# NASA HIGH EFFICIENCY CENTRIFUGAL COMPRESSOR DATA ARCHIVE

**Contact and Maintainer:**
Herbert "Trey" Harrison
herbert.harrison@nasa.gov
NASA Glenn Research Center
Cleveland, OH

**Contributors:**
Tammy Nguyen-Huynh
NASA Glenn Research Center
Cleveland, OH

## SUMMARY

*The datasets contained in this archive are associated with the High Efficiency Centrifugal Compressor (HECC) in the Small Engine Components Compressor Test Facility, colloquially referred to as CE-18, at NASA Glenn Research Center. The archive is accessible at https://storage.googleapis.com/hecc-data/NASA-HECC-Data-Archive.zip. The documentation contained herein provides context for the data hosted on data.nasa.gov. The datasets and accompanying content in this document will be updated periodically as additional data is procured and analyzed. The revision of the document is provided by date in the footer, and the revision updates are provided in the Revisions section. Please contact Trey Harrison (email: herbert.harrison@nasa.gov) for inquiries related to the dataset and documentation or to be added to an email list to be notified of updates and additions to the archive.*

## 1. CONTENTS

## 2. REVISION HISTORY

| | |
|---|---|
| March 2023 | Initial publication of archive with HECC vaned diffuser, vaneless diffuser, and transition duct data at design tip clearance. |
| August 2023 | • Included notes about geometry discrepancies between models and blade sections (Section 4.5)<br>• Provided HECC impeller cold blade sections (Section 6.2 Coordinates – HECC Impeller Cold Coordinate HECC As-Manufactured Cold Coordinates (Cold, With Fillets))<br>• Added HECC vaneless diffuser solid model (Section 7.6 Models) |
| February 2024 | • Section 4.5 Design-Intent and As-Manufactured Geometry Differences updated<br>• Added tip clearance data to the archive and Read-Me<br>• Section 7.3 Data – Transition Duct Inlet updated to include relevant impeller exit survey metadata<br>• Publications added to HECC Data Archive |
| July 2024 | • Updates throughout the archive to clarify geometry, in particular to Section 4.5 Design-Intent and As-Manufactured Geometry Differences<br>• Geometry nomenclature updated for clarity<br>• Added inlet survey data (Section 6.4 Data - Stage Inlet Surveys)<br>• Added Turbo Expo 2024 publications |

## 3. NOMENCLATURE

$b$ blade height
$c_p$ specific heat at constant pressure
$D$ diameter
$\dot{m}$ mass flow rate
$N_c$ corrected speed
$r$ radius
$T$ temperature
$U$ wheel speed
$\rho$ density
$\Phi$ inlet flow coefficient
$\psi$ Loading coefficient

### 3.1 Acronyms

BLM baseline metal (inlet)
BLP baseline plastic (inlet)
EGV exit guide vane
FLA forward looking aft
HECC High Efficiency Centrifugal Compressor
MH modified hub (inlet)
TPR total pressure ratio
TDC top dead center

## 4. GENERAL NOTES

### 4.1 Convention

The coordinate system for the entire HECC vaned data set is cylindrical with the impeller axis of rotation serving as the axis of rotation in the coordinate system. Per the convention in the report published by Medic et al. [1], the axial coordinate is 0 at the impeller leading edge and increasing in the forward-looking-aft (FLA) direction. The distance units in this section are in inches. Finally, the azimuthal direction is oriented such that top dead center (TDC) is equivalent to 0° and positive counter-clockwise oriented from the FLA direction which corresponds to the direction of the impeller rotation.

### 4.2 Backface Bleed

The mass flow rate through the backface bleed flow path is not measured directly. However, the differential pressure across the labyrinth seal at the impeller backface is recorded at all times. This value is documented in the parameter `CLSDP`. A positive value of `CLSDP` indicates flow out from the main flow path exiting through the backface bleed. Typically, `CLSDP` is maintained at a value of approximately 0.5psid. In some cases, the value is set to 0.0psid with goal of reducing the assumptions in numerical simulations which do not account for bleed flow.

### 4.3 Gas Properties

Real gas properties were used in calculation of any given performance or corrected parameters associated with the experimental data accounting for humidity. The calculations were conducted in REFPROP [2] according to the procedures given by Berdanier et al. [3] and Lou et al. [4].

