

# *Advanced Rotating Machinery Dynamics*

# ARMD™

## Version 6.2

**THE COMPLETE SOFTWARE PACKAGE FOR**

- **Rotor Dynamics**
- **Torsional Vibration**
- **Fluid-Film Bearings**
- **Rolling-Element Bearings**
- **Lubricant Performance**
- **Tools / Utilities**

**Workstation and Enterprise Licensing Available**

Please contact **Dr. Andreas Laschet** as RBTS' consultant and representation for the regions **Europe, Middle East, Africa** with the following communication details:

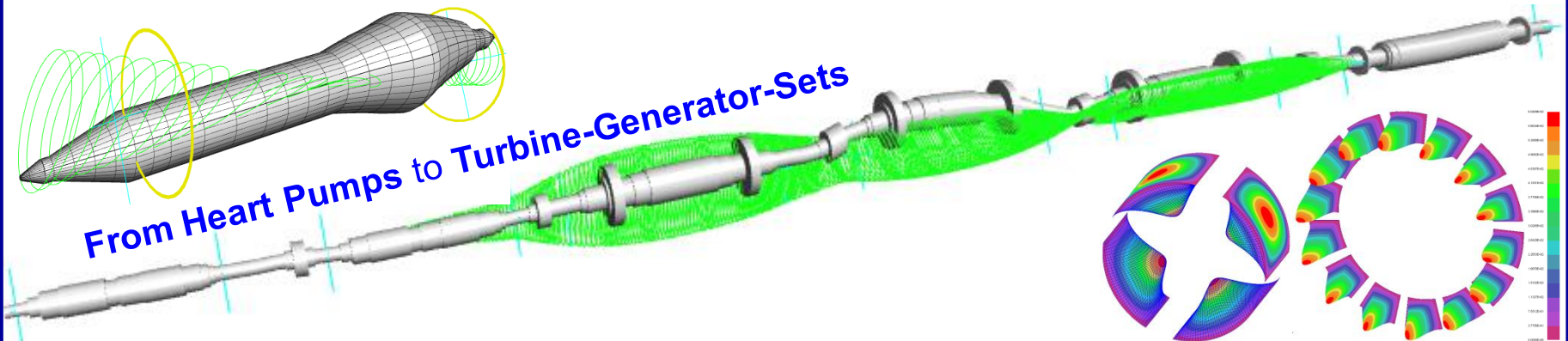
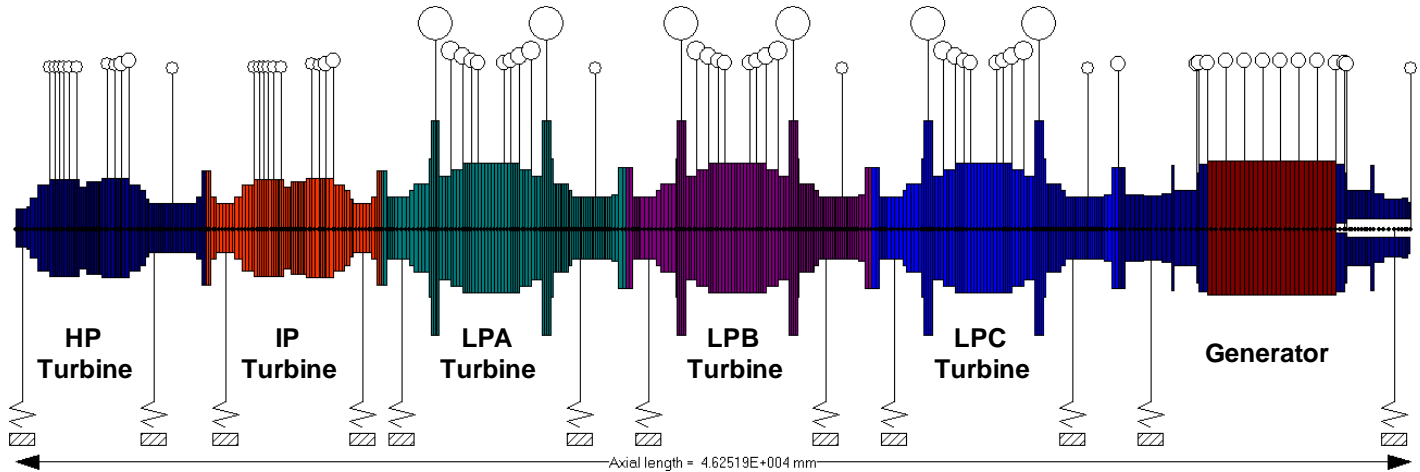
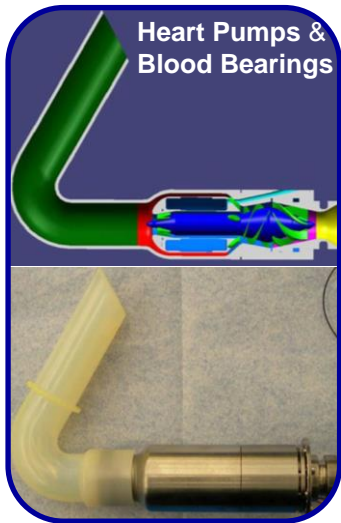
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# Advanced Rotating Machinery Dynamics

# 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.

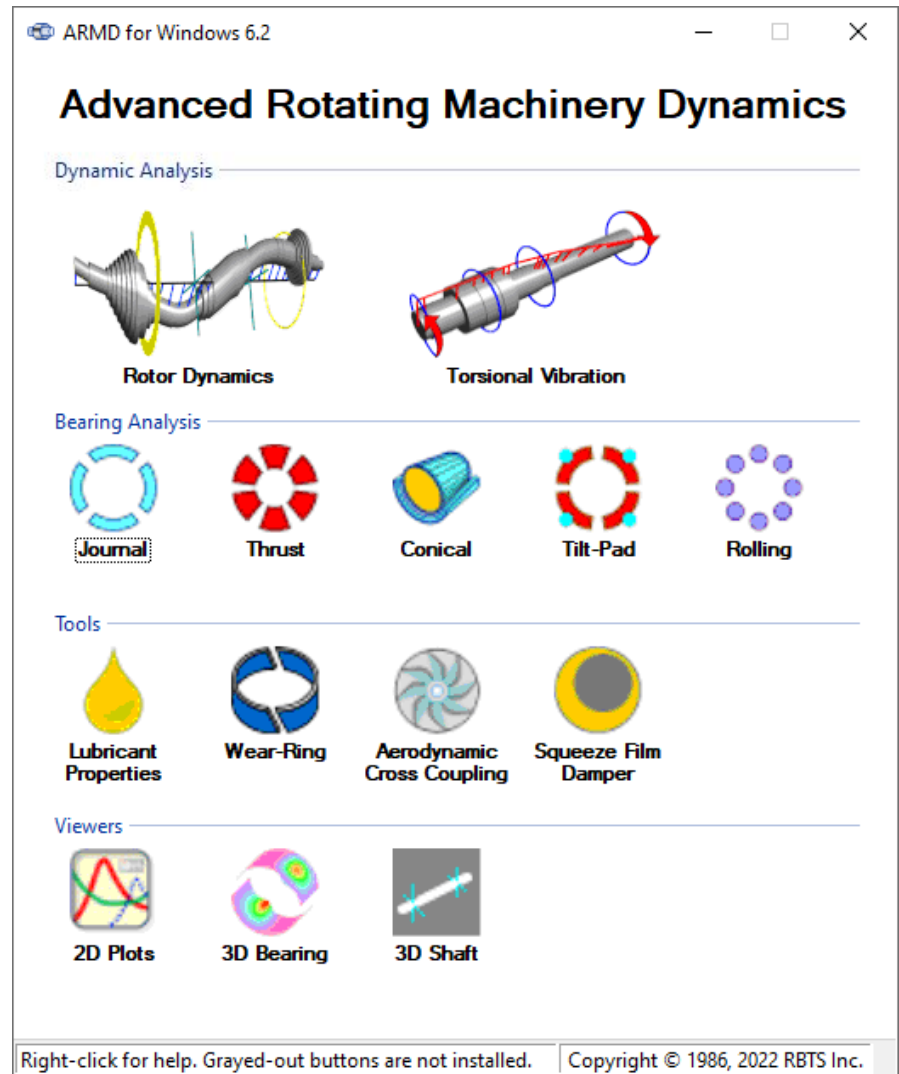
**ARMD** consists of five main modules:

- **Rotor Dynamics**
- **Torsional Vibration**
- **Fluid-Film Bearings**
- **Rolling-Element Bearings**
- **Lubricant Performance**
- **Utilities & Support Tools**

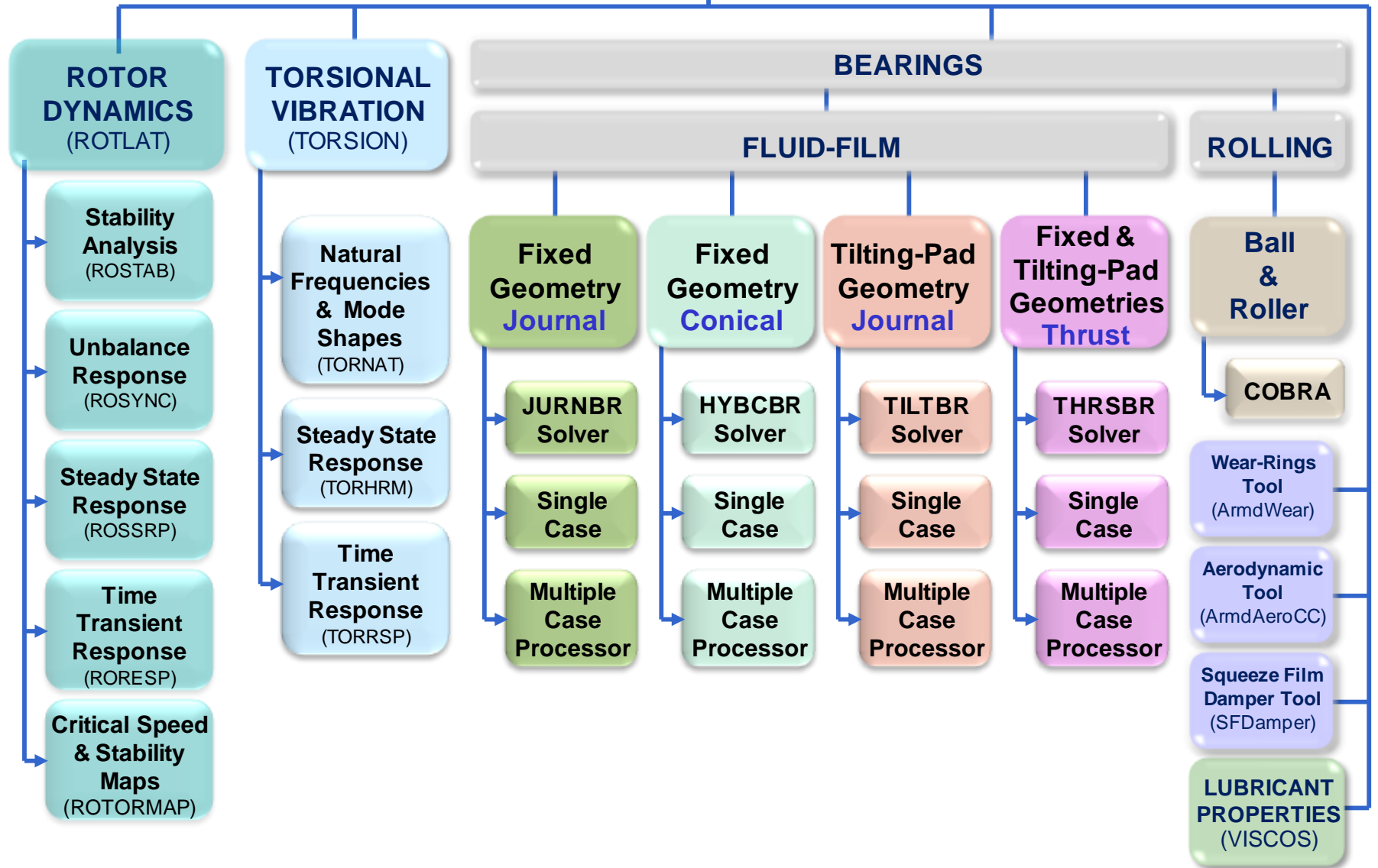
With a variety of features, including:

