Advanced Rotating Machinery Dynamics

ARMD™

Version 6.0

THE COMPLETE SOFTWARE PACKAGE FOR

- **Rotor Dynamics**
- **Torsional Vibration**
- **Fluid-Film Bearings**
- **Rolling-Element Bearings**
- **Lubricant Analysis**

Rev:20190430

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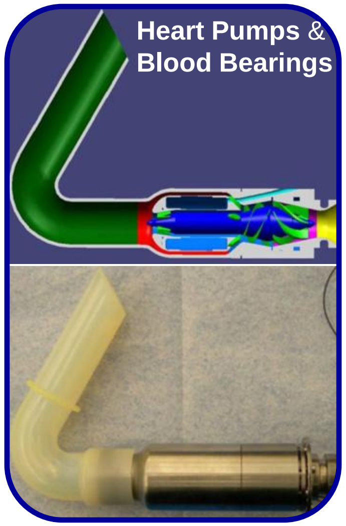
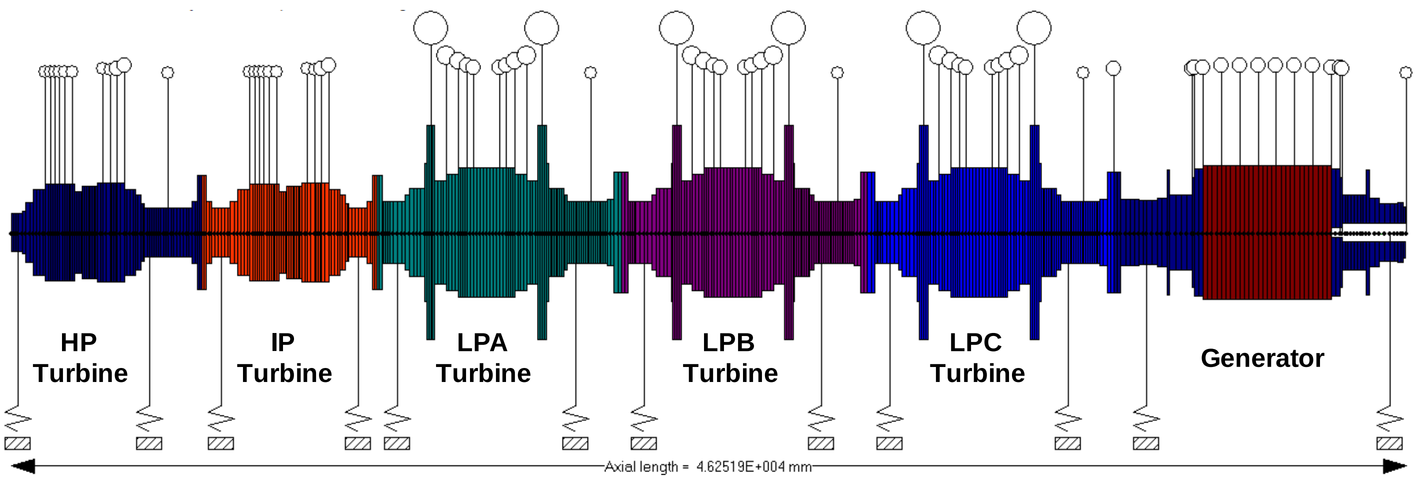
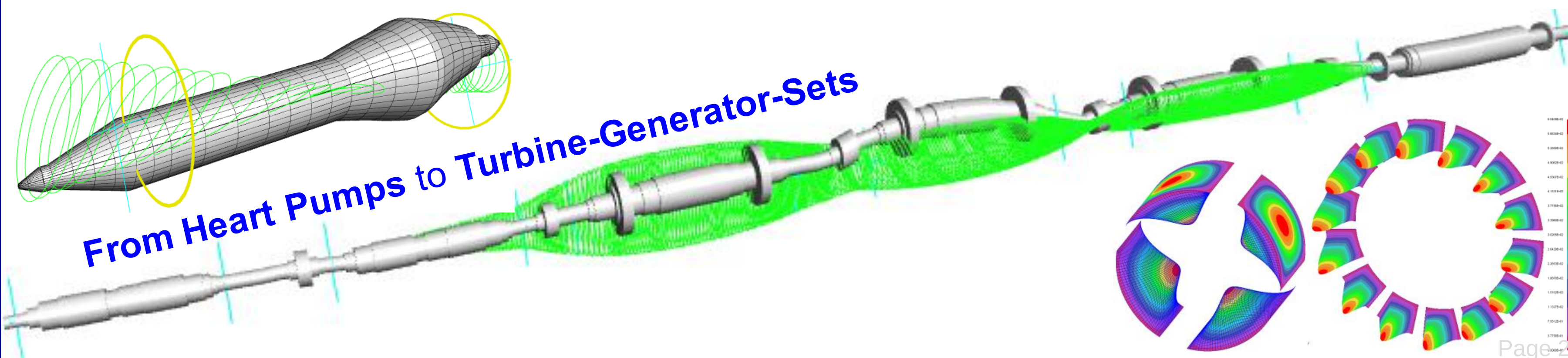
Advanced Rotating Machinery Dynamics

ARMD™

THE COMPLETE SOFTWARE UTILIZED WORLDWIDE







Advanced Rotating Machinery Dynamics

ARMD is the most complete software package available to help you evaluate any bearing, rotor/bearing system, or mechanical drive train. Using leading edge technology and a host of valuable capabilities, **ARMD** has been proven effective and accurate in the design, analysis and trouble shooting of rotating machinery by machinery manufacturers, equipment packagers and end users around the world.

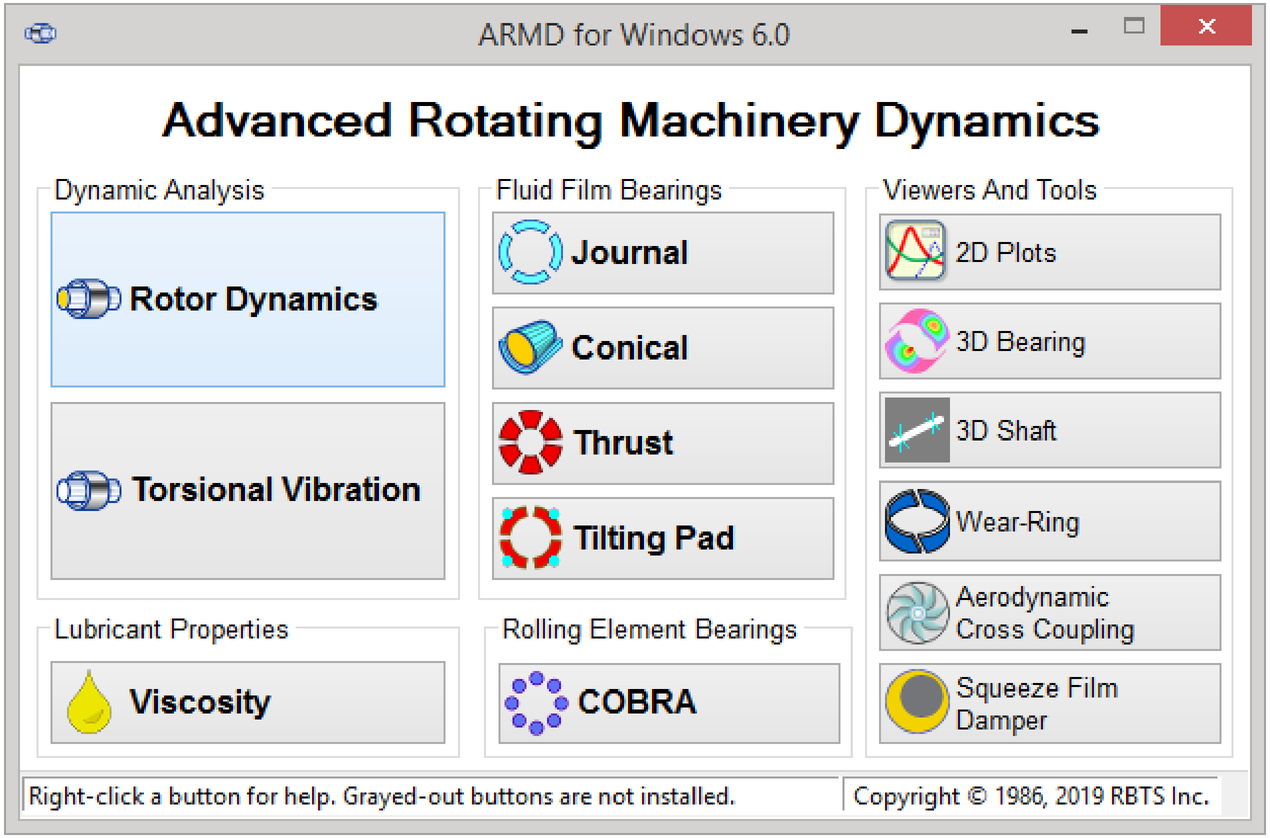
ARMD consists of five main modules:

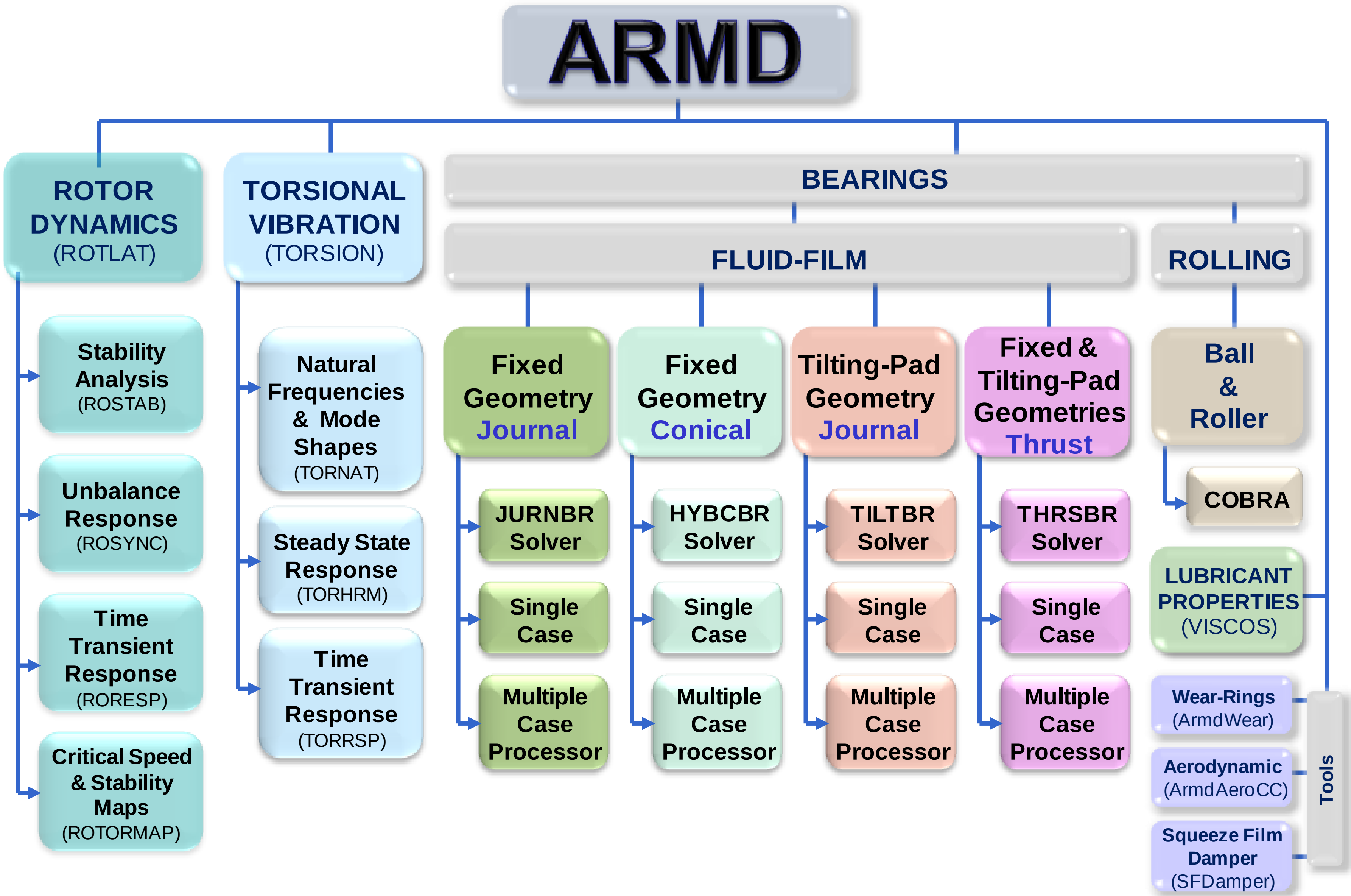
- **Rotor Dynamics**
- **Torsional Vibration**
- **Lubricant Performance**
- **Bearing Analysis**
- **Utilities & Support Tools**

