Manual for Curved Beam Model Piston Ring Design Tool (CBM-RDT)

(Console Version 1.0)

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Introduction

Curved Beam Model Ring Design Tool is an analytical tool that can be used in the design process of single-piece piston ring. It consists of 5 prime modules, each corresponding to a function summarized below:

1. Calculate geometric parameters of the ring cross section.
2. Calculate the ring free-shape, its final shape when subjected to a constant radial pressure (this final shape is called ovality) and the force distribution in circular bore. Knowing one of these distributions, this model determines the other two.
3. Calculate the ring-bore and ring-liner conformability: ring-bore and ring-groove interactions include asperity and lubrication forces along with gas, inertia and initial tangential load forces. Bore, groove upper and lower flanks distortions are also considered. Ring thermal expansion effect and radial temperature gradient moment are included in the model. Piston secondary motion and variation of oil viscosity on the liner with its temperature in addition to the existence of fuel spot are considered as well. A radial plot function is made separately to the computation one so that user can define the more convenient graphic parameters for the plot: magnification coefficient for bore distortion and ring-liner clearance, number of forces to represent and the maximum acceptable value to be represented for forces.
4. Conformability module for different ring gap locations defined uniformly along the bore circumferential direction. A radial plot animation function is made separately to the computation one. In addition to the graphic parameters mentioned in point 3, user can choose the number of frames per second for the video that will be created.
5. Calculate the ring static twist under FixOD or FixID constraint that is similar to practical measurement of static twist angle.

The first module is run always and is the first one to be executed. The other modules have independent inputs and outputs. They all require some of the outputs of the geometric parameters of the ring cross-section module as input. The following sections provide a description of these inputs and outputs.

The radial direction will be denoted by y and the axial one by z.

Module 1: Ring cross-section parameters calculation

Inputs

Ring cross-section can be defined:

1. By giving the points' coordinates:
   a. By providing the number of points defining the cross section
   b. Then providing the points' coordinates millimeters and in clockwise order with the outer-diameter (OD) on the left as shown in Figure 1. Each point will have an id.
   c. Provide the id for the upper OD point (#6 in Figure 1), the upper ID (#7 in Figure 1), lower ID (#1 in Figure 1), lower OD (#2 in Figure 1), lower end point (#3 in Figure 1), minimum point (#4 in Figure 1), upper end point (#5 in Figure 1).
   d. Linear coefficients for upper and lower edge factor (denoted by a_{21} and a_{22} respectively). Upper and lower edge factor are the linear coefficients in the parabolic shape parts of the running face: between lower end point (#3 in Figure 1) and minimum point (#4 in Figure 1) and between upper end point (#5 in Figure 1) and minimum point (#4 in Figure 1).

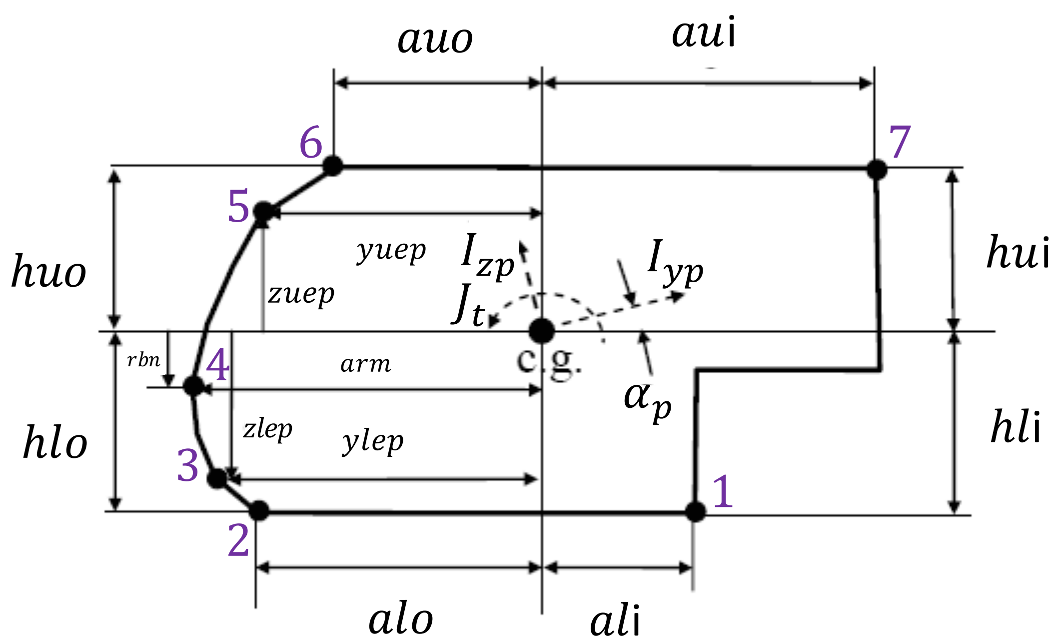

Figure 1

2. By providing the ring cross section parameters listed in the table below and shown in Figure 1.

Nomenclature	Variable designation	Comment	Unit
Upper OD width	auo	Positive sign	mm
Upper OD height	huo	Positive sign	mm

Upper ID width	aui	Positive sign	mm
Upper ID height	hui	Positive sign	mm
Lower ID width	ali	Positive sign	mm
Lower ID height	hli	Positive sign	mm
Lower OD width	alo	Positive sign	mm
Lower OD height	hlo	Positive sign	mm
Lower end point width	$ylep$	Positive sign	mm
Lower end point axial location	$zlep$	Negative sign	mm
Minimum point width	arm	Positive sign	mm
Minimum point axial location	rbn	Positive sign if minimum point located above the gravity center point of the cross section and negative otherwise (negative sign in Figure 1)	mm
Upper end point width	$yuep$	Positive sign	mm
Upper end point axial location	$zuep$	Positive sign	mm
Linear coefficient for upper edge shape factor	a_{21}		
Linear coefficient for lower edge shape factor	a_{11}		

Outputs

The outputs differ regarding the inputs provided.

1. If the inputs are defined using method 1, the outputs are the following:

Nomenclature	Variable designation	Comment	Unit
Center of mass radial coordinate	y_c	Can be positive or negative based on the points'	mm

		coordinates provided	
Center of mass axial coordinate	z_c	Can be positive or negative based on the points' coordinates provided	mm
Upper OD width	auo	Positive sign	mm
Upper OD height	huo	Positive sign	mm
Upper ID width	aui	Positive sign	mm
Upper ID height	hui	Positive sign	mm
Lower ID width	ali	Positive sign	mm
Lower ID height	hli	Positive sign	mm
Lower OD width	alo	Positive sign	mm
Lower OD height	hlo	Positive sign	mm
Lower end point width	$ylep$	Positive sign	mm
Lower end point axial location	$zlep$	Negative sign	mm
Minimum point width	arm	Positive sign	mm
Minimum point axial location	rbn	Positive sign if minimum point located above the gravity center point of the cross section and negative otherwise (negative sign in Figure 1)	mm
Upper end point width	$yuep$	Positive sign	mm
Upper end point axial location	$zuep$	Positive sign	mm
Ring upper flank angle	θ_{rt}	Positive sign. Analogous to θ_{rb} shown in Figure 2.	deg
Ring lower flank angle	θ_{rb}	Positive sign. Shown in Figure 2.	deg
Lower edge width	$rb1$	Positive sign. Axial distance between lower end point (#3 in Figure 1) and	mm

		minimum point (#4 in Figure 1)	
Upper edge width	$rb2$	Positive sign. Axial distance between upper end point (#5 in Figure 1) and minimum point (#4 in Figure 1)	mm
Quadratic coefficient for upper edge shape factor	a_{22}		mm
Quadratic coefficient for lower edge shape factor	a_{12}		mm
Cross section area	Ac		mm^2
Moment of inertia in plane	I_z		mm^4
Moment of inertia out of plane	I_y		mm^4
Product of inertia	I_{yz}		mm^4
Principal moment of inertia in plane	I_{zp}		mm^4
Principal moment of inertia out of plane	I_{yp}		mm^4
Principal angle	α_p		deg
Polar moment of inertia	I_p		mm^4
Torsional factor	J_t		mm^4

2. If the inputs are defined using method 2, the outputs are the following:

Nomenclature	Variable designation	Comment	Unit
Ring upper flank angle	θ_{rt}	Positive sign. Analogous to θ_{rb} shown in Figure 2.	deg
Ring lower flank angle	θ_{rb}	Positive sign. Shown in Figure 2.	deg
Lower edge width	$rb1$	Positive sign. Axial distance between	mm

		lower end point (#3 in Figure 1) and minimum point (#4 in Figure 1)	
Upper edge width	$rb2$	Positive sign. Axial distance between upper end point (#5 in Figure 1) and minimum point (#4 in Figure 1)	mm
Quadratic coefficient for upper edge shape factor	a_{22}		mm
Quadratic coefficient for lower edge shape factor	a_{12}		mm
Cross section area	Ac		mm^2
Moment of inertia in plane	I_z		mm^4
Moment of inertia out of plane	I_y		mm^4
Product of inertia	I_{yz}		mm^4
Principal moment of inertia in plane	I_{zp}		mm^4
Principal moment of inertia out of plane	I_{yp}		mm^4
Principal angle	α_p		deg
Polar moment of inertia	I_p		mm^4
Torsional factor	J_t		mm^4

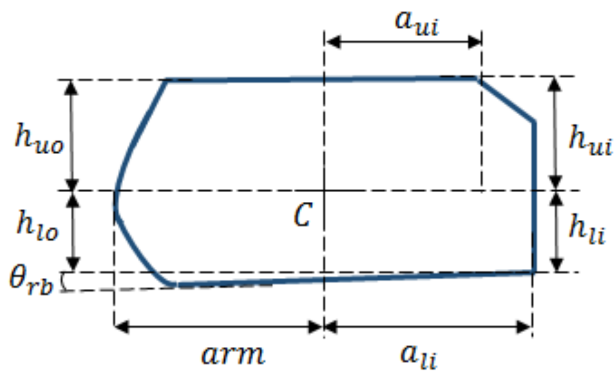

Figure 2

Module 2: Free-shape, ovality and force distribution in radial bore

This module consists of 3 sub-models each computing two of the three distributions from the third one. Inputs and outputs of each of these sub-modules are provided below.

