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COMDES-MELT: A Turbofan Engine Icing Risk Analysis Tool, User's Manual

Philip C. E. Jorgenson and Joseph P. Veres
Glenn Research Center, Cleveland, Ohio

An Erratum was added to this report September 2020.

March 2020

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National Aeronautics and
Space Administration

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Erratum

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This Technical Memorandum is the user's manual for the releasable version of the code, which is available on the NASA Software Repository, https://software.nasa.gov/.

Page 83, Section 7.4.1.1 Input File: Replace data with the following.

comdes.dat

```
         Single Centrifugal SRW HPC Option # 2 Low Ns  1-20-2010
     30.0       159.25     1119.39      38620.0       Wact        Pt1          Tt1         RPM
      5          1          0           0.00        Fluid       Stages       IDUMMY      DUMMY
      0.00       46.900     000.00      0.00        DropDia     InDist       RHinlet     IWC
***icing***
      2.70        0.00      406.44      0.00        Psin        DUMMY        Tsin        DUMMY
***icing***
    607.8         0.00    00000.00      0           Vin         DUMMY        Altitude    IDUMMY
***icing***
      3.40        2.41        5.88        5.88      1 R1tip       R1hub        R2tip       R2hub
      0.3300      0.380      30           0.0300      1.0         B1axial      B2axial     NBLAD       THK
CFS
      0.0         0.0000      0.000       1.0000      1.0         StatorT      StatorM     StatorH     FSGV
CFMid
      0.9800      0.9500      1.1000      0.9000      1.0         AeroB1       AeroB2      POTS        POTH
CFHub
      0.842       0.9220      0.917       0.0000      EfficiT     EfficiM      EfficiH     BLEED
      0.00        0.00        0.00        0.00        DUMMY       DUMMY        DUMMY       DUMMY
      0.8500      0.16        1.460       0.00        SlipF       DiffLoss     Solidity    RPM2
     51.50       50.60       48.00        0.0         BetaBlade1T BetaBlade1M  BetaBlade1H expo3
     23.50       23.50       23.50        2           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
      6.35        6.35        0.38       67.5         R3s         R3h          B3X         BetB3
     74           0.03        0.95        0.01        Blan3       Blath3       Blok3       Wbar23
      6.60       10.60        0.95        0.015       RCG         Athrt        BlokTH      Wbar2T
      9.55        9.55        0.37       55.0         R4S         R4H          B4X         BetB4
     74           0.03        0.95        1.30        Blan4       Blath4       Blok4       SolidStat
     10.50       10.10        0.00       50.0         R5s         R5h          B5X         BetB5
     95           0.03        0.95        0.01        Blan5       Blath5       Blok5       Wbar56
     0.00         0.000       0.95        0.015       RCG2        Athrt2       BlokTH      Wbar5T
     10.50       10.10        0.0         0.0         R6S         R6H          B6X         BetB6
     95           0.03        0.95        1.30        Blan6       Blath6       Blok6       SolidStat
     10.50       10.10        0.00        1.0         R7S         R7h          B7X         Length67
      2           0.01        0.98        0.000       Blan7       Blath7       Blok7       Wbar67
     10.50       10.10        0.0         1.0         R8S         R8h          B8X         Length78
      2           0.01        0.98        0.00        Blan8       Blath8       Blok8       Wbar78
```

Page 85, Section 7.4.1.2 Output File: Insert "Overall Exit Conditions" data.

```
  OVERALL EXIT CONDITIONS; ALL           1   STAGES


  Del Enthal   DelHT/U1^2  GHP      MassFloS1cor  OPR     Efficiency    Rotor1Inc  TR      AxHubLen

   2935275.00     2.2355  4976.2515    4.068      2.5715   0.71662       6.0454    1.3959    5.673
```

Contents

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Summary

The computational tool COMDES-MELT was developed to predict the susceptibility of turbofan engines to ice accretion when flying in an ice crystal environment. COMDES-MELT is a first-generation computational tool that can estimate the conditions at which the accretion of ice can occur, location within the turbofan engine compression system, and at which engine operating points within the flight trajectory. This is accomplished by tracking the parameters of static wet bulb temperature, ice particle melt ratio, and the ice-water to airflow rates ratio as ice crystals are ingested into the engine compression system. It has been used successfully to predict engine operating points for simulation in an altitude wind tunnel with ice crystal ingestion. These engine tests occur in a simulated ice crystal cloud environment. This predictive analysis has been used to generate the test matrix in preparation for tests in the Propulsion Systems Laboratory, an altitude test facility at the NASA Glenn Research Center. Furthermore, due to the speed of the code during an engine icing test, adjustments to the test matrix can be provided to the test engineer in real time to focus on a particular area of ice accretion susceptibility. The use of the COMDES-MELT code will be examined in this manual.

1.0 Introduction

Commercial airlines flying through clouds with high ice water content have experienced engine icing events (Ref. 1). These events have been attributed to ice crystal ingestion into the turbofan engine, which results in accretion on the components of the compression system. The total number of engine icing events per year appears to be increasing since 2002 (Ref. 2). The engine events have occured at altitudes between 10,000 and 40,000 ft and at temperatures between the International Standard Atmosphere (ISA) and 36 °R above ISA temperature. As ice crystals are ingested into the fan and low-pressure compression system, the air static temperature typically increases and a portion of the ice crystals melt due to the warmer air. This allows the ice-water mixture to stick and accrete upon impacting the metal surfaces of the compressor components. It is hypothesized that this allows the ice-water mixture to cover the metal surfaces of the compressor stationary components, which leads to ice accretion through evaporative cooling. The accreted ice can cause the occurrence of one or more of the following failure modes: uncommanded loss of thrust control (engine rollback), compressor surge or stall, ice shedding resulting in structural damage to the downstream compressor blades, and possible combustor flameout.

A computational tool has been developed and applied to the compression systems of turbofan engines to predict the locations where there is an ice accretion risk at various altitudes and operating conditions in a flight trajectory. The primary purpose of this user's manual is to demonstrate the use of this icing risk prediction tool.

2.0 Key Features

The primary focus of this user's manual is to describe the COMDES (Ref. 3) mean-line compressor flow analysis computer code and its effective implementation and use as an engine icing risk prediction tool COMDES-MELT (Refs. 4 and 5). This analysis tool has the capability of computing the risk of ice accretion in the turbofan engine compression system by tracking key parameters through the compression system blade rows at all engine operating points within the flight trajectory. The results from an engine system thermodynamic cycle code or experimental data is required to provide boundary conditions to the COMDES code, which together with an ice particle melt code, MELT, has the capability of determining the rate of sublimation, melt, and evaporation of ice particles as they travel through the compressor blade rows.

The COMDES-MELT code computes the velocity, pressure, temperature, and flow angles at the leading and trailing edges of each blade row and at the hub, mean, and tip sections. This compressor code includes the ability to calculate the effects of water vapor on the fluid properties of the air-water vapor mixture based on the mole fraction of air to water vapor. The relative humidity at the engine inlet is specified, and the local specific humidity (mass of water to mass of air) is computed through each component of the inlet-fan low-pressure compressor (LPC), taking the sublimation, melt, and evaporation into consideration, as well as the local air temperature. The resulting effect of the humid air on the performance of the compressor is computed. Several key parameters have been identified as early indicators of an ice accretion risk: the local wet-bulb temperature, the melt ratio within each blade row, and the ice water to airflow rate ratio (IWAR). The local wet-bulb temperature is calculated at each blade row. The geometry section of the code is defined by simple circular arc rotors and stators, including stage axial gaps. As the ice particles pass through the compression rotors, stators, and gaps, the ice particle melting and evaporation model computes the local melt ratio, change in enthalpy, and particle temperature and diameter through each compressor component. The ratio of IWAR is computed at the inlet based on the ice water content in the atmosphere and the mass flow rate of air entering the engine. If the limiting values of these key parameters are met, there is a risk that ice will accrete on the surfaces of the compressor. With these parameters as the precursors to ice accretion, the blade row within the compression system can be identified that is likely to experience ice buildup at a particular engine operating condition in the vehicle flight trajectory.

Assumptions are made in predicting the complex physics involved in engine icing. Specifically, the code does not directly estimate ice accretion and does not have models for ice particle breakup or erosion. The code is used to determine the risk of icing by computing engine operating points in the flight trajectory over a range of atmospheric ice conditions (discrete ice particle sizes and concentrations). The computational tool can be used to assess specific turbofan engines as to their susceptibility to ice accretion in an ice crystal environment. Without additional information about the wall heat transfer, this code is limited to adiabatic flow paths.

In the following sections, this user's manual includes a general description of the analysis code and its current capabilities. The code execution, input and output file variable descriptions, and example cases, with their output and corresponding input files, are described as well. The example section includes information on how an input file is created and the sensitivity of the rotor exit flow angle, pressure, and temperature to the slip factor, blockage, and efficiency specified as parameters. In addition, a stage-matching example is provided, which illustrates how a single stage can be the limiting component in the overall performance of the compressor. The COMDES code is capable of analyzing axial, centrifugal, and mixed axial and centrifugal compressors. Though the icing analysis has been computed only on axial compressors, examples of centrifugal and mixed axial and centrifugal compressor analysis without ice particle ingestion are included for completeness.

3.0 COMDES-MELT: Engine Icing Risk Prediction Tool

The engine icing risk prediction code COMDES-MELT is a mean-line compressor analysis code coupled with an ice crystal thermodynamic state code. A general description of the mean-line code will be given followed by specifics of how the enthalpy exchange between ice particles and the air is incorporated into the flow analysis. In a following section, an example is outlined where a conceptual design is generated. Its performance is predicted and compressor maps are generated. It is then further analyzed for icing risk.

The COMDES code is based on the compressible fluid flow equations and the Euler equation. The rotor efficiency and stator (or diffusion system) losses at the design point are input items into the code. The design point rotor efficiency is modeled at offdesign by an empirical correlation with rotor incidence. The relative velocity ratio and the diffusion factor through the rotor are correlated to the onset of stall. The equations and variables used in the mean-line analysis are listed in the governing equations section of this user's manual.

3.1 Flow Path and Velocity Triangle Definitions

COMDES is a compressor analysis code and requires specific input parameters: geometric, aerothermodynamic, and kinematic. The rotor hub and tip radii from the centerline that define the flow path are input at the leading and trailing edges as shown in Figure 1. Other input parameters are the inlet total pressure and temperature, mass flow, shaft rotational speed, rotor aerodynamic blockages at the inlet and exit, efficiency, and slip factor.

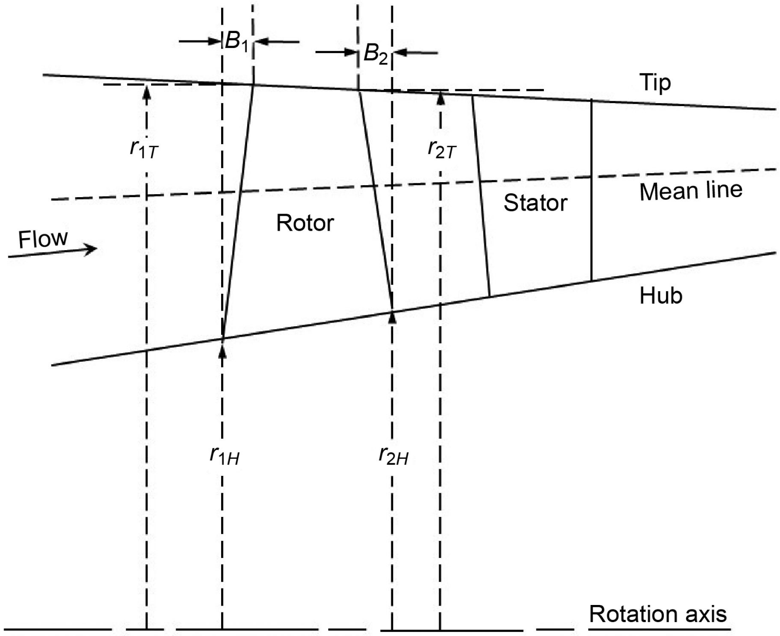

Figure 1.—Axial compressor flow path geometry input parameters to COMDES. Edge sweep is B; blade radius is r. Subscripts: leading edge is 1; trailing edge is 2; hub is H; tip is T.

The code computes the pressure and temperature rise through the rotor. The mass flow is then varied through the compressor along a constant speed line to determine flow conditions that result in choke or surge. Choke is determined as the limit of flow where small increases in corrected mass flow results in large drops in calculated pressure ratio, and eventually, the code will fail to converge on the rotor exit velocity triangles. Surge has been determined empirically from the NASA Stage 37 and the 74–A compressor data correlated to the values of rotor diffusion factor and relative velocity ratios at the tested surge point (Ref. 3).

At each point along each speed line, the iteration begins with solving for the static pressure and temperature at the rotor leading edge, based on the available area, incidence, mass flow rate, and the inlet total pressure and temperature. Once the inlet Mach number and static pressure and temperature have been computed, all of the components of the absolute and relative velocities and flow angles are determined as shown in Figure 2.

The rotor exit deviation angle is taken into consideration in the iterative calculations and is specified as an input item in terms of a slip factor as defined by Equation (28) in the next section. The code calculates all of the components of the rotor exit velocity diagram shown in Figure 2 by solving Equations (20) to (36), presented in Section 4.3, simultaneously using an iterative technique. All of the components of velocity at the rotor trailing edge are derived from the enthalpy rise as calculated from Equations (21) and (22) in terms of temperature rise across the rotor, and the Euler equation. An analogous illustration of the inlet and exit velocity diagrams for the centrifugal impeller is included in Example Case (4) (see Figure 26).

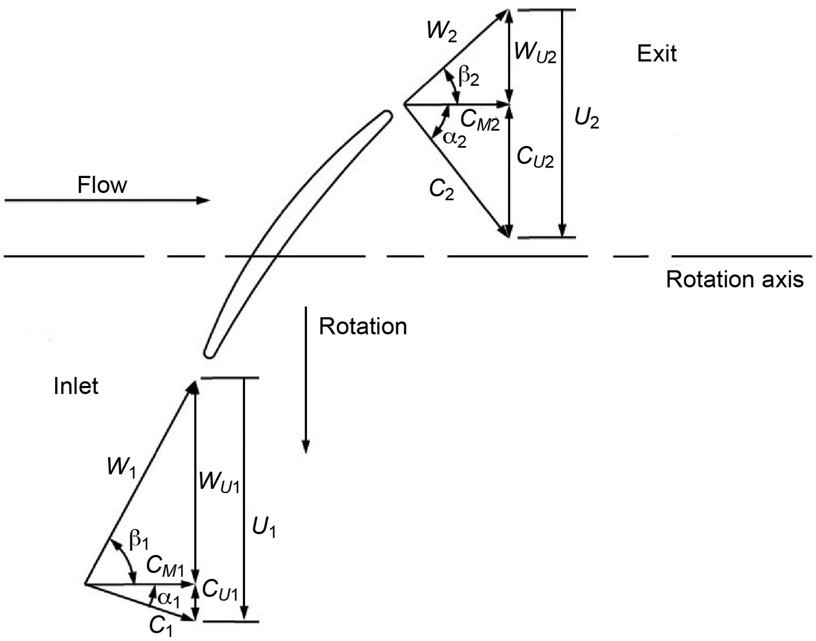

Figure 2.—Axial rotor inlet and exit velocity triangles. Absolute velocity is C; rotor peripheral velocity is U; relative velocity is W; absolute flow angle is α; relative flow angle is β. Subscripts: leading edge is 1; trailing edge is 2; meridional is M; tangential is U.

The mean-line computer code is executed to estimate the performance of the compressor at off-design, or part-speed, operation. To determine the efficiency at off-design conditions, the compressor rotor efficiency at the design point is input. Note that the design point efficiency is that value only at a rotor incidence of 6° just ahead of the rotor, not including metal blockage at the leading edge. This design point incidence was also determined empirically from analysis of test data (Ref. 3). The design point efficiency is assumed to be the same along all speed lines, and is varied only as a function of rotor incidence angle. The losses through the stators due to incidence are not varied directly but are lumped into the efficiency calculation, which is a function of rotor incidence as defined by Equation (36). This is a simplification which assumes that as the flow rate changes along a speed line, both the rotor and the stator experience a change of incidence from their design value, and therefore, a reduction in efficiency occurs. A model for stator loss variation with incidence that is separate from the efficiency deration due to incidence of the rotor can be included in a future version of the code. Also, the stator and rotor total-pressure loss coefficients need to be replaced in a future version of the code by a better correlation as a function of Mach number and incidence.

3.2 Rotor and Stator Blade Geometry Generator

The geometry generator produces compressor blades that are in the shape of a circular arc. The code generates rotor blades and stator vanes based on the values of the blade angles at the leading and trailing edges, the tip solidity, and the flow path radii. The circular arc-shaped mean camber lines of the blades are created at the hub, mean, and tip section of each rotor and stator of the stage. The compressor blade shapes used in the analysis are based on the circular arcs, which act as reasonable approximations of the actual rotors and stators (Figure 3). This represents one stage of the multistage fan core and LPC. With this method, the blade-to-blade distances and passage chord lengths can be computed with reasonable accuracy. The lengths are used to estimate ice particle residence time which is required for calculating the sublimation, melt, and evaporation rates.

The tip solidity, number of blades, and flow path inner and outer radii are input parameters. The simple circular arc blade camber line is generated by the code at the hub, mean, and tip sections. The same procedure is followed to provide the stator vane camber line with simple circular arc shape. The following equations define the rotor blade and stator vane (referred to as airfoils in the following) camber geometric shape. The chord, $\overline{C}$, is determined from the tip solidity, σ, the tip radius, r_T, and the number of airfoils, N, by Equation (1).

$$\overline{C} = \frac{2\pi r_T \sigma}{N} \tag{1}$$

The true chord can be closely approximated by the following equation, which is for the isosceles triangle illustrated in Figure 4 where θ is the blade arc angle.

$$\overline{C} = 2r_c \sin\frac{\theta}{2} \tag{2}$$

The following equations are used to solve for the coordinates of the airfoil leading and trailing edges and the coordinates of the center of the circular arc, which defines the arc radius r_c at the blade midchord. The leading and trailing edge blade metal angles are defined by β_{B1} and β_{B2}, respectively.

$$r_c{}^2 = X_1{}^2 + Y_1{}^2 \tag{3}$$

$$r_c{}^2 = X_2{}^2 + Y_2{}^2 \tag{4}$$

$$\sin\beta_{B1} = \frac{X_1}{r_c} \tag{5}$$

$$\cos\beta_{B2} = \frac{Y_2}{r_c} \tag{6}$$

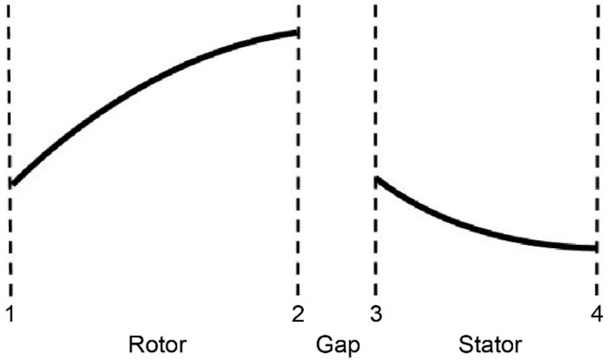

Figure 3.—Rotor and stator blade mean camber line at the midspan section for a typical stage. The station numbers 1 and 2 refer to the rotor leading and trailing edges, respectively, while stations 3 and 4 refer to the stator leading and trailing edges, respectively.

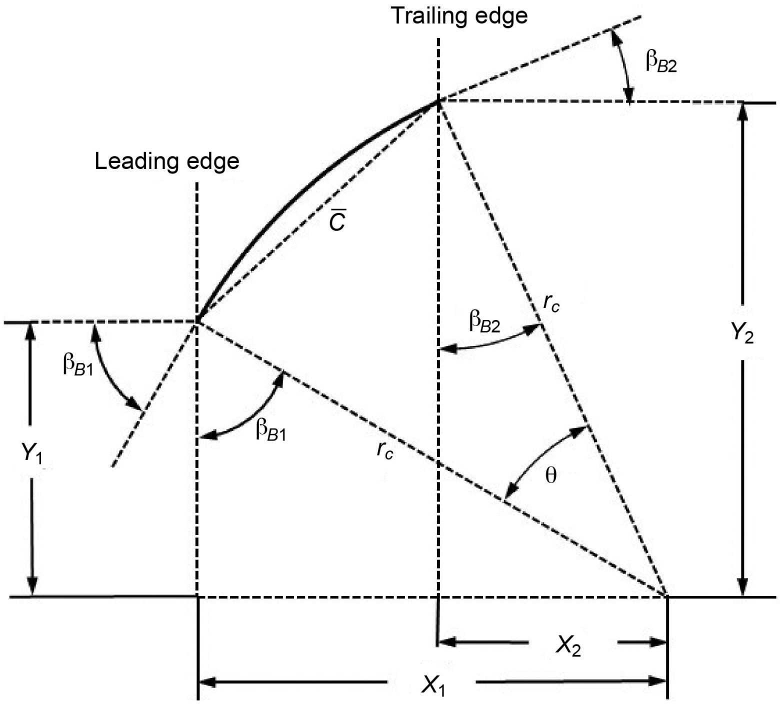

Figure 4.—Compressor airfoil camber line geometry creation in COMDES. Simple circular arc camber line with radius r_c is generated in compressor code based on input values of tip solidity of rotor and stator, and metal angles at leading and trailing edges β_B. Where chord is $\bar{C}$, θ is blade arc angle, and subscripts 1 and 2 are leading and trailing edges, respectively.

The airfoil section coordinates shown in Figure 4 are determined using the previous equations for a circular arc. Both the rotor blades as well as the stator vanes are generated with a single circular arc. The geometric data previously described can be found in the geometry file (geometry.out) generated when the COMDES-MELT code is executed. The rotor blade and stator vane circular arc camber line geometries at the hub, mean, and tip are written to the file Plot_Geometry.dat and can be adapted for any plotting application.

3.3 Governing Equations

The rotor annular area A is calculated from the hub and tip radii from the centerline by Equation (7) with r and B defined as illustrated in Figure 1. The aerodynamic blockages, λ, are specified as input parameters at the leading and trailing edges of the rotor in the mean-line analysis, and are not varied at off-design operating conditions.

$$A = \lambda\pi\left(r_T + r_H\right)\left[\left(r_T - r_H\right)^2 + B^2\right]^{1/2} \tag{7}$$

The static temperature T_S is a function of the total temperature T_t and the Mach number M with γ being the ratio of specific heats as shown in Equation (8).

$$\frac{T_t}{T_S} = 1 + \frac{\gamma - 1}{2} M^2 \tag{8}$$

The static pressure P_S is a function of the total pressure P_t and M as shown in Equation (9).

$$\frac{P_t}{P_S} = \left(\frac{T_t}{T_S}\right)^{\frac{\gamma}{\gamma-1}} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma-1}} \tag{9}$$

The volume flow rate Q into the rotor is determined by Equation (10) in terms of the mass flow rate m, P_S, and T_S.

$$Q = \frac{m T_S R}{P_S} \tag{10}$$

The absolute meridional velocity C_M at the rotor inlet is shown in Equation (11) as a function of Q and inlet area.

$$C_M = \frac{Q}{A} \tag{11}$$

The tangential component of absolute velocity C_U is determined from the C_M and the inlet swirl angle α as shown in Equation (12).

$$C_U = C_M \tan(\alpha) \tag{12}$$

The absolute total velocity C is determined from the C_M and the C_U as shown in Equation (13).

$$C = \left(C_M{}^2 + C_U{}^2\right)^{1/2} \tag{13}$$

The speed of sound a is determined from the T_S and the gas properties, universal gas constant $\Re$ and conversion factor g_c, as shown in Equation (14).

$$a = \left(\gamma \Re T_S g_c\right)^{1/2} \tag{14}$$

The M is determined from C and a as shown in Equation (15).

$$M = {}^{C}\!/_{a} \tag{15}$$

The flow coefficient of the rotor Φ is defined by Equation (16) in terms of the axial component of velocity and the rotor peripheral tip speed U_T.

$$\Phi = \frac{C_M}{U_T} \tag{16}$$

The relative flow angle β_F is determined by Equation (17) where U is the rotor peripheral velocity.

$$\beta_F = \tan^{-1}\left[\frac{U - C_U}{C_M}\right] \tag{17}$$

The blade metal angle β_B, flow angle β_F, and incidence i for a given relative velocity, W, are illustrated in Figure 5. The rotor incidence angle i_R is defined as the difference between the relative flow angle and the blade angle at the rotor leading edge just upstream of the blade by Equation (18).

$$i_R = \beta_F - \beta_B \tag{18}$$

The relative velocity at the rotor leading edge is determined by Equation (19).

$$W = \frac{C_M}{\cos(\beta_F)} \tag{19}$$

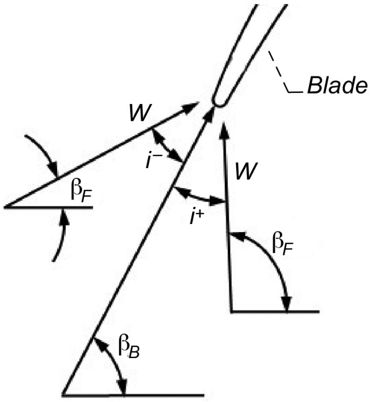

Figure 5.—Axial compressor rotor leading edge blade metal angle β_B, flow angle β_F, and incidence i. Relative velocity is W.

The rotor total-to-total adiabatic efficiency η is defined by Equation (20).

$$\eta = \frac{\left(\frac{P_{t2}}{P_{t1}}\right)^{\gamma-1/\gamma} - 1}{\frac{T_{t2}}{T_{t1}} - 1} \tag{20}$$

The enthalpy rise ΔH is calculated in terms of temperature rise across the rotor by Equation (21) where J is a units conversion and c_P is the specific heat of the gas and the Euler Equation (22), which is based on the change in tangential velocity from inlet to exit.

$$\Delta H = J c_P g_c \left(T_{t2} - T_{t1}\right) \tag{21}$$

$$\Delta H = U_2 C_{U2} - U_1 C_{U1} \tag{22}$$

The C_M at the rotor trailing exit is determined from the density, mass flow rate, and area as shown in Equation (23).

$$C_{M2} = \frac{mRT_{S2}}{P_{S2} A_2} \tag{23}$$

The relative velocity at the rotor exit is determined from Equation (24).

$$W_2 = \left[\left(U_2 - C_{U2}\right)^2 + C_{M2}{}^2\right]^{1/2} \tag{24}$$

The absolute flow angle at the rotor exit is determined from the relation shown in Equation (25).

$$\alpha_2 = \tan^{-1}\left(\frac{C_{U2}}{C_{M2}}\right) \tag{25}$$

The C at the rotor exit is determined from Equation (26).

$$C_2 = \left(C_{U2}{}^2 + C_{M2}{}^2\right)^{1/2} \tag{26}$$

The tangential component of relative velocity at the rotor exit is determined from Equation (27).

$$W_{U2} = \left(W_2^2 - C_{M2}{}^2\right)^{1/2} \tag{27}$$

The slip factor δ is the difference between the theoretical and absolute fluid tangential velocities normalized with blade peripheral speed as described by Equation (28). The slip factor is an input item and is typically from 0.93 to 0.96 for axial compressors. For centrifugal compressors, the slip factor can be on the order of 0.80 to 0.90, depending on number of blades and exit blade angle.

$$\delta = \frac{C_{U2} + \mathrm{C}_{M2} \tan\left(\beta_{\mathrm{B2}}\right)}{U_2} \tag{28}$$

The relative flow angle at the rotor exit is determined from Equation (29).

$$\beta_{F2} = \tan^{-1}\left[\frac{(U_2 - C_{U2})}{C_{M2}}\right] \tag{29}$$

The rotor diffusion factor *DF* at the root-mean-square radius is calculated by Equation (30).

$$DF = 1 - \frac{W_2}{W_1} + \frac{(r_1 C_{U1} - r_2 C_{U2})}{(r_1 + r_2) W_1 \sigma} \tag{30}$$

The incidence at the stator vane leading edge i_V can be estimated by Equation (31).

$$i_V = \alpha_2 - \beta_V \tag{31}$$

The stator loss coefficient ω_V is defined by Equation (32).

$$\omega_V = \frac{P_{t4} - P_{t2}}{P_{t2} - P_{S2}} \tag{32}$$

The power, $\overline{P}$, required to drive the compressor is calculated from Equation (33).

$$\overline{P} = \frac{\Delta H m}{550 g_c} \tag{33}$$

The inlet guide vane setting angle versus loss of total pressure that is used by the code was determined empirically from the NASA 74–A compressor, which has a flap-style variable inlet guide vane, and is shown in Equation (34). As such, these losses are considered a good approximation for the 76–B compressor, which also has similar flap-style inlet guide vanes. Note that these losses would likely be different for other types of variable guide vane configurations and may not provide an accurate representation of losses.

$$\Delta P_t = 0.0059374 - 0.00055463747S + 0.00007424S^2 + 0.000000458487S^3 \tag{34}$$

The total pressure at the exit of the variable inlet guide vane is obtained from Equation (35).

$$P_{t\text{exit}} = P_{t\text{inlet}}(1 - \Delta P_t) \tag{35}$$

The efficiency of the rotor as a function of incidence, shown in Equation (36), was determined empirically from the Stage 37 and 74–A compressors analyzed in this report and is currently the model in the compressor code for estimating the off-design efficiency. This same model is used on all speed lines for rotor efficiency deration versus incidence.

$$\Delta\eta = 0.0006 i_R^3 - 0.0185 i_R^2 + 0.1699 i_R + 0.5187 \tag{36}$$

4.0 Engine Icing Risk Prediction

In order to perform an engine icing study, it is necessary to have the geometry of the compressor (e.g., LPC) in adequate detail such that the flow conditions between each blade row can be computed with the mean-line compressor flow code. This data can be obtained from a streamline curvature code, conceptual design, or from experimental data. For this report, the data is extracted from a conceptual design.

4.1 An Example for Fan and Low-Pressure Compressor With Conceptual Design

The conceptual design task was performed for a notional turbofan engine in the 40,000 lbf thrust class having a bypass ratio of 5.8 with the mean-line compressor flow analysis code. The rotor and stator blade shapes were approximated with simple circular arcs. The conceptual design effort of the notional fan core and LPC determined the key dimensions that define the blade and flow path geometry. Figure 6 illustrates the notional fan and LPC that is used as an example in this user's manual.

The overall design point objectives for the full fan, fan tip, and fan core with LPC are described in Table I. The conceptual sizing study of the fan and LPC flow path was completed with the COMDES mean-line compressor flow analysis code. The resulting flow path showing the rotor blade and stator vane leading and trailing edges is illustrated in Figure 6. The key geometric and design point aerodynamic details of the fan core and LPC resulting from the mean-line conceptual design are summarized in Table II. This conceptual design will be used to conduct an icing risk analysis of the resulting notional fan and LPC at an operating point in a flight trajectory.

TABLE I.—FAN AND LOW-PRESSURE COMPRESSOR (LPC) DESIGN POINT OBJECTIVES

Fan, full	
Flow, corrected, lbm/s	1,033.6
Pressure ratio	1.40
Efficiency, percent	89.6
Shaft speed, corrected, RPM	3,761.1
Fan, tip	
Flow, corrected, lbm/s	861.2
Pressure ratio	1.426
Efficiency, percent	90.0
Shaft speed, corrected, RPM	3,761.1
Fan-core and LPC	
Flow, corrected, lbm/s	172.3
Pressure ratio	2.23
Efficiency, percent	87.0

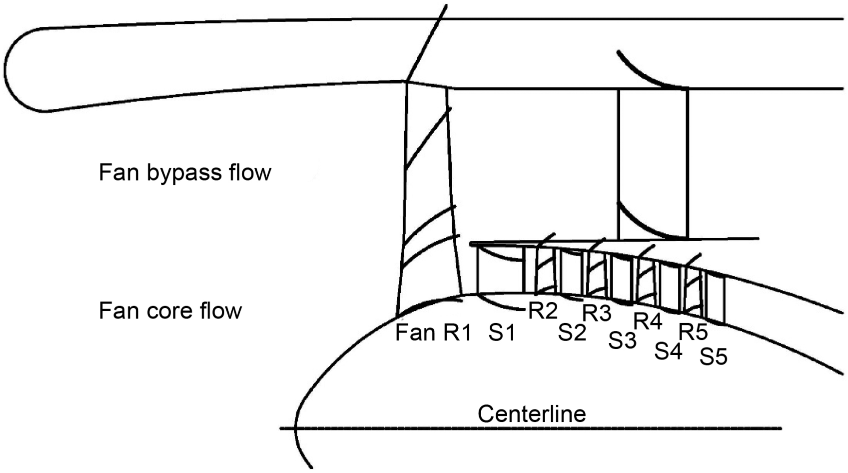

Figure 6.—Fan and low-pressure compressor of notional high bypass ratio turbofan engine.

TABLE II.—FAN CORE AND LOW-PRESSURE COMPRESSOR (LPC) DESIGN POINT GEOMETRIC AND AERODYNAMIC PARAMETERS

Parameter	Fan-hub rotor 1	Fan-hub stator 1	LPC rotor 2	LPC stator 2	LPC rotor 3	LPC stator 3	LPC rotor 4	LPC stator 4	LPC rotor 5	LPC stator 5
Leading edge										
Pressure static, psia	13.67	14.67	16.61	18.785	20.12	22.45	23.91	26.41	27.88	30.04
Temperature static, R	508.0	522.1	542.22	564.55	576.56	597.76	609.40	629.48	640.0	656.21
Mach no., abs	0.38	0.638	0.46	0.534	0.42	0.499	0.39	0.449	0.34	0.417
Blade angle, deg	47.20	35.4	42.3	30.6	23.5	31.5	43.80	32.4	44.80	33.0
Absolute flow angle, deg	0	36.15	0	31.22	0	32.18	0	33.00	0	0
Tip radius, in.	20.63	20.6171	20.5304	20.3433	20.0960	19.6905	19.3131	18.8420	18.2524	17.6890
Hub radius, in.	12.51	15.1021	15.2113	15.2026	15.0546	14.8484	14.3197	13.7204	13.0749	12.2606
Trailing edge										
Pressure static, psia	14.69	16.35	18.76	19.79	22.40	23.56	26.19	27.53	30.06	31.22
Temperature static, R	521.86	539.72	563.96	573.81	597.00	606.82	627.60	637.69	655.84	663.90
Mach no., abs	0.63	0.481	0.53	0.448	0.49	0.413	0.46	0.368	0.41	0.338
Blade angle, deg	12.7	0	23.5	0	23.5	0	23.5	0	23.5	0
Absolute flow angle, deg	36.93	0	31.59	0	32.30	0	32.27	0	33.24	0
Tip radius, in.	20.63	20.5733	20.4459	20.1704	19.9256	19.4117	19.0737	18.4850	17.9280	17.2148
Hub radius, in.	15.0	15.1901	15.2230	15.2026	14.8484	14.4742	13.9111	13.2848	12.4811	11.6228

4.2 Performance of Notional Turbine Engine System Model Through Typical Commercial Aircraft Flight Trajectory

In order to perform the engine icing study, the COMDES engine model was executed at numerous operating conditions through a flight trajectory. The inlet conditions of ice crystal concentrations in g/m^3, particle size, and the elevated ISA temperature were varied parametrically between 0 and 36 R, since that is in the range of where engine icing events have been reported (Refs. 1 and 2). The detailed analysis of the fan core and LPC with the COMDES code was obtained at each operating condition. A system model (Ref. 6) was utilized to determine the performance of the notional 40,000 lbf thrust class engine through a typical flight trajectory of a commercial aircraft (Figure 7).

The notional flight trajectory (Refs. 4 and 7) used in this study includes takeoff, climb, two cruise altitudes, and one descent profile. The first cruise altitude is at 35,000 ft, where the engine thrust is reduced from 100 percent down to 69.9 percent of maximum thrust at the end of the cruise. The aircraft then proceeds to 39,000 ft where again the thrust reduces from 100 percent down to 76.8 percent maximum thrust at that altitude. The engine is then spooled back to 10 percent maximum thrust at 39,000 ft as it prepares to descend in altitude. The engine is maintained at 10 percent maximum thrust as it descends to 10,000 ft, which was the lowest altitude that was analyzed in this study. The ambient temperature at 10,000 ft altitude was considered to be above that which would support ice crystals in the atmosphere.

Figure 8 and Figure 9 illustrate the baseline pressure ratio and efficiency characteristic maps of the fan core and LPC and the superimposed operating points through the flight trajectory. The baseline maps have no additional blockage due to ice accretion. These maps were generated by the compressor code prior to any ice crystal ingestion. The engine icing risk compressor flow analysis code, COMDES-MELT, is then executed with ice crystal ingestion (particle size and concentration) at specific operating points within the flight trajectory to determine if there is a risk of ice accretion.

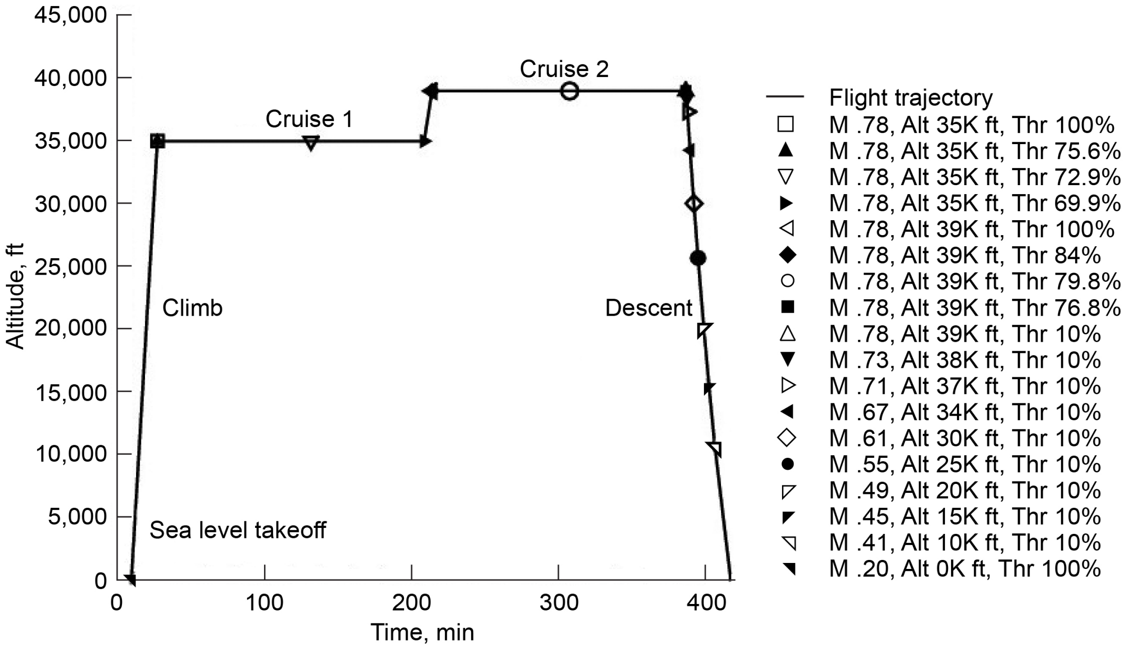

Figure 7.—Flight trajectory for typical commercial aircraft. The notional 40,000 lbf thrust engine is “flown” through vehicle flight trajectory to determine blade row where conditions for ice accretion may be possible.

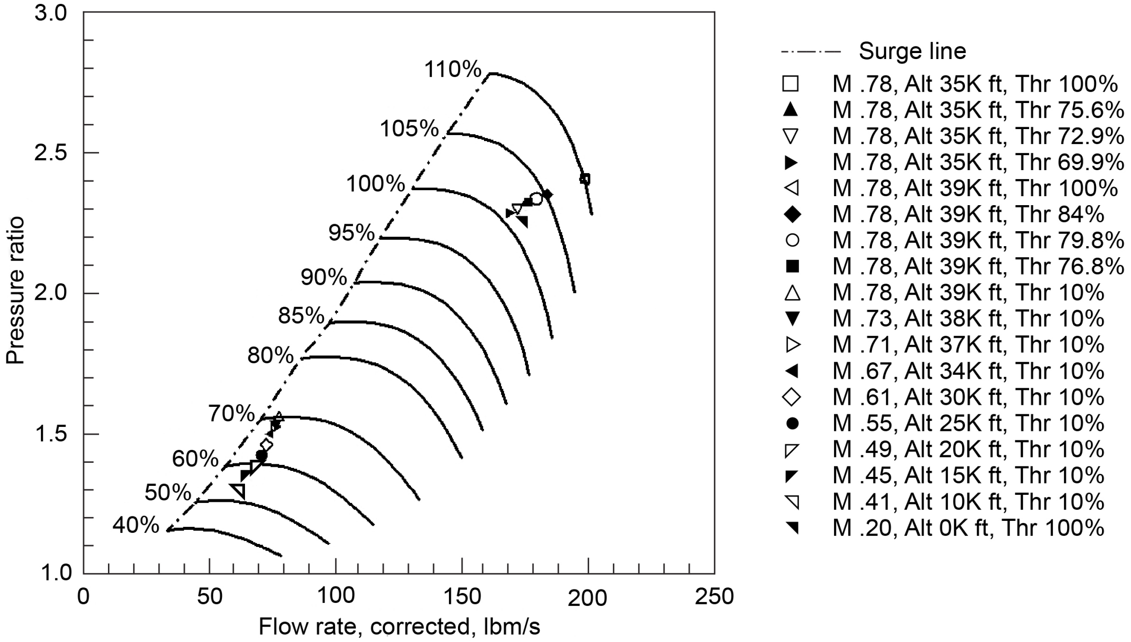

Figure 8.—Fan core and low-pressure compressor (LPC) pressure ratio showing baseline performance. Operating points of fan core and LPC throughout flight trajectory are superimposed onto baseline pressure ratio map.

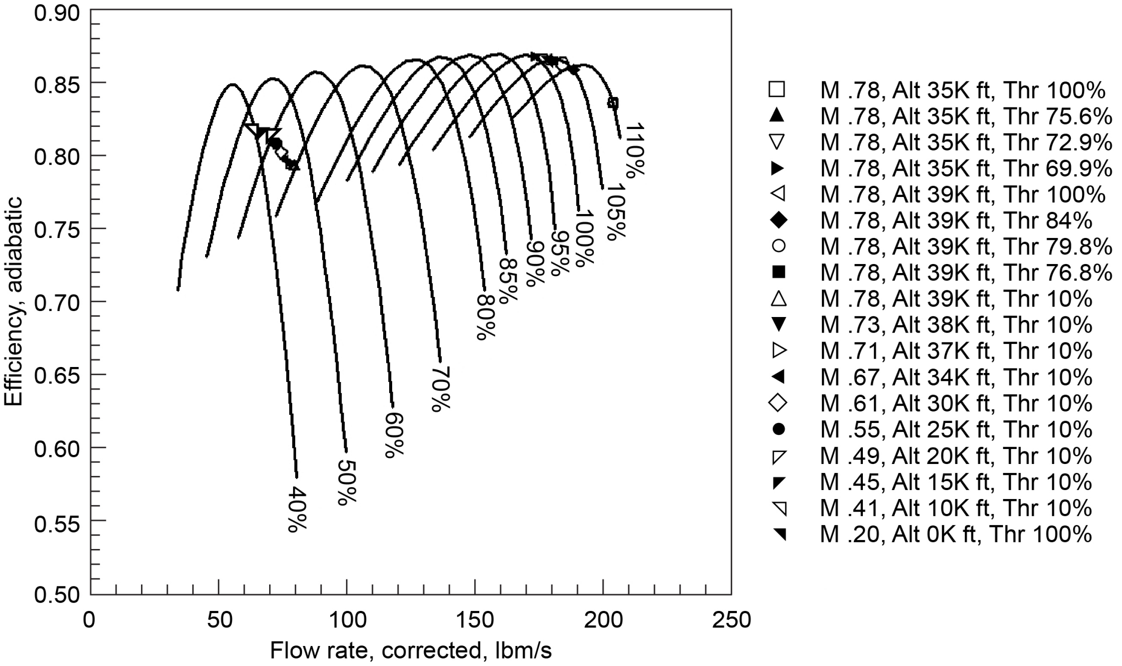

Figure 9.—Fan core and low-pressure compressor (LPC) performance showing baseline efficiency map. Operating points of fan core and LPC throughout flight trajectory are superimposed onto baseline efficiency maps.

The risk of ice accretion in the compression system is a function of location in the flight trajectory where the engine is operating and the atmospheric conditions of temperature and pressure, as well as the ice particle concentration and size.

A range of ice particle concentrations and diameters were analyzed with the icing risk code, at various ambient temperatures above the ISA standard. The performance of the fan and LPC stages were analyzed in terms of the local static wet-bulb temperature (T_{WBS}) and the particle melt ratio. As the engine is operated through the flight trajectory, the local values of wet-bulb temperature (T_{WB}) at each blade and stator row are calculated with the compressor flow code. It is assumed that ice accretion can only occur at values of T_{WBS} that are below the temperature of 498 R. This assumption is based on observations (Refs. 8 and 9) that showed significant growth rates and buildup of ice at values of T_{WBS} between 492 and 498 R. It was also found that the IWAR was needed to support ice accretion. Values of IWAR in general need to be above 0.002 for ice accretion to occur. As an example, the distribution of T_{WBS} and particle melt ratio are provided (see Figure 13), illustrating how each of these parameters are computed for one operating point that indicates a risk for this notional engine.