With a variety of features, including:

- **A user-friendly interface**
- **Advanced project and file management system**
- **Graphics/text capabilities**
- **Inter-module communication and data exchange**

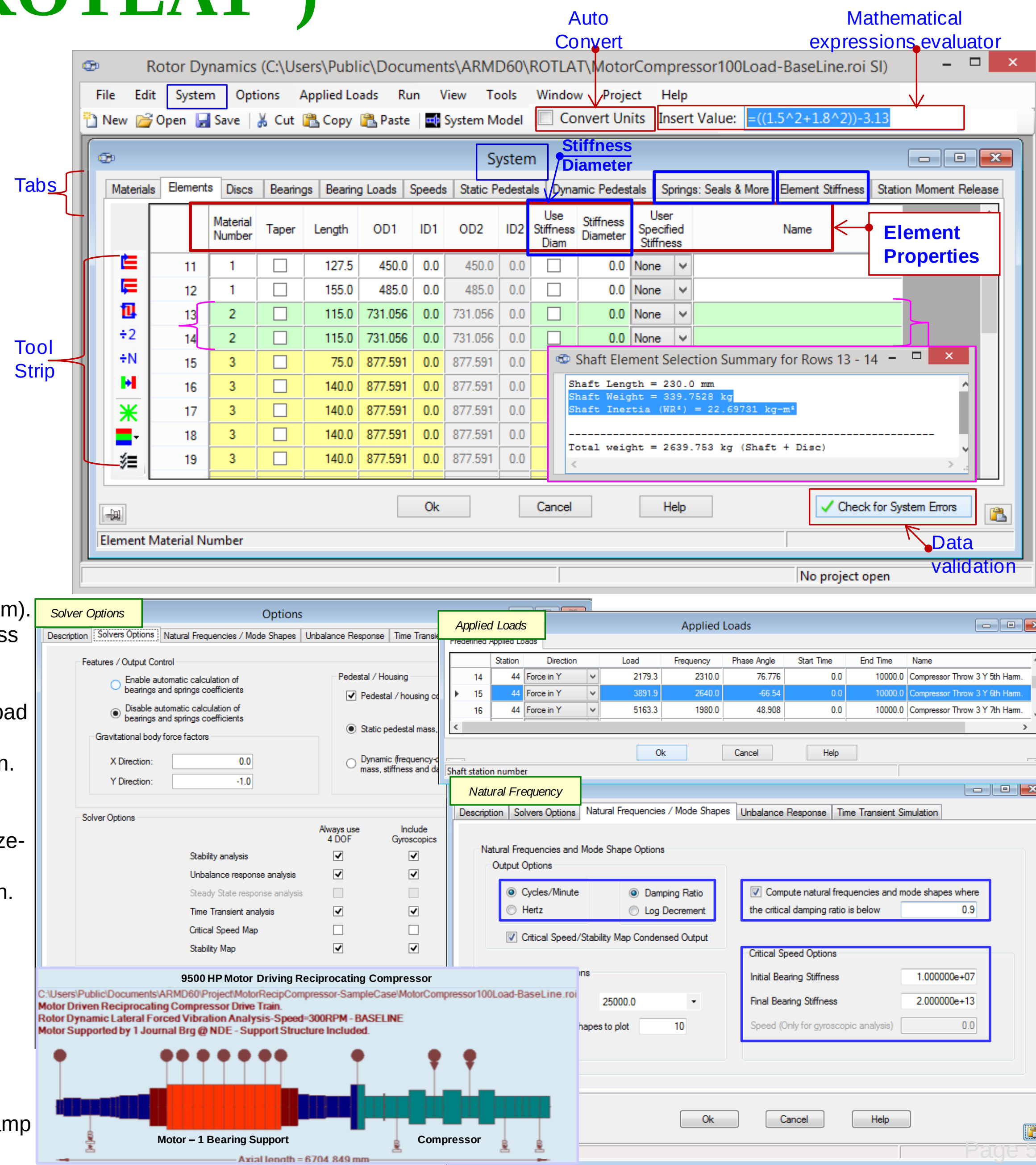
All of which operate seamlessly In an integrated environment.




ARMD
ROTOR DYNAMICS (ROTLAT)
Stability Analysis (ROSTAB)
Unbalance Response (ROSYNC)
Time Transient Response (RORESP)
Critical Speed & Stability Maps (ROTORMAP)
TORSIONAL VIBRATION (TORSION)
Natural Frequencies & Mode Shapes (TORNAT)
Steady State Response (TORHRM)
Time Transient Response (TORRSP)
BEARINGS
FLUID-FILM
Fixed Geometry Journal
JURNBR Solver
Single Case
Multiple Case Processor
Fixed Geometry Conical
HYBCBR Solver
Single Case
Multiple Case Processor
Tilting-Pad Geometry Journal
TILTBR Solver
Single Case
Multiple Case Processor
Fixed & Tilting-Pad Geometries Thrust
THRSBR Solver
Single Case
Multiple Case Processor
ROLLING
Ball & Roller
COBRA
LUBRICANT PROPERTIES (VISCOS)
Wear-Rings (ArmdWear)
Aerodynamic (ArmdAeroCC)
Squeeze Film Damper (SFDamper)
Tools

Rotor Dynamics (ROTLAT™)

The rotor dynamics lateral vibration analysis package ROTLAT is a finite element based software for performing damped and undamped natural-frequencies / critical-speeds, mode shapes, stability, unbalance response, and time-transient response. ROTLAT consists of four sub-modules: ROSTAB, ROTORMAP, ROSYNC, and RORESP integrated by ROTLAT's user interface. The user interface controls the sub-modules to provide a complete rotor/bearing system dynamic analysis environment integrating the rotating assembly with its support bearings, wear-rings, seals, aerodynamic effects, support structural flexibilities, etc.



ROTLAT incorporates advanced modeling features and capabilities including the following:

- Rotor of various configurations: Solid, Hollow, Tapered & Stepped.
- Shaft material damping.
- Gyroscopic effects (discs with angular degrees of freedom).
- Element geometry, stiffness diameter, or element stiffness (i.e. flexible connections or plates).
- Bearings of all types: Cylindrical, Conical, Tilting Pad & Rolling Element with/without moment stiffness or tilting-pad pitch degrees of freedom.
- Bearing models linked to rotating assembly at any station.
- Bearings vertical elevation for accurate bearings load computation of multi-bearing systems.
- Springs: wear-rings, seals, aero-dynamic effects, squeeze-film dampers, etc.
- Springs models linked to rotating assembly at any station.
- Bearings support systems; casing and foundations.
- Static foundation/pedestal flexibility (mass, stiffness and damping).
- Dynamic (frequency dependent) foundation flexibility.
- Discs: couplings, impellers, sleeves, etc.
- Moment release (pin-joint) at shaft stations.
- Multiple unbalance forces at any location and phase orientation along the shaft.
- External excitations and body forces: sinusoidal, step, ramp and pulse type functions.

NATURAL FREQUENCY, MODE SHAPE & STABILITY

- Natural frequencies & mode shapes
- Damped and undamped simulation
- Stability parameters (damping ratio, logarithmic decrement)
- Rotor orbit direction (forward/reverse precession)
- Critical speed map
- Stability map / Campbell diagrams
- Bearing reaction forces
- Shaft weight, deflection, centerline slope
- Shaft moment, shear, & fiber stress diagrams

UNBALANCE RESPONSE

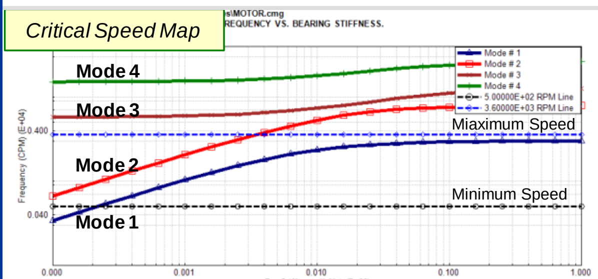
(Synchronous response)

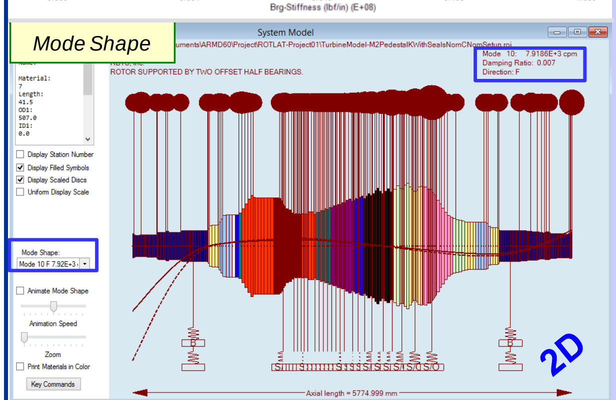
- Multiple unbalance planes/forces
- Magnitude and phase (Bode plot)
- Dynamic forces and moments
- Vibratory amplitudes and orbits
- Forces and moments transmitted to bearing and foundation
- Foundation vibratory amplitudes
- API Amplification factors

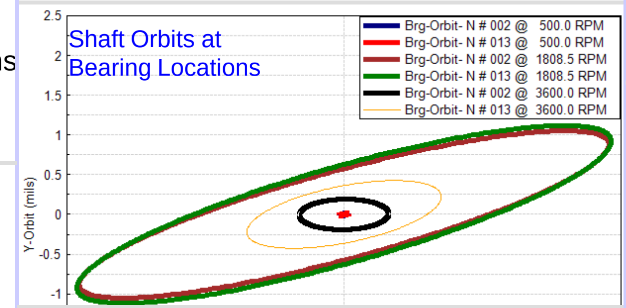
TIME-TRANSIENT RESPONSE

(Non-synchronous response)

- Gravitational and external forces: Multiple sinusoidal, step, ramp, pulse and unbalance
- Vibratory amplitudes time history
- Rotor orbits
- Dynamic forces and moments
- Dynamic stresses
- Transmitted forces and moments
- Pedestal vibratory amplitudes

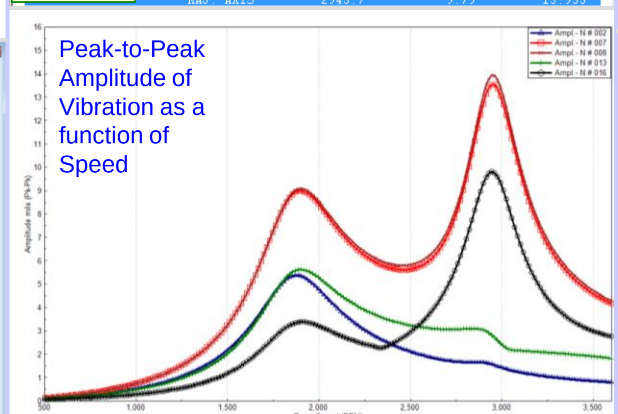


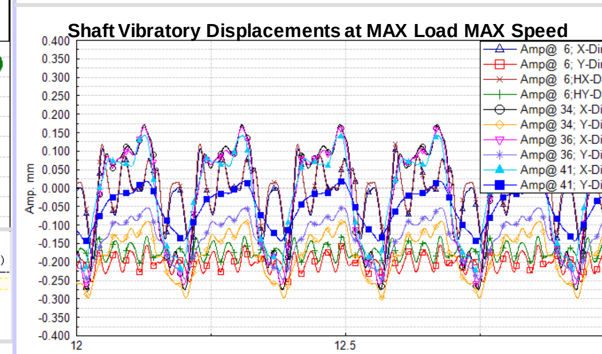


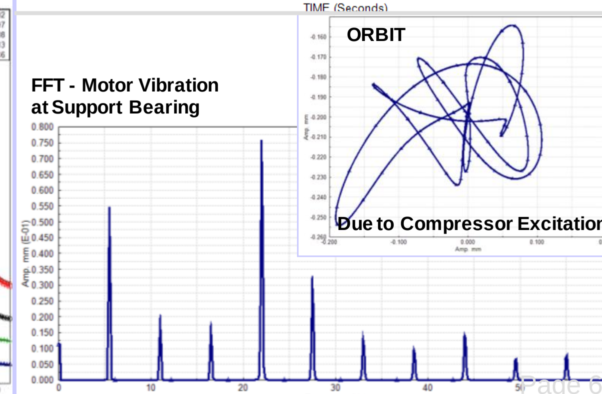


Amplification Factors

	MEASUREMENT TYPE	FREQUENCY (CPM)	AMPLIFICATION FACTOR	AMPLITUDE (mils Pk-Pk)
– Motor Rotor Mid-Axial-Span				
	X-AXIS	1886.4	3.91	8.123
	Y-AXIS	2945.7	10.08	13.926
	MAJ. AXIS	1902.0	3.54	9.092
	MAJ. AXIS	2945.7	9.79	13.935

