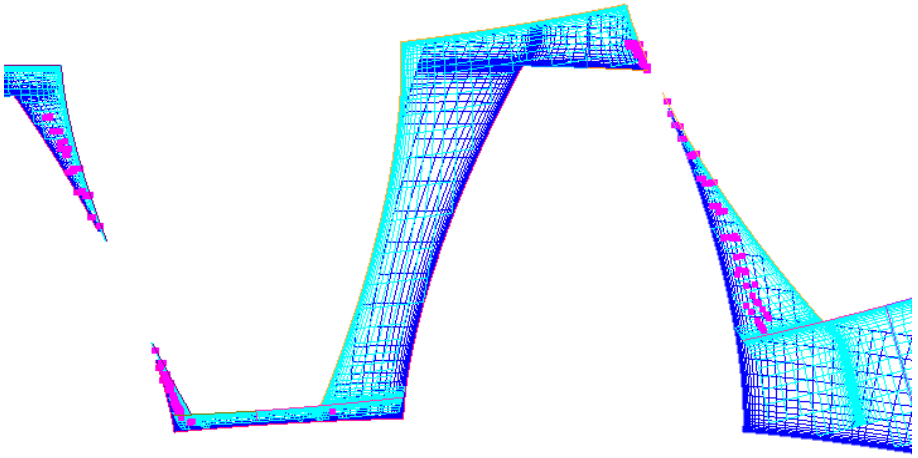


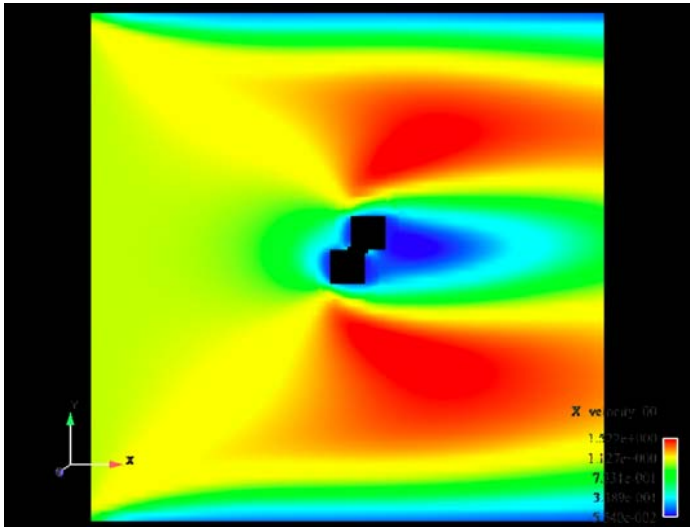




- Contact enabler

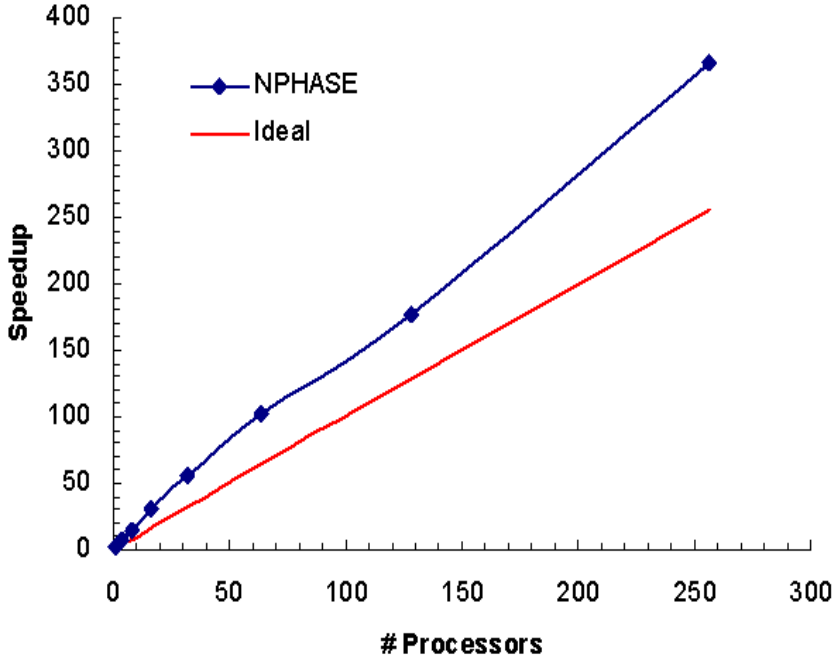






- Supercomputing resources
  - 2,000,000 processor hours on Columbia
  - NPHASE-PSU up and running for large scale gear simulations

