Labyseal

Pre&post-processor for LabyDRBSF

LABYRINTH SEAL ANALYSIS

FOR

TURBOMACHINERY ROTORDYNAMICS ANALYSIS

Users Manual

Version 1.1

April 20, 2016

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Christiansburg, VA 24073

Contact information ....

This program was developed in the mid 1980's for rotor dynamics design evaluation of machinery having toothed labyrinth seals. Options exist in the data entry to estimate the leakage flow entry swirl into the first tooth of the seal. The program compares well to CFD analysis of similar seals but the effects are slightly larger in DYNLAB (LabyDRBSF.exe), hence if the system is stable with DYNLAB coefficients, the machine will likely be stable concerning labyrinth seal effects.

The current version has a new pre & post-processor with new features to assist in the analysis of several options of bladed labyrinth seals. The new frontend (Labyseal.exe) was written by Dr. Wen Jeng Chen and includes a very helpful graphic display of the leak-path and indication of tooth placement.

The latest version is now available as a part of DyRoBeS.

See Appendix E for more information about the program.

Please see Appendix F for the download instructions that will be useful if you decide to purchase the program.

<u>Any problems, bug reports or suggestions regarding this program should be directed to:</u>

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gokirk@vt.edu

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LABYSEAL / LabyDRBSF for labyrinth seal analysis

Introduction to general operation

To execute the program:

1. Load the Labyseal setup files as explained in Appendix F .
2. Make a run directory for saving outputs and input file
3. Click on Labyseal.exe to execute the pre-processor or use the run option in DyRoBeS.
4. Input data is saved in filename.LSI
5. Bottom of input window shows important results, toggle to other speed cases.
6. Program results saved in output file filename.ORG
7. Shorter version of current output saved in fixed name file CURRENT.ORG.
8. Stiffness and damping values saved in file filename.LSO for use by rotor response programs.

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Additional information about the analysis program input detail format can be found in Appendix C of this document

Please note the following:

MuxG input gas viscosity units !!!! are [LBm/(Ft-sec)]

Kinematic viscosity = MuxG / 12/PS*Z*R*TABS [in^2/sec]

Centipoises = MuxG/12/386/1.45E-7 [cp]

Description of Labyseal features

Option to elect English or metric units initially

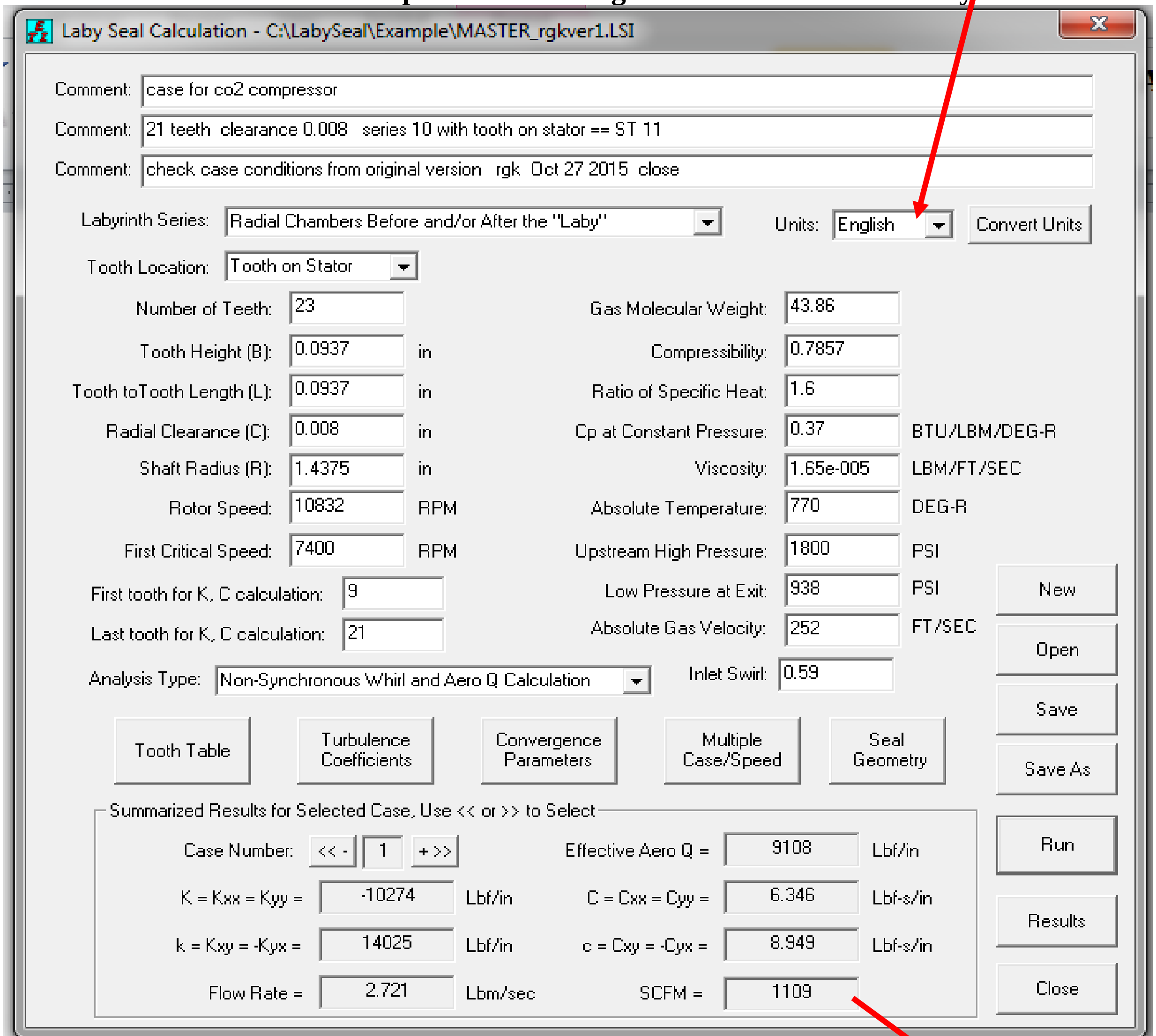
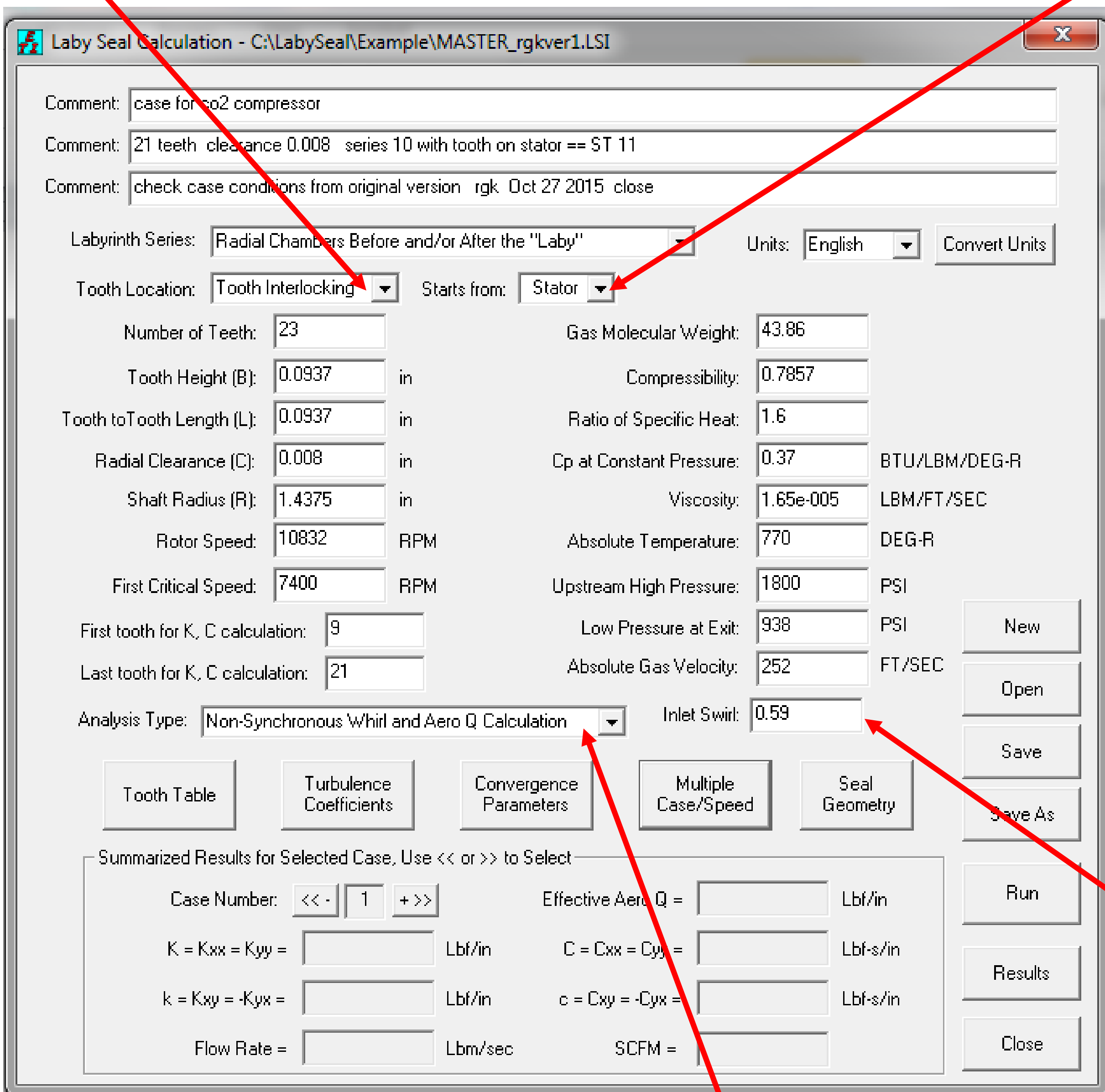


Figure 1 Window for Labyseal.exe after execution by clicking Run button
Results for speed case 1 showing in lower part of window

Note: Flow parameter SCFM (Standard cubic feet per min) is calculated for 60 degF and 14.7 psia.

Option of tooth on stator, or rotor, or interlocking.

For interlocking only option of first tooth on rotor or stator



Option of synchronous or non-synchronous whirl solution

Figure 2 Program window with interlocking teeth, shown prior to hitting Run

Note: Inlet swirl is inlet swirl ratio, gas swirl velocity / (rotor surface velocity)