Inputs of sub-model computing the free-shape and the ovality from the force distribution in radial bore

Inputs that need to be provided by the user.

Nomenclature	Variable designation	Comment	Unit
Bore diameter	D_b		mm
Ring Young modulus	E_r		GPa
Gap size when ring is closed to circular bore	gap		mm
Gap size when ring is closed to ovality (under constant pressure)	$gap2$		mm
Force distribution in radial bore		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the pressure times ring height (axial width).	deg & N/m

IsPovAvg		1 to consider the constant linear force in computing the ovality equal to the average of the force distribution in radial bore provided, 0 to provide its value (Pov).	
Constant linear force to consider in computing the ovality (pressure times the ring height (axial width))	Pov	Positive sign. User needs to provide this value only when IsPovAvg=0.	N/m
Number of elements for the FEM	Nbe	Positive integer	
Number of points within one element	Npe	Positive integer	
Tolerance for Newton-Raphson algorithm convergence used to compute the ovality	$Newton_{tol}$	Positive sign. Suggested value: 10^{-6}	
Maximum number of Newton-Raphson algorithm iterations used to compute the ovality	It_{Max}	Positive integer. Suggested value: 100	
Magnifying coefficient for the radial plot of the ovality	k	Positive sign. Suggested values: in order of 10	

Inputs provided by the ring cross-section parameters calculation module.

Nomenclature	Variable designation	Comment	Unit
Moment of inertia in plane	I_z		mm^4
Minimum point width	arm		mm

Outputs of sub-model computing the free-shape and the ovality from the force distribution in radial bore

Two text files are generated:

- fs_frompr.txt containing two columns: 1st column contains the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one the free-shape in usual representation in millimeters.
- rov_frompr.txt containing two columns: 1st column contains the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one the ovality in usual representation in millimeters.

Three plots are generated:

- Curve of the free-shape in usual representation in millimeters as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.
- Radial plot of the ovality (closed shape of the ring under the constant pressure).
- Curve of the ovality in usual representation in microns as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.

Inputs of sub-model computing the force distribution in radial bore and ovality from the free-shape

Inputs that need to be provided by the user.

Nomenclature	Variable designation	Comment	Unit
Bore diameter	D_b		mm
IsBDist		1 to take into account bore distortion when computing the force distribution in radial bore, 0 otherwise	
Highest order in the Fourier series for bore distortion.	$Norder$	Non-zero positive integer. User has to provide this value if IsBDist=1.	
Ampdata		1 to provide the amplitudes and phases of bore distortion directly, 0 to provide dr distribution. User has to provide this value if IsBDist=1.	

Amplitudes for bore distortion	A_b	Positive values. Number of amplitudes to provide is equal to $Norder$ (0^{th}, 2^{nd},…,$Norder^{th}$ amplitudes). User has to provide this value if IsBDist=1 and Ampdata=1.	μm
Phases for bore distortion	ϕ_b	Number of phases to provide is equal to $Norder - 1$ (2^{nd},3^{rd},…,$Norder^{th}$ phases). User has to provide this value if IsBDist=1 and Ampdata=1.	rad
Bore distortion distribution dr		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the bore distortion dr in microns. User has to provide this value if IsBDist=1 and Ampdata=0.	deg & μm
Gap size when ring is closed to circular bore	gap		mm
Gap size when ring is closed to ovality (under constant pressure)	$gap2$		mm
Ring density	ρ_r		kg/m^3
Ring Young modulus	E_r		GPa
Ring Poisson ratio	ν_r		
Ring thermal expansion coefficient	α_T		$1/K$
Ring gap position	t_g	Ring gap position in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°)	deg
Ring temperature	T_r		$Celsuis$

Number of elements for the FEM	Nbe	Positive integer	
Number of points within one element	Npe	Positive integer	
Liner Young modulus	E_l		GPa
Liner Poisson ratio	ν_l		
Plateau ratio	PR		
Liner surface roughness standard deviation	σ_p		μm
Piston upper land reference diameter	$Drldu$		mm
Ring groove root diameter	Drg		mm
Piston lower land reference diameter	$Drldl$		mm
Ring groove inner axial height	hgi		mm
Ring groove upper flank angle	θ_{gt}		rad
Ring groove lower flank angle	θ_{gb}		rad
Ring groove upper flank surface roughness standard deviation	σ_{gt}		μm
Ring groove lower flank surface roughness standard deviation	σ_{gb}		μm
Groove Poisson ratio	ν_g		
Groove Young modulus	E_g		GPa
Radius increase at the upper land during engine operation	$Exp_{land,u}$		μm
Radius increase at the lower land	$Exp_{land,l}$		μm

during engine operation			
Top ring groove radius increase during engine operation	Exp_{gr}		μm
z coefficient for the asperity ring/liner and ring/groove contact interaction	z	6.804 is the adopted value in the simplified formulation	
K coefficient for the asperity ring/liner and ring/groove contact interaction	K	1.198e-4 is the adopted value in the simplified formulation	
A coefficient for the asperity ring/liner and ring/groove contact interaction	A	4.4068e-5 is the adopted value in the simplified formulation	
Ω coefficient for the asperity ring/liner and ring/groove contact interaction	Ω	4 is the adopted value in the simplified formulation	
Friction coefficient for the asperity ring/liner and ring/groove contact interaction	fc_{dry}		
Constant coefficient for the asperity ring/liner and ring/groove contact interaction	$cfct$	1 is the adopted value in the simplified formulation	
IsGDist		1 to take into account groove distortion when computing the force distribution in radial bore, 0 otherwise	
Number of orders starting from the 2nd one in the Fourier series for	$Norder_u$	Non-zero positive integer. User has to provide this value if IsGDist=1.	

groove upper flank distortion			
Ampdatau		1 to provide the amplitudes and phases of groove upper flank distortion directly, 0 to provide dz distribution. User has to provide this value if IsBDist=1.	
Amplitudes for groove upper flank distortion	A_{gu}	Positive values. Number of amplitudes to provide is equal to $Norder_u$ (0^{th}, 2^{nd},…, ${Norder_u}^{th}$ amplitudes). User has to provide this value if IsGDist=1 and Ampdatau=1.	
Phases for groove upper flank distortion	ϕ_{gu}	Number of phases to provide is equal to $Norder_u - 1$ (2^{nd},3^{rd},…, ${Norder_u}^{th}$ phases). User has to provide this value if IsBDist=1 and Ampdatau=1.	
Groove upper flank distortion distribution dz		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the groove upper flank distortion dz in microns. User has to provide this value if IsGDist=1 and Ampdatau=0.	deg & μm
Number of orders starting from the 2^{nd} one in the Fourier series for groove lower flank distortion	$Norder_l$	Non-zero positive integer. User has to provide this value if IsGDist=1.	
Ampdatal		1 to provide the amplitudes and phases of ring lower flank distortion directly, 0 to provide dz distribution. User has to provide this value if IsGDist=1.	
Amplitudes for groove lower flank distortion	A_{gl}	Positive values. Number of amplitudes to provide is equal to $Norder_l$ (0^{th}, 2^{nd},…, ${Norder_l}^{th}$	

		amplitudes). User has to provide this value if IsGDist=1 and Ampdatal=1.	
Phases for groove lower flank distortion	ϕ_{gl}	Number of phases to provide is equal to $Norder_l - 1$ (2^{nd},3^{rd},..., $Norder_l{}^{th}$ phases). User has to provide this value if IsGDist=1 and Ampdatal=1.	
Groove lower flank distortion distribution dz		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the groove lower flank distortion dz in microns. User has to provide this value if IsGDist=1 and Ampdatal=0.	deg & μm
Groove thermal tilting – upper flank	$tilt_{thu}$		rad
Groove thermal tilting – lower flank	$tilt_{thl}$		rad
IsPovAvg		1 to consider the constant linear force in computing the ovality equal to the average of the force distribution in radial bore that will be computed, 0 to provide its value (Pov)	
Constant linear force to consider in computing the ovality (pressure times the ring height (axial width))	Pov	Positive sign. User needs to provide this value only when IsPovAvg=0.	N/m
IsFreeshape		1 to provide the free-shape coordinates and 0 to provide the free-shape curvature	
Free-shape distribution		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed	deg & mm

		frame with respect to the ring and the second one contains the free-shape coordinates in usual representation in millimeters. User has to provide this value if IsFreeshape=1.	
Free-shape curvature distribution		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the free-shape curvature coordinates in usual representation in 1/m. User has to provide this value if IsFreeshape=0.	deg & $1/m$
Tolerance for Newton-Raphson algorithm convergence used to compute the force distribution	$Newton_{tol}$	Positive sign. Suggested value: 10^{-6}	
Maximum number of Newton-Raphson algorithm iterations used to compute the force distribution	It_{Max}	Positive integer. Suggested value: 100	
Tolerance for Newton-Raphson algorithm convergence used to compute the ovality	$Newton_{tol2}$	Positive sign. Suggested value: 10^{-6}	
Maximum number of Newton-Raphson algorithm iterations used to compute the ovality	It_{Max2}	Positive integer. Suggested value: 100	
Magnifying coefficient for the	k	Positive sign. Suggested values: in order of 10	

radial plot of the ovality			

Inputs provided by the ring cross-section parameters calculation module.