Columbia system as NAS

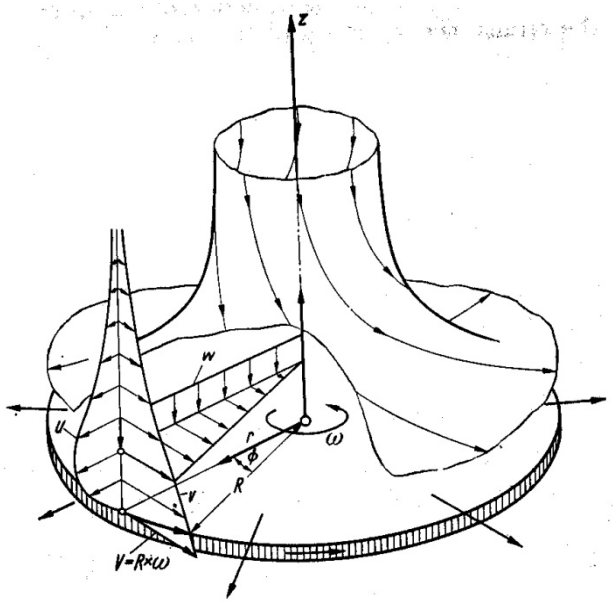


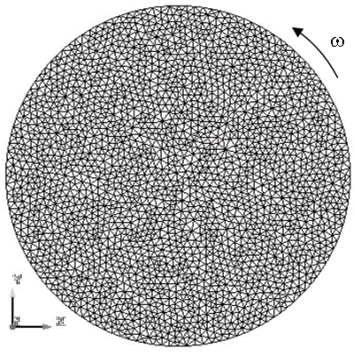
Excellent parallel efficiency

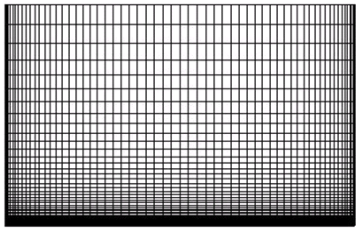
- Hierarchal Approach:
  - Relevant verification
  - Non-moving gears
  - Free cylinders
  - Single gears
  - Enclosed cylinders
  - Multiple gears
  - NGRC test configuration
  - Industry configurations