4.3 Energy Balance Between Ice Particle and Air

As the ice passes through the inlet, fan, and LPC blade rows, it is continuously absorbing heat from the warmer air through the compressor blades. The amount of energy that the ice particle absorbs from the air while it experiences sublimation, melt, and evaporation will be described in the subsequent Section 4.6. The transfer of energy between the air and ice particle can be expressed as a change in enthalpy. The enthalpy increase of the ice particle is equal to the enthalpy decrease of the air, which results in a decrease of the total temperature of the air. The energy balance between the ice particle and air is determined iteratively with the results from the compressor code and the particle melt code exchanging boundary conditions of static temperature and pressure and change in enthalpy until convergence. The change in total temperature of the air through the rotor is a function of the enthalpy rise due to the work input by the rotor, and the enthalpy that the ice particle removes from the air, as determined from the particle melt code. To account for effects of the energy exchange between the ice particle and air through the compressor rotor, the Euler equation energy balance in the compressor code has been modified to account for the enthalpy exchange between the particle and air, and is represented by the following equation, where the subscripts 1 and 2 represent the conditions at the rotor leading edge (station 1) and trailing edge (station 2), respectively (Figure 3).

$$Jc_{p_{\mathrm{wet}}} g_c \left(T_2 - T_1\right) = \left(U_2 C_{U2} - U_1 C_{U1}\right) - \Delta H_{\mathrm{melt}(2-1)} \tag{37}$$

The solution of flow conditions at the rotor exit is obtained by executing the compressor code and the particle melt code iteratively, by passing boundary conditions of static temperature and velocity from the compressor code to the MELT code, where the enthalpy change (ΔH_{melt}) of the ice particle is calculated, and returned to the compressor code and the change in air temperature due to the change in enthalpy is calculated. A similar iterative process is utilized to calculate the change in air temperature due to enthalpy exchange between the air and ice particles through the gaps between the rotor and stator, and through the stator vanes, where the subscripts 2 and 3 represent the inlet and outlet of the gap, and subscripts 3 and 4 represent the conditions at the stator leading and trailing edge, respectively (Figure 3). Note that when calculating the air temperature in the gap, the subscripts 3 and 4 are replaced with subscripts 2 and 3, respectively, in the following equation.

$$Jc_{p\mathrm{wet}} g_c \left(T_4 - T_3\right) = \Delta H_{\mathrm{melt}(4-3)} \tag{38}$$

4.4 Water Vapor

The COMDES code includes the capability of modeling the effects of water vapor on the gas properties of air. The model is based on a specified value of specific humidity at the inlet of the engine and compressor. The values for fluid properties of the water vapor and air are obtained in COMDES from the GASPLUS (Ref. 10) code. The mole fraction of water vapor to air is used to compute the average mole weight of the fluid (M_w, M_a), gas constant, and specific heat ratios for water vapor (c_{p_w}) and air (c_{p_a}). Molar flow rates (F_w, F_a) are given by

$$F_w = \frac{W_w}{M_w} \tag{39}$$

$$F_a = \frac{W_a}{M_a} \tag{40}$$

Mole fractions (χ_w, χ_a) are given by

$$\chi_w = \frac{F_w}{\left(F_w + F_a\right)} \tag{41}$$

$$\chi_a = 1 - \chi_w = \frac{F_a}{\left(F_w + F_a\right)} \tag{42}$$

Mass fractions (w_w, w_a) are given by

$$w_w = 1 - w_a = \frac{\chi_w M_w}{\chi_a M_a + \chi_w M_w} \tag{43}$$

$$w_a = \frac{\chi_a M_a}{\chi_a M_a + \chi_w M_w} \tag{44}$$

Average molar mass of the mixture:

$$M_{\text{wet}} = \chi_a M_a + \chi_w M_w \tag{45}$$

The specific heat of the air and water vapor mixture ($c_{p_{\text{wet}}}$) is calculated with the following formula:

$$c_{p_{\text{wet}}} = w_a c_{p_a} + w_w c_{p_w} \tag{46}$$

Average gas constant of the air and water vapor mixture (R_{wet}), in terms of the universal gas constant ($\Re$):

$$R_{\text{wet}} = \frac{\Re}{(\chi_a M_a + \chi_w M_w)} = \frac{\Re}{M_{\text{wet}}} \tag{47}$$

The ratio of specific heats for the air and water vapor mixture γ_{wet}:

$$\gamma_{\text{wet}} = \frac{1}{\left(1 - R_{\text{wet}} / \left(J c_{p\,\text{wet}}\right)\right)} \tag{48}$$

4.5 Wet-Bulb Temperature

The T_{WB} parameter is utilized as one of the key indicators of whether there is a risk of ice accretion within one of the compressor blade rows. A mathematical derivation of a T_{WB} for application in analysis of mixed-phase icing tests has been derived and implemented into the mean-line compressor flow analysis code (Ref. 5), thus enabling the multistage code to compute the local T_{WB} at each rotor and stator leading and trailing edge and at the stator throat. In this derivation, T_{WB} is the temperature of an evaporating wet adiabatic surface and is a function of the surrounding air temperature (dry-bulb) and pressure and moisture content. The T_{WB} is obtained by equating the rate of heat transfer to a surface to the heat loss by evaporation. During this process, it is assumed that the surface remains wet and the water on the surface is at T_{WB}. It is assumed that the process is steady state, with adiabatic boundaries, except at the edge of the boundary layer. The static pressure remains constant, and the partial pressure of water vapor at the surface is assumed to be the saturation value at the surface temperature. Figure 10 illustrates the conceptual representation of the control volume for the thermodynamic balance model that is utilized to derive the T_{WB}.

An energy balance performed on the control volume $\tilde{V}$ with the given assumptions is shown in Equation (49) where ρ_a is the density of air, $\dot{m}_w$ is the evaporation rate, t is time, h is the convective heat transfer coefficient, T_M is the averaged control volume temperature, A_s is the surface area, and L_v is the latent heat of evaporation.

$$\rho_a \tilde{V} c_{p_a} \frac{dT_M}{dt} = hA_s (T_\infty - T_s) - \dot{m}_w L_v \tag{49}$$

Assuming a steady state process, the previous equation can be rearranged to solve for the surface temperature T_s as shown in Equation (50).

$$T_s = T_\infty - \frac{\dot{m}_w L_v}{hA_s} \tag{50}$$

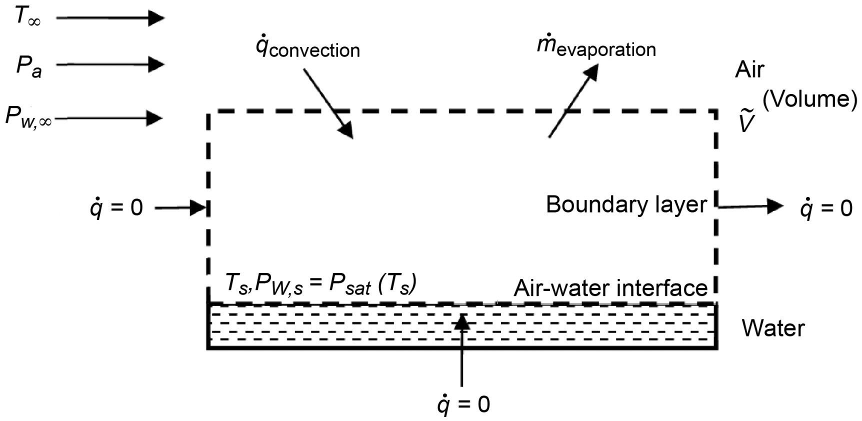

Figure 10.—Control volume for thermodynamic balance model. Temperature is T; pressure is P; evaporation rate of water is $\dot{m}$; heat flux is $\dot{q}$; control volume is $\tilde{V}$. Subscripts: air is a; surface is s; water vapor is w; saturated is sat; free stream is ∞.

Examination of this equation shows that T_{WB} will be less than the free-stream temperature T_∞ when there is evaporation from the surface given the assumptions previously stated.

To determine the amount of mass evaporated leaving the top of the boundary layer, it is assumed that the process is steady (i.e., no accumulation in the control volume). The evaporated water leaving the control volume is resupplied to the surface at T_{WB} through the impingement of partially melted ice crystal on the surface. It is also assumed that saturated conditions exist at the water and air interface. Under these assumptions, the mass flux leaving the control volume is shown in Equation (51) where h_m is the mass transfer coefficient.

$$\dot{m}_w = h_m A_s \rho_a \left(w_s - w_\infty \right) \tag{51}$$

Combining the mass flux leaving the control volume, Equation (51), with the energy balance, Equation (50), provides another expression for the T_s, as shown in Equation (52):

$$T_s = T_\infty - \frac{h_m}{h} L_v \rho_a \left(w_s - w_\infty \right) \tag{52}$$

Invoking the Chilton-Colburn analogy of heat and mass transfer yields another expression for the T_s equation. This analogy is valid for both local and bulk transfer coefficients as well as laminar or turbulent conditions. The properties' values are evaluated at the average of the free-stream and the surface temperature. A more detailed derivation of this expression is presented in Reference 11.

$$T_s = T_\infty - \frac{L_v}{c_{p_a} \mathrm{Le}^{2/3}} \left(\frac{M_w}{M_a} \right) \frac{T_M}{P_a} \left[\frac{P_{w,s}}{T_s} - \frac{P_{w,\infty}}{T_\infty} \right] \tag{53}$$

Equation (53) can be solved iteratively. The T_S is the T_{WB}, based on the prior assumptions. The dimensionless variable Le is the Lewis number.

The partial pressure of water vapor P_w at the surface is assumed to be the saturation value P_{sat} at the T_s, Equation (54). The P_w outside the boundary layer can be defined based on the ambient relative humidity, ϕ, as shown in Equation (55).

$$P_{w,s} = \phi_s P_{sat,s} \quad \text{evaluated at } T_{WB} \quad (\phi_s = 1.0\text{, fully saturated}) \tag{54}$$

$$P_{w,\infty} = \phi_\infty P_{sat,\infty} \quad \text{evaluated at } T_\infty \tag{55}$$

4.6 Ice Particle Melting and Evaporation

The capability to model ice particle and evaporation is available in the COMDES compressor analysis code as implemented in the subroutine named MELT. The MELT code calculates the change in phase of an ice particle which sublimates, melts, and evaporates, as it passes through the fan and LPC rotor blades and stator vanes. The ice particle residence times through the compressor of existing engines are estimated based on the velocities at the leading and trailing edge of each blade row, the blade chords, and the axial spacing of the gap between the rotors and stators. This provides a reasonable estimate of the actual residence times of the ice crystals through each blade passage and gap, resulting in an accurate estimate of the sublimation, melt, and evaporation physics. The inlet specific humidity and the ice particle concentration (g/m^3) and size distributions are specified at the inlet to the engine. Values for ice particle size and concentrations in the atmosphere are varied parametrically, as there is limited data currently available on the ice crystal content of high-altitude convective clouds.

After the flow conditions through the blade rows have been calculated by the compressor code, the static temperatures, pressures, and velocities are passed to the ice melting subroutine to determine the rate of melting and evaporation, and thus, the local melt ratio in each blade row. The ice particle sublimation, melt, and evaporation equations are shown below. These calculations take into consideration the local temperatures, pressures, and residence times as they traverse the blade passages and gaps between blades at their mid span location. Conservation of mass on each particle results in the following equation for the ice particle size d as a function of position, where Sh is the Sherwood number, D_v is the diffusion coefficient of water vapor into air, x is the distance traveled by the particle, V_∞ is the air free stream velocity, and ρ_i is the ice particle density.

$$d^2 = d_o^2 - \frac{4\mathrm{Sh}\rho_a D_v}{\rho_i V_\infty}(x - x_o)(w_s - w_\infty) \tag{56}$$

Similarly, the rise in specific humidity S_h is related to the amount of mass lost by the particle and is given by the following equation where IWC is the ice water content.

$$S_h = S_{h,o} + \frac{IWC}{\rho_a}\left[1 - \left(\frac{d}{d_o}\right)^3\right] \tag{57}$$

Equating the heat absorbed by the particles to a decrease in enthalpy in the airstream provides the decrease in air temperature and L_s is defined as the latent heat of sublimation.

$$T_a = T_{a,o} + \frac{L_s}{c_{p_a}}\frac{IWC}{\rho_a}\left[1 - \left(\frac{d}{d_o}\right)^3\right] \tag{58}$$

The enthalpy increase of the particle through the compressor is equal to the heat absorbed from conduction plus the energy provided by evaporation, resulting in the following equation for the change in ice particle temperature prior to melt. Here Nu is the Nusselt number and Sc is the Schmidt number.

$$\frac{dT_i}{dx} = \frac{\mathrm{Nu}}{\tau_T V_\infty}(T_a - T_i) + \frac{L_s \mathrm{Sh}}{\tau_T c_{p_a} V_\infty} \frac{\mathrm{Pr}}{\mathrm{Sc}}(w_\infty - w_s) \tag{59}$$

The mass fractions of water vapor in the previous equation are given by the following equations:

$$w_\infty = \phi_\infty \frac{M_w}{M_a} \frac{P_{w,\infty}}{P_a} \tag{60}$$

$$w_s = \phi_s \frac{M_w}{M_a} \frac{P_{w,s}}{P_a} \quad (\phi_s = 1.0, \text{ fully saturated}) \tag{61}$$

The nondimensionalization of the previous energy equation results in the following term for the thermal response time τ_T where k is the thermal conductivity.

$$\tau_T = \frac{c_{p_i} \rho_i d^2}{6k_a} \tag{62}$$

The Nu and Sh numbers in these equations are provided by assuming spherical particles. If other particle geometries are of interest, the correlations can be easily modified for those cases. Prandtl number Pr is the same for all particles. The variable μ is the dynamic viscosity.

$$\mathrm{Pr} = \left(\frac{c_p \mu}{k}\right)_a \tag{63}$$

$$\mathrm{Nu} = \frac{hd}{k_a} \tag{64}$$

$$\mathrm{Nu} = 2 + 0.6\,\mathrm{Re}^{1/2}\,\mathrm{Pr}^{1/3} \tag{65}$$

The Sc is defined by the following equation:

$$\mathrm{Sc} = \frac{\mu_a}{\rho_a D_v} \tag{66}$$

The Sh is defined by the following equation:

$$\mathrm{Sh} = \frac{h_m d}{D_v} \tag{67}$$

$$\mathrm{Sh} = 2 + 0.6\,\mathrm{Re}^{1/2}\,\mathrm{Sc}^{1/3} \tag{68}$$

The Reynolds number Re in the previous equation is based on the particle size and the relative velocity of the particle V_d with the airstream, V_∞:

$$\mathrm{Re} = \frac{\rho_a \left| V_\infty - V_d \right| d}{\mu_a} \tag{69}$$

Once the particle starts to melt, its temperature no longer changes. In this case, the previous energy equation can be written as a change in the enthalpy or a change in the melt fraction n_{melt} as shown in Equation (70) where L_f is the latent heat of fusion.

$$\frac{dn_{\mathrm{melt}}}{dx} = \frac{c_{p_i}}{L_f} \frac{\mathrm{Nu}}{\tau_T V_\infty} (T_a - T_i) + \frac{c_{p_i}}{L_f} \frac{L_s \mathrm{Sh}}{\tau_T \, c_{p_a} V_\infty} \frac{\mathrm{Pr}}{\mathrm{Sc}} (w_\infty - w_s) \tag{70}$$

The local fluid conditions of temperature and pressure are used in the previous equations to determine the rate of sublimation, ice melt, and evaporation. The distance the ice particle traverses through the compressor rotors and stators is determined from the length of the engine inlet, and the geometry of the rotor blades, stator vanes, and the axial gaps between the rotors and stators. The distance through the fan and LPC blade rows is estimated from the true blade chord of the rotors and stators at the midspan, and the axial distance through the gaps between the blades, as illustrated in Figure 11.

Note that each stage is analyzed at the blade edges as shown in Figure 4. Here, the simple circular arc blade camber line shapes are utilized and provide a means of easily estimating the geometry of the compressor rotor blades and stator vanes. This geometry is used as the distance traveled by the water and ice particle. The COMDES and MELT codes exchange boundary conditions of pressure, temperature, and velocity to estimate the residence time of the particle through each blade row, as well as to determine the rate of ice sublimation, melt, and evaporation.

Figure 11 illustrates the ice particle path through the rotor blades in the relative frame of reference, while the path through the stator vanes is in the absolute frame of reference. The calculations of ice sublimation, melt, and evaporation are performed in increments from the leading to trailing edges of each rotor and stator, as well as through the axial gap between the blades. As the engine is flown through the flight trajectory, the ice particle sublimation, melt, and evaporation is calculated in each rotor and stator blade row. The amount of water due to sublimation and evaporation is added to the local value of specific humidity, thus having an effect on the local ϕ, and likewise on the local T_{WB} calculation in the compressor code. The MELT code is also used to evaluate the particle conditions through the engine inlet, which is then provided as ice particle initial conditions at the leading edge of the fan core.

A flow chart that describes the COMDES-MELT compressor analysis is illustrated in Figure 12. The COMDES-MELT code is executed with a standard input data file that has a format that will be described in a later section. If an icing risk analysis is being conducted, each component goes through an iterative process where the ice exchanges enthalpy with the air. The stage calculation is repeated until the performance of all stages have been computed. There are several output files that result from this computation and will be described in detail in a later section of this user's manual.

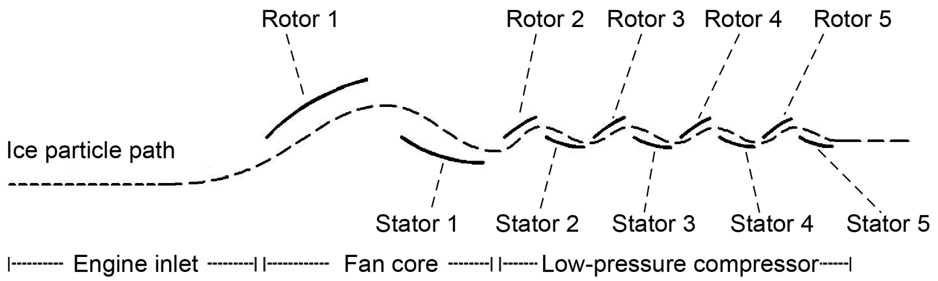

Figure 11.—Ice particle path through fan core and low-pressure compressor (LPC) stages. Rotor and stator blade mean camber line chord at the midspan section is used to estimate distance traveled and residence time of ice particles.

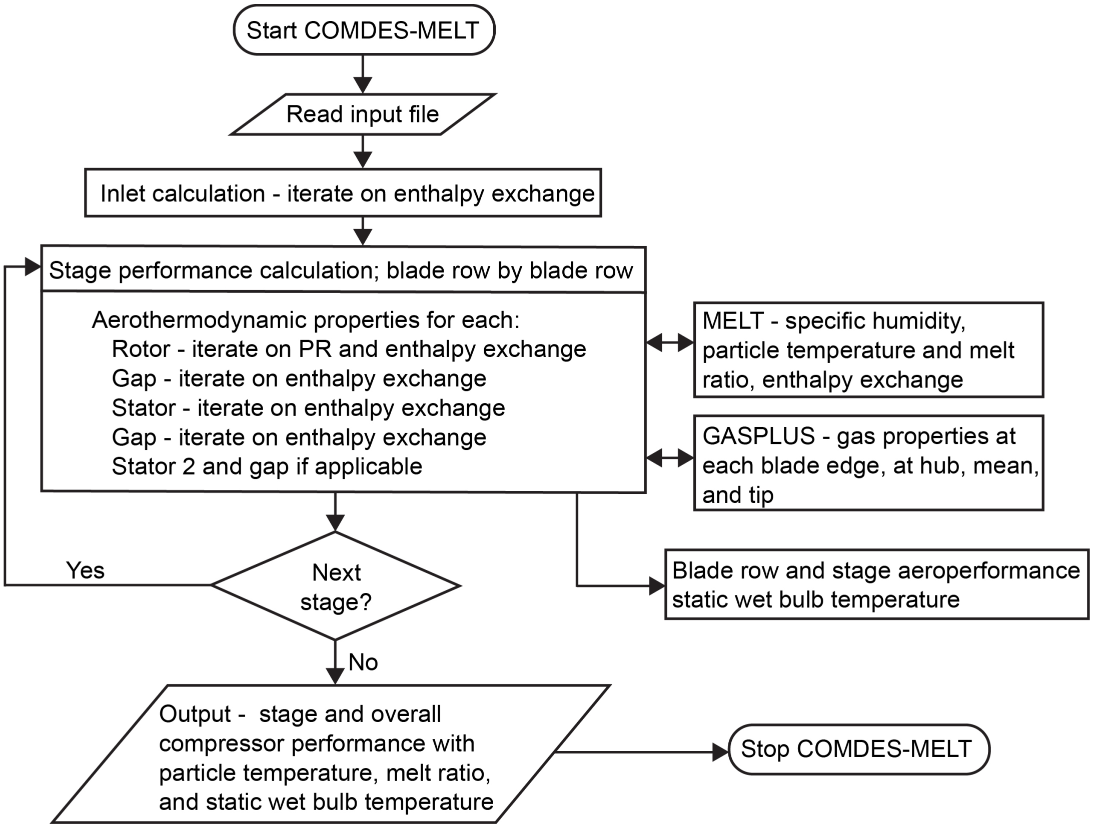

Figure 12.—Flowchart of COMDES-MELT compressor analysis code. Pressure ratio is PR.

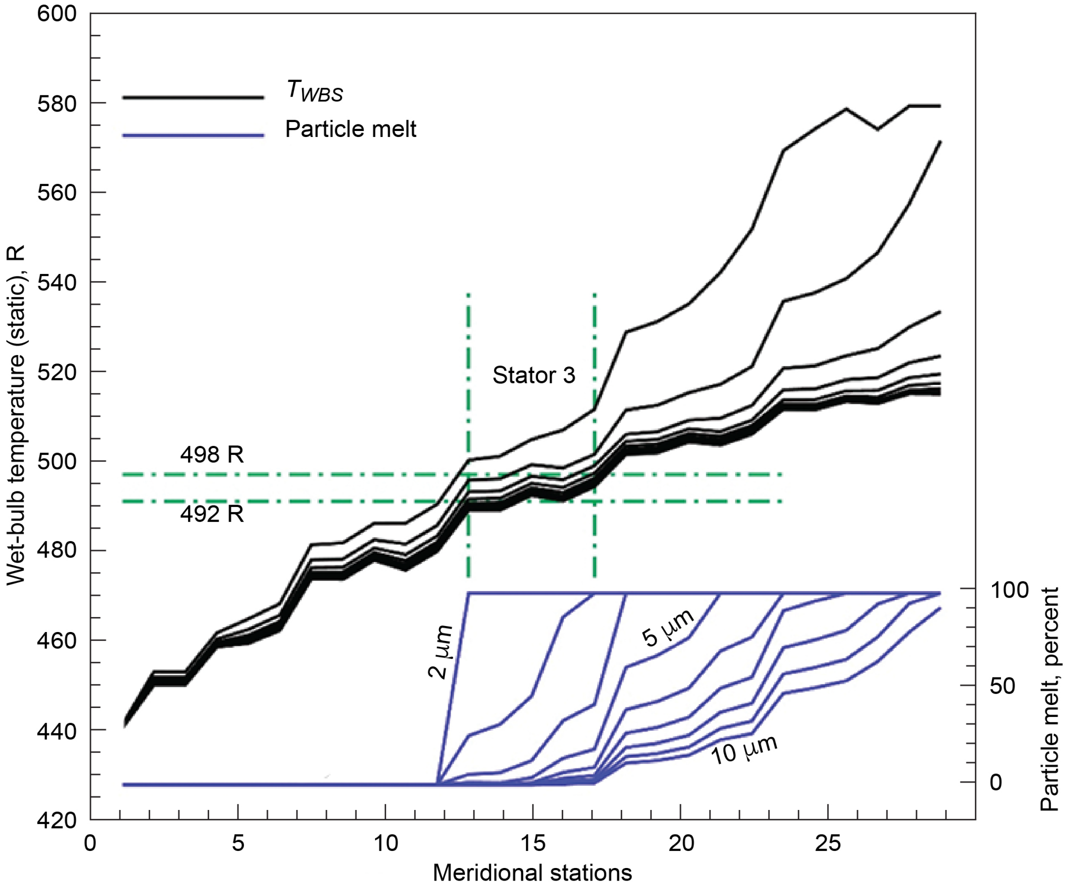

Figure 13.—Distribution of static wet-bulb temperature T_{WBS} and particle melt ratio. Risk of ice accretion indicated in stator 3 where T_{WBS} is within the range of 492 and 498 R with non-zero particle melt ratio.

The distribution of static T_{WB} and particle melt ratio for the notional high bypass ratio turbofan engine fan-core and LPC stations are illustrated in Figure 13. As the ice particle passes through the compressor components, the particle temperature increases. Sublimation, melt, and evaporation of the ice particle contributes to the change in specific humidity and temperature of the air.

For example, at an engine operating condition at an altitude of 40,000 ft with an inlet temperature 25 °R above ISA temperature, the particles have a nonzero melt ratio in stator 3 while the T_{WBS} is within the range of 492 to 498 °R, and the IWAR was 0.006. These three risk parameters indicate that there is a risk of ice accretion in stator 3 at this operating condition. The input and corresponding output files for this operating condition is provided as Example Case (1) for the ice particle size of 5 μm. The data used to create this figure is found in the file plot.out, also included as an example for the case with a particle size of 5 μm.

In a following section, this operating point for the notional fan and LPC is provided as an example with all the necessary input and output files used to generate the previous plot. A sensitivity study was also conducted to show the effects of prescribed slip, blockage, and efficiency values on the rotor exit conditions of temperature, flow angle, and pressure. In this case, the COMDES code was executed on the full fan rotor at its design point while varying the parameters of slip, blockage, and efficiency to understand their effects. In addition, a stage-matching example is presented, which includes computing the maps of each stage and determining the stage that limits the notional overall performance of the compressor.

The computational tool, COMDES-MELT, has been applied successfully to several turbofan engine compressor geometries that have been tested in the Propulsion Systems Laboratory at the NASA Glenn Research Center. The sole purpose of these tests and analysis was to determine if there was a risk of ice accretion in the compression system (Refs. 8 and 9) at simulated altitudes while operating in an ice crystal cloud environment. The COMDES-MELT code was used as a predictive tool to help guide the test plan to reduce the number of test points required in the expensive wind tunnel testing. The COMDES-MELT code provided engine operating conditions where there was a risk of ice accretion at specific locations within the compression system.

5.0 Code Installation and Execution

In this section, a general description will be provided for the installation, compilation, and execution of the code COMES-MELT along with a brief explanation of the output files that are produced.

5.1 Installation

The code executable, input, and output files are contained in the working directory. Most distributions of the COMDES-MELT code will be precompiled without the source. If the source code is supplied, there is a source directory where files are modified and recompiled with the procedure described as follows. This software, executable, source code, or results shall not be used for Federal Aviation Administration (FAA)/Joint Aviation Authorities (JAA) certification or airworthiness certification (i.e., 14 CFR Parts 23, 25, 27, 29, and 33).

5.2 Compiling

A Fortran compiler is used to compile the source codes and link the object files to produce an executable file. An example of this procedure is provided as follows:

First compiling the codes:

```
ifort –c COMDES-MELT-RV.1.f
ifort –c gasplus.f
ifort –c Icing.f90
ifort –c DropTemp.f90
```

and then linking the object files with:

```
ifort –o COMDES-MELT-RV.1.exe COMDES-MELT-RV.1.obj gasplus.obj Icing.obj DropTemp.obj
```

to produce the executable file COMDES-MELT-RV.1.exe. This executable file is then copied to a working directory.

5.3 Execution

Most distributions of the code will be with the executable file, COMDES-MELT-RV.1.exe, only. This code is executed in the working directory with the command:

```
COMDES-MELT-RV.1.exe
```

When the code is executed, a disclaimer statement is generated that is accepted with an input of “Y” or rejected with an input of “N.” The disclaimer statement reads: “THIS SOFTWARE, EXECUTABLE, SOURCE

CODE, OR RESULTS SHALL NOT BE USED FOR FAA/JAA CERTIFICATION OR AIRWORTHINESS CERTIFICATION (I.E., 14 CFR PARTS 23, 25, 27, 29, AND 33).” If the disclaimer is accepted the COMDES-MELT code reads the file, comdes.dat, the input file, and produces the file, comdes.out, the corresponding output file. Other relevant output files are generated and include:

geometry.out
Plot_Geometry.dat
Melt.out
Melt_Frac.out
plot.out
Stage_Perf.out
Comp_Perf.out

Detail of the input file and output files data will be described in the next section followed by a section of examples. The example section includes information on how an input file is created, the sensitivity of the exit pressure, temperature, and flow angle to the slip factor, blockage, and efficiency specified as parameters. An example of stage matching that would be required if a compressor is designed using this code through analysis is also provided. The two files “Stage_Perf.out” and “Comp_Perf.out” are produced to give an abbreviated indication of the stage and overall compressor performance, respectively, for a given operating condition.

Two files (ERROR.LOG and fort.13) are generated during an execution of the COMDES-MELT code and are produced by the GASPLUS code when parameters are outside its valid operating range.

6.0 Input and Output Data Files and Variable Description

The input and output data files that are used with the COMDES-MELT code are described in this section with a brief variable explanation.

6.1 Introduction

In this section, the input files for executing COMDES and the resulting output files generated by COMDES will be described in detail. The dimensions and units used in the input file and the output files are outlined in Table III.

6.2 Units

The units used in COMDES are described in the Table III.

TABLE III.—UNITS USED IN COMDES INPUT AND OUTPUT FILES

Length	in.
Area	in^2
Pressure	lbf/in^2
Temperature	°R
Velocity	ft/s
Wheel speed (N1 and N2)	RPM
Mass flow	lbm/s
Angle	degree
Drop diameter	µm
Ice water content	g/m^3
Altitude	ft

These units are consistent between input and output files. The icing parameters are in metric units to be consistent with what is used in the airframe icing research community.

6.3 Input and Output File Structures

The pages that follow provide a variable listing of the input and output files followed by a full description of each variable in the order of appearance in each file. Several places in these files are redundant (i.e., stage 2, stage 3, etc.) and a note is included to show that lines were omitted for clarity.

In general, the input file includes an inlet or fan-face condition section (lines 1 to 6 below) followed by stage conditions that includes inputs of geometry, efficiency, slip factor, etc. (lines 7 to 20). If there is a tandem or second stator that input follows the stage stator (lines 21 to 25). Additional stage input data is then inserted to represent the full extent of the compressor. A region downstream of the final stage is included if a gooseneck and strut region is part of the calculation (lines 40 to 43). Sample input files are included after the input and output file descriptions, which provide guidance on the range for some of the input variables. This software, executable, source code, or results shall not be used for FAA/JAA certification, or airworthiness certification (i.e., 14 CFR Parts 23, 25, 27, 29, and 33).

6.3.1 Core Program Input—List of Required Data

```
Line #
 1    Title
 2    Wact        Pt1         Tt1         RPM1
 3    Fluid       Stages      IDUMMY*     DUMMY**
 4    DropDia     InDist      RSHinlet    IWC
 5    Psin        DUMMY**     Tsin        DUMMY**
 6    Vin         DUMMY**     Altitude    IDUMMY*
 STAGE Calculation variables are repeated for each Stages
 7    R1tip       R1hub       R2tip       R2hub
 8    B1axial     B2axial     NBLAD       THK      CFS
 9    StatorT     StatorM     StatorH     FSGV     CFMid
 10   AeroB1      AeroB2      POTS        POTH     CFHub
 11   EfficiT     EfficiM     EfficiH     BLEED
 12   DUMMY**     DUMMY**     DUMMY**     DUMMY**
 13   SlipF       Wbar24      SolidRotor  RPM2
 14   BetaBlade1T BetaBlade1M BetaBlade1H expo3
 15   BetaBlade2T BetaBlade2M BetaBlade2H stat2
 16   R3s         R3h         B3X         BetB3
 17   Blan3       Blath3      Blok3       Wbar23
 18   RCG         Athrt       BlokTH      Wbar2T
 19   R4S         R4H         B4X         BetB4
 20   Blan4       Blath4      Blok4       SolidStat1
IF 2ND STATOR←see line 15 repeat lines 16-20
 21   R5s         R5h         B5X         BetB5
 22   Blan5       Blath5      Blok5       Wbar46
 23   RCG2        Athrt2      BlokTH2     Wbar4T
 24   R6S         R6H         B6X         BetB6
 25   Blan6       Blath6      Blok6       SolidStat2
 STAGE 2+ Repeat lines 7-20 (or 7-25 if tandem stators) for additional stage calculations
 .
 .  (Stage input variables are repeated for multiple stage compressors as
 .  describe above which is controlled by the "Stages" variable in line 3)
 .
 .
GooseNeck and Strut
 40. R7S        R7h         B7X         Length67
 41. Blan7      Blath7      Blok7       Wbar67
 42. R8S        R8h         B8X         Length78
 43. Blan8      Blath8      Blok8       Wbar78


*  IDUMMY - integer input variable that is not used in the computation.
** DUMMY  - real input variable that is not used in the computation.
```

6.3.2 Core Program Input—Data Definitions (by Line Number) With Required Format

Line #

1. Title (1A100)
2. Wact Pt1 Tt1 RPM1 (4F12.4)
    - Wact—actual weight flow of fluid, lbm/s
    - Pt1—inlet total pressure, psia
    - Tt1—inlet total temperature, R
    - RPM1—physical rotational speed of the low speed shaft, RPM
3. Fluid Stages IDUMMY DUMMY (3I12,F12.4)
    - Fluid—operating fluid:
        - 1–hydrogen
        - 2–oxygen
        - 3–nitrogen
        - 4–water
        - 5–air
        - 6–helium
        - 7–carbon dioxide
    - Stages—number of stages in the compressor; compute one stage at a time when setting up multistage
    - IDUMMY—no longer used = 0
    - DUMMY—no longer used = 0.0
4. DropDia InDist RHinlet IWC (4F12.4)
    - DropDia—when running with ice crystals this sets the diameter of the particle, µm (icing risk analysis only)
    - InDist—length of the inlet, in. (icing risk analysis only)
    - RSHinlet—ϕ or S_h set at the inlet:
        - if RSHinlet > 1.0, it is ϕ, percent
        - if RSHinlet ≤ 1.0, it is S_h
    - IWC — Ice water content, g/m^3
5. Psin DUMMY Tsin DUMMY (4F12.4)
    - Psin—static pressure at the inlet, psia (icing risk analysis only)
    - DUMMY—no longer used = 0.0
    - Tsin—static temperature at the inlet, R (icing risk analysis only)
    - DUMMY—no longer used = 0.0
6. Vin DUMMY Altitude IDUMMY (3F12.4,I12)
    - Vin—Velocity at the inlet, ft/s (icing risk analysis only)
    - DUMMY—no longer used = 0.0
    - Altitude—altitude of operating point, ft. Note: inlet pressure determines altitude.
    - IDUMMY—no longer used = 0

STAGE 1

7. R1tip R1hub R2tip R2hub
    - R1tip—tip radius of rotor at leading edge (LE), in.
    - R1hub—hub radius of rotor at LE, in.
    - R2tip—tip radius of rotor at trailing edge (TE), in.
    - R2hub—hub radius of rotor at TE, in.

8. B1axial B2axial NBLAD THK CFS (2F12.4,I12,2I12.4)
   - B1axial—rotor lean at the LE from hub to tip, in.
   - B2axial—rotor lean at the TE from hub to tip, in.
   - NBLAD—number of rotor blades
   - THK—rotor blade thickness, in. (e.g., 0.020 in.)
   - CFS—relaxation factor used to adjust the internally calculated initial pressure ratio at the rotor tip, usually set to 1.0 but can be within the range of 0.8 to 1.1, for convergence
9. StatorT StatorM StatorH FSGV CFMid (5F12.4)
   - StatorT—tip swirl from upstream stator coming into rotor LE, positive or negative angle, degree
   - StatorM—mean swirl from upstream stator coming into rotor LE, degree
   - StatorH—hub swirl from upstream stator coming into rotor LE, degree
   - FSGV—unused input, set = 1.0
   - CFMid—relaxation factor used to adjust the internally calculated initial pressure ratio at the rotor mid, usually set to 1.0 but can be within the range of 0.8 to 1.1, for convergence
10. AeroB1 AeroB2 POTS POTH CFHub (5F12.4)
   - AeroBL—Aeroblockage at rotor LE, 0.98 is a good first guess, 1.0 = no aeroblockage, (0.98 = 2 percent blockage)
   - AeroB2—aeroblockage at rotor TE, 0.95 is a good first guess, (0.95 ~ 5 percent blockage)
   - POTS—potential ratio = (shroud velocity)/(mid velocity) use 1.0 for axials unless wall curvature effects are known from previous computational fluid dynamics (CFD) analysis, or streamline curvature code
   - POTH—potential ratio = (hub velocity)/(mid velocity) use 1.0 for axials (see previous)
   - CFHub—relaxation factor used to adjust the internally calculated initial pressure ratio at the rotor hub, usually set to 1.0 but can be within the range of 0.8 to 1.1, for convergence
11. EfficiT EfficiM EfficiH BLEED (4F12.4)
   - EfficiT—rotor efficiency at tip, adiabatic, 0.93 is a good first guess, and indicates 93 percent efficiency (this can vary from 0.87 to 0.95) to match rotor exit test P_t and T_t rake data, or two-dimensional (2D) streamline curvature results
   - EfficiM—rotor efficiency at mean, adiabatic, see EfficiT
   - EfficiH—rotor efficiency at hub, adiabatic, see EfficiT
   - BLEED—0.0 = zero bleed; 0.1 = 10 percent bleed (mass flow bleed-off from upstream stage)
12. DUMMY DUMMY DUMMY DUMMY (4F12.4)
   - DUMMY—no longer used = 0.0
   - DUMMY—no longer used = 0.0
   - DUMMY—no longer used = 0.0
   - DUMMY—no longer used = 0.0
13. SlipF Wbar24 SolidRotor RPM2 (4F12.4)
   - SlipF—rotor slip factor, Equation (28) (0.82 to 0.87 centrifugal; 0.88 to 0.92 axial)
   - Wbar24—stator pressure loss coefficient Equation (32) (0.15 to 0.25 centrifugal radial diffusers or volute; 0.03 to 0.07 axial stators); vary to match test data (or numerical 2D streamline curvature code) wall static pressure at stator exit
   - SolidRotor—rotor solidity at tip (1.4 to 2.2 at tip)
   - RPM2—physical rotational speed of the high-pressure compressor (HPC), RPM2 needs to be set to a value less than 10.0 if LPC single spool analysis → RPM2 = RPM1
14. BetaBlade1T BetaBlade1M BetaBlade1H expo3 (4F12.4)
   - BetaBlade1T—rotor blade LE tip metal angle, degree
   - BetaBlade1M—rotor blade LE mean metal angle, degree
   - BetaBlade1H—rotor blade LE hub metal angle, degree

expo3—exponent for stator 2 incidence loss model Mach number deration. If input of expo3 = 0.0 there is no correction to loss bucket (range of 1.0 to 2.0)

15. BetaBlade2T BetaBlade2M BetaBlade2H stat2 (3F12.4,I12)
    - BetaBlade2T—rotor blade TE tip metal angle, degree
    - BetaBlade2M—rotor blade TE mean metal angle, degree
    - BetaBlade2H—rotor blade TE hub metal angle, degree
    - Stat2—flag to indicate if there is a second stator (tandem): 0 = no, 2 = yes
16. R3s R3h B3X BetB3 (4F12.4)
    - R3s—stator LE tip radius, from the center line, in.
    - R3h—stator LE hub radius, from the center line, in.
    - B3X—stator LE sweep (axial distance in in.)
    - BetB3—stator vane LE metal angle, at the root-mean-square (RMS) radius, degree
17. Blan3 Blath3 Blok3 Wbar23 (I12,3F12.4)
    - Blan3—number of stator vanes
    - Blath3—stator vane normal thickness, in. (e.g., 0.015 in.)
    - Blok3—stator vane LE blockage (1.0 is no aerodynamic blockage; 0.98 is 2 percent aeroblockage) vary to match test data (or numerical 2D code) wall static pressure
    - Wbar23—rotor blade to stator vane gap total pressure loss coefficient (annular duct loss between blade rows, rotor TE to stator LE) range 0.01 to 0.02
18. RCG Athrt BlokTH Wbar2T (4F12.4)
    - RCG—stator vane radius of center of gravity (root-mean-square RMS radius of stator throat; utilized for centrifugal radial diffusers, where it determines the diffuser loading and the static pressure recovery from the impeller TE to the diffuser throat). For axials, it can be the RMS radius of the LE
    - Athrt—stator vane throat area at the RCG (if 0.0 code calculates an approximate value), in.^{2}
    - BlokTH—stator vane throat blockage, (1.0 is no aerodynamic blockage; 0.98 is 2 percent aeroblockage)
    - Wbar2T—stator vane throat loss coefficient; set to 0.05
19. R4S R4H B4X BetB4 (4F12.4)
    - R4s—stator TE tip radius, in.
    - R4h—stator TE hub radius, in.
    - B4X—stator TE axial distance from hub to tip, caused by sweep, in.
    - BetB4—stator vane TE metal angle, degree
20. Blan4 Blath4 Blok4 SolidStat1 (I12,3F12.4)
    - Blan4—number of stator vanes
    - Blath4—stator vane normal thickness, in.
    - Blok4—stator vane TE blockage (1.0 is no aerodynamic blockage; 0.98 is 2 percent aeroblockage) vary to match test data (or numerical 2D streamline curvature code) wall static pressure
    - SolidStat1—stator vane solidity 1.4 to 2.2

IF 2ND STATOR← see line 15 repeat lines 16-20

21. R5s R5h B5X BetB5 (4F12.4)
    - R5s—stator LE tip radius, in.
    - R5h—stator LE hub radius, in.
    - B5X—stator LE lean, in.
    - BetB5—stator vane LE metal angle, degree
22. Blan5 Blath5 Blok5 Wbar46 (I12,3F12.4)
    - Blan5—number of stator vanes

- Blath5—stator vane normal thickness, in.
- Blok5—stator vane LE blockage (1.0 is no aerodynamic blockage; 0.98 is 2 percent aeroblockage)
- Wbar46—tandem stator gap total pressure loss coefficient (annular duct loss between blade rows, stator TE to stator LE) range 0.01 to 0.02

23. RCG2 Athrt2 BlokTH2 Wbar4T (4F12.4)
    - RCG2—stator vane
    - Athrt2—stator vane throat area, in^2
    - BlokTH2—stator vane throat blockage (1.0 is no aerodynamic blockage; 0.98 is 2 percent aeroblockage)
    - Wbar4T—stator vane throat loss coefficient
24. R6S R6H B6X BetB6 (4F12.4)
    - R6s—stator TE tip radius, in.
    - R6h—stator TE hub radius, in.
    - B6X—stator TE lean, in.
    - BetB6—stator vane TE metal angle, degree
25. Blan6 Blath6 Blok6 SolidStat2 (I12,3F12.4)
    - Blan6—number of stator vanes
    - Blath6—stator vane normal thickness, in.
    - Blok6—stator vane TE blockage (1.0 is no aerodynamic blockage; 0.98 is 2 percent aeroblockage)
    - SolidStat2—stator 2 vane solidity

STAGE 2+ Repeat lines 7-20 (or 7-25 if tandem stators) for additional stage calculations

.