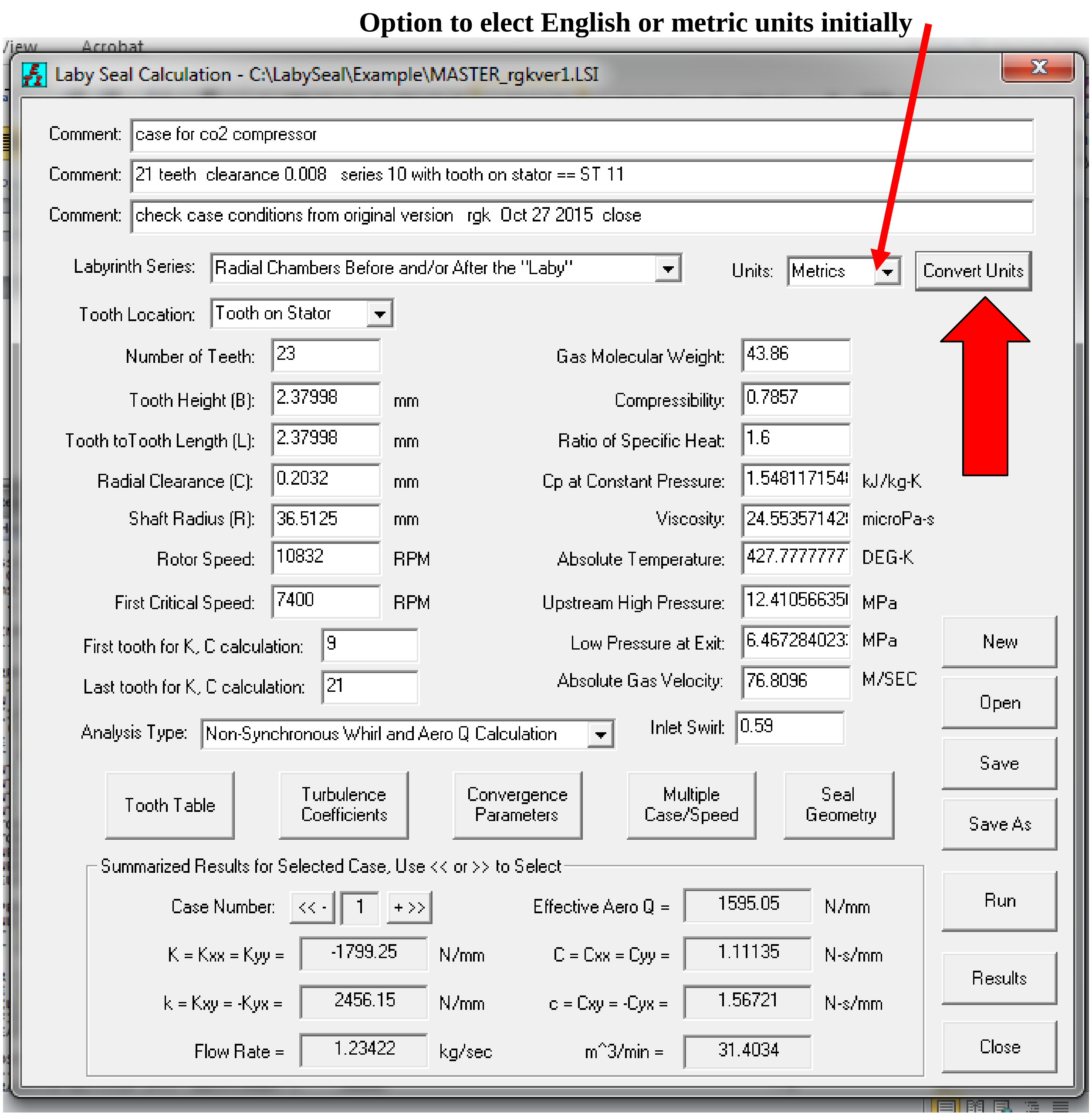
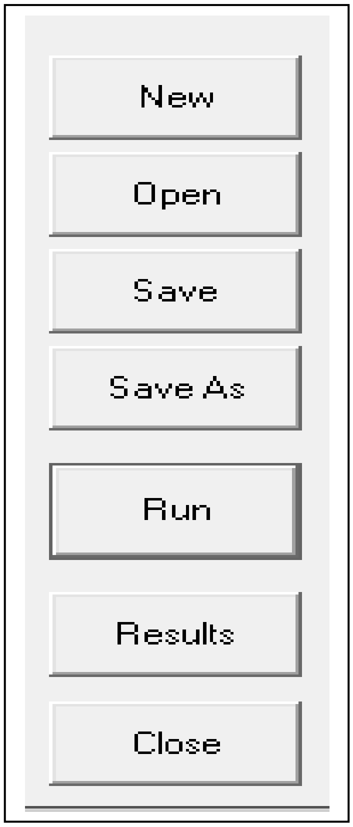


Figure 3 Example of unit conversion of the file shown in Figure 1 using the metric button option noted by arrow above.

Buttons on right side of data entry window are used for file operations



Open a new blank window

Open an existing data file filename.LSI

Save modified file with current filename

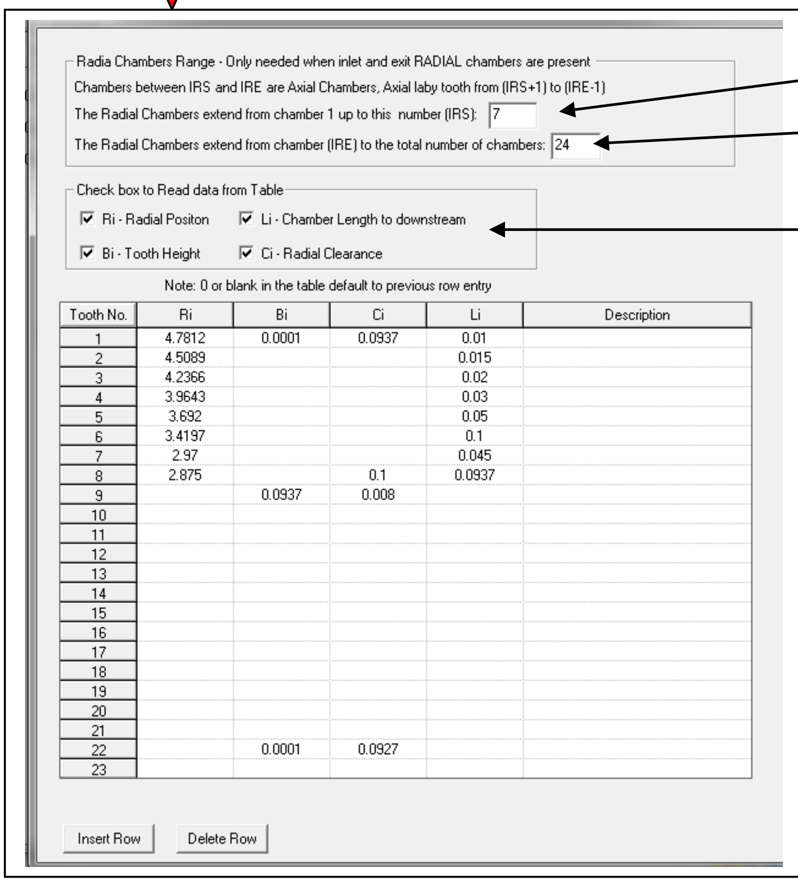
Save modified file with new filename

Run the current file with LabyDRBSF.exe

View full output filename.ORG in English units

Close Labyseal window

The horizontal buttons in Labyseal window will open supporting additional data entry options



Tooth No.	Ri	Bi	Ci	Li	Description
1	4.7812	0.0001	0.0937	0.01	
2	4.5089			0.015	
3	4.2366			0.02	
4	3.9643			0.03	
5	3.692			0.05	
6	3.4197			0.1	
7	2.97			0.045	
8	2.875		0.1	0.0937	
9		0.0937	0.008		
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22		0.0001	0.0927		
23					

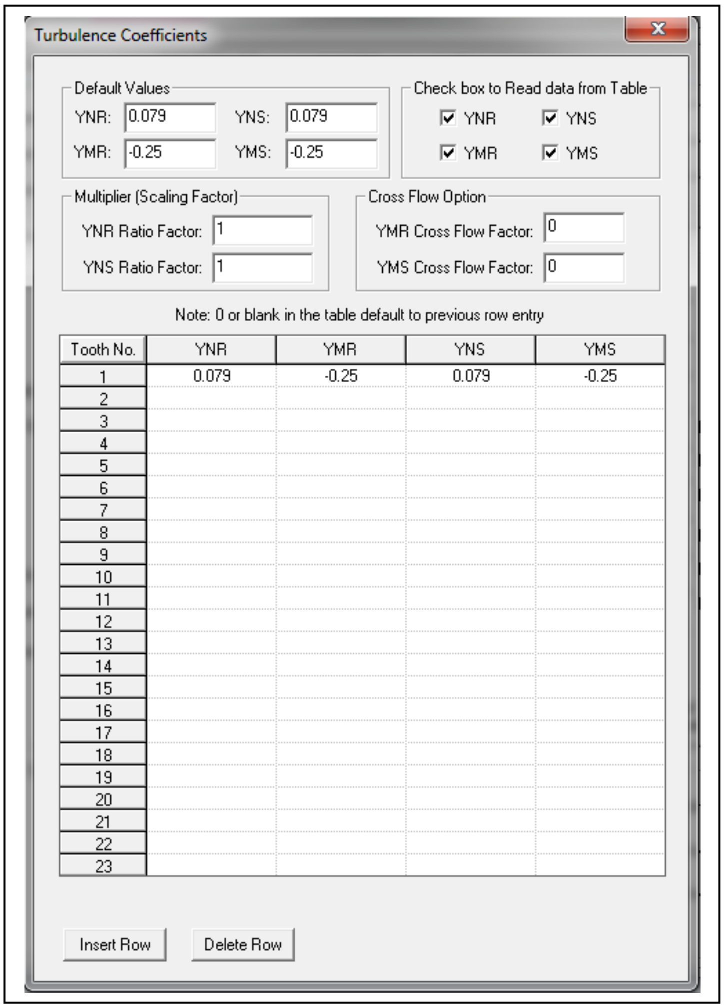
IRS= radial teeth stop at this tooth

IRE = where radial series 20 teeth start for a radial exit leak- path

Keep these 4 checked

Blank entries default to prior data entry in a given column for R, B, C, L

Table input window for teeth radius R, tooth height B, radial clearance C. and chamber length to right of tooth L, plus a description area to describe the teeth if desired.



Normally these stay as given

YNR YNS are global scaling factors

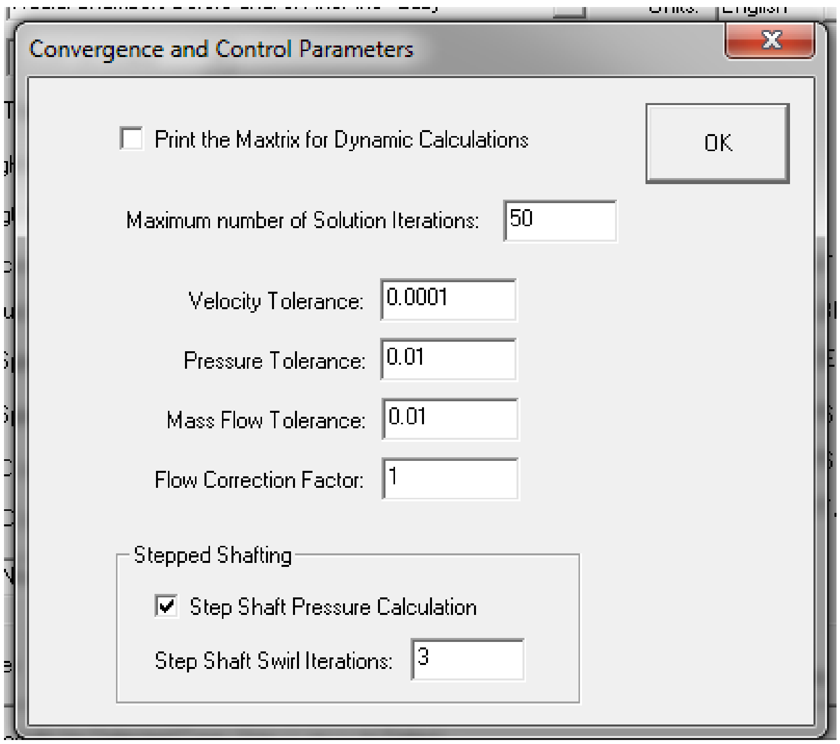
YMR YMS give crossflow when == 0
Value of 1 will stop crossflow effects

Blanks default to prior column value when the program Run button is clicked. So this table has all teeth with same coefficients.

Table input window for turbulence parameters and additional keys in upper section

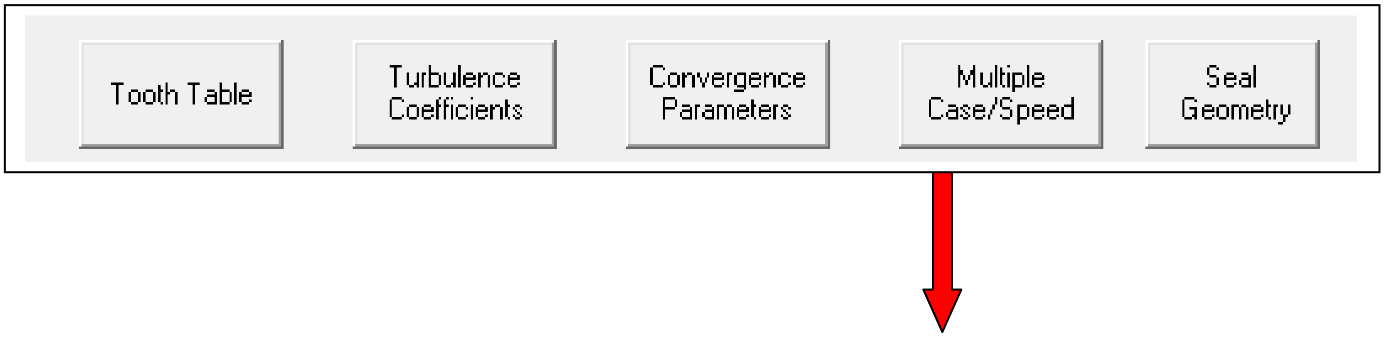
- **Blasius pipe flow factors are N = 0.033 and M = -0.25**
- **honeycomb flow factors are N = 0.015 and M = -0.025**
- **default values are per YAMADA, ie., N = 0.079 and M = -0.25**