Verification Studies

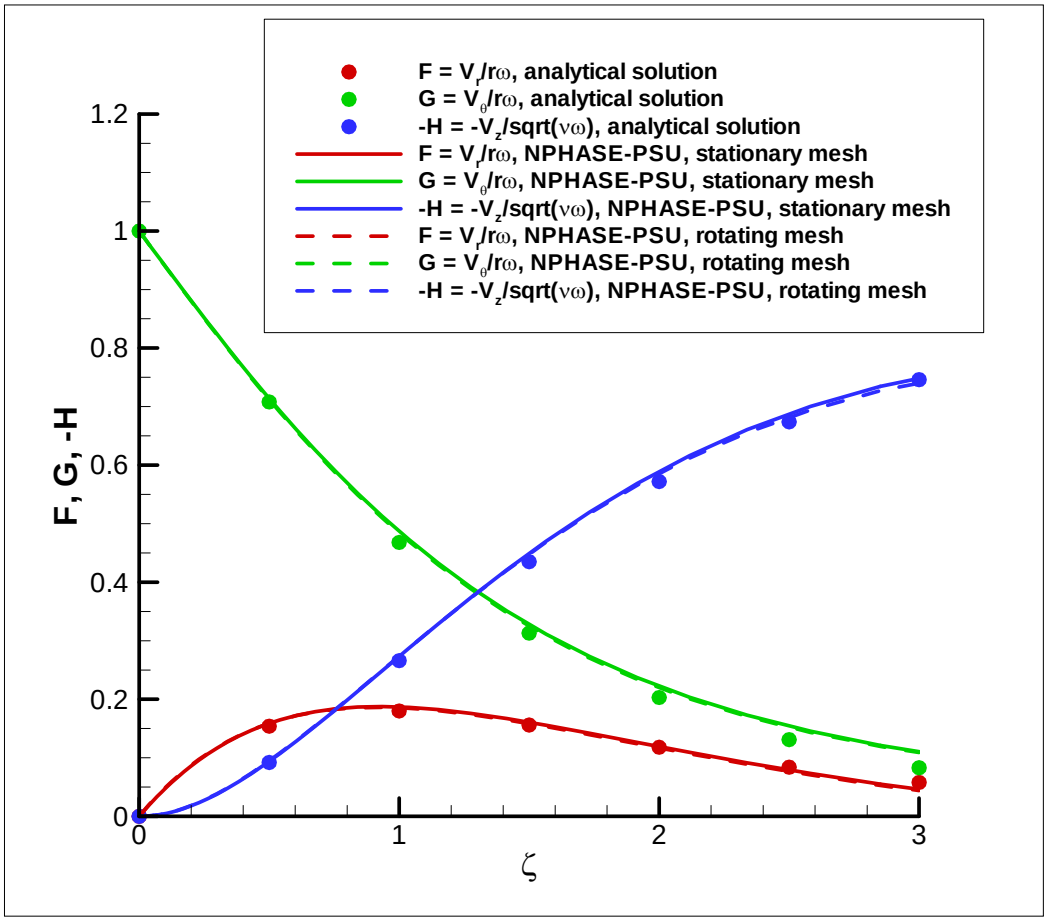
3D flow near a rotating disc



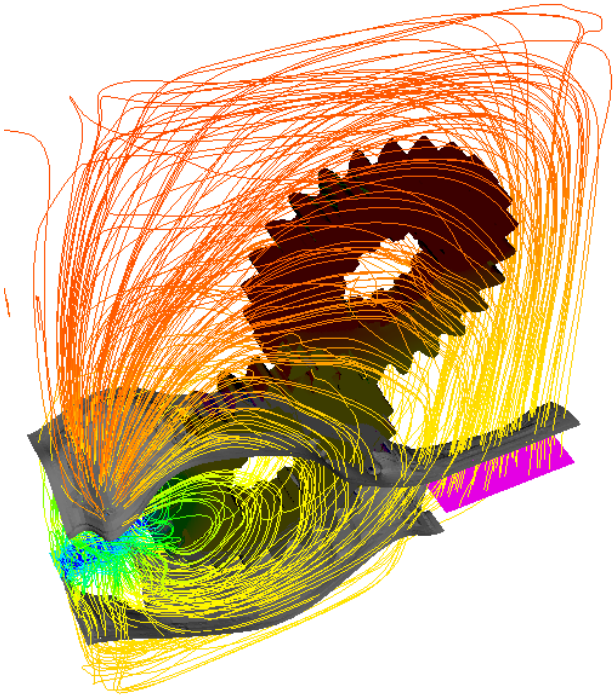




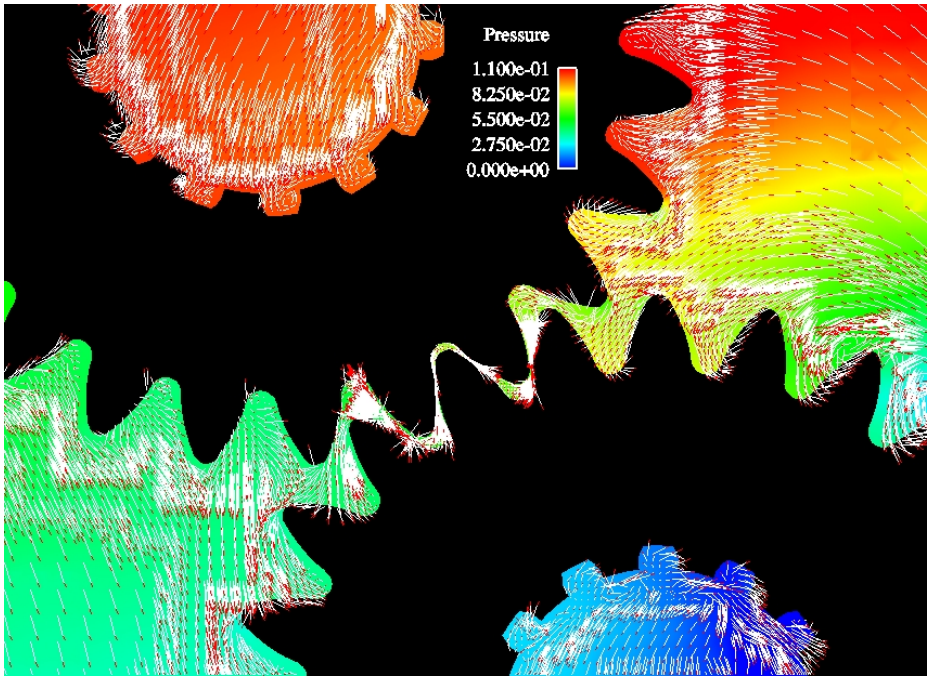
spinning wall boundary



- Hierarchal Approach: relevant verification ➔non-moving gears ➔ free cylinders ➔ single gears ➔ enclosed cylinders ➔ multiple gears



Elements of NPHASE-PSU simulation of notional 2-gear system. Non-rotating, 1-phase, octree mesh.