Gooseneck and Strut

40. R7S R7h B7X Length67 (4F12.4)
    - R7S—strut/duct tip radius (LE), in.
    - R7h—strut/duct hub radius (LE), in.
    - B7X—strut/duct lean (LE), in.
    - Length67—duct length, in.
41. Blan7 Blath7 Blok7 Wbar67 (I12,3F12.4)
    - Blan7—number of strut blades in duct; that is, 3 to 5 struts
    - Blath7—blade thickness, in.
    - Blok7—blockage in duct (1.0 is unblocked)
    - Wbar67—loss model in duct; 0.02
42. R8S R8h B8X Length78 (4F12.4)
    - R8S—strut/duct tip radius (TE), in.
    - R8h—strut/duct hub radius (TE), in.
    - B8X—strut/duct lean (TE), in.
    - Length78—strut/duct length, in.
43. Blan8 Blath8 Blok8 Wbar78 (I12,3F12.4)
    - Blan8—number of strut blades in duct; that is, 3 to 5 struts
    - Blath8—strut blade thickness, inches
    - Blok8—strut blockage (1.0 is unblocked)
    - Wbar78—strut loss model; 0.02

6.3.3 Core Program Output—General Block Description

Record #

```
1.  Title
2.  BLEED               DPInc           EfDer           SH

3.  W act               RPM act Pt              Tt              POTS            POTH            AeroBl
4.  W Kg/sec    Wdry            H2Ovap_Lb/s     H2Ovap_g/m^3    m^3/min IWAR            IWC
5.  W cor               RPM cor GAMMA           Cp              R               Blades          THK             Area1UB
6.  CFM         SCFM            A1/A*           Area1           A*              AthrRotor       ChokeMargin     AnnularArea

7.  Station   1.  ROTOR LEADING EDGE CONDITIONS, STAGE   1
8.  R1          Stator          Alfa            C1              CU1             Cm1             Mabs            Mrel            U1cor    FlowCoeff
9.  BetaFlo     BetaBlade       Incid           U1              W1              Ps1             Ts1             TwetBulb1       RH

10. Station   2.  ROTOR EXIT CONDITIONS, STAGE   1
11. B2 axial    THK             AeroBl          Blades2 Area2           Area2UB
12. R2          C2              Cu2             Cm2             Ao2             Mach2           Chord           AxChord Rcircle
13. U2          W2              Wu2             MachRel2 DelRCu         Eff2uC          Eff2incC AvgREff  Ws1/W2
14. Pt2         PR              Ps2             Tt2             TR              Ts2             TwetBulb2       RH              Tt2avg      PR2avg
15. Alfa2               Beta FLO Beta BLADE     Deviat          Slip F. DiffFct Solidity Convergence    Iter

16. Station   3. STATOR ROW #1
17. blockage3   XBladeGap       Vane#           Area3           Tt3             TwetBulb3       MeltFract       Area3UB

18. ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
19. R3m         C3              Cu3             Cm3             Ao3             Mach3           cp 2-3          Stat Ax Chd
20. Pt3         Ps3             Ts3             RH3             FloAlpha3       VaneAlpha3      Incid3

21. Station   4. STATOR / VANED DIFFUSER THROAT:
22. RCG         Cth             Cuth            Cmth            Aoth            Machth          cp 2-Th  Stat Chord
23. BlockageTh  PtTh            PsTh            TsTh            TwetBulbTh      AreaTh          w2-Th           DiffFact4

24. Station   5. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
25. R4          C4              Cu4             Cm4             Ao4             Mach4           cp 3-4          Stator Gap
26. Blockage4   Ps4             Ts4             TwetBulb4       VaneAlpha4      Vane Thk4       w2-4OD          cp 2-4

27. STAGE EXIT CONDITIONS, STAGE          1
28. Eff4        Pt4             PR              TR              Tt4             Del T           Ns              Ns nondim
29. Del Enthalpy Del_H/U^2      GHP             Reynolds#       Specif Humid    Area4           Area4UB
30. Station   1.  ROTOR LEADING EDGE CONDITIONS, STAGE   2-N
  .
.       Stage 2 - N (N is the total number of stages) output repeat of variables Stations 1 - 5 (Records 1 - 28) from above
  .
31. OVERALL EXIT CONDITIONS; ALL        N   STAGES  (N is the total number of stages)
32. Del Enthalpy GHP            MassFloS1cor    OPR             Efficiency              Rotor1Inc  TR      AxHubLen
```

6.3.4 Core Program Output—Data Definitions (by Record Number)

Record 1:

Title	as written in input file

Record 2:

BLEED	bleed from upstream of stage (0.1 = 10 percent)
DPInc	incidence at the Blade RMS radius (mean)
EfDer	efficiency deration from the nominal (1.0 is no deration; 0.98 is 2 percent deration) calculated from the incidence versus loss bucket for the rotor
SH	S_h at the inlet

Record 3:

W act	actual mass flow of the gas
RPM act	actual and physical rotational speed
Pt	inlet P_t at rotor 1 LE (or engine inlet, if applicable)
Tt	inlet T_t at rotor 1 LE (or engine inlet, if applicable)
POTS	potential ratio at the tip and shroud (ratio of the tip and shroud to the mean meridional velocity) (1.0 to 1.2) depends on curvature, the smaller the radius of curvature, upstream of the rotor, the larger the ratio (e.g., POTS 1.2 typical for multistage centrifugal compressors)
POTH	potential ratio at the hub (ratio of the hub to the mean meridional velocity) (1.0 to 0.7) depends on curvature, the smaller the radius of curvature, upstream of the rotor, the smaller the ratio (e.g., POTH 0.8 typical for multistage centrifugal compressors)
AeroBl	aeroblockage at the LE—accounts for boundary layer blockage but does not include metal blockage

Record 4:

W Kg/sec	actual mass flow in kg/s
Wdry	if SH > 0, the actual mass flow of dry air (Wdry = Wact if SH = 0.0)
H2Ovap_Lb/s	water vapor mass flow rate in the air
H2Ovap_g/m^3	water vapor volumetric flow rate in the air, metric
m^3/min	m^3/min of air/gas flow, total (air + vapor)
IWAR	ice water flow rate to air/gas flow rate (total, air + ice/water) ratio
IWC	ice water content in g/m^3

Record 5:

W cor	corrected mass flow rate of gas, corrected with pressure and temperature only (not with mole weight)
RPM cor	corrected rotational speed
GAMMA	ratio of specific heats; c_p/c_v
Cp	specific heat at constant pressure
R	gas constant (1,545/gas mole weight)
Blades	number of rotor blades at the LE (if centrifugal with splitter blades, set to NBLAN in input to negative value and the number of blades at the TE will be doubled, that is, NBLAN = –18 then Blades2 = 36)
THK	thickness normal to the camber line at the LE, diameter if the LE is circular
Area1UB	full area without metal blockage or aeroblockage, conical area (not necessarily annular)

Record 6:

CFM	ft^3/min of gas flow with vapor

SCFM	standard ft^3/min at standard temperature and pressure (STP) (14.696 psia and 518.6 R)
A1/A*	area ratio of the actual annular area over the critical area (area for Mach = 1.0, choke)
Area1	total aerodynamic area reduced by the aeroblockage, conical normal to the meridional direction (washer to cone to cylinder for centrifugal with no inducer)
A*	critical area computed based on the mass flow, P_t, and T_t for choked flow (Mach = 1.0)
AthrRotor	calculated approximate rotor throat based on annular area and the rotor LE blade angle (beta)
ChokeMargin	amount the flow can be increased before the rotor chokes, a value of 1.8 means that the mass flow can be increased by 80 percent before the flow chokes
AnnularArea	pure annular area hub to tip no blockage, annulus face area, “washer”

Record 7:

Station 1. ROTOR LEADING EDGE CONDITIONS, STAGE 1

Record 8:

TIP, MEAN, and HUB

R1	radius from centerline to hub (input), mean (calculated), and tip (input) of the flow path
Stator	α from upstream stator (swirl angle and prewhirl) as measured from the axial direction
Alfa	α
C1	absolute total flow velocity
CU1	absolute tangential flow velocity
Cm1	absolute meridional flow velocity
Mabs	absolute Mach number
Mrel	relative Mach number
U1cor	rotor tip speed corrected to STP
FlowCoeff	C_1/U_1; flow coefficient: ratio of absolute total velocity to the physical tip speed

Record 9:

BetaFlo	β_F
BetaBlade	β_B with respect to the meridional direction (axial compressor is axial and radial compressor is radial)
Incid	incidence: difference between the flow and the blade angle, positive incidence is the norm, for high relative Mach number (>1.2) rotors; 6 is design point incidence
U1	peripheral and tangential velocity of the blade
W1	relative total gas velocity
Ps1	static pressure
Ts1	static temperature
TwetBulb1	T_{WB} based on the local T_t and ϕ, see plot.out output file for T_{WBS} (static is used to determine icing risk)
RH	local value of ϕ

Record 10:

Station 2. ROTOR EXIT (TRAILING EDGE) CONDITIONS, STAGE 1

Record 11:

B2 axial	axial projection distance on the axial line from hub to tip (always positive even in the case of negative sweep)
THK	blade thickness normal to the camber line at TE, diameter if the TE is circular
AeroBl	aerodynamic blockage, that is, 0.95 is 5 percent blockage
Blades2	number of rotor blades

Area2	total aerodynamic area reduced by the aeroblockage and blade blockage, conical normal to the meridional direction (washer to cone to cylinder for centrifugal with no inducer)
Area2UB	full area without metal blockage or aeroblockage, conical area (not necessarily annular)
Record 12:	
R2	radius from centerline to hub, mean (calculated), and tip of the flow path
C2	absolute total flow velocity
Cu2	absolute tangential flow velocity
Cm2	absolute meridional flow velocity
Ao2	local speed of sound based on static temperature
Mach2	absolute Mach number
Chord	chord length of the rotor blade
AxChord	axial chord length of the rotor blade
Rcircle	radius of curvature of the camber line
Record 13:	
U2	peripheral and tangential velocity of the blade
W2	relative total gas velocity
Wu2	relative tangential gas velocity
MachRel2	relative Mach number
DelRCu	change in tangential velocity from the inlet to the outlet at a given radius
Eff2uC	adiabatic efficiency—input at each radius; best efficiency point (BEP)
Eff2incC	efficiency after deration due to incidence loss
AvgREff	average rotor efficiency at all spans
Ws1/W2	ratio of rotor relative tip velocity to relative mean velocity used to determine the diffusion through the rotor; the “diffuser analogy” is used to determine the rotor surge point. Stable if Ws1/W2 < 1.9; surge if Ws1/W2 > 1.9; if DiffFct > 0.62 (see following), then that determines the surge point even if Ws1/W2 < 1.9
Record 14:	
Pt2	P_t
PR	P_t ratio across the rotor (total exit to total inlet (T-T))
Ps2	static pressure
Tt2	T_t
TR	T_t ratio across the rotor (T-T)
Ts2	static temperature
TwetBulb2	T_{WB} based on T_t and ϕ
RH	ϕ
Tt2avg	average T_t
PR2avg	average P_t ratio (T-T)
Record 15:	
Alfa2	α
Beta FLO	β_F
Beta BLADE	β_B with respect to the meridional direction (axial compressor is axial and radial compressor is radial)
Deviat	deviation angle in degrees: difference between the flow angle and the blade angle
Slip F.	δ: the difference between the theoretical and absolute fluid tangential velocities normalized with the blade physical/peripheral/tangential velocity

DiffFct	DF; used to determine the diffusion through the rotor; used to determine the rotor surge point. Flow in the rotor is stable if DiffFct < 0.62; surge if DiffFct > 0.62; if Ws1/W2 reaches 1.9 then that determines the surge point even if DiffFct is < 0.62
Solidity	blade solidity (see input description)
Convergence	level of convergence of pressure ratio (PR)
Iter	number of iterations to achieve convergence at each blade span, if 10,000 iterations are reached the solution did not converge, turn on the print variable (1) in the input file to get more information. Possible need to adjust the initial guess on the pressure factor or mass flow needs to be adjusted down

Record 16:

Station 3. STATOR ROW #1

Record 17:

blockage3	aerodynamic blockage, that is, 0.95 is 5 percent blockage
XBladeGap	calculated axial gap; distance between rotor TE hub to the stator LE hub
Vane#	number of stator vanes
Area3	total aerodynamic area reduced by the aeroblockage and blade blockage, conical normal to the meridional direction (washer to cone to cylinder for centrifugal)
Tt3	T_t
TwetBulb3	T_{WB} based on T_t
MeltFract	ice particle melt fraction if the MELT code is used for ice particle ingestion analysis
Area3UB	full area without metal blockage or aeroblockage, conical area (not necessarily annular)

Record 18:

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE

Record 19:

R3m	RMS radius from centerline (calculated from input values of R3s and R3h)
C3	absolute total flow velocity
Cu3	absolute tangential flow velocity
Cm3	absolute meridional flow velocity
Ao3	local speed of sound based on static temperature
Mach3	local Mach number
cp 2-3	static pressure recovery coefficient from rotor TE to stator LE
Stat Ax Chd	stator axial chord

Record 20:

Pt3	P_t
Ps3	static pressure
Ts3	static temperature
RH3	ϕ
FloAlpha3	α
VaneAlpha3	β_B
Incid3	incidence angle at stator LE; difference between the α and the β (design point incidence = 0 degree)

Record 21:

Station 4. STATOR / VANED DIFFUSER THROAT:

Record 22:

RCG	stator vane radius of center of gravity of the conical/annular area (RMS radius of stator throat; utilized for centrifugal radial diffusers, where it determines the diffuser loading

	and the static pressure recovery from the impeller trailing edge to the diffuser throat). For axials, it can be the RMS radius of the leading edge
Cth	absolute total flow velocity
Cuth	absolute tangential flow velocity
Cmth	absolute meridional flow velocity
Aoth	local speed of sound based on static temperature
Machth	local Mach number
cp 2-Th	static pressure recovery coefficient from rotor TE to stator throat. Note: this parameter has been correlated with stall for centrifugal compressor stages having radial vaned diffusers. Stall is likely to occur if the value is > 0.45
Stat Chord	stator chord; see file geometry.out

Record 23:

BlockageTh	aerodynamic blockage, that is 0.95 is 5 percent blockage
PtTh	P_t at the stator throat
PsTh	static pressure at the stator throat
TsTh	static temperature at the stator throat
TwetBulbTh	T_{WB} based on the T_t at the stator throat
AreaTh	aerodynamic throat area
w2-Th	loss coefficient (input) rotor exit to throat of stator (or radial diffuser throat)
DiffFact4	DF; stable if DiffFact4 < 0.5 for axial stators

Record 24:

Station 5. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):

Record 25:

R4	RMS radius from centerline (calculated from input values of R4s and R4h)
C4	absolute total flow velocity
Cu4	absolute tangential flow velocity
Cm4	absolute meridional flow velocity
Ao4	local speed of sound based on static temperature
Mach4	Mach number
cp 3-4	static pressure recovery coefficient from stator LE to stator TE. Note: stator stall can occur above values of 0.5 (< 0.7 for radial diffuser of centrifugal stage)
Stator Gap	axial gap distance between stator TE to the LE of the next blade row along the hub

Record 26:

Blockage4	aerodynamic blockage, that is, 0.95 is 5 percent blockage
Ps4	static pressure
Ts4	static temperature
TwetBulb4	T_{WB} based on T_t
VaneAlpha4	stator TE physical/metal vane angle
Vane Thk4	stator thickness normal to the camber line at the TE
w2-4OD	off-design pressure loss coefficient (calculated from input w2-4 derated by the incidence angle)
cp 2-4	static pressure recovery coefficient from rotor TE to stator TE

Record 27:

STAGE EXIT CONDITIONS, STAGE 1

Record 28:

Eff4	stage efficiency

Pt4	P_t at stage exit
PR	stage pressure ratio (total to total)
TR	stage temperature ratio (total to total)
Tt4	T_t at stage exit
Del T	T_t rise through the rotor
Ns	specific speed; for axials between 200 and 500; for centrifugals between 40 and 120
Ns nondim	specific speed, nondimensional

Record 29:

Del Enthalpy	change in enthalpy for the stage
Del_H/U^2	head coefficient
GHP	gas horsepower
Reynolds#	Reynolds number based on blade span and mean absolute velocity at the rotor LE
Specif Humid	local S_h
Area4	total aerodynamic area reduced by the aeroblockage and blade blockage, conical normal to the meridional direction (washer to cone to cylinder for centrifugal)
Area4UB	full area without metal blockage or aeroblockage, conical area (not necessarily annular)

Record 30:

Station 1. ROTOR LEADING EDGE CONDITIONS, STAGE 2 – N (N is the total number of stages)

.

Stage 2 – N (N is the total number of stages) output repeat of variables stations 1 - 5 (records 1 - 29) from previous information

.

.

.

Record 31:

OVERALL EXIT CONDITIONS; ALL N STAGES (N is the total number of stages)

Record 32:

Del Enthalpy	overall change in enthalpy for N stage compressor
GHP	overall gas horsepower for N stage compressor (working fluid not including horsepower due to bearing and seal friction losses)
MassFloS1cor	corrected mass flow into stage 1 same as Wcor
OPR	overall pressure ratio for N stages (T-T)
Efficiency	overall efficiency for N stages (T-T)
Rotor1Inc	rotor incidence of stage 1 at RMS radius
TR	overall temperature ratio for N stages (T-T)
AxHubLen	total axial length for an axial compressor including gaps; measured along the hub

7.0 Input File Setup and Example Cases for Axial, Centrifugal, and Mixed Axial and Centrifugal

This section describes how an input file is constructed to match design conditions and offdesign analysis. Adjustments to the slip factor, efficiency, and blockage models are necessary to match the compressor data, on and off design, see Section 7.1.5. The details for these example cases include the input data file followed by the corresponding output files including the files “geometry.out” and “Plot_Geometry.dat.” The output files “plot.out” and “Melt_Frac.out” will be described in the section where an icing risk analysis was conducted.

7.1 Example Case (1): 40,000 lbf Thrust Turbofan Bypass Ratio = 5.0

The input and output files that are used and generated for the full fan of this example case are provided along with a plot of the stage blade geometries.

7.1.1 Full Fan

See Figure 14 for a plot of the stage blade geometries.

7.1.1.1 Input File

comdes.dat

```
    Fan-FULL   Bypass Ratio = 5.0  Design Point
   1060.00       15.107     522.8      3776.0         Wact        Pt1          Tt1         RPM
      5           1           0           0.0         Fluid       Stages       IDUMMY      DUMMY
      0.00        8.000       0.00        0.0         DropDia     InDist       RHinlet     IWC         ***icing***
     14.30        0.0       536.0         0.0         Psin        DUMMY        Tsin        DUMMY       ***icing***
    318.0         0.0      1000.          0           Vin         DUMMY        Altitude    IDUMMY      ***icing***
     39.25       12.5100     37.5        15.00      1 R1tip       R1hub        R2tip       R2hub
      0.7000      0.700      32           0.050       1.0         B1axial      B2axial     NBLAD       THK      CFS
      0.0         0.0000      0.000       1.000       0.9         StatorT      StatorM     StatorH     FSGV     CFMid
      0.9800      0.9500      1.0000      1.000       0.9         AeroB1       AeroB2      POTS        POTH     CFHub
      0.915       0.915       0.915       0.0000      EfficiT     EfficiM      EfficiH     BLEED
      0.000       0.000       0.000       0.000       DUMMY       DUMMY        DUMMY       DUMMY
      0.9250      0.035       1.66        0.00        SlipF       DiffLoss     Solidity    RPM2
     60.00       54.2        38.62        2.0         BetaBlade1T BetaBlade1M  BetaBlade1H expo3
     56.5        42.50       -9.3         0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
     37.5        15.0         0.0        36.0         R3s         R3h          B3X         BetB3
     33           0.06        0.95        0.01        Blan3       Blath3       Blok3       Wbar23
     33.0         0.000       0.95        0.015       RCG         Athrt        BlokTH      Wbar2T
     37.5        15.0         0.0         0.0         R4S         R4H          B4X         BetB4
     33           0.06        0.95        1.40        Blan4       Blath4       Blok4       SolidStat
     37.5        15.0         0.00        2.0         R7S         R7h          B7X         Length67
      4           0.01        0.98        0.000       Blan7       Blath7       Blok7       Wbar67
     37.5        15.0         0.0         2.0         R8S         R8h          B8X         Length78
      4           0.01        0.98        0.00        Blan8       Blath8       Blok8       Wbar78
```

7.1.1.2 Output Files

comdes.out

```
*********************************************************************
**************** AXIAL & CENTRIFUGAL COMPRESSOR BLADE DESIGN 1-D ****
*******************   COMDES-MELT Release Version 1    **************
*********************   Gasplus Fluid Properties   ******************
*********************************************************************

    Fan-FULL   Bypass Ratio = 5.0  Design Point

  COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   1
  BLEED =  0.000   DPInc = 7.807   EfDer =  0.999    SH =  0.000000E+00

  W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
 1060.0000   3776.0000     15.1069    522.8000      1.0000      1.0000      0.9800

  W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
  481.8182   1060.0000      0.0000      0.0000  25665.4922      0.0000      0.0000

  W cor     RPM cor        GAMMA       Cp          R          Blades       THK         Area1UB
 1035.5107   3761.1646      1.4014      0.2486     53.3483          32      0.0500   4349.6499

  CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
  906368.250  831728.375   1.4133   4262.6572   3016.0134   2749.8923      0.9118   4348.1602

  Station   1.  ROTOR LEADING EDGE CONDITIONS, STAGE   1
          R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel  U1cor    FlowCoeff
  TIP     39.25     0.00    -0.02   510.31    -0.18   510.31     0.46     1.27  1288.24    0.395
  MEAN    29.13     0.00    -0.02   510.31    -0.18   510.31     0.46     0.99
  HUB     12.51     0.00    -0.02   510.31    -0.18   510.31     0.46     0.60
```

```
      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     68.47    60.00     8.47  1293.36  1390.56    13.03   501.07   498.16     0.00
MEAN    62.01    54.20     7.81   959.87  1087.25    13.03   501.07   498.16     0.00
HUB     38.94    38.62     0.32   412.23   656.12    13.03   501.07   498.16     0.00
Station   2.  ROTOR EXIT CONDITIONS, STAGE   1    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.7000      0.0500      0.9500          32   3492.9453   3712.8020

        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP     37.50   643.97   455.96   454.75  1179.92     0.55    12.22     7.24   200.12
MEAN    28.56   651.14   398.93   514.62  1147.89     0.57    10.75     7.55    52.75
HUB     15.00   825.89   557.06   609.74  1107.75     0.75     8.31     8.04    10.23

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP   1235.69   902.66   779.73     0.77 17105.38     0.92     0.91
MEAN   941.08   747.50   542.14     0.65 11398.34     0.92     0.91     0.91     1.84
HUB    494.28   612.96    62.78     0.55  8358.12     0.92     0.91

        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP     25.23     1.67    20.60   613.37     1.17   578.77   542.20     0.00
MEAN    21.44     1.42    17.23   583.15     1.12   547.77   529.12     0.00   587.86  1.46
HUB     19.60     1.30    13.54   567.05     1.08   510.14   521.59     0.00

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     45.08    59.75    56.50     3.25     0.93     0.45     1.66      0.00009     71
MEAN    37.78    46.49    42.50     3.99     0.93     0.41     1.88      0.00014     48
HUB     42.41    -5.88    -9.30     3.42     0.93     0.20     3.38      0.00059     34

Station   3. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      2.0099          33   3483.1338    587.8585    531.2699      0.0000   3711.0066

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
 28.5591    642.1721    398.9342    503.2261   1153.8083      0.5566      0.1255      9.5067

Pt3         Ps3         Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
 22.0406     17.8555    553.4500      0.0000     38.4057     36.0000      2.4057

Station   4. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
 33.0000    521.3896    129.6643    505.0092   1165.8477      0.4472      0.4086      9.9960

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500     21.9760     19.1552    565.1891    531.2116   3477.8428      0.0230      0.4629

Station   5. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4      cp 3-4   Stator Gap
 28.5591    487.3962      0.0000    487.3962   1168.7524      0.4170      0.3756      2.3767

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500     19.4273    568.0524    531.1416      0.0000      0.0600      0.0386      0.4634

STAGE EXIT CONDITIONS, STAGE            1
Eff4         Pt4         PR          TR         Tt4          Del T      Ns          Ns nondim
  0.9009     21.8987      1.4496      1.1244    587.8585     65.0585    390.5479      3.0275

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 404965.062       0.265   24258.039  7066593.5       0.00000  3392.49585  3711.00635

OVERALL EXIT CONDITIONS; ALL          1   STAGES
Del Enthal   DelHT/U1^2  GHP      MassFloS1cor  OPR     Efficiency    Rotor1Inc  TR      AxHubLen
  404965.06     0.2421 24258.0391 1035.511      1.4496   0.90088       7.8072    1.1244   21.933
```

geometry.out—Key geometric details for a compressor stage.

```
       R1      Beta1   R2      Beta2    Sol     Rc      Chord   AxC     X1      Y1      X2      Y2     Theta
TIP    39.250  60.000  37.500  56.500   1.660 200.120  12.223   6.432 173.309 100.060 166.878 110.454   3.500
MID    29.130  54.200  28.559  42.500   1.880  52.751  10.753   7.146  42.785  30.857  35.638  38.892  11.700
HUB    12.510  38.620  15.000  -9.300   3.383  10.232   8.310   8.040   6.386   7.994   1.654  10.097  47.920
```

```
  Blade > Stator Gap (2->3)   2.009935
       R3      Beta3   R4      Beta4     Sol     Rc      Chord   AxC     X3      Y3      X4       Y4     Theta
TIP    37.500  36.000  37.500   0.000    1.400  16.174   9.996   9.507   9.507  13.085   0.000  16.174  36.000
MID    28.559  36.000  28.559   0.000    1.783  16.174   9.996   9.507   9.507  13.085   0.000  16.174  36.000
HUB    15.000  36.000  15.000   0.000    3.394  16.174   9.996   9.507   9.507  13.085   0.000  16.174  36.000

  Stator > Blade Gap (4->1)    2.376685
  Cumul Axial Length (1->5)  Stage   21.93310                1
```

Data geometry description at each rotor, gap, stator, see Figure 3 and Figure 4:

R1	radius from centerline to hub, mid, and tip at the rotor LE
Beta1	rotor LE hub, mid, and tip metal angle, degree
R2	radius from centerline to hub, mid, and tip at the rotor TE
Beta2	rotor TE hub, mid, and tip metal angle, degree
Sol	solidity at hub, mid, and tip of rotor
Rc	arc radius at the rotor midchord
Chord	chord of the rotor at the hub, mid, and tip
AxC	axial chord of the rotor at the hub, mid, and tip
X1	axial distance from blade LE to circular arc center coordinates, rotor
Y1	tangential distance from blade LE to circular arc center coordinates, rotor
X2	axial distance from blade TE to circular arc center coordinates, rotor
Y2	tangential distance from blade TE to circular arc center coordinates, rotor
Theta	included angle between LE and TE of the rotor

Blade > Stator Gap (2–>3)   axial gap distance between rotor and stator

R3	radius from centerline to hub, mid, and tip at the stator LE
Beta3	stator LE hub, mid, and tip metal angle, degree
R4	radius from centerline to hub, mid, and tip at the stator TE
Beta4	stator TE hub, mid, and tip metal angle, degree
Sol	solidity at hub, mid, and tip of stator
Rc	arc radius at the stator midchord
Chord	chord of the stator at the hub, mid, and tip
AxC	axial chord of the stator at the hub, mid, and tip
X3	axial distance from blade LE to circular arc center coordinates equivalent to X_1 in Figure 4, stator
Y3	tangential distance from blade LE to circular arc center coordinates equivalent to Y_1 in Figure 4, stator
X4	axial distance from blade TE to circular arc center coordinates equivalent to X_2 in Figure 4, stator
Y4	tangential distance from blade TE to circular arc center coordinates equivalent to Y2 in Figure 4, stator
Theta	included angle between LE and TE of the stator

Stator > Blade Gap (4–>1)   axial gap distance between stator and following rotor

Cumul Axial Length (1–>5) Stage   axial length for compete stage at the hub

Plot_Geometry.dat—Rotor blade and stator vane geometries for plotting at the tip, mid, and hub circular arc camber line sections.

```
TITLE = "Blade Geometry"
VARIABLES =        i       Thetas   xs   ys   Thetam   xm   ym   Thetah   xh   yh
ZONE T =" Blade 1", I = 41.0
    1    30.000  -3.216  -5.374  35.800  -3.573  -4.430  51.380  -4.020  -1.960
    2    30.087  -3.063  -5.110  36.092  -3.415  -4.212  52.578  -3.851  -1.829
    3    30.175  -2.909  -4.845  36.385  -3.256  -3.994  53.776  -3.680  -1.700
    4    30.262  -2.756  -4.581  36.677  -3.096  -3.778  54.974  -3.506  -1.576
    5    30.350  -2.601  -4.317  36.970  -2.934  -3.562  56.172  -3.330  -1.455
    6    30.437  -2.447  -4.054  37.262  -2.772  -3.348  57.370  -3.151  -1.337
    7    30.525  -2.292  -3.790  37.555  -2.608  -3.134  58.568  -2.969  -1.224
    8    30.612  -2.136  -3.527  37.847  -2.443  -2.921  59.766  -2.786  -1.114
    9    30.700  -1.981  -3.264  38.140  -2.278  -2.708  60.964  -2.600  -1.009
   10    30.787  -1.824  -3.002  38.432  -2.111  -2.497  62.162  -2.412  -0.907
   11    30.875  -1.668  -2.739  38.725  -1.943  -2.287  63.360  -2.221  -0.809
   12    30.962  -1.511  -2.477  39.017  -1.774  -2.077  64.558  -2.029  -0.715
   13    31.050  -1.353  -2.215  39.310  -1.604  -1.868  65.756  -1.835  -0.625
   14    31.137  -1.195  -1.953  39.602  -1.433  -1.660  66.954  -1.639  -0.539
   15    31.225  -1.037  -1.692  39.895  -1.260  -1.453  68.152  -1.441  -0.458
   16    31.312  -0.879  -1.431  40.187  -1.087  -1.247  69.350  -1.242  -0.380
   17    31.400  -0.719  -1.170  40.480  -0.913  -1.042  70.548  -1.041  -0.307
   18    31.487  -0.560  -0.909  40.772  -0.738  -0.837  71.746  -0.839  -0.237
   19    31.575  -0.400  -0.648  41.065  -0.561  -0.634  72.944  -0.635  -0.173
   20    31.662  -0.240  -0.388  41.357  -0.384  -0.431  74.142  -0.430  -0.112
   21    31.750  -0.079  -0.128  41.650  -0.205  -0.229  75.340  -0.223  -0.056
   22    31.837   0.082   0.132  41.942  -0.026  -0.029  76.538  -0.016  -0.004
   23    31.925   0.243   0.391  42.235   0.155   0.171  77.736   0.193   0.044
   24    32.012   0.405   0.650  42.527   0.336   0.370  78.934   0.402   0.087
   25    32.100   0.567   0.909  42.820   0.519   0.568  80.132   0.613   0.126
   26    32.187   0.730   1.168  43.112   0.702   0.765  81.330   0.824   0.160
   27    32.275   0.893   1.427  43.405   0.887   0.961  82.528   1.036   0.191
   28    32.362   1.056   1.685  43.697   1.072   1.156  83.726   1.248   0.216
   29    32.450   1.220   1.943  43.990   1.259   1.351  84.924   1.461   0.237
   30    32.538   1.384   2.201  44.282   1.446   1.544  86.122   1.674   0.254
   31    32.625   1.549   2.458  44.575   1.635   1.736  87.320   1.888   0.266
   32    32.713   1.714   2.716  44.867   1.825   1.928  88.518   2.102   0.274
   33    32.800   1.879   2.973  45.160   2.015   2.118  89.716   2.316   0.277
   34    32.888   2.045   3.229  45.452   2.206   2.307  90.914   2.530   0.276
   35    32.975   2.211   3.486  45.745   2.399   2.496  92.112   2.743   0.270
   36    33.063   2.377   3.742  46.037   2.592   2.683  93.310   2.957   0.260
   37    33.150   2.544   3.998  46.330   2.786   2.870  94.508   3.171   0.246
   38    33.238   2.712   4.254  46.622   2.982   3.055  95.706   3.384   0.227
   39    33.325   2.879   4.509  46.915   3.178   3.240  96.904   3.596   0.203
   40    33.413   3.047   4.765  47.207   3.375   3.423  98.102   3.808   0.175
   41    33.500   3.216   5.020  47.500   3.573   3.606  99.300   4.020   0.143
ZONE T =" Stator 1", I = 41.0
    1    54.000   5.296   2.375  54.000   5.296   2.375  54.000   5.296   2.375
    2    54.900   5.503   2.227  54.900   5.503   2.227  54.900   5.503   2.227
    3    55.800   5.712   2.083  55.800   5.712   2.083  55.800   5.712   2.083
    4    56.700   5.923   1.941  56.700   5.923   1.941  56.700   5.923   1.941
    5    57.600   6.137   1.804  57.600   6.137   1.804  57.600   6.137   1.804
    6    58.500   6.352   1.669  58.500   6.352   1.669  58.500   6.352   1.669
    7    59.400   6.570   1.538  59.400   6.570   1.538  59.400   6.570   1.538
    8    60.300   6.790   1.410  60.300   6.790   1.410  60.300   6.790   1.410
    9    61.200   7.011   1.286  61.200   7.011   1.286  61.200   7.011   1.286
   10    62.100   7.235   1.166  62.100   7.235   1.166  62.100   7.235   1.166
   11    63.000   7.460   1.049  63.000   7.460   1.049  63.000   7.460   1.049
   12    63.900   7.688   0.935  63.900   7.688   0.935  63.900   7.688   0.935
   13    64.800   7.917   0.825  64.800   7.917   0.825  64.800   7.917   0.825
   14    65.700   8.147   0.719  65.700   8.147   0.719  65.700   8.147   0.719
   15    66.600   8.380   0.616  66.600   8.380   0.616  66.600   8.380   0.616
   16    67.500   8.614   0.517  67.500   8.614   0.517  67.500   8.614   0.517
   17    68.400   8.849   0.422  68.400   8.849   0.422  68.400   8.849   0.422
   18    69.300   9.086   0.330  69.300   9.086   0.330  69.300   9.086   0.330
   19    70.200   9.324   0.242  70.200   9.324   0.242  70.200   9.324   0.242
   20    71.100   9.564   0.158  71.100   9.564   0.158  71.100   9.564   0.158
   21    72.000   9.805   0.077  72.000   9.805   0.077  72.000   9.805   0.077
   22    72.900  10.047   0.001  72.900  10.047   0.001  72.900  10.047   0.001
   23    73.800  10.291  -0.072  73.800  10.291  -0.072  73.800  10.291  -0.072
   24    74.700  10.535  -0.141  74.700  10.535  -0.141  74.700  10.535  -0.141
   25    75.600  10.781  -0.206  75.600  10.781  -0.206  75.600  10.781  -0.206
```

```
   26    76.500  11.027  -0.267  76.500  11.027  -0.267  76.500  11.027  -0.267
   27    77.400  11.275  -0.325  77.400  11.275  -0.325  77.400  11.275  -0.325
   28    78.300  11.523  -0.378  78.300  11.523  -0.378  78.300  11.523  -0.378
   29    79.200  11.772  -0.428  79.200  11.772  -0.428  79.200  11.772  -0.428
   30    80.100  12.022  -0.473  80.100  12.022  -0.473  80.100  12.022  -0.473
   31    81.000  12.273  -0.515  81.000  12.273  -0.515  81.000  12.273  -0.515
   32    81.900  12.524  -0.553  81.900  12.524  -0.553  81.900  12.524  -0.553
   33    82.800  12.776  -0.587  82.800  12.776  -0.587  82.800  12.776  -0.587
   34    83.700  13.028  -0.617  83.700  13.028  -0.617  83.700  13.028  -0.617
   35    84.600  13.281  -0.642  84.600  13.281  -0.642  84.600  13.281  -0.642
   36    85.500  13.534  -0.664  85.500  13.534  -0.664  85.500  13.534  -0.664
   37    86.400  13.787  -0.682  86.400  13.787  -0.682  86.400  13.787  -0.682
   38    87.300  14.041  -0.696  87.300  14.041  -0.696  87.300  14.041  -0.696
   39    88.200  14.295  -0.706  88.200  14.295  -0.706  88.200  14.295  -0.706
   40    89.100  14.549  -0.712  89.100  14.549  -0.712  89.100  14.549  -0.712
   41    90.000  14.803  -0.714  90.000  14.803  -0.714  90.000  14.803  -0.714
```

Data geometry description for the hub, mid, and tip circular arcs for the rotor blade and stator vane of each compressor stage, see Figure 14.

The data for this example case consists of a single stage: a rotor blade and stator vane. If a larger compressor was considered, the stage geometric data would be repeated to be consistent with the number of stages analyzed. The first and second lines in the file contain the title and the list of variables, respectively, that are available for plotting. There are a total of 41 points that represent each circular arc airfoil camber line. Each "ZONE" represents a rotor blade or a stator vane at the tip (θs, xs, ys), mid (θm, xm, ym), and hub (θh, xh, yh) section. The variables θ, x, and y are the triples that are the angle and x, y coordinates of the circular arc sweep through the 41 point discretization of the circular arc camber line from the LE to TE of the blade or vane section. Figure 14 illustrates a plot of the data above.

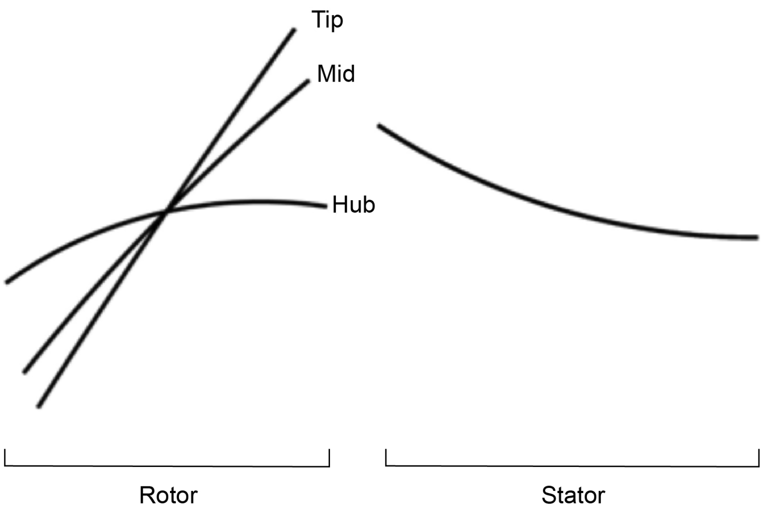

Figure 14.—Rotor blade and stator vane circular arc camber line data plotted from "Plot_Geometry.dat" file. Single stage is plotted showing rotor blade (hub, mid, and tip) and stator vane (mid) circular arc camber line geometries.

7.1.2 Fan Bypass

The input and output files in this section are for the analysis of the fan bypass for this example case.

7.1.2.1 Input File

comdes.dat

```
    Fan-BYPASS   Bypass Ratio = 5.0  Design Point
    883.3        15.107    522.8       3776.0         Wact        Pt1          Tt1         RPM
      5           1          0           0.0          Fluid       Stages       IDUMMY      DUMMY
      0.00        8.000      0.00        0.0          DropDia     InDist       RHinlet     IWC         ***icing***
     14.30        0.0      536.0         0.0          Psin        DUMMY        Tsin        DUMMY       ***icing***
    318.0         0.0     1000.          0            Vin         DUMMY        Altitude    IDUMMY      ***icing***
     39.25       20.6300    37.5        20.63       1 R1tip       R1hub        R2tip       R2hub
      0.7000      0.700     32           0.050        1.0         B1axial      B2axial     NBLAD       THK      CFS
      0.0         0.0000     0.000       1.000        0.9         StatorT      StatorM     StatorH     FSGV     CFMid
      0.9800      0.9500     1.0000      1.000        0.9         AeroB1       AeroB2      POTS        POTH     CFHub
      0.915       0.915      0.915       0.0000       EfficiT     EfficiM      EfficiH     BLEED
      0.000       0.000      0.000       0.0000       DUMMY       DUMMY        DUMMY       DUMMY
      0.9250      0.035      1.66        0.00         SlipF       DiffLoss     Solidity    RPM2
     60.00       54.2       50.47        2.0          BetaBlade1T BetaBlade1M  BetaBlade1H expo3
     56.5        44.00      24.2          0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
     37.5        20.63       0.0        40.0          R3s         R3h          B3X         BetB3
     33           0.06       0.95        0.01         Blan3       Blath3       Blok3       Wbar23
      0.0         0.000      0.95        0.015        RCG         Athrt        BlokTH      Wbar2T
     37.5        20.63       0.0         0.0          R4S         R4H          B4X         BetB4
     33           0.06       0.95        1.40         Blan4       Blath4       Blok4       SolidStat
     37.5        20.63       0.00        2.0          R7S         R7h          B7X         Length67
      4           0.01       0.98        0.000        Blan7       Blath7       Blok7       Wbar67
     37.5        20.63       0.0         2.0          R8S         R8h          B8X         Length78
      4           0.01       0.98        0.00         Blan8       Blath8       Blok8       Wbar78
```

7.1.2.2 Output Files

comdes.out

```
*********************************************************************
**************** AXIAL & CENTRIFUGAL COMPRESSOR BLADE DESIGN 1-D ****
*******************   COMDES-MELT Release Version 1    **************
*********************   Gasplus Fluid Properties   ******************
*********************************************************************

    Fan-BYPASS   Bypass Ratio = 5.0  Design Point

  COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   1
  BLEED =  0.000   DPInc = 8.521   EfDer =  0.997    SH =  0.000000E+00

  W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
  883.3000   3776.0000     15.1069    522.8000      1.0000      1.0000      0.9800

  W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
  401.5000    883.3000      0.0000      0.0000  21597.3047      0.0000      0.0000

  W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
  862.8931   3761.1646      1.4014      0.2486     53.3483          32      0.0500   3505.2422

  CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
  762701.562  693080.750   1.3668   3435.1372   2513.2429   2220.7261      0.8836   3502.7678

  Station   1.  ROTOR LEADING EDGE CONDITIONS, STAGE   1

          R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
  TIP     39.25     0.00    -0.02   532.87    -0.18   532.87     0.49     1.28  1288.24    0.412
  MEAN    31.35     0.00    -0.02   532.87    -0.18   532.87     0.49     1.06
  HUB     20.63     0.00    -0.02   532.87    -0.18   532.87     0.49     0.79

        BetaFlo   BetaBlade Incid   U1       W1         Ps1     Ts1     TwetBulb1  RH
  TIP     67.61    60.00     7.61  1293.36  1399.00    12.85   499.11   498.16     0.00
  MEAN    62.72    54.20     8.52  1033.17  1162.66    12.85   499.11   498.16     0.00
  HUB     51.92    50.47     1.45   679.80   863.90    12.85   499.11   498.16     0.00

  Station   2.  ROTOR EXIT CONDITIONS, STAGE   1    SOLUTION IS CONVERGED
  B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
    0.7000      0.0500      0.9500          32   2903.6260   3083.4636
```

```
          R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
  TIP     37.50   643.01   451.88   457.46  1179.20     0.55    12.22     7.24   200.12
  MEAN    30.26   665.63   441.00   498.58  1157.03     0.58    10.91     7.55    61.39
  HUB     20.63   679.93   373.46   568.18  1123.82     0.61    10.11     8.04    22.25

         U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
  TIP   1235.69   907.54   783.82     0.77 16952.53     0.92     0.91
  MEAN   997.26   747.00   556.26     0.65 13352.30     0.92     0.91     0.91     1.82
  HUB    679.80   645.50   306.33     0.57  7708.32     0.92     0.91

          Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
  TIP     25.11     1.66    20.51    612.56     1.17   578.06    541.84     0.00
  MEAN    22.68     1.50    18.12    593.50     1.14   556.53    533.72     0.00   589.89  1.48
  HUB     19.21     1.27    15.00    563.61     1.08   525.04    519.92     0.00

          Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
  TIP     44.65    59.73    56.50      3.23     0.93     0.45     1.66      0.00010     67
  MEAN    41.49    48.13    44.00      4.13     0.93     0.46     1.77      0.00027     57
  HUB     33.32    28.33    24.20      4.13     0.93     0.34     2.50      0.00002     27

  Station   3. STATOR ROW #1
  blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
    0.9500      2.0099          33   2895.0393    589.8918    532.1749      0.0000   3080.8125

  ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
  R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
   30.2642    672.7497    441.0006    508.0459   1152.3959      0.5838     -0.0955      9.3931

  Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
   22.2858     17.6896    552.1353      0.0000     40.9591     40.0000      0.9591

  Station   4. STATOR / VANED DIFFUSER
  RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
   30.2642    559.8395    154.3127    538.1523   1164.3728      0.4808      0.2468      9.9960

  BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
    0.9500     22.2274     18.9730    563.7550    532.1224   2738.7583      0.0231      0.5175

  Station   5. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
  R4         C4          Cu4         Cm4        Ao4            Mach4      cp 3-4   Stator Gap
   30.2642    482.1255      0.0000    482.1255   1171.2854      0.4116      0.4426      2.3483

  Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
    0.9500     19.7240    570.5114    532.0667      0.0000      0.0600      0.0369      0.4153

  STAGE EXIT CONDITIONS, STAGE            1
  Eff4         Pt4         PR           TR        Tt4          Del T      Ns          Ns nondim
    0.9037     22.1658      1.4673      1.1283    589.8918     67.0919    350.0365      2.7135

  Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
   417700.906       0.274   20849.992  5138243.0       0.00000  2827.08154  3080.81274


  OVERALL EXIT CONDITIONS; ALL           1   STAGES

  Del Enthal    DelHT/U1^2  GHP      MassFloS1cor  OPR     Efficiency    Rotor1Inc  TR      AxHubLen
    417700.91     0.2497 20849.9922  862.893      1.4673   0.90366       8.5213    1.1283   21.791
```

geometry.out

```
       R1      Beta1   R2      Beta2    Sol     Rc      Chord   AxC     X1      Y1      X2      Y2     Theta
TIP    39.250  60.000  37.500  56.500   1.660 200.120  12.223   6.432 173.309 100.060 166.878 110.454   3.500
MID    31.354  54.200  30.264  44.000   1.773  61.393  10.915   7.146  49.793  35.912  42.647  44.162  10.200
HUB    20.630  50.470  20.630  24.200   2.496  22.248  10.112   8.040  17.160  14.160   9.120  20.293  26.270

  Blade > Stator Gap (2->3)   2.009935
       R3      Beta3   R4      Beta4    Sol     Rc      Chord   AxC     X3      Y3      X4      Y4     Theta
TIP    37.500  40.000  37.500   0.000   1.400  14.613   9.996   9.393   9.393  11.194   0.000  14.613  40.000
MID    30.264  40.000  30.264   0.000   1.682  14.613   9.996   9.393   9.393  11.194   0.000  14.613  40.000
HUB    20.630  40.000  20.630   0.000   2.468  14.613   9.996   9.393   9.393  11.194   0.000  14.613  40.000

  Stator > Blade Gap (4->1)    2.348287
  Cumul Axial Length (1->5)  Stage   21.79111               1
```

7.1.3 Fan Core and Four-Stage Low-Pressure Compressor (No Ice Crystals)

The input and output files in this section are for the analysis of the fan core and four-stage LPC without ice crystal ingestion for this example case.