Nomenclature	Variable designation	Comment	Unit
Upper OD width	auo	Positive sign	mm
Upper OD height	huo	Positive sign	mm
Upper ID width	aui	Positive sign	mm
Upper ID height	hui	Positive sign	mm
Lower ID width	ali	Positive sign	mm
Lower ID height	hli	Positive sign	mm
Lower OD width	alo	Positive sign	mm
Lower OD height	hlo	Positive sign	mm
Ring upper flank angle	θ_{rt}	Positive sign. Analogous to θ_{rb} shown in Figure 2.	deg
Ring lower flank angle	θ_{rb}	Positive sign. Shown in Figure 2.	deg
Lower edge width	$rb1$	Positive sign. Axial distance between lower end point (#3 in Figure 1) and minimum point (#4 in Figure 1)	mm
Upper edge width	$rb2$	Positive sign. Axial distance between upper end point (#5 in Figure 1) and minimum point (#4 in Figure 1)	mm
Minimum point axial location	rbn	Positive sign if minimum point located above the gravity center point of the cross section and negative otherwise (negative sign in Figure 1)	mm
Quadratic coefficient for upper edge shape factor	a_{22}		mm
Quadratic coefficient for lower edge shape factor	a_{12}		mm
Linear coefficient for upper edge shape factor	a_{21}		

Linear coefficient for lower edge shape factor	a_{11}		
Minimum point width	arm	Positive sign	mm
Cross section area	Ac		mm^2
Principal moment of inertia in plane	I_{zp}		mm^4
Principal moment of inertia out of plane	I_{yp}		mm^4
Moment of inertia in plane	I_z		mm^4
Principal angle	α_p		deg
Polar moment of inertia	I_p		mm^4
Torsional factor	J_t		mm^4

Outputs of sub-model computing the force distribution in radial bore and ovality from the free-shape

Two text files are generated:

- rforce_fromfs.txt containing two columns: 1st column contains the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one the radial linear force in N/m.
- rov_fromfs.txt containing two columns: 1st column contains the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one the ovality in usual representation in millimeters.

Three plots are generated:

- Curve of the radial linear force in N/m as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.
- Radial plot of the ovality (closed shape of the ring under the constant pressure).
- Curve of the ovality in usual representation in microns as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.

The code also displays the tangential load determined from the force distribution computed.

Inputs of sub-model computing the force distribution in radial bore and free-shape from the ovality

Inputs that need to be provided by the user.

Nomenclature	Variable designation	Comment	Unit
Bore diameter	D_b		mm
Ring Young modulus	E_r		GPa
Gap size when ring is closed to circular bore	gap		mm
Gap size when ring is closed to ovality (under constant pressure)	$gap2$		mm
Number of elements for the FEM	Nbe	Positive integer	
Number of points within one element	Npe	Positive integer	
Ovality distribution		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the ovality radial coordinates in usual representation in microns.	deg & μm
Constant linear force to consider in computing the ovality (pressure times the ring height (axial width))	Pov	Positive sign.	N/m
IsBDist		1 to take into account bore distortion when computing the force distribution in radial bore, 0 otherwise	
Highest order in the Fourier series for bore distortion.	$Norder$	Non-zero positive integer. User has to provide this value if IsBDist=1.	
Ampdata		1 to provide the amplitudes and phases of bore distortion directly, 0 to provide dr distribution. User	

		has to provide this value if IsBDist=1.	
Amplitudes for bore distortion	A_b	Positive values. Number of amplitudes to provide is equal to $Norder$ (0th, 2nd,…,Norderth amplitudes). User has to provide this value if IsBDist=1 and Ampdata=1.	μm
Phases for bore distortion	ϕ_b	Number of phases to provide is equal to $Norder - 1$ (2nd,3rd,…,Norderth phases). User has to provide this value if IsBDist=1 and Ampdata=1.	rad
Bore distortion distribution dr		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the bore distortion dr in microns. User has to provide this value if IsBDist=1 and Ampdata=0.	deg & μm
Ring density	ρ_r		kg/m^3
Ring Poisson ratio	ν_r		
Ring thermal expansion coefficient	α_T		$1/K$
Ring gap position	t_g	Ring gap position in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°)	deg
Ring temperature	T_r		$Celsuis$
Liner Young modulus	E_l		GPa
Liner Poisson ratio	ν_l		
Plateau ratio	PR		
Liner surface roughness standard deviation	σ_p		μm
Piston upper land reference diameter	$Drldu$		mm

Ring groove root diameter	Drg		mm
Piston lower land reference diameter	$Drldl$		mm
Ring groove inner axial height	hgi		mm
Ring groove upper flank angle	θ_{gt}		rad
Ring groove lower flank angle	θ_{gb}		rad
Ring groove upper flank surface roughness standard deviation	σ_{gt}		μm
Ring groove lower flank surface roughness standard deviation	σ_{gb}		μm
Groove Poisson ratio	ν_g		
Groove Young modulus	E_g		GPa
Radius increase at the upper land during engine operation	$Exp_{land,u}$		μm
Radius increase at the lower land during engine operation	$Exp_{land,l}$		μm
Top ring groove radius increase during engine operation	Exp_{gr}		μm
z coefficient for the asperity ring/liner and ring/groove contact interaction	z	6.804 is the adopted value in the simplified formulation	
K coefficient for the asperity ring/liner and ring/groove contact interaction	K	1.198e-4 is the adopted value in the simplified formulation	

A coefficient for the asperity ring/liner and ring/groove contact interaction	A	4.4068e-5 is the adopted value in the simplified formulation	
Ω coefficient for the asperity ring/liner and ring/groove contact interaction	Ω	4 is the adopted value in the simplified formulation	
Friction coefficient for the asperity ring/liner and ring/groove contact interaction	fc_{dry}		
Constant coefficient for the asperity ring/liner and ring/groove contact interaction	$cfct$	1 is the adopted value in the simplified formulation	
IsGDist		1 to take into account groove distortion when computing the force distribution in radial bore, 0 otherwise	
Number of orders starting from the 2^{nd} one in the Fourier series for groove upper flank distortion	$Norder_u$	Non-zero positive integer. User has to provide this value if IsGDist=1.	
Ampdatau		1 to provide the amplitudes and phases of groove upper flank distortion directly, 0 to provide dz distribution. User has to provide this value if IsBDist=1.	
Amplitudes for groove upper flank distortion	A_{gu}	Positive values. Number of amplitudes to provide is equal to $Norder_u$ (0^{th}, 2^{nd},…, ${Norder_u}^{th}$ amplitudes). User has to provide this value if IsGDist=1 and Ampdatau=1.	

Phases for groove upper flank distortion	ϕ_{gu}	Number of phases to provide is equal to $Norder_u - 1$ (2nd,3rd,…, $Norder_u$ th phases). User has to provide this value if IsBDist=1 and Ampdatau=1.	
Groove upper flank distortion distribution dz		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the groove upper flank distortion dz in microns. User has to provide this value if IsGDist=1 and Ampdatau=0.	deg & μm
Number of orders starting from the 2nd one in the Fourier series for groove lower flank distortion	$Norder_l$	Non-zero positive integer. User has to provide this value if IsGDist=1.	
Ampdatal		1 to provide the amplitudes and phases of ring lower flank distortion directly, 0 to provide dz distribution. User has to provide this value if IsGDist=1.	
Amplitudes for groove lower flank distortion	A_{gl}	Positive values. Number of amplitudes to provide is equal to $Norder_l$ (0th, 2nd,…, $Norder_l$ th amplitudes). User has to provide this value if IsGDist=1 and Ampdatal=1.	
Phases for groove lower flank distortion	ϕ_{gl}	Number of phases to provide is equal to $Norder_l - 1$ (2nd,3rd,…, $Norder_l$ th phases). User has to provide this value if IsGDist=1 and Ampdatal=1.	
Groove lower flank distortion distribution dz		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder	deg & μm

		from thrust side (0°) to thrust side (360°) and the second one contains the groove lower flank distortion dz in microns. User has to provide this value if IsGDist=1 and Ampdatal=0.	
Groove thermal tilting – upper flank	$tilt_{thu}$		rad
Groove thermal tilting – lower flank	$tilt_{thl}$		rad
Tolerance for Newton-Raphson algorithm convergence used to compute the force distribution	$Newton_{tol}$	Positive sign. Suggested value: 10^{-6}	
Maximum number of Newton-Raphson algorithm iterations used to compute the force distribution	It_{Max}	Positive integer. Suggested value: 100	

Inputs provided by the ring cross-section parameters calculation module.