- **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™)

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.

Auto Convert

Mathematical expressions evaluator

System

Stiffness Diameter

Use Stiffness Diam

Stiffness Diameter

User Specified Stiffness

Name

Element Properties

Material Number

| Material Number | Taper | Length | OD1     | ID1 | OD2     | ID2 | Use Stiffness Diam       | Stiffness Diameter | User Specified Stiffness | Name |
|-----------------|-------|--------|---------|-----|---------|-----|--------------------------|--------------------|--------------------------|------|
| 11              | 1     | 127.5  | 450.0   | 0.0 | 450.0   | 0.0 | <input type="checkbox"/> | 0.0                | None                     |      |
| 12              | 1     | 155.0  | 485.0   | 0.0 | 485.0   | 0.0 | <input type="checkbox"/> | 0.0                | None                     |      |
| 13              | 2     | 115.0  | 731.056 | 0.0 | 731.056 | 0.0 | <input type="checkbox"/> | 0.0                | None                     |      |
| 14              | 2     | 115.0  | 731.056 | 0.0 | 731.056 | 0.0 | <input type="checkbox"/> | 0.0                | None                     |      |
| 15              | 3     | 75.0   | 877.591 | 0.0 | 877.591 | 0.0 | <input type="checkbox"/> | 0.0                | None                     |      |
| 16              | 3     | 140.0  | 877.591 | 0.0 | 877.591 | 0.0 | <input type="checkbox"/> | 0.0                | None                     |      |
| 17              | 3     | 140.0  | 877.591 | 0.0 | 877.591 | 0.0 | <input type="checkbox"/> | 0.0                | None                     |      |
| 18              | 3     | 140.0  | 877.591 | 0.0 | 877.591 | 0.0 | <input type="checkbox"/> | 0.0                | None                     |      |
| 19              | 3     | 140.0  | 877.591 | 0.0 | 877.591 | 0.0 | <input type="checkbox"/> | 0.0                | None                     |      |

Shaft Element Selection Summary for Rows 13 - 14

Shaft Length = 230.0 mm  
 Shaft Weight = 339.7528 kg  
 Shaft Inertia (IP\*) = 22.69731 kg-m<sup>2</sup>  
 Total weight = 2639.753 kg (Shaft + Disc)

Check for System Errors

Data validation

Solver Options

Applied Loads

| Station | Type | Direction      | Load       | Frequency | Harmonic | Phase Angle |         |
|---------|------|----------------|------------|-----------|----------|-------------|---------|
| 5       | 44   | Time Transient | Force in X | 20256.0   | 2640.0   | 0.0         | 31.147  |
| 6       | 44   | Time Transient | Force in X | 47135.0   | 2310.0   | 0.0         | 15.094  |
| 7       | 44   | Time Transient | Force in X | 56625.0   | 1650.0   | 0.0         | 94.624  |
| 8       | 44   | Time Transient | Force in X | 91693.0   | 660.0    | 0.0         | -129.44 |
| 9       | 44   | Time Transient | Force in X | 119250.0  | 990.0    | 0.0         | 58.541  |
| 10      | 44   | Time Transient | Force in X | 70769.0   | 330.0    | 0.0         | 166.48  |

Natural Frequency, Mode Shapes & Stability

Natural Frequencies and Mode Shape Options

Output Options

Cycles/Minute  Damping Ratio  Compute natural frequencies and mode shapes where the critical damping ratio is below 0.9

Hertz  Log Decrement

Critical Speed/Stability Map Condensed Output

Critical Speed Options

Initial Bearing Stiffness 1.000000e+07  
 Final Bearing Stiffness 2.000000e+13  
 Speed (Only for gyroscopic analysis) 0.0

9500 HP Motor Driving Reciprocating Compressor

C:\Users\Public\Documents\ARMD60\Project\MotorRecipCompressor-SampleCase\MotorCompressor100Load-BaseLine.roi

Motor Driven Reciprocating Compressor Drive Train

Rotor Dynamic Lateral Forced Vibration Analysis-Speed-300RPM - BASELINE

Motor Supported by 1 Journal Brg @ NDE - Support Structure Included

25000.0

to plot 10

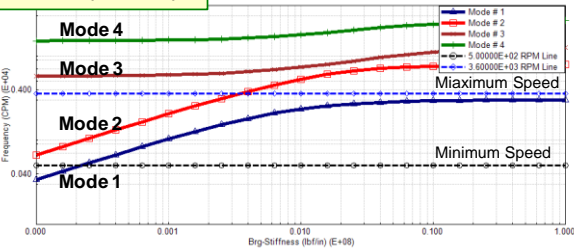
Axial length = 6704.849 mm



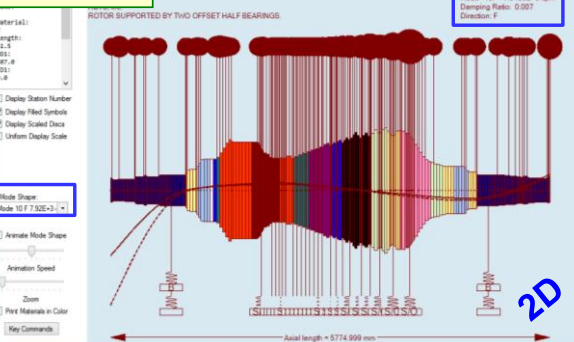
## NATURAL FREQUENCY, MODE SHAPE & STABILITY

- 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

Critical Speed Map

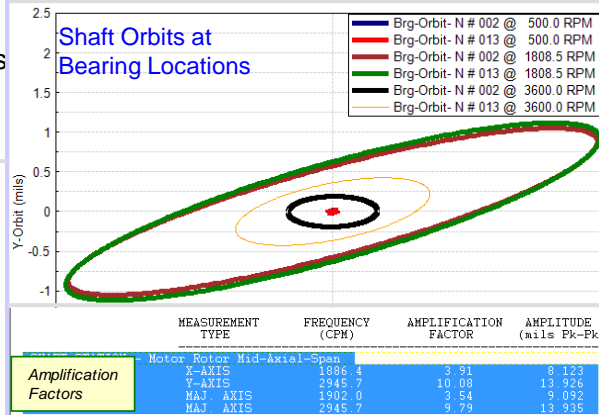


Mode Shape

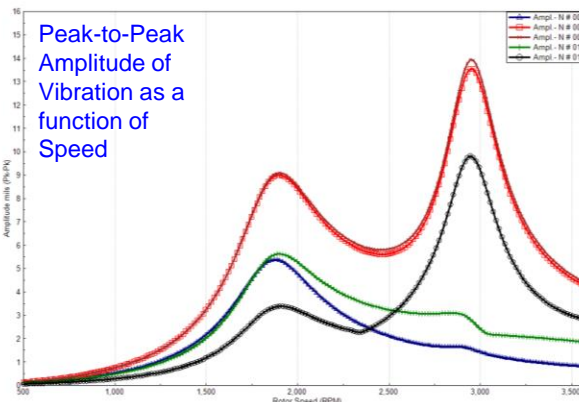


## Synchronous UNBALANCE & STEADY-STATE RESPONSE

- Multiple unbalance planes/forces
- Various types of external excitations & body forces including sinusoidal/harmonic
- Magnitude and phase (Bode plot)
- Dynamic forces and moments
- Vibratory amplitudes and orbits
- Forces and moments transmitted to bearing and foundation
- Foundation vibratory amplitudes
- Rotor shape plots (amplitude & phase)
- API Amplification factors

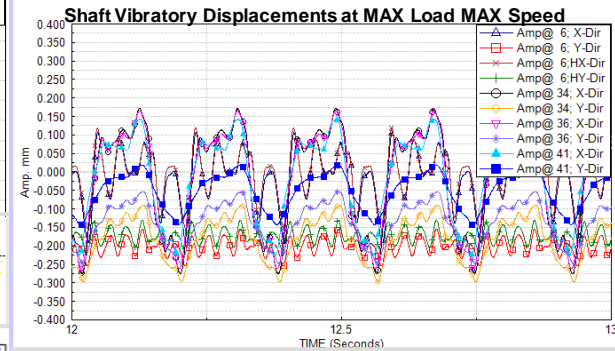


Peak-to-Peak Amplitude of Vibration as a function of Speed

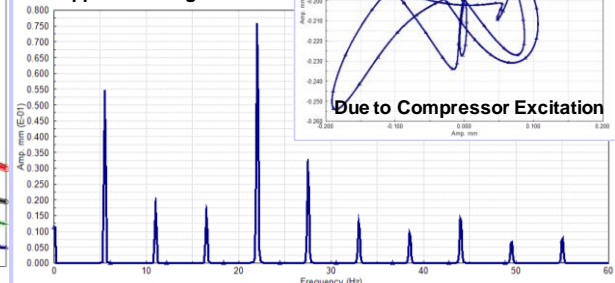


## TIME-TRANSIENT RESPONSE (Non-synchronous response)

- 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



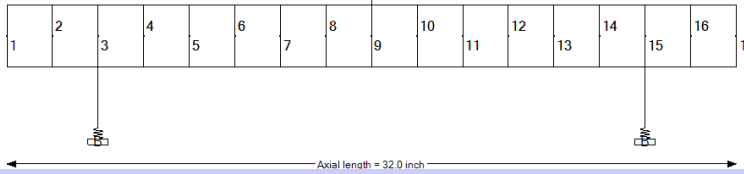
FFT - Motor Vibration at Support Bearing