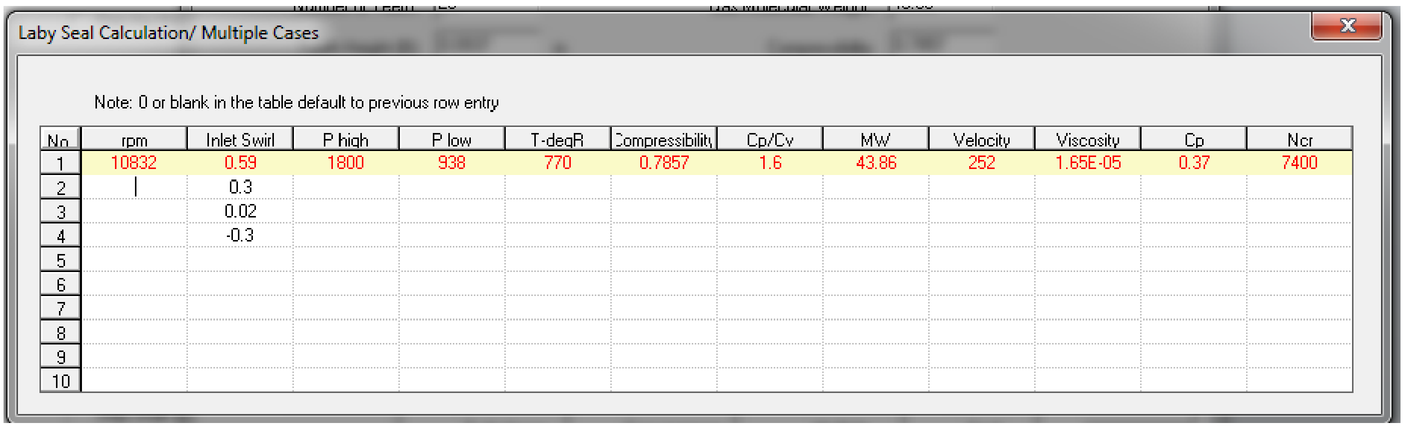
Normal values are given automatically



Convergence and control parameters

Speed case option





No	rpm	Inlet Swirl	P high	P low	T-degR	Compressibility	Cp/Cv	MW	Velocity	Viscosity	Cp	Ncr
1	10832	0.59	1800	938	770	0.7857	1.6	43.86	252	1.65E-05	0.37	7400
2		0.3										
3		0.02										
4		-0.3										
5												
6												
7												
8												
9												
10												

Max of 10, zero defaults to last speed value entered, value required in at least one column to activate increase of speed case count. This example has 4 speed case conditions.

RPM Swirl ratio Pin Pout TdegR Z cp/cv MW Inlet vel. Viscosity Cp Ncr

==

Rotor speed rev per minute

Inlet swirl ratio, tangential velocity over surface speed of rotor at tooth 1

Inlet pressure

Discharge pressure

Absolute temperature of gas, average in seal

Compressibility of gas, Z

Ratio of cp / cv for gas in seal

Moleweight of gas in seal

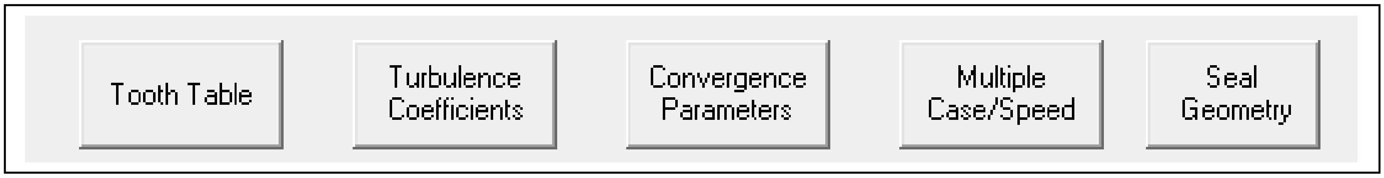
Inlet gas velocity at chamber in front of tooth 1

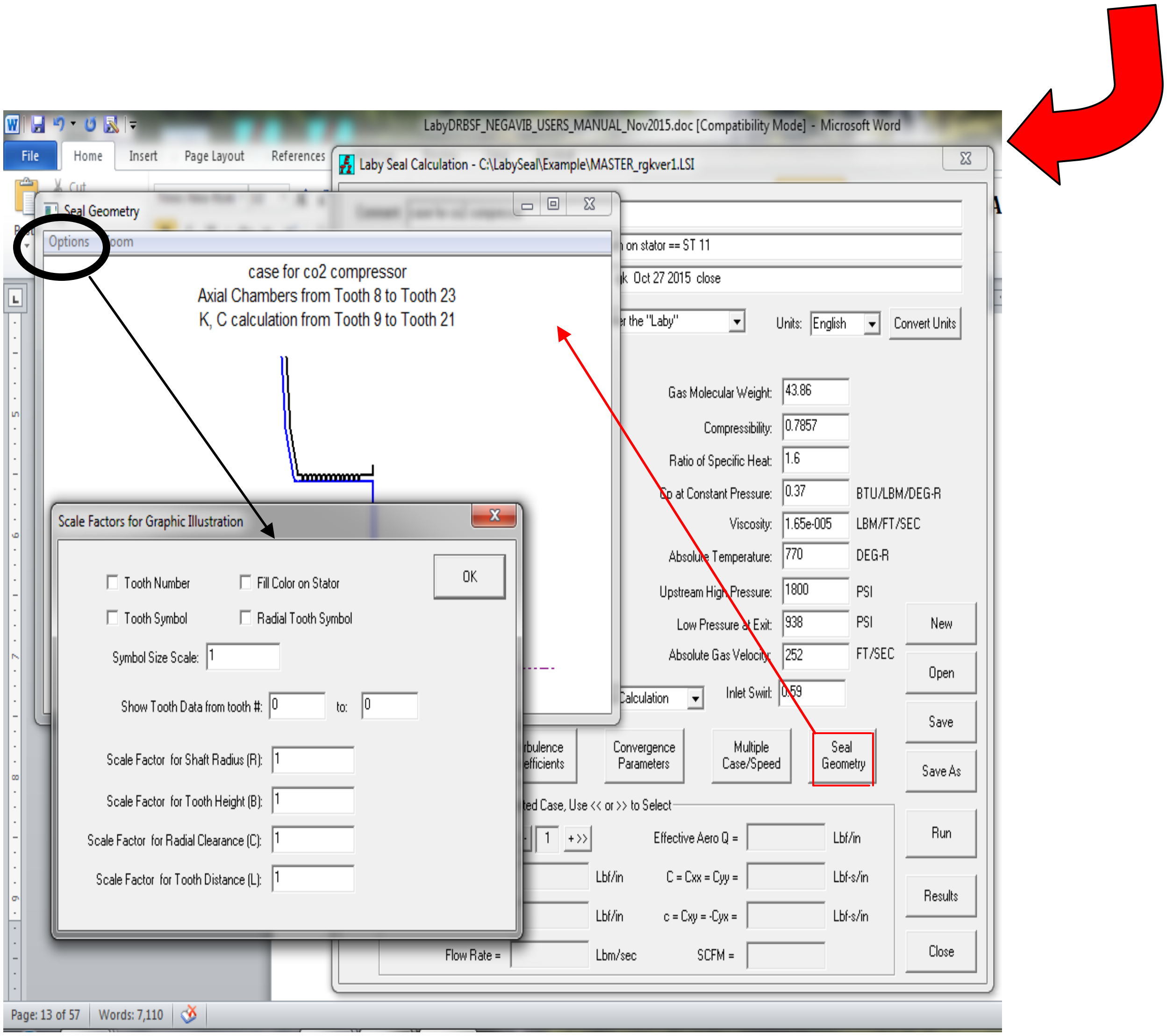
Viscosity of gas in units specified by unit selection

Specific heat at constant pressure, Cp

Ncr is the critical speed of shaft for approximate evaluation of Effective Q or Effective C

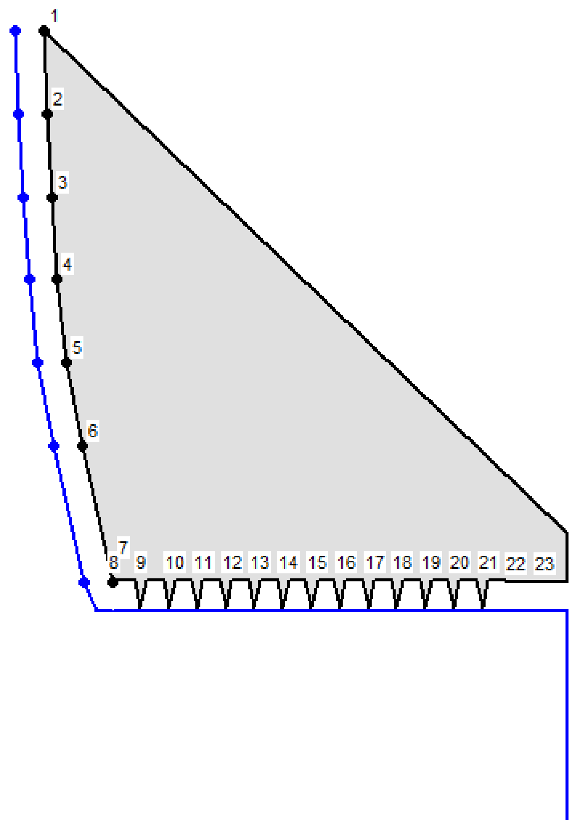
Option to examine seal leak-path and tooth placement



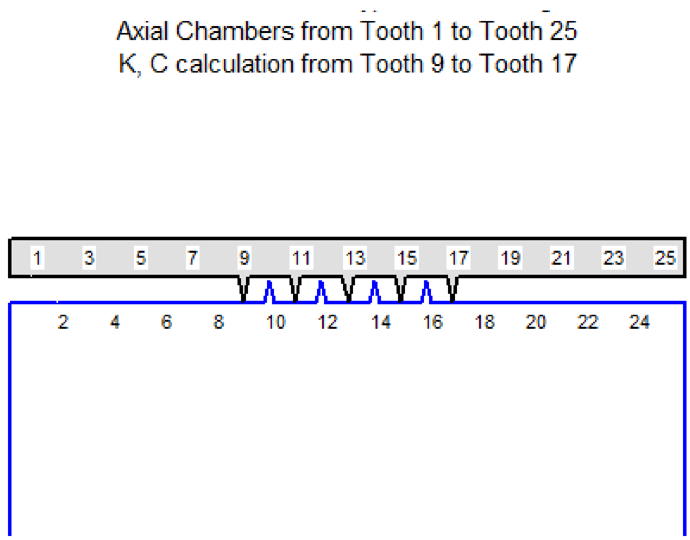


Window showing when Options selected on Seal Geometry window.
To change scale select the Zoom option.

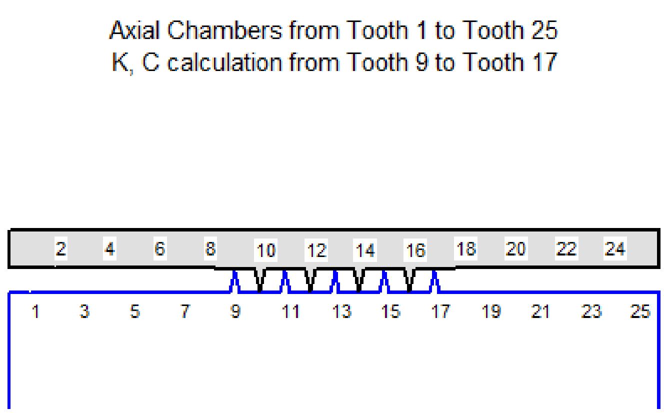
Examples of series and tooth type selection



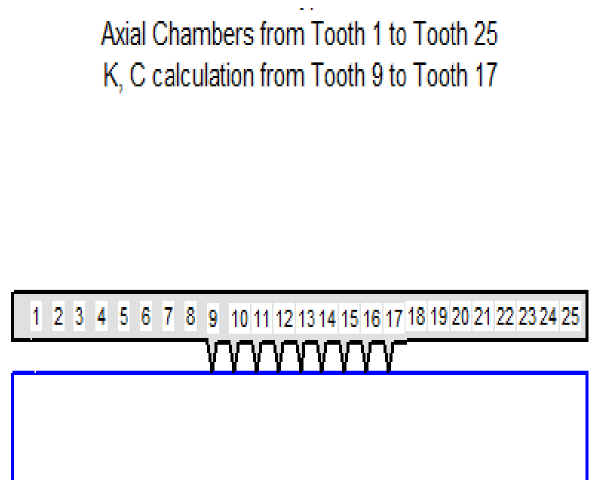
Series 10 type 1, on stator teeth



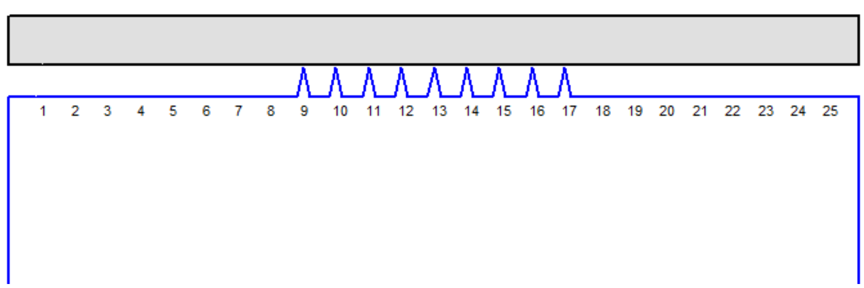
Series 00 type 3, interlocking, first on stator (odd tooth)