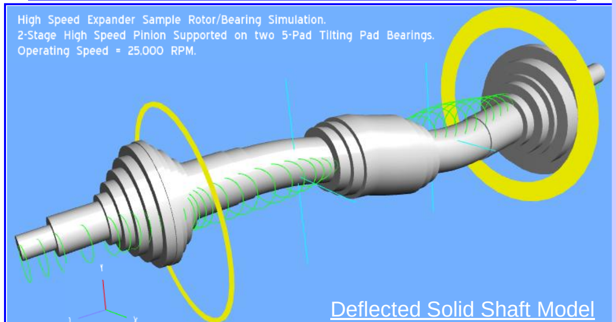




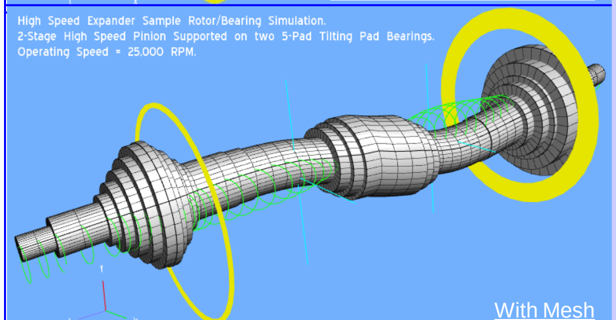


3-Dimesional Presentations of Lateral Rotor Dynamic Simulation Results for Enhanced Visualization & Diagnostics

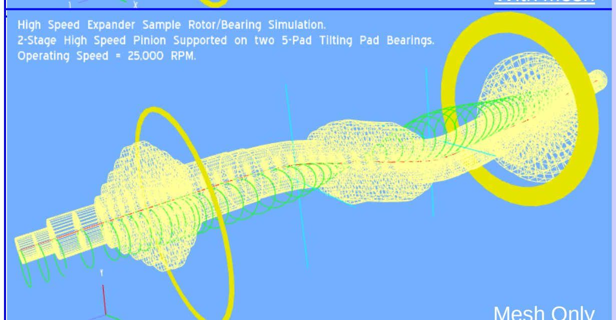
Various Options of Model & Mode Shape Presentation



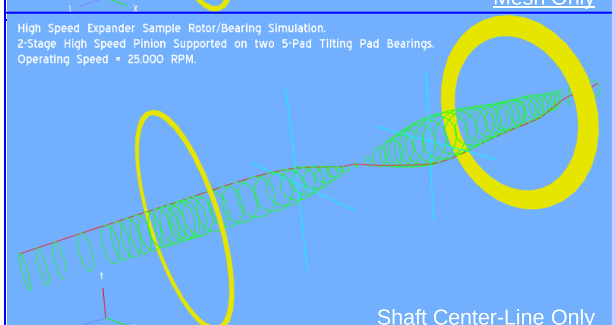
Deflected Solid Shaft Model



With Mesh



Mesh Only



Shaft Center-Line Only

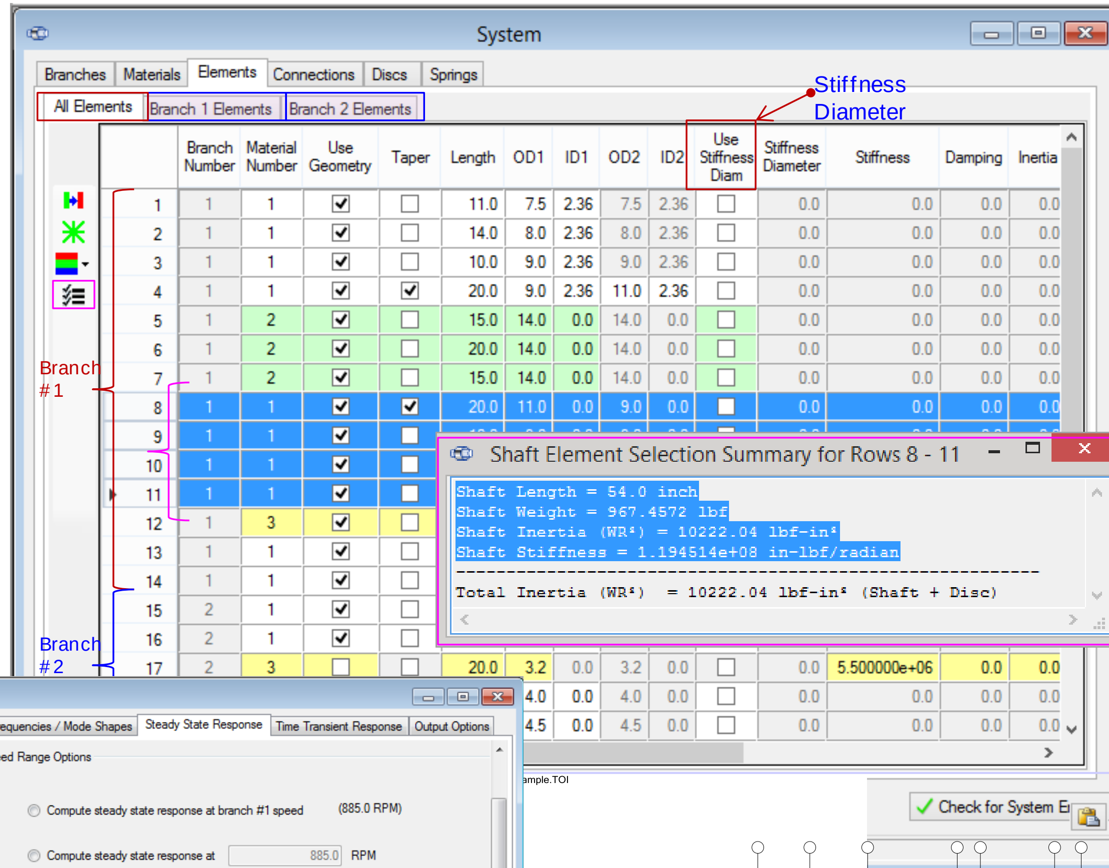
Animated Unbalance Response

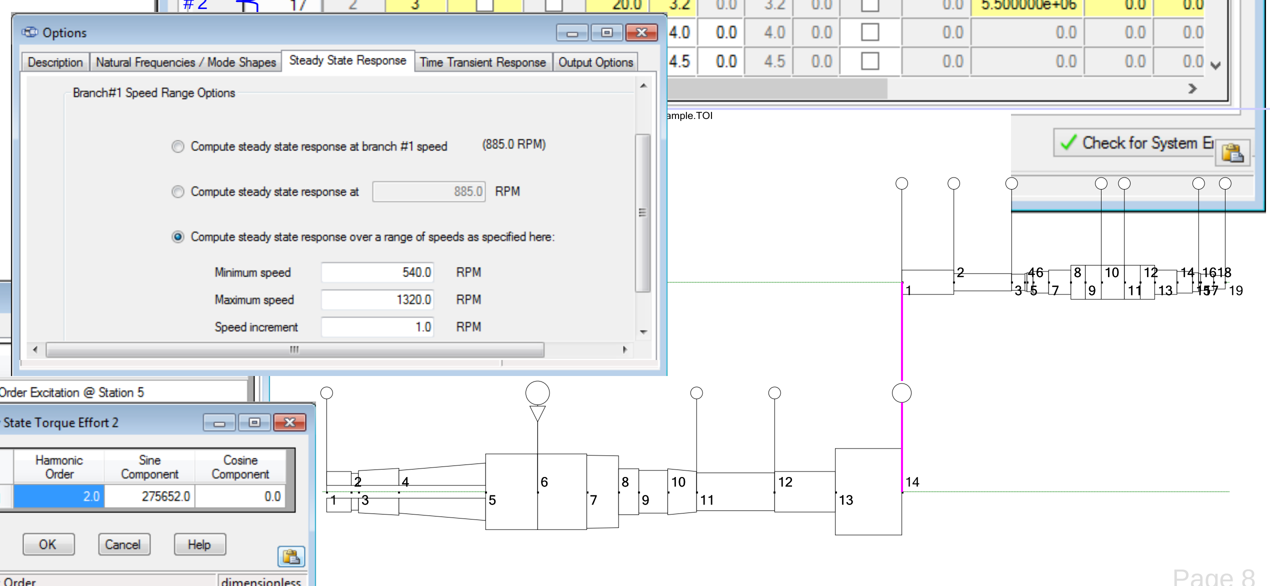
Torsional Vibration (TORSION™)

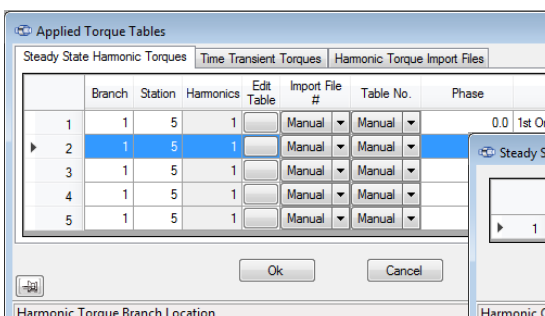
The torsional vibration package uses a finite-element based formulation for performing damped and undamped torsional natural frequencies, mode shapes, steady-state and time-transient response of mechanical drive trains. TORSION consists of three sub-modules: TORNAT, TORHRM and TORRSP integrated by TORSION's user interface. The user interface controls the sub-modules to provide a complete torsional vibration analysis environment.

TORSION accepts/imports models generated with the rotor dynamics package "ROTLAT" and has the same advanced modeling features and capabilities including the following:

- Modeling of multi-shaft/multi-branch systems
- Coupling torsional stiffness and damping
- Gear tooth flexibility
- Element stiffness/mass/inertia diameter
- Torsional springs to ground
- Various types of external excitations
- Synchronous motor start-up torque
- Load torques from such equipment as compressors, pumps, fans, mills, etc.
- Electrical faults for motor and generator
- User specified time varying torques
- Many more…

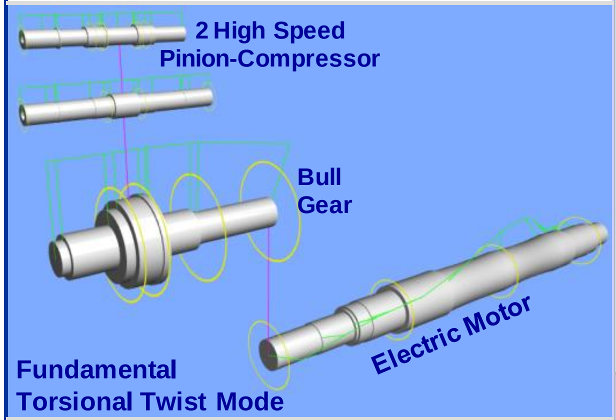


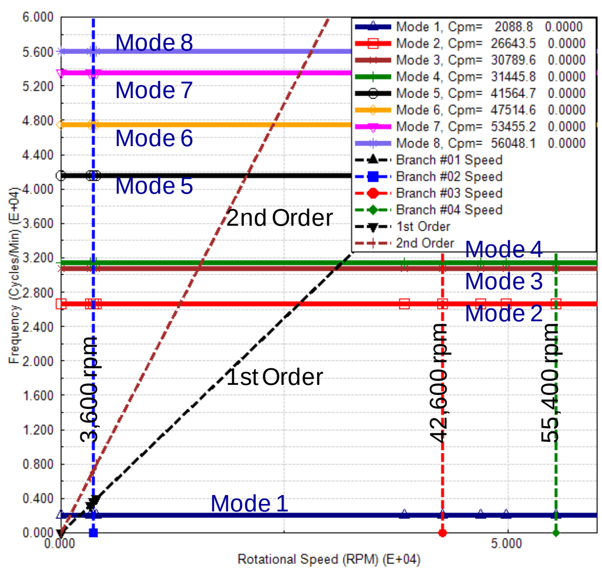




NATURAL FREQUENCIESY & MODE SHAPES

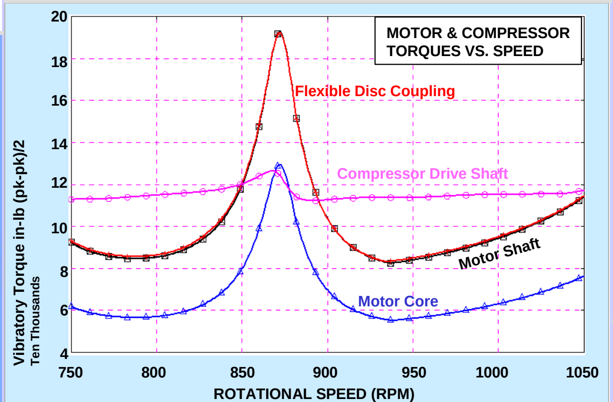
- Damped and undamped simulation
- Natural frequencies
- Growth factors and damping ratios
- Vibration mode shapes
- Critical speed map / Campbell diagrams