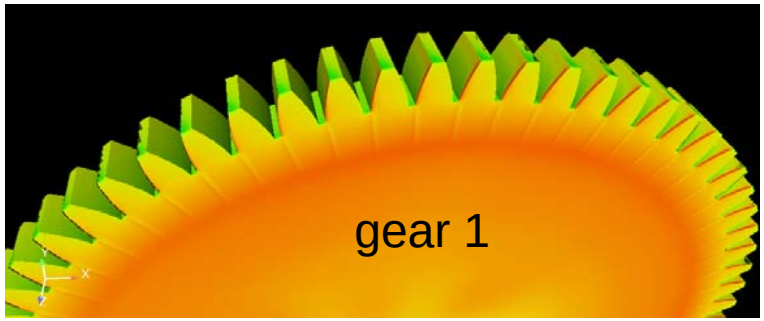


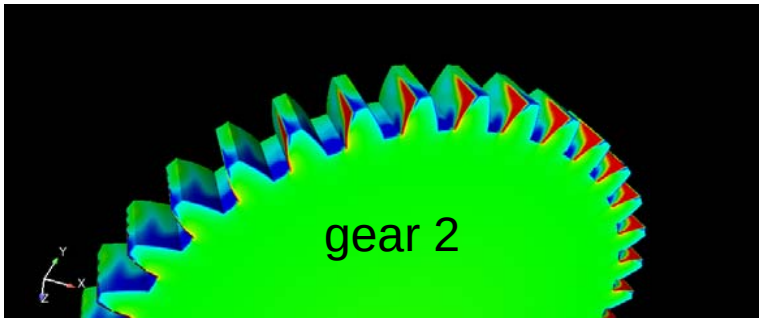
Elements of NPHASE-PSU simulation of notional 2-gear system. Non-rotating, 1-phase, octree mesh. Detail of gear teeth interface region.

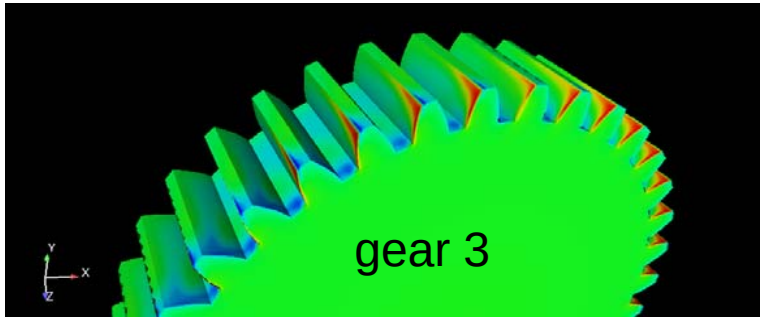
Diab Gear Validation

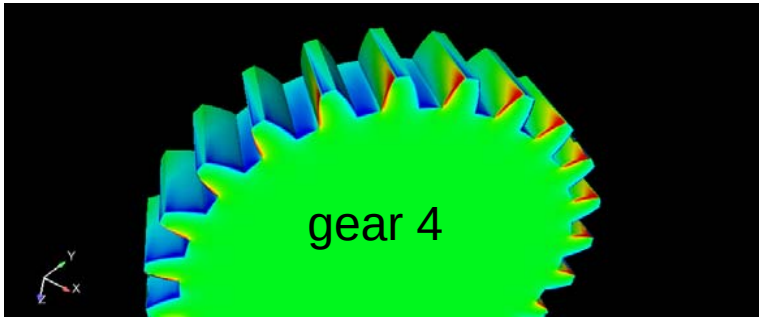
	Pitch diameter (mm)	Tooth width (mm)	Module (mm)
Gear 1	288	30	4
Gear 2	144	30	4
Gear 3	144	60	4
Gear 4	144	60	6
Disk	300	30	