Series 00 type 3, interlocking, first on rotor (odd tooth)

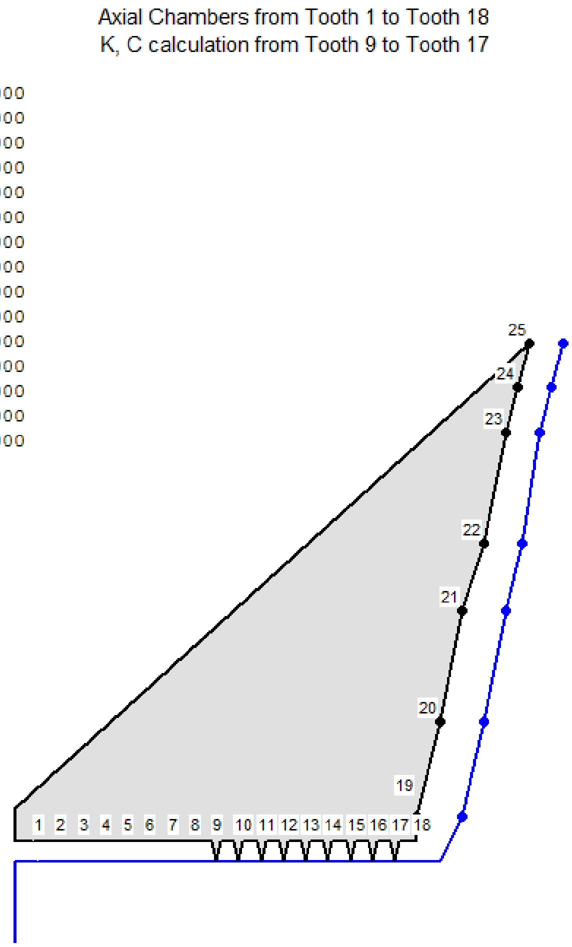


Series 00 type 1, tooth on stator



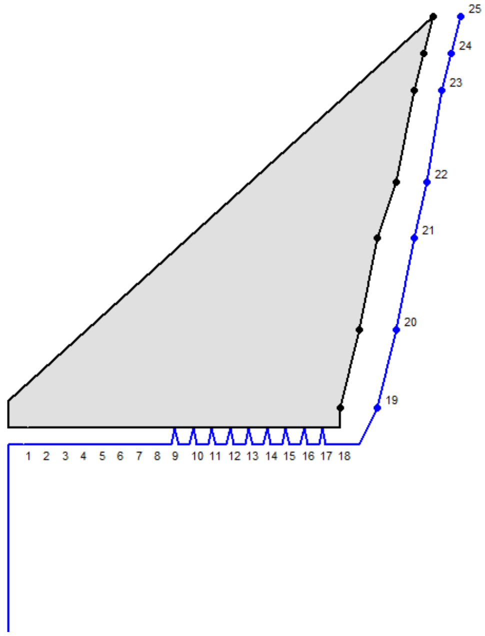
Series 00 type 2, tooth on rotor

Tooth	R	B	C	L
7	2.87500	0.00010	0.09000	0.10000
8	2.87500	0.00010	0.09000	0.10000
9	2.87500	0.09000	0.00300	0.10000
10	2.87500	0.09000	0.00300	0.10000
11	2.87500	0.09000	0.00300	0.10000
12	2.87500	0.09000	0.00300	0.10000
13	2.87500	0.09000	0.00300	0.10000
14	2.87500	0.09000	0.00300	0.10000
15	2.87500	0.09000	0.00300	0.10000
16	2.87500	0.09000	0.00300	0.10000
17	2.87500	0.09000	0.00300	0.10000
18	2.87500	0.00010	0.09000	0.30000
19	3.07500	0.00010	0.20000	0.10000
20	3.50000	0.00010	0.20000	0.10000
21	4.00000	0.00010	0.20000	0.10000



Series 20 type 1, tooth on stator

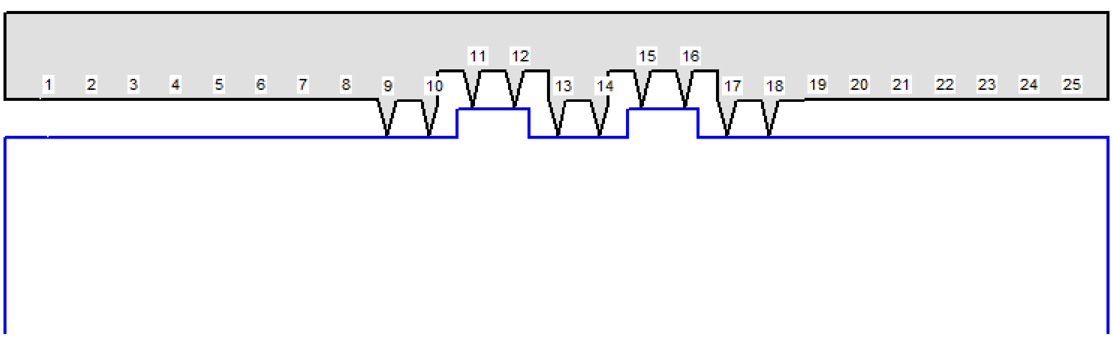
Option on Seal Geometry, to list selected teeth values, activated for 7 – 21 in this example.



Series 20 type 2 tooth on rotor

Example from Dr. Kirk all axial series 00 type 1 tooth on statorr stepped shaft, covered inlet and outlet
Axial Chambers from Tooth 1 to Tooth 25
K, C calculation from Tooth 9 to Tooth 18

Tooth	R	B	C	L
9	2.87500	0.09000	0.00800	0.10000
10	2.87500	0.09000	0.00800	0.10000
11	2.95000	0.09000	0.00800	0.10000
12	2.95000	0.09000	0.00800	0.10000
13	2.87500	0.09000	0.00800	0.10000
14	2.87500	0.09000	0.00800	0.10000
15	2.95000	0.09000	0.00800	0.10000
16	2.95000	0.09000	0.00800	0.10000
17	2.87500	0.09000	0.00800	0.10000
18	2.87500	0.09000	0.00800	0.10000



Series 00 type 1 tooth on stator

Example original version data file for 21 tooth analysis for 13 tooth balance drum seal:

```
----- CASE FOR CO2 COMPRESSOR THAT WENT UNSTABLE      R.G.KIRK
     DATA FOR SEAL WITH 21 TEETH  CLEARANCE AT 0.00800  IBM-PC VERSION
     -------------------========  --------------------

 ROTOR SPEED-RPM;NSPD;TYPE WHIRL,0=SYN,1=NON;SPD = 10832.000    4    0
 RAD OPT;SERIES;TYP 1 STA./2 ROT/3 I-LOCK;STEP;I;IRS= 8ST=11 IS=1 IB=1
 RADIAL OPT.;NUMBER OF TEETH; PLUS RANGE FOR KXY;IRE= 0NT=21NS= 9NE=21
 TOOTH HEIGHT(IF KEY=1,INSERT LINE(S) 7G10.2)KEY =        1B=       .01
      .01
     0.01    0.0937
   0.0937
 TOOTH SPACING ( KEY=1,INSERT LINE(S) 7G10.2)KEY =        1L=      0.01
     0.01                                          0.0
   0.0937    0.0937
    .0937
 TOOTH CLEARANCE(KEY=1,INSERT LINE(S) 7G10.2)KEY =        1C=    0.0937
   0.0937
   .17500     0.008
   .00800
 SHAFT RADIUS   (KEY=1,INSERT LINE(S) 7G10.2)KEY =        1RS    4.7812
   4.7812    4.5089    4.2366    3.9643    3.6920    3.4197    3.1473
    2.875
    2.875
 SURFACE CONSTANT(DEFAULT=0.079);*F5.1;KEY   YNR =      .079  1.0INR=1
     .079
     .079
     .079
 SURFACE CONSTANT(DEFAULT=-0.25);XFLOWI1;KEY YMR =     -0.25XFR 0IMR=1
    -0.25
    -0.25
    -0.25
 SURFACE CONSTANT(DEFAULT=0.079);*F5.1;KEY   YNS =      .079  1.0INS=1
     .079
     .079
     .079
 SURFACE CONSTANT(DEFAULT=-0.25);XFLOWI1;KEY YMS =     -0.25XFS 0IMS=1
    -0.25
    -0.25
    -0.25
 GAS SWIRL AT INLET(PERCENT SPD); NCR-RPM; SWIRL =      0.59NC    7400.0
 GAS PRESSURE AT INLET; GAS VELOCITY (FT/SEC) PS =   1800.00 V     252.0
 GAS PRESSURE AT EXIT ;                      PE =    938.00
 GAS MOLEWEIGHT                             MW =     43.86
 GAS TEMPERATURE                          TABS =    770.00
```

GAS COMPRESSIBILITY Z = 0.7857
GAS RATIO OF SPECIFIC HEATS; AND CP GAMMA = 1.60CP 0.37
GAS VISCOSITY MU * G (LBM/FT/SEC) MUXG = 1.65E-05
MASS FLOW (LB/SEC)(IF P(I)>0); FCFAC,F5.1: MDOT = 0.00 0.0
CHAMBER PRESSURES 7G10.2 PER LINE(IF KEY=1) KEY = 0
CHAMBER TEMP. 7G10.2 (IF KEY=1;-2=VARA;0=TABS) = -2
MAX SOLUTION ITERATIONS,VC,MDOT(DEFAULT=50)ITER =50
TOLERANCE DFAULT = 1E-4*RS*OMEGA TOLERV = 1.0E-2
PRESSURE TOLERANCE (DEFAULT = 0.01) TOLERP = 10.0
MASS FLOW TOLERANCE (DEFAULT = 0.0001) TOLERP = .10
PRINTMATRIX SETUP (= 1 TO PRINT ALL) KEYDMP = 0
(IF NSPD>1INPUT NSPD LINES AS FOLLOWS(6G10.2,2F5.1)0 DEFAULTS INIT. V.

SPEED	SWIRL	PS	PE	TABS	Z	GAMMA	MW
10832.000	0.59	1800.00	938.00	770.00	0.7857	1.60	43.86
0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.0
0.0	-0.30	0.0	0.0	0.0	0.0	0.0	0.0