Nomenclature	Variable designation	Comment	Unit
Upper OD width	auo	Positive sign	mm
Upper OD height	huo	Positive sign	mm
Upper ID width	aui	Positive sign	mm
Upper ID height	hui	Positive sign	mm
Lower ID width	ali	Positive sign	mm
Lower ID height	hli	Positive sign	mm
Lower OD width	alo	Positive sign	mm
Lower OD height	hlo	Positive sign	mm
Ring upper flank angle	θ_{rt}	Positive sign. Analogous to θ_{rb} shown in Figure 2.	deg
Ring lower flank angle	θ_{rb}	Positive sign. Shown in Figure 2.	deg
Lower edge width	$rb1$	Positive sign. Axial distance between lower end point (#3 in Figure 1) and minimum point (#4 in Figure 1)	mm

Upper edge width	$rb2$	Positive sign. Axial distance between upper end point (#5 in Figure 1) and minimum point (#4 in Figure 1)	mm
Minimum point axial location	rbn	Positive sign if minimum point located above the gravity center point of the cross section and negative otherwise (negative sign in Figure 1)	mm
Quadratic coefficient for upper edge shape factor	a_{22}		mm
Quadratic coefficient for lower edge shape factor	a_{12}		mm
Linear coefficient for upper edge shape factor	a_{21}		
Linear coefficient for lower edge shape factor	a_{11}		
Minimum point width	arm	Positive sign	mm
Cross section area	Ac		mm^2
Principal moment of inertia in plane	I_{zp}		mm^4
Principal moment of inertia out of plane	I_{yp}		mm^4
Moment of inertia in plane	I_z		mm^4
Principal angle	α_p		deg
Polar moment of inertia	I_p		mm^4
Torsional factor	J_t		mm^4

Outputs of sub-model computing the force distribution in radial bore and free-shape from the ovality

Two text files are generated:

- rforce_fromov.txt containing two columns: 1st column contains the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one the radial linear force in N/m.
- fs_fromov.txt containing two columns: 1st column contains the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one the free-shape in usual representation in millimeters.

Three plots are generated:
- Curve of the free-shape in usual representation in millimeters as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.
- Curve of the radial linear force in N/m as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.

The code also displays the tangential load determined from the force distribution computed.

Module 3: Calculate the ring-bore and ring-liner conformability for specific ring gap location

This module consists of 2 sub-models. The first one performs the computation related to the conformability study for one specific ring gap position. The second one uses the result of the first sub-model to generate the radial plots. Inputs and outputs of each of these sub-modules are provided below.

Inputs of sub-model performing the computation related to the conformability study for one specific ring gap location

Inputs that need to be provided by the user.

Nomenclature	Variable designation	Comment	Unit
IsBDist		1 to take into account bore distortion when computing the force distribution in radial bore, 0 otherwise	
IsPTilt		1 to take into account piston dynamic tilt, 0 otherwise	
IsGDist		1 to take into account groove distortion when computing the force distribution in radial bore, 0 otherwise	

IsFreeshape		1 to provide the free-shape coordinates or curvature and 0 to provide the radial pressure distribution for the circular bore	
Bore diameter	D_b		mm
Gap size when ring is closed to circular bore	gap		mm
Ring Young modulus	E_r		GPa
Ring density	ρ_r		kg/m^3
Ring Poisson ratio	ν_r		
Ring thermal expansion coefficient	α_T		$1/K$
Ring gap position	t_g	Ring gap position in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°)	deg
Ring temperature	T_r		$Celsuis$
Ring temperature increase from ID to OD distribution		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the radial ring temperature increase from ID to OD in Celsius.	deg & $Celsius$
Number of elements for the FEM	Nbe	Positive integer	
Number of points within one element for contact and lubrication force calculation	Npe	Positive integer	
Number of points within one element for gas force calculation	Nge	Positive integer	

Highest order in the Fourier series for bore distortion.	$Norder$	Non-zero positive integer. User has to provide this value if IsBDist=1.	
Ampdata		1 to provide the amplitudes and phases of bore distortion directly, 0 to provide dr distribution. User has to provide this value if IsBDist=1.	
Amplitudes for bore distortion	A_b	Positive values. Number of amplitudes to provide is equal to $Norder$ (0^{th}, 2^{nd},…,$Norder^{th}$ amplitudes). User has to provide this value if IsBDist=1 and Ampdata=1.	μm
Phases for bore distortion	ϕ_b	Number of phases to provide is equal to $Norder - 1$ (2^{nd},3^{rd},…,$Norder^{th}$ phases). User has to provide this value if IsBDist=1 and Ampdata=1.	rad
Bore distortion distribution dr		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the bore distortion dr in microns. User has to provide this value if IsBDist=1 and Ampdata=0.	deg & μm
Piston tilt angle	β_p	User has to provide this value if IsPTilt=1.	deg
Piston offset	off	Positive sign.	mm
zk coefficient for oil viscosity calculation	zk		
Temp1 variable for oil viscosity calculation	$Temp_1$		$Celsius$
Temp2 variable for oil viscosity calculation	$Temp_2$		$Celsius$
Oil density	ρ_{oil}		kg/m^3

hlratio coefficient for oil viscosity calculation	$hlratio$		
Beta1 coefficient for oil viscosity calculation	β_1		
Beta2 coefficient for oil viscosity calculation	β_2		
Viscosity of oil located within the groove		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the viscosity of oil located within the groove in Pa.s.	deg & $Pa.s$
Liner Young modulus	E_l		GPa
Liner Poisson ratio	ν_l		
Plateau ratio	PR		
Liner surface roughness standard deviation	σ_p		μm
Piston upper land reference diameter	$Drldu$		mm
Ring groove root diameter	Drg		mm
Piston lower land reference diameter	$Drldl$		mm
Ring groove inner axial height	hgi		mm
Ring groove upper flank angle	θ_{gt}		rad
Ring groove lower flank angle	θ_{gb}		rad
Ring groove upper flank surface roughness standard deviation	σ_{gt}		μm
Ring groove lower flank surface	σ_{gb}		μm

roughness standard deviation			
Groove Poisson ratio	ν_g		
Groove Young modulus	E_g		GPa
Radius increase at the upper land during engine operation	$Exp_{land,u}$		μm
Radius increase at the lower land during engine operation	$Exp_{land,l}$		μm
Top ring groove radius increase during engine operation	Exp_{gr}		μm
z coefficient for the asperity ring/liner and ring/groove contact interaction	z	6.804 is the adopted value in the simplified formulation	
K coefficient for the asperity ring/liner and ring/groove contact interaction	K	1.198e-4 is the adopted value in the simplified formulation	
A coefficient for the asperity ring/liner and ring/groove contact interaction	A	4.4068e-5 is the adopted value in the simplified formulation	
Ω coefficient for the asperity ring/liner and ring/groove contact interaction	Ω	4 is the adopted value in the simplified formulation	
Friction coefficient for the asperity ring/liner and ring/groove contact interaction	fc_{dry}		

Constant coefficient for the asperity ring/liner and ring/groove contact interaction	$cfct$	1 is the adopted value in the simplified formulation	
IsGDist		1 to take into account groove distortion when computing the force distribution in radial bore, 0 otherwise	
Number of orders starting from the 2nd one in the Fourier series for groove upper flank distortion	$Norder_u$	Non-zero positive integer. User has to provide this value if IsGDist=1.	
Ampdatau		1 to provide the amplitudes and phases of groove upper flank distortion directly, 0 to provide dz distribution. User has to provide this value if IsBDist=1.	
Amplitudes for groove upper flank distortion	A_{gu}	Positive values. Number of amplitudes to provide is equal to $Norder_u$ (0th, 2nd,…, ${Norder_u}^{th}$ amplitudes). User has to provide this value if IsGDist=1 and Ampdatau=1.	
Phases for groove upper flank distortion	ϕ_{gu}	Number of phases to provide is equal to $Norder_u - 1$ (2nd,3rd,…, ${Norder_u}^{th}$ phases). User has to provide this value if IsBDist=1 and Ampdatau=1.	
Groove upper flank distortion distribution dz		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the groove upper flank distortion dz in microns. User has to provide this value if IsGDist=1 and Ampdatau=0.	deg & μm