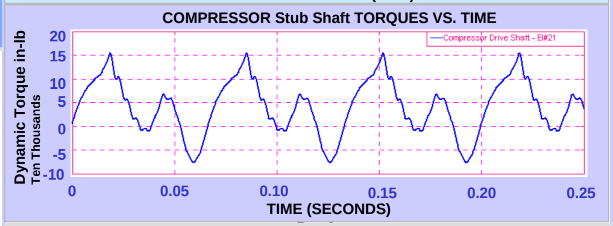


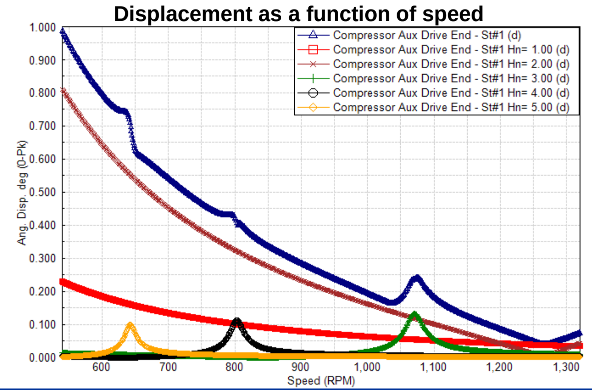


STEADY STATE RESPONSE

- Vibratory amplitudes (displacement, velocity and acceleration)
- Dynamic torques
- Dynamic stresses
- Dynamic heat dissipation





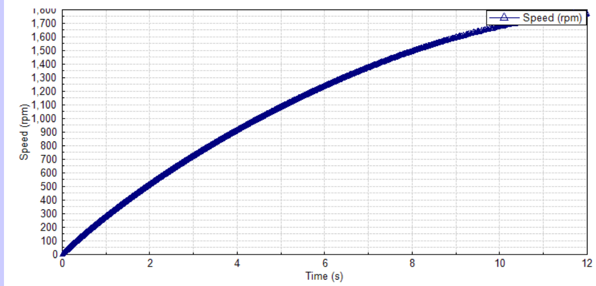


TIME-TRANSIENT RESPONSE

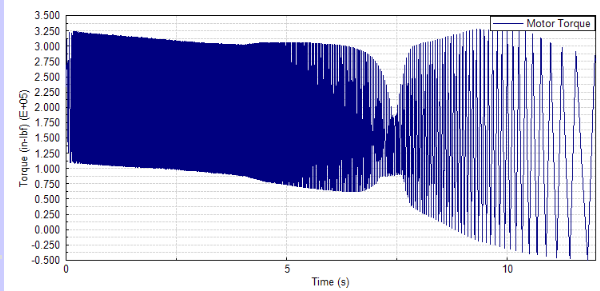
- Dynamic shaft-torque time-history
- Dynamic stresses
- Fatigue life

Sample of synchronous motor-gearbox-compressor time-transient startup and calculated system response torques.

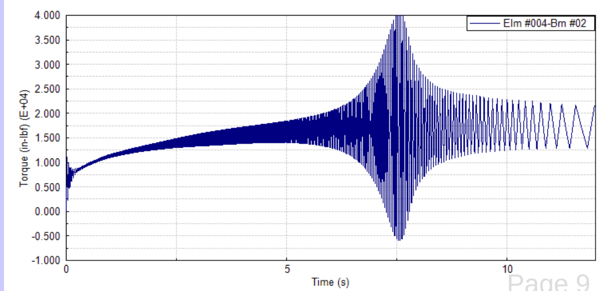
Motor Startup Speed



Motor Startup Average Torque



High Speed Shaft Torque

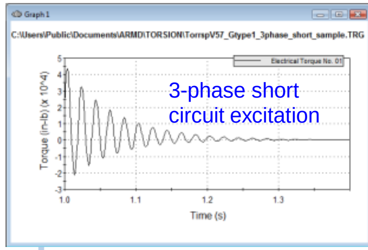


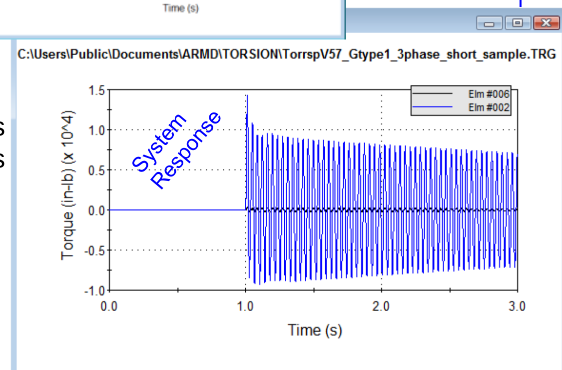
Time varying excitations include:

- Electrically induced exciting torques, associated with generator and induction motor operation, can be considered in the time-transient response simulation module.

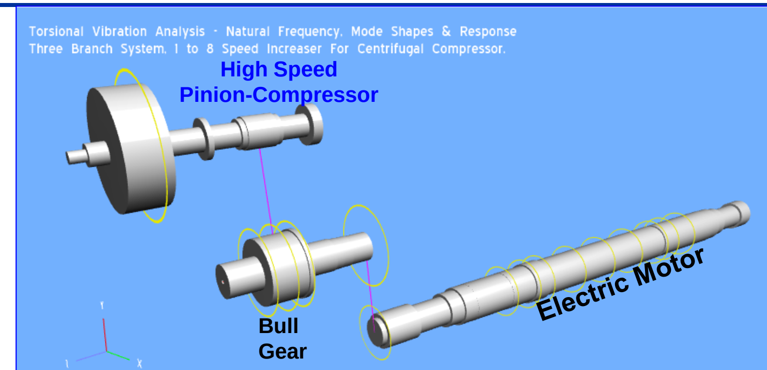
  Generator
  Type 1: 3-phase short circuit
  Type 2: Line-to-Line short circuit
  Type 3: False-coupling short circuit

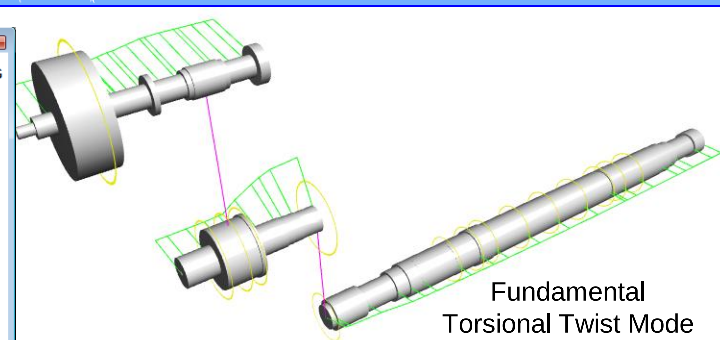
  Induction Motor
  Type 4: Start from standstill (across the line start)
  Type 5: 3-phase short circuit at terminals
  Type 6: 2-phase short circuit at terminals
  Type 7: High-speed automatic reclosing

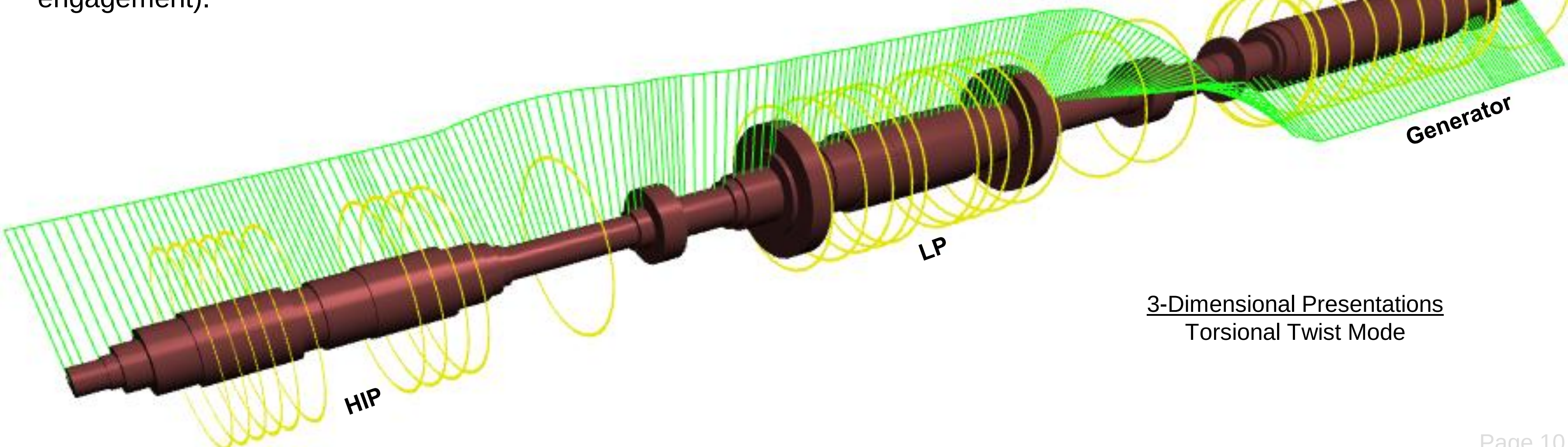




- User torque table (.csv file format) representing time-varying exciting torque at any location (e.g. simulation of clutch engagement).







<u>3-Dimensional Presentations</u>
Torsional Twist Mode

Bearings

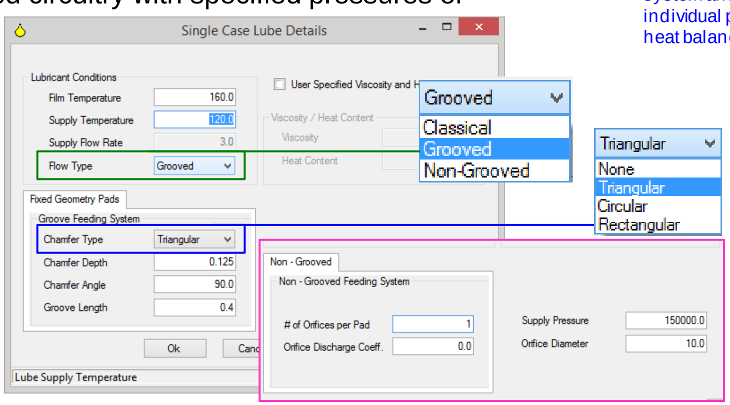
Fluid-Film Lubricated Journal & Thrust Bearings with Fixed or Tilting-Pad Configurations
Practically any Bearing or Bearing System Available in the Industry can be Analyzed

The ARMD software package has the capabilities of evaluating both fluid-film and rolling-element bearings. Practically any bearing or bearing system available in the industry can be modeled and evaluated with one of the bearing solution modules.

The FLUID-FILM bearing modules (JURNBR, HYBCBR, TILTBR, and THRSBR) solve the lubrication problem in two dimensions eliminating any approximation typically associated with one dimensional analysis or with look-up table methods.

