AXIAL-FLOW TURBINE AERODYNAMIC PERFORMANCE ANALYSIS (Program AxTurb)

AIR-15KW-OPEN-56X17.ATD

Date: 15/05/2015 Time: 08:25

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Case Data: Equivalent Mass Flow = 800
           Equivalent Speed = 120
           Equivalent Mass Flow/Actual Mass Flow = 1
           Equivalent Speed/Actual Speed = 1
           Inlet Governor Valve Pressure Ratio = 1
           End-Walls At Blade Tip Are Linear
           Streamline Curvature Effects Are Not Considered
           Reynolds Number Corrections Include Surface Finish Effects
           Moisture Loss Is Not Considered
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Inlet Flow Profile Data:

 Distance     Total      Total    Flow
 From Hub  Temperature  Pressure  Angle
   0.00 %       59.00      14.73    90.00
  25.00 %       59.00      14.73    90.00
  50.00 %       59.00      14.73    90.00
  75.00 %       59.00      14.73    90.00
 100.00 %       59.00      14.73    90.00
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No Turbine Inlet Seal
Turbine Discharge Seal Leakage Ignored
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Units: Temperature: deg F                    Velocity: ft/sec
       Pressure: psi                         Viscosity: lbm/ft/s
       Density: lbm/ft3                      Mass Flow Rate: lbm/sec
       Enthalpy: btu/lbm                     Volume Flow Rate: cfm
       Entropy: btu/lbm/deg F                Head: ft-lb/lbm
       Length: in                            Power: Hp
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SUMMARY OF GAS THERMODYNAMIC EQUATION OF STATE
 Using Original Redlich-Kwong Model
       To Create A Pseudo-Perfect Gas Model
 Gas Mixture: 100.00% Air

 Molecular Weight = 28.96
 Critical Temperature =-222.5 deg F
 Critical Pressure = 534.521 psi
 Critical Compressibility Factor = 0.2896
 Acentric Factor = 0.0357
 Cp = 2.5079E-01 + (-4.8441E-05 + (6.2531E-08 + -1.6048E-11 * T ) * T ) *
T
      [Cp in btu/lbm/deg F, T in deg R]
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SUMMARY OF THE GEOMETRY OF THE GAS PATH END-WALL CONTOURS

 z = Axial Coordinate      Rc = Radius Of Curvature
 r = radial Coordinate     Phi = Contour Slope Angle With z
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     ----------- Hub -------------- ---------- Shroud -------------
Upstream
        z       r     Phi   1/Rc        z       r     Phi   1/Rc    Blade
Type
  1  0.0000  9.0000   0.0  0.0000    0.0000  65.000   0.0  0.0000    None
  2  10.000  9.0000   0.0  0.0000    10.000  65.000   0.0  0.0000    None
  3  20.000  8.9415  -0.3  0.0000 *  20.000  65.058   0.3  0.0000 *  None
  4  32.000  8.8714  -0.3  0.0000    32.000  65.129   0.3  0.0000
Rotor
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  * Upstream Contour Or Contour Slope Discontinuity

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SUMMARY OF THE GEOMETRY FOR ALL BLADE ROWS

 Beta1 = Inlet Blade Angle       BetaG = Blade Gauging Angle =
arcsin(O/S)
 O = Throat Width                Tmax = Maximum Thickness
 T2 = Trailing Edge Thickness    Rc = Suction Surface Radius Of Curvature
 S = Blade Pitch                 C = Blade Chord
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Geometry For Rotor 1