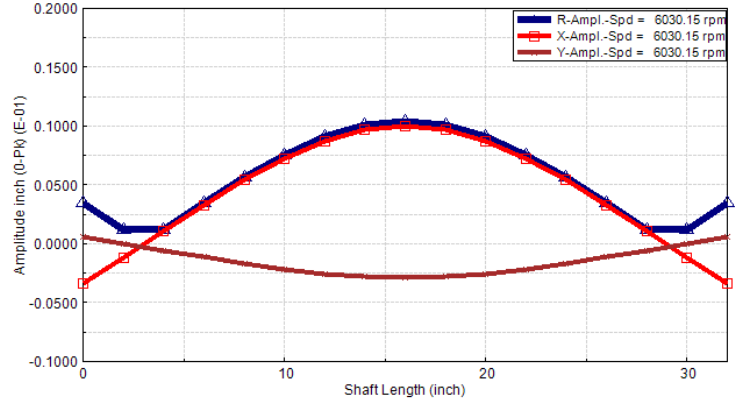
C:\Users\Public\Documents\ARM61\ROTLAT1\Samples\SSResponseSample1-JeffcottRotor.roi  
 STEADY STATE SIMULATION EXAMPLE - Single Disc Rotor System Model.  
 Operating Speed Range 1,000 to 10,000 Rpm -1st Critical Around 6250 RPM  
 Two Bearings Support at Stations 3 and 15.

**Jeffcott Rotor Model**



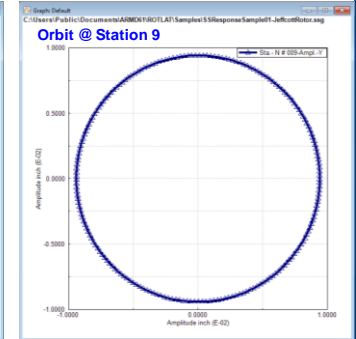
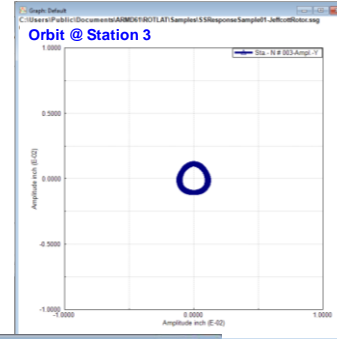
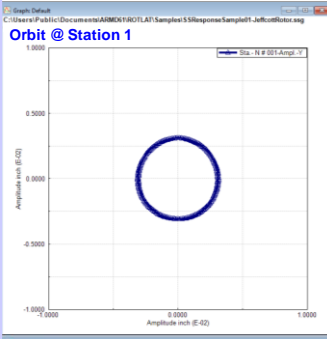
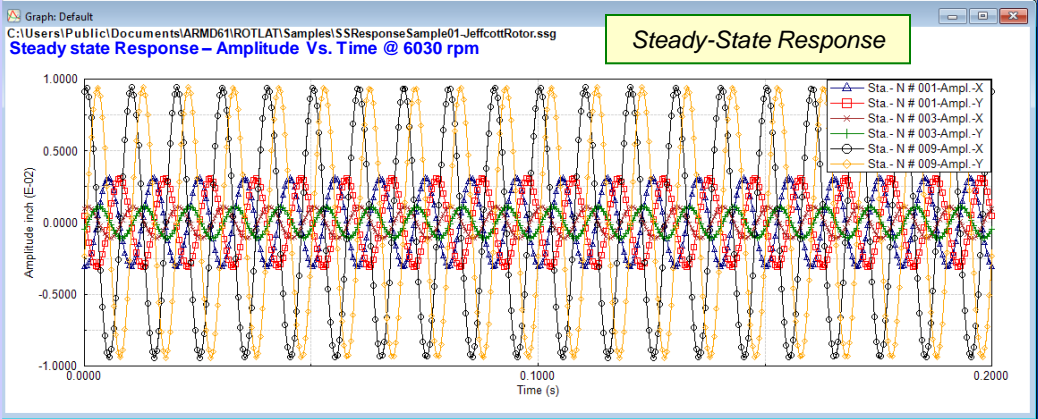
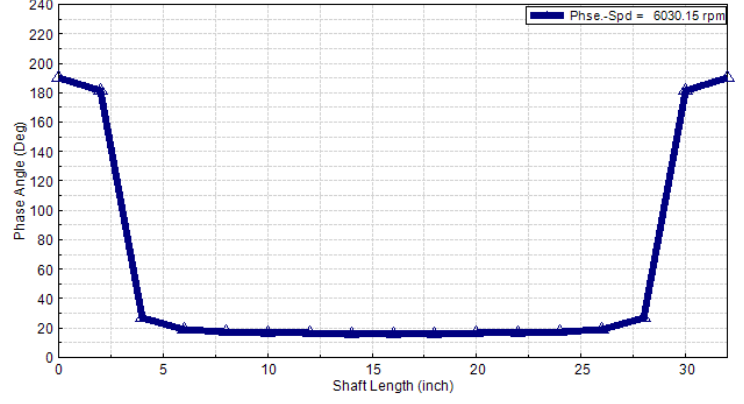
Graph: Default  
 C:\Users\Public\Documents\ARM61\Project\ROTLAT61-Samples\Folder\SteadyStateResponseSample\Cases\SSResponseSample01-JeffcottRotor.sgx

**Rotor Shape Plot At Select Speed – Displacements.**

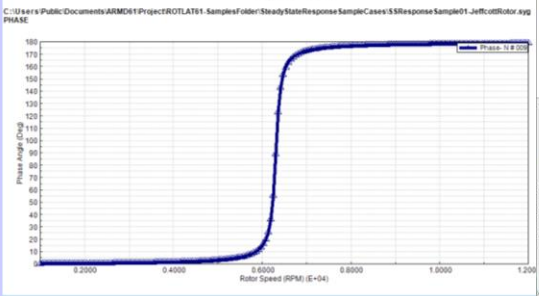
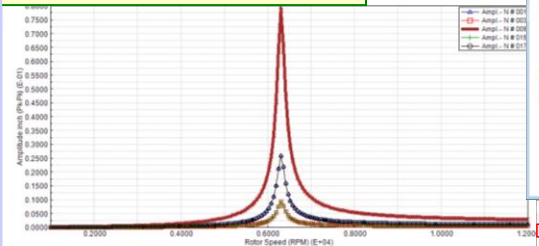


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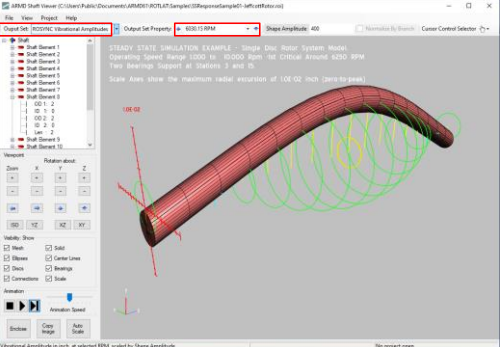
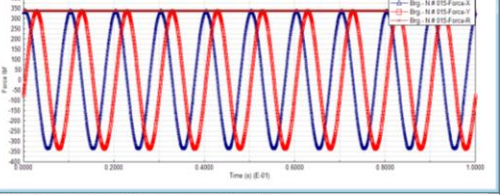
**Rotor Shape Plot At Select Speed – Phase Angle.**



**Amplitude & Phase Vs. Speed**



**Steady State Response – Transmitted Forces to Bearing Vs. Time @ 6030 rpm**





# 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...

The screenshot displays the TORSION software interface. At the top, the 'System' window shows a table of elements with columns for Branch Number, Material Number, Use Geometry, Taper, Length, OD1, ID1, OD2, ID2, Use Stiffness Diam, Stiffness Diameter, Stiffness, Damping, and Inertia. A 'Branch #1' group is highlighted in blue, and a 'Branch #2' group is highlighted in yellow. A 'Shaft Element Selection Summary for Rows 8 - 11' dialog box is open, showing the following data:

|  |  |
|--|--|
| Shaft Length = 54.0 inch   |  |
| Shaft Weight = 967.4572 lbf  |  |
| Shaft Inertia (WR <sup>2</sup> ) = 10222.04 lbf-in <sup>2</sup>                |  |
| Shaft Stiffness = 1.194514e+08 in-lbf/radian                                   |  |
| -----  |  |
| Total Inertia (WR <sup>2</sup> ) = 10222.04 lbf-in <sup>2</sup> (Shaft + Disc) |  |

Below the main table, an 'Options' dialog box is open, showing 'Branch#1 Speed Range Options' with the following settings:

- Compute steady state response at branch #1 speed (885.0 RPM)
- Compute steady state response at 885.0 RPM
- Compute steady state response over a range of speeds as specified here:
  - Minimum speed: 540.0 RPM
  - Maximum speed: 1320.0 RPM
  - Speed increment: 1.0 RPM

At the bottom left, the 'Applied Torque Tables' dialog box is open, showing a table of harmonic torques:

| Branch | Station | Harmonics | Edit Table | Import File # | Table No. | Phase |
|--------|---------|-----------|------------|---------------|-----------|-------|
| 1      | 1       | 5         | 1          | Manual        | Manual    |       |
| 2      | 1       | 5         | 1          | Manual        | Manual    |       |
| 3      | 1       | 5         | 1          | Manual        | Manual    |       |
| 4      | 1       | 5         | 1          | Manual        | Manual    |       |
| 5      | 1       | 5         | 1          | Manual        | Manual    |       |