### 4.4 Tip Clearance

Tip clearance is measured at 3 locations in the HECC: inlet, knee, and exducer. At each meridional location, there is only a single tip clearance probe, and the runtime value of tip clearance is set based on the single tip clearance value at the exducer. However, rub probes are used to calibrate the tip clearance probes as well as to evaluate the eccentricity of the impeller clearance. Based on the eccentricity, the measured value of tip clearance at the exit (`TCEX1`) is set to compensate for the eccentricity. As such, refer to the channel `TCEXSET` for the "set" value of the tip clearance. The difference between `TCEX1` and `TCEXSET` for each dataset will be documented throughout the relevant sections of this document. Details of the tip clearance measurements are given in reference [5].

### 4.5 Design-Intent and As-Manufactured Geometry Differences

Detailed investigations presented by Robles Vega et al. [6] have identified significant differences between the intended design blade sections of the HECC impeller (provided in the HECC Vaned Diffuser Report [1]) and the actual, manufactured impeller geometry. A summary of the findings is as follows:

1) The physical, manufactured HECC impeller is different from the intended design geometry (referred to hereafter as the "Design-Intent Geometry") presented by Medic et al. [1] with key differences in the splitter leading edge metal angle, impeller exit radius, and blade thickness. These differences are too great to be attributed to errors in the hot-to-cold transformation process.
2) The physical, manufactured HECC impeller (referred to hereafter as the "As-Manufactured Geometry) is accurately represented at cold, unloaded conditions by the solid models contained in the HECC Data Archive.
3) The Design-Intent Geometry achieves improved performance relative to the As-Manufactured Geometry.

Users of the Data Archive are strongly encouraged to, at minimum, read Robles Vega et al.'s Abstract and Conclusions sections.

Guidelines for use of the HECC geometry are as follows:

1) The Design-Intent Geometry was used for the pre-test performance predictions of HECC. It is the intended shape of the impeller at hot, loaded conditions.
2) The As-Manufactured Geometry is the actual, fabricated impeller geometry that has been experimentally tested. All experimental results are for the As-Manufactured Geometry.
3) The impeller solid model contained in the data archive is an accurate representation of the As-Manufactured Impeller at cold, unloaded conditions.
4) The discrepancies between the Design-Intent and As-Manufactured Geometries appear to be isolated to the impeller. If further discrepancies are observed, please contact Trey Harrison at herbert.harrison@nasa.gov to notify NASA of the issue.

**TABLE 1.** HECC VANED CONFIGURATION BLADE NUMBERS.

| | |
|---|---|
| Impeller blade number (main/splitter) | 15/15 |
| Diffuser vane number (main/splitter) | 20/20 |
| Exit guide vane number | 60 |

## 5. INTRODUCTION

The High Efficiency Centrifugal Compressor (HECC) was developed with the following goals according to Medic et al. [1]:

- to identify key technical barriers in the advancement of state-of-the-art of small centrifugal compressor stages,
- delineate measurements required to provide insight into the flow physics of the technical barriers,
- to design, fabricate, install, and test a state-of-the-art research compressor that is representative of the rear stage of an axial-centrifugal aero-engine,
- and acquire detailed aerodynamic performance and research quality data to clarify flow physics and establish detailed data sets for future application.

At the present revision, there are two different diffuser configurations and three different inlet configurations available for the HECC. The originally developed vaned diffuser featured aggressive design targets intended to advance state-of-the-art technology, and the follow-up vaneless diffuser test was developed to better understand the impeller performance in isolation from the vaned diffuser. The three inlet configurations are the (1) baseline metal inlet, (2) baseline plastic inlet, and (3) modified-hub plastic inlet. The baseline metal and baseline plastic inlets are the exact same, but as suggested by their names, manufactured from metal and plastic, respectively. The modified-hub inlet features the same shroud contour as the baseline inlets, but the hub curvature is more aggressive. The modified-hub inlet was developed to understand the effect of an aggressive S-duct configuration on centrifugal compressor performance.

Extensive documentation of the HECC vaned diffuser stage design and performance can be found in the report published by Medic et al. [1]. Braunscheidel et al. [7] give a briefer review of the vaned diffuser configuration with less emphasis on the design process as well as additional aerodynamic data. A facility published in 2023 by Harrison et al. documents the present state of the Small Engine Components Compressor Test Facility and vaneless diffuser performance with all three inlet configurations [8]. Robles Vega et al. [9], Robles Vega et al. [6], and Harrison et al. [5], review the Design-Intent and As-Manufactured impeller geometries in detail and extensively investigate the effect of the size of the tip gap on the impeller performance and flow physics. All publications relevant to the HECC published with NASA affiliation are included in the *Publications* directory.