 Number Of Blades = 17                 Fractional Shielding = 0
 Blade Is Unshrouded                   Blade Clearance = 0.1235
 Surface Finish = 0.000045             Throat Blockage = 0
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$H
     Radius   Beta1   BetaG     O       C     Tmax     T2     1/Rc
S/C
  1  8.8710   96.23   31.17  1.6970  15.190  3.0370  0.0656  0.0000
0.2158
  2  15.900  101.08   41.61  3.9024  14.380  2.8770  0.1176  0.0000
0.4087
  3  22.940  105.77   45.79  6.0774  14.280  2.8560  0.1695  0.0000
0.5937
  4  29.970  110.25   47.04  8.1064  14.450  2.8910  0.2215  0.0000
0.7666
  5  37.000  114.49   46.85  9.9769  14.770  2.9550  0.2735  0.0000
0.9259
  6  44.030  118.46   45.91  11.688  15.190  3.0390  0.3255  0.0000
1.0713
  7  51.060  122.15   44.58  13.246  15.690  3.1380  0.3775  0.0000
1.2028
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  8  58.100  125.57   43.06  14.661  16.250  3.2500  0.4294  0.0000
1.3215
  9  65.130  128.72   41.47  15.941  16.860  3.3710  0.4814  0.0000
1.4278
$

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SUMMARY OF ABSOLUTE FLOW AT ALL STATIONS

  r = Radius                    Cm = Meridional Velocity
  Cu = Tangential Velocity      C = Absolute Velocity
  M = Mach Number               Alpha = Flow Angle With Tangent
  Tt = Total Temperature        T = Static Temperature
  Pt = Total Pressure           P = Static Pressure
  Rho = Static Density          Weq = Equivalent Mass Flow
  Pr = Ave. Pressure Ratio      Eta = Ave. Adiabatic Efficiency
  Ht = Total Enthalpy           (T-T) = Total-To-Total
  (T-S) = Total-To-Static
  Note: Alpha is in the blade exit convention.  When matching a
downstream
  stationary blade, use (180 - Alpha) to estimate its inlet flow angle.
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 Station Number 1 (Duct Section), Weq = 800, Admission = 100 %
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$H
    r     Cm     Cu      C      M    Alpha   Pt     Tt      P      T
Rho
 9.0000 115.89 0.0000 115.89 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
 24.474 115.89 0.0000 115.89 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
 33.422 115.89 0.0000 115.89 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
 40.435 115.89 0.0000 115.89 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
 46.400 115.89 0.0000 115.89 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
 51.682 115.89 0.0000 115.89 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
 56.471 115.89 0.0000 115.89 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
 60.885 115.89 0.0000 115.89 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
 65.000 115.89 0.0000 115.89 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
$

$0
 Station Number 2 (Duct Section), Weq = 800, Admission = 100 %
$

$H
    r     Cm     Cu      C      M    Alpha   Pt     Tt      P      T
Rho
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```
 9.0000 115.91 0.0000 115.91 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
 24.474 115.91 0.0000 115.91 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
 33.422 115.91 0.0000 115.91 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
 40.435 115.91 0.0000 115.91 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
 46.400 115.91 0.0000 115.91 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
 51.682 115.91 0.0000 115.91 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
 56.471 115.91 0.0000 115.91 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
 60.885 115.91 0.0000 115.91 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
 65.000 115.91 0.0000 115.91 0.1040 90.000 14.730 59.000 14.619 57.882
0.0764
$

$0
 Station Number 3 (Duct Section), Weq = 800, Admission = 100 %
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$H
    r      Cm      Cu       C       M    Alpha   Pt      Tt       P       T
Rho
 8.9415 115.67 0.0000 115.67 0.1038 90.000 14.730 59.000 14.619 57.886
0.0764
 24.475 115.67 0.0000 115.67 0.1038 90.000 14.730 59.000 14.619 57.886
0.0764
 33.438 115.67 0.0000 115.67 0.1038 90.000 14.730 59.000 14.619 57.886
0.0764
 40.462 115.67 0.0000 115.67 0.1038 90.000 14.730 59.000 14.619 57.886
0.0764
 46.436 115.67 0.0000 115.67 0.1038 90.000 14.730 59.000 14.619 57.886
0.0764
 51.724 115.67 0.0000 115.67 0.1038 90.000 14.730 59.000 14.619 57.886
0.0764
 56.519 115.67 0.0000 115.67 0.1038 90.000 14.730 59.000 14.619 57.886
0.0764
 60.939 115.67 0.0000 115.67 0.1038 90.000 14.730 59.000 14.619 57.886
0.0764
 65.058 115.67 0.0000 115.67 0.1038 90.000 14.730 59.000 14.619 57.886
0.0764
$