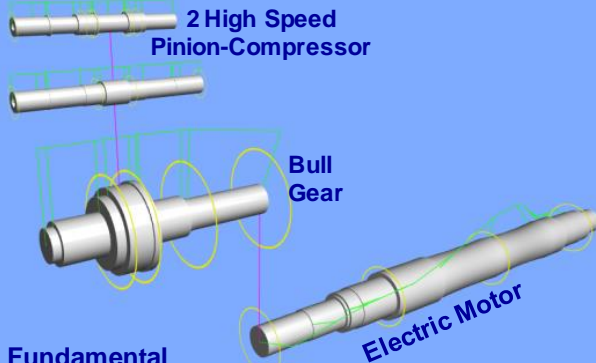
At the bottom center, the 'Steady State Torque Effort 2' dialog box is open, showing a table of torque components:

| Harmonic Order | Sine Component | Cosine Component |
|----------------|----------------|------------------|
| 1              | 2.0            | 275652.0         |

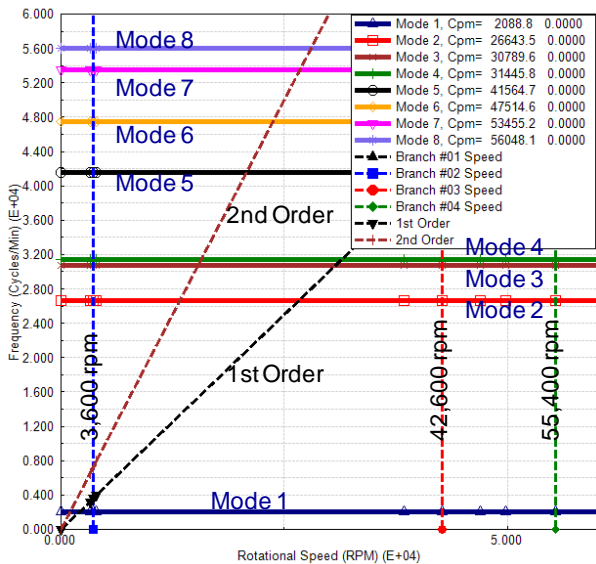
At the bottom right, a schematic diagram of a shaft system is shown, with elements numbered 1 through 19. The shaft is supported by bearings and has various components attached, including a motor/generator at the right end.

## NATURAL FREQUENCIES & MODE SHAPES

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

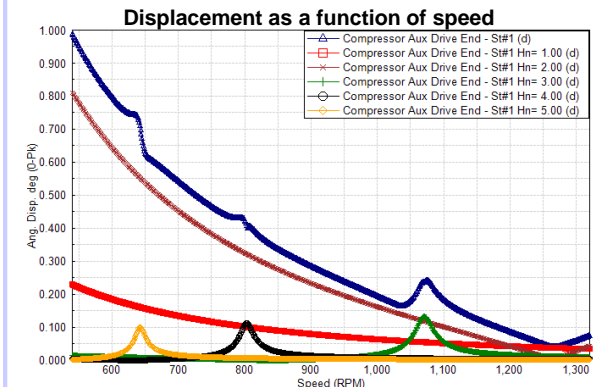
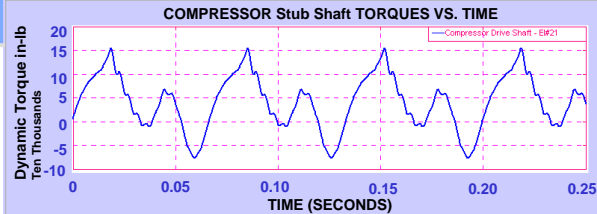
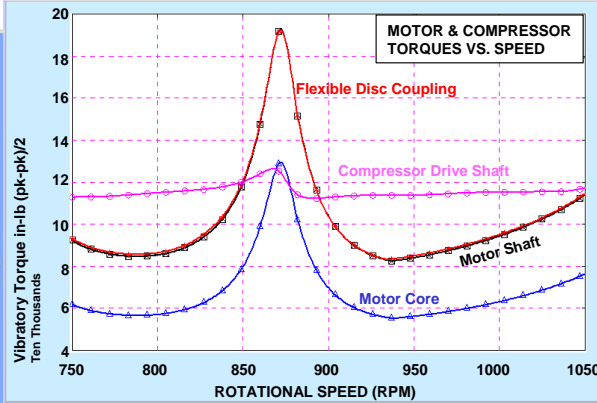


### Fundamental Torsional Twist Mode



## STEADY STATE RESPONSE

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

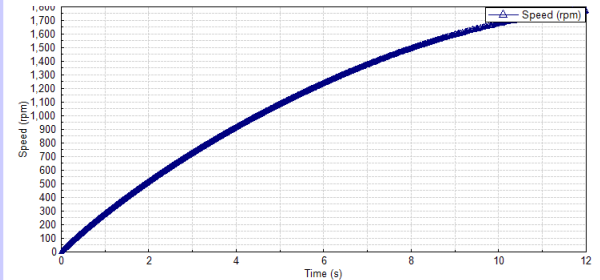


## TIME-TRANSIENT RESPONSE

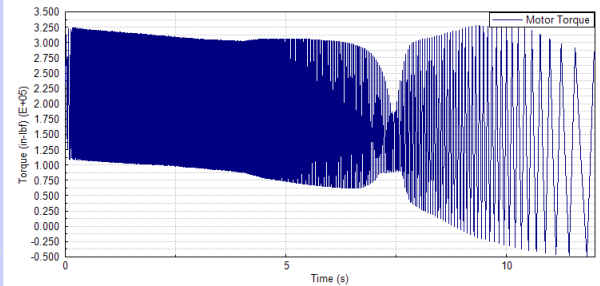
- Dynamic shaft-torque time-history
- Dynamic stresses
- Fatigue life

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

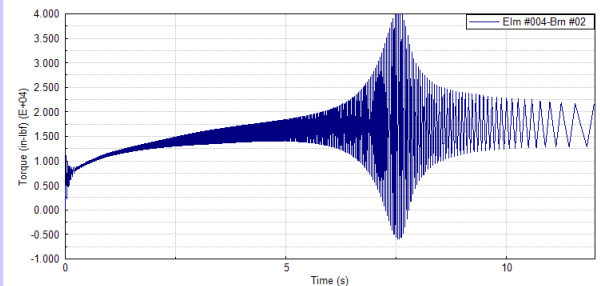
### Motor Startup Speed



### Motor Startup Average Torque



### High Speed Shaft Torque

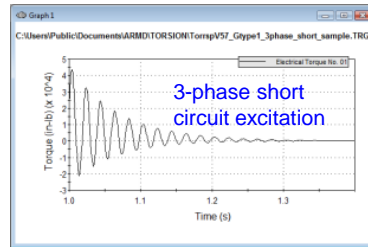


## Time varying excitations include:

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

### Generator

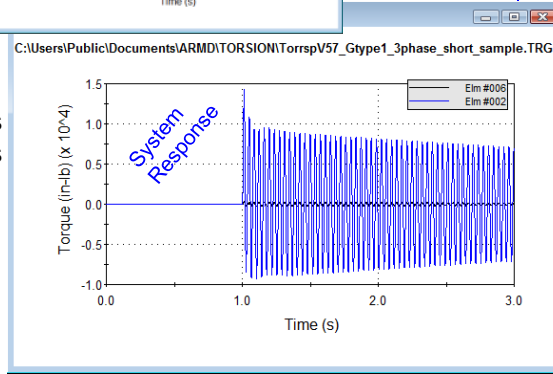
- Type 1: 3-phase short circuit
- Type 2: Line-to-Line short circuit
- Type 3: False-coupling short circuit



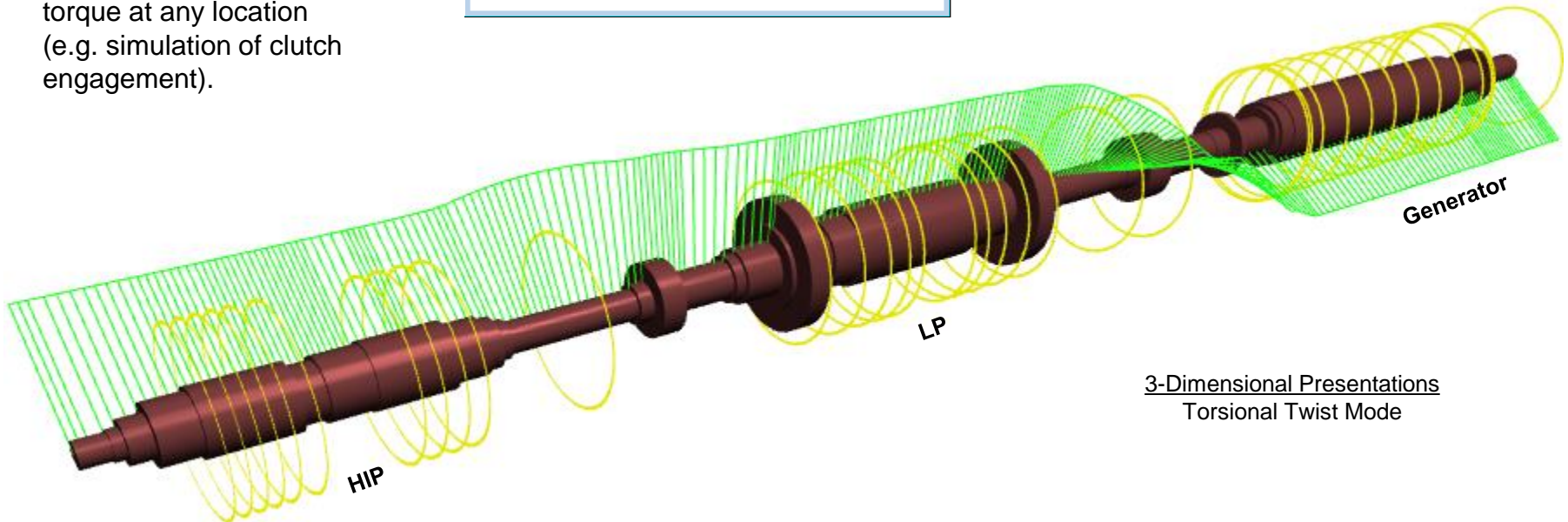
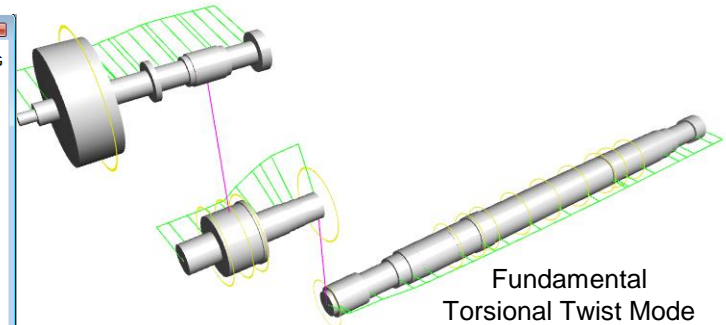
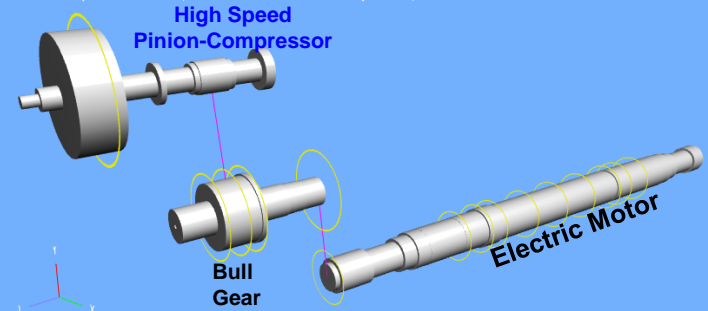
### Induction Motor