7.1.3.1 Input File

comdes.dat

```
Fan-CORE + 4 LPC Stages  Bypass Ratio = 5.0  Design Point
176.664      15.107     522.81     3776.0         Wact        Pt1          Tt1         RPM
  5           5           0           0.0         Fluid       Stages       IDUMMY      DUMMY
  5.00       46.900       0.0021      0.0         DropDia     InDist       RHinlet     IWC         ***icing***
 14.17        0.0       469.58        0.0         Psin        DUMMY        Tsin        DUMMY       ***icing***
159.42        0.0       40000.        0           Vin         DUMMY        Altitude    IDUMMY      ***icing***
 20.63       12.5100     20.63       15.00      1 R1tip       R1hub        R2tip       R2hub
  0.7000      0.700      32           0.050       1.0         B1axial      B2axial     NBLAD       THK      CFS
  0.0         0.0000      0.000       1.000       0.9         StatorT      StatorM     StatorH     FSGV     CFMid
  0.9800      0.9500      1.0000      1.000       0.9         AeroB1       AeroB2      POTS        POTH     CFHub
  0.915       0.915       0.915       0.0000      EfficiT     EfficiM      EfficiH     BLEED
  0.000       0.000       0.000       0.0000      DUMMY       DUMMY        DUMMY       DUMMY
  0.9250      0.035      1.8          0.00        SlipF       DiffLoss     Solidity    RPM2
 50.47       47.2        38.62        2.0         BetaBlade1T BetaBlade1M  BetaBlade1H expo3
 24.2        12.70      -9.3           0          BetaBlade2T BetaBlade2M  BetaBlade2H stat2
 20.617      15.102       0.0         35.400      R3s         R3h          B3X         BetB3
 33           0.06        0.95        0.01        Blan3       Blath3       Blok3       Wbar23
 00.0         0.000       0.95        0.015       RCG         Athrt        BlokTH      Wbar2T
 20.573      15.19        0.0         0.0         R4S         R4H          B4X         BetB4
 33           0.06        0.95        1.40        Blan4       Blath4       Blok4       SolidStat
 20.55       15.21        20.42      15.223     2 R1tip       R1hub        R2tip       R2hub
  0.5000      0.500      56           0.050       1.0         B1axial      B2axial     NBLAD       THK      CFS
  0.0         0.0000      0.000       1.000       0.9         StatorT      StatorM     StatorH     FSGV     CFMid
  0.9800      0.9500      1.0000      1.000       0.9         AeroB1       AeroB2      POTS        POTH     CFHub
  0.915       0.915       0.915       0.0000      EfficiT     EfficiM      EfficiH     BLEED
  0.000       0.000       0.000       0.0000      DUMMY       DUMMY        DUMMY       DUMMY
  0.9250      0.035      1.4          0.00        SlipF       DiffLoss     Solidity    RPM2
 46.36       42.3        37.84        0.00        BetaBlade1T BetaBlade1M  BetaBlade1H expo3
 31.50       23.50        6.50        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
 20.343      15.207       0.0         30.600      R3s         R3h          B3X         BetB3
 73           0.06        0.95        0.01        Blan3       Blath3       Blok3       Wbar23
 00.0         0.000       0.95        0.015       RCG         Athrt        BlokTH      Wbar2T
 20.170      15.117       0.0         0.0         R4S         R4H          B4X         BetB4
 73           0.06        0.95        1.40        Blan4       Blath4       Blok4       SolidStat
 20.07       15.05       19.81       14.85      3 R1tip       R1hub        R2tip       R2hub
  0.5000      0.500      56           0.050       1.0         B1axial      B2axial     NBLAD       THK      CFS
  0.0         0.0000      0.000       1.000       0.9         StatorT      StatorM     StatorH     FSGV     CFMid
  0.9800      0.9500      1.0000      1.000       0.9         AeroB1       AeroB2      POTS        POTH     CFHub
  0.915       0.915       0.915       0.0000      EfficiT     EfficiM      EfficiH     BLEED
  0.000       0.000       0.000       0.0000      DUMMY       DUMMY        DUMMY       DUMMY
  0.9250      0.035      1.4          0.00        SlipF       DiffLoss     Solidity    RPM2
 46.36       43.4        38.84        0.00        BetaBlade1T BetaBlade1M  BetaBlade1H expo3
 31.50       23.50        6.50        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
 19.690      14.741       0.0         31.500      R3s         R3h          B3X         BetB3
 73           0.06        0.95        0.01        Blan3       Blath3       Blok3       Wbar23
 00.0         0.000       0.95        0.015       RCG         Athrt        BlokTH      Wbar2T
 19.411      14.474       0.0         0.0         R4S         R4H          B4X         BetB4
 73           0.06        0.95        1.40        Blan4       Blath4       Blok4       SolidStat
 19.26       14.32       18.88       13.89      4 R1tip       R1hub        R2tip       R2hub
  0.5000      0.500      56           0.050       1.0         B1axial      B2axial     NBLAD       THK      CFS
  0.0         0.0000      0.000       1.000       0.9         StatorT      StatorM     StatorH     FSGV     CFMid
  0.9800      0.9500      1.0000      1.000       0.9         AeroB1       AeroB2      POTS        POTH     CFHub
  0.915       0.915       0.915       0.0000      EfficiT     EfficiM      EfficiH     BLEED
  0.000       0.000       0.000       0.0000      DUMMY       DUMMY        DUMMY       DUMMY
  0.9250      0.035      1.4          0.00        SlipF       DiffLoss     Solidity    RPM2
 46.36       43.8        37.84        0.00        BetaBlade1T BetaBlade1M  BetaBlade1H expo3
 31.50       23.50        6.50        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
 18.842      13.720       0.0         32.400      R3s         R3h          B3X         BetB3
 73           0.06        0.95        0.01        Blan3       Blath3       Blok3       Wbar23
 00.0         0.000       0.95        0.015       RCG         Athrt        BlokTH      Wbar2T
 18.485      13.284       0.0         0.0         R4S         R4H          B4X         BetB4
 73           0.06        0.95        1.40        Blan4       Blath4       Blok4       SolidStat
 18.32       13.07       17.94       12.59      5 R1tip       R1hub        R2tip       R2hub
  0.5000      0.500      56           0.050       1.0         B1axial      B2axial     NBLAD       THK      CFS
  0.0         0.0000      0.000       1.000       0.9         StatorT      StatorM     StatorH     FSGV     CFMid
  0.9800      0.9500      1.0000      1.000       0.9         AeroB1       AeroB2      POTS        POTH     CFHub
  0.915       0.915       0.915       0.0000      EfficiT     EfficiM      EfficiH     BLEED
  0.000       0.000       0.000       0.0000      DUMMY       DUMMY        DUMMY       DUMMY
  0.9250      0.035      1.4          0.00        SlipF       DiffLoss     Solidity    RPM2
 47.36       44.8        38.84        0.00        BetaBlade1T BetaBlade1M  BetaBlade1H expo3
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     31.50       23.50        6.50        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
     17.689      12.260       0.0         33.000      R3s         R3h          B3X         BetB3
     73           0.06        0.95        0.02        Blan3       Blath3       Blok3       Wbar23
     00.0         0.000       0.95        0.03        RCG         Athrt        BlokTH      Wbar2T
     17.239      11.622       0.0         0.0         R4S         R4H          B4X         BetB4
     73           0.06        0.95        1.40        Blan4       Blath4       Blok4       SolidStat
     17.239      11.622       0.00        2.0         R7S         R7h          B7X         Length67
      4           0.01        0.98        0.000       Blan7       Blath7       Blok7       Wbar67
     17.239      11.622       0.0         2.0         R8S         R8h          B8X         Length78
      4           0.01        0.98        0.00        Blan8       Blath8       Blok8       Wbar78
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7.1.3.2 Output Files

comdes.out

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*********************************************************************
**************** AXIAL & CENTRIFUGAL COMPRESSOR BLADE DESIGN 1-D ****
*******************   COMDES-MELT Release Version 1    **************
*********************   Gasplus Fluid Properties   ******************
*********************************************************************

    Fan-CORE + 4 LPC Stages  Bypass Ratio = 5.0  Design Point

  COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   1
  BLEED =  0.000   DPInc = 5.912   EfDer =  0.999    SH =  0.210000E-02

  W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
  176.6640   3776.0000     15.1069    522.8100      1.0000      1.0000      0.9800

  W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
   80.3018    176.2930      0.3710      2.4438   4140.3765      0.0000      0.0000

  W cor     RPM cor        GAMMA       Cp         R           Blades       THK         Area1UB
  172.5842   3761.1287      1.3987      0.2502     53.4164          32      0.0500    848.5279

  CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
  146216.000  138504.844    1.6521    831.5574    503.3270    619.7536      1.2313    845.3924

  Station   1.  ROTOR LEADING EDGE CONDITIONS, STAGE   1

          R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
  TIP     20.63     0.00    -0.02   422.00    -0.15   422.00     0.38     0.72   677.10    0.621
  MEAN    17.06     0.00    -0.02   422.00    -0.15   422.00     0.38     0.64
  HUB     12.51     0.00    -0.02   422.00    -0.15   422.00     0.38     0.53

        BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
  TIP     58.17    50.47     7.70   679.80   800.25    13.66   508.04   506.03    27.56
  MEAN    53.11    47.20     5.91   562.16   703.05    13.66   508.04   506.03    27.56
  HUB     44.34    38.62     5.72   412.23   590.03    13.66   508.04   506.03    27.56

  Station   2.  ROTOR EXIT CONDITIONS, STAGE   1    SOLUTION IS CONVERGED
  B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
    0.7000      0.0500      0.9500          32    594.6702    635.0460

          R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
  TIP     20.63   669.55   381.55   550.20  1125.59     0.59     7.29     6.52    16.04
  MEAN    18.04   704.82   422.65   564.03  1119.89     0.63     7.43     6.80    12.53
  HUB     15.00   811.28   554.24   592.44  1109.37     0.73     7.49     7.25     9.22

         U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
  TIP    679.80   625.83   298.25     0.56  7874.33     0.92     0.91
  MEAN   594.32   589.58   171.67     0.53  7625.35     0.92     0.91     0.91     1.33
  HUB    494.28   595.47    59.96     0.54  8315.36     0.92     0.91

          Pt2       PR       Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
  TIP     19.31     1.28     15.20   564.24     1.08   527.06   529.83    15.47
  MEAN    19.16     1.27     14.68   562.93     1.08   521.73   530.39    17.99   564.57  1.28
  HUB     19.57     1.30     13.71   566.56     1.08   511.97   536.08    23.90

          Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
  TIP     34.74    28.46    24.20     4.26     0.93     0.35     1.80      0.00047     22
  MEAN    36.85    16.93    12.70     4.23     0.93     0.30     2.22      0.00111     35
  HUB     43.09    -5.78    -9.30     3.52     0.93     0.16     3.05      0.00122     42
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Station   3. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      1.8117          33    577.5464    564.5723    531.4438      0.0000    618.8633
ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
 18.0711    719.5446    421.8260    582.9299   1119.7871      0.6426     -0.0119      5.2355

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
 19.2975     14.6213    521.6359     17.9838     35.8907     35.4000      0.4907

Station   4. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
 18.0711    595.8393    145.7605    577.7355   1134.1595      0.5254      0.2908      5.4957

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500     19.2240     15.9310    535.1331    528.1395    577.5480      0.0253      0.3999

Station   5. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4       cp 3-4   Stator Gap
 18.0829    582.6066      0.0000    582.6066   1135.4991      0.5131      0.2968      1.3089

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500     16.0090    536.4304    527.8182      0.0000      0.0600      0.0395      0.3070

STAGE EXIT CONDITIONS, STAGE             1
Eff4         Pt4         PR          TR        Tt4          Del T      Ns          Ns nondim
  0.8763     19.1552      1.2680      1.0799    564.5723     41.7623    217.6874      1.6875

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 261616.797       0.566    2611.836  1774469.4       0.00210   542.74530   604.79504


COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   2
BLEED =  0.000   DPInc = 7.014   EfDer =  1.000    SH =  0.210000E-02

W act     RPM act        Pt         Tt            POTS        POTH        AeroBl
176.6640   3776.0000     19.1552    564.5723      1.0000      1.0000      0.9800

W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 80.3018    176.2930      0.3710      2.7937   3621.7927      0.0000      0.0000

W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
141.4425   3619.3481      1.3985      0.2503     53.4164          56      0.0500    602.5374

CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
127902.398  138504.844   1.4524    590.4866    406.5490    474.1340      1.1662    599.9134

Station   6.  ROTOR LEADING EDGE CONDITIONS, STAGE   2

        R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
TIP     20.55     0.00    -0.02   512.30    -0.18   512.30     0.45     0.74   649.05    0.757
MEAN    18.08     0.00    -0.02   512.30    -0.18   512.30     0.45     0.69
HUB     15.21     0.00    -0.02   512.30    -0.18   512.30     0.45     0.63

      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     52.90    46.36     6.54   677.16   849.25    16.69   542.82   526.71    10.04
MEAN    49.31    42.30     7.01   595.71   785.83    16.69   542.82   526.71    10.04
HUB     44.38    37.84     6.54   501.20   716.81    16.69   542.82   526.71    10.04

Station   7.  ROTOR EXIT CONDITIONS, STAGE   2    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.5000      0.0500      0.9500          56    541.5062    584.6252

        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP     20.42   599.40   306.91   514.87  1168.17     0.51     3.21     2.81    12.40
MEAN    18.01   614.25   321.34   523.50  1164.03     0.53     3.30     2.93    10.11
HUB     15.22   668.54   403.25   533.23  1159.96     0.58     3.37     3.12     6.23

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP    672.88   631.68   365.97     0.54  6270.63     0.92     0.91
MEAN   593.46   590.00   272.12     0.51  5790.48     0.92     0.91     0.91     1.44
HUB    501.63   542.23    98.37     0.47  6141.42     0.92     0.91
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        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP     22.99     1.20    19.22   597.55     1.06   567.76   541.24     5.38
MEAN    22.68     1.18    18.77   595.02     1.05   563.74   540.47     5.91   596.48  1.19
HUB     22.91     1.20    18.30   596.87     1.06   559.82   542.02     6.48

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F.  DiffFct  Solidity  Convergence Iter
TIP     30.80  35.41      31.50     3.91     0.93     0.38     1.40      0.00042     22
MEAN    31.54  27.47      23.50     3.97     0.93     0.37     1.63      0.00098     31
HUB     37.10  10.45       6.50     3.95     0.93     0.39     1.97      0.00051     33

Station   8. STATOR ROW #1
blockage3     XBladeGap Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      0.7798          73    523.5558    596.4807    541.2429      0.0000    573.6071

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
 17.9595   632.0330    322.2403    543.7158   1163.5891      0.5432     -0.0221      2.3644

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
 22.8212     18.6760    563.3723      5.9483     30.6537     30.6000      0.0537

Station   9. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
 17.9595    547.7831    116.1339    535.3310   1172.0541      0.4674      0.2078      2.4513

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500     22.7749     19.6124   571.6121     540.1403    540.8125      0.0213      0.2231

Station  10. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4       cp 3-4   Stator Gap
 17.8235   606.5960      0.0000    606.5960   1166.2430      0.5201      0.0518      0.5911

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500     18.8909    565.9897    540.7750      0.0000      0.0600      0.0366      0.0319

STAGE EXIT CONDITIONS, STAGE             2
Eff4         Pt4         PR          TR         Tt4          Del T      Ns          Ns nondim
  0.8796     22.7121      1.1857      1.0565    596.4807     31.9084    247.2050      1.9163

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 200009.547       0.442    1996.784  1570979.9       0.00210   466.10056   560.16235


COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   3
BLEED =  0.000   DPInc = 6.792   EfDer =  1.000    SH =  0.210000E-02

W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
176.6640   3776.0000     22.7121    596.4807      1.0000      1.0000      0.9800

W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 80.3018    176.2930      0.3710      3.1808   3181.0784      0.0000      0.0000

W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
117.9940   3659.1458      1.3982      0.2505     53.4164          56      0.0500    556.6108

CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
112338.719  138504.844   1.5471    545.4786    352.5860    429.7651      1.2189    553.8704

Station  11.  ROTOR LEADING EDGE CONDITIONS, STAGE   3

        R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
TIP     20.07     0.00    -0.02   487.28    -0.17   487.28     0.41     0.70   640.86    0.737
MEAN    17.74     0.00    -0.02   487.28    -0.17   487.28     0.41     0.65
HUB     15.05     0.00    -0.02   487.28    -0.17   487.28     0.41     0.59

      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     53.62    46.36      7.26   661.34   821.61     20.19   576.81   539.52     4.36
MEAN    50.19    43.40      6.79   584.52   761.11     20.19   576.81   539.52     4.36
HUB     45.51    38.84      6.67   495.92   695.38     20.19   576.81   539.52     4.36

Station  12.  ROTOR EXIT CONDITIONS, STAGE   3    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.5000      0.0500      0.9500          56    502.4182    542.8196
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        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP     19.81   577.94   301.78   492.89  1200.99     0.48     3.11     2.72    12.03
MEAN    17.51   591.58   316.23   499.97  1197.34     0.49     3.22     2.84     9.33
HUB     14.85   643.34   394.77   507.99  1193.74     0.54     3.28     3.03     5.89
       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP    652.78   605.10   351.00     0.50  5981.54     0.92     0.91
MEAN   576.87   563.83   260.64     0.47  5539.04     0.92     0.91     0.91     1.46
HUB    489.33   516.71    94.57     0.43  5864.80     0.92     0.91

        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP     26.80     1.18    22.87   627.92     1.05   600.24   552.24     2.63
MEAN    26.48     1.17    22.41   625.59     1.05   596.60   551.51     2.84   626.94  1.17
HUB     26.71     1.18    21.93   627.31     1.05   593.01   552.64     3.05

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     31.48    35.46    31.50     3.96     0.93     0.39     1.40      0.00035     22
MEAN    32.31    27.53    23.50     4.03     0.93     0.39     1.62      0.00118     32
HUB     37.85    10.55     6.50     4.05     0.93     0.40     1.94      0.00104     31

Station  13. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      0.7565          73    487.9654    626.9401    552.0973      0.0000    535.3244

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
 17.3924    606.4476    318.3029    516.1995   1197.1470      0.5066     -0.0156      2.2836

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
 26.6189     22.3465    596.4758      2.8369     31.6591     31.5000      0.1591

Station  14. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
 17.3924    529.7297    115.5570    516.9721   1204.3553      0.4398      0.2044      2.3726

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500     26.5769     23.2743    603.6976    551.4423    498.3970      0.0199      0.2419

Station  15. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4      cp 3-4   Stator Gap
 17.1214    574.2238      0.0000    574.2238   1200.2572      0.4784      0.0750      0.5709

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500     22.6671    599.6335    551.7104      0.0000      0.0600      0.0366      0.0617

STAGE EXIT CONDITIONS, STAGE            3
Eff4         Pt4         PR          TR        Tt4          Del T      Ns          Ns nondim
  0.8803     26.5056      1.1670      1.0511    626.9401     30.4594    239.8310      1.8592

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 191044.703       0.448    1907.284  1730067.9       0.00210   434.74258   525.55774


COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   4
BLEED =  0.000   DPInc = 6.732   EfDer =  1.000    SH =  0.210000E-02

W act     RPM act        Pt         Tt            POTS        POTH        AeroBl
176.6640   3776.0000     26.5056    626.9401      1.0000      1.0000      0.9800

W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 80.3018    176.2930      0.3710      3.5772   2828.5518      0.0000      0.0000

W cor     RPM cor        GAMMA       Cp          R            Blades       THK         Area1UB
100.8453   3668.6252      1.3979      0.2506     53.4164          56      0.0500    523.8064

CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
 99889.359  138504.844   1.6566    513.3303    309.8729    401.0588      1.2943    521.1437

Station  16.  ROTOR LEADING EDGE CONDITIONS, STAGE   4

        R1      Stator    Alfa     C1      CU1       Cm1       Mabs      Mrel   U1cor   FlowCoeff
TIP     19.26     0.00    -0.02   460.59    -0.16   460.59     0.38      0.65   616.59    0.726
MEAN    16.97     0.00    -0.02   460.59    -0.16   460.59     0.38      0.60
HUB     14.32     0.00    -0.02   460.59    -0.16   460.59     0.38      0.55
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      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     54.04    46.36     7.68   634.65   784.30    23.99   609.37   550.96     2.19
MEAN    50.53    43.80     6.73   559.22   724.60    23.99   609.37   550.96     2.19
HUB     45.70    37.84     7.86   471.87   659.51    23.99   609.37   550.96     2.19

Station  17.  ROTOR EXIT CONDITIONS, STAGE   4    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.5000      0.0500      0.9500          56    477.1383    516.2928

        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP     18.88   549.35   289.30   467.00  1230.88     0.45     2.97     2.60    11.47
MEAN    16.57   560.00   299.43   473.23  1227.36     0.46     3.08     2.71     8.74
HUB     13.89   605.41   368.68   480.21  1223.88     0.49     3.11     2.88     5.76

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP    622.13   573.47   332.83     0.47  5464.98     0.92     0.91
MEAN   546.14   533.68   246.71     0.43  4965.36     0.92     0.91     0.91     1.47
HUB    457.70   488.39    89.03     0.40  5123.17     0.92     0.91

        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP     30.62     1.16    26.71   655.64     1.05   630.66   561.80     1.47
MEAN    30.22     1.14    26.21   653.02     1.04   627.05   560.95     1.57   654.17  1.15
HUB     30.35     1.14    25.68   653.85     1.04   623.50   561.52     1.67

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     31.78    35.48    31.50     3.98     0.93     0.40     1.40      0.00036     21
MEAN    32.32    27.53    23.50     4.03     0.93     0.39     1.62      0.00135     29
HUB     37.51    10.50     6.50     4.00     0.93     0.40     1.94      0.00176     30

Station  18. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      0.7209          73    476.4520    654.1712    561.3143      0.0000    523.9628

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
 16.4812    560.4597    301.1112    472.7019   1228.3756      0.4563      0.0271      2.1803

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
 30.3530     26.3204    628.1697      1.5355     32.4971     32.4000      0.0971

Station  19. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
 16.4812    495.6020    111.1490    482.9775   1233.8801      0.4017      0.2233      2.2705

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500     30.3199     27.1353    633.8417    560.9500    480.4178      0.0179      0.2570

Station  20. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4      cp 3-4   Stator Gap
 16.0960    524.9850      0.0000    524.9850   1231.4290      0.4263      0.0927      0.5451

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500     26.6943    631.3631    561.0234      0.0000      0.0600      0.0366      0.1182

STAGE EXIT CONDITIONS, STAGE            4
Eff4         Pt4         PR          TR         Tt4          Del T      Ns          Ns nondim
  0.8799     30.2414      1.1409      1.0434    654.1712     27.2311    245.8912      1.9061

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 170918.797       0.442    1706.358  1894891.5       0.00210   425.14447   519.08722


COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   5
BLEED =  0.000   DPInc = 6.641   EfDer =  1.000    SH =  0.210000E-02

W act     RPM act        Pt         Tt            POTS        POTH        AeroBl
176.6640   3776.0000     30.2414    654.1712      1.0000      1.0000      0.9800

W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 80.3018    176.2930      0.3710      3.9713   2547.8423      0.0000      0.0000

W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
 88.0665   3682.0144      1.3974      0.2508     53.4164          56      0.0500    520.0693
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CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
 89976.195  138504.844   1.8360    509.6679    277.5936    390.2764      1.4059    517.7266


Station  21.  ROTOR LEADING EDGE CONDITIONS, STAGE   5

        R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
TIP     18.32     0.00    -0.02   418.10    -0.14   418.10     0.34     0.59   588.63    0.693
MEAN    15.91     0.00    -0.02   418.10    -0.14   418.10     0.34     0.54
HUB     13.07     0.00    -0.02   418.10    -0.14   418.10     0.34     0.48

      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     55.30    47.36     7.94   603.68   734.44    27.96   639.71   560.57     1.26
MEAN    51.44    44.80     6.64   524.36   670.75    27.96   639.70   560.57     1.26
HUB     45.86    38.84     7.02   430.68   600.34    27.96   639.71   560.57     1.26

Station  22.  ROTOR EXIT CONDITIONS, STAGE   5    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.5000      0.0500      0.9500          56    475.3082    515.3698

        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP     17.94   513.03   285.69   426.13  1258.35     0.41     2.82     2.45    10.21
MEAN    15.50   517.44   284.44   432.25  1254.39     0.41     2.92     2.55     7.91
HUB     12.59   551.39   333.76   438.90  1250.47     0.44     2.95     2.72     5.29

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP    591.16   524.31   305.47     0.42  5127.88     0.92     0.91
MEAN   510.67   487.87   226.23     0.39  4410.43     0.92     0.91     0.91     1.51
HUB    414.86   446.33    81.10     0.36  4203.98     0.92     0.91

        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP     34.44     1.14    30.72   681.08     1.04   659.31   570.22     0.91
MEAN    33.83     1.12    30.09   677.32     1.04   655.16   568.97     0.97   678.21  1.12
HUB     33.65     1.11    29.45   676.23     1.03   651.08   568.75     1.03

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     33.84    35.63    31.50     4.13     0.93     0.42     1.40      0.00021     21
MEAN    33.35    27.63    23.50     4.13     0.93     0.40     1.64      0.00136     31
HUB     37.25    10.47     6.50     3.97     0.93     0.39     2.01      0.00284     29

Station  23. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      0.6802          73    462.6711    678.2124    569.2645      0.0000    510.8013

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3         Ao3            Mach3      cp 2-3    Stat Ax Chd
 15.2185    531.6449    289.6560    445.8090   1253.9929      0.4240     -0.0345      2.0437

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
 33.8936     29.9593    654.8327      0.9710     33.0130     33.0000      0.0130

Station  24. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
 15.2185    475.6450    108.6139    463.0779   1258.4282      0.3780      0.1500      2.1315

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500     33.8421     30.6703    659.5006    569.0118    461.2568      0.0332      0.2603

Station  25. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4      cp 3-4   Stator Gap
 14.7013    498.0562      0.0000    498.0562   1256.6731      0.3963      0.1030      0.5109

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500     30.3644    657.6986    569.0802      0.0000      0.0600      0.0366      0.0712

STAGE EXIT CONDITIONS, STAGE            5
Eff4         Pt4         PR          TR         Tt4          Del T      Ns          Ns nondim
  0.8811     33.8291     1.1186      1.0368     678.2124     24.0412    256.1537      1.9857

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 151012.625       0.432    1507.626  2112125.2       0.00210   410.39981   509.29071
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  OVERALL EXIT CONDITIONS; ALL           5   STAGES

  Del Enthal   DelHT/U1^2  GHP      MassFloS1cor  OPR     Efficiency    Rotor1Inc  TR      AxHubLen
    974602.50     2.1090  9729.8877  172.584      2.2393   0.86776       5.9125    1.2972   41.379
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geometry.out

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       R1      Beta1   R2      Beta2    Sol     Rc      Chord   AxC     X1      Y1      X2      Y2      Theta
TIP    20.630  50.470  20.630  24.200   1.800  16.043   7.291   5.797  12.374  10.211   6.576  14.633  26.270
MID    17.060  47.200  18.036  12.700   2.219  12.535   7.434   6.441   9.197   8.517   2.756  12.228  34.500
HUB    12.510  38.620  15.000  -9.300   3.049   9.222   7.490   7.247   5.756   7.206   1.490   9.101  47.920

  Blade > Stator Gap (2->3)   1.811653
       R3      Beta3   R4      Beta4    Sol     Rc      Chord   AxC     X3      Y3      X4      Y4      Theta
TIP    20.617  35.400  20.573   0.000   1.400   9.038   5.496   5.235   5.235   7.367   0.000   9.038  35.400
MID    18.071  35.400  18.083   0.000   1.549   9.038   5.496   5.235   5.235   7.367   0.000   9.038  35.400
HUB    15.102  35.400  15.190   0.000   1.853   9.038   5.496   5.235   5.235   7.367   0.000   9.038  35.400

  Stator > Blade Gap (4->1)    1.308875
  Cumul Axial Length (1->5)  Stage   15.60264              1

       R1      Beta1   R2      Beta2    Sol     Rc      Chord   AxC     X1      Y1      X2      Y2      Theta
TIP    20.550  46.360  20.420  31.500   1.400  12.402   3.208   2.495   8.975   8.559   6.480  10.575  14.860
MID    18.078  42.300  18.010  23.500   1.628  10.109   3.302   2.772   6.803   7.477   4.031   9.270  18.800
HUB    15.210  37.840  15.223   6.500   1.974   6.235   3.368   3.119   3.825   4.924   0.706   6.195  31.340

  Blade > Stator Gap (2->3)  0.7797533
       R3      Beta3   R4      Beta4    Sol     Rc      Chord   AxC     X3      Y3      X4      Y4      Theta
TIP    20.343  30.600  20.170   0.000   1.400   4.645   2.451   2.364   2.364   3.998   0.000   4.645  30.600
MID    17.960  30.600  17.823   0.000   1.217   4.645   2.451   2.364   2.364   3.998   0.000   4.645  30.600
HUB    15.207  30.600  15.117   0.000   1.437   4.645   2.451   2.364   2.364   3.998   0.000   4.645  30.600

  Stator > Blade Gap (4->1)   0.5911098
  Cumul Axial Length (1->5)  Stage   22.45695              2

       R1      Beta1   R2      Beta2    Sol     Rc      Chord   AxC     X1      Y1      X2      Y2      Theta
TIP    20.070  46.360  19.810  31.500   1.400  12.032   3.112   2.421   8.707   8.303   6.287  10.259  14.860
MID    17.738  43.400  17.507  23.500   1.620   9.328   3.224   2.690   6.409   6.778   3.720   8.554  19.900
HUB    15.050  38.840  14.850   6.500   1.942   5.887   3.279   3.026   3.692   4.586   0.666   5.850  32.340

  Blade > Stator Gap (2->3)  0.7564600
       R3      Beta3   R4      Beta4    Sol     Rc      Chord   AxC     X3      Y3      X4      Y4      Theta
TIP    19.690  31.500  19.411   0.000   1.400   4.370   2.373   2.284   2.284   3.726   0.000   4.370  31.500
MID    17.392  31.500  17.121   0.000   1.216   4.370   2.373   2.284   2.284   3.726   0.000   4.370  31.500
HUB    14.741  31.500  14.474   0.000   1.435   4.370   2.373   2.284   2.284   3.726   0.000   4.370  31.500

  Stator > Blade Gap (4->1)   0.5708885
  Cumul Axial Length (1->5)  Stage   29.09369              3

       R1      Beta1   R2      Beta2    Sol     Rc      Chord   AxC     X1      Y1      X2      Y2      Theta
TIP    19.260  46.360  18.880  31.500   1.400  11.467   2.966   2.307   8.298   7.914   5.991   9.777  14.860
MID    16.971  43.800  16.574  23.500   1.617   8.737   3.079   2.563   6.047   6.306   3.484   8.012  20.300
HUB    14.320  37.840  13.890   6.500   1.938   5.765   3.114   2.884   3.536   4.552   0.653   5.728  31.340

  Blade > Stator Gap (2->3)  0.7209471
       R3      Beta3   R4      Beta4    Sol     Rc      Chord   AxC     X3      Y3      X4      Y4      Theta
TIP    18.842  32.400  18.485   0.000   1.400   4.069   2.270   2.180   2.180   3.436   0.000   4.069  32.400
MID    16.481  32.400  16.096   0.000   1.228   4.069   2.270   2.180   2.180   3.436   0.000   4.069  32.400
HUB    13.720  32.400  13.284   0.000   1.475   4.069   2.270   2.180   2.180   3.436   0.000   4.069  32.400

  Stator > Blade Gap (4->1)   0.5450748
  Cumul Axial Length (1->5)  Stage   35.42380              4

       R1      Beta1   R2      Beta2    Sol     Rc      Chord   AxC     X1      Y1      X2      Y2      Theta
TIP    18.320  47.360  17.940  31.500   1.400  10.213   2.818   2.177   7.513   6.918   5.336   8.708  15.860
MID    15.913  44.800  15.498  23.500   1.637   7.906   2.922   2.418   5.571   5.610   3.153   7.251  21.300
HUB    13.070  38.840  12.590   6.500   2.011   5.294   2.949   2.721   3.320   4.123   0.599   5.260  32.340

  Blade > Stator Gap (2->3)  0.6801976
       R3      Beta3   R4      Beta4    Sol     Rc      Chord   AxC     X3      Y3      X4      Y4      Theta
TIP    17.689  33.000  17.239   0.000   1.400   3.752   2.132   2.044   2.044   3.147   0.000   3.752  33.000
MID    15.219  33.000  14.701   0.000   1.248   3.752   2.132   2.044   2.044   3.147   0.000   3.752  33.000
HUB    12.260  33.000  11.622   0.000   1.550   3.752   2.132   2.044   2.044   3.147   0.000   3.752  33.000

  Stator > Blade Gap (4->1)   0.5109345
  Cumul Axial Length (1->5)  Stage   41.37946              5
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7.1.4 Fan Core and Four-Stage Low-Pressure Compressor (With Ice Crystal Ingestion)

The input and output files in this section are those used for the analysis of the fan core and four-stage LPC with ice crystal ingestion for this example case.

With ice crystals: IWC = 2.0 g/m^3, 5 μm; 40,000 ft altitude, Mach 0.70

Atmospheric conditions: from standard atmosphere (ISA + 25 R):
Pamb (Pstatic)= 2.72 psia
Tamb (Tstatic)= 415 R

Get engine inlet conditions: from compressibility tables (Mach 0.70):
Pt inlet = 3.773 psia
Tt inlet = 455.7 R

Fan N1corrected: 102.7 percent of design
(Full-fan physical tip speed = 1,328 ft/s, below the typical tip speed limit of approximately 1,500 ft/s)
Wcorrected: 100.0 percent of design

7.1.4.1 Input File

comdes.dat

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Fan-CORE + 4 LPC Stages  Bypass Ratio = 5.0  Design Wcorrected & N1 corrected
 47.26        3.773     455.7      3620.0         Wact        Pt1         Tt1         RPM
  5           5           0           0.0         Fluid       Stages      IDUMMY      DUMMY
  5.00      46.900      100.00        2.0         DropDia     InDist      RHinlet     IWC         ***icing***
 14.17        0.0       469.58        0.0         Psin        DUMMY       Tsin        DUMMY       ***icing***
159.42        0.0       40000.        0           Vin         DUMMY       Altitude    IDUMMY      ***icing***
 20.63       12.5100     20.63       15.00      1 R1tip       R1hub       R2tip       R2hub
  0.7000      0.700      32           0.050       1.0         B1axial     B2axial     NBLAD       THK      CFS
  0.0         0.0000      0.000       1.000       0.9         StatorT     StatorM     StatorH     FSGV     CFMid
  0.9800      0.9500      1.0000      1.000       0.9         AeroB1      AeroB2      POTS        POTH     CFHub
  0.915       0.915       0.915       0.0000      EfficiT     EfficiM     EfficiH     BLEED
  0.000       0.000       0.000       0.0000      DUMMY       DUMMY       DUMMY       DUMMY
  0.9250      0.035       1.8         0.00        SlipF       DiffLoss    Solidity    RPM2
 50.47       47.2        38.62        2.0         BetaBlade1T BetaBlade1M BetaBlade1H expo3
 24.2        12.70       -9.3          0          BetaBlade2T BetaBlade2M BetaBlade2H stat2
 20.617      15.102       0.0         35.400      R3s         R3h         B3X         BetB3
 33           0.06        0.95        0.01        Blan3       Blath3      Blok3       Wbar23
 00.0         0.000       0.95        0.015       RCG         Athrt       BlokTH      Wbar2T
 20.573      15.19        0.0         0.0         R4S         R4H         B4X         BetB4
 33           0.06        0.95        1.40        Blan4       Blath4      Blok4       SolidStat
 20.55       15.21       20.42       15.223     2 R1tip       R1hub       R2tip       R2hub
  0.5000      0.500      56           0.050       1.0         B1axial     B2axial     NBLAD       THK      CFS
  0.0         0.0000      0.000       1.000       0.9         StatorT     StatorM     StatorH     FSGV     CFMid
  0.9800      0.9500      1.0000      1.000       0.9         AeroB1      AeroB2      POTS        POTH     CFHub
  0.915       0.915       0.915       0.0000      EfficiT     EfficiM     EfficiH     BLEED
  0.000       0.000       0.000       0.0000      DUMMY       DUMMY       DUMMY       DUMMY
  0.9250      0.035       1.4         0.00        SlipF       DiffLoss    Solidity    RPM2
 46.36       42.3        37.84        0.00        BetaBlade1T BetaBlade1M BetaBlade1H expo3
 31.50       23.50        6.50        0           BetaBlade2T BetaBlade2M BetaBlade2H stat2
 20.343      15.207       0.0         30.600      R3s         R3h         B3X         BetB3
 73           0.06        0.95        0.01        Blan3       Blath3      Blok3       Wbar23
 00.0         0.000       0.95        0.015       RCG         Athrt       BlokTH      Wbar2T
 20.170      15.117       0.0         0.0         R4S         R4H         B4X         BetB4
 73           0.06        0.95        1.40        Blan4       Blath4      Blok4       SolidStat
 20.07       15.05       19.81       14.85      3 R1tip       R1hub       R2tip       R2hub
  0.5000      0.500      56           0.050       1.0         B1axial     B2axial     NBLAD       THK      CFS
  0.0         0.0000      0.000       1.000       0.9         StatorT     StatorM     StatorH     FSGV     CFMid
  0.9800      0.9500      1.0000      1.000       0.9         AeroB1      AeroB2      POTS        POTH     CFHub
  0.915       0.915       0.915       0.0000      EfficiT     EfficiM     EfficiH     BLEED
  0.000       0.000       0.000       0.0000      DUMMY       DUMMY       DUMMY       DUMMY
  0.9250      0.035       1.4         0.00        SlipF       DiffLoss    Solidity    RPM2
 46.36       43.4        38.84        0.00        BetaBlade1T BetaBlade1M BetaBlade1H expo3
 31.50       23.50        6.50        0           BetaBlade2T BetaBlade2M BetaBlade2H stat2
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     19.690      14.741       0.0         31.500      R3s         R3h          B3X         BetB3
     73           0.06        0.95        0.01        Blan3       Blath3       Blok3       Wbar23
     00.0         0.000       0.95        0.015       RCG         Athrt        BlokTH      Wbar2T
     19.411      14.474       0.0         0.0         R4S         R4H          B4X         BetB4
     73           0.06        0.95        1.40        Blan4       Blath4       Blok4       SolidStat
     19.26       14.32      18.88        13.89      4 R1tip       R1hub        R2tip       R2hub
      0.5000      0.500       56          0.050       1.0         B1axial      B2axial     NBLAD       THK      CFS
      0.0         0.0000      0.000       1.000       0.9         StatorT      StatorM     StatorH     FSGV     CFMid
      0.9800      0.9500      1.0000      1.000       0.9         AeroB1       AeroB2      POTS        POTH     CFHub
      0.915       0.915       0.915       0.0000      EfficiT     EfficiM      EfficiH     BLEED
      0.000       0.000       0.000       0.0000      DUMMY       DUMMY        DUMMY       DUMMY
      0.9250      0.035       1.4         0.00        SlipF       DiffLoss     Solidity    RPM2
     46.36       43.8       37.84         0.00        BetaBlade1T BetaBlade1M  BetaBlade1H expo3
     31.50       23.50        6.50        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
     18.842      13.720       0.0         32.400      R3s         R3h          B3X         BetB3
     73           0.06        0.95        0.01        Blan3       Blath3       Blok3       Wbar23
     00.0         0.000       0.95        0.015       RCG         Athrt        BlokTH      Wbar2T
     18.485      13.284       0.0         0.0         R4S         R4H          B4X         BetB4
     73           0.06        0.95        1.40        Blan4       Blath4       Blok4       SolidStat
     18.32       13.07      17.94        12.59      5 R1tip       R1hub        R2tip       R2hub
      0.5000      0.500       56          0.050       1.0         B1axial      B2axial     NBLAD       THK      CFS
      0.0         0.0000      0.000       1.000       0.9         StatorT      StatorM     StatorH     FSGV     CFMid
      0.9800      0.9500      1.0000      1.000       0.9         AeroB1       AeroB2      POTS        POTH     CFHub
      0.915       0.915       0.915       0.0000      EfficiT     EfficiM      EfficiH     BLEED
      0.000       0.000       0.000       0.0000      DUMMY       DUMMY        DUMMY       DUMMY
      0.9250      0.035       1.4         0.00        SlipF       DiffLoss     Solidity    RPM2
     47.36       44.8       38.84         0.00        BetaBlade1T BetaBlade1M  BetaBlade1H expo3
     31.50       23.50        6.50        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
     17.689      12.260       0.0         33.000      R3s         R3h          B3X         BetB3
     73           0.06        0.95        0.02        Blan3       Blath3       Blok3       Wbar23
     00.0         0.000       0.95        0.03        RCG         Athrt        BlokTH      Wbar2T
     17.239      11.622       0.0         0.0         R4S         R4H          B4X         BetB4
     73           0.06        0.95        1.40        Blan4       Blath4       Blok4       SolidStat
     17.239      11.622       0.00        2.0         R7S         R7h          B7X         Length67
      4           0.01        0.98        0.000       Blan7       Blath7       Blok7       Wbar67
     17.239      11.622       0.0         2.0         R8S         R8h          B8X         Length78
      4           0.01        0.98        0.00        Blan8       Blath8       Blok8       Wbar78
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7.1.4.2 Output Files

comdes.out

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*********************************************************************
*************** AXIAL & CENTRIFUGAL COMPRESSOR BLADE DESIGN 1-D ****
*******************   COMDES-MELT Release Version 1    **************
*********************   Gasplus Fluid Properties   *****************
*********************************************************************

    Fan-CORE + 4 LPC Stages  Bypass Ratio = 5.0  Design Wcorrected & N1 corrected

  COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   1
  BLEED =  0.000   DPInc = 6.654   EfDer =  1.000    SH =  0.139470E-02

  W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
   47.2600   3620.0000      3.7730    455.7065      1.0000      1.0000      0.9800

  W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
   21.4818     47.1941      0.0659      0.4653   3863.3096      0.0060      2.0000

  W cor     RPM cor        GAMMA       Cp          R            Blades       THK         Area1UB
  172.5860   3862.1326      1.4010      0.2490     53.3935          32      0.0500    848.5279

  CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
  136431.484   37062.211   1.6534    831.5574    502.9416    619.7536      1.2323    845.3924

  Station   1.  ROTOR LEADING EDGE CONDITIONS, STAGE   1

          R1      Stator    Alfa     C1      CU1       Cm1       Mabs      Mrel   U1cor   FlowCoeff
  TIP     20.63     0.00    -0.02   393.76    -0.14   393.76     0.38      0.74   695.28    0.604
  MEAN    17.06     0.00    -0.02   393.76    -0.14   393.76     0.38      0.65
  HUB     12.51     0.00    -0.02   393.76    -0.14   393.76     0.38      0.54

        BetaFlo   BetaBlade Incid   U1       W1          Ps1    Ts1     TwetBulb1  RH
  TIP     58.87    50.47     8.40   651.71   761.55     3.41   442.79   453.81    79.63
  MEAN    53.85    47.20     6.65   538.94   667.57     3.41   442.79   453.81    79.63
  HUB     45.11    38.62     6.49   395.20   557.97     3.41   442.79   453.81    79.63
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Station   2.  ROTOR EXIT CONDITIONS, STAGE   1    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.7000      0.0500      0.9500          32    594.6702    635.0460

        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP     20.63   631.13   374.55   507.97  1054.13     0.60     7.29     6.52    16.04
MEAN    18.04   663.46   409.39   522.10  1048.14     0.63     7.43     6.80    12.53
HUB     15.00   762.28   528.30   549.51  1037.76     0.73     7.49     7.25     9.22

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP    651.71   578.67   277.16     0.55  7729.72     0.92     0.91
MEAN   569.77   546.17   160.38     0.52  7386.02     0.92     0.91     0.91     1.36
HUB    473.86   552.20    54.45     0.53  7926.27     0.92     0.91

        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP      4.92     1.30     3.86   494.88     1.09   461.69   481.96    40.57
MEAN     4.86     1.29     3.71   493.13     1.08   456.46   482.79    49.92   494.63  1.30
HUB      4.95     1.31     3.46   495.87     1.09   447.47   490.20    72.12

        Alfa2  Beta FLO Beta BLADE  Deviat    Slip F. DiffFct   Solidity  Convergence Iter
TIP     36.40    28.62    24.20     4.42     0.93     0.38     1.80      0.00062     25
MEAN    38.10    17.08    12.70     4.38     0.93     0.32     2.22      0.00127     34
HUB     43.87    -5.66    -9.30     3.64     0.93     0.18     3.05      0.00010     41

Station   3. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      1.8117          33    577.5464    494.6273    484.0565      0.0000    618.8633

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
 18.0711    676.6714    408.5916    539.3858   1048.1318      0.6456     -0.0095      5.2355

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
  4.8949      3.6982    456.5078     50.0089     37.1444     35.4000      1.7444

Station   4. STATOR / VANED DIFFUSER
RCG         Cth         Cuth         Cmth       Aoth           Machth     cp 2-Th   Stat Chord
 18.0711    547.7717    134.0017    531.1284   1063.0168      0.5153      0.3189      5.4957

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500      4.8752      4.0673    469.6565    479.2444    577.5480      0.0260      0.4243

Station   5. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4       cp 3-4   Stator Gap
 18.0829    535.6375      0.0000    535.6375   1064.1667      0.5033      0.3247      1.3089

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500      4.0868    470.7619    479.9468      0.0000      0.0600      0.0394      0.3347

STAGE EXIT CONDITIONS, STAGE            1
Eff4         Pt4         PR           TR         Tt4           Del T      Ns          Ns nondim
  0.8772      4.8587      1.2878      1.0854    494.6215     38.9213    213.1781      1.6525

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 242829.766       0.572     648.527   526223.9       0.00187   542.74530   604.79504


COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   2
BLEED =  0.000   DPInc = 7.636   EfDer =  0.999   SH =  0.195749E-02

W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
 47.2600   3620.0000      4.8587    494.6201      1.0000      1.0000      0.9800

W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 21.4818     47.1675      0.0925      0.7538   3347.2468      0.0052      2.0000

W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
139.6273   3707.0652      1.3996      0.2498     53.4118          56      0.0500    602.5374

CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
118206.898   37053.988   1.4505    590.4866    407.0942    474.1340      1.1647    599.9134

Station   6.  ROTOR LEADING EDGE CONDITIONS, STAGE   2

        R1      Stator    Alfa     C1      CU1       Cm1       Mabs      Mrel   U1cor   FlowCoeff
TIP     20.55     0.00    -0.02   480.45    -0.17    480.45     0.45      0.76   664.78    0.740
MEAN    18.08     0.00    -0.02   480.45    -0.17    480.45     0.45      0.70
HUB     15.21     0.00    -0.02   480.45    -0.17    480.45     0.45      0.64
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      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     53.50    46.36     7.14   649.18   807.76      4.23   475.44   478.90    29.70
MEAN    49.94    42.30     7.64   571.10   746.44      4.23   475.44   478.90    29.70
HUB     45.01    37.84     7.17   480.49   679.60      4.23   475.44   478.90    29.70

Station   7.  ROTOR EXIT CONDITIONS, STAGE   2    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.5000      0.0500      0.9500          56    541.5062    584.6252

        R2      C2       Cu2      Cm2      Ao2         Mach2    Chord  AxChord  Rcircle
TIP     20.42   562.22   308.79   469.83  1096.90      0.51     3.21     2.81    12.40
MEAN    18.01   574.88   318.06   478.88  1092.38      0.53     3.30     2.93    10.11
HUB     15.22   624.89   389.14   488.94  1087.97      0.57     3.37     3.12     6.23

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP    645.08   577.77   336.28     0.53  6308.99      0.92     0.91
MEAN   568.94   540.62   250.88     0.49  5731.22      0.92     0.91      0.91     1.50
HUB    480.90   497.47    91.76     0.46  5926.34      0.92     0.91

        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP      5.94     1.22     4.96   526.50     1.06   500.24   495.10    14.56
MEAN     5.83     1.20     4.83   523.58     1.06   496.12   494.32    16.65   524.88  1.21
HUB      5.87     1.21     4.69   524.56     1.06   492.12   496.12    18.97

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     33.32    35.59    31.50     4.09     0.93     0.42     1.40      0.00071     25
MEAN    33.59    27.65    23.50     4.15     0.93     0.41     1.63      0.00102     34
HUB     38.52    10.63     6.50     4.13     0.93     0.41     1.97      0.00116     33

Station   8. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3      Tt3       TwetBulb3      MeltFract   Area3UB
  0.9500      0.7798          73    523.5558    524.8783    495.4347      0.0000    573.6071

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3           Mach3      cp 2-3    Stat Ax Chd
 17.9595    590.7197    318.9518    497.2116   1092.0568      0.5409     -0.0187      2.3644

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
  5.8684      4.8097    495.9213     17.2172     32.6794     30.6000      2.0794

Station   9. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
 17.9595    498.3300    105.6495    487.0020   1101.1957      0.4525      0.2478      2.4513

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500      5.8557      5.0886    504.2740    493.5365    540.8125      0.0221      0.2612

Station  10. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4           Mach4      cp 3-4   Stator Gap
 17.8235    550.7924      0.0000    550.7924   1096.1786      0.5025      0.0992      0.5911

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500      4.9148    499.7148    495.4424      0.0000      0.0600      0.0381      0.0824

STAGE EXIT CONDITIONS, STAGE            2
Eff4         Pt4         PR          TR        Tt4          Del T      Ns          Ns nondim
  0.8790      5.8389      1.2017      1.0612    524.8765     30.2588    239.0605      1.8532

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 189423.453       0.455     505.894   470817.4       0.00267   466.10056   560.16235


COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   3
BLEED =  0.000   DPInc = 7.726   EfDer =  0.999    SH =  0.275878E-02

W act     RPM act        Pt         Tt            POTS        POTH        AeroBl
 47.2600   3620.0000      5.8389    524.8750      1.0000      1.0000      0.9800

W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 21.4818     47.1296      0.1304      1.2227   2908.1367      0.0045      2.0000

W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
114.8840   3749.1382      1.3984      0.2505     53.4378          56      0.0500     556.6108

CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
102699.875   37042.258   1.5623    545.4786    349.1518    429.7651      1.2309    553.8704
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Station  11.  ROTOR LEADING EDGE CONDITIONS, STAGE   3

        R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
TIP     20.07     0.00    -0.02   451.86    -0.16   451.86     0.41     0.70   656.62    0.713
MEAN    17.74     0.00    -0.02   451.86    -0.16   451.86     0.41     0.65
HUB     15.05     0.00    -0.02   451.86    -0.16   451.86     0.41     0.59

      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     54.53    46.36     8.17   634.02   778.69     5.20   507.96   493.63    13.84
MEAN    51.13    43.40     7.73   560.37   719.97     5.20   507.96   493.63    13.84
HUB     46.47    38.84     7.63   475.44   656.02     5.20   507.96   493.63    13.84

Station  12.  ROTOR EXIT CONDITIONS, STAGE   3    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.5000      0.0500      0.9500          56    502.4182    542.8196

        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP     19.81   540.57   305.66   445.86  1130.10      0.48     3.11     2.72    12.03
MEAN    17.51   551.68   314.49   453.26  1126.08      0.49     3.22     2.84     9.33
HUB     14.85   598.69   381.37   461.50  1122.14      0.53     3.28     3.03     5.89

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP    625.81   548.89   320.15     0.49  6058.29     0.92     0.91
MEAN   553.04   512.20   238.55     0.45  5508.44     0.92     0.91     0.91     1.53
HUB    469.12   469.77    87.75     0.42  5665.63     0.92     0.91

        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP      7.00     1.20     5.99   555.40     1.06   531.19   507.82     8.45
MEAN     6.89     1.18     5.85   552.63     1.05   527.41   507.12     9.39   553.82  1.19
HUB      6.92     1.19     5.70   553.42     1.05   523.72   508.47    10.41

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     34.43    35.68    31.50     4.18     0.93     0.43     1.40      0.00105     23
MEAN    34.75    27.76    23.50     4.26     0.93     0.42     1.62      0.00134     32
HUB     39.57    10.77     6.50     4.27     0.93     0.43     1.94      0.00161     30

Station  13. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3      Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      0.7565          73    487.9654    553.8145    508.0614      0.0103    535.3244

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3          Cm3         Ao3            Mach3      cp 2-3    Stat Ax Chd
 17.3924    564.9846    316.5562    467.9741   1125.9592      0.5018     -0.0128      2.2836

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
  6.9279      5.8350    527.4150      9.7165     34.0760     31.5000      2.5760

Station  14. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
 17.3924     477.7821    104.2249    466.2755   1133.9329      0.4213      0.2516      2.3726

BlockageTh   PtTh        PsTh       TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500      6.9160      6.1220     534.9377    506.6222    498.3970      0.0209      0.2863

Station  15. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4         Ao4            Mach4      cp 3-4   Stator Gap
 17.1214    517.0918      0.0000    517.0918   1130.4536      0.4574      0.1292      0.5709

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500      5.9762    531.6927    507.9520      0.0000      0.0600      0.0389      0.1180

STAGE EXIT CONDITIONS, STAGE            3
Eff4         Pt4         PR          TR         Tt4          Del T      Ns          Ns nondim
  0.8791      6.8964      1.1811      1.0551    553.7888     28.9412    229.7855      1.7813

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 181815.969       0.464     485.577   520427.9       0.00391   434.74258   525.55774


COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   4
BLEED =  0.000   DPInc = 7.916   EfDer =  0.999    SH =  0.402059E-02

W act     RPM act        Pt         Tt             POTS        POTH        AeroBl
 47.2600   3620.0000      6.8964    553.7784      1.0000      1.0000      0.9800

W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 21.4818     47.0700      0.1900      2.0215   2563.6169      0.0040      2.0000

W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
 96.9879   3759.9319      1.3967      0.2515     53.4787          56      0.0500    523.8064
```

```
CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
 90533.273   37023.723   1.6892    513.3303    303.8878    401.0588      1.3198    521.1437

Station  16.  ROTOR LEADING EDGE CONDITIONS, STAGE   4

        R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
TIP     19.26     0.00    -0.02   423.28    -0.15   423.28     0.37     0.65   631.93    0.696
MEAN    16.97     0.00    -0.02   423.28    -0.15   423.28     0.37     0.60
HUB     14.32     0.00    -0.02   423.28    -0.15   423.28     0.37     0.54


      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     55.18    46.36     8.82   608.43   741.30     6.27   538.99   506.59     8.18
MEAN    51.72    43.80     7.92   536.11   683.18     6.27   538.99   506.59     8.18
HUB     46.91    37.84     9.07   452.38   619.63     6.27   538.99   506.59     8.18

Station  17.  ROTOR EXIT CONDITIONS, STAGE   4    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.5000      0.0500      0.9500          56    477.1383    516.2928

        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP     18.88   512.72   294.52   419.69  1160.04     0.44     2.97     2.60    11.47
MEAN    16.57   520.57   299.03   426.11  1156.20     0.45     3.08     2.71     8.74
HUB     13.89   561.06   356.53   433.21  1152.41     0.49     3.11     2.88     5.76

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP    596.43   516.99   301.90     0.45  5563.42     0.92     0.91
MEAN   523.58   481.66   224.54     0.42  4958.60     0.92     0.91     0.91     1.54
HUB    438.79   440.95    82.26     0.38  4954.32     0.92     0.91

        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP      8.08     1.17     7.07   581.66     1.05   559.96   517.90     5.28
MEAN     7.94     1.15     6.91   578.63     1.04   556.26   517.08     5.78   579.63  1.16
HUB      7.94     1.15     6.76   578.61     1.04   552.63   517.82     6.32

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     35.06    35.73    31.50     4.23     0.93     0.44     1.40      0.00119     24
MEAN    35.06    27.79    23.50     4.29     0.93     0.43     1.62      0.00048     32
HUB     39.45    10.75     6.50     4.25     0.93     0.43     1.94      0.00104     28

Station  18. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      0.7209          73    476.4520    579.6042    517.5048      0.6762    523.9628

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
 16.4812    521.2689    300.7142    425.7842   1157.0745      0.4505      0.0269      2.1803

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
  7.9785      6.9438    557.2090      5.7369     35.2320     32.4000      2.8320

Station  19. STATOR / VANED DIFFUSER
RCG         Cth         Cuth         Cmth       Aoth           Machth     cp 2-Th   Stat Chord
 16.4812    444.4072     99.6675    433.0867   1163.3550      0.3820      0.2711      2.2705

BlockageTh  PtTh        PsTh       TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500      7.9688      7.2049    563.3000    516.4457    480.4178      0.0190      0.3063

Station  20. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4      cp 3-4   Stator Gap
 16.0960    470.0504      0.0000    470.0504   1161.2367      0.4048      0.1520      0.5451

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500      7.1010    561.2796    516.9836      0.0000      0.0600      0.0394      0.1746

STAGE EXIT CONDITIONS, STAGE             4
Eff4         Pt4         PR          TR        Tt4          Del T      Ns          Ns nondim
  0.8836      7.9469      1.1523      1.0464    579.4802     25.8532    234.1671      1.8152

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 162999.625       0.458     435.324   572371.0       0.00475   425.14447   519.08722

COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   5
BLEED =  0.000   DPInc = 8.019   EfDer =  0.998    SH =  0.493731E-02

W act     RPM act        Pt         Tt            POTS        POTH        AeroBl
 47.2600   3620.0000      7.9469    579.4626      1.0000      1.0000      0.9800

W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 21.4818     47.0267      0.2333      2.7747   2293.5586      0.0036      2.0000
```

```
W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
 83.8205   3775.4858      1.3953      0.2523     53.5084          56      0.0500    520.0693

CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
 80996.250   37010.207   1.8882    509.6679    269.9282    390.2764      1.4459    517.7266

Station  21.  ROTOR LEADING EDGE CONDITIONS, STAGE   5
        R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
TIP     18.32     0.00    -0.02   381.41    -0.13   381.41     0.33     0.59   603.58    0.659
MEAN    15.91     0.00    -0.02   381.41    -0.13   381.41     0.33     0.54
HUB     13.07     0.00    -0.02   381.41    -0.13   381.41     0.33     0.48

      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     56.62    47.36     9.26   578.74   693.22     7.38   567.49   516.17     4.90
MEAN    52.82    44.80     8.02   502.70   631.12     7.38   567.49   516.17     4.90
HUB     47.28    38.84     8.44   412.89   562.19     7.38   567.49   516.17     4.90

Station  22.  ROTOR EXIT CONDITIONS, STAGE   5    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.5000      0.0500      0.9500          56    475.3082    515.3698

        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP     17.94   479.28   290.76   381.00  1187.13     0.40     2.82     2.45    10.21
MEAN    15.50   480.44   284.56   387.11  1182.95     0.41     2.92     2.55     7.91
HUB     12.59   509.27   323.05   393.69  1178.82     0.43     2.95     2.72     5.29

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP    566.73   470.45   275.97     0.40  5218.66     0.92     0.91
MEAN   489.58   438.05   205.02     0.37  4412.04     0.92     0.91     0.91     1.59
HUB    397.72   400.71    74.68     0.34  4068.90     0.92     0.91

        Pt2       PR       Ps2     Tt2        TR      Ts2     TwetBulb2   RH      Tt2avg  PR2avg
TIP      9.16     1.15     8.19   605.56     1.05   586.66   527.48     4.12
MEAN     8.97     1.13     8.01   601.53     1.04   582.54   526.32     4.50    602.30  1.13
HUB      8.88     1.12     7.82   599.81     1.04   578.47   526.29     4.92

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     37.35    35.92    31.50     4.42     0.93     0.47     1.40      0.00142     22
MEAN    36.32    27.91    23.50     4.41     0.93     0.44     1.64      0.00217     29
HUB     39.37    10.74     6.50     4.24     0.93     0.43     2.01      0.00128     31

Station  23. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract    Area3UB
  0.9500      0.6802          73    462.6711    602.3022    527.1013      1.0000    510.8013

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3         Ao3            Mach3      cp 2-3    Stat Ax Chd
 15.2185    493.5620    289.7749    399.5423   1182.4731      0.4174     -0.0329      2.0437

Pt3         Ps3         Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
  8.9842      7.9735    582.3434      4.7215     35.9521     33.0000      2.9521

Station  24. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth        Aoth           Machth     cp 2-Th    Stat Chord
 15.2185    424.4456     96.9225    413.2313   1187.6863      0.3574      0.2092      2.1315

BlockageTh   PtTh        PsTh       TsTh        TwetBulbTh  AreaTh       w2-Th      DiffFact4
  0.9500      8.9688      8.2143    587.5535    526.4504    461.2568      0.0354      0.3124

Station  25. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4         Ao4            Mach4      cp 3-4    Stator Gap
 14.7013    444.1916      0.0000    444.1916   1186.2103      0.3745      0.1662      0.5109

Blockage4    Ps4        Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500      8.1415    586.1629    527.8693      0.0000      0.0600      0.0396      0.1363

STAGE EXIT CONDITIONS, STAGE            5
Eff4         Pt4         PR          TR         Tt4          Del T      Ns          Ns nondim
  0.8751      8.9646      1.1281      1.0394    602.2983     22.8406    241.9290      1.8754

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 144902.188       0.451     386.991   640835.7       0.00793   410.39981   509.29071


OVERALL EXIT CONDITIONS; ALL           5   STAGES

Del Enthal    DelHT/U1^2  GHP      MassFloS1cor  OPR     Efficiency    Rotor1Inc  TR      AxHubLen
  921971.00     2.1707  2462.3127  172.586      2.3760   0.86582       6.6540    1.3217   41.379
```