Complete performance predictions of hydrodynamic, hydrostatic, and hybrid lubricated journal, conical and thrust bearings operating in the laminar and/or turbulent regime can be generated.

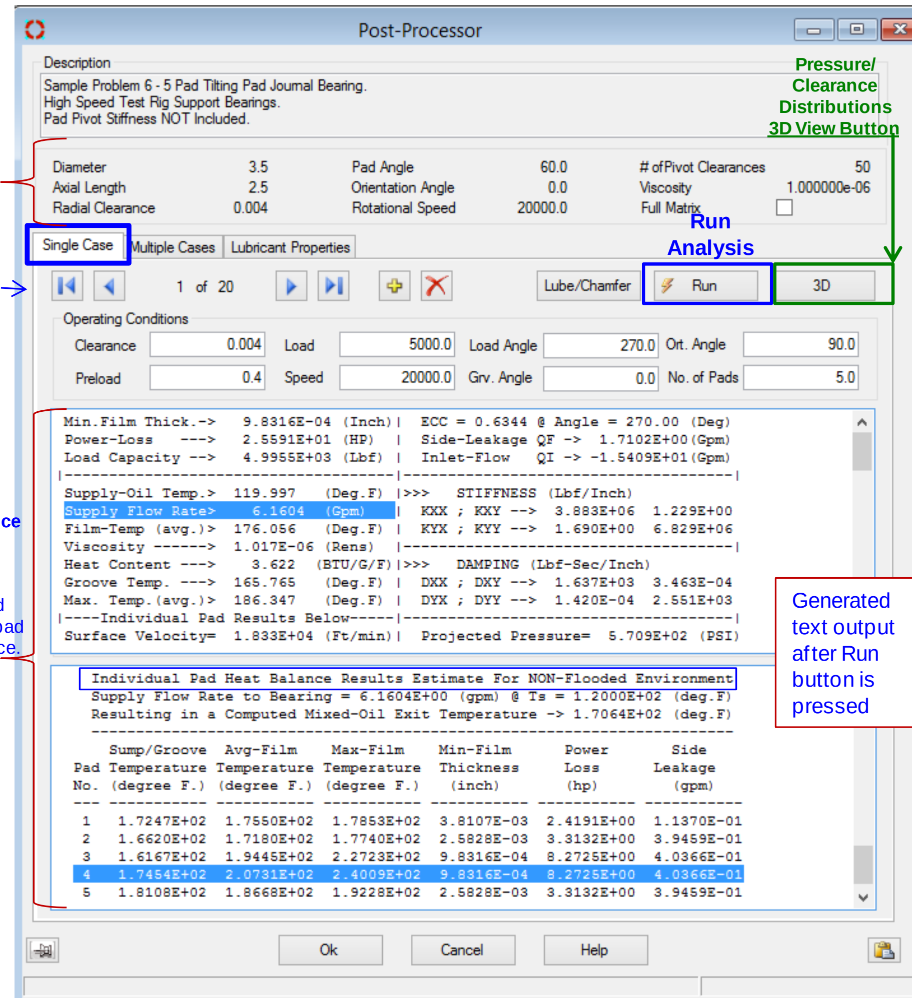
Simulation capabilities include such effects as misalignment, pressurized boundaries or grooves, cavitation, surface deviations (structural deformation), lubricant feed circuitry with specified pressures or restrictors (capillary, orifice, or flow control valve), groove geometry and chamfers.



Modeled Bearing Details

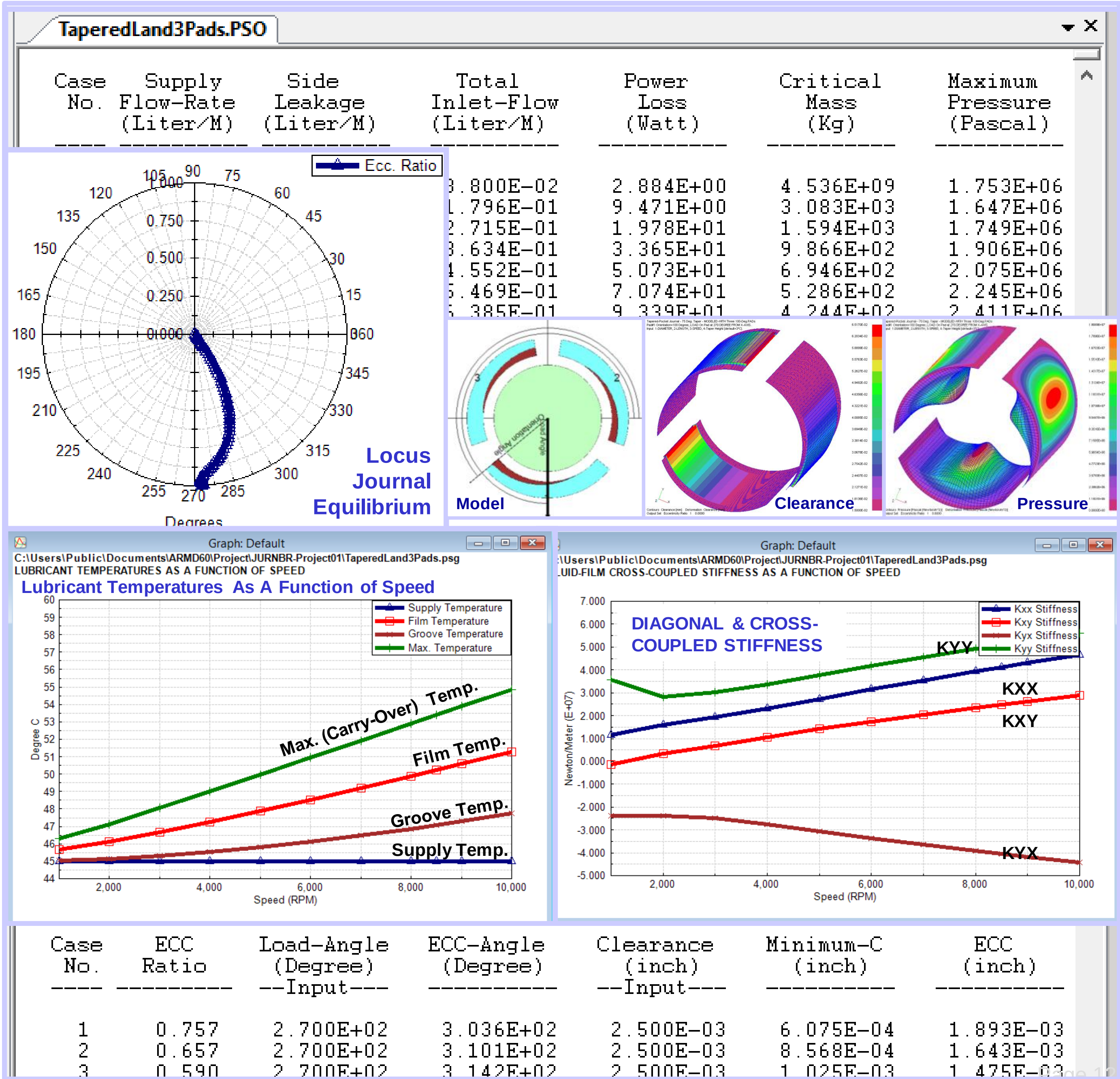
Scroll through cases.

Complete Bearing Performance Results including bearing system and individual pad heat balance.



Results include:

- Load capacity / journal position
- Attitude angle
- Viscous power loss
- Righting moments
- Flow requirements
- Stability (bearing whirl)
- Spring and damping coefficients
- Clearance and pressure distribution
- Recess pressures and flows
- Heat balance and temperature rises



The **FLUID-FILM** bearing modules incorporate numerous templates for common bearings used in industry. In addition, bearing configurations that can be evaluated with the various solution modules include but not limited to:

Fixed Geometry Cylindrical and Conical Journal Bearings (JURNR & HYBCBR)

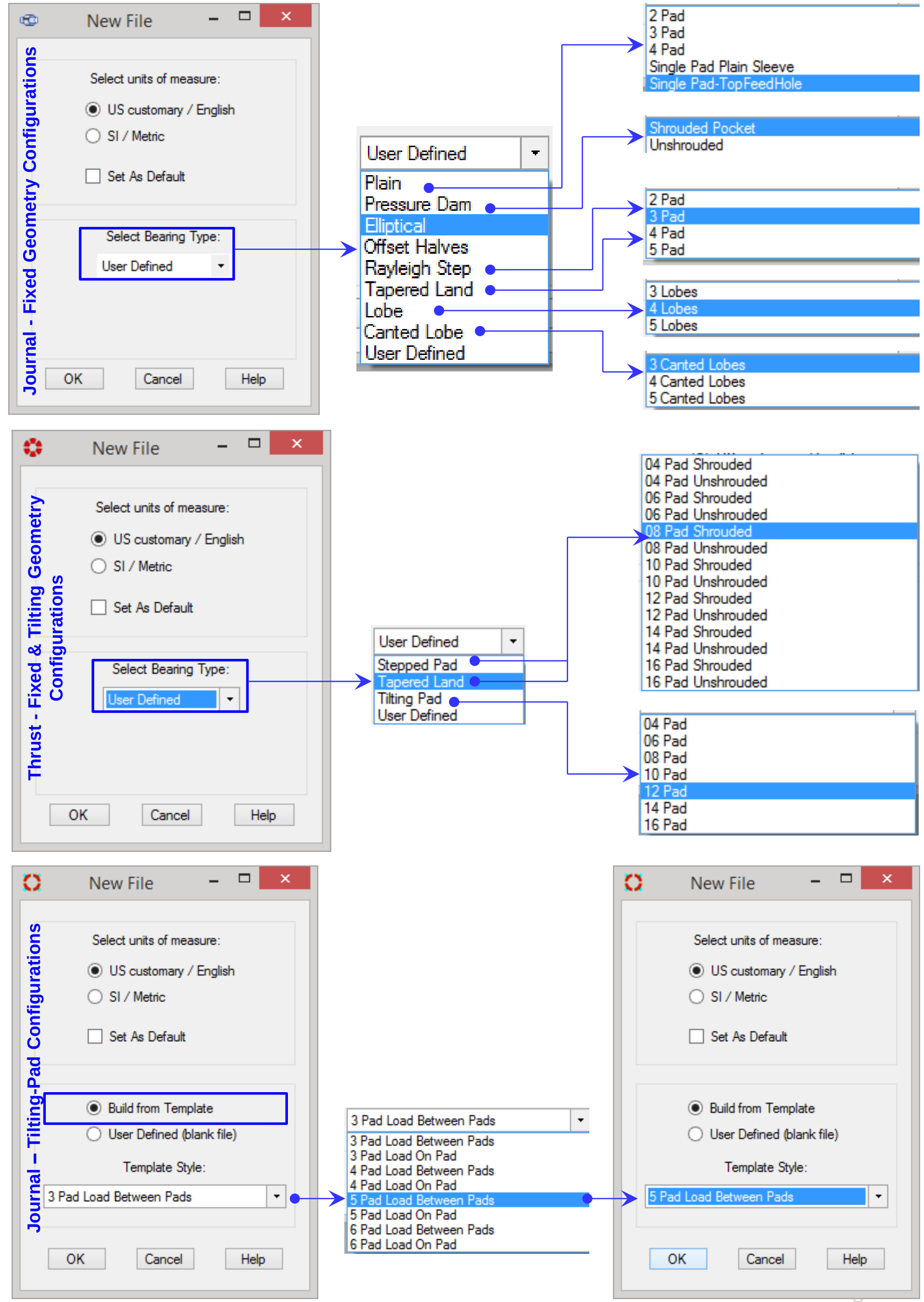
- Plain surface
- Multi-groove
- Pressure dam
- Elliptical or lemon
- Rayleigh step or pocket
- Tapered land
- Lobe or canted lobe
- Any configurable pad surfaces
- Multi-recess

Fixed and Tilting-Pad Geometry Thrust Bearings (THRSBR)

- Plain surface
- Multi-groove
- Step land
- Step pocket
- Tapered land
- Tapered pocket
- Tilting pad
- Compound taper
- Any configurable pad surface

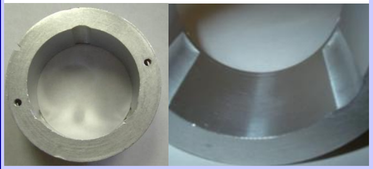
Tilting-Pad Journal Bearings (TILTBR)

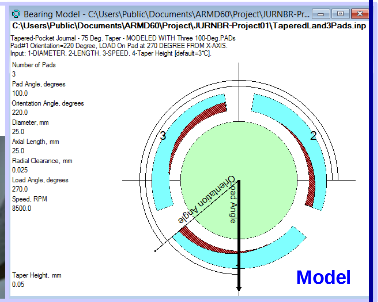
- Central pivot
- Offset pivot
- Evenly spaced pads
- Grouped pads
- Load between pads
- Load on pad
- Any load direction
- Any preload
- Leading/trailing edges taper
- Fluid-inertia force effects

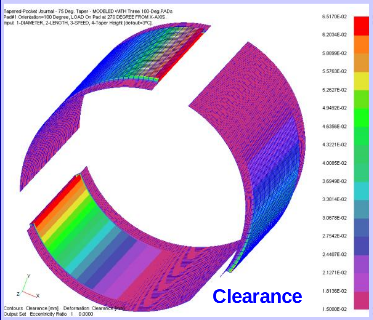


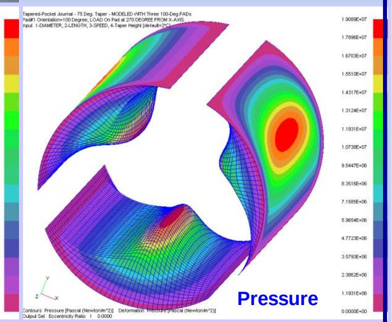
Sample Presentations – 3D Fluid-Film Bearing Pressure & Clearance Distributions.