- 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

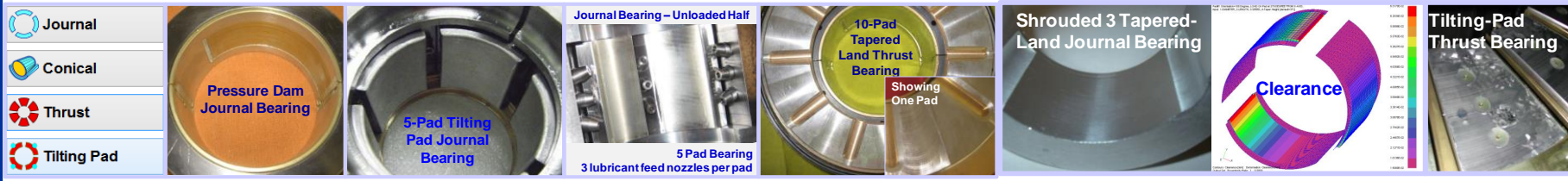
- User torque table (.csv file format) representing time-varying exciting torque at any location (e.g. simulation of clutch engagement).



Torsional Vibration Analysis - Natural Frequency, Mode Shapes & Response  
Three Branch System, 1 to 8 Speed Increaser For Centrifugal Compressor.



# 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, TILTR, 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.

Post-Processor
Pressure/Clearance Distributions 3D View Button

Description  
 Sample Problem 6 - 5 Pad Tilting Pad Journal Bearing.  
 High Speed Test Rig Support Bearings.  
 Pad Pivot Stiffness NOT Included.

|                  |       |                   |         |                       |                          |
|------------------|-------|-------------------|---------|-----------------------|--------------------------|
| Diameter         | 3.5   | Pad Angle         | 60.0    | # of Pivot Clearances | 50                       |
| Axial Length     | 2.5   | Orientation Angle | 0.0     | Viscosity             | 1.000000e-06             |
| Radial Clearance | 0.004 | Rotational Speed  | 20000.0 | Full Matrix           | <input type="checkbox"/> |

**Run Analysis**

Single Case | Multiple Cases | Lubricant Properties

1 of 20

Operating Conditions

|           |       |       |         |            |       |             |      |
|-----------|-------|-------|---------|------------|-------|-------------|------|
| Clearance | 0.004 | Load  | 5000.0  | Load Angle | 270.0 | Ort. Angle  | 90.0 |
| Preload   | 0.4   | Speed | 20000.0 | Grv. Angle | 0.0   | No. of Pads | 5.0  |

---

Min. Film Thick. -> 9.8316E-04 (Inch) | ECC = 0.6344 @ Angle = 270.00 (Deg)  
 Power-Loss -> 2.5591E+01 (HP) | Side-Leakage QF -> 1.7102E+00 (Gpm)  
 Load Capacity -> 4.9965E+03 (Lbf) | Inlet-Flow QI -> -1.5409E+01 (Gpm)

---

Supply-Oil Temp. -> 119.997 (Deg. F) |>>> STIFFNESS (Lbf/Inch)  
 Supply Flow Rate -> 6.1604 (Gpm) | KXX ; KKY -> 3.883E+06 1.229E+00  
 Film-Temp (avg.) -> 176.056 (Deg. F) | KYX ; KYY -> 1.690E+00 6.825E-06  
 Viscosity -> 1.017E-06 (Reyn) |>>> DAMPING (Lbf-Sec/Inch)  
 Heat Content -> 3.622 (BTU/G/F) | DXK ; DXY -> 1.637E+03 3.463E-04  
 Groove Temp. -> 165.765 (Deg. F) | DYX ; DYY -> 1.420E-04 2.551E+03  
 Max. Temp. (avg.) -> 186.347 (Deg. F) |>>> Individual Pad Results Below

---

Surface Velocity = 1.833E+04 (Ft/min) | Projected Pressure = 5.709E+02 (PSI)

---

Individual Pad Heat Balance Results Estimate For NON-Flooded Environment  
 Supply Flow Rate to Bearing = 6.1604E+00 (gpm) @ Ts = 1.2000E+02 (deg. F)  
 Resulting in a Computed Mixed-Oil Exit Temperature -> 1.7064E+02 (deg. F)

| Pad No. | Sump/Groove Temp. (degree F.) | Avg-Film Temp. (degree F.) | Max-Film Temp. (degree F.) | Min-Film Thickness (inch) | Power Loss (hp) | Side Leakage (gpm) |
|---------|-------------------------------|----------------------------|----------------------------|---------------------------|-----------------|--------------------|
| 1       | 1.7247E+02                    | 1.7550E+02                 | 1.7853E+02                 | 3.8107E-03                | 2.4191E+00      | 1.1370E-01         |
| 2       | 1.6620E+02                    | 1.7180E+02                 | 1.7740E+02                 | 2.5828E-03                | 3.3132E+00      | 3.9459E-01         |
| 3       | 1.6167E+02                    | 1.9445E+02                 | 2.2723E+02                 | 9.8316E-04                | 8.2725E+00      | 4.0366E-01         |
| 4       | 1.7454E+02                    | 2.0731E+02                 | 2.4009E+02                 | 9.8316E-04                | 8.2725E+00      | 4.0366E-01         |
| 5       | 1.8108E+02                    | 1.8668E+02                 | 1.9228E+02                 | 2.5828E-03                | 3.3132E+00      | 3.9459E-01         |

Generated text output after Run button is pressed

Modeled Bearing Details

Scroll through cases.

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

Single Case Lube Details

Lubricant Conditions

Solve For: Film Temp

Film Temperature: 160.0

Supply Temperature: 120.0

Row Type: Grooved

Supply Flow Rate: 3.0

Groove Feeding System

Chamber Type: Triangular

Chamber Depth: 0.125

Chamber Angle: 90.0

Orifice Diameter: [input]

Orifice Discharge Coeff.: 0.0

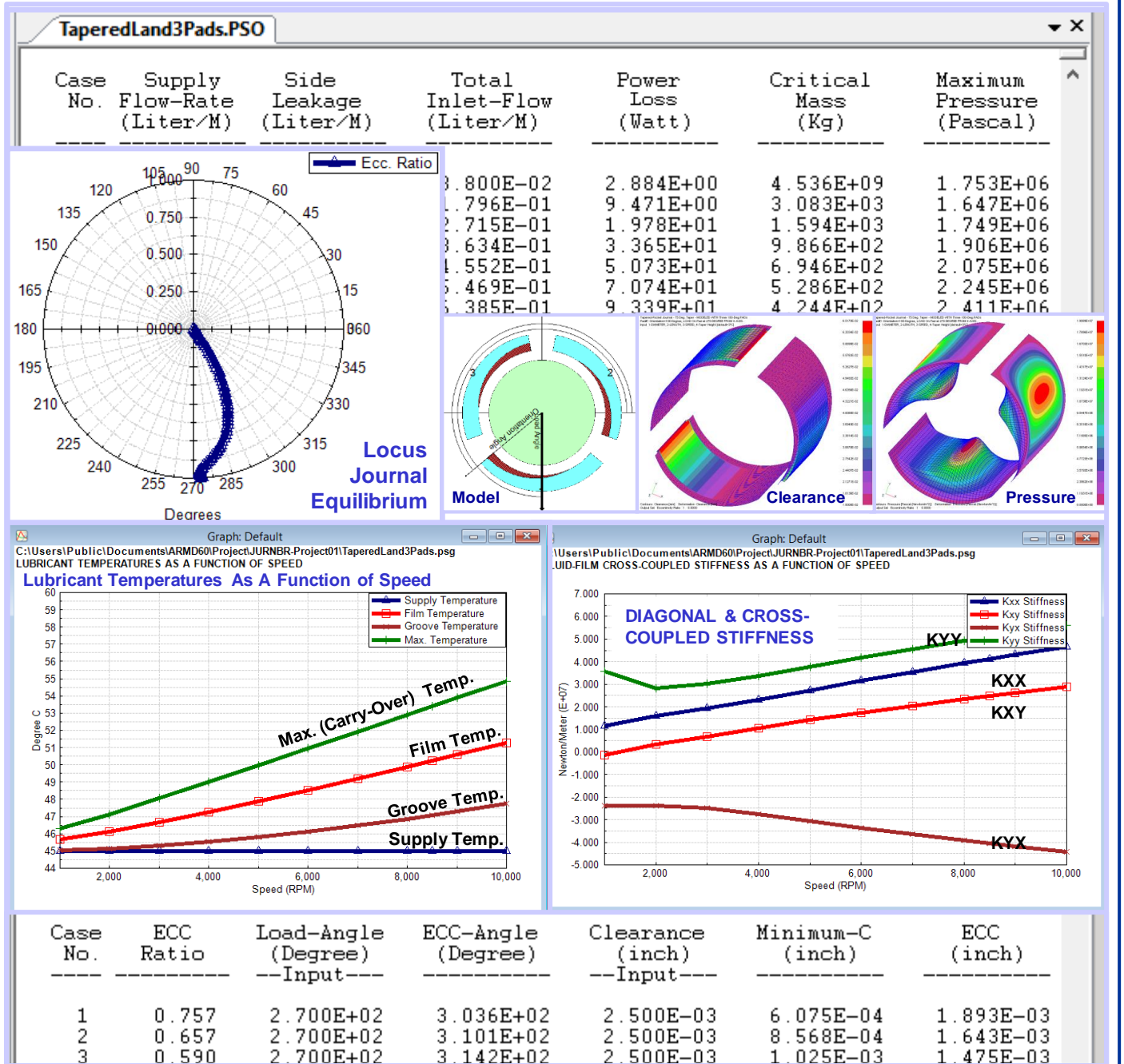
Supply Pressure: 150000.0

Orifice Diameter: 10.0



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)