New data file structure ***MASTER_rgkver1.LSI*** for LabyDRBSF:
This file is created by Labyseal.exe frontend.

```
2.0    // Version Number
case for co2 compressor
21 teeth  clearance 0.008   series 10 with tooth on stator == ST 11
check case conditions from original version   rgk  Oct 27 2015  close
 10832  0 0 0 0 0 0 0 0 0 0  // Speed rpm, // units 0 ==English  1 == metric
 1  0 0 0 0 0 0 0 0 0 0  // Whirl Type
 11  1 0 0 0 0 0 0 0 0 0  // Tooth Series + Tooth Location, // Interlocking  start key  1 stator  0 rotor
 23  0 0 0 0 0 0 0 0 0 0  // # of Teeth, NT
 9  0 0 0 0 0 0 0 0 0 0  // 1st Tooth, NS
 21  0 0 0 0 0 0 0 0 0 0  // Last Tooth, NE
 0.0937  0 0 0 0 0 0 0 0 0 0  // Tooth Height, B
 0.0937  0 0 0 0 0 0 0 0 0 0  // Chamber Length, L
 0.008  0 0 0 0 0 0 0 0 0 0  // Radial Clr, C
 1.4375  0 0 0 0 0 0 0 0 0 0  // Shaft Radius, R for tooth 1
 0.59  0 0 0 0 0 0 0 0 0 0  // Swirl Inlet  at region ahead of tooth 1
 7400  0 0 0 0 0 0 0 0 0 0  // 1st Critical Speed
 1800  0 0 0 0 0 0 0 0 0 0  // High Pressure
 252  0 0 0 0 0 0 0 0 0 0  // Gas Velocity
 938  0 0 0 0 0 0 0 0 0 0  // Low Pressure
 43.86  0 0 0 0 0 0 0 0 0 0  // Mole Weight
 770  0 0 0 0 0 0 0 0 0 0  // Absolute T
 0.7857  0 0 0 0 0 0 0 0 0 0  // Compressibility
 1.6  0 0 0 0 0 0 0 0 0 0  // ratio specific heat
 0.37  0 0 0 0 0 0 0 0 0 0  // Cp
 1.65E-005  0 0 0 0 0 0 0 0 0 0  // Viscosity
 1  0 0 0 0 0 0 0 0 0 0  // Flow Correction Factor
 0.01  0 0 0 0 0 0 0 0 0 0  // Tolerance
 4  0 0 0 0 0 0 0 0 0 0  // # of cases
 7  0 0 0 0 0 0 0 0 0 0  // IRS
 1  0 0 0 0 0 0 0 0 0 0  // ISTEP Step Shaft Press Calc
 3  0 0 0 0 0 0 0 0 0 0  // IISP
 24  0 0 0 0 0 0 0 0 0 0  // IRE
 1  0 0 0 0 0 0 0 0 0 0  // KEYB
 1  0 0 0 0 0 0 0 0 0 0  // KEYL
 1  0 0 0 0 0 0 0 0 0 0  // KEYC
 1  0 0 0 0 0 0 0 0 0 0  // KEYR
 0.079  0 0 0 0 0 0 0 0 0 0  // YNRO
 1  0 0 0 0 0 0 0 0 0 0  // RRFA
 1  0 0 0 0 0 0 0 0 0 0  // INR KEY
 -0.25  0 0 0 0 0 0 0 0 0 0  // YMR
 0  0 0 0 0 0 0 0 0 0 0  // KRRAX
 1  0 0 0 0 0 0 0 0 0 0  // IMR KEY
```

```
0.079  0 0 0 0 0 0 0 0 0  // YNSO
1  0 0 0 0 0 0 0 0 0  // SRFA
1  0 0 0 0 0 0 0 0 0  // INS KEY
-0.25  0 0 0 0 0 0 0 0 0  // YMS
0  0 0 0 0 0 0 0 0 0  // KRSAX
1  0 0 0 0 0 0 0 0 0  // IMS KEY
50  0 0 0 0 0 0 0 0 0  // No. Iteration
0.0001  0 0 0 0 0 0 0 0 0  // Tolerance Velocity
0.01  0 0 0 0 0 0 0 0 0  // Tolerance Mass Flow
0  0 0 0 0 0 0 0 0 0  // PRINT MATRIX, Table R, B, L, C below
1 4.7812 0.0001 0.01 0.0937 0 0 0 0 0 0    // Table input for teeth, NT lines
2 4.5089 0.0001 0.015 0.0937 0 0 0 0 0 0
3 4.2366 0.0001 0.02 0.0937 0 0 0 0 0 0
4 3.9643 0.0001 0.03 0.0937 0 0 0 0 0 0
5 3.692 0.0001 0.05 0.0937 0 0 0 0 0 0
6 3.4197 0.0001 0.1 0.0937 0 0 0 0 0 0
7 2.97 0.0001 0.045 0.0937 0 0 0 0 0 0
8 2.875 0.0001 0.0937 0.1 0 0 0 0 0 0
9 2.875 0.0937 0.0937 0.008 0 0 0 0 0 0
10 2.875 0.0937 0.0937 0.008 0 0 0 0 0 0
11 2.875 0.0937 0.0937 0.008 0 0 0 0 0 0
12 2.875 0.0937 0.0937 0.008 0 0 0 0 0 0
13 2.875 0.0937 0.0937 0.008 0 0 0 0 0 0
14 2.875 0.0937 0.0937 0.008 0 0 0 0 0 0
15 2.875 0.0937 0.0937 0.008 0 0 0 0 0 0
16 2.875 0.0937 0.0937 0.008 0 0 0 0 0 0
17 2.875 0.0937 0.0937 0.008 0 0 0 0 0 0
18 2.875 0.0937 0.0937 0.008 0 0 0 0 0 0
19 2.875 0.0937 0.0937 0.008 0 0 0 0 0 0
20 2.875 0.0937 0.0937 0.008 0 0 0 0 0 0
21 2.875 0.0937 0.0937 0.008 0 0 0 0 0 0
22 2.875 0.0001 0.0937 0.0927 0 0 0 0 0 0
23 2.875 0.0001 0.0937 0.0927 0 0 0 0 0 0
1 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0   // Table for turbulent shear flow parameters, NT lines
2 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
3 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
4 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
5 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
6 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
7 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
8 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
9 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
10 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
11 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
12 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
13 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
```

14 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
15 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
16 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
17 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
18 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
19 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
20 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
21 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
22 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0
23 0.079 -0.25 0.079 -0.25 0 0 0 0 0 0 // next lines are speed options information
10832 0.59 1800 938 770 0.7857 1.6 43.86 252 1.65E-005 0.37 7400 0 0 0 0 0 0 0 0 0 0
0 0.3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0.02 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 -0.3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Appendix - A

<u>List of files provided with LABYSEAL</u>

LabyDRBSF.EXE	-	Labyseal analysis executable program
LABYSEAL.EXE	-	Frontend window where data files are created
MASTER_rgkver1.LSI	-	Example data file for leak path and seal model
MASTER_rgkver1.LSO	-	Example output file from MASTER_rgkver1.LSI run
CURRENT.ORG	-	Example summary file for MASTER_rgkver1.LSI

Appendix – B

LABYRINTH TYPES
and
NOMENCLATURE for DYNLAB

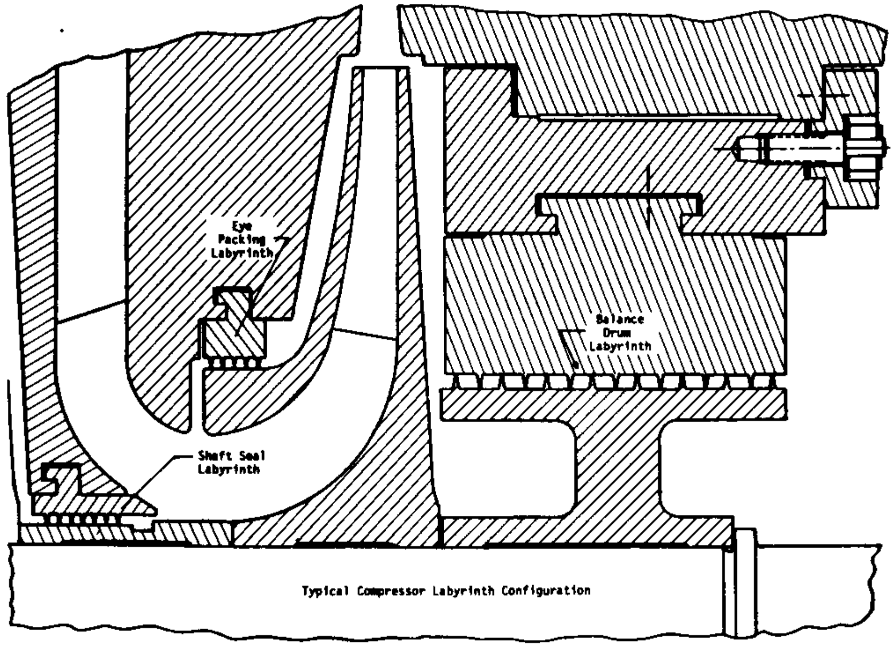


Figure B-1a Typical Compressor Labyrinth Seal Configuration

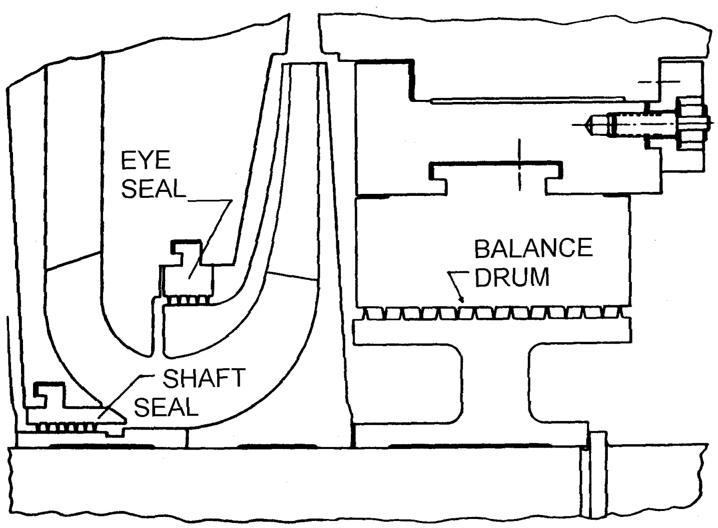


Figure B-1b Typical Compressor Labyrinth Seal Configuration

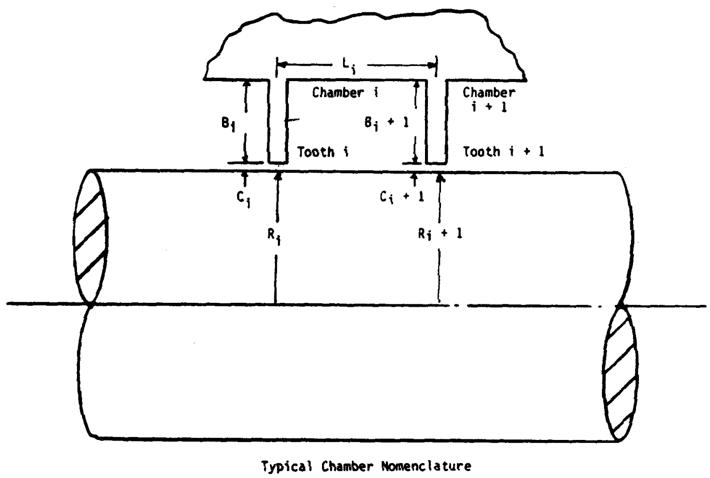


Figure B-2 Typical Chamber Nomenclature

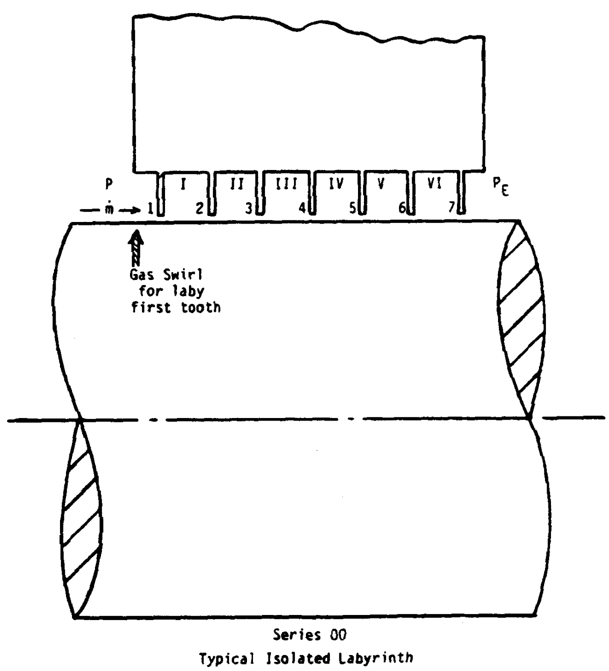
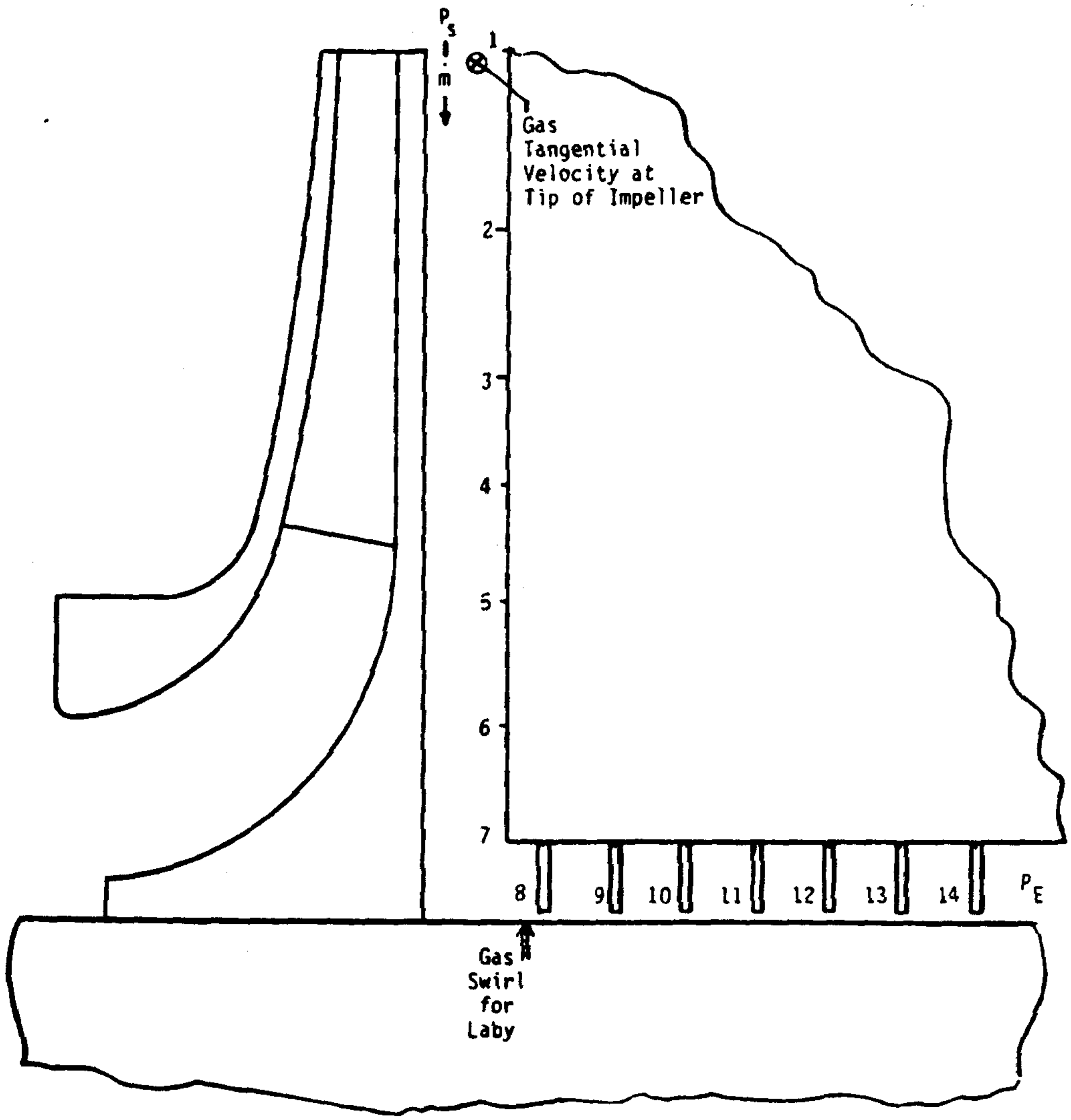