Sample - Three (3) pad, fixed geometry cylindrical journal bearing, with tapered pocket configuration for high speed multi-stage centrifugal compressor operating at 8500 rpm.

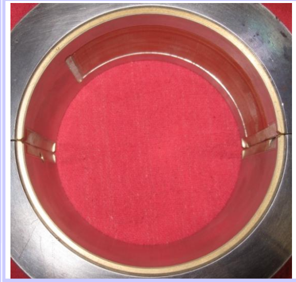


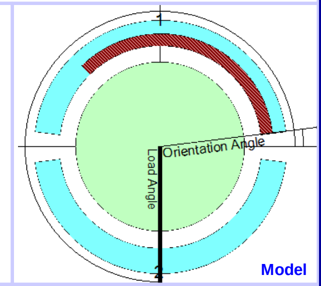


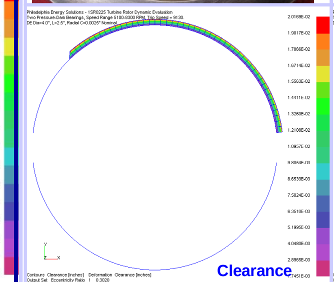


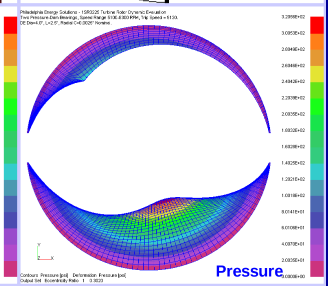


Sample – Pressure-Dam Journal Bearing for High Speed Turbine Application Operating at 9300 rpm

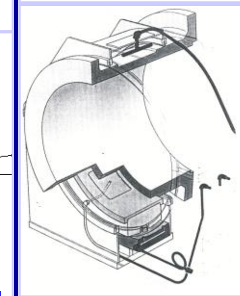


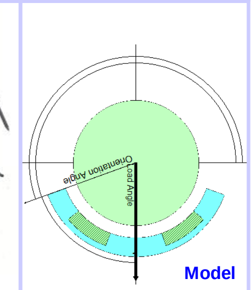


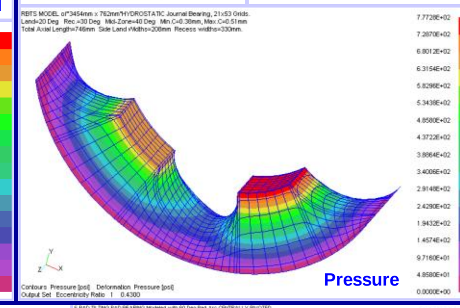




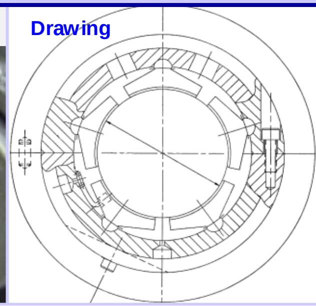
Sample Hydrostatic/Hybrid Bearing for Mining Application

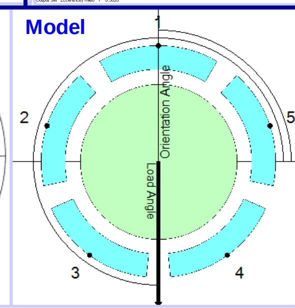


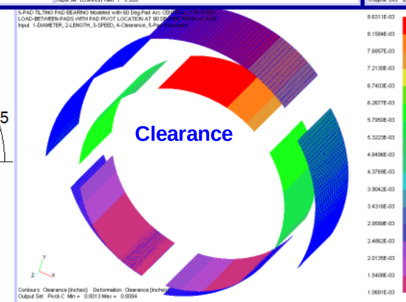


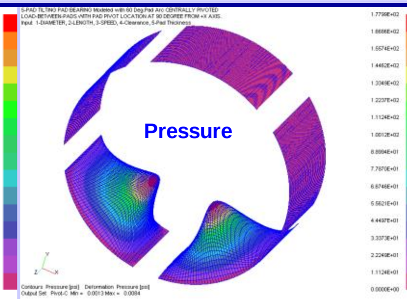


Journal Bearing – Unloaded Half

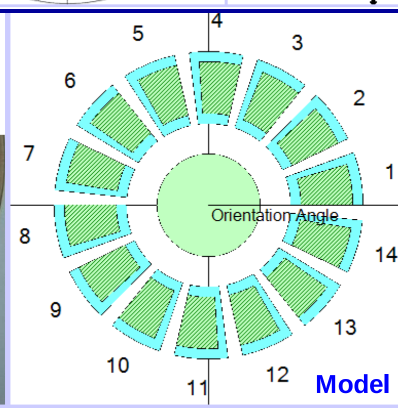


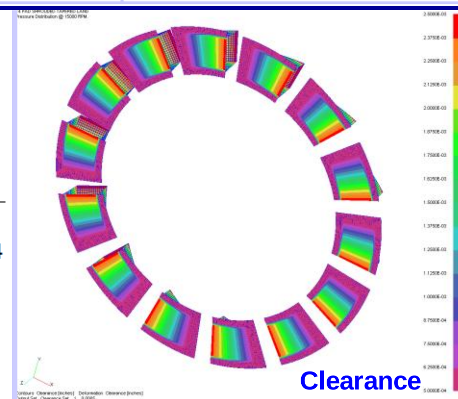


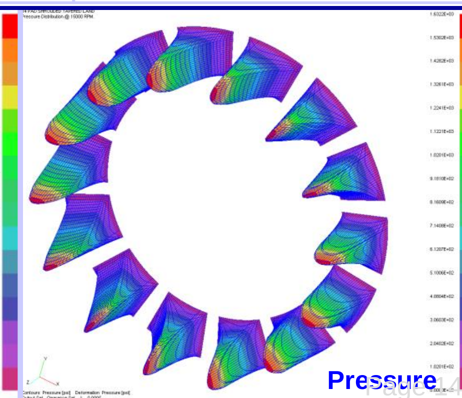




Sample - Gearbox Thrust Bearing 14 pad shrouded tapered land configuration operating at 15KRPM







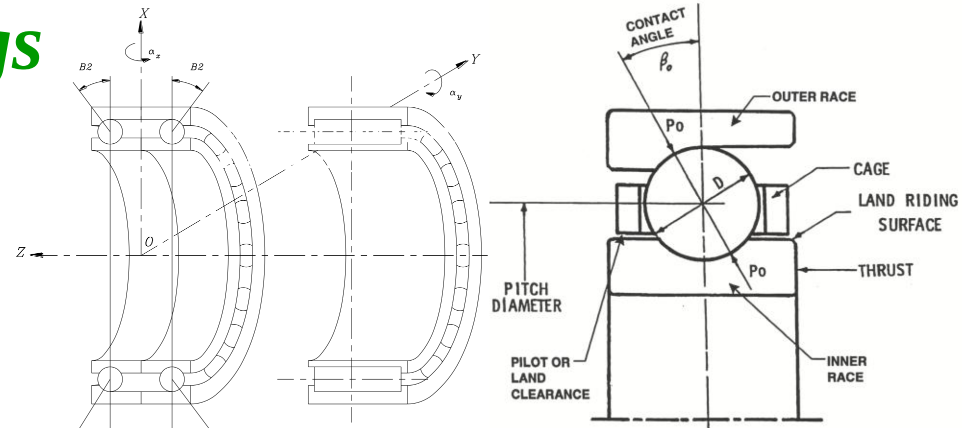
Rolling-Element Bearings

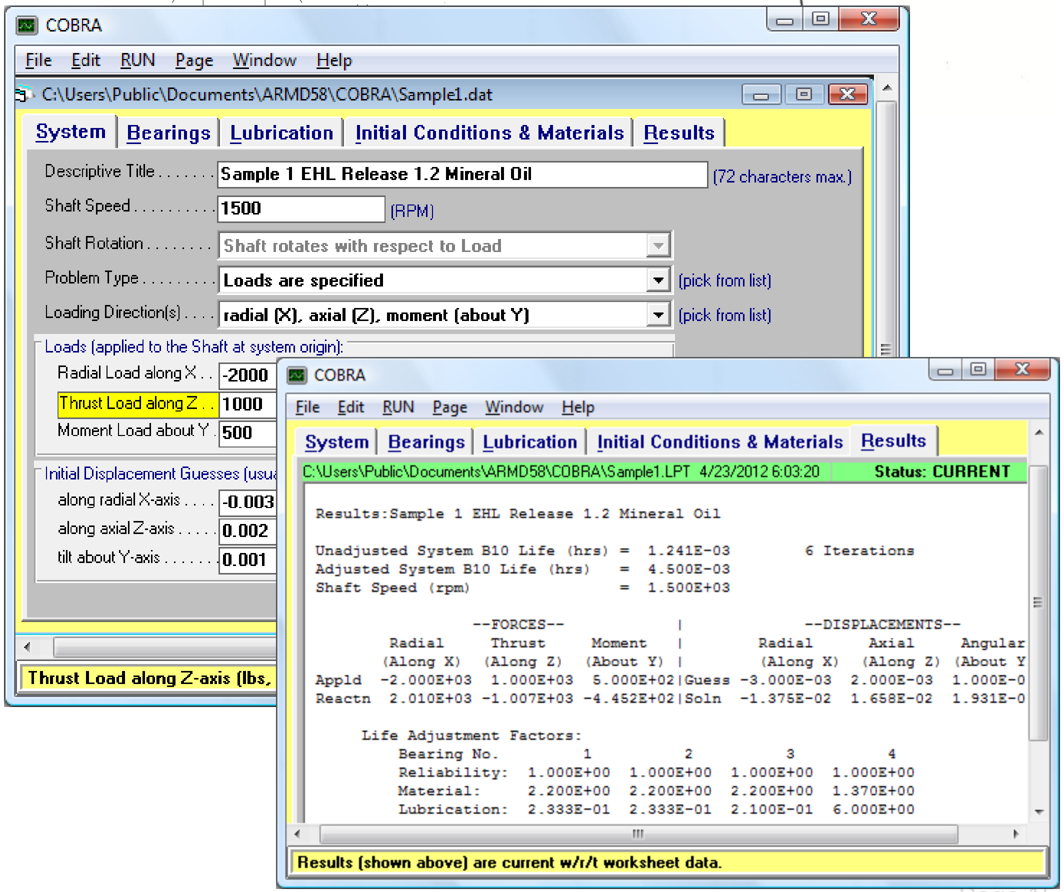
The **ROLLING-ELEMENT** bearing module [**COBRA**] predicts the performance of up to six bearings of different types mounted on a shaft and experiencing radial, thrust and moment loading. Bearing types include:

- Conrad (radial) ball
- Angular contact ball
- Cylindrical roller
- Tapered roller
- Spherical roller