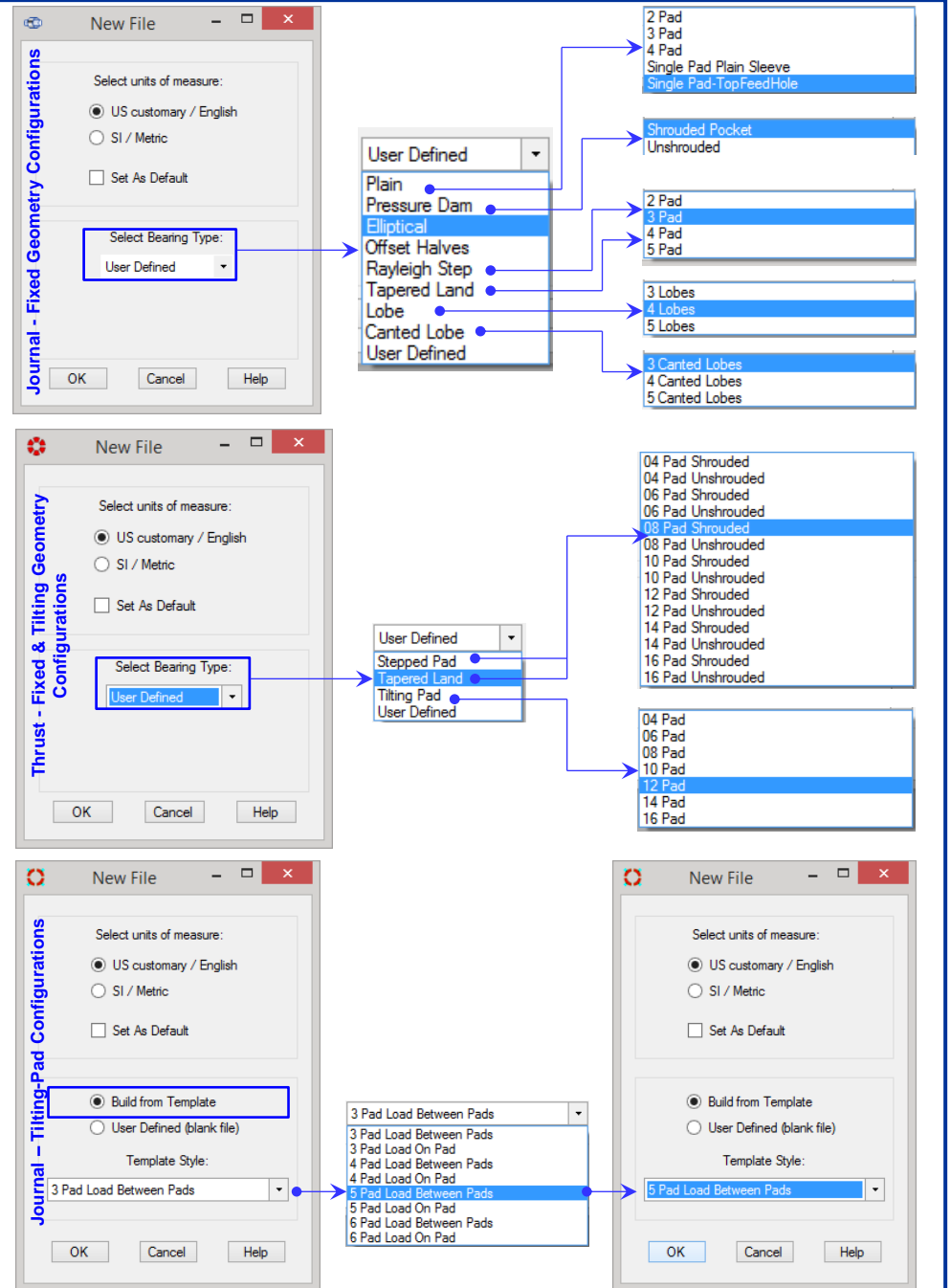
- Plain surface
- Multi-groove
- Pressure dam
- Elliptical or lemon
- Rayleigh step or pocket
- Tapered land
- Lobe or canted lobe
- Any configurable pad surfaces
- Multi-recess

### 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

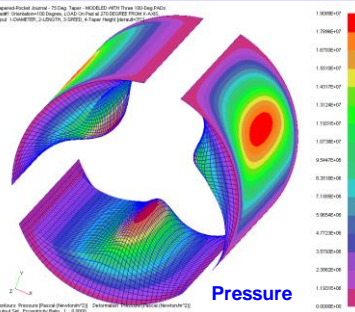
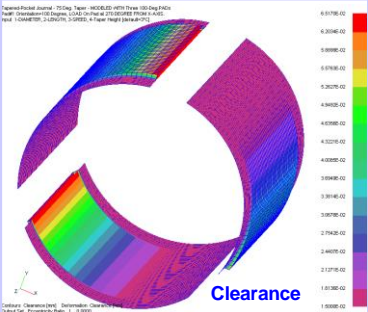
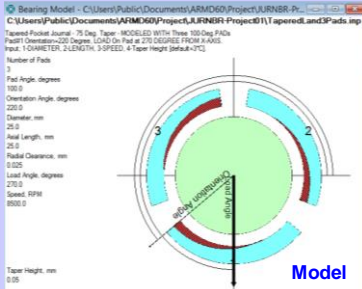
### Tilting-Pad Journal Bearings (TILTBR)

- 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

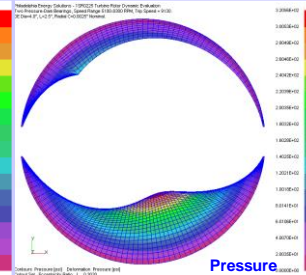
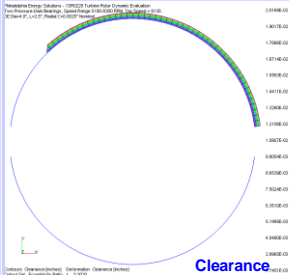
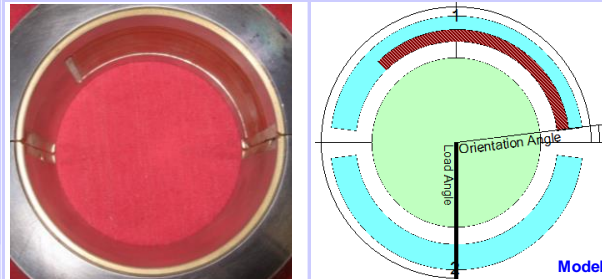


# Sample Presentations – 3D Fluid-Film Bearing Pressure & Clearance Distributions.

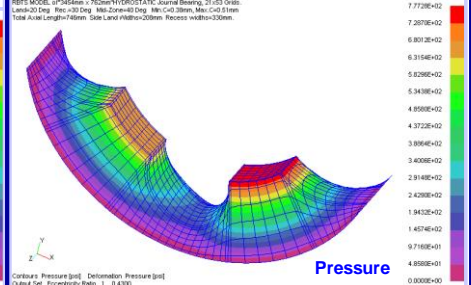
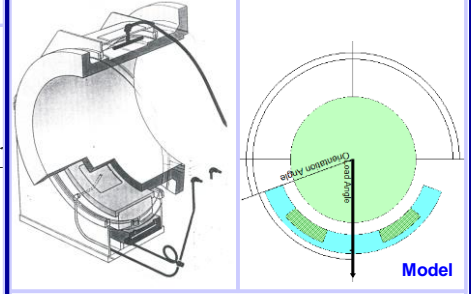
Sample - Three (3) pad, fixed geometry cylindrical journal bearing, with tapered pocket configuration for high speed multi-stage centrifugal compressor operating at 8500 rpm.



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



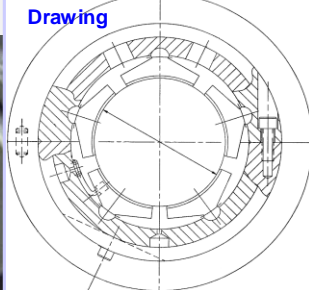
Sample Hydrostatic/Hybrid Bearing for Mining Application



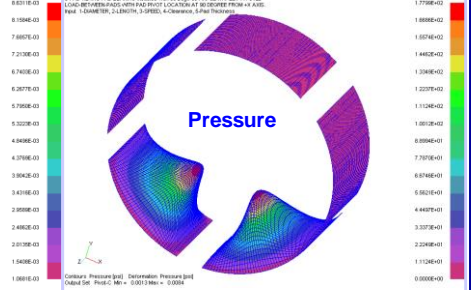
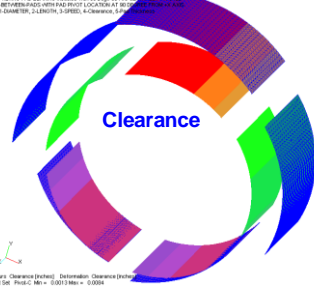
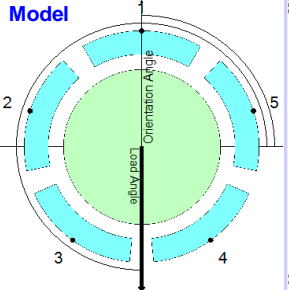
Journal Bearing – Unloaded Half



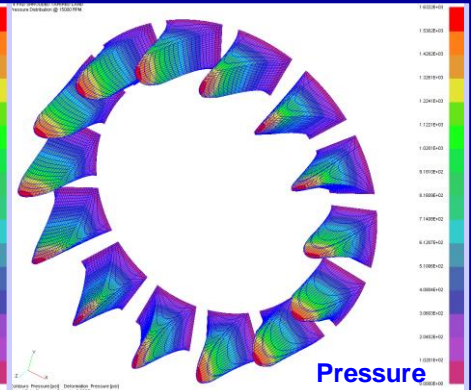
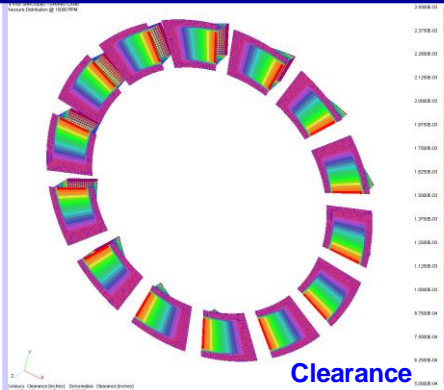
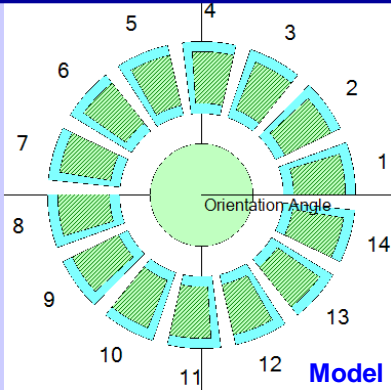
Drawing