Figure B-3 Typical Series 00 Seal



Series 10
Typical System for Balance Drum Configuration

Figure B-4 Typical Series 10 Shaft Seal

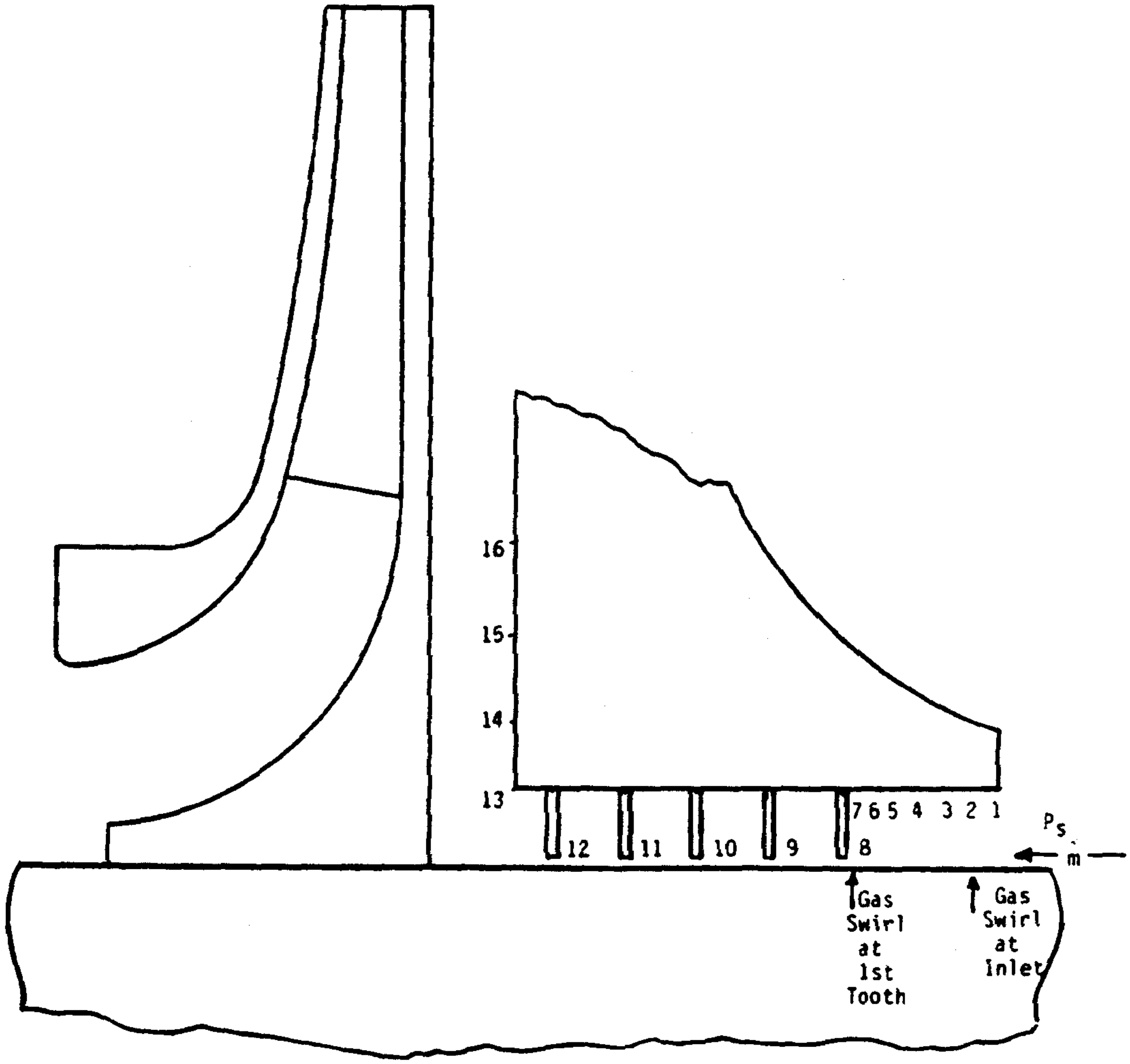


Figure B-5 Typical Series 20 Shaft Seal

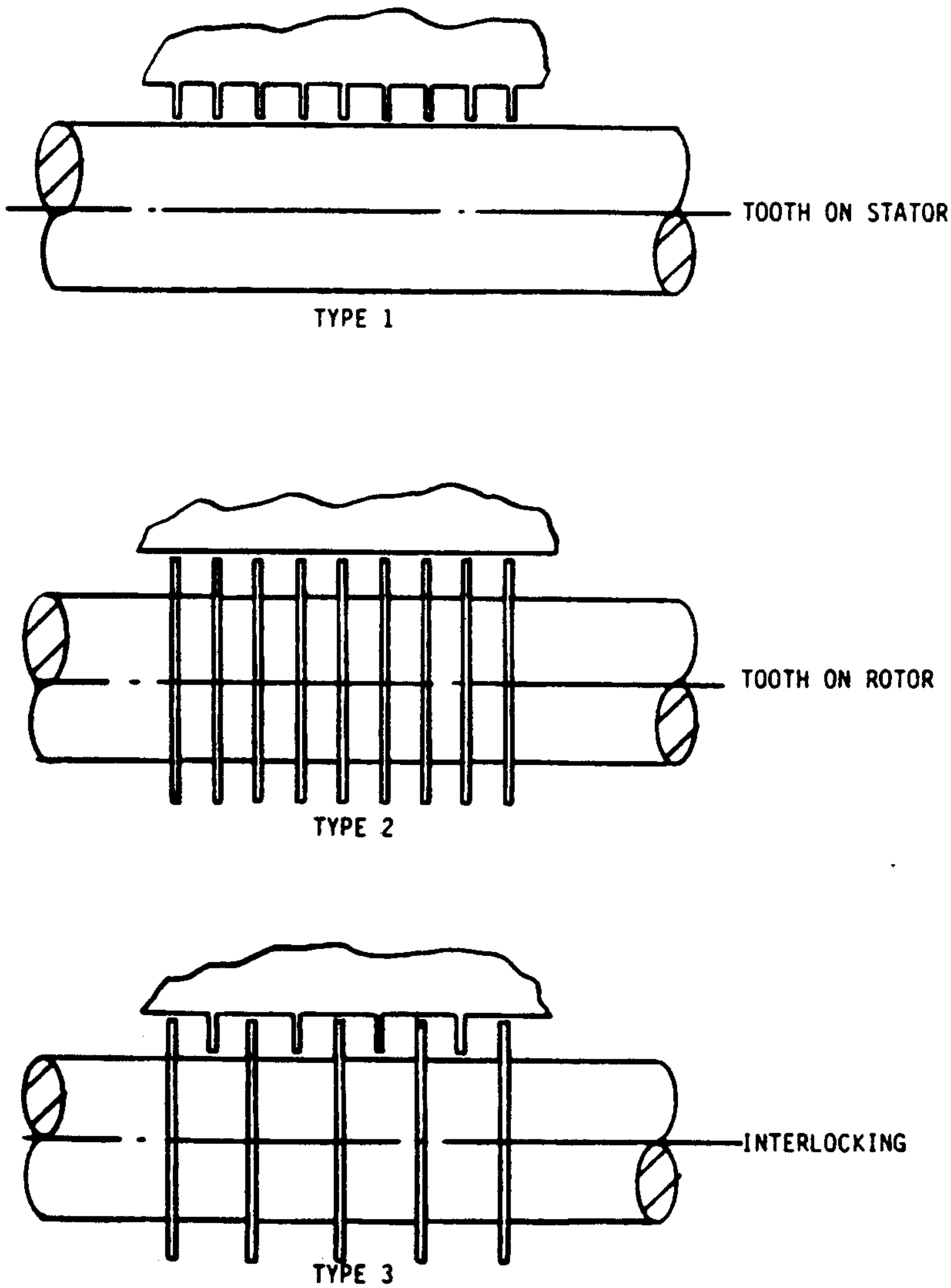
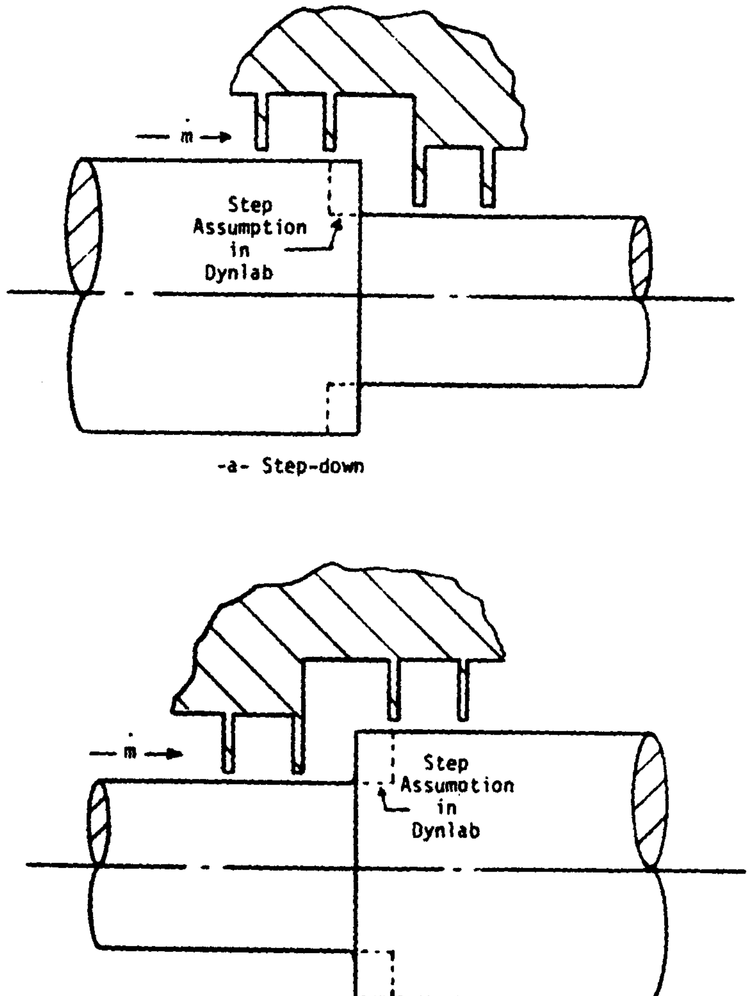


Figure B-6 Type Seal Designation for DYNLAB



-b- Step-up

Chamber Configuration for Stepped Shaft Labyrinth

Figure B-7 Typical Step Assumption in DYNLAB

Appendix – C

USERS DETAIL MANUAL FOR THE PROGRAM DYNLAB

A PROGRAM FOR THE ANALYSIS OF

LABYRINTH SEALS

The following example file and comments are given to allow the program DYNLAB to be used to calculate the dynamic stiffness and damping of labyrinth type gas seals, without the use of the frontend. This data file can be used to generate information necessary for stability calculations.