The program allows the evaluation of misalignment, offsets, preload, clearance, or end-play on bearing performance. Bearing preload from spacer grinding or shimming, as well as preload springs is included. Individual bearings can be made to "float". Results include:

- Ball load distribution
- Stress distribution
- Bearing reaction loads & displacements
- System reaction loads & displacements
- Hertz contact stress
- B10 life
- Contact angles
- Spring/stiffness rate



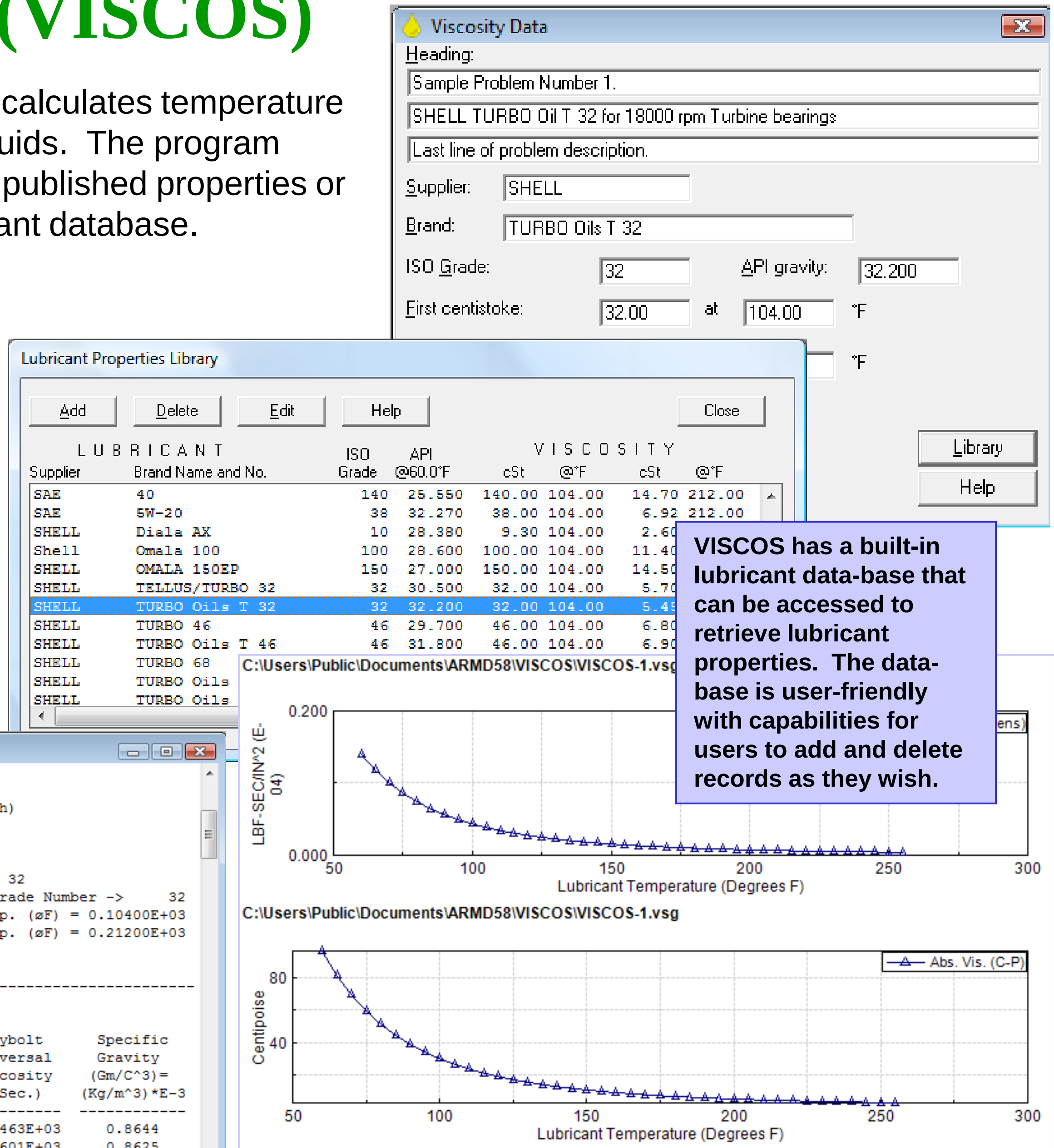


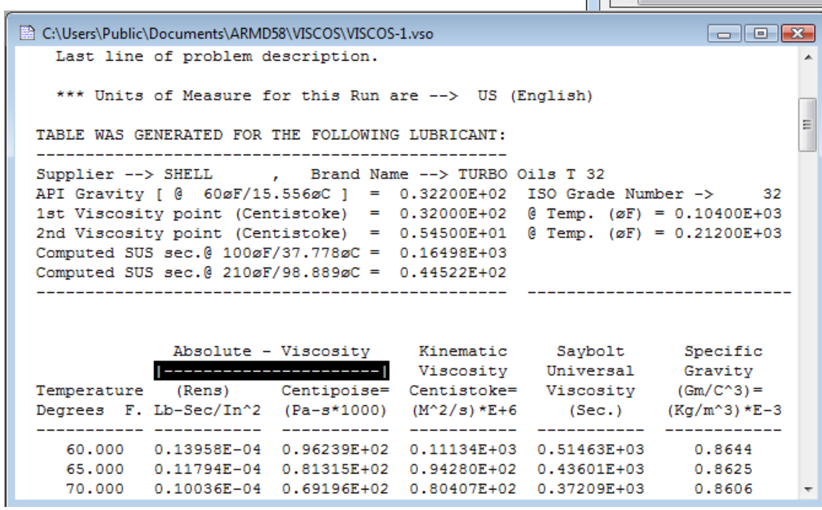
Lubricant Module (VISCOS)

The **LUBRICANT** module [VISCOS] calculates temperature dependent properties of lubricating fluids. The program requires the user to specify lubricant published properties or to select them from the built-in lubricant database.

VISCOS generates, as a function of temperature, such parameters as:

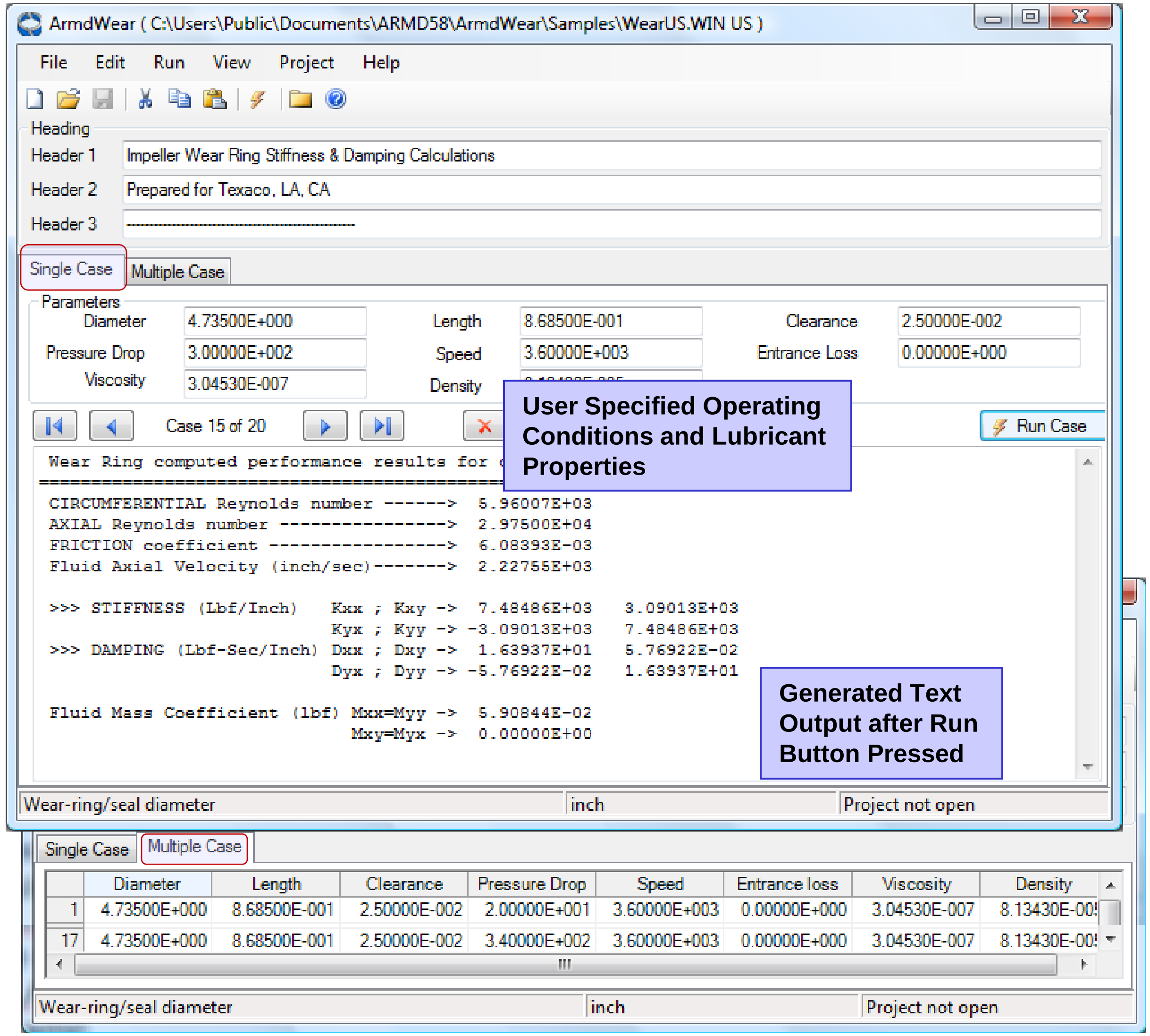
- Absolute viscosity
- Kinematic viscosity
- Saybolt universal viscosity
- Specific gravity
- Weight density
- Specific heat
- Heat content
- Thermal conductivity





Wear-Rings <u>*tool*</u>

ArmdWear is an ARMD utility for computing wear-ring/seal performance properties including dynamic coefficients (stiffness and damping) of incompressible fluids such as those found in boiler feed pumps.



The computation is based on Black and Jenssen "Effect of High Pressure Ring Seals on Pump Rotor Vibrations". The simulation in ArmdWear can be performed for a single point of operation or as a function of operating parameters such as Diameter, Length, Clearance, Pressure Drop, Speed, Fluid Viscosity or Density.

Wear-ring input data files can also be linked to ARMD rotor models developed in the rotor dynamic package ROTLAT, for automatic wear-ring dynamic coefficients (stiffness & camping) calculations and inclusion in the rotor dynamic simulations.