Number of orders starting from the 2nd one in the Fourier series for groove lower flank distortion	$Norder_l$	Non-zero positive integer. User has to provide this value if IsGDist=1.	
Ampdatal		1 to provide the amplitudes and phases of ring lower flank distortion directly, 0 to provide dz distribution. User has to provide this value if IsGDist=1.	
Amplitudes for groove lower flank distortion	A_{gl}	Positive values. Number of amplitudes to provide is equal to $Norder_l$ (0^{th}, 2^{nd},…, ${Norder_l}^{th}$ amplitudes). User has to provide this value if IsGDist=1 and Ampdatal=1.	
Phases for groove lower flank distortion	ϕ_{gl}	Number of phases to provide is equal to $Norder_l - 1$ (2^{nd},3^{rd},…, ${Norder_l}^{th}$ phases). User has to provide this value if IsGDist=1 and Ampdatal=1.	
Groove lower flank distortion distribution dz		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the groove lower flank distortion dz in microns. User has to provide this value if IsGDist=1 and Ampdatal=0.	deg & μm
Groove thermal tilting – upper flank	$tilt_{thu}$		rad
Groove thermal tilting – lower flank	$tilt_{thl}$		rad
Minimum oil film thickness to consider for liner lubrication	$minoil$	Suggested value: half the liner surface standard deviation ($\sigma_p/2$)	μm
Lubrication cases threshold	$oilthreshold$	Ratio between oil film thickness on liner by liner surface roughness	

		standard deviation to consider as threshold between partially and fully flooded lubrication cases. Suggested value: 10	
Viscosity factor for fuel spots	$oilviscosityfactor$	Factor by which the oil viscosity should be divided in regions where we have fuel spots. Suggested value: 100	
Gas pressure in groove upper region distribution	P_u	Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the gas pressure in groove upper region in Bar.	deg & Bar
Gas pressure in groove inner region distribution	P_i	Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the gas pressure in groove inner region in Bar.	deg & Bar
Gas pressure in groove lower region distribution	P_d	Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the gas pressure in groove lower region in Bar.	deg & Bar
Piston speed	V_p	The axial axis is positively pointing upwards.	$m.s^{-1}$
Piston acceleration	A_p	The axis is positively pointing upwards	$m.s^{-2}$
Oil film thickness left on liner into the ring distribution	$hrls$	Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed	deg & μm

		frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the oil film thickness left on liner into the ring in microns.	
Oil film thickness on the upper groove flank distribution	hot	Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the oil film thickness on the upper groove flank in microns.	deg & μm
Oil film thickness on the lower groove flank distribution	hob	Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the oil film thickness on the lower groove flank in microns.	deg & μm
Liner temperature distribution	$Temp_l$	Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the temperature liner in Celsius. This temperature distribution will be used to compute oil viscosity.	deg & $Celsius$
Fuel spots distribution	$isfuel$	Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the fuel spots (1 for existence of fuel, 0 for non-existence).	deg & $\emptyset$

b coefficient for fully flooded correlation	b	Suggested value: 2.1	
c coefficient for fully flooded correlation	c	Suggested value: 0.102	
d coefficient for fully flooded correlation	d	Suggested value: -0.04	
e coefficient for fully flooded correlation	e	Suggested value: 0.90229	
Correlation pressure for deterministic partially flooded forces	Ph	Suggested value: 398.56	Bar
Correlation exponent for deterministic partially flooded forces	K_{OCR}	Suggested value: 2.523	
Reference viscosity for deterministic partially flooded forces	μ_U	Suggested value: 1.5e-2	$Pa.m$
ap coefficient for deterministic partially flooded forces	ap	Suggested value: 0.039342	
cp1 coefficient for exponent Kp in deterministic partially flooded forces	cp_1	Suggested value: -2.965331	
cp2 coefficient for exponent Kp in deterministic partially flooded forces	cp_2	Suggested value: 1.499148	
F0 coefficient for deterministic	F_0	Suggested value: 0.098577	

partially flooded shear force			
cf1 coefficient for exponent Kp in deterministic partially flooded forces	cf_1	Suggested value: -0.383954	
cf2 coefficient for exponent Kp in deterministic partially flooded forces	cf_2	Suggested value: 0.138443	
Ring width to use for the deterministic hydrodynamic correlation	r_w		mm
IsFreeshaped		1 to provide the free-shape coordinates and 0 to provide the free-shape curvature. User has to provide this value if IsFreeshape=1.	
Free-shape distribution		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the free-shape coordinates in usual representation in millimeters. User has to provide this value if IsFreeshape=1 and IsFreeshaped=1.	deg & mm
Free-shape curvature distribution		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the free-shape curvature coordinates in usual representation in 1/m. User has to provide this value if	deg & $1/m$

		IsFreeshape=1 and Isfreeshaped=0.	
Force distribution in radial bore		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the pressure times ring height (axial width). User has to provide this value if IsFreeshape=0.	deg & N/m
Tolerance for Newton-Raphson algorithm convergence	$Newton_{tol}$	Positive sign. Suggested value: 10^{-6}	
Maximum number of Newton-Raphson algorithm iterations	It_{Max}	Positive integer. Suggested value: 100	

Inputs provided by the ring cross-section parameters calculation module.

Nomenclature	Variable designation	Comment	Unit
Upper OD width	auo	Positive sign	mm
Upper OD height	huo	Positive sign	mm
Upper ID width	aui	Positive sign	mm
Upper ID height	hui	Positive sign	mm
Lower ID width	ali	Positive sign	mm
Lower ID height	hli	Positive sign	mm
Lower OD width	alo	Positive sign	mm
Lower OD height	hlo	Positive sign	mm
Ring upper flank angle	θ_{rt}	Positive sign. Analogous to θ_{rb} shown in Figure 2.	deg
Ring lower flank angle	θ_{rb}	Positive sign. Shown in Figure 2.	deg
Lower edge width	$rb1$	Positive sign. Axial distance between lower end point (#3 in Figure 1) and minimum point (#4 in Figure 1)	mm
Upper edge width	$rb2$	Positive sign. Axial distance between upper end point (#5 in	mm

		Figure 1) and minimum point (#4 in Figure 1)	
Minimum point axial location	rbn	Positive sign if minimum point located above the gravity center point of the cross section and negative otherwise (negative sign in Figure 1)	mm
Quadratic coefficient for upper edge shape factor	a_{22}		mm
Quadratic coefficient for lower edge shape factor	a_{12}		mm
Linear coefficient for upper edge shape factor	a_{21}		
Linear coefficient for lower edge shape factor	a_{11}		
Minimum point width	arm	Positive sign	mm
Cross section area	Ac		mm^2
Principal moment of inertia in plane	I_{zp}		mm^4
Principal moment of inertia out of plane	I_{yp}		mm^4
Moment of inertia in plane	I_z		mm^4
Moment of inertia out of plane	I_y		mm^4
Principal angle	α_p		deg
Polar moment of inertia	I_p		mm^4
Torsional factor	J_t		mm^4

Outputs of sub-model performing the computation related to the conformability study for one specific ring gap location

One text file is generated res_conf_one_gap.txt. It contains 20 columns, specified below from the left to the right:

- Column 1: Circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. This angles distribution will be used for the ring's coordinates and clearances results from column 2 to column 10.
- Column 2: Ring liner clearance in microns. Always non-negative.
- Column 3: Ring neutral axis lift in microns. The zero level is located at the middle of the groove inner region. The axial axis is positively pointing upwards.
- Column 4: Ring radial coordinate in microns. This is defined respect to the nominal radius defined by $R_r = \left(\frac{D_b}{2} - arm\right) * (1 + \alpha_T(T_r - 25))$. A positive radial coordinate means that the ring cross-section centroid is located outside the circle with a radius equal to the nominal one.
- Column 5: Ring twist angle in degrees. A positive ring twist angle means the ring cross section is rotated in the clockwise direction with the ring's outer-diameter (OD) on the left as shown in Figure 1 and Figure 2.
- Column 6: Minimum liner clearance point location with respect to the centroid in microns. A positive sign means that this point is located above the centroid axial level.
- Column 7: Upper OD point clearance with the groove in microns. Always non-negative.
- Column 8: Upper ID point clearance with the groove in microns. Always non-negative.
- Column 9: Lower OD point clearance with the groove in microns. Always non-negative.
- Column 10: Lower ID point clearance with the groove in microns. Always non-negative.
- Column 11: Circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. This angles distribution will be used for forces, moments and stresses results from column 12 to column 20.
- Column 12: Radial force in N/m (force per unit circumferential length of the ring). A positive sign corresponds to a compression force.
- Column 13: Ring-liner radial force in N/m (force per unit circumferential length of the ring).
- Column 14: Axial force in N/m (force per unit circumferential length of the ring). The axial axis is positively pointing upwards.
- Column 15: Twist moment in N (moment per unit circumferential length of the ring). The angular orientation is positive in the clockwise direction with the ring's outer-diameter (OD) on the left as shown in Figure 1 and Figure 2.
- Column 16: Bending moment at the ring cross-section centroid in Nm.
- Column 17: Stress at upper OD point in MPa. A positive sign corresponds to extension.
- Column 18: Stress at upper ID point in MPa. A positive sign corresponds to extension.
- Column 19: Stress at lower OD point in MPa. A positive sign corresponds to extension.
- Column 20: Stress at lower ID point in MPa. A positive sign corresponds to extension.