Typical Data File (exact column format has been lost in this word file)

```
  ----- CASE FOR CO2 COMPRESSOR THAT WENT UNSTABLE      R.G.KIRK
  DATA FOR SEAL WITH 21 TEETH  CLEARANCE AT 0.00800  IBM-PC VERSION
  ------------------========  --------------------

ROTOR SPEED-RPM;NSPD;TYPE WHIRL,0=SYN,1=NON;SPD = 10832.000    4    0
RAD OPT;SERIES;TYP 1 STA./2 ROT/3 I-LOCK;STEP;I;IRS= 8ST=11 IS=1 IB=1
RADIAL OPT.;NUMBER OF TEETH; PLUS RANGE FOR KXY;IRE= 0NT=21NS= 9NE=21
TOOTH HEIGHT(IF KEY=1,INSERT LINE(S) 7G10.2)KEY =         1B=       .01
      .01
    0.01    0.0937
  0.0937
TOOTH SPACING ( KEY=1,INSERT LINE(S) 7G10.2)KEY =         1L=      0.01
    0.01                                            0.0
  0.0937    0.0937
   .0937
TOOTH CLEARANCE(KEY=1,INSERT LINE(S) 7G10.2)KEY =         1C=    0.0937
  0.0937
  .17500     0.008
  .00800
SHAFT RADIUS   (KEY=1,INSERT LINE(S) 7G10.2)KEY =         1RS    4.7812
  4.7812    4.5089    4.2366    3.9643    3.6920    3.4197    3.1473
   2.875
   2.875
SURFACE CONSTANT(DEFAULT=0.079);*F5.1;KEY   YNR =      .079  1.0INR=1
    .079
    .079
    .079
SURFACE CONSTANT(DEFAULT=-0.25);XFLOWI1;KEY YMR =     -0.25XFR 0IMR=1
   -0.25
```

```
    -0.25
    -0.25
 SURFACE CONSTANT(DEFAULT=0.079);*F5.1;KEY   YNS =      .079  1.0INS=1
     .079
     .079
     .079
 SURFACE CONSTANT(DEFAULT=-0.25);XFLOWI1;KEY YMS =     -0.25XFS 0IMS=1
    -0.25
    -0.25
    -0.25
 GAS SWIRL AT INLET(PERCENT SPD); NCR-RPM; SWIRL =      0.59NC    7400.0
 GAS PRESSURE AT INLET; GAS VELOCITY (FT/SEC) PS =   1800.00 V     252.0
 GAS PRESSURE AT EXIT ;                     PE =    938.00
 GAS MOLEWEIGHT                            MW =     43.86
 GAS TEMPERATURE                         TABS =    770.00
 GAS COMPRESSIBILITY                        Z =    0.7857
 GAS RATIO OF SPECIFIC HEATS; AND CP       GAMMA =      1.60CP      0.37
 GAS VISCOSITY MU * G (LBM/FT/SEC)         MUXG =  1.65E-05
 MASS FLOW (LB/SEC)(IF P(I)>0); FCFAC,F5.1: MDOT =      0.00  0.0
 CHAMBER PRESSURES 7G10.2 PER LINE(IF KEY=1) KEY =         0
 CHAMBER TEMP. 7G10.2 (IF KEY=1;-2=VARA;0=TABS)  =        -2
 MAX SOLUTION ITERATIONS,VC,MDOT(DEFAULT=50)ITER =50
 TOLERANCE DFAULT = 1E-4*RS*OMEGA        TOLERV =    1.0E-2
 PRESSURE TOLERANCE (DEFAULT = 0.01)      TOLERP =      10.0
 MASS FLOW TOLERANCE (DEFAULT = 0.0001)   TOLERP =       .10
 PRINTMATRIX SETUP ( = 1 TO PRINT ALL)    KEYDMP =         0
 (IF NSPD>1INPUT NSPD LINES AS FOLLOWS(6G10.2,2F5.1)0 DEFAULTS INIT. V.
    SPEED            SWIRL       PS         PE        TABS       Z          GAMMA    MW
 10832.000           0.59   ..............................................1800.00    938.00    770.00    0.7857      1.60          43.86
       0.0            0.3      ................................................. 0.0          0.0          0.0        0.0            0.0          0.0
       0.0            0.02     ................................................  0.0          0.0          0.0        0.0            0.0          0.0
       0.0           -0.30     ............................................... 0.0          0.0          0.0        0.0            0.0          0.0
```

Brief Explanation of Parameters.

It should be noted that values will default to last value read if zero or blank.

Three comment lines for job identification followed by a line that is for instruction

(see example data file above).

80 COL. COMMENT   Format (10A8)

80 COL. COMMENT   Format (10A8)

80 COL. COMMENT   Format (10A8)

<Blank line>

ROTOR SPEED-RPM; NSPD; TYPE WHIRL, 0=SYN, 1=NON;   SPD=XXXX.XNSPXX TY=0

Format (50x, G10.2, I2, 4x, I1) SPD, NSPD, KWTYP

- rotor speed, SPD, and number of cases, NSPD to be run
- limit of 10 cases to be run in one input at this time
- type whirl, KWTYP, for seal solution, 0 = synchronous; 1 = non-synch.
- non-synch whirl is at the system natural frequency as given on SWIRL line

RAD OPT; SERIES;TYP 1 STA./2 ROT/3 I-LOCK;STEP;I;IRS=XXST=YX IS=X IB=X

Format (50x, 3x, I2, 3x, I2, 4x, I1, 4x, I1) IRS, TYPE, ISTEP, IISP

-- series and type labyrinth;

- series 00 have all axial chambers
- series 10 have radial chambers before and/or after the “laby”
- series 20 have radial chambers after the “laby”
- option for series 10 : radial chambers from tooth 1 to IRS
- default value for IRS = NS on next line
- step shaft pressure calc. option ; IS = 1 = yes, 0 = no
- also the number of iterations on swirl for stepped shafting

  and for the temperature calculation procedure
- defaults of IB = 2 for IS = 0 and IB = 3 for IS = 1

RADIAL OPT ; NUMBER OF TEETH; PLUS RANGE FOR KXY; IRE=XXNT=XXNS=XXNE=XX

Format (50x, 3x, I2, 3x, I2, 3x, I2, 3x, I2) IRE, NT, NSKQS, NSKQE

- option for series 10 and 20 : radial chambers for tooth IRE to NT
- default value for IRE = NE
- Number of teeth or blades in labyrinth and equivalent system
- also range of teeth for k,c calcs.
- NS = tooth number for start and NE = last tooth for k,c calc
- current limit of <u>50</u> for number of chambers (teeth) input

TOOTH HEIGHT (IF KEY=1, INSERT LINE(S) 7G10.2)KEY =0 B= ___________.XX

Format (50x, I10, 2x, G10.2) KEYB, B

- add lines after control line if KEY = 1
- option allows variable chamber parameters
- zero values will default to last non-zero value
- if KEY = 0 all chambers default to value given by B

TOOTH SPACING (KEY=1,INSERT LINE(s)) KEY = 0l= ______.XX

Format (50x, I10, 2x, G10.2) KEYL, L

- add lines after control line if KEY = 1
- option allows variable chamber parameters
- zero values will default to last non-zero value
- if KEY = 0 all chambers default to value given by L

TOOTH CLEARANCE (KEY=1,INSERT LINE(S)) KEY = 0C = .XXX

Format (50x, I10, 2x, G10.2) KEYC, C

- add lines after control line if KEY = 1
- option allows variable chamber parameters
- zero values will default to last non-zero value
- if KEY = 0 all chambers default to value given by C

SHAFT RADIUS (KEY=1, INSERT LINE(S) 7G10.2) KEY = 0RS = _______XX.XX

Format (50x, I10, 2x, G10.2) KEYR, RS

- add lines after control line if KEY = 1
- option allows variable chamber parameters
- zero values will default to last non-zero value
- if KEY = 0 all chambers default to value given by RS

SURFACE CONSTANT(DEFAULT=0.079); F5.1, KEY YNR = _________.079 1.0INR=0
Format (50x, G10.2, F5.1, 4x, I1)

SURFACE CONSTANT(DEFAULT=-0.25) ;XFLOWI1;KEYYMR = _________-0.25XFR=0IMR=0
Format (50x, G10.2, 3x, I2, 4x, I1)

SURFACE CONSTANT(DEFAULT=0.079);*F5.1;KEY YNS = __________.079 1.0INS=0
Format (50x, G10.2, F5.1, 4x, I1)

SURFACE CONSTANT (DEFAULT=-0.25);XFLOWI1;KEY YMS = __-0.25XFS=0IMS=0
Format (50x, G10.2, 3x, I2, 4x, I1)

- use the given default values on these 4 lines usually
- YNR and YNS have ratio factor as option in cols. 61-65
- YMR and YMS have cross flow factor as option in col. 65; 0 = yes
- YMR and YMS have option to input factors per chamber with KEY=1
- if KEY = 0 all chambers default to value given by KEY line
- zero values will default to last non-zero value
- **Blasius pipe flow factors are N = 0.033 and M = -0.25**
- **honeycomb flow factors are N = 0.015 and M = -0.025**
- **default values are per YAMADA, ie., N == = 0.079 and M = -0.25**

GAS SWIRL AT INLET(PERCENT SPD); NCR-RPM; SWIRL = __.XXNC__XXXX.X

Format (50x, G10.2, 2x, G10.2) Swirl, NCR

- gas swirl at inlet to first chamber of system, ratio of gas
- angular velocity to that of the rotor.
- system natural frequency and perturbation whirl rate if option
- on speed line = 1: equivalent K-xy calculated with N-cr.
- default value for N-cr and whirl is rotor speed (ie., SPD on line 1)

GAS PRESSURE AT INLET; gas velocity (FT/SEC) PS = _____XXX.X V____XXX.X

Format (50x, G10.2, 2x, G10.2) PS, VABS

- gas static pressure before the first chamber of the system
- gas absolute velocity for calculation of total temperature

GAS PRESSURE AT EXIT PE = _____XX.X

Format (50x, G10.2) PE

-- gas static pressure after the last chamber of the system

GAS MOLEWEIGHT MW = ____XX.X

Format (50x, G10.2) MW

-- input molecular weight for the gas

GAS TEMPERATURE TABS =___XXX.X

Format (50x, G10.2) TABS

- input absolute temperature at inlet
- this can be static temperature if velocity specified on PS line

GAS COMPRESSIBILITY Z = ______.XX

Format (50x, G10.2) Z

- input Z compressibility factor for the gas

GAS RATIO OF SPECIFIC HEATS; AND CP GAMMA = ___X.XXCP ____X.X

Format (50x, G10.2, 2x, G10.2) GAMMA, CP

- input ratio of specific heats for the gas
- also specific heat at constant pressure, CP

GAS VISCOSITY MU * G (LBM/FT/SEC MUXG = ____X.XXE-XX

Format (50x, G10.2) MUxG

- **input gas viscosity note units !!!!) LBm/(Ft-sec)**

  Kinematic viscosity = MuxG / 12/PS*Z*R*TABS in^2/sec

  Centipoises = MuxG/12/386/1.45E-7 cp

MASS FLOW (LB/SEC) (IF P(I)>0); FCFAC,F5.1: MDOT = ____X.XX _X.X

Format (50x, G10.2, F5.1)

- leave mass flow blank if using pressure solution of program
- flow correction factor can be used to match flow to actual
- flow if this is known for the specific tooth type!!!!