7.1.4.2.1 plot.out

The file plot.out is produced from an execution of the COMDES-MELT code. It provides information for each station of the calculation and is mainly used to determine if there is a risk of ice accretion. The variables Twbs and MeltFrac are two of the parameters that determine icing risk.

```
      xx       alt        SH            RH         g/m3      Twbt       Twbs        Tt         Ts          Pt         Ps         Mach     Enthalpy   MeltFrac
ZONE T=" M   , Alt   40000. ft,  Thr  %", I = 25.0
     1.0000 40000.0000   0.1395E-02    79.6302     0.4653   453.8118   441.4793   455.7065   442.7897     3.7730     3.4124     0.3814   -40.2053     0.0000
     2.0000 40000.0000   0.1580E-02    49.9181     0.4653   482.7891   451.5374   494.6282   456.4637     4.8597     3.7099     0.6330    44.5418     0.0000
     3.0000 40000.0000   0.1591E-02    50.0076     0.4653   484.0566   451.5749   494.6277   456.5084     4.8950     3.6982     0.6456     2.9166     0.0000
     4.0000 40000.0000   0.1641E-02    30.8983     0.4653   479.2446   460.0702   494.6242   469.6571     4.8752     4.0673     0.5153    21.6704     0.0000
     5.0000 40000.0000   0.1869E-02    33.6638     0.4653   479.9470   461.3481   494.6219   470.7624     4.8587     4.0868     0.5033    14.2352     0.0000
     6.0000 40000.0000   0.1958E-02    29.6973     0.7538   478.9024   464.3555   494.6205   475.4442     4.8587     4.2304     0.4493     8.7184     0.0000
     7.0000 40000.0000   0.2268E-02    16.6485     0.7538   494.3181   476.1749   524.8802   496.1218     5.8320     4.8294     0.5263    50.1516     0.0000
     8.0000 40000.0000   0.2336E-02    17.2167     0.7538   495.4352   476.1867   524.8796   495.9228     5.8684     4.8098     0.5409     3.8885     0.0000
     9.0000 40000.0000   0.2413E-02    13.6024     0.7538   493.5372   480.4937   524.8779   504.2755     5.8557     5.0886     0.4525    10.3667     0.0000
    10.0000 40000.0000   0.2670E-02    17.3257     0.7538   495.4430   478.7365   524.8777   499.7165     5.8389     4.9149     0.5025     1.2757     0.0000
    11.0000 40000.0000   0.2759E-02    13.8356     1.2228   493.6303   482.9136   524.8763   507.9594     5.8389     5.2047     0.4089     9.0612     0.0000
    12.0000 40000.0000   0.3355E-02     9.3942     1.2228   507.1157   492.5249   553.8177   527.4135     6.8909     5.8491     0.4899    53.5052     0.0126
    13.0000 40000.0000   0.3478E-02     9.7161     1.2228   508.0621   492.6884   553.8160   527.4171     6.9280     5.8351     0.5018    10.7746     0.0103
    14.0000 40000.0000   0.3594E-02     8.1613     1.2228   506.6229   496.0190   553.8110   534.9395     6.9161     6.1221     0.4213    31.2993     0.0367
    15.0000 40000.0000   0.3911E-02     9.6692     1.2228   507.9525   495.1137   553.7901   531.6945     6.8965     5.9762     0.4574   130.3384     0.1392
    16.0000 40000.0000   0.4021E-02     8.1780     2.0216   506.5873   498.2862   553.7797   538.9930     6.8965     6.2696     0.3719    65.0653     0.1866
    17.0000 40000.0000   0.4450E-02     5.7796     2.0216   517.0820   505.4290   579.6332   556.2624     7.9445     6.9149     0.4502   721.3027     0.6138
    18.0000 40000.0000   0.4527E-02     5.7368     2.0216   517.5052   505.8555   579.6054   557.2106     7.9785     6.9439     0.4505   173.2100     0.6763
    19.0000 40000.0000   0.4587E-02     5.0235     2.0216   516.4462   508.1948   579.5739   563.3010     7.9689     7.2050     0.3820   195.8688     0.7687
    20.0000 40000.0000   0.4755E-02     5.4500     2.0216   516.9839   507.6157   579.4796   561.2794     7.9470     7.1011     0.4048   587.3492     1.0000
    21.0000 40000.0000   0.4937E-02     4.8976     2.7748   516.1749   510.1423   579.4617   567.4915     7.9470     7.3825     0.3267   111.1108     1.0000
    22.0000 40000.0000   0.6406E-02     4.5013     2.7748   526.3210   516.9411   602.3027   582.5356     8.9664     8.0064     0.4061   105.7949     1.0000
    23.0000 40000.0000   0.6712E-02     4.7218     2.7748   527.1019   517.1427   602.3017   582.3435     8.9843     7.9736     0.4174     6.0845     1.0000
    24.0000 40000.0000   0.7009E-02     4.4083     2.7748   526.4510   519.1953   602.2994   587.5533     8.9689     8.2144     0.3574    14.5129     1.0000
    25.0000 40000.0000   0.7927E-02     5.1308     2.7748   527.8698   519.6741   602.2977   586.1629     8.9648     8.1416     0.3745    10.4327     1.0000
    26.0000 40000.0000   0.9351E-02     5.3700     2.7748   528.3302   523.0033   602.2925   591.9167     8.9648     8.4278     0.2992    32.1823     1.0000
    27.0000 40000.0000   0.1092E-01     6.2791     2.7748   530.0453   524.4763   602.2901   591.8270     8.9648     8.4217     0.3012    15.3438     1.0000
```

xx	station number
alt	altitude
SH	S_h
RH	ϕ
g/m3	grams of water vapor per cubic meter of air (not IWC)
Twbt	total T_{WB}
Twbs	T_{WBS}
Pt	P_t
Ps	P_S
Mach	Mach number
Enthalpy	enthalpy—the amount of enthalpy exchanged between the ice particle and the air
MeltFrac	particle melt fraction—ratio of liquid to liquid and ice

The underlined station numbers in the file plot.out listing indicate the region where icing risk conditions exist; that is, Twbs and MeltFrac with a significant IWAR (0.006) as indicated in the comdes.out file. In this case, the risk of ice is in stator 3 (stations 13 to 15) of the LPC.

7.1.4.2.2 Melt_Frac.out (snippet)

The Melt_Frac.out file is produced during the execution of the MELT subroutine. It provides information about the particle state and the amount of enthalpy extracted from the air and provided to the particle. This data is produced for each blade row, gap, and vane row of a stage.

```
INLET, Station  0.0000000E+00

 Pstatic(psia)    14.17000       3.412358
 Tstatic(R)       469.5800       442.7870
 Velocity(ft/s)   159.4200       393.7570
 Distance(in)    0.0000000E+00   46.90000
 Nsteps                 2000
 Dist(in)        DropTemp(R)        MeltFraction      spHumidity   RelHumidity    cp       deltaTemp   cp*deltaTemp*conv  cp*deltaTemp       dpm
       0.023438     469.579987       0.000000        0.152266E-02   100.000000  1.939702   0.000000E+00   0.000000E+00   0.000000E+00   0.500000E-05
       0.046877     469.566589       0.000000        0.152232E-02   100.000000  1.939702  -0.790982E-03  -0.506638E-02  -0.153427E-02   0.500000E-05
.     (LINES OF SIMILAR DATA SNIPPED FOR CLARITY)
.
      46.853039     441.747345       0.000000        0.139398E-02    79.565613  1.939702  -0.978843E-02  -0.656714E-01  -0.189866E-01   0.498931E-05
      46.876476     441.729706       0.000000        0.139430E-02    79.513458  1.939702  -0.979494E-02  -0.657151E-01  -0.189993E-01   0.498928E-05
      46.899914     441.712067       0.000000        0.139463E-02    79.461212  1.939702  -0.980204E-02  -0.657627E-01  -0.190130E-01   0.498924E-05
 ENTHALPY SUM  -40.20848

 ROTOR Mean, Station   1.000000

 Pstatic(psia)    3.412356       3.709634
 Tstatic(R)       442.7874       456.4540
 Velocity(ft/s)   393.7594       663.4747
 Distance(in)     46.90000       54.33419
 Nsteps                  600
 Dist(in)        DropTemp(R)        MeltFraction      spHumidity   RelHumidity    cp       deltaTemp   cp*deltaTemp*conv  cp*deltaTemp       dpm
      46.912373     441.702240       0.000000        0.139482E-02    79.470749  1.939702  -0.545536E-02  -0.366005E-01  -0.105818E-01   0.498922E-05
      46.924744     441.690521       0.000000        0.139509E-02    79.405312  1.939702  -0.651159E-02  -0.436868E-01  -0.126305E-01   0.498919E-05
      46.937115     441.680084       0.000000        0.139536E-02    79.339783  1.939702  -0.580504E-02  -0.389465E-01  -0.112601E-01   0.498916E-05
      46.949486     441.670807       0.000000        0.139563E-02    79.274139  1.939702  -0.514103E-02  -0.344916E-01  -0.997207E-02   0.498913E-05
.     (LINES OF SIMILAR DATA SNIPPED FOR CLARITY)
.
```

Station name and number

Pstatic	LE and TE static pressures
Tstatic	LE and TE static temperatures
Velocity	LE and TE velocities
Distance	LE and TE distance from station 1 in inches
Nsteps	the number of integration steps taken for integration in the subroutine MELT
Dist	distance the particle has traveled (distance)
DropTemp	temperature of the particle in Rankine
MeltFraction	particle melt fraction—ratio of liquid to liquid and ice

spHumidity	S_h
RelHumidity	ϕ
cp	constant pressure specific heat
deltaTemp	change in temperature
cp*deltaTemp*conv	temperature change multiplied by specific heat and a conversion constant
cp*deltaTemp	temperature change multiplied by specific heat
dpm	particle diameter
ENTHALPY SUM	cumulative sum of enthalpy for each component (rotor, gap, stator, etc.)

Care must be taken in interpreting the data in this file as there are currently solutions at the hub, mean, and tip regions of the rotor, which are then passed to the gap and stator at their mean line. This may appear as though there is a discontinuity in particle temperature, melt fraction, etc.

7.1.5 Sensitivity of Rotor Exit Conditions to Slip, Blockage, and Efficiency

A sensitivity study was conducted to show the effects of prescribed slip, blockage, and efficiency values on the rotor exit conditions. In this case, the full-fan case was used and executed at its design point while varying the parameters of slip, blockage, and efficiency to understand these effects (Figure 15 to Figure 17).

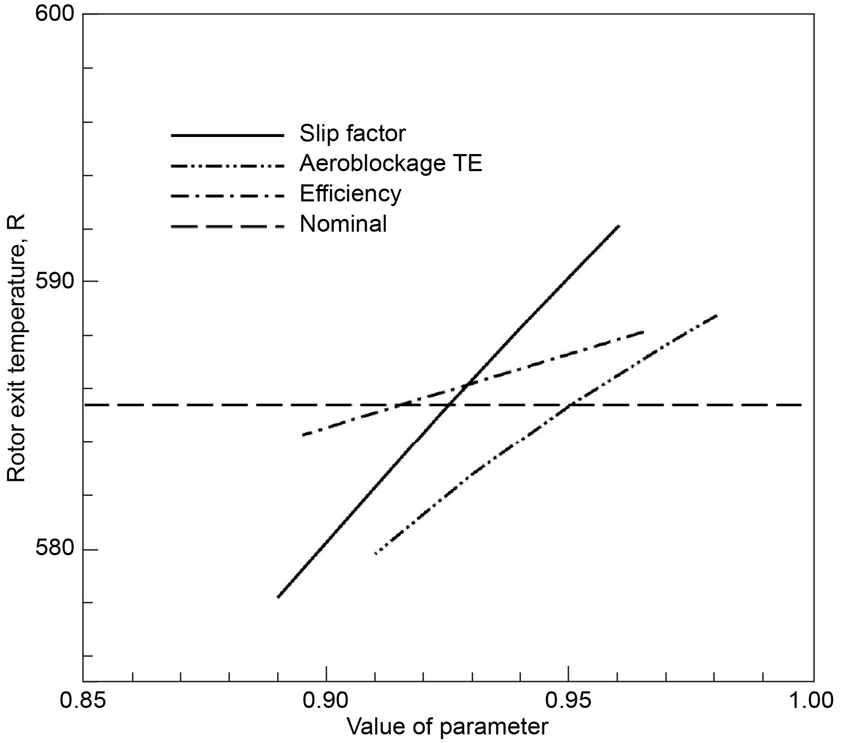

Figure 15.—Sensitivity of rotor exit temperature to slip, blockage, and efficiency.

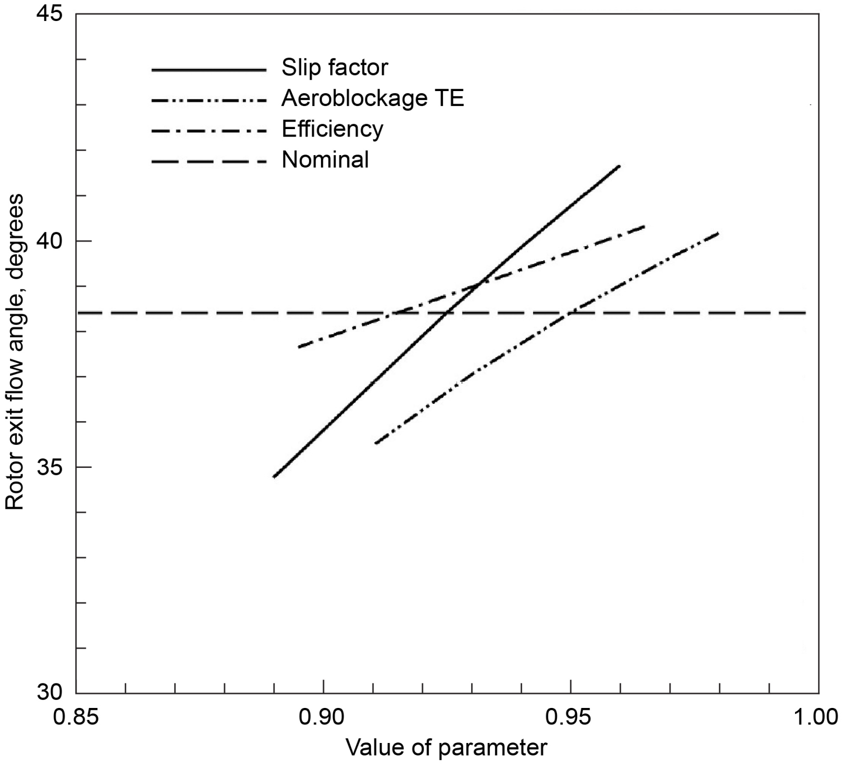

Figure 16.—Sensitivity of rotor exit flow angle to slip, blockage, and efficiency.

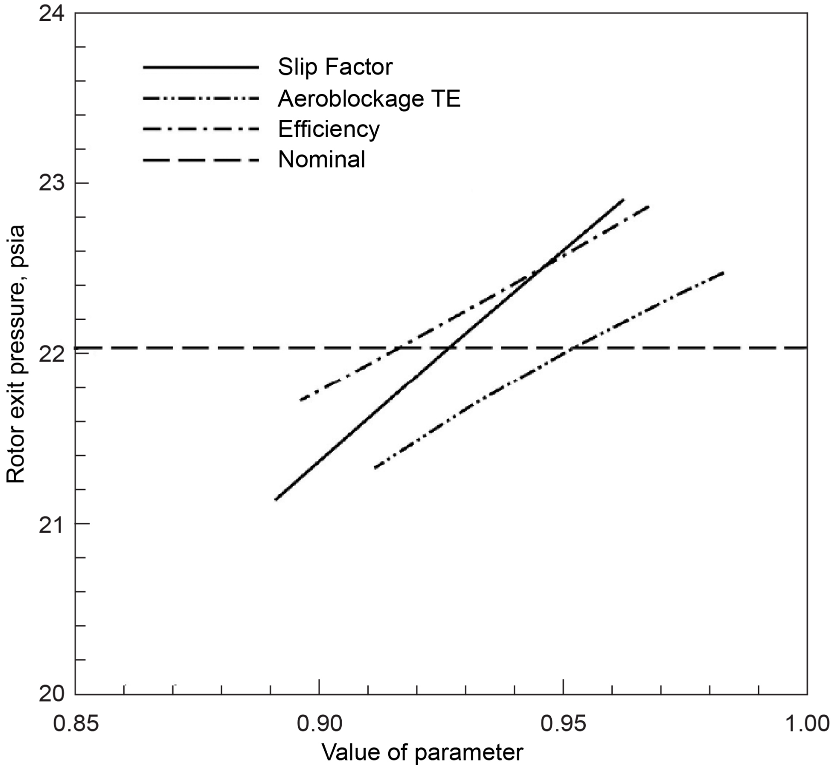

Figure 17.—Sensitivity of rotor exit pressure to slip, blockage, and efficiency.

```
TITLE = "COMDES Parameter Sensitivity"
VARIABLES = Value, Pt3, Tt3, FlowAngle3
Zone T ="Slip", I = 4.0
0.89     21.1405  580.6187 34.7638
0.925    22.0389  587.8586 38.401
0.94     22.4144  590.801  39.8429
0.96     22.9078  594.6    41.6628
Zone T ="AeroB2", I = 5.0
0.98     22.4776  591.2195 40.1589
0.97     22.3382  590.159  39.6068
0.95     22.0389  587.8586 38.401
0.93     21.7061  585.2581 37.0343
0.91     21.3286  582.2524 35.4613
Zone T ="Efficiency", I = 6.0
0.965    22.8663  590.6035 40.3059
0.955    22.6964  590.0615 39.924
0.935    22.3627  588.9634 39.1611
0.915    22.0389  587.8586 38.401
0.905    21.8795  587.2942 38.0211
0.895    21.7236  586.7374 37.6439
Zone T ="Nominal", I = 2.0
0.8      22.0389  587.8586 38.401
1.05     22.0389  587.8586 38.401
```

7.1.6 Stage-Matching Example

This stage-matching example is provided to illustrate how a single stage can be the limiting component in the overall performance of the compressor. Figure 18 shows the overall performance of the five-stage compressor. Figure 19 illustrates the performance of stage 1 of the compressor in isolation with the surge and choke limitations of stage 5 indicated. Figure 20 and Figure 21 look at the performance of each stage within the overall compression system. In Figure 21, stage 5 head coefficient is plotted for the rotor only, while the efficiency is for the stage, which includes the stator loss. The high incidence produces a large stator loss, which results in a low efficiency. The rotor produces a positive ΔP_t and ΔT_t, which gives the rise in enthalpy across the rotor. At low corrected flow rates, the rotor relative velocity ratio, Ws1/W2, (relative blade tip velocity/relative TE velocity at the mean) (1.82 at station 1 corrected mass flow 136, station 5 corrected mass flow 67) is moving toward surge in stage 5, which limits the range of the compressor. At the higher flow rates, the stage 5 rotor is wind milling.

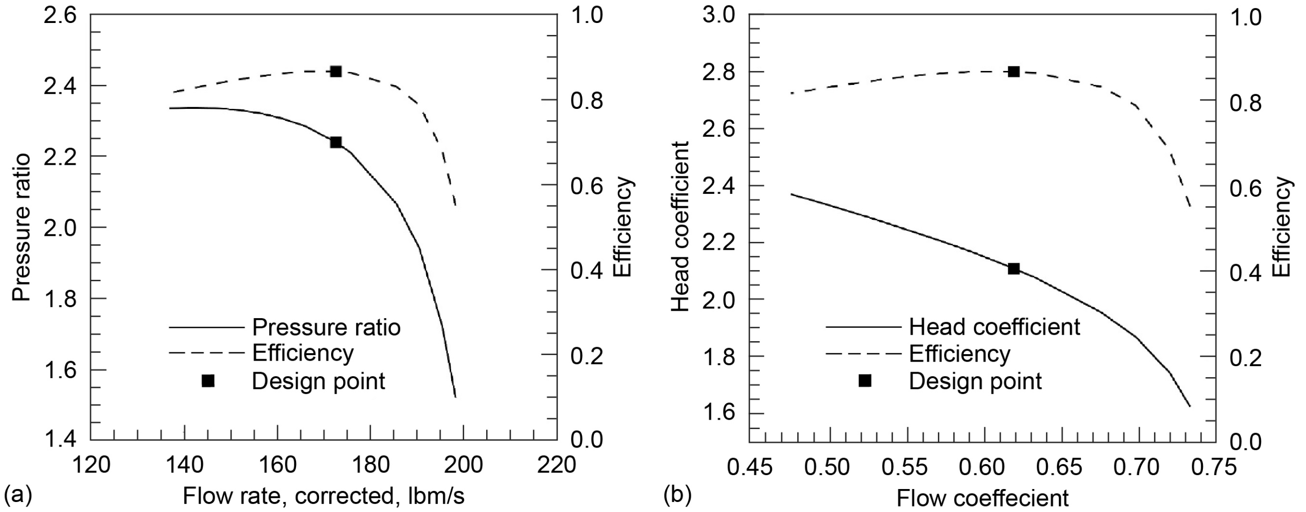

Figure 18.—Overall performance of five-stage compressor with design point indicated (design operating condition coincides with design point for each stage). (a) Pressure ratio and efficiency versus corrected flow rate. (b) Head coefficient and efficiency versus flow coefficient.

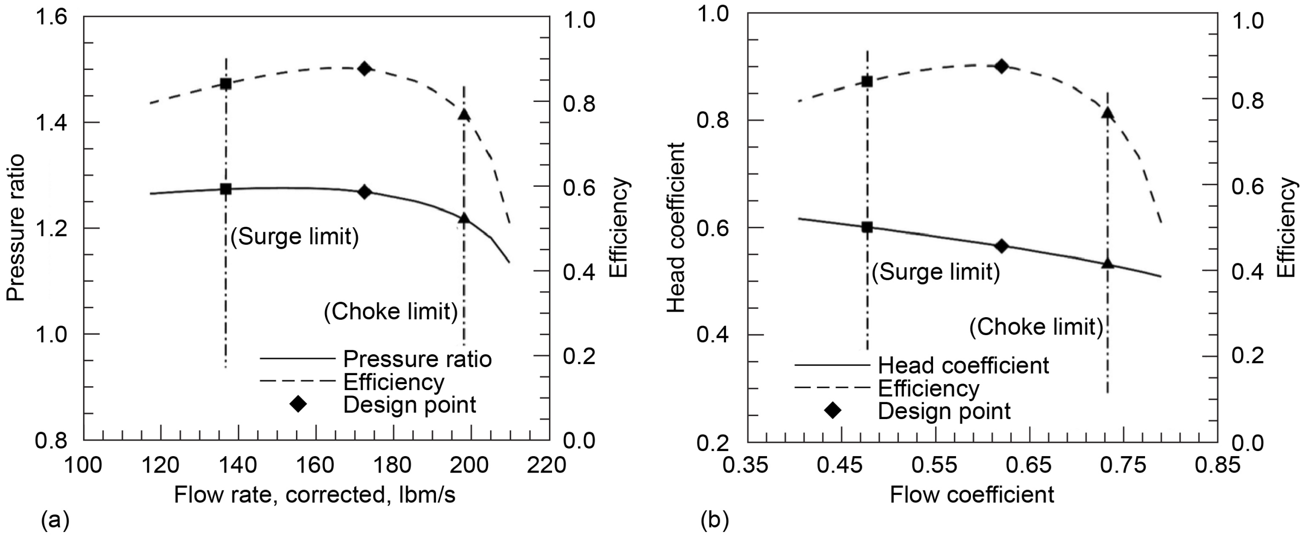

Figure 19.—Stage 1 performance with stage 5 limits for choke (corrected mass flow 198) and surge (corrected mass flow 137) and design operating point. (a) Pressure ratio and efficiency versus corrected flow rate. (b) Head coefficient and efficiency versus flow coefficient.

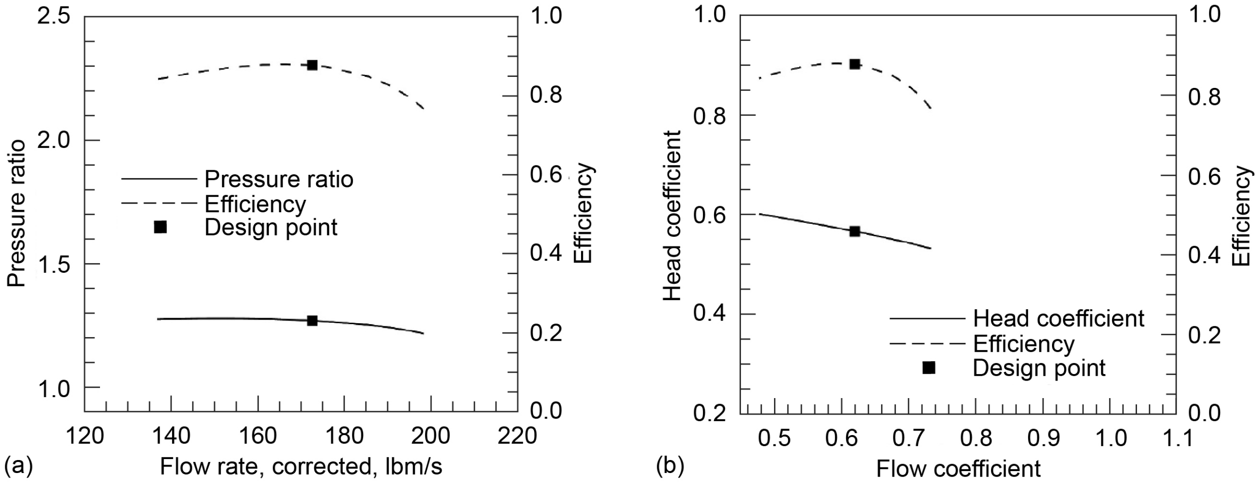

Figure 20.—Stage 1 performance within overall compression system limited by stage 5 surge and choke points, with design operating point indicated. (a) Pressure ratio and efficiency versus corrected flow rate. (b) Head coefficient and efficiency versus flow coefficient. This within system performance of stage 1 can be compared with the isolated stage 1 performance illustrated in Figure 19.

7.1.7 40K Turbofan Fan Core and Four-Stage Low-Pressure Compressor Performance Characteristics

Figure 18 to Figure 21 showcase the pressure ratio and efficiency versus the corrected mass flow and the head coeffcient and efficiency versus the flow coefficient.