Six plots are generated:

- The first one contains the curve of the ring-liner clearance and the ring radial coordinate as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. Both are plotted in microns.
- The second plot gives the curve of the ring neutral axis lift and the minimum liner clearance point location with respect to the centroid as a function of the circumferential

direction angles in degrees defined with respect to the fixed frame with respect to the ring. Both are given in microns. It also gives the ring twist angle in degrees as a function of the same circumferential direction angles in degrees.

- The third plot displays the 4 curves of lower/upper OD/ID clearances with the groove, all in microns and as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.
- The fourth plot contains the curve of the radial force, ring-liner radial force and axial one all in N/m as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. It also gives the twist moment in N as a function of the same circumferential direction angles in degrees.
- The fifth plot gives the bending moment at the ring cross-section centroid in Nm as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.
- The sixth plot displays the 4 curves of stresses at lower/upper OD/ID points all in MPa as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.

The code also displays the tangential load determined from the force distribution computed.

Inputs of sub-model performing the radial plots related to the conformability study for one specific ring gap location

Inputs that need to be provided by the user.

Nomenclature	Variable designation	Comment	Unit
Magnification coefficient for radial plot of bore distortion and ring liner clearance	$mag1$	Positive sign. Suggested value: 3000	
Number of radial forces to represent	$numforce$	Positive integer. Suggested value: 200	
Maximum acceptable value for forces to be represented	$fstop$	Positive sign.	N/m

This code also uses bore distortion, FEM related, ring gap size, ring-liner clearance, radial force and ring-liner force inputs and outputs of the sub-model performing the computation related to the conformability study for one specific ring gap location.

Outputs of sub-model performing the radial plots related to the conformability study for one specific ring gap location

Two plots are generated:

- The first one contains radial plot of the bore and the ring with the specified magnification coefficient. It also contains scaled lines showing the ring-liner forces based on the number of forces to be represented and the maximum acceptable value specified. It also displays separate message(s) if the bore or/and the ring is(are) misrepresented because of the magnification coefficient. It also shows the ring gap location within the bore fixed reference from thrust to thrust side and shows a message in case the force is truncated somewhere based on the maximum acceptable value for force to be represented that has been chosen.
- The second one contains radial plot of the bore and the ring with the specified magnification coefficient. It also contains scaled lines showing the radial forces based on the number of forces to be represented and the maximum acceptable value specified. It also displays separate message(s) if the bore or/and the ring is(are) misrepresented because of the magnification coefficient. It also shows the ring gap location within the bore fixed reference from thrust to thrust side and shows a message in case the force is truncated somewhere based on the maximum acceptable value for force to be represented that has been chosen.

Module 4: Calculate the ring-bore and ring-liner conformability for different ring gap locations

This module consists of 2 sub-models. The first one performs the computation related to the conformability study for different ring gap positions. The second one uses the result of the first sub-model to generate the radial plots. Inputs and outputs of each of these sub-modules are provided below.

Inputs of sub-model performing the computation related to the conformability study for different ring gap locations

Inputs that need to be provided by the user.

Nomenclature	Variable designation	Comment	Unit
IsBDist		1 to take into account bore distortion when computing the force distribution in radial bore, 0 otherwise	
IsPTilt		1 to take into account piston dynamic tilt, 0 otherwise	

IsGDist		1 to take into account groove distortion when computing the force distribution in radial bore, 0 otherwise	
IsFreeshape		1 to provide the free-shape coordinates or curvature and 0 to provide the radial pressure distribution for the circular bore	
Bore diameter	D_b		mm
Gap size when ring is closed to circular bore	gap		mm
Ring Young modulus	E_r		GPa
Ring density	ρ_r		kg/m^3
Ring Poisson ratio	ν_r		
Ring thermal expansion coefficient	α_T		$1/K$
Ring temperature	T_r		$Celsuis$
Ring temperature increase from ID to OD distribution		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the radial ring temperature increase from ID to OD in Celsius.	deg & $Celsius$
Number of elements for the FEM	Nbe	Positive integer	
Number of points within one element for contact and lubrication force calculation	Npe	Positive integer	
Number of points within one element for gas force calculation	Nge	Positive integer	
Highest order in the Fourier series for bore distortion.	$Norder$	Non-zero positive integer. User has to provide this value if IsBDist=1.	

Ampdata		1 to provide the amplitudes and phases of bore distortion directly, 0 to provide dr distribution. User has to provide this value if IsBDist=1.	
Amplitudes for bore distortion	A_b	Positive values. Number of amplitudes to provide is equal to $Norder$ (0^{th}, 2^{nd},…,$Norder^{th}$ amplitudes). User has to provide this value if IsBDist=1 and Ampdata=1.	μm
Phases for bore distortion	ϕ_b	Number of phases to provide is equal to $Norder - 1$ (2^{nd},3^{rd},…,$Norder^{th}$ phases). User has to provide this value if IsBDist=1 and Ampdata=1.	rad
Bore distortion distribution dr		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the bore distortion dr in microns. User has to provide this value if IsBDist=1 and Ampdata=0.	deg & μm
Piston tilt angle	β_p	User has to provide this value if IsPTilt=1.	deg
Piston offset	off	Positive sign.	mm
zk coefficient for oil viscosity calculation	zk		
Temp1 variable for oil viscosity calculation	$Temp_1$		$Celsius$
Temp2 variable for oil viscosity calculation	$Temp_2$		$Celsius$
Oil density	ρ_{oil}		kg/m^3
hlratio coefficient for oil viscosity calculation	$hlratio$		

Beta1 coefficient for oil viscosity calculation	β_1		
Beta2 coefficient for oil viscosity calculation	β_2		
Viscosity of oil located within the groove		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the viscosity of oil located within the groove in Pa.s.	deg & $Pa.s$
Liner Young modulus	E_l		GPa
Liner Poisson ratio	ν_l		
Plateau ratio	PR		
Liner surface roughness standard deviation	σ_p		μm
Piston upper land reference diameter	$Drldu$		mm
Ring groove root diameter	Drg		mm
Piston lower land reference diameter	$Drldl$		mm
Ring groove inner axial height	hgi		mm
Ring groove upper flank angle	θ_{gt}		rad
Ring groove lower flank angle	θ_{gb}		rad
Ring groove upper flank surface roughness standard deviation	σ_{gt}		μm
Ring groove lower flank surface roughness standard deviation	σ_{gb}		μm

Groove Poisson ratio	ν_g		
Groove Young modulus	E_g		GPa
Radius increase at the upper land during engine operation	$Exp_{land,u}$		μm
Radius increase at the lower land during engine operation	$Exp_{land,l}$		μm
Top ring groove radius increase during engine operation	Exp_{gr}		μm
z coefficient for the asperity ring/liner and ring/groove contact interaction	z	6.804 is the adopted value in the simplified formulation	
K coefficient for the asperity ring/liner and ring/groove contact interaction	K	1.198e-4 is the adopted value in the simplified formulation	
A coefficient for the asperity ring/liner and ring/groove contact interaction	A	4.4068e-5 is the adopted value in the simplified formulation	
Ω coefficient for the asperity ring/liner and ring/groove contact interaction	Ω	4 is the adopted value in the simplified formulation	
Friction coefficient for the asperity ring/liner and ring/groove contact interaction	fc_{dry}		
Constant coefficient for the asperity ring/liner	$cfct$	1 is the adopted value in the simplified formulation	

and ring/groove contact interaction			
IsGDist		1 to take into account groove distortion when computing the force distribution in radial bore, 0 otherwise	
Number of orders starting from the 2nd one in the Fourier series for groove upper flank distortion	$Norder_u$	Non-zero positive integer. User has to provide this value if IsGDist=1.	
Ampdatau		1 to provide the amplitudes and phases of groove upper flank distortion directly, 0 to provide dz distribution. User has to provide this value if IsBDist=1.	
Amplitudes for groove upper flank distortion	A_{gu}	Positive values. Number of amplitudes to provide is equal to $Norder_u$ (0th, 2nd,…, $Norder_u$ th amplitudes). User has to provide this value if IsGDist=1 and Ampdatau=1.	
Phases for groove upper flank distortion	ϕ_{gu}	Number of phases to provide is equal to $Norder_u - 1$ (2nd,3rd,…, $Norder_u$ th phases). User has to provide this value if IsBDist=1 and Ampdatau=1.	
Groove upper flank distortion distribution dz		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the groove upper flank distortion dz in microns. User has to provide this value if IsGDist=1 and Ampdatau=0.	deg & μm
Number of orders starting from the 2nd one in the Fourier series for	$Norder_l$	Non-zero positive integer. User has to provide this value if IsGDist=1.	