Geometry and predicted pressure distributions for 4 Diab gears



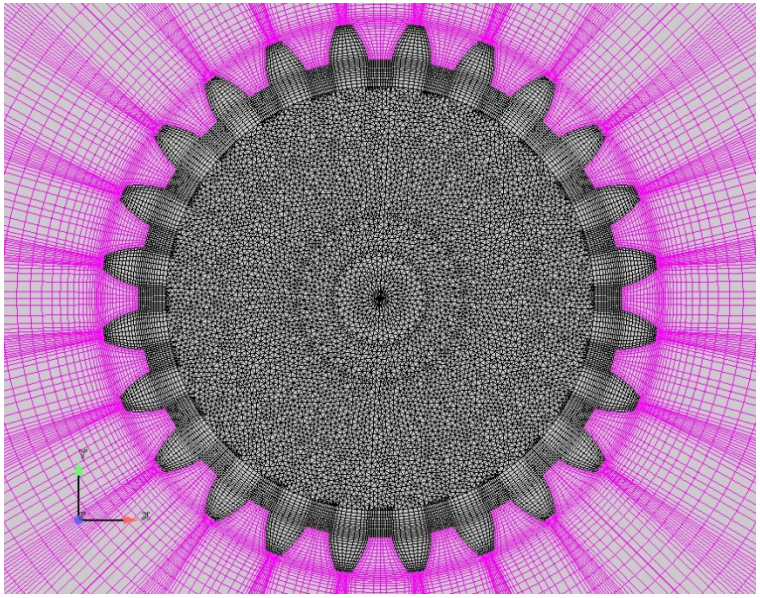




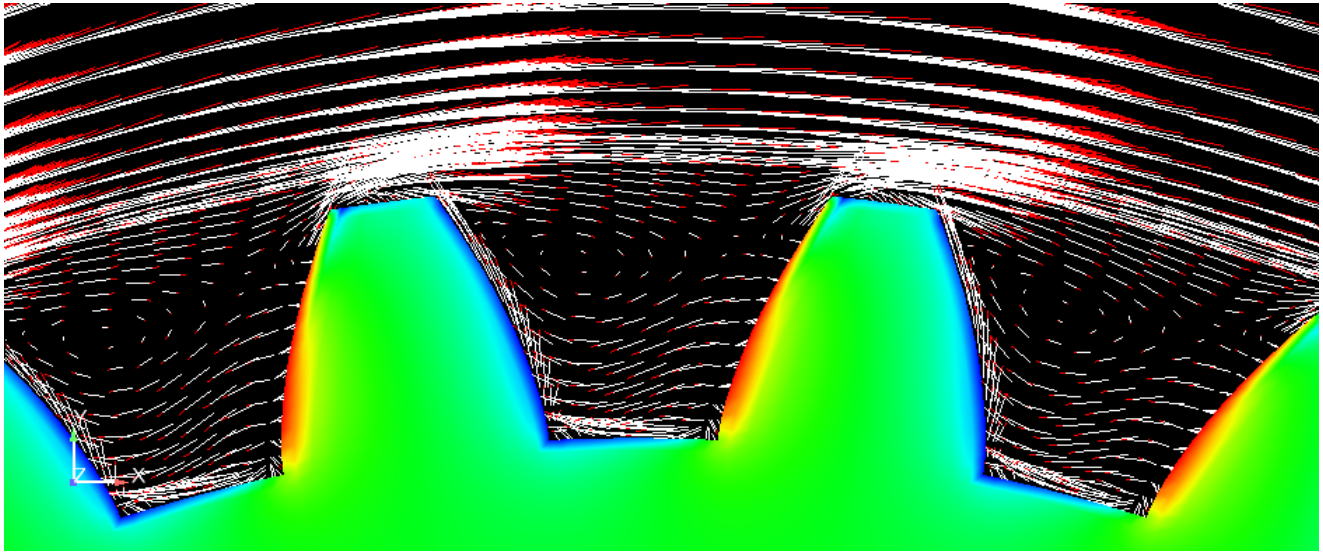


Diab Gear Validation

3D mesh topology

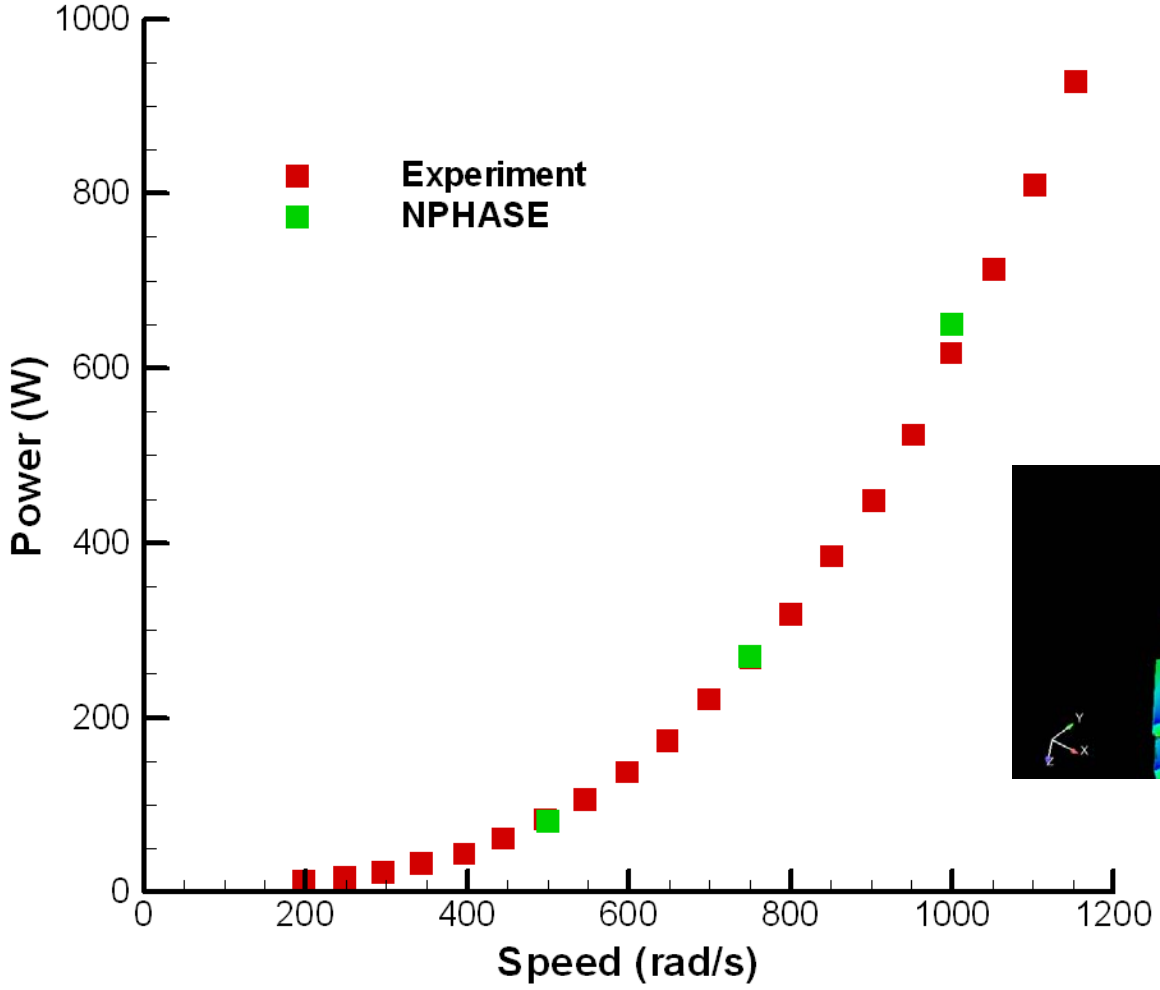