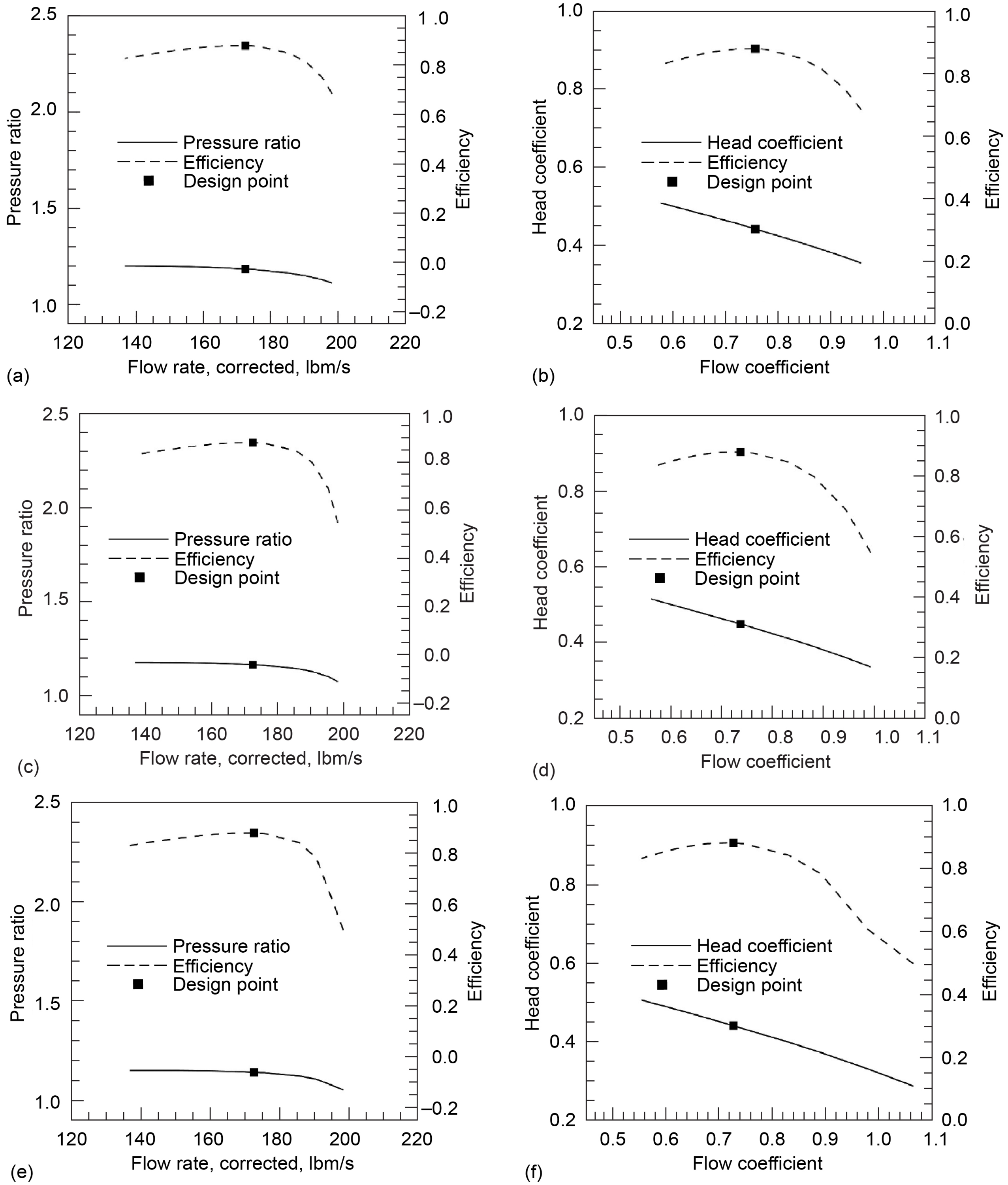

Figure 21.—Stages 2 through 5 performance within the overall compression system limited by the stage 5 surge and choke points, with design operating point indicated. Pressure ratio and efficiency to corrected flow rate. (a) Stage 2, (c) stage 3, (e) stage 4, and (g) stage 5. Head coefficient and efficiency to flow coefficient. (b) Stage 2, (d) stage 3, (f) stage 4, (h) stage 5.

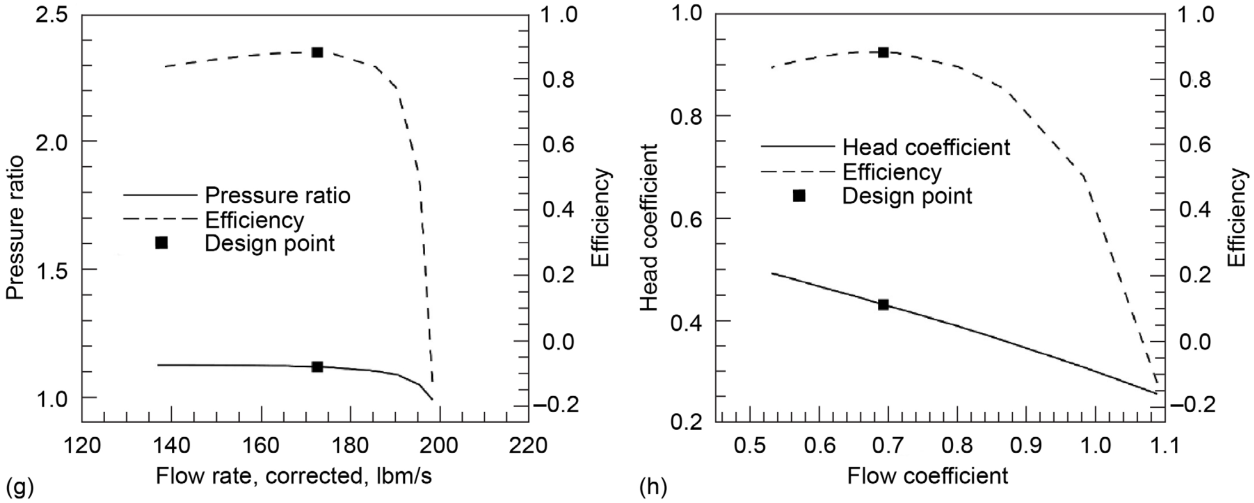

Figure 21.—Concluded.

TABLE IV.—VEHICLE AND ENGINE SYSTEM MODEL

Component	Low-pressure compressor	High-pressure compressor (HPC) option 1 (all-axial four stage)	HPC option 2 (centrifugal stage)
Mass flow, lbm/s	30.0	30.0	30.0
Pressure ratio	13.0	2.73	2.57
Shaft speed, rpm	24,800	32,650	38,620

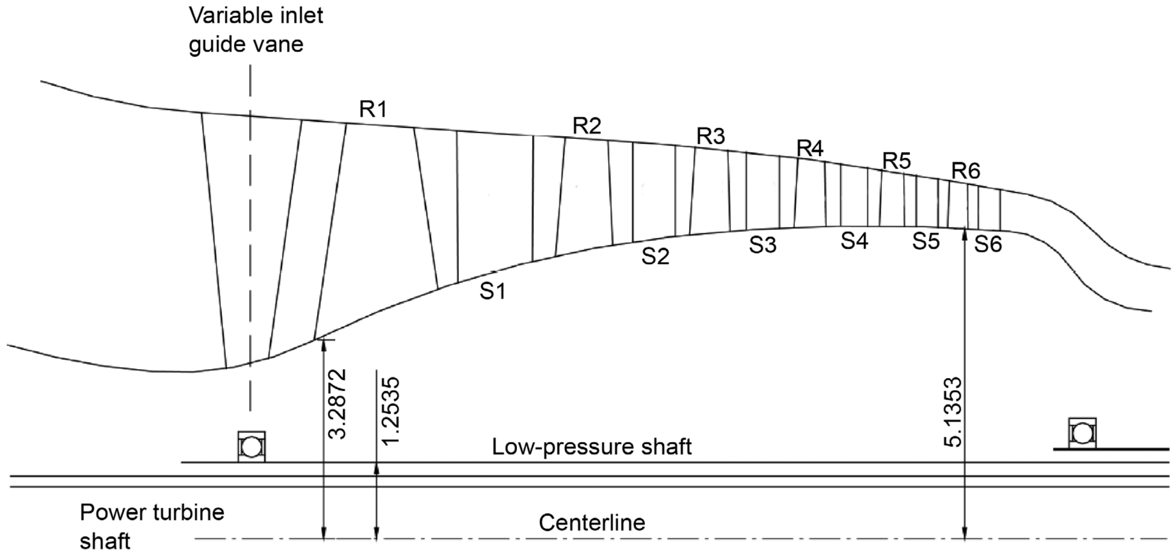

Figure 22.—Flow path for the six-stage axial low-pressure compressor of the Large Civil Transport Rotor Engine (Ref. 12). Pressure ratio = 10.83; efficiency = 84.2 adiabatic; speed = 24,800 RPM; power = 6,400 HP; tip speed = 1,476 ft/s.

7.2 Example Case (2): Large Civil Transport Rotor Engine

Table IV is the design table illustrating a vehicle and engine system model.
The LPC has 6 axial stages as seen in Figure 22.

7.2.1 Input File

comdes.dat

```
SRW 6 Axial Stage LPC 100% RPM 0 IGV 0 S1 0 S2  1-14-2011
 30.0        14.7000    518.6700      24800.0     Wact        Pt1          Tt1         RPM
  5           6           0           0.00        Fluid       Stages       IDUMMY      DUMMY
  0.00        0.000      00.00        0.00        DropDia     InDist       RHinlet     IWC         ***icing***
  14.7        0.00      518.7         0.00        Psin        DUMMY        Tsin        DUMMY       ***icing***
550.0         0.00    00000.00        0           Vin         DUMMY        Altitude    IDUMMY      ***icing***
  6.900       3.2872      6.8219      4.1321    1 R1tip       R1hub        R2tip       R2hub
  0.3000      0.3000     21           0.0300      1.0         B1axial      B2axial     NBLAD       THK      CFS
  0.0         0.0000      0.000       1.0000      1.0         StatorT      StatorM     StatorH     FSGV     CFMid
  0.9800      0.9500      1.1000      0.9000      1.0         AeroB1       AeroB2      POTS        POTH     CFHub
  0.9100      0.910       0.910       0.0000      EfficiT     EfficiM      EfficiH     BLEED
  0.0000      0.0000      0.0000      0.0000      DUMMY       DUMMY        DUMMY       DUMMY
  0.9200      0.045       1.68        0.00        SlipF       DiffLoss     Solidity    RPM2
 61.3000     58.15       48.400       0.00        BetaBlade1T BetaBlade1M  BetaBlade1H expo3
 59.20       48.80       11.70        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
  6.7719      4.2419      0.0         45.6        R3s         R3h          B3X         BetB3
 38           0.03        0.95        0.01        Blan3       Blath3       Blok3       Wbar23
 00.0         0.000       0.95        0.015       RCG         Athrt        BlokTH      Wbar2T
  6.6828      4.5907      0.0         0.0         R4S         R4H          B4X         BetB4
 38           0.03        0.95        1.603       Blan4       Blath4       Blok4       SolidStat
  6.6459      4.6796      6.5962      4.8635    2 R1tip       R1hub        R2tip       R2hub
  0.2000      0.2000     32           0.0300      1.0         B1axial      B2axial     NBLAD       THK      CFS
  0.0         0.0000      0.000       1.0000      1.0         StatorT      StatorM     StatorH     FSGV     CFMid
  0.9800      0.9500      1.1000      0.9000      1.0         AeroB1       AeroB2      POTS        POTH     CFHub
  0.9050      0.905       0.905       0.0000      EfficiT     EfficiM      EfficiH     BLEED
  0.0000      0.0000      0.0000      0.0000      DUMMY       DUMMY        DUMMY       DUMMY
  0.9200      0.061       1.45        0.00        SlipF       DiffLoss     Solidity    RPM2
 58.70       57.60       55.30        0.00        BetaBlade1T BetaBlade1M  BetaBlade1H expo3
 55.2        48.8        35.00        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
  6.5671      4.9158      0.0         47.3        R3s         R3h          B3X         BetB3
 66           0.03        0.95        0.01        Blan3       Blath3       Blok3       Wbar23
 00.0         0.000       0.95        0.015       RCG         Athrt        BlokTH      Wbar2T
  6.5163      5.0054      0.0         0.0         R4S         R4H          B4X         BetB4
 66           0.03        0.95        1.50        Blan4       Blath4       Blok4       SolidStat
  6.4878      5.0305      6.4360      5.0914    3 R1tip       R1hub        R2tip       R2hub
  0.1500      0.1500     36           0.0300      1.0         B1axial      B2axial     NBLAD       THK      CFS
  0.0         0.0000      0.000       1.0000      1.0         StatorT      StatorM     StatorH     FSGV     CFMid
  0.9800      0.9500      1.1000      0.9000      1.0         AeroB1       AeroB2      POTS        POTH     CFHub
  0.9000      0.900       0.900       0.0000      EfficiT     EfficiM      EfficiH     BLEED
  0.0000      0.0000      0.0000      0.0000      DUMMY       DUMMY        DUMMY       DUMMY
  0.9200      0.067       1.38        0.00        SlipF       DiffLoss     Solidity    RPM2
 60.3000     60.00       59.200       0.00        BetaBlade1T BetaBlade1M  BetaBlade1H expo3
 56.50       52.10       43.60        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
  6.4045      5.1110      0.0         48.5        R3s         R3h          B3X         BetB3
 79           0.03        0.95        0.01        Blan3       Blath3       Blok3       Wbar23
 00.0         0.000       0.95        0.015       RCG         Athrt        BlokTH      Wbar2T
 19.411      14.474       0.0         0.0         R4S         R4H          B4X         BetB4
 79           0.03        0.95        1.40        Blan4       Blath4       Blok4       SolidStat
  6.3053      5.1553      6.2478      5.1727    4 R1tip       R1hub        R2tip       R2hub
  0.1000      0.1000     44           0.0300      1.0         B1axial      B2axial     NBLAD       THK      CFS
  0.0         0.0000      0.000       1.0000      1.0         StatorT      StatorM     StatorH     FSGV     CFMid
  0.9800      0.9500      1.1000      0.9000      1.0         AeroB1       AeroB2      POTS        POTH     CFHub
  0.8950      0.895       0.895       0.0000      EfficiT     EfficiM      EfficiH     BLEED
  0.0000      0.0000      0.0000      0.0000      DUMMY       DUMMY        DUMMY       DUMMY
  0.9200      0.071       1.30        0.00        SlipF       DiffLoss     Solidity    RPM2
 60.700      60.8        60.700       0.00        BetaBlade1T BetaBlade1M  BetaBlade1H expo3
 56.60       53.30       46.70        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
  6.2111      5.1777      0.0         48.7        R3s         R3h          B3X         BetB3
 96           0.03        0.95        0.01        Blan3       Blath3       Blok3       Wbar23
 00.0         0.000       0.95        0.015       RCG         Athrt        BlokTH      Wbar2T
 18.485      13.284       0.0         0.0         R4S         R4H          B4X         BetB4
 96           0.03        0.95        1.361       Blan4       Blath4       Blok4       SolidStat
  6.1113      5.1742      6.0534      5.168     5 R1tip       R1hub        R2tip       R2hub
  0.1000      0.100      51           0.0300      1.0         B1axial      B2axial     NBLAD       THK      CFS
  0.0         0.0000      0.000       1.0000      1.0         StatorT      StatorM     StatorH     FSGV     CFMid
  0.9800      0.9500      1.1000      0.9000      1.0         AeroB1       AeroB2      POTS        POTH     CFHub
  0.8900      0.890       0.890       0.0000      EfficiT     EfficiM      EfficiH     BLEED
  0.0000      0.0000      0.0000      0.0000      DUMMY       DUMMY        DUMMY       DUMMY
  0.9200      0.073       1.270       0.00        SlipF       DiffLoss     Solidity    RPM2
 60.4000     60.90       61.2000      0.00        BetaBlade1T BetaBlade1M  BetaBlade1H expo3
```

```
     55.50      52.30       47.40        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
      6.0198      5.1647      0.0         45.0        R3s         R3h          B3X         BetB3
    115           0.06        0.95        0.02        Blan3       Blath3       Blok3       Wbar23
      6.0       23.000        0.95        0.03        RCG         Athrt        BlokTH      Wbar2T
     17.239     11.622        0.0         0.0         R4S         R4H          B4X         BetB4
    115           0.03        0.95        1.374       Blan4       Blath4       Blok4       SolidStat
      5.9245      5.1525      5.8729      5.1353    6 R1tip       R1hub        R2tip       R2hub
      0.1000      0.100      60           0.0300      1.0         B1axial      B2axial     NBLAD       THK      CFS
      0.0         0.0000      0.000       1.0000      1.0         StatorT      StatorM     StatorH     FSGV     CFMid
      0.9800      0.9500      1.1000      0.9000      1.0         AeroB1       AeroB2      POTS        POTH     CFHub
      0.8850      0.885       0.885       0.0000      EfficiT     EfficiM      EfficiH     BLEED
      0.0000      0.0000      0.0000      0.0000      DUMMY       DUMMY        DUMMY       DUMMY
      0.9200      0.057      1.26         0.00        SlipF       DiffLoss     Solidity    RPM2
     58.1000     58.50       59.3000      0.00        BetaBlade1T BetaBlade1M  BetaBlade1H expo3
     53.00      50.60       46.50        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
      5.8430      5.1473      0.0         43.0        R3s         R3h          B3X         BetB3
    123           0.06        0.95        0.02        Blan3       Blath3       Blok3       Wbar23
      6.0       23.000        0.95        0.03        RCG         Athrt        BlokTH      Wbar2T
      5.7797      5.0958      0.0         0.0         R4S         R4H          B4X         BetB4
    123           0.03        0.95        1.474       Blan4       Blath4       Blok4       SolidStat
      5.8430      5.1473      0.00        2.0         R7S         R7h          B7X         Length67
      4           0.01        0.98        0.000       Blan7       Blath7       Blok7       Wbar67
      5.8430      5.1473      0.0         2.0         R8S         R8h          B8X         Length78
      4           0.01        0.98        0.00        Blan8       Blath8       Blok8       Wbar78
```

7.2.2 Output File

comdes.out

```
*********************************************************************
**************** AXIAL & CENTRIFUGAL COMPRESSOR BLADE DESIGN 1-D ****
*******************   COMDES-MELT Release Version 1    **************
*********************   Gasplus Fluid Properties    *****************
*********************************************************************

    SRW 6 Axial Stage LPC 100% RPM 0 IGV 0 S1 0 S2  1-14-2011

  COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   1
  BLEED =  0.000   DPInc = 5.997   EfDer =  0.999    SH =  0.000000E+00

  W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
   30.0000  24800.0000     14.6999    518.6700      1.1000      0.9000      0.9800

  W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
   13.6364     30.0000      0.0000      0.0000    760.4573      0.0000      0.0000

  W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
   29.9991  24800.7188      1.4015      0.2486     53.3483          21      0.0300    116.0221

  CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
   26855.293   23539.482   1.3013    113.7017     87.3738     64.9162      0.7430    115.6242

  Station   1.  ROTOR LEADING EDGE CONDITIONS, STAGE   1
          R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
  TIP      6.90     0.00    -0.02   623.54    -0.21   623.54      0.58    1.50  1493.30    0.380
  MEAN     5.40     0.00    -0.02   566.86    -0.20   566.86      0.52    1.20
  HUB      3.29     0.00    -0.02   510.17    -0.18   510.17      0.47    0.80

        BetaFlo   BetaBlade Incid   U1       W1         Ps1     Ts1     TwetBulb1  RH
  TIP     67.34    61.30      6.04 1493.30  1618.46    11.73   486.22   495.69     0.00
  MEAN    64.15    58.15      6.00 1169.63  1299.93    12.21   491.86   495.69     0.00
  HUB     54.36    48.40      5.96  711.42   875.58    12.66   496.95   495.69     0.00

  Station   2.  ROTOR EXIT CONDITIONS, STAGE   1    SOLUTION IS CONVERGED
  B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
    0.3000      0.0300      0.9500          21     86.8613     93.1381

          R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
  TIP      6.82   743.29   581.36   463.14  1211.88     0.61     3.43     1.91    93.56
  MEAN     5.64   740.58   515.15   532.05  1175.03     0.63     3.18     2.00    19.49
  HUB      4.13   918.14   699.60   594.60  1149.06     0.80     2.46     2.13     3.90
```

```
       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP   1476.40  1007.77   895.04     0.83  3967.48     0.91     0.91
MEAN  1220.55   883.56   705.40     0.75  2906.35     0.91     0.91     0.91     1.93
HUB    894.27   625.66   194.67     0.54  2891.40     0.91     0.91

        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP     31.32     2.13    24.29   656.65     1.27   610.54   559.02     0.00
MEAN    25.98     1.77    19.88   619.74     1.19   573.98   544.71     0.00   631.87  1.89
HUB     25.91     1.76    17.01   619.22     1.19   548.88   544.50     0.00

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     51.46    62.64    59.20     3.44     0.92     0.48     1.68      0.00007    115
MEAN    44.08    52.97    48.80     4.17     0.92     0.42     1.96      0.00018     60
HUB     49.64    18.13    11.70     6.43     0.92     0.46     2.50      0.00049     55

Station   3. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      0.5317          38     80.4232    631.8702    549.5632      0.0000     87.5402

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
  5.6503    754.5968    514.1817    552.2985   1185.5018      0.6365      0.1605      1.6547

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
 27.6631     21.0563    584.3815      0.0000     42.9531     45.6000     -2.6469

Station   4. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
  5.6503    719.9306    225.3369    683.7568   1189.6989      0.6051      0.1513      1.7949

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500     27.5412     21.5027    588.6710    549.4588     67.4523      0.0266      0.2999

Station   5. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4      cp 3-4   Stator Gap
  5.7330    689.7365      0.0000    689.7365   1193.2628      0.5780      0.1002      0.4137

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500     21.7184    592.2217    549.1984      0.0000      0.0300      0.0677      0.1806

STAGE EXIT CONDITIONS, STAGE             1
Eff4         Pt4         PR          TR        Tt4          Del T      Ns          Ns nondim
  0.8843     27.2394      1.8530      1.2183    631.8702    113.2003    291.3328      2.2584

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 704975.188       0.323    1195.164  1046373.7       0.00000    63.27254    74.09536


COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   2
BLEED =  0.000   DPInc = 6.655   EfDer =  1.000    SH =  0.000000E+00

W act     RPM act        Pt         Tt            POTS        POTH        AeroBl
 30.0000  24800.0000     27.2394    631.8702      1.1000      0.9000      0.9800

W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 13.6364     30.0000      0.0000      0.0000    494.5772      0.0000      0.0000

W cor     RPM cor        GAMMA       Cp         R            Blades       THK         Area1UB
 17.8689  22469.6250      1.4005      0.2490     53.3483          32      0.0300     70.3221

CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
 17465.828   23539.482   1.3421     68.9157     51.3502     39.4607      0.7685     69.9612

Station   6.  ROTOR LEADING EDGE CONDITIONS, STAGE   2

        R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
TIP      6.65     0.00    -0.02   659.94    -0.23   659.94     0.55     1.32  1303.12    0.417
MEAN     5.75     0.00    -0.02   599.95    -0.21   599.95     0.50     1.15
HUB      4.68     0.00    -0.02   539.95    -0.19   539.95     0.45     0.95

      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     65.36    58.70     6.66  1438.31  1582.69    22.15   595.58   549.20     0.00
MEAN    64.25    57.60     6.65  1243.87  1381.18    22.98   601.90   549.20     0.00
HUB     61.94    55.30     6.64  1012.76  1147.87    23.75   607.58   549.20     0.00
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Station   7.  ROTOR EXIT CONDITIONS, STAGE   2    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.2000      0.0300      0.9500          32     58.0639     62.7943

        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP      6.60    781.37   609.02   489.52  1316.09     0.59     1.88     1.15    30.75
MEAN     5.79    762.25   544.50   533.42  1290.75     0.59     1.90     1.20    12.38
HUB      4.86    805.25   570.28   568.52  1273.05     0.63     1.82     1.28     5.15

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP   1427.56   953.75   818.54     0.72  4018.73     0.90     0.90
MEAN  1254.15   887.77   709.65     0.69  3156.57     0.90     0.90     0.90     1.84
HUB   1052.56   745.53   482.29     0.59  2774.41     0.90     0.90

        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP     51.50     1.89    40.57   771.39     1.22   720.52   596.83     0.00
MEAN    45.35     1.66    35.81   741.46     1.17   693.05   587.48     0.00   747.01  1.71
HUB     42.80     1.57    32.69   728.19     1.15   674.17   583.21     0.00

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     51.21    59.12    55.20     3.92     0.92     0.53     1.45      0.00011     90
MEAN    45.59    53.07    48.80     4.27     0.92     0.47     1.68      0.00016     53
HUB     45.09    40.31    35.00     5.31     0.92     0.48     1.98      0.00021     39

Station   8. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      0.3201          66     53.4854    747.0098    589.2399      0.0000     59.5700

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
  5.8005    793.1229    543.9836    577.1705   1291.8364      0.6139      0.0200      0.8590

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
 46.4455     36.0161    694.6949      0.0000     43.3045     47.3000     -3.9955

Station   9. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
  5.8005    837.9829    271.7140    792.7086   1286.0309      0.6516     -0.1539      0.9378

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500     46.2655     34.7881    688.6486    589.1183    42.0700      0.0277      0.3394

Station  10. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4      cp 3-4   Stator Gap
  5.8102    705.9301      0.0000    705.9301   1301.8038      0.5423      0.1115      0.2148

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500     37.1787    705.5840    588.5323      0.0000      0.0300      0.1119      0.0807

STAGE EXIT CONDITIONS, STAGE            2
Eff4         Pt4         PR          TR         Tt4          Del T      Ns          Ns nondim
  0.8610     45.4068      1.6670      1.1822     747.0098    115.1396    229.8738      1.7820

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 719174.500       0.353    1219.236   791600.3       0.00000    43.02640    54.68928

COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   3
BLEED =  0.000   DPInc = 6.597   EfDer =  1.000    SH =  0.000000E+00

W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
 30.0000  24800.0000     45.4068    747.0098      1.1000      0.9000      0.9800

W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 13.6364     30.0000      0.0000      0.0000    337.8088      0.0000      0.0000

W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
 10.5598  22809.4609      1.3986      0.2500     53.3483          36      0.0300     53.0122

CFM          SCFM        A1/A*      Area1       A*          AthrRotor  ChokeMargin  AnnularArea
 11929.604   23539.482   1.5503     51.9519     33.5114     27.5109      0.8209     52.7336
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Station  11.  ROTOR LEADING EDGE CONDITIONS, STAGE   3

        R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
TIP      6.49     0.00    -0.02   598.22    -0.21   598.22     0.46     1.16  1291.36    0.387
MEAN     5.81     0.00    -0.02   543.84    -0.19   543.84     0.41     1.04
HUB      5.03     0.00    -0.02   489.45    -0.17   489.45     0.37     0.90

      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     66.93    60.30     6.63  1404.10  1526.41    39.38   717.30   588.53     0.00
MEAN    66.60    60.00     6.60  1256.34  1369.16    40.38   722.41   588.53     0.00
HUB     65.80    59.20     6.60  1088.71  1193.82    41.30   727.11   588.53     0.00

Station  12.  ROTOR EXIT CONDITIONS, STAGE   3    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.1500      0.0300      0.9500          36     45.1580     48.9959

        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP      6.44   737.47   564.52   474.53  1409.47     0.52     1.55     0.91    23.38
MEAN     5.80   716.20   511.76   501.04  1391.99     0.51     1.62     0.95    11.73
HUB      5.09   734.40   517.75   520.85  1380.09     0.53     1.63     1.02     6.00

         U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP   1392.88   954.65   828.36     0.68  3634.61     0.90     0.90
MEAN  1255.84   897.05   744.08     0.64  2970.71     0.90     0.90     0.90     1.74
HUB   1101.89   782.62   584.14     0.57  2636.90     0.90     0.90

        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP     74.47     1.64    61.81   872.72     1.17   827.57   625.23     0.00
MEAN    68.38     1.51    57.10   849.76     1.14   807.18   618.85     0.00   853.56  1.53
HUB     65.46     1.44    53.99   838.21     1.12   793.44   615.60     0.00

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     49.95    60.19    56.50     3.69     0.92     0.51     1.38      0.00017     67
MEAN    45.61    56.04    52.10     3.94     0.92     0.46     1.60      0.00011     44
HUB     44.83    48.28    43.60     4.68     0.92     0.46     1.85      0.00039     32

Station  13. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      0.2538          79     41.5429    853.5625    619.8912      0.0000     46.7950

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
  5.7940    748.9904    512.5384    546.1603   1391.1523      0.5384     -0.0137      0.6502

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
 69.3203     56.9333    807.1265      0.0000     43.1810     48.5000     -5.3190

Station  14. STATOR / VANED DIFFUSER
RCG         Cth          Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
  5.7940    842.0095    279.6828    794.2024   1380.4034      0.6100     -0.3247      0.7131

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500     69.1240     53.7976    794.9160    619.7861     31.3433      0.0266      1.0635

Station  15. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4      cp 3-4   Stator Gap
 17.1214     43.2751      0.0000     43.2751   1430.4662      0.0303      0.8908      0.1626

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500     67.9682    853.4075    619.1855      0.0000      0.0300      0.1208      0.8755

STAGE EXIT CONDITIONS, STAGE            3
Eff4         Pt4         PR          TR        Tt4          Del T      Ns          Ns nondim
  0.8500     68.0117      1.4978      1.1426    853.5625    106.5527    200.6499      1.5554

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 668847.812       0.345    1133.916   933604.1       0.00000   464.35901   525.55774


COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   4
BLEED =  0.000   DPInc = 6.565   EfDer =  1.000    SH =  0.000000E+00

W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
 30.0000  24800.0000     68.0117    853.5625      1.1000      0.9000      0.9800
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W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 13.6364     30.0000      0.0000      0.0000    253.3617      0.0000      0.0000

W cor     RPM cor        GAMMA       Cp         R           Blades       THK         Area1UB
  6.9310  23201.1641      1.3958      0.2513     53.3483          44      0.0300     41.5615

CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
  8947.385   23539.482   1.7045     40.7302     23.8958     20.7314      0.8676     41.4052

Station  16.  ROTOR LEADING EDGE CONDITIONS, STAGE   4

        R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
TIP      6.31     0.00    -0.02   571.76    -0.20   571.76     0.41     1.05  1276.59    0.381
MEAN     5.76     0.00    -0.02   519.79    -0.18   519.79     0.37     0.96
HUB      5.16     0.00    -0.02   467.81    -0.16   467.81     0.33     0.86

      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     67.27    60.70      6.57  1364.60  1479.72    60.72   826.55   619.19     0.00
MEAN    67.37    60.80      6.57  1246.38  1350.59    61.94   831.13   619.19     0.00
HUB     67.26    60.70      6.56  1115.71  1209.97    63.07   835.48   619.19     0.00

Station  17.  ROTOR EXIT CONDITIONS, STAGE   4    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.1000      0.0300      0.9500          44     35.4486     38.7395

        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP      6.25   701.88   505.49   486.94  1485.87     0.47     1.16     0.68    16.21
MEAN     5.74   686.16   464.82   504.74  1473.62     0.47     1.23     0.71     9.42
HUB      5.17   706.35   483.23   515.19  1467.06     0.48     1.27     0.75     5.23

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP   1352.15   976.70   846.66     0.66  3159.46     0.89     0.89
MEAN  1241.28   926.09   776.46     0.63  2667.01     0.89     0.89      0.89     1.63
HUB   1119.48   818.68   636.25     0.56  2500.41     0.89     0.89

        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP     99.51     1.46    85.45   962.26     1.13   921.57   648.10     0.00
MEAN    94.03     1.38    81.08   945.32     1.11   906.43   643.73     0.00   949.05  1.40
HUB     92.22     1.36    78.73   939.58     1.10   898.38   642.24     0.00

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     46.07   60.10     56.60      3.50     0.92     0.47      1.30     0.00003     50
MEAN    42.64   56.97     53.30      3.67     0.92     0.43      1.50     0.00013     36
HUB     43.17   51.00     46.70      4.30     0.92     0.44      1.73     0.00033     28

Station  18. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3      Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      0.1886          96     32.2979    949.0532    644.6548      0.0000     36.9740

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
  5.7178    726.2781    466.2602    556.8494   1471.8896      0.4934     -0.0361      0.5041

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
 95.1180     80.5915    905.6486      0.0000     39.9401     48.7000     -8.7599

Station  19. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
  5.7178    915.2496    305.2154    862.8588   1450.8912      0.6308     -0.6777      0.5533

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500     94.8139     72.6016    880.1555    644.5212    23.6696      0.0325      1.0684

Station  20. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4       cp 3-4   Stator Gap
 16.0960     36.5041      0.0000     36.5041   1507.0150      0.0242      0.8390      0.1260

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500     92.7786    948.9434    643.6342      0.0000      0.0300      0.1805      0.8167

STAGE EXIT CONDITIONS, STAGE             4
Eff4        Pt4          PR          TR         Tt4          Del T      Ns          Ns nondim
  0.8177     92.8166      1.3647      1.1119    949.0532     95.4907    187.6902      1.4550
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Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 603167.625       0.330    1022.566  1118423.0       0.00000   448.42819   519.08722

COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   5
BLEED =  0.000   DPInc = 6.005   EfDer =  0.999    SH =  0.000000E+00

W act     RPM act        Pt         Tt            POTS        POTH        AeroBl
 30.0000  24800.0000     92.8166    949.0532      1.1000      0.9000      0.9800

W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 13.6364     30.0000      0.0000      0.0000    205.1698      0.0000      0.0000

W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
  5.0099  23519.9648      1.3925      0.2529     53.3483          51      0.0300     33.4130

CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
  7245.503   23539.482   1.7764     32.7447     18.4332     16.3940      0.8894     33.2244

Station  21.  ROTOR LEADING EDGE CONDITIONS, STAGE   5
        R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
TIP      6.11     0.00    -0.02   574.91    -0.20   574.91     0.39     0.97  1254.31    0.395
MEAN     5.66     0.00    -0.02   522.64    -0.18   522.64     0.35     0.89
HUB      5.17     0.00    -0.02   470.38    -0.16   470.38     0.32     0.81

      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     66.51    60.40     6.11  1322.61  1442.34    83.74   921.91   643.63     0.00
MEAN    66.90    60.90     6.00  1225.41  1332.38    85.27   926.42   643.63     0.00
HUB     67.22    61.20     6.02  1119.80  1214.74    86.67   930.87   643.63     0.00

Station  22.  ROTOR EXIT CONDITIONS, STAGE   5    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.1000      0.0300      0.9500          51     28.5458     31.4115

        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP      6.05   688.17   458.18   513.46  1549.90     0.44     0.95     0.57    11.08
MEAN     5.63   685.92   442.37   524.21  1542.59     0.44     1.01     0.59     6.77
HUB      5.17   697.11   449.86   532.53  1537.22     0.45     1.08     0.63     4.48

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP   1310.08   994.67   851.90     0.64  2774.78     0.89     0.89
MEAN  1218.05   936.20   775.68     0.61  2490.72     0.89     0.89     0.89     1.55
HUB   1118.46   854.76   668.60     0.56  2325.73     0.89     0.89

        Pt2       PR      Ps2     Tt2        TR     Ts2      TwetBulb2   RH     Tt2avg  PR2avg
TIP    125.56     1.35   109.74  1043.92     1.10  1005.04   667.33     0.00
MEAN   121.88     1.31   106.48  1034.21     1.09   995.58   664.95     0.00  1035.57  1.32
HUB    119.77     1.29   104.09  1028.57     1.08   988.67   663.57     0.00

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     41.74    58.92    55.50     3.42     0.92     0.43     1.27      0.00009     37
MEAN    40.16    55.95    52.30     3.65     0.92     0.41     1.45      0.00037     31
HUB     40.19    51.46    47.40     4.06     0.92     0.41     1.69      0.00012     24

Station  23. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      0.1571         115     22.9383   1035.5664    665.1730      0.0000     30.0458

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
  5.6086    810.7252    443.9102    678.3943   1530.6191      0.5297     -0.3519      0.4175

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
122.0923    100.9795    981.8271      0.0000     33.1989     45.0000    -11.8011

Station  24. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth        Aoth           Machth     cp 2-Th   Stat Chord
  6.0000    737.6679    227.9519    701.5639   1537.9580      0.4796     -0.2110      0.4519

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500    120.9950    103.4712    991.0514    664.7609    23.0000      0.0902      1.0631

Station  25. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4      cp 3-4   Stator Gap
 14.7013    32.4792      0.0000     32.4792   1571.8368      0.0207      0.8904      0.1044
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Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500    119.7785   1035.4801    664.3136      0.0000      0.0300      0.1657      0.8320

STAGE EXIT CONDITIONS, STAGE             5
Eff4         Pt4         PR           TR        Tt4          Del T      Ns          Ns nondim
  0.8118    119.8140      1.2909      1.0912   1035.5664     86.5132    180.8001      1.4016

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 550172.500       0.321     932.722  1310604.4       0.00000   425.99030   509.29071

COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   6
BLEED =  0.000   DPInc = 7.171   EfDer =  1.000    SH =  0.000000E+00

W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
 30.0000  24800.0000    119.8140   1035.5664      1.1000      0.9000      0.9800

W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 13.6364     30.0000      0.0000      0.0000    173.3370      0.0000      0.0000

W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
  3.8447  23742.1777      1.3890      0.2546     53.3483          60      0.0300     27.0896

CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
  6121.339   23539.482   1.7836     26.5478     14.8841     14.1345      0.9496     26.8652

Station  26.  ROTOR LEADING EDGE CONDITIONS, STAGE   6

        R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
TIP      5.92     0.00    -0.02   597.67    -0.21   597.67     0.39     0.91  1227.46    0.424
MEAN     5.55     0.00    -0.02   543.34    -0.19   543.34     0.35     0.85
HUB      5.15     0.00    -0.02   489.01    -0.17   489.01     0.31     0.78

      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     65.01    58.10     6.91  1282.19  1414.83   108.20  1006.41   664.31     0.00
MEAN    65.67    58.50     7.17  1201.55  1318.86   110.16  1011.17   664.31     0.00
HUB     66.32    59.30     7.02  1115.11  1217.77   111.95  1016.04   664.31     0.00

Station  27.  ROTOR EXIT CONDITIONS, STAGE   6    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.1000      0.0300      0.9500          60     23.1821     25.7420

        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP      5.87   704.05   440.39   549.31  1606.87     0.44     0.77     0.49     8.71
MEAN     5.52   697.92   417.52   559.26  1600.24     0.44     0.84     0.51     6.10
HUB      5.14   708.30   426.86   565.23  1596.53     0.44     0.91     0.55     4.07

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP   1271.02   995.83   830.63     0.62  2587.58     0.88     0.88
MEAN  1193.87   956.82   776.35     0.60  2304.25     0.88     0.88     0.88     1.49
HUB   1111.39   887.73   684.53     0.56  2192.92     0.88     0.88

        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP    155.15     1.29   136.11  1123.44     1.08  1083.00    685.28     0.00
MEAN   150.96     1.26   132.59  1113.82     1.08  1074.08    683.02     0.00  1115.76  1.27
HUB    149.33     1.25   130.58  1110.03     1.07  1069.10    682.12     0.00

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     38.72    56.52    53.00     3.52     0.92     0.42     1.26      0.00037     36
MEAN    36.74    54.23    50.60     3.63     0.92     0.38     1.44      0.00037     31
HUB     37.06    50.45    46.50     3.95     0.92     0.37     1.68      0.00040     24

Station  28. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      0.1370         123     17.9419   1115.7618    683.3568      0.0000     24.0205

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
  5.5061    867.8878    418.2986    760.4312   1584.2594      0.5478     -0.4746      0.4093

Pt3         Ps3         Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
151.4371    123.7077   1054.5884      0.0000     28.8143     43.0000    -14.1857
```

```
Station  29. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
  6.0000    614.0399    181.5765    586.5790   1607.4213      0.3820      0.1284      0.4400

BlockageTh   PtTh        PsTh       TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500    149.7212    135.4982   1085.1000    682.7960     23.0000      0.1117      0.0232

Station  30. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4       cp 3-4   Stator Gap
  5.4485    990.4385      0.0000    990.4385   1569.9607      0.6309     -0.3441      0.1023

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500    114.1660   1036.2054    682.5295      0.0000      0.0300      0.1549     -1.0114

STAGE EXIT CONDITIONS, STAGE            6
Eff4         Pt4         PR          TR         Tt4          Del T      Ns          Ns nondim
  0.8094    148.9117      1.2429      1.0774   1115.7618     80.1954    174.7721      1.3548

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 513613.938       0.318     870.744  1496132.5       0.00000    14.66639    23.36639


OVERALL EXIT CONDITIONS; ALL           6   STAGES

Del Enthal    DelHT/U1^2  GHP      MassFloS1cor  OPR     Efficiency    Rotor1Inc  TR      AxHubLen
 3759951.50     1.6861  6374.3481   29.999     10.1300   0.80239       5.9967    2.1512   13.560
```

7.3 Example Case (3): Large Civil Transport Rotor Engine

The input and output files in this section are those used for the analysis of option 1 for the HPC consisting of four-stage axial compressor for this example case.

7.3.1 High-Pressure Compressor: Option 1 Four Axial Stages

Figure 23 illustrates the four-stage HPC configuration for the Large Civil Transport Rotor Engine.

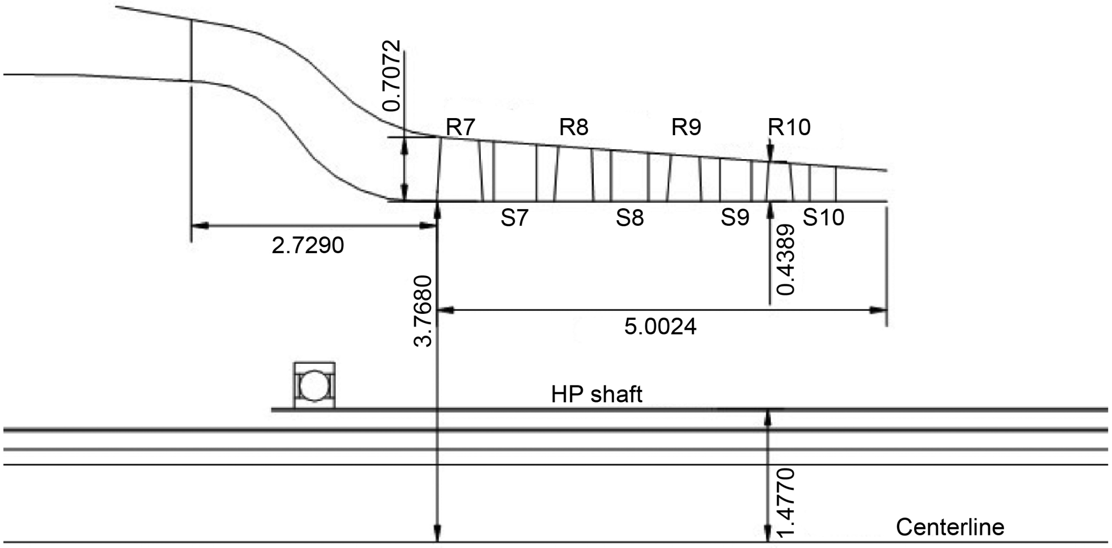

Figure 23.—Flow path for the four-stage axial high-pressure (HP) compressor of the Large Civil Transport Rotor Engine, option 1 (Ref. 12).