In the interest of brevity, the details of each of those reports is not contained herein. Instead, this document serves the specific purpose of being a map for navigation and utilization the open experimental data associated with the HECC test article. The proceeding sections give the structure of the directories in the dataset and necessary details for utilization of data, such as column header descriptions.

## 6. HECC VANED DIFFUSER DATA SET

The *HECC Vaned Configuration* directory contains the *Coordinates*, *Data*, and *Models* subdirectories which contain blade section information, experimental data, and solid models, respectively, associated with the HECC vaned diffuser configuration. For reference, the blade numbers of each component in the stage are provided in Table 1. The convention for the dataset is given in Section 4.1 Convention.

### 6.1 Coordinates – HECC Design-Intent Stage Coordinates (Hot, No Fillets)

The *HECC Design-Intent Stage Coordinates (Hot, No Fillets)* directory contains the Design-Intent hub, shroud, impeller main blade, impeller splitter blade, diffuser main vane, diffuser splitter vane, and exit guide vane (EGV) coordinates of the HECC vaned diffuser configuration. The Design-Intent Impeller differs from the As-Manufactured Impeller as discussed in Section 4.5 Design-Intent and As-Manufactured Geometry Differences. As of the present revision to the archive, the differences between the As-Manufactured and Design-Intent Geometries are isolated to the impeller, and there is good agreement between Design-Intent and As-Manufactured Geometries for the diffuser vanes and the exit guide vanes.

The component defined by the files is explicitly included in each file name. The blade sections are as given in the original report published by Medic et al. [1] and reproduced here do not include the fillets that are present in the actual hardware on the impeller blades, diffuser vanes, and exit guide vanes. The fillets on the hardware can be viewed in the solid model discussed in section 6.5 Models. The coordinates account for the expected deformation of the components associated with the temperatures and loadings of the stage at design conditions.

With the exception of the flow path hub and shroud files, the coordinates are space delimited with three columns. A single line header defines the columns: `X`, `R*THETA`, and `R` which correspond to the axial, radius*angle, and radial directions. Specifically, the `R*THETA` column is the radial coordinate multiplied by the azimuthal coordinate in radians. The blade sections are specified in single complete loops for each file with the lowest increment in the filename corresponding the hub location and increasing increment moving towards the shroud.

The flow path hub and shroud files contain only two columns and are tab delimited. The column headers `x` and `r` are the axial and radial coordinate, respectively, given in inches and radians.

### 6.2 Coordinates – HECC Impeller Cold Coordinate HECC As-Manufactured Cold Coordinates (Cold, With Fillets)

The *HECC As-Manufactured Cold Coordinates (Cold, With Fillets)* contains the As-Manufactured impeller blade section data extracted from the impeller solid model contained in the Data Archive. The impeller blade sections are given in the same convention as specified in 6.1 Coordinates – HECC Design-Intent Stage Coordinates (Hot, No Fillets).

## 6.3 Data

The *Data* directory contains multiple files. Critical to interpretation of the actual data is the *HECCvaned_metaData.csv* which contains metadata associated with the instrumentation and calculated parameters of the experiment in comma delimited format. Excluding the single line header, each row is either instrumentation from the experiment or a calculated quantity. The single line column header has entries with data in each column as follows:

- `CN`: channel name corresponding to value in data files
- `DESCRIPTION`: description of the channel
- `UNITS`: units of the channel
  - `DEG F`: degrees Fahrenheit
  - `DEG R`: degrees Rankine
  - `MIL`: thousandths of an inch
  - `PSIA`: absolute pressure in lbf/in$^2$
  - `PSID`: differential pressure in lbf/in$^2$
  - `RPM`: rotations per minute
- `CAT`: category of the channel
  - `AERO` for aerodynamic instrumentation
  - `CALC` for calculated parameter
  - `FLAG` for noting data purpose or instrumentation configuration
- `SCAT`: subcategory for instrumentation type
  - `DP`: differential pressure
  - `MISC`: miscellaneous
  - `PS`: static pressure
  - `PT`: total pressure
  - `RH`: relative humidity
  - `RPM`: rotational speed
  - `TC`: tip clearance
  - `TM`: metal temperature
  - `TT`: total temperature
- `R`: radial coordinate of instrumentation in inches
- `THETA`: azimuthal coordinate of instrumentation in degrees (see section 6 for convention)
- `Z`: axial coordinate of instrumentation in inches (see section 6 for convention)
- `SPAN`: spanwise location of instrumentation in percent increasing from hub=0% to shroud=100%