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 Station Number 4 (Rotor No. 1 Exit), Weq = 800, Admission = 100 %

  Pr(T-T) = 1.003,  Eta(T-T) =0.86185,  Pr(T-S) = 1.013,  Eta(T-S)
=0.20315
$

$H
    r      Cm      Cu       C       M    Alpha   Pt      Tt       P       T
Rho
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```
 8.8714 128.03 -181.2 221.87 0.1997 144.76 14.685 58.720 14.282 54.622
0.0751
 23.568 125.09 -74.48 145.58 0.1308 120.77 14.693 58.694 14.518 56.930
0.0760
 32.326 121.46 -59.36 135.19 0.1214 116.04 14.692 58.665 14.541 57.144
0.0761
 39.348 118.16 -52.78 129.41 0.1162 114.07 14.689 58.638 14.551 57.244
0.0761
 45.438 115.30 -48.95 125.26 0.1125 113.00 14.686 58.612 14.557 57.306
0.0761
 50.921 112.82 -46.34 121.96 0.1095 112.33 14.684 58.589 14.561 57.350
0.0761
 55.966 110.58 -44.34 119.14 0.1070 111.85 14.681 58.567 14.564 57.386
0.0761
 60.680 108.53 -42.67 116.62 0.1047 111.46 14.679 58.549 14.567 57.416
0.0761
 65.129 106.66 -41.24 114.36 0.1027 111.14 14.677 58.532 14.569 57.443
0.0762
$

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SUMMARY OF RELATIVE FLOW FOR ALL BLADE ROWS

   Suffix 1 = Blade Inlet                Suffix 2 = Blade Exit
   W = Relative Velocity                 Tt = Relative Total Temperature
   M = Relative Mach Number              Pt = Relative Total Pressure
   h = Static Enthalpy                   H = Absolute Total Enthalpy
   Beta = Relative Flow Angle Measured   R = Rotor Reaction
          From Concave Side Of Blade       = (h1 - h2) / (H1 - H2)
$

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 Rotor No. 1

$H
   W1     W2   Beta1 Beta2   M1     M2     Tt1    Tt2    Pt1    Pt2     R
 116.05 229.52  94.6  33.9 0.1041 0.2066 59.007 59.007 14.731 14.714
11.647
 118.47 159.62 102.5  51.6 0.1063 0.1434 59.055 59.051 14.735 14.728
3.126
 120.85 153.10 106.8  52.5 0.1085 0.1375 59.102 59.095 14.740 14.734
2.219
 123.19 150.98 110.1  51.5 0.1105 0.1356 59.150 59.141 14.745 14.739
1.774
 125.47 150.38 112.8  50.1 0.1126 0.1350 59.197 59.189 14.750 14.744
1.496
 127.72 150.53 115.1  48.5 0.1146 0.1352 59.244 59.237 14.754 14.748
1.303
 129.93 151.08 117.1  47.0 0.1166 0.1356 59.292 59.286 14.759 14.753
1.157
 132.10 151.86 118.9  45.6 0.1186 0.1363 59.339 59.336 14.764 14.757
1.041
 134.24 152.82 120.5  44.3 0.1205 0.1372 59.386 59.387 14.768 14.762
0.947
$