7.3.1.1 Input File

comdes.dat

```
      Four Axials  HPC 100%  SRW 1-21-2011
     30.0       159.25     1119.39      32650.0       Wact        Pt1          Tt1         RPM
      5           4           0           0.00        Fluid       Stages       IDUMMY      DUMMY
      0.00       46.900     000.00        0.00        DropDia     InDist       RHinlet     IWC        ***icing***
      2.70        0.00      406.44        0.00        Psin        DUMMY        Tsin        DUMMY       ***icing***
    607.8         0.00    00000.00        0           Vin         DUMMY        Altitude    IDUMMY      ***icing***
      4.4752      3.768       4.4442      3.7680    1 R1tip       R1hub        R2tip       R2hub
      0.1000      0.100       59          0.0300      1.0         B1axial      B2axial     NBLAD       THK      CFS
      0.0         0.0000      0.000       1.0000      1.0         StatorT      StatorM     StatorH     FSGV     CFMid
      0.9800      0.9500      1.1000      0.9000      1.0         AeroB1       AeroB2      POTS        POTH     CFHub
      0.920       0.920       0.920       0.0000      EfficiT     EfficiM      EfficiH     BLEED
      0.00        0.00        0.00        0.00        DUMMY       DUMMY        DUMMY       DUMMY
      0.9270      0.0629      1.50        0.00        SlipF       DiffLoss     Solidity    RPM2
     53.2000     54.10       54.5000      0.00        BetaBlade1T BetaBlade1M  BetaBlade1H expo3
     40.30       35.60       27.30        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
      4.4387      3.768       0.0         35.5        R3s         R3h          B3X         BetB3
     74           0.03        0.95        0.01        Blan3       Blath3       Blok3       Wbar23
     00.0         0.000       0.95        0.015       RCG         Athrt        BlokTH      Wbar2T
      4.4102      3.768       0.0         0.0         R4S         R4H          B4X         BetB4
     74           0.03        0.95        1.30        Blan4       Blath4       Blok4       SolidStat
      4.3791      3.768       4.3519      3.7680    2 R1tip       R1hub        R2tip       R2hub
      0.1000      0.100       60          0.0300      0.9         B1axial      B2axial     NBLAD       THK      CFS
      0.0         0.0000      0.000       1.0000      0.9         StatorT      StatorM     StatorH     FSGV     CFMid
      0.9800      0.9500      1.1000      0.9000      0.9         AeroB1       AeroB2      POTS        POTH     CFHub
      0.915       0.915       0.915       0.0000      EfficiT     EfficiM      EfficiH     BLEED
      0.00        0.00        0.00        0.00        DUMMY       DUMMY        DUMMY       DUMMY
      0.9270      0.0663      1.450       0.00        SlipF       DiffLoss     Solidity    RPM2
     54.7000     55.60       56.1000      0.00        BetaBlade1T BetaBlade1M  BetaBlade1H expo3
     41.20       37.00       30.70        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
      4.4354      3.768       0.0         38.5        R3s         R3h          B3X         BetB3
     81           0.03        0.95        0.01        Blan3       Blath3       Blok3       Wbar23
     00.0         0.000       0.95        0.015       RCG         Athrt        BlokTH      Wbar2T
      4.3189      3.768       0.0         0.0         R4S         R4H          B4X         BetB4
     81           0.03        0.95        1.30        Blan4       Blath4       Blok4       SolidStat
      4.2868      3.768       4.2636      3.7680    3 R1tip       R1hub        R2tip       R2hub
      0.1000      0.100       68          0.0300      0.9         B1axial      B2axial     NBLAD       THK      CFS
      0.0         0.0000      0.000       1.0000      0.9         StatorT      StatorM     StatorH     FSGV     CFMid
      0.9800      0.9500      1.1000      0.9000      0.9         AeroB1       AeroB2      POTS        POTH     CFHub
      0.915       0.915       0.915       0.0000      EfficiT     EfficiM      EfficiH     BLEED
      0.00        0.00        0.00        0.00        DUMMY       DUMMY        DUMMY       DUMMY
      0.9270      0.0712      1.450       0.00        SlipF       DiffLoss     Solidity    RPM2
     54.9000     55.80       56.4000      0.00        BetaBlade1T BetaBlade1M  BetaBlade1H expo3
     40.20       36.50       30.70        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
      4.2677      3.768       0.0         30.5        R3s         R3h          B3X         BetB3
     94           0.03        0.95        0.01        Blan3       Blath3       Blok3       Wbar23
     00.0         0.000       0.95        0.015       RCG         Athrt        BlokTH      Wbar2T
      4.2396      3.768       0.0         0.0         R4S         R4H          B4X         BetB4
     94           0.03        0.95        1.30        Blan4       Blath4       Blok4       SolidStat
      4.2069      3.768       4.1896      3.7680    4 R1tip       R1hub        R2tip       R2hub
      0.1000      0.100       80          0.0300      0.9         B1axial      B2axial     NBLAD       THK      CFS
      0.0         0.0000      0.000       1.0000      0.9         StatorT      StatorM     StatorH     FSGV     CFMid
      0.9800      0.9500      1.1000      0.9000      0.9         AeroB1       AeroB2      POTS        POTH     CFHub
      0.915       0.915       0.915       0.0000      EfficiT     EfficiM      EfficiH     BLEED
      0.00        0.00        0.00        0.00        DUMMY       DUMMY        DUMMY       DUMMY
      0.9270      0.0753      1.450       0.00        SlipF       DiffLoss     Solidity    RPM2
     54.7000     55.60       56.5000      0.00        BetaBlade1T BetaBlade1M  BetaBlade1H expo3
     38.70       35.00       29.90        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
      4.2022      3.768       0.0         30.0        R3s         R3h          B3X         BetB3
    104           0.03        0.95        0.01        Blan3       Blath3       Blok3       Wbar23
     00.0         0.000       0.95        0.015       RCG         Athrt        BlokTH      Wbar2T
      4.1978      3.768       0.0         0.0         R4S         R4H          B4X         BetB4
    104           0.03        0.95        1.30        Blan4       Blath4       Blok4       SolidStat
      4.1978      3.768       0.00        2.0         R7S         R7h          B7X         Length67
      4           0.01        0.98        0.000       Blan7       Blath7       Blok7       Wbar67
      4.1978      3.768       0.0         2.0         R8S         R8h          B8X         Length78
      4           0.01        0.98        0.00        Blan8       Blath8       Blok8       Wbar78
```

7.3.1.2 Output File

comdes.out

```
*********************************************************************
**************** AXIAL & CENTRIFUGAL COMPRESSOR BLADE DESIGN 1-D ****
*******************   COMDES-MELT Release Version 1    **************
*********************   Gasplus Fluid Properties   ******************
*********************************************************************

        Four Axials  HPC 100%  SRW 1-21-2011

  COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   1
  BLEED =  0.000   DPInc = 6.015   EfDer =  0.999    SH =  0.000000E+00

  W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
   30.0000  32650.0000    159.2484   1119.3900      1.1000      0.9000      0.9800

  W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
   13.6364     30.0000      0.0000      0.0000    144.8933      0.0000      0.0000

  W cor     RPM cor        GAMMA       Cp         R           Blades       THK         Area1UB
    4.0681  22225.4531      1.3855      0.2563     53.3483          59      0.0300     18.4964

  CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
    5116.858   23539.482   1.5240     18.1265     11.8942     10.6401      0.8946     18.3142

  Station   1.  ROTOR LEADING EDGE CONDITIONS, STAGE   1

          R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
  TIP      4.48      0.00     -0.02   745.24    -0.26   745.24      0.47     0.92   867.96    0.531
  MEAN     4.14      0.00     -0.02   677.49    -0.23   677.49      0.42     0.85
  HUB      3.77      0.00     -0.02   609.74    -0.21   609.74      0.38     0.77

        BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
  TIP     59.70    53.20     6.50  1275.10  1477.13   137.41  1074.34   686.19     0.00
  MEAN    60.11    54.10     6.01  1178.66  1359.70   141.03  1082.16   686.19     0.00
  HUB     60.41    54.50     5.91  1073.60  1234.85   144.37  1089.21   686.19     0.00

  Station   2.  ROTOR EXIT CONDITIONS, STAGE   1    SOLUTION IS CONVERGED
  B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
    0.1000      0.0300      0.9500          59     15.6041     17.6353

          R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
  TIP      4.44   900.42   620.38   652.60  1672.45     0.54     0.71     0.55     3.16
  MEAN     4.12   904.53   610.11   667.78  1664.31     0.54     0.76     0.57     2.37
  HUB      3.77   936.84   644.11   680.30  1658.10     0.57     0.80     0.61     1.71

         U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
  TIP   1266.26   918.18   645.88     0.55  2758.24     0.92     0.92
  MEAN  1173.89   873.94   563.78     0.53  2514.63     0.92     0.92     0.92     1.71
  HUB   1073.60   804.53   429.49     0.49  2427.79     0.92     0.92

          Pt2       PR      Ps2     Tt2         TR     Ts2      TwetBulb2   RH      Tt2avg  PR2avg
  TIP    224.74     1.41   184.85  1241.86     1.11  1176.15   715.31     0.00
  MEAN   218.28     1.37   178.89  1231.05     1.10  1164.73   712.77     0.00  1233.37  1.38
  HUB    216.02     1.36   174.29  1227.19     1.10  1156.05   711.87     0.00

          Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
  TIP     43.55    44.70    40.30     4.40     0.93     0.52     1.50      0.00006     33
  MEAN    42.42    40.17    35.60     4.57     0.93     0.49     1.73      0.00010     27
  HUB     43.43    32.27    27.30     4.97     0.93     0.48     2.00      0.00058     22

  Station   3. STATOR ROW #1
  blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract    Area3UB
    0.9500      0.1520          74     15.0130   1233.3678    713.2232      0.0000     17.2921

  ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
  R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
    4.1170    926.9187    610.5531    697.4261   1661.8674      0.5578     -0.0234      0.4666

  Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
  219.2762    177.9482   1164.1696      0.0000     41.2001     35.5000      5.7001
```

```
Station   4. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
  4.1170    794.0248    194.7802    769.7637   1674.7329      0.4741      0.2073      0.4899

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500    218.5336    187.7069   1182.6305    713.0366     13.7889      0.0284      0.2495

Station   5. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4       cp 3-4   Stator Gap
  4.1017    931.2610      0.0000    931.2610   1660.6831      0.5608     -0.0682      0.1167

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500    175.1279   1163.7079    712.4553      0.0000      0.0300      0.0854     -0.1045

STAGE EXIT CONDITIONS, STAGE             1
Eff4         Pt4         PR          TR        Tt4          Del T      Ns          Ns nondim
  0.8661    216.2335      1.3578      1.1018   1233.3678    113.9778    162.0266      1.2560

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 736437.125       0.459    1248.502   710722.0       0.00000    11.41982    16.49978


COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   2
BLEED =  0.000   DPInc = 6.323   EfDer =  1.000    SH =  0.000000E+00

W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
 30.0000  32650.0000    216.2335  1233.3678      1.1000      0.9000      0.9800

W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 13.6364     30.0000      0.0000      0.0000    115.1641      0.0000      0.0000

W cor     RPM cor        GAMMA       Cp         R           Blades       THK         Area1UB
  3.1449  21173.6152      1.3793      0.2596     53.3483          60      0.0300     15.8491

CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
  4066.981   23539.482   1.7058     15.5321     9.1055      8.7135      0.9569     15.6410

Station   6.  ROTOR LEADING EDGE CONDITIONS, STAGE   2

        R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
TIP      4.38     0.00    -0.02   683.09    -0.24   683.09     0.41     0.85   809.12    0.498
MEAN     4.08     0.00    -0.02   621.00    -0.21   621.00     0.37     0.78
HUB      3.77     0.00    -0.02   558.90    -0.19   558.90     0.33     0.72

      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     61.30    54.70     6.60  1247.71  1422.67   193.34  1195.96   712.46     0.00
MEAN    61.92    55.60     6.32  1163.92  1319.41   197.18  1202.56   712.46     0.00
HUB     62.50    56.10     6.40  1073.60  1210.53   200.70  1208.31   712.46     0.00

Station   7.  ROTOR EXIT CONDITIONS, STAGE   2    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.1000      0.0300      0.9500          60     13.3432     15.1118

        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP      4.35   868.23   600.43   627.14  1745.98     0.50     0.66     0.50     2.81
MEAN     4.07   871.87   594.61   637.65  1739.89     0.50     0.71     0.52     2.20
HUB      3.77   890.03   610.93   647.24  1734.60     0.51     0.76     0.55     1.73

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP   1239.97   895.72   639.54     0.51  2614.04     0.92     0.91
MEAN  1159.77   852.06   565.16     0.49  2421.19     0.92     0.91     0.91     1.68
HUB   1073.60   795.60   462.67     0.46  2302.70     0.92     0.91

        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP    290.93     1.35   246.26  1348.00     1.09  1287.62   738.93     0.00
MEAN   284.86     1.32   240.52  1339.55     1.09  1278.65   737.00     0.00  1340.63  1.32
HUB    281.17     1.30   235.52  1334.35     1.08  1270.89   735.81     0.00

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     43.75    45.56    41.20      4.36    0.93     0.52     1.45      0.00014     46
MEAN    43.00    41.55    37.00      4.55    0.93     0.49     1.66      0.00031     36
HUB     43.35    35.56    30.70      4.86    0.93     0.47     1.93      0.00029     35
```

```
Station   8. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      0.1383          81     14.7994   1340.6338    737.1583      0.0000     17.2001

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
  4.1153    816.2090    588.1330    565.9478   1743.7570      0.4681      0.1230      0.4223

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
285.2036    246.0433   1287.6243      0.0000     46.1013     38.5000      7.6013

Station   9. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
  4.1153    691.8416    183.7228    667.0013   1753.2676      0.3946      0.3376      0.4473

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500    284.3996    255.9223   1302.6188    736.9893     12.8558      0.0279      0.1153

Station  10. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4      cp 3-4   Stator Gap
  4.0528    951.3206      0.0000    951.3206   1729.8645      0.5499     -0.4221      0.1056

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500    229.5142   1268.8771    736.2527      0.0000      0.0300      0.1054     -0.2507

STAGE EXIT CONDITIONS, STAGE             2
Eff4         Pt4         PR          TR        Tt4          Del T      Ns          Ns nondim
  0.8523    280.9202      1.2992      1.0870   1340.6338    107.2660    148.8458      1.1538

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 702000.625       0.457    1190.121   648676.6       0.00000     9.30090    13.99603

COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   3
BLEED =  0.000   DPInc = 6.220   EfDer =  1.000    SH =  0.000000E+00

W act     RPM act        Pt         Tt            POTS        POTH        AeroBl
 30.0000  32650.0000    280.9202   1340.6338      1.1000      0.9000      0.9800

W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 13.6364     30.0000      0.0000      0.0000     95.6428      0.0000      0.0000

W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
  2.4043  21317.7715      1.3732      0.2628     53.3483          68      0.0300     13.3698

CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
  3377.593   23539.482   1.7953     13.1024      7.2984      7.1706      0.9825     13.1282

Station  11.  ROTOR LEADING EDGE CONDITIONS, STAGE   3
        R1      Stator    Alfa     C1      CU1       Cm1       Mabs      Mrel   U1cor   FlowCoeff
TIP      4.29     0.00    -0.02   672.11    -0.23   672.11     0.38     0.79   797.46    0.500
MEAN     4.04     0.00    -0.02   611.01    -0.21   611.01     0.35     0.74
HUB      3.77     0.00    -0.02   549.91    -0.19   549.91     0.31     0.68

      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     61.18     54.90     6.28  1221.42  1394.33   254.32  1304.85   736.25     0.00
MEAN    62.02     55.80     6.22  1149.88  1302.33   258.79  1310.79   736.25     0.00
HUB     62.88     56.40     6.48  1073.60  1206.41   262.90  1316.66   736.25     0.00

Station  12.  ROTOR EXIT CONDITIONS, STAGE   3    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.1000      0.0300      0.9500          68     11.1393     12.7570

        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP      4.26    866.89   587.27   637.66  1809.77     0.48     0.57     0.43     2.23
MEAN     4.02    871.21   584.95   645.64  1805.13     0.48     0.62     0.45     1.84
HUB      3.77    891.67   607.91   652.31  1801.48     0.49     0.66     0.48     1.49

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP   1214.81    894.65   627.53     0.49  2504.90     0.92     0.91
MEAN  1146.38    855.60   561.43     0.47  2354.35     0.92     0.91     0.91     1.64
HUB   1073.60    801.48   465.68     0.44  2291.33     0.92     0.91
```

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        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP    365.33     1.30   313.11  1449.11     1.08  1389.62   760.89     0.00
MEAN   359.79     1.28   307.65  1442.59     1.08  1382.51   759.42     0.00  1443.86  1.28
HUB    357.49     1.27   303.28  1439.87     1.07  1376.92   758.80     0.00

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     42.64    44.54    40.20     4.34     0.93     0.50     1.45      0.00065     39
MEAN    42.18    41.01    36.50     4.51     0.93     0.48     1.66      0.00000     36
HUB     42.98    35.52    30.70     4.82     0.93     0.47     1.91      0.00022     34

Station  13. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      0.1205          94     10.6454   1443.8579    759.6096      0.0000     12.6149

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
  4.0256    896.7473    584.6310    679.9722   1801.5952      0.4978     -0.0453      0.3578

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
360.3426    305.2574   1380.6364     0.0000     40.6885     30.5000     10.1885

Station  14. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
  4.0256    750.0560    158.5054    733.1166   1813.8141      0.4135      0.2236      0.3708

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500    358.9107    319.8323   1399.6471    759.3522    10.0564      0.0371      0.0652

Station  15. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4      cp 3-4   Stator Gap
  4.0107   1063.8884      0.0000   1063.8884   1783.9906      0.5964     -0.4732      0.0894

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500    279.1935   1355.1078    758.3528      0.0000      0.0300      0.1415     -0.5452

STAGE EXIT CONDITIONS, STAGE             3
Eff4         Pt4         PR          TR        Tt4          Del T      Ns          Ns nondim
  0.8322    353.3931      1.2580      1.0770   1443.8579    103.2241    138.2431      1.0717

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 684200.125       0.464    1159.943   718215.8       0.00000     7.30153    11.86386


COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   4
BLEED =  0.000   DPInc = 5.909   EfDer =  0.999    SH =  0.000000E+00

W act     RPM act        Pt         Tt            POTS        POTH        AeroBl
 30.0000  32650.0000    353.3931   1443.8579      1.1000      0.9000      0.9800

W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 13.6364     30.0000      0.0000      0.0000     81.6310      0.0000      0.0000

W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
  1.9025  21416.2500      1.3672      0.2662     53.3483          80      0.0300     11.2780

CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
  2882.772   23539.482   1.8383     11.0524      6.0123      5.9132      0.9835     10.9962

Station  16.  ROTOR LEADING EDGE CONDITIONS, STAGE   4
        R1      Stator    Alfa     C1       CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
TIP      4.21     0.00    -0.02   679.44    -0.23   679.44     0.37     0.76   786.21    0.515
MEAN     3.99     0.00    -0.02   617.67    -0.21   617.67     0.34     0.71
HUB      3.77     0.00    -0.02   555.90    -0.19   555.90     0.30     0.66

      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1      TwetBulb1  RH
TIP     60.46    54.70     5.76  1198.65  1378.03   321.58  1407.72   758.35     0.00
MEAN    61.51    55.60     5.91  1137.84  1294.87   326.94  1413.35   758.35     0.00
HUB     62.63    56.50     6.13  1073.60  1209.15   331.86  1419.65   758.35     0.00

Station  17.  ROTOR EXIT CONDITIONS, STAGE   4    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.1000      0.0300      0.9500          80      9.3027     10.8322
```

```
        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP      4.19   877.91   575.34   663.11  1867.81     0.47     0.48     0.37     1.71
MEAN     3.98   887.92   584.18   668.67  1864.71     0.48     0.52     0.38     1.45
HUB      3.77   907.43   607.75   673.84  1861.97     0.49     0.56     0.41     1.22

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP   1193.72   906.70   618.38     0.49  2411.44     0.92     0.91
MEAN  1135.25   866.49   551.07     0.46  2328.46     0.92     0.91     0.91     1.59
HUB   1073.60   819.19   465.85     0.44  2290.72     0.92     0.91

        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP    447.26     1.27    385.72  1546.99     1.07  1486.69   781.49     0.00
MEAN   443.76     1.26    381.24  1543.44     1.07  1481.76   780.70     0.00  1544.08  1.26
HUB    442.17     1.25    377.20  1541.83     1.07  1477.41   780.34     0.00

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     40.95    43.00    38.70     4.30     0.93     0.49     1.45      0.00063     35
MEAN    41.14    39.49    35.00     4.49     0.93     0.47     1.65      0.00099     36
HUB     42.05    34.66    29.90     4.76     0.93     0.46     1.90      0.00015     30

Station  18. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  0.9500      0.1023         104      9.0414   1544.0840    780.7478      0.0000     10.8720

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
  3.9910    904.5092    583.2123    691.3756   1861.6190      0.4859     -0.0346      0.3188

Pt3          Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
443.7663    379.0558    1480.5123      0.0000     40.1494     30.0000     10.1494

Station  19. STATOR / VANED DIFFUSER
RCG         Cth         Cuth         Cmth       Aoth           Machth     cp 2-Th   Stat Chord
  3.9910    776.3097    161.4039    759.3455   1872.0052      0.4147      0.1988      0.3300

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500    442.1228    393.9142   1497.2725    780.4911      8.4329      0.0361      0.0551

Station  20. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4      cp 3-4   Stator Gap
  3.9887   1079.1113      0.0000   1079.1113   1843.9775      0.5852     -0.4972      0.0797

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500    346.8786   1453.8099    779.3694      0.0000      0.0300      0.1491     -0.5476

STAGE EXIT CONDITIONS, STAGE            4
Eff4         Pt4         PR          TR         Tt4          Del T      Ns          Ns nondim
  0.8233    435.0002      1.2309      1.0694   1544.0840    100.2261    129.3042      1.0024

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 672614.875       0.472    1140.302   782384.1       0.00000     6.21592    10.75588


OVERALL EXIT CONDITIONS; ALL           4   STAGES

Del Enthal   DelHT/U1^2  GHP      MassFloS1cor  OPR     Efficiency    Rotor1Inc  TR      AxHubLen
 2795253.00     1.7192  4738.8682    4.068      2.7316   0.82821       6.0148    1.3794    4.522
```

7.3.2 Large Civil Transport Rotor Six-Stage Low-Pressure Compressor and Four-Stage Axial High-Pressure Compressor

Figure 24 illustrates the six-stage LPC and four-stage HPC configuration for the Large Civil Transport Rotor Engine.

7.4 Example Case (4): Large Civil Transport Rotor Engine

The input and output files in this section are those used for the analysis of option 2 for the HPC consisting of single-stage centrifugal compressor for this example case.

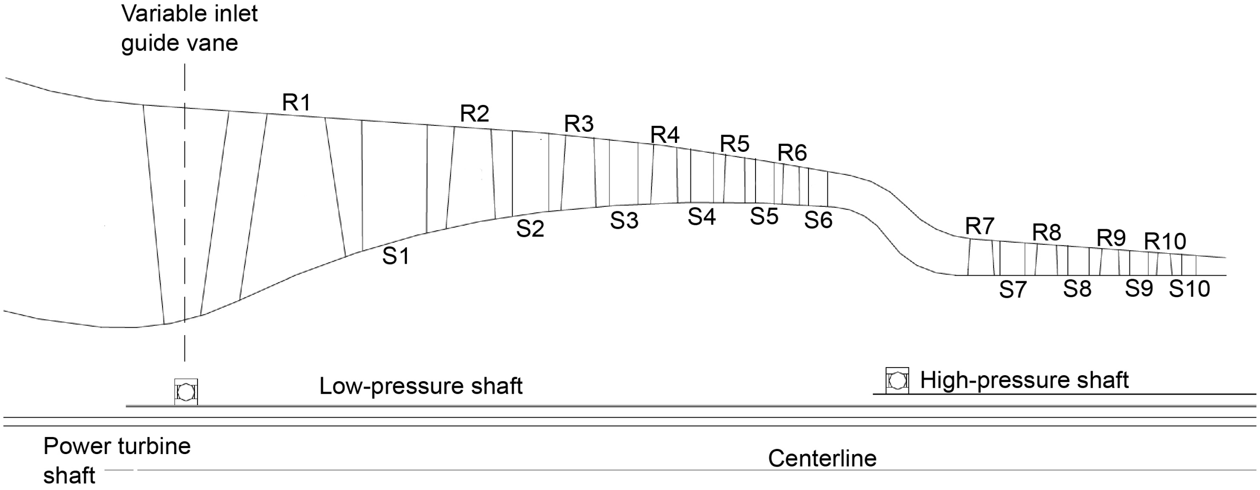

Figure 24.—Flow path for the six-stage axial low-pressure compressor with the four-stage axial high-pressure compressor of the Large Civil Transport Rotor Engine, option 1.

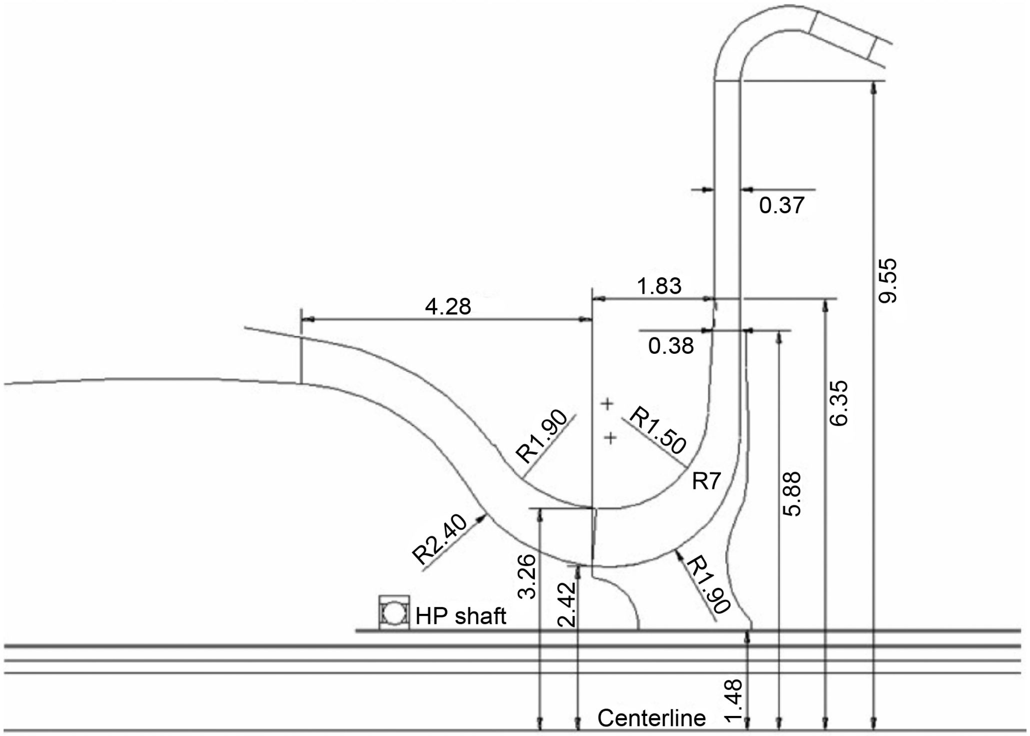

Figure 25.—Flow path for single-stage centrifugal high-pressure (HP) compressor of the Large Civil Transport Rotor Engine, option 2 (Ref. 12).

7.4.1 High-Pressure Compressor: Option 2 One Centrifugal Stage

Figure 25 illustrates the one-stage centrifugal HPC configuration for the Large Civil Transport Rotor Engine. The centrifugal impeller inlet and exit velocity diagrams are illustrated in Figure 26.

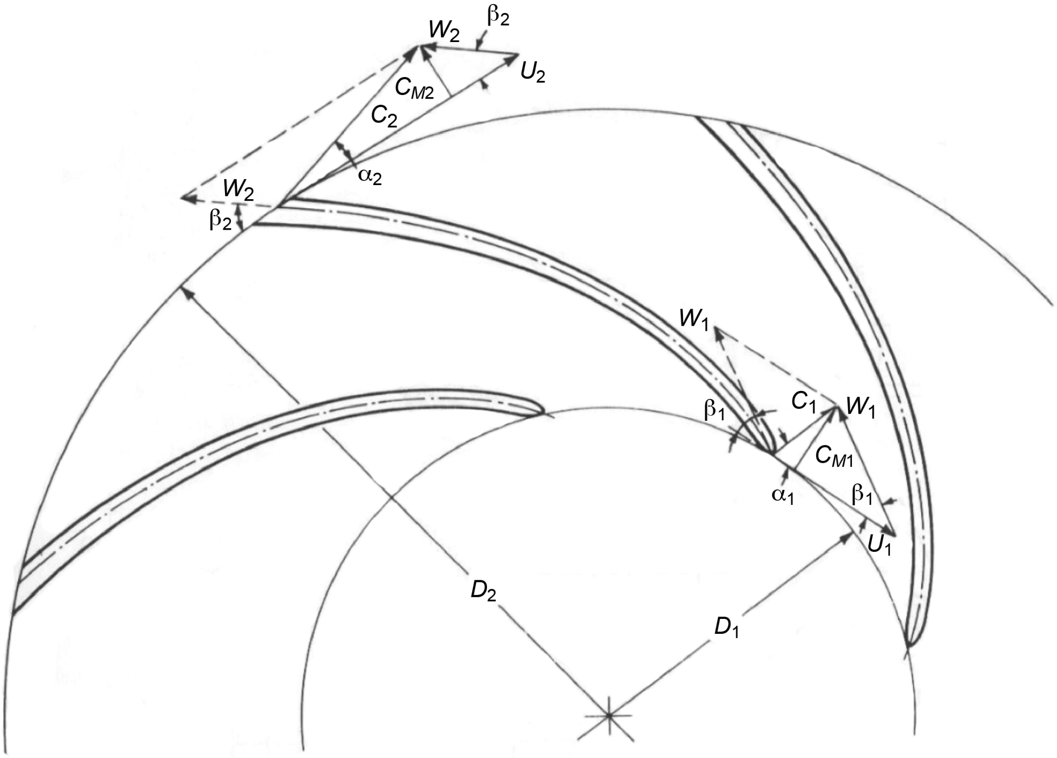

Figure 26.—Centrifugal impeller inlet and exit velocity diagrams. The impeller exit velocity triangles are the same as for an axial rotor, except the definition of meridional changes from the axial direction to the radial direction. Absolute velocity is *C*; rotor peripheral velocity is *U*; relative velocity is *W*; absolute flow angle is α; relative flow angle is β. Subscripts: leading edge is 1; trailing edge is 2; meridional is *M*.

7.4.1.1 Input File

comdes.dat

```
         Single Centrifugal SRW HPC Option # 2 Low Ns  1-20-2010
     30.0       159.25     1119.39      38620.0       Wact        Pt1          Tt1         RPM
      5           3           0           0.00        Fluid       Stages       IDUMMY      DUMMY
      0.00       46.900     000.00        0.00        DropDia     InDist       RHinlet     IWC         ***icing***
      2.70        0.00      406.44        0.00        Psin        DUMMY        Tsin        DUMMY       ***icing***
    607.8         0.00    00000.00        0           Vin         DUMMY        Altitude    IDUMMY      ***icing***
      3.40        2.41        5.88        5.88      1 R1tip       R1hub        R2tip       R2hub
      0.3300      0.380      30           0.0300      1.0         B1axial      B2axial     NBLAD       THK      CFS
      0.0         0.0000      0.000       1.0000      1.0         StatorT      StatorM     StatorH     FSGV     CFMid
      0.9800      0.9500      1.1000      0.9000      1.0         AeroB1       AeroB2      POTS        POTH     CFHub
      0.842       0.9220      0.917       0.0000      EfficiT     EfficiM      EfficiH     BLEED
      0.00        0.00        0.00        0.00        DUMMY       DUMMY        DUMMY       DUMMY
      0.8500      0.16        1.460       0.00        SlipF       DiffLoss     Solidity    RPM2
     51.50       50.60       48.00        0.0         BetaBlade1T BetaBlade1M  BetaBlade1H expo3
     23.50       23.50       23.50        2           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
      6.35        6.35        0.38       67.5         R3s         R3h          B3X         BetB3
     74           0.03        0.95        0.01        Blan3       Blath3       Blok3       Wbar23
      6.60       10.60        0.95        0.015       RCG         Athrt        BlokTH      Wbar2T
      9.55        9.55        0.37       55.0         R4S         R4H          B4X         BetB4
     74           0.03        0.95        1.30        Blan4       Blath4       Blok4       SolidStat
     10.50       10.10        0.00       50.0         R5s         R5h          B5X         BetB5
     95           0.03        0.95        0.01        Blan5       Blath5       Blok5       Wbar56
     0.00         0.000       0.95        0.015       RCG2        Athrt2       BlokTH      Wbar5T
     10.50       10.10        0.0         0.0         R6S         R6H          B6X         BetB6
     95           0.03        0.95        1.30        Blan4       Blath4       Blok4       SolidStat
     10.50       10.10        0.00        1.0         R7S         R7h          B7X         Length67
      2           0.01        0.98        0.000       Blan7       Blath7       Blok7       Wbar67
     10.50       10.10        0.0         1.0         R8S         R8h          B8X         Length78
      2           0.01        0.98        0.00        Blan8       Blath8       Blok8       Wbar78
```

7.4.1.2 Output File

comdes.out

```
*********************************************************************
**************** AXIAL & CENTRIFUGAL COMPRESSOR BLADE DESIGN 1-D ****
*******************   COMDES-MELT Release Version 1    **************
*********************   Gasplus Fluid Properties   ******************
*********************************************************************

         Single Centrifugal SRW HPC Option # 2 Low Ns  1-20-2010

  COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   1
  BLEED =  0.000   DPInc = 6.045   EfDer =  0.999    SH =  0.000000E+00

  W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
   30.0000  38620.0000    159.2484   1119.3900      1.1000      0.9000      0.9800

  W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
   13.6364     30.0000      0.0000      0.0000    144.0139      0.0000      0.0000

  W cor     RPM cor        GAMMA       Cp         R           Blades       THK         Area1UB
    4.0681  26289.3398      1.3854      0.2564     53.3483          30      0.0300     19.0476

  CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
    5085.802   23539.482   1.5693     18.6666     11.8946     12.3309      1.0367     18.0701

  Station   1.  ROTOR LEADING EDGE CONDITIONS, STAGE   1

          R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
  TIP      3.40     0.00    -0.02   719.28    -0.25   719.28     0.45     0.85   780.00    0.571
  MEAN     2.95     0.00    -0.02   653.89    -0.23   653.89     0.41     0.74
  HUB      2.41     0.00    -0.02   588.50    -0.20   588.50     0.37     0.62

        BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
  TIP     57.89    51.50     6.39  1145.88  1353.13   138.83  1077.44   686.19     0.00
  MEAN    56.65    50.60     6.05   993.16  1189.28   142.23  1084.72   686.19     0.00
  HUB     54.08    48.00     6.08   812.23  1003.18   145.36  1091.29   686.19     0.00

  Station   2.  ROTOR EXIT CONDITIONS, STAGE   1    SOLUTION IS CONVERGED
  B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
    0.3800      0.0300      0.9500          30     13.0123     14.0392

          R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
  TIP      5.88  1544.75  1419.36   609.65  1801.20     0.86     1.80     1.60     3.72
  MEAN     5.88  1546.23  1443.67   553.75  1805.90     0.86     1.99     1.67     4.24
  HUB      5.88  1546.07  1442.23   557.05  1805.62     0.86     2.20     1.78     5.18

         U2       W2       Wu2      MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
  TIP   1981.70   829.40   562.34     0.46  8346.67     0.84     0.84
  MEAN  1981.70   772.08   538.03     0.43  8489.44     0.92     0.92     0.89     1.71
  HUB   1981.70   775.46   539.47     0.43  8480.80     0.92     0.92

          Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
  TIP    443.25     2.78   275.24  1557.69     1.39  1364.30   781.61     0.00
  MEAN   489.83     3.08   304.61  1565.18     1.40  1371.43   789.14     0.00  1562.53  2.97
  HUB    486.80     3.06   302.71  1564.73     1.40  1371.01   788.67     0.00

          Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
  TIP     66.76    42.69    23.50    19.19     0.85     0.84     1.46      0.00003    162
  MEAN    69.01    44.18    23.50    20.68     0.85     0.60     3.22      0.00033    199
  HUB     68.88    44.08    23.50    20.58     0.85     0.46     4.35      0.00018    205

  Station   3. STATOR ROW #1
  blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
    0.9500      0.4458          74     13.6018   1562.5331    786.2665      0.0000     15.1613

  ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
  R3m        C3          Cu3         Cm3        Ao3             Mach3      cp 2-3    Stat Ax Chd
    6.3500   1435.9899   1336.8154    524.3961   1814.6038      0.7914      0.0535      0.8182

  Pt3         Ps3         Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
  471.5013    314.2023    1400.3114      0.0000     68.5813     67.5000      1.0813
```

```
Station   4. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
  6.6000   1416.8678   1227.0436    708.4338   1816.6155      0.7799      0.1175      0.7009

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9500    467.6732    315.2260   1405.1252    785.6934     10.6000      0.0314      0.7621

Station   5. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4       cp 3-4   Stator Gap
  9.5500    545.7169    447.0251    313.0103   1901.1146      0.2871      0.4658      0.0843

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500    387.4723   1539.1947    776.5165     55.0000      0.0300      0.3547      0.5208

Pt4        Tt4         Area4
409.7647   1562.5331     20.3112

Station   6. STATOR ROW #2
blockage5    XStatGap   Vane#       Area5       Tt5      TwetBulb5      MeltFract
  0.9500      0.2046          95     21.1900   1562.5331    776.5165      0.0000

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R5m        C5          Cu5         Cm5        Ao5            Mach5       cp4-5     StatAxChd
 10.3019    520.3502    414.3966    314.7058   1897.3145      0.2743      0.0892      0.8182

Pt5          Ps5       Ts5          RH5        FloAlpha5   VaneAlpha5   Incid5
409.7647    389.4612   1541.6371      0.0000     52.7858     50.0000      2.7858

Station   7. STATOR / VANED #2 DIFFUSER THROAT IS NOT CHOKED:
RCG        Cth         Cuth        Cmth       Aoth2          Machth      cp4-Th   StatChord
 10.3019    456.8296    228.4148    395.6260   1900.1666      0.2404      0.2839      0.9028

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh        w2-Th     TtTh
  0.9500    409.5075    393.8015   1546.4319    776.4734     15.8859      0.0115   1562.5331

Station   8. VANED DIFFUSER #2 EXIT:
R6         C6            Cu6       Cm6        Ao6            Mach6       cp5-6    StatorGap
 10.3019    291.5694      0.0000    291.5694   1905.8323      0.1530      0.6699      0.0843

Blockage6    Ps6       Ts6         TwetBulb6   MeltFract    Vane Thk6   w4-6OD      cp 2-6
  0.9500    403.0620   1555.9778    776.4747      0.0000      0.0300      0.0112      0.6079

STAGE EXIT CONDITIONS, STAGE             1
Eff6       Pt6          PR6          TR        Tt6          Del T      Ns          Ns nondim
  0.7166    409.5146      2.5715      1.3959   1562.5331    443.1431     67.7343      0.5251

Del Enthalpy  Del_H/U^2 GHP     Reynolds#   Specif Humid  DF6       W2-6     Area6
2935275.000   0.7474   4976.251 960275.06   0.00000       0.7460    0.3561    21.19
```

7.4.2 Large Civil Transport Rotor Six-Stage Low-Pressure Compressor and One Centrifugal High-Pressure Compressor Stage

Figure 27 illustrates the six-stage LPC and single-stage centrifugal HPC configuration for the Large Civil Transport Rotor Engine.

7.5 Example Case (5): Helium Compressor

The input and output files in this section are those used for the analysis of a five-stage helium compressor. The flow path for the compressor is illustrated in Figure 28.

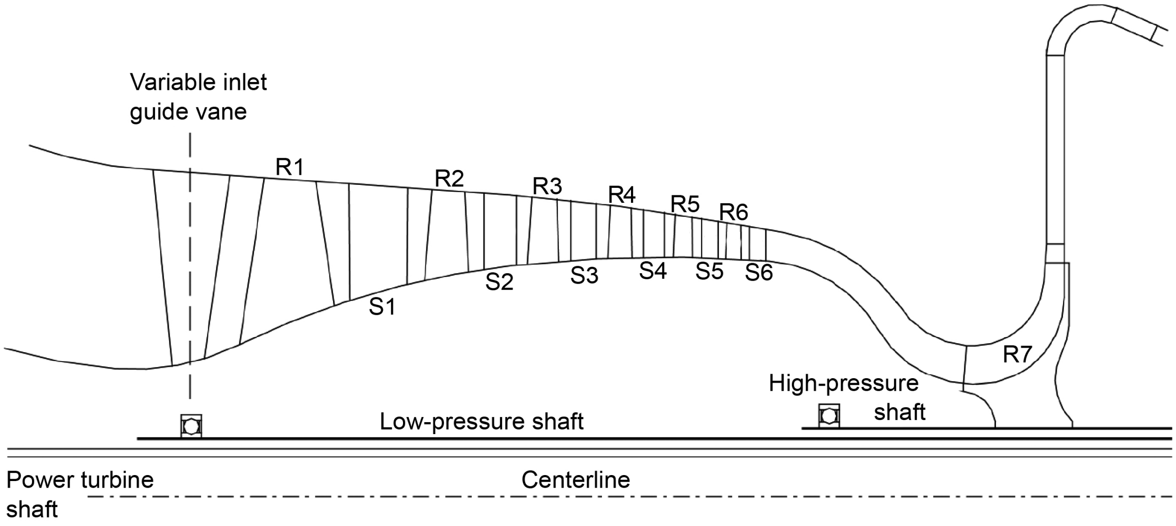

Figure 27.—Flow path for the six-stage axial low-pressure compressor with the single-stage centrifugal high-pressure compressor of the Large Civil Transport Rotor Engine, option 2.

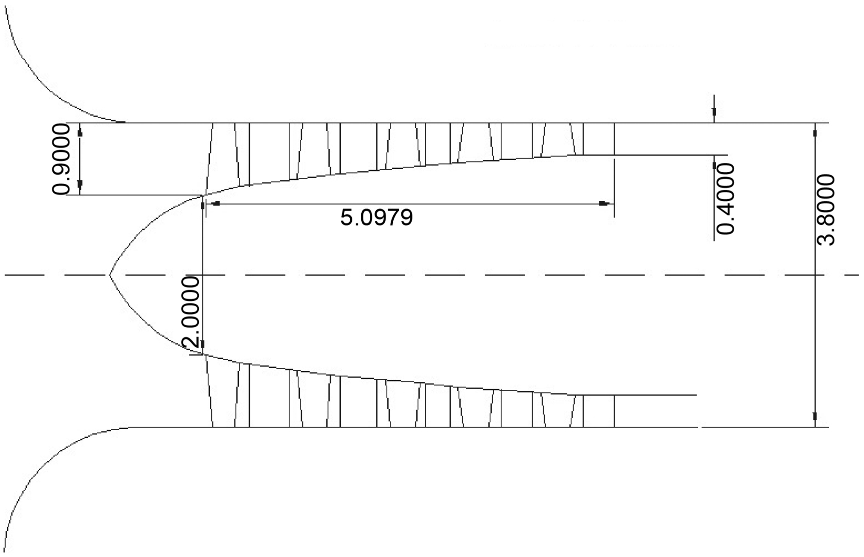

Figure 28.—Flow path for the five-stage axial helium compressor. All dimensions in inches. Shaft speed (actual) = 68,000 RPM; shaft speed (corrected) = 163,247 RPM; pressure ratio = 3.47; temperature ratio = 1.8733; efficiency = 81.2; horsepower = 14,185 HP; mass flow (actual) = 97.5 lbm/s; mass flow (corrected) = 0.7036 lbm/s; tip speed (actual) = 1,127 ft/s; tip speed (corrected stage 1) = 2,706 ft/s; inlet pressure = 848.5 psia; inlet temperature = 90 R.

7.5.1 Input File

comdes.dat

```
Helium Axial Compressor 7-7-2014
     97.5       848.47       90.0       68000.        Wact        Pt1          Tt1         RPM
      6           5           0           0.00        Fluid       Stages       IDUMMY      DUMMY
      0.00        5.920     000.00        0.00        DropDia     InDist       RHinlet     IWC         ***icing***
    780.0         0.00       88.0         0.00        Psin        DUMMY        Tsin        DUMMY       ***icing***
    472.0         0.00      000.00        0           Vin         DUMMY        Altitude    IDUMMY      ***icing***
      1.90        1.0         1.9         1.1       1 R1tip       R1hub        R2tip       R2hub
      0.05        0.05       40           0.020       1.0         B1axial      B2axial     NBLAD       THK      CFS
      0.0         0.0000      0.000       1.0000      0.9         StatorT      StatorM     StatorH     FSGV     CFMid
```