**TABLE 2.** HECC VANED **`DFLAG`** (DATA FLAG) INTERPRETATION.

| `DFLAG` Value | Meaning |
|---|---|
| 1 | Steady-state speedline recording |
| 8 | Stage inlet survey |

**TABLE 3.** HECC VANED **`CLFAG`** (CONFIGURATION FLAG) INTERPRETATION.

| `CLFAG` Value | Meaning |
|---|---|
| 1 | Modular vane total pressure rakes installed at position 1 (`MODVN1`) and position 2 (`MODVN2`) |
| 6 | Cobra-style 3-hole probe installed in the inlet duct upstream of the impeller |

- `DPITCH`: diffuser pitch location of instrumentation in percent increasing from suction side to pressure side of the diffuser vane (in the direction of impeller rotation)
- `EGVPITCH`: exit guide vane pitch location of instrumentation in percent increasing from suction side to pressure side of the diffuser vane (in the direction of impeller rotation)

Blank fields throughout the *HECCvaned_metaData.csv* spreadsheet are generally not relevant to the associated parameter.

Of particular note in the meta data are the `RDG`, `DFLAG`, and `CFLAG` parameters. Each data entry has a unique identifier referred to as a reading number that is stored in the `RDG` column of the data spreadsheet. The `DFLAG` parameter is an integer flag identifier to signal the type of reading recorded. `CFLAG` is also an integer flag identifier used to note the configuration of the compressor at the time of the respective reading. For example, this may indicate the presence or absence of survey probes or modular vanes. The integer values for the `DFLAG` and `CFLAG` used in the publicly available datasets hosted in the archive at the time of writing and their associated meanings are given in Table 2 and Table 3.

### *6.3.1 Tip Clearance*

Due to the eccentricity of the impeller relative to the shroud, the tip clearance at the impeller trailing edge varies around the circumference of the exducer. Based on the eccentricity measurements recorded with rub probes, the capacitance probe reading recorded in channel `TCEX1` is 0.003" less than the maximum clearance around the circumference. During all vaned diffuser testing discussed in Section 6, `TCEX1` was set such that the maximum clearance value around the circumference was equivalent to the intended value for clearance. The intended value for clearance is saved in the channel `TCEXSET`. `TCEXSET` is obtained by adding the difference between `TCEX1` and the maximum clearance around the circumference (again, in this section, 0.003").

As an example, if the intended value for a reading is .012", the impeller would be translated axially until the value for `TCEX1` was equal to 0.009". Since the difference between `TCEX1` and the maximum clearance value is 0.003", the maximum clearance would be 0.012", and the value of 0.012" would be recorded in the channel `TCEXSET`. In practice, the recorded values in these channels are usually with 0.0005" of the target value. Further details on the tip clearance variation in the vaned diffuser testing documented herein are given by Braunscheidel et al. [7].

*6.3.2 Experimental Data*

The experimental data is stored in separate files based on tip clearance setting. As noted in section 6.2.1, the tip clearance setting is the maximum tip clearance around the circumference and is stored in channel `TCEXSET`.

In the present revision, detailed experimental data at the design tip clearance is provided in the *HECCvanedData_12MilExitClearance.csv* file, and the compressor map in Figure 1 gives an overview of the data contained therein. The channels and descriptions in the data are included in the previously described *HECCvaned_metaData.csv* file.