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SUMMARY OF PERFORMANCE DATA FOR ALL BLADE ROWS
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 Inc = Incidence Angle                  Sinc = Stall Incidence Angle
 Dev = Deviation Angle                  Yp = Profile Loss coefficient
 Ys = Secondary Flow Loss Coefficient  Ycl = Seal/Clearance Loss
Coefficient
 dWq/W = Work Loss Due To Moisture     Yw = Lashing Wire Loss Coefficient
 YTE = Trailing Edge Loss Coefficient  Yex = Expansion Loss Coefficient
 Y = Total Loss Coefficient            Ysh = Shock/Diffusion Loss
Coefficient
 Re = Blade Chord Reynolds Number      ReLim = Re Corrected For Roughness
 KRe = Re Correction To Yp & Ys        Kp = Mach No. Correction To Yp
 Ks = Mach No. Correction To Ys        YRe/Y = Re-Dependent Fraction Of Y
 Q = Flow Quality                      Re* = Re Based On Tip Speed &
Radius
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 Rotor No. 1 Performance Data, Admission = 100.00 %

 Blade Row Efficiency = 0.9702          Blade Row Flow/Ideal Flow =
1.0000
 Blade Row Velocity Coeff = 0.9850      Blade Row Mean Flow Coeff =
2.9853
 Rotor Mean Work Coeff = 1.4013         Flow/Sonic Flow = 0.2537
 Blade Row Throat Area = 9155.27        Mean Aspect Ratio, h/c = 3.512

$H
 SL    Inc   Sinc    Dev    KRe     Kp     Ks     M1     M2     Re
ReLim
  1   1.65  28.70   2.74 0.7841 0.9979 0.9999 0.1041 0.2066 1.83E+06
1.83E+06
  2   4.27  18.86   5.61 0.8455 1.0000 1.0000 0.1063 0.1434 1.21E+06
1.21E+06
  3   5.53  17.97   5.40 0.8489 1.0000 1.0000 0.1085 0.1375 1.18E+06
1.18E+06
  4   6.36  16.89   4.90 0.8472 1.0000 1.0000 0.1105 0.1356 1.19E+06
1.19E+06
  5   6.95  16.53   4.40 0.8438 1.0000 1.0000 0.1126 0.1350 1.22E+06
1.22E+06
  6   7.39  16.07   3.93 0.8397 1.0000 1.0000 0.1146 0.1352 1.25E+06
1.25E+06
  7   7.73  15.43   3.51 0.8354 1.0000 1.0000 0.1166 0.1356 1.29E+06
1.29E+06
  8   7.99  14.64   3.13 0.8310 1.0000 1.0000 0.1186 0.1363 1.33E+06
1.33E+06
  9   8.19  14.19   2.79 0.8266 1.0000 1.0000 0.1205 0.1372 1.37E+06
1.37E+06
$

$H
 SL    Yp     Ys    Ycl    YTE    Ysh    Yex   dWq/W    Yw     Y    YRe/Y
Q
  1 0.0414 0.0124 0.0000 0.0014 0.0000 0.0000 0.0000 0.0000 0.0552 0.9804
1.0000
  2 0.0194 0.0053 0.0004 0.0007 0.0000 0.0000 0.0000 0.0000 0.0257 0.9662
1.0000
  3 0.0208 0.0039 0.0007 0.0006 0.0000 0.0000 0.0000 0.0000 0.0261 0.9549
1.0000
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  4 0.0230 0.0034 0.0011 0.0007 0.0000 0.0000 0.0000 0.0000 0.0282 0.9466
1.0000
  5 0.0222 0.0033 0.0015 0.0007 0.0000 0.0000 0.0000 0.0000 0.0276 0.9333
1.0000
  6 0.0221 0.0033 0.0018 0.0007 0.0000 0.0000 0.0000 0.0000 0.0279 0.9219
1.0000
  7 0.0231 0.0033 0.0022 0.0008 0.0000 0.0000 0.0000 0.0000 0.0293 0.9142
1.0000
  8 0.0252 0.0034 0.0025 0.0008 0.0000 0.0000 0.0000 0.0000 0.0320 0.9108
1.0000
  9 0.0282 0.0035 0.0029 0.0009 0.0000 0.0000 0.0000 0.0000 0.0355 0.9103
1.0000
Ave 0.0250 0.0046 0.0015 0.0008 0.0000 0.0000 0.0000 0.0000 0.0320 0.9376
1.0000
$