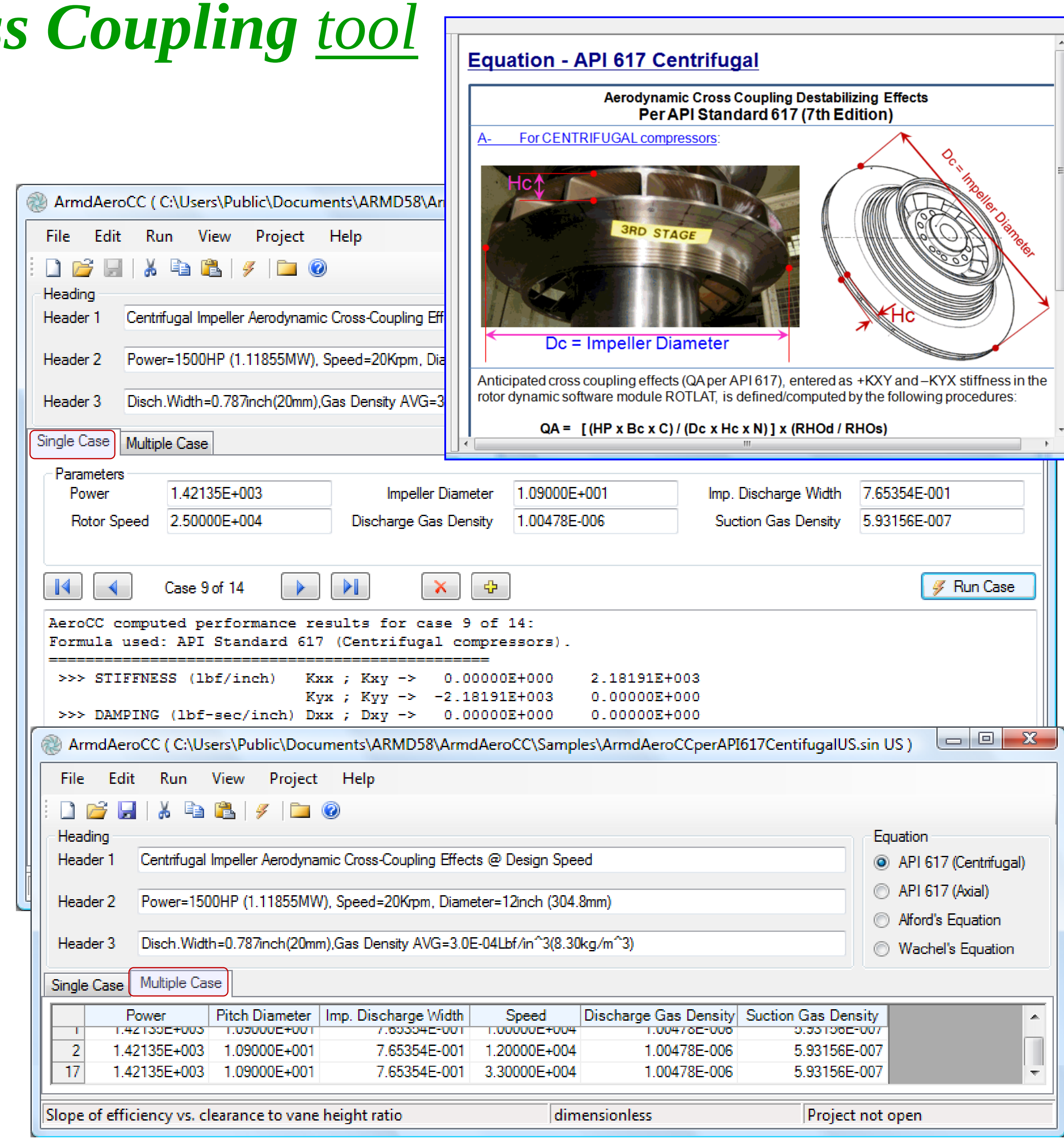
Aerodynamic Cross Coupling tool

ArmdAeroCC is an ARMD utility for computing gas compressor Aerodynamic Cross Coupling Destabilizing Effects. The computation can be based on one of the following:

A- API 617 for centrifugal impeller.
B- API 617 for axial flow rotor.
C- ALFORD's equation.
D- WACHEL's equation.

The simulation can be performed for a single point of operation or as a function of input parameters such as power, impeller diameter, impeller discharge clearance, ratio of discharge to suction densities, etc.

Created input data files can be linked to ARMD rotor models developed in the rotor dynamic package ROTLAT, for automatic aerodynamic cross-coupling coefficients calculations and destabilizing effects inclusion in the rotor dynamic simulations.



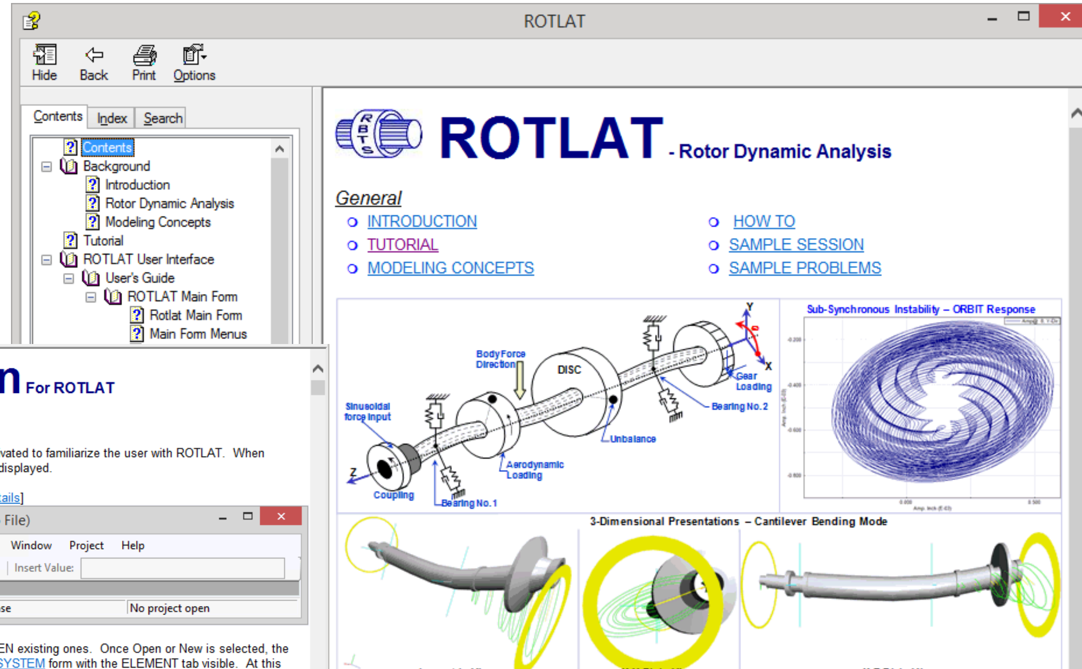
ARMD Documentation

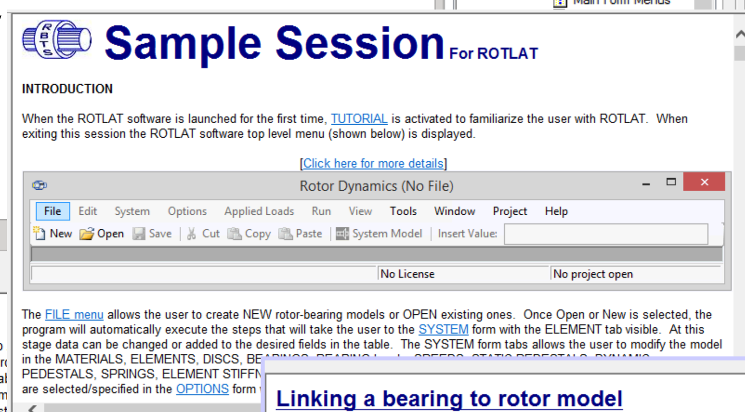
ARMD package is supplied with a printed quick start manual that covers installation, sample cases, features, and capabilities. The package also has a comprehensive electronic user's manual that includes the following sections:

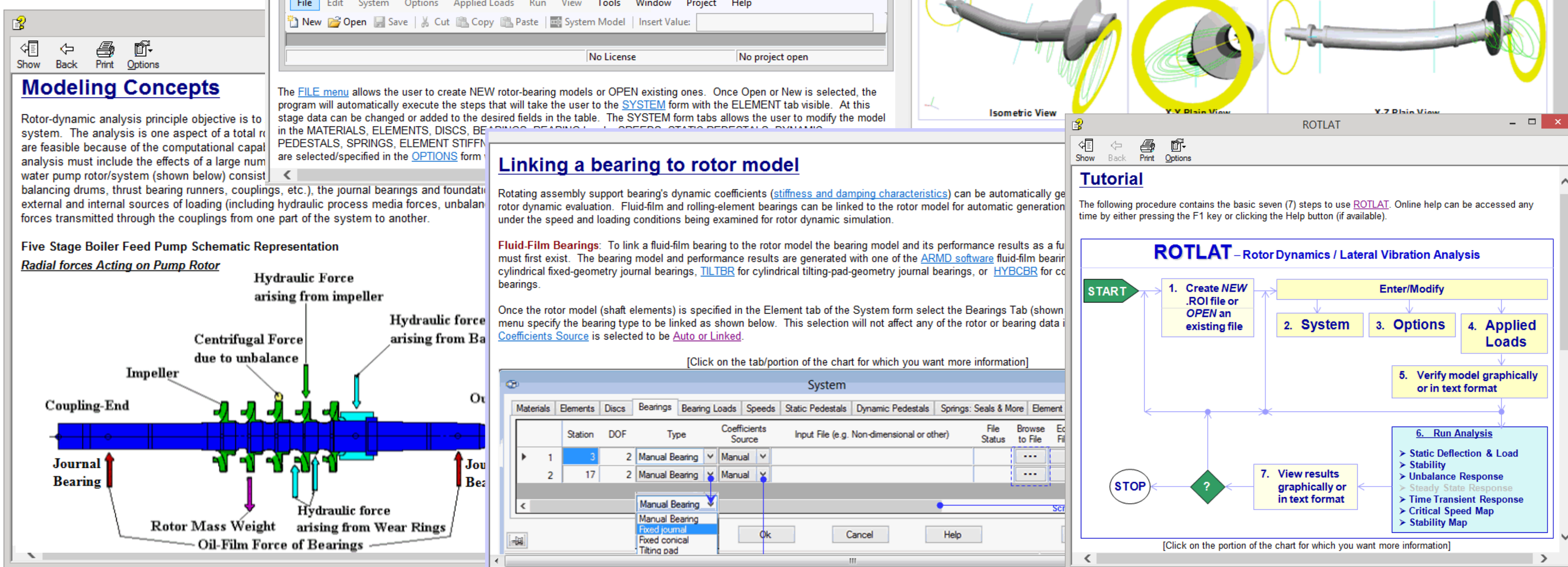
ARMD™	Introduction, Set-up, Installation and Operation	***Brochure***	***Manual***	
ROTLAT™	Rotor Dynamics Lateral Vibration	***Overview***	***Manual***	***Samples***
TORSION™	Torsional Vibration	***Overview***	***Manual***	***Samples***
JURNBR™	Cylindrical Fluid-Film Fixed Geometry Journal Bearings	***Overview***	***Manual***	***Samples***
HYBCBR™	Conical Fluid-Film Fixed Geometry Journal Bearings	***Overview***	***Manual***	***Samples***
TILTBR™	Fluid-Film Tilting-Pad Geometry Journal Bearings	***Overview***	***Manual***	***Samples***
THRSBR™	Fluid-Film Fixed and Tilting-Pad Geometry Journal Bearings	***Overview***	***Manual***	***Samples***
COBRA™	Rolling-Element Bearings	***Overview***	***Manual***	***Samples***
VISCOS™	Lubricant Temperature Dependent Properties	***Overview***	***Manual***	***Samples***

Advanced Rotating Machinery Dynamics

ARMD incorporates advanced technical and user interface features with built-in help utilities in each of its modules to simplify modeling, analysis, presentation, and interpretation of results. Tutorials and step by step sample sessions with advanced graphical presentation are among the many features implemented in the new version.







Purchasing Options

ARMD is constructed from various solution modules. It can be tailored to suit your needs and budget. You may purchase any combination of programs or all if you wish. Licensing is available as a single seat or multi-seat network configuration.

With your purchase, the package includes the software (CD or download), quick start manual, electronic user's manual, technology transfer and training session (optional), updates, maintenance, and support.

System Requirements

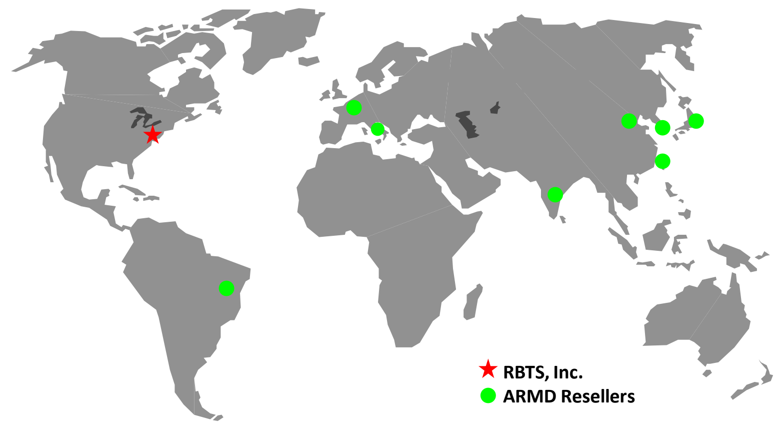
Microsoft Windows 7, 8 10 or higher (32 or 64 bit).

Remember, with **RBTS**, you get more than just the software, you get the company with more than 50 years of experience in the areas of tribology and machinery dynamics.

ARMD™

The Worldwide Leading Software For Rotating Machinery Analysis

***A**dvanced*
***R**otating*
***M**achinery*
***D**ynamics*



RBTS' software has gained international reputation for its:

- **Technical Capabilities**
- **Completeness**
- **User Friendliness**
- **Support & Service**