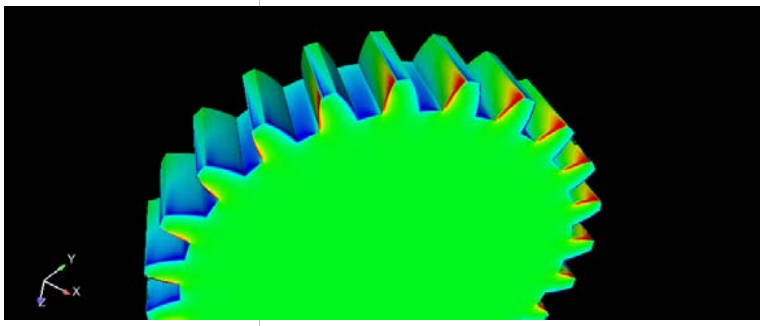
Secondary flows within gear teeth



Diab Gear Validation

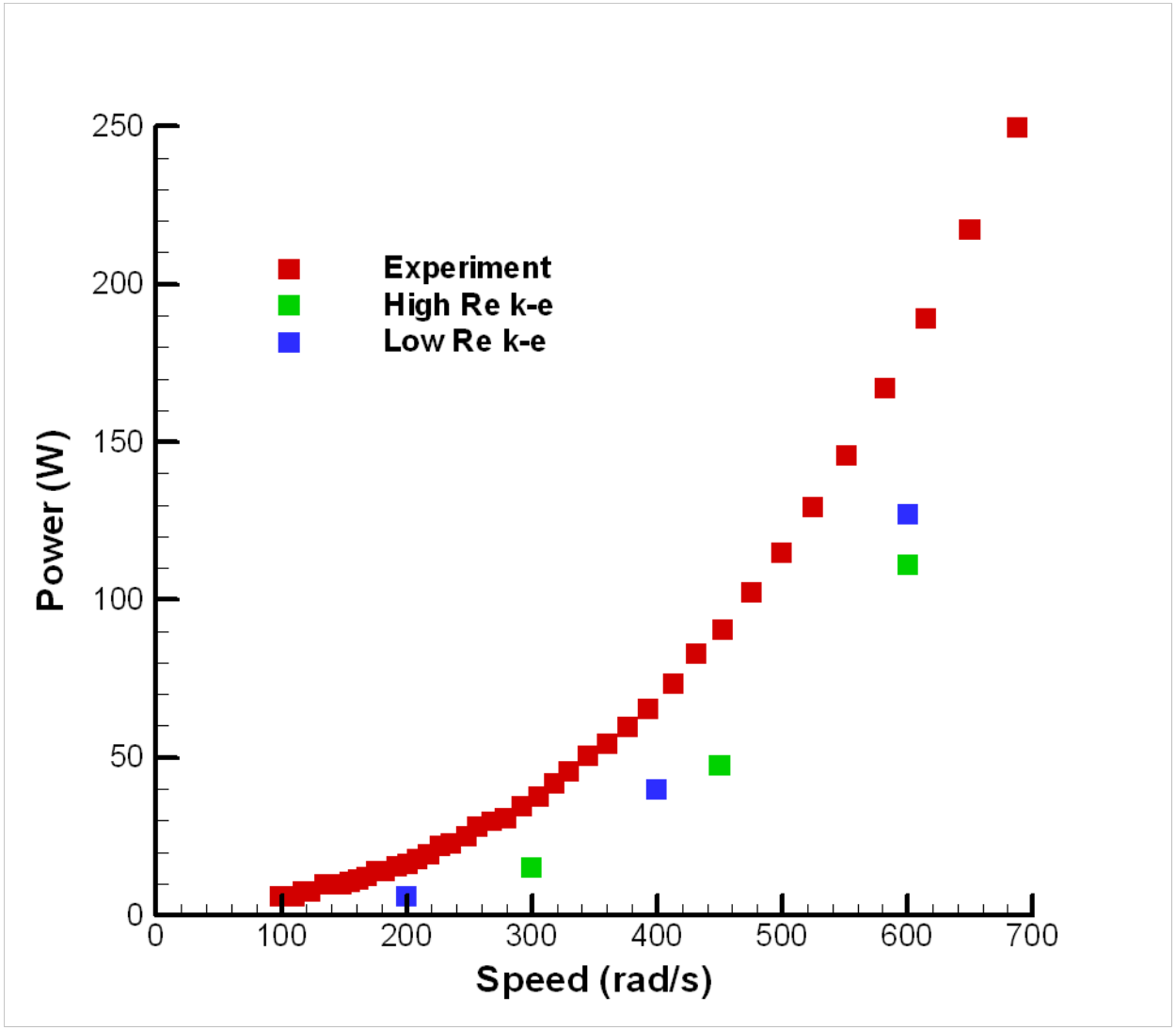
Comparison of predicted and measured windage losses