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STAGE PERFORMANCE DATA

 (T-T) = Total-To-Total                 (T-S) = Total-To-Static
 (S-S) = Static-To-Static               Cis = Stage Spouting Velocity
 PrTT = (T-T) Pressure Ratio            EtaTT = (T-T) Efficiency
 PrTS = (T-S) Pressure Ratio            EtaTS = (T-S) Efficiency
 R = Reaction = Dh-Rotor/DH             Rp = Pressure Reaction = DP-
Rotor/DPT
 Work Coefficient = DH/U/U              DH = Stage Total Enthalpy Drop
 Flow Coefficient = Cmin/U              DPT = Stage Total Pressure Drop
 Meq = (T-S) Cis/Exit Sound Speed       U = Mean Wheel Speed
 W* = Ideal Choked Nozzle Mass Flow     W = Stage Mass Flow
 a* = Inlet Sonic Velocity              Cmin = Average Stage Inlet Cm
 Re* = Machine Re (Based On Last        Rec = Stage Average Blade Chord Re
       Rotor Tip Speed & Radius)        [R Excudes Leakage & Parasitic
Work]
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Performance Of Stage Number 1 (Stations 1 To 4)

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Stream  ---- Stage Performance --- - Reaction -- - Performance From Inlet
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  Line   PrTT   PrTS  EtaTT  EtaTS      R     Rp   PrTT   PrTS  EtaTT
EtaTS
     1  1.003  1.031  0.619  0.062 11.647  7.488  1.003  1.031  0.619
0.062
     2  1.003  1.015  0.814  0.143  3.126  2.710  1.003  1.015  0.814
0.143
     3  1.003  1.013  0.867  0.175  2.219  2.043  1.003  1.013  0.867
0.175
     4  1.003  1.012  0.874  0.200  1.774  1.666  1.003  1.012  0.874
0.200
     5  1.003  1.012  0.881  0.222  1.496  1.428  1.003  1.012  0.881
0.222
     6  1.003  1.012  0.886  0.242  1.303  1.261  1.003  1.012  0.886
0.242
     7  1.003  1.011  0.885  0.259  1.157  1.132  1.003  1.011  0.885
0.259
     8  1.003  1.011  0.880  0.274  1.041  1.030  1.003  1.011  0.880
0.274
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     9  1.004  1.011  0.874  0.288  0.947  0.948  1.004  1.011  0.874
0.288
  Ave:  1.003  1.013  0.862  0.203  2.745  2.190  1.003  1.013  0.862
0.203

      Stage Power = 103.82 Hp          U/Cis (T-S) = 0.2577
      Stage Work = 0.0917 btu/lbm      U/Cis (T-T) = 0.5308
      Work Coefficient = 1.53          U/Cis (S-S) = 0.4045
      Flow Coefficient = 2.991         Meq = 0.135
      Cis/a* (T-T) = 0.0717            U/a* = 0.0381
      Cis/a* (T-S) = 0.1477            W/W* = 0
      Mean Specific Speed = 1.175      Re* = 2.3548E+06
      Rec = 1.2212E+06                 Rec/Re* =  0.5186
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TURBINE OVERALL PERFORMANCE DATA

 The Performance Analysis Is Converged
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OPERATING CONDITIONS

 Inlet Governor Valve Pressure Ratio = 1
 Inlet Admission = 100 %
 Inlet Mass Flow = 800 lbm/sec
 Inlet Total Pressure = 14.73 psi
 Inlet Total Enthalpy = 124.42 btu/lbm
 Inlet Total Temperature = 59 deg F
 Rotation Speed = 120 rpm
 Discharge Mass Flow = 800 lbm/sec
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PERFORMANCE AT THE LAST STAGE EXIT