groove lower flank distortion			
Ampdatal		1 to provide the amplitudes and phases of ring lower flank distortion directly, 0 to provide dz distribution. User has to provide this value if IsGDist=1.	
Amplitudes for groove lower flank distortion	A_{gl}	Positive values. Number of amplitudes to provide is equal to $Norder_l$ (0^{th}, 2^{nd},…, $Norder_l{}^{th}$ amplitudes). User has to provide this value if IsGDist=1 and Ampdatal=1.	
Phases for groove lower flank distortion	ϕ_{gl}	Number of phases to provide is equal to $Norder_l\ -1$ (2^{nd},3^{rd},…, $Norder_l{}^{th}$ phases). User has to provide this value if IsGDist=1 and Ampdatal=1.	
Groove lower flank distortion distribution dz		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the groove lower flank distortion dz in microns. User has to provide this value if IsGDist=1 and Ampdatal=0.	deg & μm
Groove thermal tilting – upper flank	$tilt_{thu}$		rad
Groove thermal tilting – lower flank	$tilt_{thl}$		rad
Minimum oil film thickness to consider for liner lubrication	$minoil$	Suggested value: half the liner surface standard deviation ($\sigma_p/2$)	μm
Lubrication cases threshold	$oilthreshold$	Ratio between oil film thickness on liner by liner surface roughness standard deviation to consider as threshold between partially and fully flooded lubrication cases. Suggested value: 10	

Viscosity factor for fuel spots	$oilviscosityfactor$	Factor by which the oil viscosity should be divided in regions where we have fuel spots. Suggested value: 100	
Gas pressure in groove upper region distribution	P_u	Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the gas pressure in groove upper region in Bar.	deg & Bar
Gas pressure in groove inner region distribution	P_i	Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the gas pressure in groove inner region in Bar.	deg & Bar
Gas pressure in groove lower region distribution	P_d	Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the gas pressure in groove lower region in Bar.	deg & Bar
Piston speed	V_p	The axial axis is positively pointing upwards.	$m.s^{-1}$
Piston acceleration	A_p	The axis is positively pointing upwards	$m.s^{-2}$
Oil film thickness left on liner into the ring distribution	$hrls$	Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one	deg & μm

		contains the oil film thickness left on liner into the ring in microns.	
Oil film thickness on the upper groove flank distribution	hot	Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the oil film thickness on the upper groove flank in microns.	deg & μm
Oil film thickness on the lower groove flank distribution	hob	Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the oil film thickness on the lower groove flank in microns.	deg & μm
Liner temperature distribution	$Temp_l$	Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the temperature liner in Celsius. This temperature distribution will be used to compute oil viscosity.	deg & $Celsius$
Fuel spots distribution	$isfuel$	Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the fuel spots (1 for existence of fuel, 0 for non-existence).	deg & $\emptyset$

b coefficient for fully flooded correlation	b	Suggested value: 2.1	
c coefficient for fully flooded correlation	c	Suggested value: 0.102	
d coefficient for fully flooded correlation	d	Suggested value: -0.04	
e coefficient for fully flooded correlation	e	Suggested value: 0.90229	
Correlation pressure for deterministic partially flooded forces	Ph	Suggested value: 398.56	Bar
Correlation exponent for deterministic partially flooded forces	K_{OCR}	Suggested value: 2.523	
Reference viscosity for deterministic partially flooded forces	μ_U	Suggested value: 1.5e-2	$Pa.m$
ap coefficient for deterministic partially flooded forces	ap	Suggested value: 0.039342	
cp1 coefficient for exponent Kp in deterministic partially flooded forces	cp_1	Suggested value: -2.965331	
cp2 coefficient for exponent Kp in deterministic partially flooded forces	cp_2	Suggested value: 1.499148	
F0 coefficient for deterministic	F_0	Suggested value: 0.098577	

partially flooded shear force			
cf1 coefficient for exponent Kp in deterministic partially flooded forces	cf_1	Suggested value: -0.383954	
cf2 coefficient for exponent Kp in deterministic partially flooded forces	cf_2	Suggested value: 0.138443	
Ring width to use for the deterministic hydrodynamic correlation	r_w		mm
IsFreeshaped		1 to provide the free-shape coordinates and 0 to provide the free-shape curvature. User has to provide this value if IsFreeshape=1.	
Free-shape distribution		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the free-shape coordinates in usual representation in millimeters. User has to provide this value if IsFreeshape=1 and IsFreeshaped=1.	deg & mm
Free-shape curvature distribution		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the free-shape curvature coordinates in usual representation in 1/m. User has to provide this value if	deg & $1/m$

		IsFreeshape=1 and Isfreeshaped=0.	
Force distribution in radial bore		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the pressure times ring height (axial width). User has to provide this value if IsFreeshape=0.	deg & N/m
Tolerance for Newton-Raphson algorithm convergence	$Newton_{tol}$	Positive sign. Suggested value: 10^{-6}	
Maximum number of Newton-Raphson algorithm iterations	It_{Max}	Positive integer. Suggested value: 100	
Number of ring gap positions equally spaced between 0 and 359 degrees within bore fixed reference from thrust to thrust side to consider	num_{Tg}	Positive integer	

Inputs provided by the ring cross-section parameters calculation module.

Nomenclature	Variable designation	Comment	Unit
Upper OD width	auo	Positive sign	mm
Upper OD height	huo	Positive sign	mm
Upper ID width	aui	Positive sign	mm
Upper ID height	hui	Positive sign	mm
Lower ID width	ali	Positive sign	mm
Lower ID height	hli	Positive sign	mm
Lower OD width	alo	Positive sign	mm
Lower OD height	hlo	Positive sign	mm
Ring upper flank angle	θ_{rt}	Positive sign. Analogous to θ_{rb} shown in Figure 2.	deg

Ring lower flank angle	θ_{rb}	Positive sign. Shown in Figure 2.	deg
Lower edge width	$rb1$	Positive sign. Axial distance between lower end point (#3 in Figure 1) and minimum point (#4 in Figure 1)	mm
Upper edge width	$rb2$	Positive sign. Axial distance between upper end point (#5 in Figure 1) and minimum point (#4 in Figure 1)	mm
Minimum point axial location	rbn	Positive sign if minimum point located above the gravity center point of the cross section and negative otherwise (negative sign in Figure 1)	mm
Quadratic coefficient for upper edge shape factor	a_{22}		mm
Quadratic coefficient for lower edge shape factor	a_{12}		mm
Linear coefficient for upper edge shape factor	a_{21}		
Linear coefficient for lower edge shape factor	a_{11}		
Minimum point width	arm	Positive sign	mm
Cross section area	Ac		mm^2
Principal moment of inertia in plane	I_{zp}		mm^4
Principal moment of inertia out of plane	I_{yp}		mm^4
Moment of inertia in plane	I_z		mm^4
Moment of inertia out of plane	I_y		mm^4
Principal angle	α_p		deg

Polar moment of inertia	I_p		mm^4
Torsional factor	J_t		mm^4

Outputs of sub-model performing the computation related to the conformability study for different ring gap locations

20 text files are generated. They are specified below:

- res_theer.txt: Contains one column with the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. This angles distribution will be used for the ring's coordinates and clearances results given in the text files: "res_hmin.txt", "res_zr.txt", "res_yr.txt", "res_alr.txt", "res_z0.txt", "res_uoc.txt", "res_uic.txt", "res_loc.txt", "res_lic.txt".

- res_hmin.txt: Ring liner clearance in microns. Always non-negative. It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in "res_theer.txt" i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

- res_zr.txt: Ring neutral axis lift in microns. The zero level is located at the middle of the groove inner region. The axial axis is positively pointing upwards. It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in "res_theer.txt" i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

- res_yr.txt: Ring radial coordinate in microns. This is defined respect to the nominal radius defined by $R_r = \left(\frac{D_b}{2} - arm\right) * (1 + \alpha_T(T_r - 25))$. A positive radial coordinate means that the ring cross-section centroid is located outside the circle with a radius equal to the nominal one. It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in "res_theer.txt" i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

- res_alr.txt: Ring twist angle in degrees. A positive ring twist angle means the ring cross section is rotated in the clockwise direction with the ring's outer-diameter (OD) on the left as shown in Figure 1 and Figure 2. It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in "res_theer.txt" i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

- res_z0.txt: Minimum liner clearance point location with respect to the centroid in microns. A positive sign means that this point is located above the centroid axial level. It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in "res_theer.txt" i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

- res_uoc.txt: Upper OD point clearance with the groove in microns. Always non-negative. It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in "res_theer.txt" i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

- res_uic.txt: Upper ID point clearance with the groove in microns. Always non-negative. It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in "res_theer.txt" i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

- res_loc.txt: Lower OD point clearance with the groove in microns. Always non-negative. It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in "res_theer.txt" i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

- res_lic.txt: Lower ID point clearance with the groove in microns. Always non-negative. It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in "res_theer.txt" i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

- res_thee.txt: Contains one column with the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. This angles distribution will be used for forces, moments and stresses results given in the text files: "res_fy.txt",

”res_fl.txt”, ”res_fz.txt”, ”res_m.txt”, ”res_Mfinal.txt”, ”res_S_uo.txt”, ”res_S_lo.txt”, ”res_S_ui.txt”, ”res_S_li.txt”.