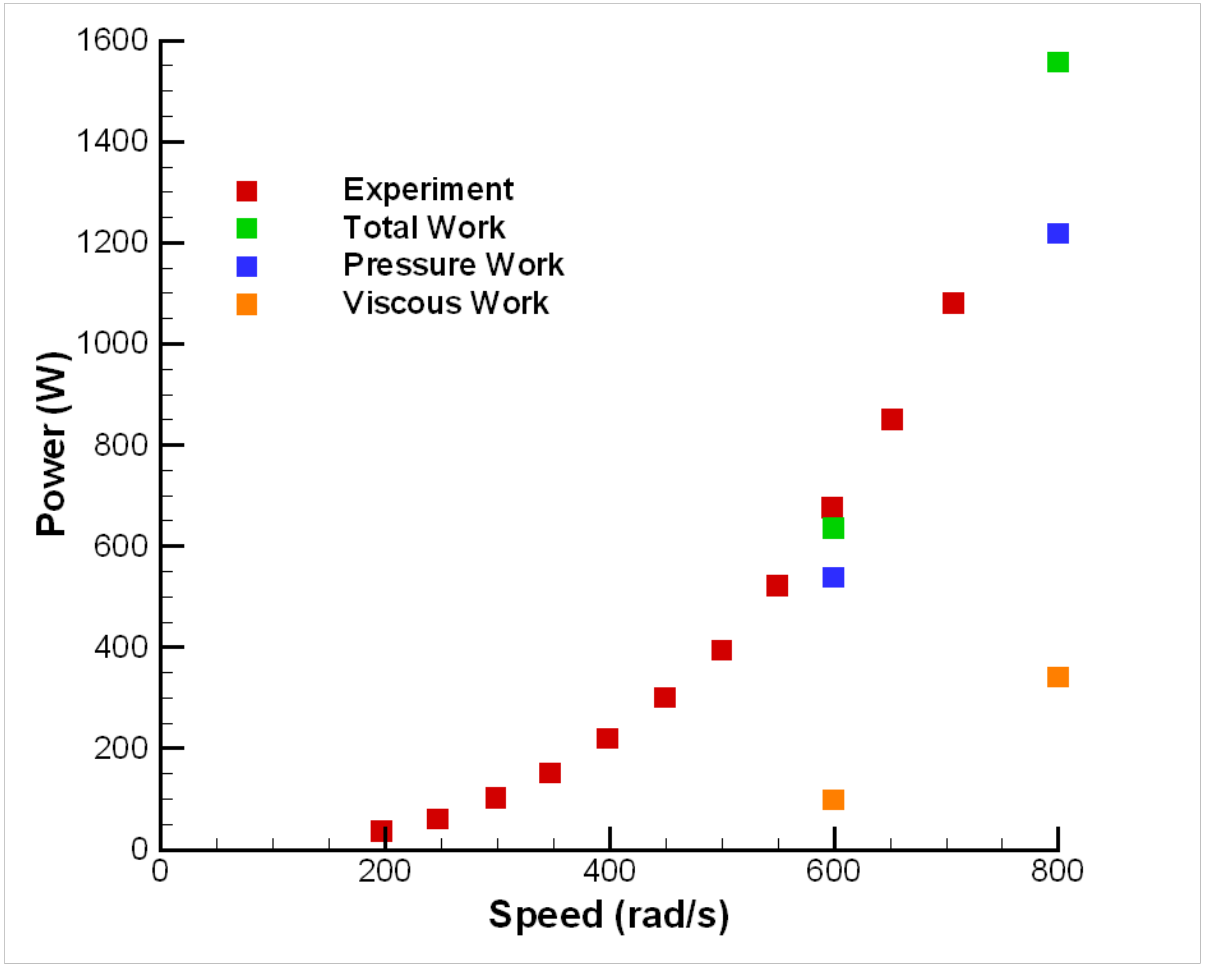
Diab Gear Validation

- Low Re vs. high Re turbulence model, Diab disc

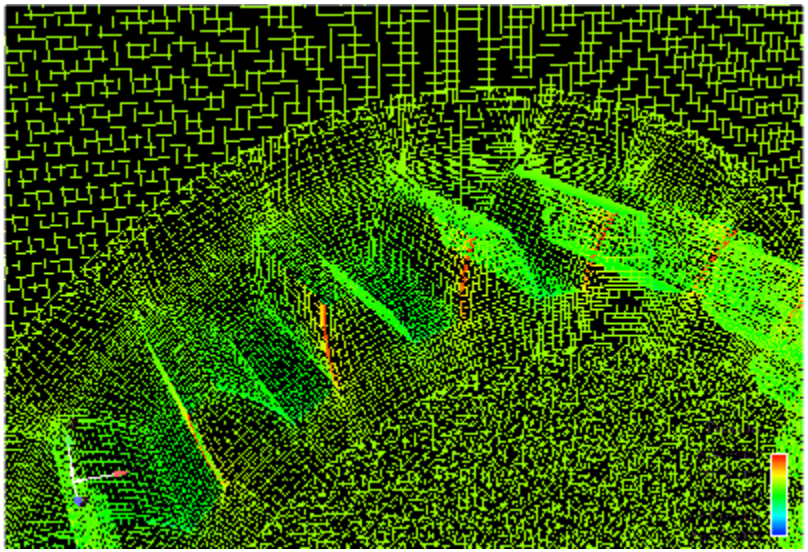


Diab Gear Validation

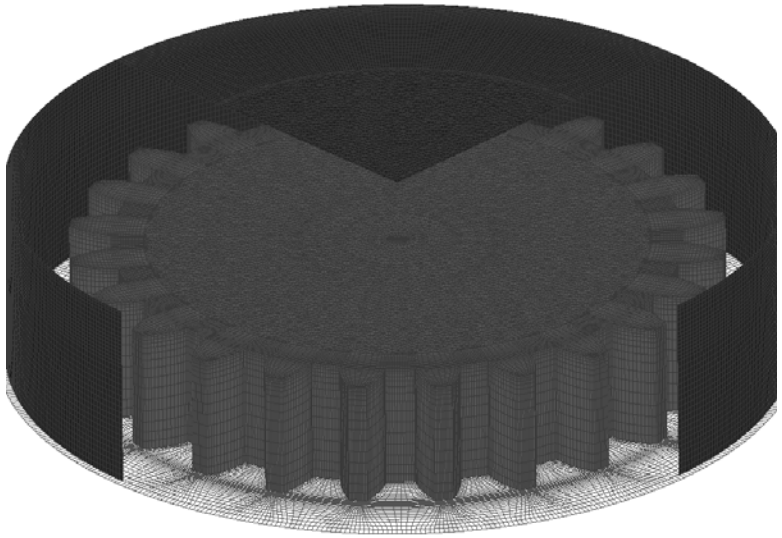
- Viscous vs. pressure losses, Diab gear 1