Model



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





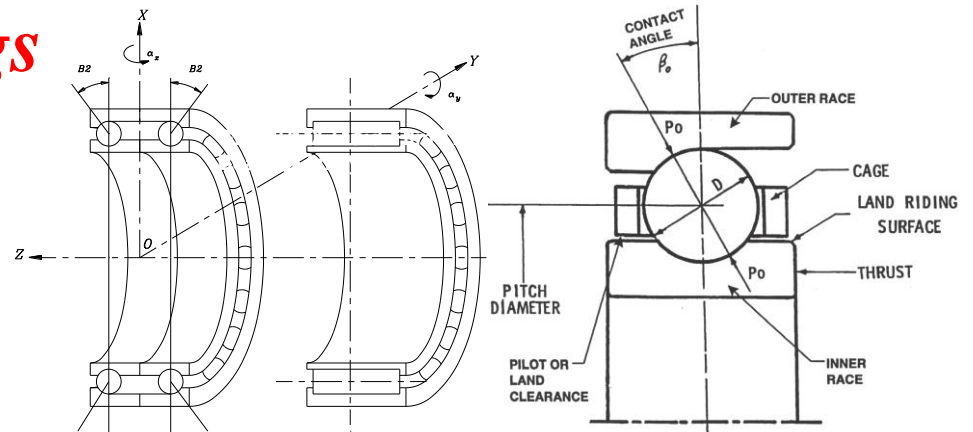
# Rolling-Element Bearings

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



COBRA

File Edit RUN Page Window Help

C:\Users\Public\Documents\ARMD58\COBRA\Sample1.dat

System Bearings Lubrication Initial Conditions & Materials Results

Descriptive Title: Sample 1 EHL Release 1.2 Mineral Oil (72 characters max.)

Shaft Speed: 1500 (RPM)

Shaft Rotation: Shaft rotates with respect to Load

Problem Type: Loads are specified (pick from list)

Loading Direction(s): radial (X), axial (Z), moment (about Y) (pick from list)

Loads (applied to the Shaft at system origin):

Radial Load along X: -2000

Thrust Load along Z: 1000

Moment Load about Y: 500

Initial Displacement Guesses (usual):

along radial X-axis: -0.003

along axial Z-axis: 0.002

tilt about Y-axis: 0.001

Thrust Load along Z-axis (lbs.)

---

COBRA

File Edit RUN Page Window Help

C:\Users\Public\Documents\ARMD58\COBRA\Sample1.LPT 4/23/2012 6:03:20 Status: CURRENT

Results: Sample 1 EHL Release 1.2 Mineral Oil

Unadjusted System B10 Life (hrs) = 1.241E-03 6 Iterations

Adjusted System B10 Life (hrs) = 4.500E-03

Shaft Speed (rpm) = 1.500E+03

| --FORCES--       |                  |                  | --DISPLACEMENTS-- |                 |                   |
|------------------|------------------|------------------|-------------------|-----------------|-------------------|
| Radial (Along X) | Thrust (Along Z) | Moment (About Y) | Radial (Along X)  | Axial (Along Z) | Angular (About Y) |
| Appld -2.000E+03 | 1.000E+03        | 5.000E+02        | Guess -3.000E-03  | 2.000E-03       | 1.000E-0          |
| Reactn 2.010E+03 | -1.007E+03       | -4.452E+02       | Soln -1.375E-02   | 1.658E-02       | 1.931E-0          |

Life Adjustment Factors:

| Bearing No.  | 1         | 2         | 3         | 4         |
|--------------|-----------|-----------|-----------|-----------|
| Reliability: | 1.000E+00 | 1.000E+00 | 1.000E+00 | 1.000E+00 |
| Material:    | 2.200E+00 | 2.200E+00 | 2.200E+00 | 1.370E+00 |
| Lubrication: | 2.333E-01 | 2.333E-01 | 2.100E-01 | 6.000E+00 |

Results (shown above) are current w/r/t worksheet data.



# 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

**Viscosity Data**

Description / Report Title  
Sample Problem Number 1.

MOBIL DTE 797 Oil for 1800 rpm Turbine bearings

Last line of problem description.

Lubricant Product

Supplier: MOBIL

Brand Name: DTE 797 Turbine Oil

Properties

ISO Grade: 32      API Gravity: 32.6

First Centistoke: 32.0 at 104.0 °F

**Lubricant Library**

|    | Supplier | BrandName            | ISO Grade | API Gravity | 1st Kinematic Viscosity Point | 1st Kinematic Viscosity Temp. | 2nd Kinematic Viscosity Point | 2nd Kinematic Viscosity Temp. |
|----|----------|----------------------|-----------|-------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| 32 | MOBIL    | DTE 10 Excel Series  | 68        | 32.65       | 68.4                          | 104.0                         | 11.17                         | 212.0                         |
| 33 | MOBIL    | DTE 10 Excel Series  | 100       | 29.845      | 99.8                          | 104.0                         | 13.0                          | 212.0                         |
| 34 | MOBIL    | DTE 10 Excel Series  | 150       | 29.113      | 155.6                         | 104.0                         | 17.16                         | 212.0                         |
| 35 | MOBIL    | DTE 797 Turbine Oil  | 32        | 32.6        | 32.0                          | 104.0                         | 5.4                           | 212.0                         |
| 36 | MOBIL    | DTE AGMA 1           | 30        | 30.6        | 43.7                          | 104.0                         | 6.5                           | 212.0                         |
| 37 | MOBIL    | DTE Heavy Medium Oil | 68        | 31.14       | 65.1                          | 104.0                         | 8.7                           | 212.0                         |
| 38 | MOBIL    | DTE Heavy Oil        | 100       | 29.3        | 95.1                          |                               |                               |                               |
| 39 | MOBIL    | DTE Light Oil        | 32        | 34.97       | 31.0                          |                               |                               |                               |

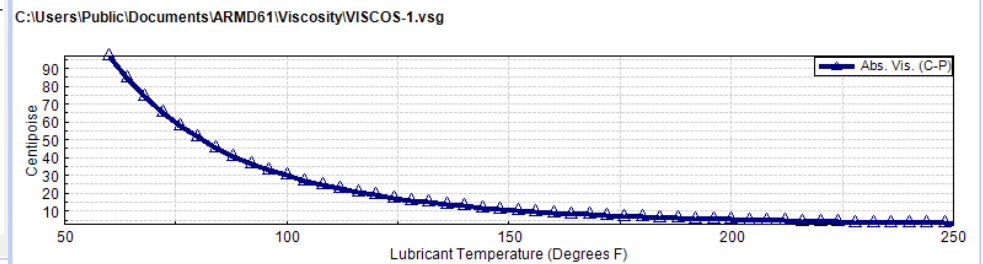
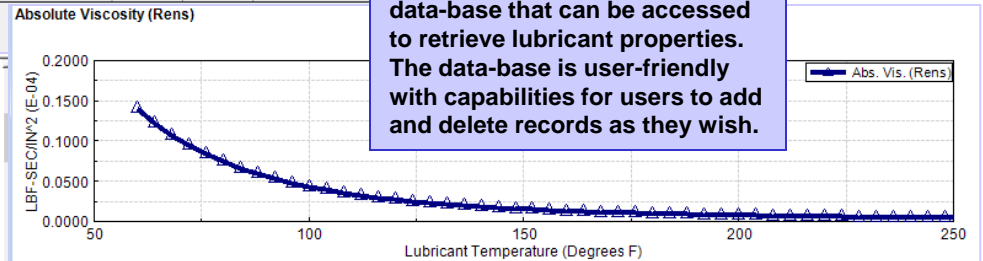
VISCOS has a built-in lubricant data-base that can be accessed to retrieve lubricant properties. The data-base is user-friendly with capabilities for users to add and delete records as they wish.

Last line of problem description.  
\*\*\* Units of Measure for this Run are --> US (English)

TABLE WAS GENERATED FOR THE FOLLOWING LUBRICANT:

Supplier --> MOBIL      Brand Name --> DTE 797 Turbine Oil  
 API Gravity [ @ 60°F/15.556°C ] = 0.32600E+02      ISO Grade Number -> 32  
 1st Viscosity point (Centistoke) = 0.32000E+02      @ Temp. (°F) = 0.10400E+03  
 2nd Viscosity point (Centistoke) = 0.54000E+01      @ Temp. (°F) = 0.21200E+03  
 Computed SUS sec. @ 100°F/37.778°C = 0.16509E+03  
 Computed SUS sec. @ 210°F/98.889°C = 0.44359E+02

| Temperature<br>Degrees F. | Absolute - Viscosity             |                            | Kinematic<br>Viscosity<br>Centistoke=<br>(M <sup>2</sup> /s)*E+6 | Saybolt<br>Universal<br>Viscosity<br>(Sec.) | Specific<br>Gravity<br>(Gm/C <sup>3</sup> )=<br>(Kg/m <sup>3</sup> )*E-3 |
|---------------------------|----------------------------------|----------------------------|--|---|--|
|                           | (Rens)<br>Lb-Sec/In <sup>2</sup> | Centipoise=<br>(Pa-s*1000) |  |   |  |
| 60.000                    | 0.14063E-04                      | 0.96961E+02                | 0.11245E+03  | 0.51976E+03                                 | 0.8623   |
| 64.000                    | 0.12268E-04                      | 0.84583E+02                | 0.98266E+02  | 0.45439E+03                                 | 0.8608   |
| 68.000                    | 0.10752E-04                      | 0.74131E+02                | 0.86276E+02  | 0.39913E+03                                 | 0.8592   |
| 72.000                    | 0.94654E-05                      | 0.65261E+02                | 0.76089E+02  | 0.35220E+03                                 | 0.8577   |
| 76.000                    | 0.83685E-05                      | 0.57699E+02                | 0.67391E+02  | 0.31217E+03                                 | 0.8562   |



# *Wear-Rings tool*

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 & damping) calculations and inclusion in the rotor dynamic simulations.