- res_fy.txt: Radial force in N/m (force per unit circumferential length of the ring). A positive sign corresponds to a compression force. It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res_thee.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

- res_fl.txt: Ring-liner radial force in N/m (force per unit circumferential length of the ring). It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res_thee.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

- res_fz.txt: Axial force in N/m (force per unit circumferential length of the ring). The axial axis is positively pointing upwards. It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res_thee.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

- res_m.txt: Twist moment in N (moment per unit circumferential length of the ring). The angular orientation is positive in the clockwise direction with the ring’s outer-diameter (OD) on the left as shown in Figure 1 and Figure 2. It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res_thee.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

- res_Mfinal.txt: Bending moment at the ring cross-section centroid in Nm. It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res_thee.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

- res_S_uo.txt: Stress at upper OD point in MPa. A positive sign corresponds to extension. It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res_thee.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

- res_S_ui.txt: Stress at upper ID point in MPa. A positive sign corresponds to extension. It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in "res_thee.txt" i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

- res_S_lo.txt: Stress at lower OD point in MPa. A positive sign corresponds to extension. It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in "res_thee.txt" i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

- res_S_li.txt: Stress at lower ID point in MPa. A positive sign corresponds to extension. It has num_{Tg} columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in "res_thee.txt" i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

Inputs of sub-model performing the radial plots related to the conformability study for different ring gap locations

Inputs that need to be provided by the user.

Nomenclature	Variable designation	Comment	Unit
Magnification coefficient for radial plot of bore distortion and ring liner clearance	$mag1$	Positive sign. Suggested value: 3000	
Number of radial forces to represent	$numforce$	Positive integer. Suggested value: 200	
Maximum acceptable value for forces to be represented	$fstop$	Positive sign.	N/m

Frame rate of the animation for the total radial force	$v.FrameRate$	Number of frames per second for the video that will be generated. Suggested value: 1	$frames/s$
Frame rate of the animation for the ring-liner radial force	$vl.FrameRate$	Number of frames per second for the video that will be generated. Suggested value: 1	$frames/s$

This code also uses bore distortion, FEM related, ring gap size, ring-liner clearance, radial force and ring-liner force inputs and outputs of the sub-model performing the computation related to the conformability study for different ring gap locations.

Outputs of sub-model performing the radial plots related to the conformability study for different ring gap locations

Two videos are generated:

- The first one contains a fix radial plot of the bore and a moving one the ring based on its gap location using the specified magnification coefficient. For each ring gap location, it plots scaled lines showing the ring-liner forces based on the number of forces to be represented and the maximum acceptable value specified. For each ring gap location, it also displays separate message(s) if the bore or/and the ring is(are) misrepresented because of the magnification coefficient. It also shows the ring gap location within the bore fixed reference from thrust to thrust side and shows a message in case the force is truncated somewhere based on the maximum acceptable value for force to be represented that has been chosen.
- The second one contains a fix radial plot of the bore and a moving one the ring based on its gap location using the specified magnification coefficient. For each ring gap location, it plots scaled lines showing the radial forces based on the number of forces to be represented and the maximum acceptable value specified. For each ring gap location, it also displays separate message(s) if the bore or/and the ring is(are) misrepresented because of the magnification coefficient. It also shows the ring gap location within the bore fixed reference from thrust to thrust side and shows a message in case the force is truncated somewhere based on the maximum acceptable value for force to be represented that has been chosen.

Module 5: Ring static twist under FixOD or FixID constraint

This module performs the computation related to ring static twist under FixOD or FixID constraint. Inputs and outputs provided below.

Inputs

Inputs that need to be provided by the user.

Nomenclature	Variable designation	Comment	Unit
IsFreeshape		1 to provide the free-shape coordinates or curvature and 0 to provide the radial pressure distribution for the circular bore	
Bore diameter	D_b		mm
Gap size when ring is closed to circular bore	gap		mm
Ring Young modulus	E_r		GPa
Ring density	ρ_r		kg/m^3
Ring Poisson ratio	ν_r		
Ring thermal expansion coefficient	α_T		$1/K$
Number of elements for the FEM	Nbe	Positive integer	
Number of points within one element for contact and lubrication force calculation	Npe	Positive integer	
Liner Young modulus	E_l		GPa
Liner Poisson ratio	ν_l		
Plateau ratio	PR		
Liner surface roughness standard deviation	σ_p		μm
z coefficient for the asperity ring/liner and ring/groove contact interaction	z	6.804 is the adopted value in the simplified formulation	
K coefficient for the asperity ring/liner and ring/groove contact interaction	K	1.198e-4 is the adopted value in the simplified formulation	

A coefficient for the asperity ring/liner and ring/groove contact interaction	A	4.4068e-5 is the adopted value in the simplified formulation	
Ω coefficient for the asperity ring/liner and ring/groove contact interaction	Ω	4 is the adopted value in the simplified formulation	
Friction coefficient for the asperity ring/liner and ring/groove contact interaction	fc_{dry}		
Constant coefficient for the asperity ring/liner and ring/groove contact interaction	$cfct$	1 is the adopted value in the simplified formulation	
IsFreeshaped		1 to provide the free-shape coordinates and 0 to provide the free-shape curvature. User has to provide this value if IsFreeshape=1.	
Free-shape distribution		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the free-shape coordinates in usual representation in millimeters. User has to provide this value if IsFreeshape=1 and IsFreeshaped=1.	deg & mm
Free-shape curvature distribution		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the free-shape curvature coordinates in	deg & $1/m$

		usual representation in 1/m. User has to provide this value if IsFreeshape=1 and Isfreeshaped=0.	
Force distribution in radial bore		Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the pressure times ring height (axial width). User has to provide this value if IsFreeshape=0.	deg & N/m
Tolerance for Newton-Raphson algorithm convergence	$Newton_{tol}$	Positive sign. Suggested value: 10^{-6}	
Maximum number of Newton-Raphson algorithm iterations	It_{Max}	Positive integer. Suggested value: 100	

Inputs provided by the ring cross-section parameters calculation module.

Nomenclature	Variable designation	Comment	Unit
Upper OD width	auo	Positive sign	mm
Upper OD height	huo	Positive sign	mm
Upper ID width	aui	Positive sign	mm
Upper ID height	hui	Positive sign	mm
Lower ID width	ali	Positive sign	mm
Lower ID height	hli	Positive sign	mm
Lower OD width	alo	Positive sign	mm
Lower OD height	hlo	Positive sign	mm
Ring upper flank angle	θ_{rt}	Positive sign. Analogous to θ_{rb} shown in Figure 2.	deg
Ring lower flank angle	θ_{rb}	Positive sign. Shown in Figure 2.	deg
Lower edge width	$rb1$	Positive sign. Axial distance between lower end point (#3 in Figure 1) and minimum point (#4 in Figure 1)	mm

Upper edge width	$rb2$	Positive sign. Axial distance between upper end point (#5 in Figure 1) and minimum point (#4 in Figure 1)	mm
Minimum point axial location	rbn	Positive sign if minimum point located above the gravity center point of the cross section and negative otherwise (negative sign in Figure 1)	mm
Quadratic coefficient for upper edge shape factor	a_{22}		mm
Quadratic coefficient for lower edge shape factor	a_{12}		mm
Linear coefficient for upper edge shape factor	a_{21}		
Linear coefficient for lower edge shape factor	a_{11}		
Minimum point width	arm	Positive sign	mm
Cross section area	Ac		mm^2
Principal moment of inertia in plane	I_{zp}		mm^4
Principal moment of inertia out of plane	I_{yp}		mm^4
Moment of inertia in plane	I_z		mm^4
Principal angle	α_p		deg
Polar moment of inertia	I_p		mm^4
Torsional factor	J_t		mm^4

Outputs

One text file is generated res_stat_twist.txt. It contains 9 columns, specified below from the left to the right:

- Column 1: Circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. This angles distribution will be used for the ring's coordinates, clearances, forces and moment results from column 2 to column 9.
- Column 2: Ring radial coordinate in microns. This is defined respect to the nominal radius defined by $R_r = \left(\frac{D_b}{2} - arm\right) * (1 + \alpha_T(T_r - 25))$. A positive radial coordinate means that the ring cross-section centroid is located outside the circle with a radius equal to the nominal one.
- Column 3: Ring liner clearance in microns. Always non-negative.
- Column 4: Ring twist angle in degrees. A positive ring twist angle means the ring cross section is rotated in the clockwise direction with the ring's outer-diameter (OD) on the left as shown in Figure 1 and Figure 2.
- Column 5: Lower OD point clearance with the groove in microns. Always non-negative.
- Column 6: Lower ID point clearance with the groove in microns. Always non-negative.
- Column 7: Radial force in N/m (force per unit circumferential length of the ring). A positive sign corresponds to a compression force.
- Column 8: Axial force in N/m (force per unit circumferential length of the ring). The axial axis is positively pointing upwards.
- Column 9: Twist moment in N (moment per unit circumferential length of the ring). The angular orientation is positive in the clockwise direction with the ring's outer-diameter (OD) on the left as shown in Figure 1 and Figure 2.

Three plots are generated:

- The first one contains the curve of the ring radial coordinate and the ring-liner clearance as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. Both are plotted in microns. It also gives the ring twist angle in degrees as a function of the same circumferential direction angles in degrees.
- The second plot displays the 2 curves of lower OD/ID clearances with the lower plate, both in microns and as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.
- The third plot contains the curve of the radial force and axial one, both in N/m as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. It also gives the twist moment in N as a function of the same circumferential direction angles in degrees.

The code also displays the tangential load determined from the force distribution computed.