```
 0.9500      0.9500      1.0000      1.0000       0.9         AeroB1       AeroB2      POTS        POTH     CFHub
 0.880       0.875       0.850       0.0000       EfficiT     EfficiM      EfficiH     BLEED
 0.00        0.00        0.00        0.00         DUMMY       DUMMY        DUMMY       DUMMY
 0.915       0.03        1.8         0.00         SlipF       DiffLoss     Solidity    RPM2
57.5        52.0        40.5         2.0          BetaBlade1T BetaBlade1M  BetaBlade1H expo3
46.5        31.5         3.5         0            BetaBlade2T BetaBlade2M  BetaBlade2H stat2
 1.9         1.1161      0.05       38.5          R3s         R3h          B3X         BetB3
31           0.02        0.95        0.00         Blan3       Blath3       Blok3       Wbar23
 1.9         0.0         0.97        0.015        RCG         Athrt        BlokTH      Wbar2T
 1.9         1.03        0.05        0.0          R4S         R4H          B4X         BetB4
31           0.01        0.98        1.36         Blan4       Blath4       Blok4       SolidStat1
 1.90        1.195       1.9         1.25       2 R1tip       R1hub        R2tip       R2hub
 0.05        0.05       40           0.020        1.0         B1axial      B2axial     NBLAD       THK      CFS
 0.0         0.0000      0.000       1.0000       0.9         StatorT      StatorM     StatorH     FSGV     CFMid
 0.9500      0.9500      1.0000      1.0000       0.9         AeroB1       AeroB2      POTS        POTH     CFHub
 0.880       0.875       0.850       0.0000       EfficiT     EfficiM      EfficiH     BLEED
 0.00        0.00        0.00        0.00         DUMMY       DUMMY        DUMMY       DUMMY
 0.915       0.03        1.8         0.00         SlipF       DiffLoss     Solidity    RPM2
57.0        52.5        44.5         2.0          BetaBlade1T BetaBlade1M  BetaBlade1H expo3
44.5        31.5         7.5         0            BetaBlade2T BetaBlade2M  BetaBlade2H stat2
 1.9         1.2585      0.05       40.5          R3s         R3h          B3X         BetB3
33           0.02        1.00        0.00         Blan3       Blath3       Blok3       Wbar23
 0.0         0.0         0.97        0.015        RCG         Athrt        BlokTH      Wbar2T
 1.9         1.25        0.05        0.0          R4S         R4H          B4X         BetB4
33           0.01        0.98        1.36         Blan4       Blath4       Blok4       SolidStat1
 1.90        1.3107      1.9         1.35       3 R1tip       R1hub        R2tip       R2hub
 0.05        0.05       40           0.020        1.0         B1axial      B2axial     NBLAD       THK      CFS
 0.0         0.0000      0.000       1.0000       0.9         StatorT      StatorM     StatorH     FSGV     CFMid
 0.9500      0.9500      1.0000      1.0000       0.9         AeroB1       AeroB2      POTS        POTH     CFHub
 0.880       0.875       0.850       0.0000       EfficiT     EfficiM      EfficiH     BLEED
 0.00        0.00        0.00        0.00         DUMMY       DUMMY        DUMMY       DUMMY
 0.915       0.03        1.8         0.00         SlipF       DiffLoss     Solidity    RPM2
56.5        53.0        47.0         2.0          BetaBlade1T BetaBlade1M  BetaBlade1H expo3
43.5        31.5         7.5         0            BetaBlade2T BetaBlade2M  BetaBlade2H stat2
 1.9         1.3578      0.05       40.5          R3s         R3h          B3X         BetB3
51           0.02        1.00        0.00         Blan3       Blath3       Blok3       Wbar23
 0.0         0.0         0.97        0.015        RCG         Athrt        BlokTH      Wbar2T
 1.9         1.3889      0.05        0.0          R4S         R4H          B4X         BetB4
51           0.01        0.98        1.36         Blan4       Blath4       Blok4       SolidStat1
 1.90        1.40        1.9         1.4302     4 R1tip       R1hub        R2tip       R2hub
 0.05        0.05       40           0.020        1.0         B1axial      B2axial     NBLAD       THK      CFS
 0.0         0.0000      0.000       1.0000       0.9         StatorT      StatorM     StatorH     FSGV     CFMid
 0.9500      0.9500      1.0000      1.0000       0.9         AeroB1       AeroB2      POTS        POTH     CFHub
 0.880       0.875       0.850       0.0000       EfficiT     EfficiM      EfficiH     BLEED
 0.00        0.00        0.00        0.00         DUMMY       DUMMY        DUMMY       DUMMY
 0.915       0.03        1.8         0.00         SlipF       DiffLoss     Solidity    RPM2
56.5        53.0        48.0         2.0          BetaBlade1T BetaBlade1M  BetaBlade1H expo3
40.5        29.5         7.5         0            BetaBlade2T BetaBlade2M  BetaBlade2H stat2
 1.9         1.4365      0.05       42.0          R3s         R3h          B3X         BetB3
40           0.02        0.95        0.00         Blan3       Blath3       Blok3       Wbar23
 0.0         0.0         0.97        0.015        RCG         Athrt        BlokTH      Wbar2T
 1.9         1.4624      0.05        0.0          R4S         R4H          B4X         BetB4
40           0.01        0.98        1.36         Blan4       Blath4       Blok4       SolidStat1
 1.90        1.4701      1.9         1.50       5 R1tip       R1hub        R2tip       R2hub
 0.05        0.05       40           0.020        1.0         B1axial      B2axial     NBLAD       THK      CFS
 0.0         0.0000      0.000       1.0000       0.9         StatorT      StatorM     StatorH     FSGV     CFMid
 0.9500      0.9500      1.0000      1.0000       0.9         AeroB1       AeroB2      POTS        POTH     CFHub
 0.880       0.875       0.850       0.0000       EfficiT     EfficiM      EfficiH     BLEED
 0.00        0.00        0.00        0.00         DUMMY       DUMMY        DUMMY       DUMMY
 0.915       0.03        1.8         0.00         SlipF       DiffLoss     Solidity    RPM2
56.5        54.0        50.0         2.0          BetaBlade1T BetaBlade1M  BetaBlade1H expo3
40.5        29.5         7.5         0            BetaBlade2T BetaBlade2M  BetaBlade2H stat2
 1.9         1.50        0.05       42.5          R3s         R3h          B3X         BetB3
40           0.02        0.95        0.00         Blan3       Blath3       Blok3       Wbar23
 0.0         0.0         0.97        0.015        RCG         Athrt        BlokTH      Wbar2T
 1.9         1.50        0.05        0.0          R4S         R4H          B4X         BetB4
40           0.01        0.98        1.36         Blan4       Blath4       Blok4       SolidStat1
1.9          1.50        0.05        1.5          R7S         R7h          B7X         Length67
11           0.01        0.98        0.020        Blan7       Blath7       Blok7       Wbar67
1.9          1.50        0.05        1.1          R8S         R8h          B8X         Length78
11           0.01        0.98        0.02         Blan8       Blath8       Blok8       Wbar78
```

7.5.2 Output File

comdes.out

```
*********************************************************************
**************** AXIAL & CENTRIFUGAL COMPRESSOR BLADE DESIGN 1-D ****
*******************   COMDES-MELT Release Version 1    **************
*********************   Gasplus Fluid Properties   ******************
*********************************************************************

Helium Axial Compressor 7-7-2014

  COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   1
  BLEED =  0.000   DPInc = 6.363   EfDer =  1.000    SH =  0.000000E+00

  W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
   97.5000  68000.0000    848.4616     90.0000      1.0000      1.0000      0.9500

  W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
   44.3182     97.5000      0.0000      0.0000     51.1037      0.0000      0.0000

  W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
    0.7036 163247.2188      1.7558      1.3071    386.2500          40      0.0200      8.2122

  CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
    1804.708       0.000   1.5256      7.8016      5.1138      4.6584      0.9109      8.1996

  Station   1.  ROTOR LEADING EDGE CONDITIONS, STAGE   1

          R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
  TIP      1.90     0.00    -0.02   555.18    -0.19   555.18     0.41     0.92  2706.66    0.492
  MEAN     1.52     0.00    -0.02   555.18    -0.19   555.18     0.41     0.78
  HUB      1.00     0.00    -0.02   555.18    -0.19   555.18     0.41     0.60

        BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
  TIP     63.79    57.50     6.29  1127.48  1256.93   736.11    84.66    90.00     0.00
  MEAN    58.36    52.00     6.36   900.93  1058.42   736.11    84.66    90.00     0.00
  HUB     46.92    40.50     6.42   593.41   812.77   736.11    84.66    90.00     0.00

  Station   2.  ROTOR EXIT CONDITIONS, STAGE   1    SOLUTION IS CONVERGED
  B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
    0.0500      0.0200      0.9500          40      6.5676      7.5545

          R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
  TIP      1.90   717.45   414.76   585.41  1442.67     0.50     0.54     0.37     2.80
  MEAN     1.55   766.92   472.98   603.70  1425.56     0.54     0.49     0.39     1.38
  HUB      1.10   853.78   557.75   646.42  1389.68     0.61     0.45     0.41     0.70

         U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
  TIP   1127.48   922.32   712.72     0.64   788.41     0.88     0.88
  MEAN   921.22   751.92   448.24     0.53   734.55     0.88     0.87     0.87     1.62
  HUB    652.75   653.37    95.00     0.47   613.71     0.85     0.85

          Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
  TIP   1149.82     1.36   934.30   104.30     1.16    95.38   104.30     0.00
  MEAN  1125.85     1.33   884.63   103.32     1.15    93.14   103.32     0.00   102.92  1.31
  HUB   1070.17     1.26   785.09   101.13     1.12    88.51   101.13     0.00

          Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
  TIP     35.32    50.60    46.50     4.10     0.92     0.36     1.80      0.00037     29
  MEAN    38.08    36.59    31.50     5.09     0.92     0.40     2.07      0.00071     37
  HUB     40.79     8.36     3.50     4.86     0.92     0.32     2.84      0.00143     37

  Station   3. STATOR ROW #1
  blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
    0.9500      0.1034          31      6.6080    102.9178    102.9178      0.0000      7.4428

  ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
  R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
    1.5582    765.5780    471.2398    603.3595   1422.7319      0.5381     -0.0340      0.4945

  Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
 1115.2797    876.2280     92.7667      0.0000     37.9908     38.5000     -0.5092
```

```
Station   4. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth        Aoth           Machth     cp 2-Th   Stat Chord
  1.9000    699.9386    185.8730    674.8076   1435.4510      0.4876      0.1655      0.5237

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9700   1110.0492    908.9379     94.4328    102.9178      5.9774      0.0212      0.5315

Station   5. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4          C4          Cu4         Cm4        Ao4            Mach4       cp 3-4   Stator Gap
  1.5282    531.9310      0.0000    531.9310   1462.4408      0.3637      0.4711      0.1236

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9800    988.8353     98.0173    102.9178      0.0000      0.0100      0.0314      0.4886

STAGE EXIT CONDITIONS, STAGE            1
Eff4         Pt4         PR          TR          Tt4          Del T      Ns          Ns nondim
  0.8467   1107.5037      1.3053      1.1435    102.9178     12.9178    303.9084      2.3559

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 422698.188       0.333    2328.988 25861678.0       0.00000     7.01773     8.00823


COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   2
BLEED =  0.000   DPInc = 5.923   EfDer =  0.999    SH =  0.000000E+00

W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
 97.5000  68000.0000   1107.5037    102.9178      1.0000      1.0000      0.9500

W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 44.3182     97.5000      0.0000      0.0000     44.5997      0.0000      0.0000

W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
  0.5765 152658.7500      1.7497      1.3026    386.2500          40      0.0200      6.8721

CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
  1575.023  553896.062   1.5566      6.5285      4.1942      3.8858      0.9265      6.8549

Station   6.  ROTOR LEADING EDGE CONDITIONS, STAGE   2

        R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
TIP      1.90     0.00    -0.02   579.01    -0.20   579.01     0.40     0.87  2531.10    0.514
MEAN     1.59     0.00    -0.02   579.01    -0.20   579.01     0.40     0.76
HUB      1.20     0.00    -0.02   579.01    -0.20   579.01     0.40     0.63

      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     62.82    57.00     5.82  1127.48  1267.64   967.75    97.14   102.92     0.00
MEAN    58.42    52.50     5.92   941.83  1105.74   967.75    97.14   102.92     0.00
HUB     50.78    44.50     6.28   709.13   915.64   967.75    97.14   102.92     0.00

Station   7.  ROTOR EXIT CONDITIONS, STAGE   2    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.0500      0.0200      0.9500          40      5.6334      6.4514

        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
TIP      1.90   745.14   442.52   599.50  1537.08     0.48     0.54     0.38     2.47
MEAN     1.61   789.92   496.94   614.02  1523.27     0.52     0.51     0.40     1.39
HUB      1.25   876.83   593.78   645.17  1497.83     0.59     0.47     0.42     0.74

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
TIP   1127.48   910.26   684.96     0.59   841.17     0.88     0.88
MEAN   954.31   765.65   457.38     0.50   799.48     0.88     0.87     0.87     1.63
HUB    741.76   661.93   147.98     0.44   742.47     0.85     0.85

        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP   1475.49     1.33  1211.61   118.23     1.15   108.65   118.23     0.00
MEAN  1453.69     1.31  1161.79   117.47     1.14   106.71   117.47     0.00   117.37  1.31
HUB   1417.43     1.28  1069.07   116.43     1.13   103.18   116.43     0.00

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     36.43    48.81    44.50     4.31     0.92     0.38     1.80      0.00022     27
MEAN    38.98    36.68    31.50     5.18     0.92     0.42     2.04      0.00095     37
HUB     42.62    12.92     7.50     5.42     0.92     0.41     2.52      0.00051     35
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 Station   8. STATOR ROW #1
 blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
   1.0000      0.1062          33      5.9601    117.3750    117.3750      0.0000      6.3847

 ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
 R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
   1.6115    760.1998    495.9160    576.1693   1528.2654      0.4974      0.0536      0.4616

 Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
1448.8711   1177.9467    107.4121      0.0000     40.7190     40.5000      0.2190

 Station   9. STATOR / VANED DIFFUSER
 RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
   1.6115    691.5704    192.9420    664.1107   1540.4365      0.4489      0.2320      0.4920

 BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
   0.9700   1442.9897   1217.4164    109.1297    117.3750      5.2404      0.0195      0.4735

 Station  10. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
 R4         C4          Cu4         Cm4        Ao4            Mach4       cp 3-4   Stator Gap
   1.6082    582.5651      0.0000    582.5651   1557.2439      0.3741      0.3674      0.1154

 Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
   0.9800   1277.4941    111.5241    117.3750      0.0000      0.0100      0.0314      0.4314

 STAGE EXIT CONDITIONS, STAGE             2
 Eff4         Pt4         PR          TR        Tt4          Del T      Ns          Ns nondim
   0.8462   1439.4124      1.2997      1.1405    117.3750     14.4571    261.5940      2.0279

 Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
  471451.438       0.371    2597.609 21319290.0       0.00000     5.64337     6.43241


 COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   3
 BLEED =  0.000   DPInc = 6.112   EfDer =  0.999    SH =  0.000000E+00

 W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
  97.5000  68000.0000   1439.4124    117.3750      1.0000      1.0000      0.9500

 W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
  44.3182     97.5000      0.0000      0.0000     38.7492      0.0000      0.0000

 W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
   0.4429 152863.3594      1.7582      1.3089    386.2500          40      0.0200      5.9655

 CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
   1368.416  553896.062   1.6470      5.6672      3.4409      3.3467      0.9726      5.9441

 Station  11.  ROTOR LEADING EDGE CONDITIONS, STAGE   3

        R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
 TIP      1.90     0.00    -0.02   579.51    -0.20   579.51     0.37     0.81  2534.50    0.514
 MEAN     1.63     0.00    -0.02   579.51    -0.20   579.51     0.37     0.72
 HUB      1.31     0.00    -0.02   579.51    -0.20   579.51     0.37     0.62

      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
 TIP     62.80    56.50     6.30  1127.48  1267.87  1279.11   111.55   117.37     0.00
 MEAN    59.11    53.00     6.11   968.55  1128.85  1279.11   111.55   117.37     0.00
 HUB     53.32    47.00     6.32   777.79   970.10  1279.11   111.55   117.37     0.00

 Station  12.  ROTOR EXIT CONDITIONS, STAGE   3    SOLUTION IS CONVERGED
 B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
   0.0500      0.0200      0.9500          40      4.9371      5.6388

        R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
 TIP      1.90   758.13   459.19   603.25  1640.76     0.46     0.54     0.39     2.37
 MEAN     1.65   803.69   518.68   613.91  1630.37     0.49     0.52     0.41     1.39
 HUB      1.35   909.99   649.06   637.82  1611.67     0.56     0.49     0.43     0.72

       U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
 TIP   1127.48   900.29   668.29     0.55   872.84     0.88     0.88
 MEAN   978.01   766.72   459.33     0.47   855.16     0.88     0.87     0.87     1.64
 HUB    801.11   655.69   152.04     0.41   876.50     0.85     0.85
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        Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
TIP   1866.11     1.30  1557.96   133.18     1.13   123.21   133.18     0.00
MEAN  1854.30     1.29  1511.60   132.86     1.13   121.66   132.86     0.00   133.10  1.29
HUB   1852.37     1.29  1421.76   133.25     1.14   118.88   133.25     0.00

        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     37.28    47.93    43.50     4.43     0.92     0.39     1.80      0.00028     24
MEAN    40.19    36.80    31.50     5.30     0.92     0.44     2.02      0.00054     35
HUB     45.50    13.41     7.50     5.91     0.92     0.47     2.36      0.00179     35

Station  13. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  1.0000      0.1079          51      5.0174    133.0993    133.0993      0.0000      5.5728

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
  1.6513    794.1422    517.6735    602.2258   1633.7197      0.4861      0.0302      0.2987

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
1857.5942   1522.4895    122.1572      0.0000     40.6824     40.5000      0.1824

Station  14. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
  1.6513    766.4976    213.8460    736.0628   1638.7174      0.4677      0.1148      0.3183

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9700   1850.7207   1538.4973    122.9058    133.0993      4.2137      0.0191      0.3926

Station  15. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4      cp 3-4   Stator Gap
  1.6642    672.7041      0.0000    672.7041   1654.2573      0.4067      0.2417      0.0747

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9800   1603.4835    125.2478    133.0993      0.0000      0.0100      0.0314      0.2951

STAGE EXIT CONDITIONS, STAGE            3
Eff4         Pt4         PR          TR          Tt4          Del T      Ns          Ns nondim
  0.8459   1846.2820     1.2827      1.1340    133.0993     15.7244    228.1183      1.7684

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 515245.969       0.405    2838.909 21305586.0       0.00000     4.37275     5.28088


COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   4
BLEED =  0.000   DPInc = 6.555   EfDer =  1.000    SH =  0.000000E+00

W act     RPM act        Pt         Tt            POTS        POTH        AeroBl
 97.5000  68000.0000  1846.2820    133.0993      1.0000      1.0000      0.9500

W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
 44.3182     97.5000      0.0000      0.0000     33.9944      0.0000      0.0000

W cor     RPM cor        GAMMA       Cp         R            Blades       THK         Area1UB
  0.3443 153301.2188      1.7625      1.3122    386.2500          40      0.0200      5.2095

CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
  1200.499  553896.062  1.7338      4.9490      2.8544      2.9338      1.0278      5.1836

Station  16.  ROTOR LEADING EDGE CONDITIONS, STAGE   4

        R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
TIP      1.90     0.00    -0.02   582.18    -0.20   582.18     0.35     0.76  2541.76    0.516
MEAN     1.67     0.00    -0.02   582.18    -0.20   582.18     0.35     0.69
HUB      1.40     0.00    -0.02   582.18    -0.20   582.18     0.35     0.61

      BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
TIP     62.69    56.50     6.19  1127.48  1269.09  1662.59   127.20   133.10     0.00
MEAN    59.55    53.00     6.55   990.30  1148.93  1662.59   127.20   133.10     0.00
HUB     54.99    48.00     6.99   830.78  1014.62  1662.59   127.20   133.10     0.00

Station  17.  ROTOR EXIT CONDITIONS, STAGE   4    SOLUTION IS CONVERGED
B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
  0.0500      0.0200      0.9500          40      4.3367      4.9429
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         R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
 TIP      1.90   794.87   513.31   606.90  1749.42     0.45     0.54     0.40     1.93
 MEAN     1.68   835.83   564.14   616.73  1739.10     0.48     0.53     0.42     1.29
 HUB      1.43   941.00   692.71   636.90  1723.32     0.55     0.50     0.44     0.73

        U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
 TIP   1127.48   863.44   614.17     0.49   975.68     0.88     0.88
 MEAN   997.87   753.98   433.73     0.43   948.99     0.88     0.87     0.87     1.67
 HUB    848.70   655.72   155.99     0.38   990.99     0.85     0.85

         Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
 TIP   2382.00     1.29  1999.34   150.73     1.13   139.73   150.73     0.00
 MEAN  2363.15     1.28  1944.31   150.24     1.13   138.08   150.24     0.00   150.66  1.28
 HUB   2371.14     1.28  1848.75   151.00     1.13   135.59   151.00     0.00

         Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
 TIP     40.22    45.34    40.50     4.84     0.92     0.43     1.80      0.00059     23
 MEAN    42.45    35.12    29.50     5.62     0.92     0.47     2.01      0.00126     36
 HUB     47.40    13.76     7.50     6.26     0.92     0.50     2.29      0.00005     33

 Station  18. STATOR ROW #1
 blockage3    XBladeGap  Vane#      Area3      Tt3        TwetBulb3      MeltFract   Area3UB
   0.9500      0.1112          40      4.2879    150.6583    150.6583      0.0000      4.8866

 ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
 R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
   1.6843    840.3726    563.2435   623.6849   1740.8657      0.4827      0.0094      0.3789

 Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
2372.0977   1948.4457    138.3655      0.0000     42.0849     42.0000      0.0849

 Station  19. STATOR / VANED DIFFUSER
 RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
   1.6843    789.7696    228.2685    756.0618   1749.8751      0.4513      0.1307      0.4059

 BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
   0.9700   2363.7437   1988.4733    139.8014    150.6583      3.6102      0.0189      0.4816

 Station  20. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
 R4         C4          Cu4         Cm4        Ao4            Mach4      cp 3-4   Stator Gap
   1.6954    642.7379      0.0000    642.7379   1772.6711      0.3626      0.3723      0.0947

 Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
   0.9800   2106.1824    143.4676    150.6583      0.0000      0.0100      0.0314      0.3974

 STAGE EXIT CONDITIONS, STAGE             4
 Eff4         Pt4         PR          TR        Tt4          Del T      Ns          Ns nondim
   0.8466   2358.2529      1.2773      1.1319    150.6583     17.5590    196.3234      1.5219

 Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
  576803.312       0.454    3178.079 21184304.0       0.00000     3.99114     4.62250

 COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   5
 BLEED =  0.000   DPInc = 5.983   EfDer =  0.999    SH =  0.000000E+00

 W act     RPM act        Pt         Tt            POTS        POTH        AeroBl
  97.5000  68000.0000   2358.2529    150.6583      1.0000      1.0000      0.9500

 W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
  44.3182     97.5000      0.0000      0.0000     29.9175      0.0000      0.0000

 W cor     RPM cor        GAMMA       Cp          R           Blades       THK         Area1UB
   0.2693 153439.4844      1.7595      1.3101    386.2500          40      0.0200      4.5822

 CFM          SCFM        A1/A*      Area1       A*          AthrRotor  ChokeMargin  AnnularArea
   1056.525  553896.062   1.8299      4.3531      2.3789      2.5195      1.0591      4.5516

 Station  21.  ROTOR LEADING EDGE CONDITIONS, STAGE   5

         R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
 TIP      1.90     0.00    -0.02   582.49    -0.20   582.49     0.33     0.71  2544.05    0.517
 MEAN     1.70     0.00    -0.02   582.49    -0.20   582.49     0.33     0.65
 HUB      1.47     0.00    -0.02   582.49    -0.20   582.49     0.33     0.59
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       BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
 TIP     62.68    56.50     6.18  1127.48  1269.24  2150.05   144.77   150.66     0.00
 MEAN    59.98    54.00     5.98  1008.03  1164.40  2150.05   144.77   150.66     0.00
 HUB     56.27    50.00     6.27   872.37  1049.14  2150.05   144.77   150.66     0.00

 Station  22.  ROTOR EXIT CONDITIONS, STAGE   5    SOLUTION IS CONVERGED
 B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
   0.0500      0.0200      0.9500          40      3.7842      4.3058

         R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
 TIP      1.90   797.98   501.62   620.60  1851.92     0.43     0.54     0.40     1.93
 MEAN     1.71   850.49   574.77   626.87  1846.32     0.46     0.53     0.42     1.25
 HUB      1.50   972.82   729.79   643.26  1835.22     0.53     0.51     0.44     0.70

        U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
 TIP   1127.48   881.38   625.86     0.48   953.47     0.88     0.88
 MEAN  1015.76   766.44   440.98     0.42   984.19     0.88     0.87     0.87     1.65
 HUB    890.12   662.94   160.32     0.36  1094.99     0.85     0.85

         Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
 TIP   2945.34     1.25  2515.29   167.91     1.11   156.85   167.91     0.00
 MEAN  2961.83     1.26  2475.09   168.47     1.12   155.91   168.47     0.00   168.95  1.26
 HUB   3014.02     1.28  2383.09   170.47     1.13   154.04   170.47     0.00

         Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
 TIP     38.95    45.24    40.50     4.74     0.92     0.42     1.80      0.00090     23
 MEAN    42.52    35.13    29.50     5.63     0.92     0.47     1.99      0.00130     33
 HUB     48.61    14.00     7.50     6.50     0.92     0.53     2.20      0.00203     32

 Station  23. STATOR ROW #1
 blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
   0.9500      0.1112          40      3.7842    168.9509    168.9509      0.0000      4.3058

 ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
 R3m        C3          Cu3         Cm3        Ao3             Mach3      cp 2-3    Stat Ax Chd
   1.7117    849.7291    574.7733    625.8397   1849.3101      0.4595      0.0234      0.3783

 Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
2973.7288   2487.1890    156.4113     0.0000     42.5645     42.5000      0.0645

 Station  24. STATOR / VANED DIFFUSER
 RCG         Cth         Cuth        Cmth        Aoth           Machth     cp 2-Th   Stat Chord
   1.7117    799.4977    233.7505    764.5635   1857.7960      0.4303      0.1449      0.4059

 BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
   0.9700   2964.4329   2532.5715   157.8501    168.9509      3.1650      0.0180      0.5269

 Station  25. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
 R4         C4          Cu4         Cm4        Ao4             Mach4      cp 3-4   Stator Gap
   1.7117    613.3331      0.0000    613.3331   1884.4843      0.3255      0.4360      0.0946

 Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
   0.9800   2699.3140    162.4179    168.9509      0.0000      0.0100      0.0314      0.4681

 STAGE EXIT CONDITIONS, STAGE            5
 Eff4         Pt4         PR          TR         Tt4          Del T      Ns          Ns nondim
   0.8456   2957.5439      1.2541      1.1214    168.9509     18.2925    178.8205      1.3862

 Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
  599946.812       0.472    3305.595 20689816.0       0.00000     3.69451     4.27257


 OVERALL EXIT CONDITIONS; ALL           5   STAGES

 Del Enthal   DelHT/U1^2  GHP      MassFloS1cor  OPR     Efficiency    Rotor1Inc  TR      AxHubLen
  2586145.75     2.0344 14249.1807    0.704      3.4857   0.81239       6.3628    1.8772    5.215
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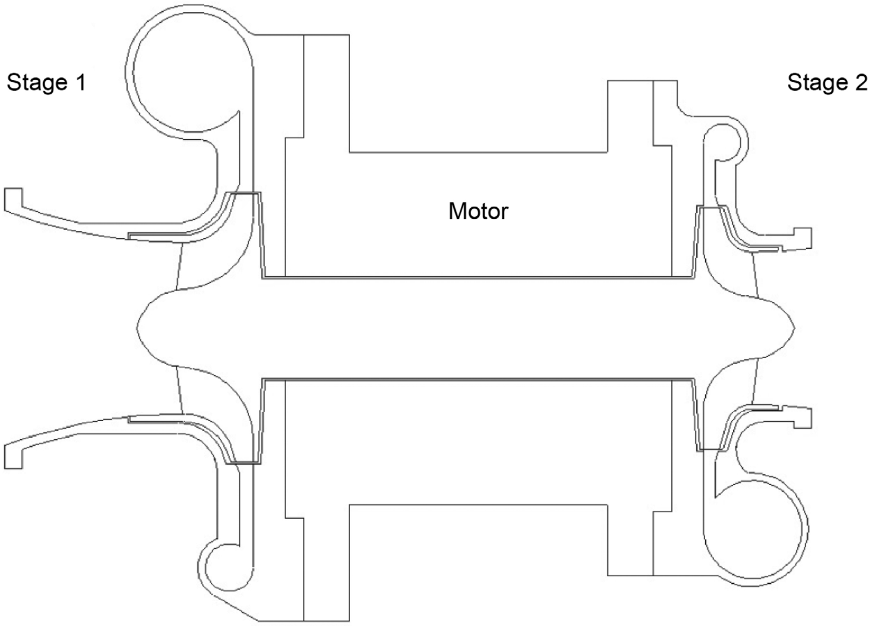

Figure 29.—Flow path for the two-stage centrifugal carbon dioxide compressor.

7.6 Example Case (6): Two-Stage Carbon Dioxide Compressor

The input and output files in this section are those used for the analysis of a two-stage carbon dioxide compressor. A cross section of the compressor is shown in Figure 29.

7.6.1 Input File

comdes.dat

```
  Centrifugal Compressor for CO2
  3.08        0.0773    383.6        1666.7       Wact        Pt1          Tt1         RPM
  7           2           0           0.00        Fluid       Stages       IDUMMY      DUMMY
 0.00        46.900     000.00        0.0         DropDia     InDist       RHinlet     IWC         ***icing***
 0.077        0.0       383.6         0.0         Psin        DUMMY        Tsin        DUMMY       ***icing***
100.00        0.0       00000.        0           Vin         DUMMY        Altitude    IDUMMY      ***icing***
 32.7        16.2        51.0        51.0       1 R1tip       R1hub        R2tip       R2hub
  0.9000      6.70       23           0.1700      1.1         B1axial      B2axial     NBLAD       THK      CFS
  0.0         0.0000      0.000       1.0000      1.1         StatorT      StatorM     StatorH     FSGV     CFMid
  0.9800      0.9500      1.1000      0.9000      1.1         AeroB1       AeroB2      POTS        POTH     CFHub
  0.89        0.89        0.89        0.0000      EfficiT     EfficiM      EfficiH     BLEED
  0.00        0.00        0.00        0.00        DUMMY       DUMMY        DUMMY       DUMMY
  0.880       0.16        1.35        0.00        SlipF       DiffLoss     Solidity    RPM2
 55.8000     52.4        42.70        2.0         BetaBlade1T BetaBlade1M  BetaBlade1H expo3
 37.00       37.0        37.00        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
 56.00       56.00        5.2        65.0         R3s         R3h          B3X         BetB3
 21           0.10        1.00        0.02        Blan3       Blathk3      Blok3       Wbar23
  0.0      2000.0         0.97        0.10        RCG         Athrt        BlokTH      Wbar2T
 83.0        83.0         5.2        30.0         R4S         R4H          B4X         BetB4
 21           0.1         0.95        1.40        Blan4       Blathk4      Blok4       SolidStat
 29.0        11.5        46.0        46.0       2 R1tip       R1hub        R2tip       R2hub
  0.90        5.8        23           0.1000      1.0         B1axial      B2axial     NBLAD       THK      CFS
  0.0         0.0000      0.000       1.0000      1.0         StatorT      StatorM     StatorH     FSGV     CFMid
  0.9800      0.9500      1.1000      0.9000      1.0         AeroB1       AeroB2      POTS        POTH     CFHub
  0.89        0.89        0.89        0.0000      EfficiT     EfficiM      EfficiH     BLEED
  0.00        0.00        0.00        0.00        DUMMY       DUMMY        DUMMY       DUMMY
  0.880       0.16        1.35        0.00        SlipF       DiffLoss     Solidity    RPM2
 61.0000     56.0        42.5000      2.0         BetaBlade1T BetaBlade1M  BetaBlade1H expo3
 37.00       37.0        37.00        0           BetaBlade2T BetaBlade2M  BetaBlade2H stat2
 50.6        50.6         4.5        65.0         R3s         R3h          B3X         BetB3
 51           0.07        1.00        0.05        Blan3       Blathk3      Blok3       Wbar23
  0.0      1600.0         0.97        0.10        RCG         Athrt        BlokTH      Wbar2T
 75.00       75.00        4.5        30.0         R4S         R4H          B4X         BetB4
```

```
     51          0.07        0.95        1.40        Blan4       Blathk4      Blok4       SolidStat
     30.0        26.0        0.83        2.634       R7S         R7h          B7X         Length67
     4           0.1         0.98        0.00        Blan7       Blath7       Blok7       Wbar67
     30.0       26.0         0.0         10.53       R8S         R8h          B8X         Length78
     4           0.1         0.98        0.00        Blan8       Blath8       Blok8       Wbar78
```

7.6.2 Output File

comdes.out

```
*********************************************************************
**************** AXIAL & CENTRIFUGAL COMPRESSOR BLADE DESIGN 1-D ****
*******************   COMDES-MELT Release Version 1    **************
*********************   Gasplus Fluid Properties   ******************
*********************************************************************

      Centrifugal Compressor for CO2
 Fluid = CO2  RG           7   35.11364

  COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   1
  BLEED =  0.000   DPInc = 6.604   EfDer =  1.000    SH =  0.000000E+00

  W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
    3.0800   1666.7000      0.0773    383.6000      1.1000      0.9000      0.9800

  W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
    1.4000      3.0800      0.0000      0.0000   6619.7456      0.0000      0.0000

  W cor     RPM cor        GAMMA       Cp         R           Blades       THK         Area1UB
  503.6974   1938.1002      1.3317      0.1813     35.1136          23      0.1700   2538.5620

  CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
  233774.094       0.000   2.0535   2487.7908   1211.5072   1635.4521      1.3499   2534.7939

  Station   1.  ROTOR LEADING EDGE CONDITIONS, STAGE   1

          R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
  TIP     32.70     0.00    -0.02   248.08    -0.09   248.08     0.33     0.71   553.04    0.474
  MEAN    25.80     0.00    -0.02   225.52    -0.08   225.52     0.30     0.58
  HUB     16.20     0.00    -0.02   202.97    -0.07   202.97     0.27     0.41


        BetaFlo   BetaBlade Incid   U1       W1          Ps1    Ts1     TwetBulb1  RH
  TIP     62.46    55.80     6.66   475.61   536.50     0.07   376.82   383.60     0.00
  MEAN    59.00    52.40     6.60   375.32   437.93     0.07   377.99   383.60     0.00
  HUB     49.27    42.70     6.57   235.62   311.05     0.07   379.06   383.60     0.00

  Station   2.  ROTOR EXIT CONDITIONS, STAGE   1    SOLUTION IS CONVERGED
  B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
    6.7000      0.1700      0.9500          23   2014.7291   2146.9646

          R2       C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
  TIP     51.00    540.65   502.56   199.33   807.61     0.67    18.81    14.59    57.58
  MEAN    51.00    540.65   502.56   199.34   807.61     0.67    20.28    15.22    75.66
  HUB     51.00    540.65   502.56   199.34   807.61     0.67    21.12    16.21   212.37

         U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
  TIP    741.78   311.38   239.22     0.39 25633.45     0.89     0.89
  MEAN   741.78   311.39   239.22     0.39 25632.51     0.89     0.89     0.89     1.72
  HUB    741.78   311.39   239.22     0.39 25631.52     0.89     0.89

          Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH      Tt2avg  PR2avg
  TIP      0.16     2.01     0.12   465.74     1.21   433.52   465.74     0.00
  MEAN     0.16     2.01     0.12   465.74     1.21   433.51   465.74     0.00   465.74  2.01
  HUB      0.16     2.01     0.12   465.74     1.21   433.51   465.74     0.00

          Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
  TIP     68.37    50.20    37.00    13.20     0.88     0.84     1.35      0.00052     87
  MEAN    68.36    50.20    37.00    13.20     0.88     0.55     2.88      0.00047     99
  HUB     68.36    50.20    37.00    13.20     0.88     0.26     4.77      0.00058    106

  Station   3. STATOR ROW #1
  blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
    1.0000      4.0534          21   1818.7435    465.7393    465.7393      0.0000   1829.6636
```

```
 ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
 R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
  56.0000    506.0438   457.6877    215.8758    811.3214       0.6237      0.0968     15.8475

 Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
   0.1549      0.1205   437.5070       0.0000     64.7483     65.0000     -0.2517

 Station   4. STATOR / VANED DIFFUSER
 RCG         Cth         Cuth       Cmth       Aoth           Machth     cp 2-Th   Stat Chord
  56.0000    253.1019   175.8194    182.0663    830.7183       0.3047      0.6087     23.4572

 BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
   0.9700      0.1493      0.1404   458.6768    465.7393   2000.0000      0.1632      0.8896

 Station   5. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
 R4         C4          Cu4         Cm4        Ao4            Mach4      cp 3-4    Stator Gap
  83.0000    154.5870     77.2935    133.8763    834.7183       0.1852      0.7354      3.9619

 Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
   0.9500      0.1458    463.1047    465.7393     30.0000       0.1000      0.1674      0.7463

 STAGE EXIT CONDITIONS, STAGE             1
 Eff4         Pt4         PR          TR        Tt4          Del T      Ns          Ns nondim
   0.8309      0.1492      1.9297      1.2141    465.7393     82.1393     93.1419      0.7220

 Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
  372864.906       0.678      64.898    34129.4       0.00000  2565.85767  2711.82251

Fluid = CO2  RG           7   35.11364

 COMPRESSOR INLET CONDITIONS - ANALYSIS, STAGE   2
 BLEED =  0.000   DPInc = 7.877   EfDer =  0.999    SH =  0.000000E+00

 W act     RPM act        Pt        Tt            POTS        POTH        AeroBl
   3.0800   1666.7000      0.1492    465.7393      1.1000      0.9000      0.9800

 W Kg/sec    Wdry      H2Ovap_Lb/s  H2Ovap_g/m^3  m^3/min      IWAR        IWC
   1.4000      3.0800      0.0000      0.0000   4056.8645      0.0000      0.0000

 W cor     RPM cor        GAMMA       Cp         R           Blades       THK         Area1UB
 287.6216   1758.9120      1.3060      0.1928     35.1136          23      0.1000   2229.5464

 CFM          SCFM        A1/A*     Area1       A*          AthrRotor  ChokeMargin  AnnularArea
 143266.812    1590.676   3.1369   2184.9553    696.5395   1328.1255      1.9067   2226.6038

 Station   6.  ROTOR LEADING EDGE CONDITIONS, STAGE   2
         R1      Stator    Alfa     C1      CU1       Cm1       Mabs     Mrel   U1cor   FlowCoeff
 TIP     29.00     0.00    -0.02   173.10    -0.06   173.10     0.21     0.55   445.12    0.373
 MEAN    22.06     0.00    -0.02   157.37    -0.05   157.37     0.19     0.43
 HUB     11.50     0.00    -0.02   141.63    -0.05   141.63     0.17     0.27

       BetaFlo   BetaBlade Incid   U1       W1         Ps1    Ts1     TwetBulb1  RH
 TIP     67.69    61.00     6.69   421.80   455.99     0.14   462.63   465.74     0.00
 MEAN    63.88    56.00     7.88   320.85   357.41     0.15   463.17   465.74     0.00
 HUB     49.75    42.50     7.25   167.26   219.21     0.15   463.66   465.74     0.00

 Station   7.  ROTOR EXIT CONDITIONS, STAGE   2    SOLUTION IS CONVERGED
 B2 axial      THK        AeroBl     Blades2       Area2      Area2UB
   5.8000      0.1000      0.9500          23   1579.8632   1676.3539

         R2      C2       Cu2      Cm2     Ao2         Mach2    Chord  AxChord  Rcircle
 TIP     46.00   489.43   457.26   174.52   862.60     0.57    16.96    12.52    40.80
 MEAN    46.00   489.43   457.26   174.52   862.60     0.57    17.97    13.06    54.42
 HUB     46.00   489.43   457.26   174.53   862.60     0.57    18.10    13.91   188.58

        U2       W2       Wu2     MachRel2  DelRCu     Eff2uC  Eff2incC  AvgREff  Ws1/W2
 TIP   669.06   274.44   211.80     0.32 21035.65     0.89     0.89
 MEAN  669.06   274.44   211.80     0.32 21035.14     0.89     0.89     0.89     1.66
 HUB   669.06   274.44   211.80     0.32 21034.39     0.89     0.89

         Pt2       PR      Ps2     Tt2        TR     Ts2     TwetBulb2   RH     Tt2avg  PR2avg
 TIP      0.24     1.63     0.20   529.14     1.14   504.30   529.14     0.00
 MEAN     0.24     1.63     0.20   529.14     1.14   504.30   529.14     0.00   529.14  1.63
 HUB      0.24     1.63     0.20   529.14     1.14   504.30   529.14     0.00
```

```
        Alfa2  Beta FLO Beta BLADE  Deviat   Slip F. DiffFct   Solidity  Convergence Iter
TIP     69.11    50.51    37.00    13.51     0.88     0.85     1.35      0.00046     66
MEAN    69.11    50.51    37.00    13.51     0.88     0.52     2.98      0.00085     72
HUB     69.11    50.51    37.00    13.51     0.88     0.04     5.76      0.00064     78

Station   8. STATOR ROW #1
blockage3    XBladeGap  Vane#      Area3       Tt3        TwetBulb3      MeltFract   Area3UB
  1.0000      3.4781          51   1414.6163    529.1428    529.1428      0.0000   1430.6813

ROTOR-STATOR GAP EXIT: STATOR LEADING EDGE
R3m        C3          Cu3         Cm3        Ao3            Mach3      cp 2-3    Stat Ax Chd
 50.6000    458.2597    415.6907    192.8813    865.2158      0.5296      0.0732      5.8962

Pt3         Ps3        Ts3         RH3         FloAlpha3   VaneAlpha3   Incid3
  0.2406      0.2011    507.3655      0.0000     65.1086     65.0000      0.1086

Station   9. STATOR / VANED DIFFUSER
RCG         Cth         Cuth        Cmth       Aoth           Machth     cp 2-Th   Stat Chord
 50.6000    223.7194    155.4086    160.9303    879.2451      0.2544      0.6452      8.7275

BlockageTh   PtTh        PsTh      TsTh        TwetBulbTh  AreaTh       w2-Th     DiffFact4
  0.9700      0.2366      0.2269    523.9525    529.1428   1600.0000      0.1385      0.8843

Station  10. STATOR / VANED DIFFUSER EXIT (TRAILING EDGE):
R4         C4          Cu4         Cm4        Ao4            Mach4       cp 3-4   Stator Gap
 75.0000    142.2885     71.1442    123.2254    881.8345      0.1614      0.7660      1.4740

Blockage4    Ps4       Ts4         TwetBulb4    VaneAlpha4   Vane Thk4   w2-4OD      cp 2-4
  0.9500      0.2314    527.0432    529.1428     30.0000      0.0700      0.1673      0.7448

STAGE EXIT CONDITIONS, STAGE            2
Eff4         Pt4         PR           TR         Tt4          Del T      Ns          Ns nondim
  0.8282      0.2353      1.5776      1.1361     529.1428     63.4035     84.5678      0.6556

Del Enthalpy    Del_H/U^2     GHP     Reynolds#   Specif Humid Area4       Area4UB
 305988.000       0.684      53.258    33400.4       0.00000  1999.28467  2120.57495



OVERALL EXIT CONDITIONS; ALL           2   STAGES

Del Enthal   DelHT/U1^2  GHP      MassFloS1cor  OPR     Efficiency    Rotor1Inc  TR      AxHubLen
  678852.88     3.0010   118.1568  503.697      3.0443   0.81408       6.6040    1.3794   64.837
```

Appendix—Nomenclature

A	inlet area, in^2
a	speed of sound, ft/s
B	edge sweep, in.
C	absolute velocity, ft/s
$\overline{C}$	chord, in.
c_P	specific heat at constant pressure, Btu/(lbm·R)
DF	diffusion factor, dimensionless
D_v	diffusion coefficient of water vapor into air, ft^2/s
d	ice particle size (diameter), m
F	molar flow rates, mol/s
g_c	unit conversion, 32.2 lbm·ft/(lbf·s^2)
ΔH	enthalpy change, ft^2/s^2
h	convective heat transfer coefficient, Btu/(h·ft^2·R)
h_m	mass transfer coefficient, ft/s
IWC	ice water content, kg/m^3
i	incidence angle, deg
J	units conversion, 778.28 ft·lbf/Btu
k	thermal conductivity, Btu/(h·ft·R)
L	latent heat, Btu/lbm
L_s	latent heat of sublimation, Btu/lbm
L_v	latent heat of evaporation, Btu/lbm
Le	Lewis number, dimensionless
M	Mach number, dimensionless
M_a	molecular weight of air
M_w	molecular weight of water vapor
M_{wet}	molecular weight of air and water mixture
m	mass flow rate, lbm/s
$\dot{m}$	evaporation rate of water, lbm/h
N	number of airfoils, dimensionless
Nu	Nusselt number, dimensionless
n_{melt}	melt fraction, dimensionless
P	pressure, psia
P_a	partial pressure of air, psia
P_w	partial pressure of water vapor, psia
$\overline{P}$	power, hp
Pr	Prandtl number, dimensionless
Q	volumetric flow, ft^3/min
$\dot{q}$	heat flux, Btu/(s·in^2)
$\mathfrak{R}$	universal gas constant, 1545.5 ft·lbf/(lbm·mol·R)
R	Gas constant, ft·lbf/(lbm·R)
r	blade radius, in.
r_H	blade hub radius, in.
r_T	blade tip radius, in.

r_c	arc radius of blade at midchord, in.
Sc	Schmidt number, dimensionless
Sh	Sherwood number, dimensionless
S_h	specific humidity
T	temperature, R
T_M	averaged temperature of control volume, R
t	time, s
U	rotor peripheral velocity, ft/s
V	velocity, ft/s
$\tilde{V}$	control volume
W	relative velocity
W_a	flow rate of air, lbm/s
W_w	flow rate of water vapor, lbm/s
w	mass fraction, dimensionless
X	distance from blade leading edge to circular arc center coordinates, in.
x	distance, in.
Y	distance from blade trailing edge to circular arc center coordinates, in.
Φ	rotor flow coefficient, dimensionless
α	absolute flow angle, deg
β	edge angles, deg
γ	ratio of specific heats
γ_{wet}	ratio of specific heats of air and water mix, dimensionless
δ	slip factor, dimensionless
η	rotor total-to-total adiabatic efficiency, dimensionless
θ	blade arc angle, deg
λ	aerodynamic blockages, dimensionless
μ	viscosity of air, absolute, lbm/(ft·s)
ρ	density, lbm/ft^3
σ	blade tip solidity, dimensionless
τ_T	thermal response time, s
ϕ	relative humidity, dimensionless
χ	mole fraction, dimensionless
ω	loss coefficient, dimensionless

Subscripts

1	leading edge rotor
2	trailing edge rotor (gap inlet)
3	leading edge stator (gap outlet)
4	trailing edge stator
a	air
B	blade metal
convection	
d	ice particle diameter

evaporation	
exit	
F	flow
f	freezing
H	hub
i	ice
inlet	
M	meridional
melt	ice melt
o	initial
R	rotor
S	static
s	water vapor at surface or sublimation
sat	saturated
T	tip or thermal
t	total
U	tangential
V	stator vane
v	evaporation
WB	wet-bulb
WBS	wet-bulb static
w	water vapor
wet	air and water mixture
∞	free-stream

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