 Total Pressure = 14.69 psi
 Static Pressure = 14.54 psi
 Total Enthalpy = 124.33 btu/lbm
 Total Enthalpy Drop = 0.0917 btu/lbm
 Total Temperature = 58.62 deg F
 Total Temperature Ratio = 1.001
 Total-To-Total Pressure Ratio = 1.003
 Total-To-Static Pressure Ratio = 1.013
 Total-To-Total Adiabatic Efficiency = 0.8619
 Total-To-Total Polytropic Efficiency = 0.8619
 Total-To-Static Adiabatic Efficiency = 0.2031
 Total-To-Static Polytropic Efficiency = 0.2031
 Total-To-Total U/Cis = 0.5308
 Total-To-Static U/Cis = 0.2577
 Static-To-Static U/Cis = 0.4045
 U/a* = 0.0381
 Total Power = 103.82 Hp
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SIMILITUDE PERFORMANCE DATA BASED ON THE INLET SONIC FLOW DATA,
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THE FIRST BLADE ROW INLET SHROUD DIAMETER AND THE FRONTAL AREA

Inlet Sonic Velocity, a* = 1018.1 ft/sec
Inlet Sonic Density, Rho* = 0.0487 lbm/ft3
Inlet Sonic Pressure, P* = 7.786 psi
Inlet Sonic Temperature, T* = -27.29 deg F
Shroud Diameter, Ds = 130.12 in
Frontal Area, AF = 13297.12 sq in
Shroud Speed, Us = 68.13 ft/sec
Inlet Mass Flow / AF / Rho* / a* = 0.1748
Shroud Speed / a* = 0.0669
Total Enthalpy Drop / a* / a* = 0.0022
Total-To-Total Cis / a* = 0.0717
Total-To-Static Cis / a* = 0.1477
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TOTAL THERMODYNAMIC CONDITION	INLET	EXIT	UNITS
Pressure	14.7300	14.6859	psi
Temperature	59.0000	58.6176	deg F
Enthalpy	124.422	124.330	btu/lbm
Density	0.07676	0.07659	lbm/ft3
Entropy	0.97521	0.97524	btu/lbm/deg F
Compressibility Factor	1.00000	1.00000	-----
Specific Heat	0.23989	0.23989	btu/lbm/deg F
Ratio Of Specific Heats	1.39974	1.39974	-----
Sound Speed	1115.52	1115.11	ft/sec
Quality	1.00000	1.00000	-----

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TURBINE BLADE FORCE & THRUST DATA

r = radius (in)
Fz = Axial Force/Unit Length (lb/in)
Fu = Tangential Force/Unit Length (lb/in)
Mz = Axial Bending Moment (in-lb)
Mu = Tangential Bending Moment (in-lb)
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Blade Forces For Rotor No. 1

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r	Fz	Fu	Mz	Mu
8.90647	1.02923	-1.1850	-1410.9	2152.28
24.0216	0.73444	-1.3065	-1293.3	2016.91
32.8820	0.81564	-1.4059	-1159.9	1793.22
39.9050	0.94100	-1.4970	-1003.2	1541.91
45.9368	1.07269	-1.5792	-831.59	1267.24
51.3222	1.20551	-1.6522	-645.46	973.542
56.2428	1.34005	-1.7150	-444.89	663.348
60.8091	1.47574	-1.7675	-229.78	338.384
65.0936	1.60997	-1.8123	0.00000	0.00000

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Number Of Active Blades = 17 (100% Admission)

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  Total Tangential Force (All Active Blades) =-1408.184 (lb)
  Total Axial Force (All Active Blades) = 969.5582 (lb)
  Total Rotor Row Thrust Force = 969.5582 (lb)

 Total Rotor Thrust Force = 969.5582 (lb)
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