Wear (C:\Users\Public\Documents\ARMD61\ArmdWear\Samples\WearUS.WIN US) - [DataForm]

File Edit Data Run View Tools Project Help

New Open Save Cut Copy Paste Run Insert Value:

Description  
Impeller Wear Ring Stiffness & Damping Calculations  
Prepared for Texaco, LA, CA

User Specified Operating Conditions and Lubricant Properties

Single Case Multiple Cases

15 of 20 Run

Operating Conditions

|               |              |         |              |               |       |
|---------------|--------------|---------|--------------|---------------|-------|
| Diameter      | 4.735        | Length  | 0.8685       | Clearance     | 0.025 |
| Pressure Drop | 300.0        | Speed   | 3600.0       | Entrance Loss | 0.0   |
| Viscosity     | 3.045300e-07 | Density | 8.134300e-05 |               |       |

Generated Text Output after Run Button Pressed

```
CIRCUMFERENTIAL Reynolds number -----> 5.96007E+03
AXIAL Reynolds number -----> 2.93769E+04
FRICTION coefficient -----> 6.10490E-03
Fluid Axial Velocity (inch/sec)-----> 2.19961E+03

>>> STIFFNESS (Lbf/Inch)  Kxx ; Kxy -> 7.49605E+03  3.12560E+03
                          Kyx ; Kyy -> -3.12560E+03  7.49605E+03
>>> DAMPING (Lbf-Sec/Inch) Dxx ; Dxy -> 1.65818E+01  6.04234E-02
                          Dyx ; Dyy -> -6.04234E-02  1.65818E+01

Fluid Mass Coefficient (lbf) Mxx=Myy -> 6.18814E-02
                              Mxy=Myx -> 0.00000E+00
```

Single Case Multiple Cases

Run

| Case No. | DIMENSIONAL KXX | SPRING KXY  | COEFFICIENTS KYX | (lbf/inch) KYY |
|----------|-----------------|-------------|------------------|----------------|
| 1        | 5.70469E+02     | 7.08723E+02 | -7.08723E+02     | 5.70469E+02    |
| 2        | 1.11694E+03     | 1.05017E+03 | -1.05017E+03     | 1.11694E+03    |
| 3        | 1.64519E+03     | 1.32666E+03 | -1.32666E+03     | 1.64519E+03    |
| 4        | 2.15945E+03     | 1.54408E+03 | -1.54408E+03     | 2.15945E+03    |
| 14       | 7.02720E+03     | 3.01731E+03 | -3.01731E+03     | 7.02720E+03    |
| 15       | 7.49605E+03     | 3.12560E+03 | -3.12560E+03     | 7.49605E+03    |
| 16       | 7.96258E+03     | 3.22982E+03 | -3.22982E+03     | 7.96258E+03    |
| 17       | 8.42868E+03     | 3.33564E+03 | -3.33564E+03     | 8.42868E+03    |
| 18       | 8.89335E+03     | 3.43966E+03 | -3.43966E+03     | 8.89335E+03    |
| 19       | 9.35640E+03     | 3.54120E+03 | -3.54120E+03     | 9.35640E+03    |
| 20       | 9.81852E+03     | 3.64218E+03 | -3.64218E+03     | 9.81852E+03    |

# 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.

**Equation - API 617 Centrifugal**

Aerodynamic Cross Coupling Destabilizing Effects  
Per API Standard 617 (7th Edition)

A- For CENTRIFUGAL compressors:

Anticipated cross coupling effects (QA per API 617), entered as +KXY and -KYX stiffness in the rotor dynamic software module ROTLAT, is defined/computed by the following procedures:

$$QA = \frac{[HP \times Bc \times C]}{(Dc \times Hc \times N)} \times (RHOD / RHOs)$$

Single Case Multiple Cases

9 of 14

Run

Parameters

|             |         |                       |              |                          |              |
|-------------|---------|-----------------------|--------------|--------------------------|--------------|
| Power       | 1421.35 | Impeller Diameter     | 10.9         | Impeller Discharge Width | 0.765354     |
| Rotor Speed | 25000.0 | Discharge Gas Density | 1.004780e-06 | Suction Gas Density      | 5.931560e-07 |

AeroCC computed performance results for case 9 of 14:  
Formula used: API Standard 617 (Centrifugal compressors).

```

>>> STIFFNESS (lbf/inch)  Kxx ; Kxy ->  0.00000E+000  2.18191E+003
                           Kyx ; Kyy -> -2.18191E+003  0.00000E+000
>>> DAMPING (lbf-sec/inch) Dxx ; Dxy ->  0.00000E+000  0.00000E+000
                           Dyx ; Dyy ->  0.00000E+000  0.00000E+000
    
```

Single Case Multiple Cases

Expand Run

| Case No. | <<< DIMENSIONAL KXX | Stiffness COEFFICIENTS (lbf/inch) KXY | KYX           | >>> KYY      |
|----------|---------------------|---------------------------------------|---------------|--------------|
| 1        | 0.00000E+000        | 5.45476E+003                          | -5.45476E+003 | 0.00000E+000 |
| 2        | 0.00000E+000        | 4.54564E+003                          | -4.54564E+003 | 0.00000E+000 |
| 3        | 0.00000E+000        | 3.89626E+003                          | -3.89626E+003 | 0.00000E+000 |
| 4        | 0.00000E+000        | 2.27282E+003                          | -2.27282E+003 | 0.00000E+000 |
| 8        | 0.00000E+000        | 2.27282E+003                          | -2.27282E+003 | 0.00000E+000 |
| 9        | 0.00000E+000        | 2.18191E+003                          | -2.18191E+003 | 0.00000E+000 |
| 10       | 0.00000E+000        | 2.09597E+003                          | -2.09597E+003 | 0.00000E+000 |

# *Advanced Rotating Machinery Dynamics*

## 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:

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



# 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.

## Sample Session For ROTLAT

**INTRODUCTION**

When the ROTLAT software is launched for the first time, [TUTORIAL](#) is activated to familiarize the user with ROTLAT. When exiting this session the ROTLAT software top level menu (shown below) is displayed.

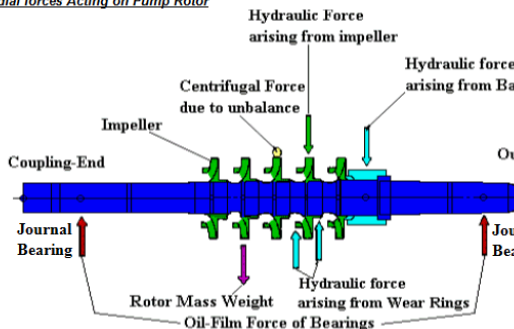
[\[Click here for more details\]](#)

## Modeling Concepts

Rotor-dynamic analysis principle objective is to system. The analysis is one aspect of a total analysis must include the effects of a large number of external and internal sources of loading (including hydraulic process media forces, unbalance forces transmitted through the couplings from one part of the system to another).

### Five Stage Boiler Feed Pump Schematic Representation

#### Radial forces Acting on Pump Rotor



## Linking a bearing to rotor model

Rotating assembly support bearing's dynamic coefficients (*stiffness and damping characteristics*) can be automatically rotor dynamic evaluation. Fluid-film and rolling-element bearings can be linked to the rotor model for automatic generation under the speed and loading conditions being examined for rotor dynamic simulation.

**Fluid-Film Bearings:** To link a fluid-film bearing to the rotor model the bearing model and its performance results as a must first exist. The bearing model and performance results are generated with one of the [ARMD software](#) fluid-film bearing models: [HYBCBR](#) for cylindrical fixed-geometry journal bearings, [TILTBFR](#) for cylindrical tilting-pad-geometry journal bearings, or [HYBCBR](#) for bearings.

Once the rotor model (shaft elements) is specified in the Element tab of the System form select the Bearings Tab (shown below) specify the bearing type to be linked as shown below. This selection will not affect any of the rotor or bearing data [Coefficients Source](#) is selected to be [Auto or Linked](#).

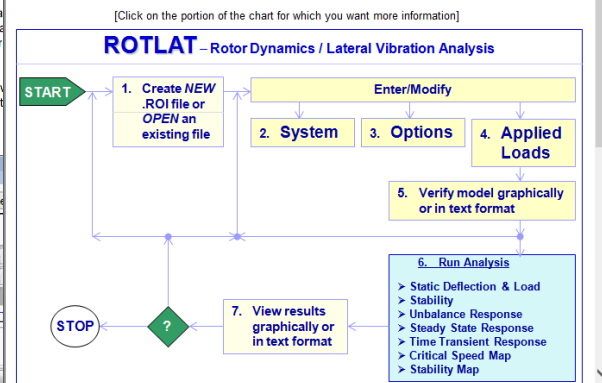
[\[Click on the tab/portion of the chart for which you want more information\]](#)

| Station | DOF | Type           | Coefficients Source | Input File (e.g. Non-dimensional or other) | File Status | Browse to File |
|---------|-----|----------------|---------------------|--|-------------|----------------|
| 1       | 3   | Manual Bearing | Manual              |  |             |                |
| 2       | 17  | Manual Bearing | Manual              |  |             |                |

Below the table, a dropdown menu shows options: Manual Bearing, Manual Bearing, Fixed journal, Fixed conical, Tilting pad. Buttons for Ok, Cancel, and Help are visible.

## Tutorial

The following procedure contains the basic seven (7) steps to use [ROTLAT](#). Online help can be accessed any time by either pressing the F1 key or clicking the Help button (if available).



## *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 10, 11 or higher (32 or 64 bit).

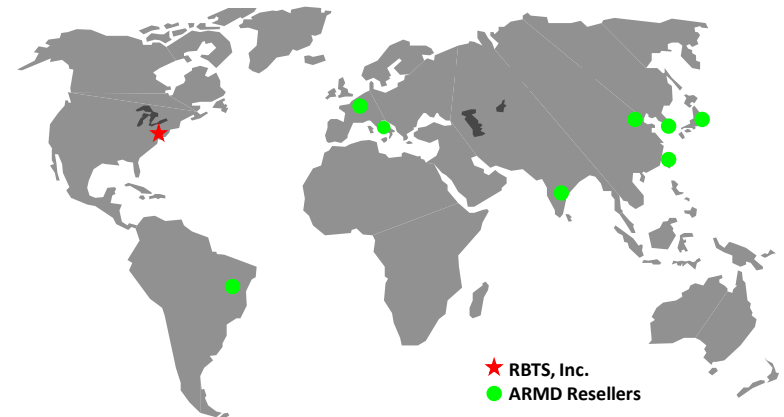
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*Please contact: Dr. Andreas Laschet*



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