CHAMBER PRESSURES 7G10.2 PER LINE (IF KEY=1) KEY = 0

- option to input chamber static pressure solution

CHAMBER TEMP. 7G10.2 (IF KEY=1;-2 VTR.;0=TABS) -2

- option to input chamber static temperature solution

MAX SOLUTION INTERATIONS, VC, MDOT (DEFAULT=50) ITER = ____50

Format (50x, I10) ITER

- option to tolerances for solutions on next 4 lines

TOLERANCE DEFAULT = 1E-4*RS*OMEGA TOLERV = ___1.0E-4

Format (50x, G10.2)

PRESSURE TOLERANCE (DEFAULT) = .01) TOLERP = ______.01

Format (50x, G10.2)

MASS FLOW TOLEANCE (DEFAULT = .0001) TOLERM = _______.01

Format (50x, G10.2)

PRINT MATRIX SETUP (= 1 TO PRINT ALL) KEYDMP = 0

Format (50x, I10)

- option to print the matrix for dynamic calcs

<blank>

<blank>

IF NSPD>1, INPUT NSPD LINES AS FOLLOWS <12G10.2> ; a 0.0 or blank will default to the value in the data input section of the last value entered for that variable.

- option to run multiple cases of speeds or other parameters
- option to have up to 10 cases is current limit.

SPEED	SWIRL	PS	PE	TABS	Z	GAMMA	MW	VABS	MUXG	CP	FNCR
XXXX.X	__.XX	XXX.X_	_XXX.X	_XXX.X	X.X	_X.X	_X.X	xxx	xxxx	xxx	xxxxx

Format (12G10.2)

SPD,SWIRL,PS,PE,TABS,Z,GAMMA,MW,VABS,MUXG,CP,FNCR

APPENDIX D

Example output for CURRENT.ORG Summary file for MASTER_RGK.LSI run with four speed cases considered.

Note:
The four cases have a tip swirl of 0.59, 0.3, 0.02, and -0.3. The swirl predicted at entrance to the balance drum seal is given in the summary table of each run (0.75, 0.59, 0.42, 0.23). This clearly shows how the inlet swirl can be changed from the tip of the wheel down the leak path.

```
>>>>>>>>>>>>>>>  CASE NO.  1   <<<<<<<<<<<<<<<

1         SOLUTION FOR LABYRINTH DYNAMIC STIFFNESS
    THE FOLLOWING SUMMARY CONDITIONS WERE GIVEN:
        ROTOR SPEED   =   10832.00 RPM    Ncr =    7400.00 CPM
        TOTAL TEMP.   =     773.43 DEG-R
        STATIC TEMP.  =     771.15 DEG-R
        INLET PRES.   =    1724.46 PSIA
        DISCH PRES.   =     938.22 PSIA
        SWIRL FACTOR  =        .75 DIM. VABS =     252.00 FT/sec
        NO. TEETH     =         13      MUXG =   .165E-04 lbm/FT/sec
        MOLEWEIGHT    =      43.86      CP =        .37 BTU/LBM/dgR

    ***<<<< STIFFNESS VALUES FOR TEETH   9 TO  21 >>>>****

    LABYRINTH DYNAMIC STIFFNESS MATRIX
        DIRECT STIFFNESS =    -10274.     LB/IN
        CROSS  STIFFNESS =     14026.     LB/IN
        DIRECT DAMPING   =     6.3462     LB-SEC/IN
        CROSS  DAMPING   =     8.9493     LB-SEC/IN
    LABYRINTH DAMPING FACTOR = C-KXY/OMEGW = -11.7536     LB-SEC/IN
        NEGATIVE WILL DRIVE SYSTEM
    LABYRINTH EFFECTIVE Q-AERO = KXY-C*OMEGW =  9108.18     LB/IN
        POSITIVE WILL DRIVE SYSTEM


    >>>>>>>>>>>>>>>  CASE NO.  2   <<<<<<<<<<<<<<<

1         SOLUTION FOR LABYRINTH DYNAMIC STIFFNESS
    THE FOLLOWING SUMMARY CONDITIONS WERE GIVEN:
        ROTOR SPEED   =   10832.00 RPM    Ncr =    7400.00 CPM
        TOTAL TEMP.   =     773.43 DEG-R
        STATIC TEMP.  =     772.03 DEG-R
        INLET PRES.   =    1759.92 PSIA
        DISCH PRES.   =     938.23 PSIA
        SWIRL FACTOR  =        .59 DIM. VABS =     252.00 FT/sec
        NO. TEETH     =         13      MUXG =   .165E-04 lbm/FT/sec
        MOLEWEIGHT    =      43.86      CP =        .37 BTU/LBM/dgR

    ***<<<< STIFFNESS VALUES FOR TEETH   9 TO  21 >>>>****

    LABYRINTH DYNAMIC STIFFNESS MATRIX
        DIRECT STIFFNESS =    -9211.1     LB/IN
        CROSS  STIFFNESS =     9459.9     LB/IN
        DIRECT DAMPING   =     5.2822     LB-SEC/IN
        CROSS  DAMPING   =     7.6518     LB-SEC/IN
    LABYRINTH DAMPING FACTOR = C-KXY/OMEGW = -6.92533     LB-SEC/IN
        NEGATIVE WILL DRIVE SYSTEM
    LABYRINTH EFFECTIVE Q-AERO = KXY-C*OMEGW =  5366.62     LB/IN
        POSITIVE WILL DRIVE SYSTEM
```

```
>>>>>>>>>>>>>>>  CASE NO.  3   <<<<<<<<<<<<<<<

1        SOLUTION FOR LABYRINTH DYNAMIC STIFFNESS
   THE FOLLOWING SUMMARY CONDITIONS WERE GIVEN:
      ROTOR SPEED   =   10832.00 RPM    Ncr =    7400.00 CPM
      TOTAL TEMP.   =     773.43 DEG-R
      STATIC TEMP.  =     772.70 DEG-R
      INLET PRES.   =    1782.14 PSIA
      DISCH PRES.   =     938.25 PSIA
      SWIRL FACTOR  =        .42 DIM. VABS =     252.00 FT/sec
      NO. TEETH     =         13      MUXG =   .165E-04 lbm/FT/sec
      MOLEWEIGHT    =      43.86      CP =        .37 BTU/LBM/dgR

   ***<<<< STIFFNESS VALUES FOR TEETH   9 TO  21 >>>>****

   LABYRINTH DYNAMIC STIFFNESS MATRIX
      DIRECT STIFFNESS =    -8148.9     LB/IN
      CROSS  STIFFNESS =     5108.9     LB/IN
      DIRECT DAMPING   =     4.4133     LB-SEC/IN
      CROSS  DAMPING   =     6.1443     LB-SEC/IN
   LABYRINTH DAMPING FACTOR = C-KXY/OMEGW = -2.17945     LB-SEC/IN
      NEGATIVE WILL DRIVE SYSTEM
   LABYRINTH EFFECTIVE Q-AERO = KXY-C*OMEGW =  1688.91     LB/IN
      POSITIVE WILL DRIVE SYSTEM



   >>>>>>>>>>>>>>>  CASE NO.  4   <<<<<<<<<<<<<<<

1        SOLUTION FOR LABYRINTH DYNAMIC STIFFNESS
   THE FOLLOWING SUMMARY CONDITIONS WERE GIVEN:
      ROTOR SPEED   =   10832.00 RPM    Ncr =    7400.00 CPM
      TOTAL TEMP.   =     773.43 DEG-R
      STATIC TEMP.  =     773.21 DEG-R
      INLET PRES.   =    1791.45 PSIA
      DISCH PRES.   =     938.25 PSIA
      SWIRL FACTOR  =        .23 DIM. VABS =     252.00 FT/sec
      NO. TEETH     =         13      MUXG =   .165E-04 lbm/FT/sec
      MOLEWEIGHT    =      43.86      CP =        .37 BTU/LBM/dgR

   ***<<<< STIFFNESS VALUES FOR TEETH   9 TO  21 >>>>****

   LABYRINTH DYNAMIC STIFFNESS MATRIX
      DIRECT STIFFNESS =    -7046.6     LB/IN
      CROSS  STIFFNESS =     419.36     LB/IN
      DIRECT DAMPING   =     3.6737     LB-SEC/IN
      CROSS  DAMPING   =     4.1480     LB-SEC/IN
   LABYRINTH DAMPING FACTOR = C-KXY/OMEGW =  3.13257     LB-SEC/IN
      NEGATIVE WILL DRIVE SYSTEM
   LABYRINTH EFFECTIVE Q-AERO = KXY-C*OMEGW = -2427.51     LB/IN
      POSITIVE WILL DRIVE SYSTEM
```

APPENDIX E

NEGAVIB
Labyrinth Seal Program

US distributor

Rodyn Vibration Analysis, Inc.
1501 Gordon Avenue
Charlottesville, VA 22903
434.326.6797
Rodyn.com

China

XecaTurbo Technologies
Mb: 86-189 1139 6280 Skype: xuefeng0909
Tel:010-8492 4950 Fax:010-8492 5792
Offices: Beijing, Shanghai, Xi'an, Changsha, Chengdu
Web: www.XecaTurbo.cn

DYNLAB Seal Analysis

References for DYNLAB Theory, Analysis and Results

Gas Labyrinth Seal Analysis Program: DYNLAB (LabyDRBSF)

Cost:: $ 6,000.00

This program was developed as a design tool for analysis of gas labyrinth seals typical of centrifugal compressor eye, shaft, and balance drum configurations. The major advantage of the labyrinth code is the ability to estimate the seal entrance swirl, given the impeller tip swirl which is a standard output of most any aerodynamic design code. The users manual explains the required input for the Dos program. The program has been tested and selected as the program of choice for toothed labyrinth designs by one major OEM compressor company and one major oil company in the US. The program has been used for 26 years at these companies. The program has been used as a consulting tool for the past 28 years.

The program can evaluate tooth on rotor, on stator or interlocking teeth. The seal can be straight through or stepped. The program input can be adjusted to estimate the influence of honeycomb seal designs with typical cell size. It can estimate actual seal entrance swirl.

A one-day short course is recommended to acquaint the users with the program capabilities and proper use for evaluation of entry swirl. The USA based in-plant course will be given for $3200 plus travel and living. International plant locations arrangements can be discussed for time and cost.

The compiled program executable and user’s manual are included in the purchase price.

Technical Papers on Gas Labyrinth Seal Analysis and Design
by R. G. Kirk

Conference Proceedings:

Kirk, R. G., and M. Simpson, "Full Load Testing of an 18,000 H.P. Gas Turbine Driven Centrifugal Compressor for Offshore Platform Service," Bently Nevada Research Corp. Symposium on Stability, NASA CP-2409, 1985.

Kirk, R. G., "Evaluation of Aerodynamic Instability Mechanisms for Centrifugal Compressors," ASME Paper 85-DET-147, presented at 1985 ASME Vibrations Conference, Cincinnati, Ohio, Sept. 11-13, 1985.

Kirk, R. G., "Influence of Disk Leakage Path on Labyrinth Seal Inlet Swirl Ratio," presented at Fourth Workshop on Rotor Dynamic Instability Problems in High Performance Turbomachinery, Texas A&M University, May, 1986, Proceedings, published as NASA- CP2443.

Kirk, R. G., "Labyrinth Seal Analysis for Centrifugal Compressor Design - Theory and Practice," Proceedings of the International Conference on Rotordynamics, Tokyo, September 14-17, 1986.

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Use of DYNLAB Program for consulting:

Dresser-Rand	Exxon	Mobil	GHH	BP	Mechanical Solutions
AMOCO	ExxonMobil	BP America	RMT	Elliott Company	York
AC Compressor	Solar	DeLaval	Joy	Conmec	Allied Signal
NREC	VECO/ARCO	BOC	Atlas Copco	ODS	

Purchase of Source Code:
ExxonMobil Dresser-Rand

Companies with .exe version
Dresser-Rand ExxonMobil BP America Lufkin- RMT Elliott Company Air Products
GE Oil&Gas DeMagDeLaval Rolls-Royce Energy Systems ODS Denmark

APPENDIX F

Download Instruction for latest LabySeal program:

1. Go to download page http://dyrobes.com/user_download/ password: dyrobes

2. Download the latest version: LabySeal_Setup.exe

3. Install the program, The installation password: LabySeal_V100

It is recommended to run the setup program – Run As Administrator

4 Install the driver, run Install_hasp_driver.BAT from the LabySeal folder
Note: If you have installed Dyrobes, you may skip this step.

5. If you use hardware protection (HL - USB dongle),
simply plug the USB dongle and you are ready to run the program.

If you use software protection (SL), run rus_cootg.exe and Collect Information. Save the information file (C2V file) and e-mail us. We will e-mail the license (V2C file) back to you.

For network license, SL is recommended due to its flexibility.

For individual license, either protection, HL or SL, is OK.

6. There will be an icon created on your desktop (LabySeal_V1.00), you may start the program from this main menu. Or you may start the program from the Windows – Start.

7 Obtain the license file for LabySeal from the distributor

8. Update your LabySeal license file. Run rus_cootg.exe with your dongly plugged and select Apply License Update in the second tab with the license file. Then the program will execute.