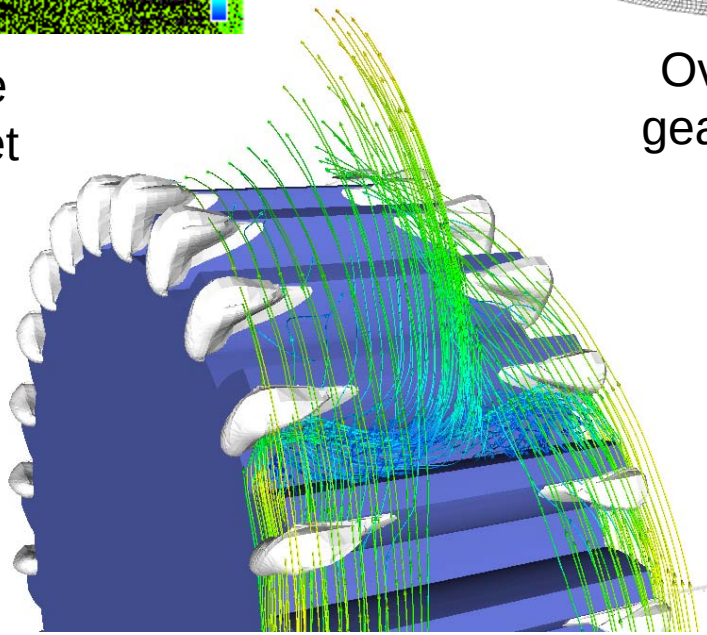
Selected visualizations



Diab gear, pressure contours, 3D overset

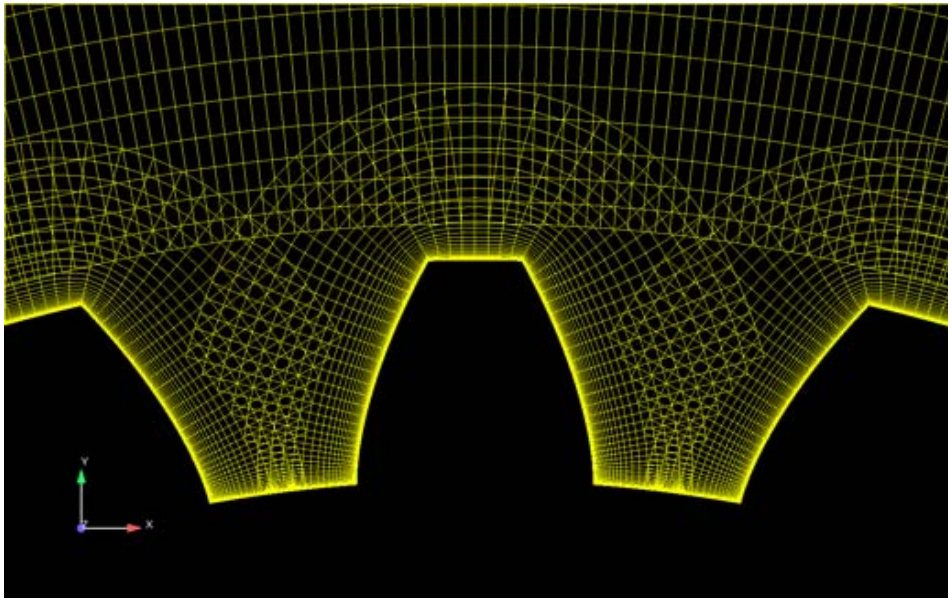


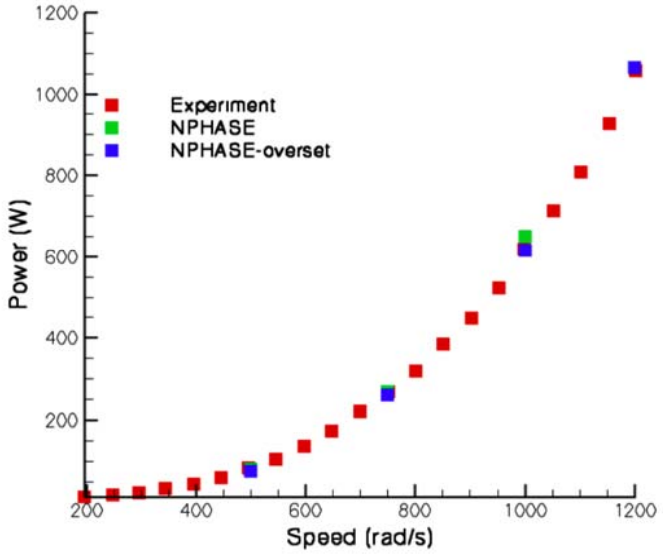
Overset grid, spur gear with shrouding



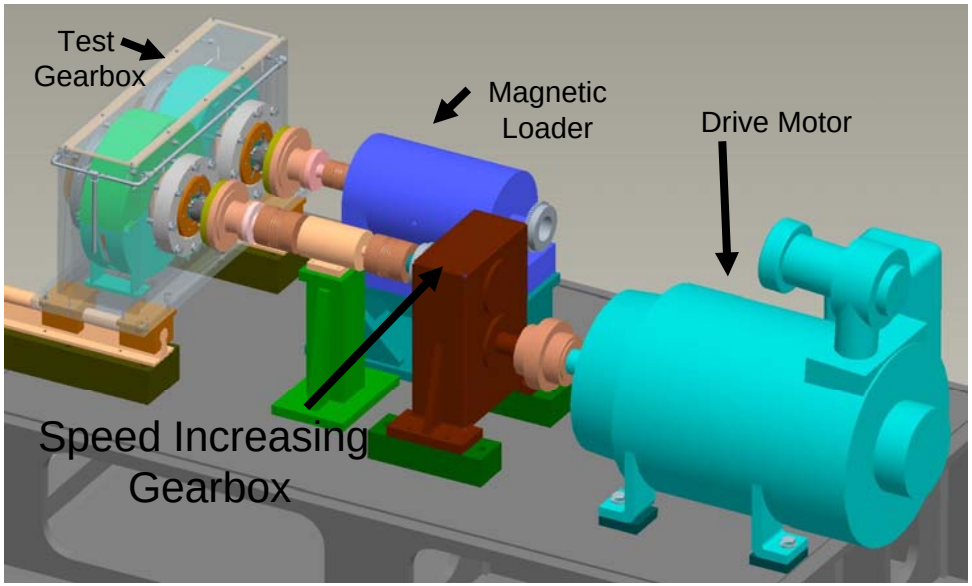
Diab gear, relative streamlines and pressure isocontours

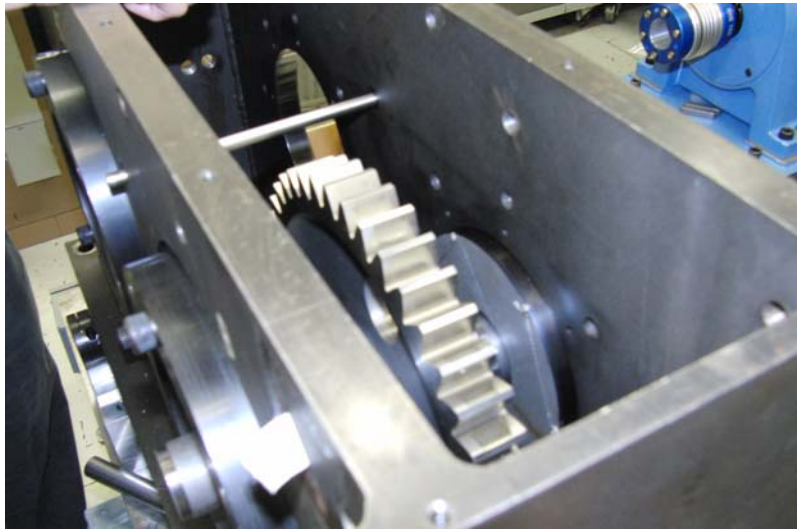
Current overset topology





NASA Glenn Windage Facility





- Test Plan
  - Phase I ➔ single gear windage.
    - Isolated gear spin down data ➔ only windage and bearing losses
    - No lubrication oil
    - Two spur gears
    - Evacuate test section to lower static pressures and vacuum
    - Variety of housing geometries
    - Oil mist and jet impingement lubrication
  - Phase II ➔ 2 gears
    - Run without lube oil ? (depending on spin down rate)
    - Shrouding for both gears
- Lots of data ➔ MUCH more than ever available
- Close coordination between

Summary Status of Modeling Effort

- 1-phase capability verified
- 1-phase capability validated for 3D rotating grid gears
  - Completed several verification cases
  - Very good comparisons with Diab data:
    - Dominant pressure effects
    - Possible underestimation of viscous work ➔ turbulence modeling
  - Moving mesh approach converges well
  - Code scales well
- Overset technology:
  - Fully established in context of moving meshes
  - New higher accuracy topology
  - New hybrid overset-immersed boundary method ➔ enables contact

Summary Status of Modeling Effort

- 2-phase under way – heirarchy of approaches:
  - Mixture density and viscosity
  - Homogeneous 2-phase
  - Full n-fluid
- Working with Glenn to define validation test matrix