### 6.4 Data - Stage Inlet Surveys

Stage inlet surveys were conducted with a cobra-style three-hole probe upstream of the impeller to quantify the flow angle and total pressure provided to the impeller. The surveys were acquired at numerous operating conditions throughout the compressor map, Figure 2. The target operating conditions for many of the surveys was an exit corrected mass flow rate of 3-lbm/s, which can be observed in Figure 3 where the stage total pressure ratio is given as a function of the stage exit corrected mass flow rate. The surveys are obtained by traversing the probe across the span of the inlet duct at an axial coordinate of -1.00 inches. The compressor is maintained at the same

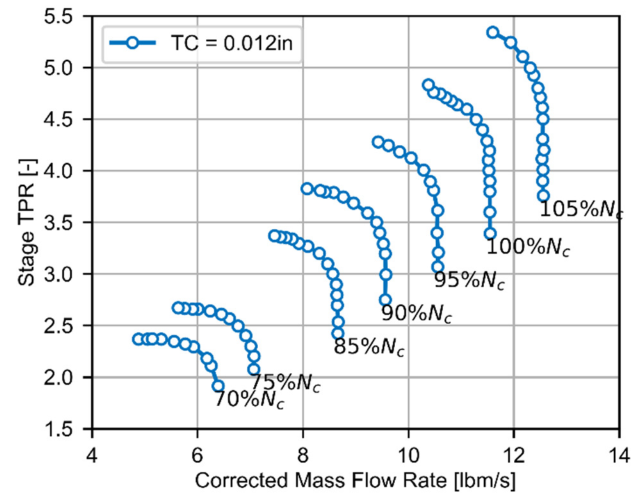


**FIGURE 1: HECC VANED DIFFUSER CONFIGURATION COMPRESSOR MAP AT 0.012" IMPELLER TRAILING EDGE CLEARANCE.**

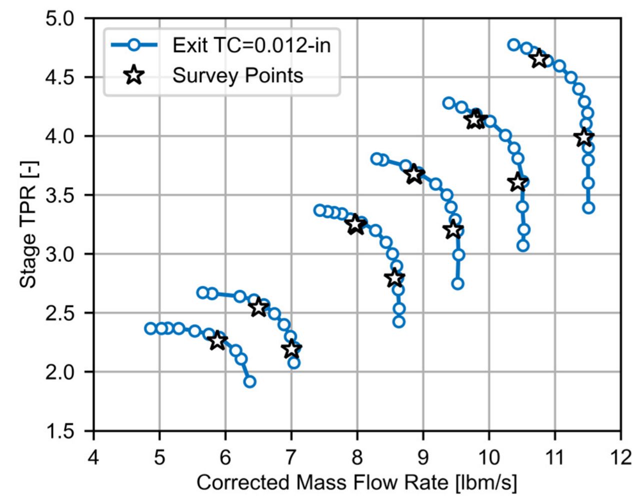


**FIGURE 2: HECC VANED DIFFUSER CONFIGURATION MAP WITH INLET SURVEY LOCATIONS INDICATED.**

operating condition throughout the survey. An example of processed survey data is given in Figure XXX. The *Data* directory contains the *Stage Inlet Surveys* directory which in turn contains the stage inlet surveys.

The filenames within the directory indicate the operating condition at which the surveys were collected and are in the following format:

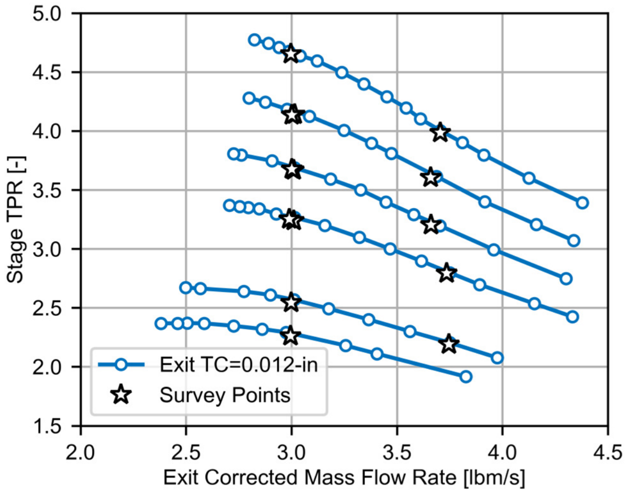


**FIGURE 3: HECC VANED DIFFUSER CONFIGURATION MAP IN TERMS OF EXIT CORRECTED MASS FLOW RATE WITH INLET SURVEY LOCATIONS INDICATED.**

- *inletFlowAngleSurvey_XXXNc_XXexitTC_X.XlabSeal_XX.XXmdot_X.XXTPR.csv*

Each series of characters between the underscores gives a specification of the operating conditions, and each X character is a numeric character giving values for each of the performance parameters within the name. The type of survey is initially given, followed by the percent corrected speed in three digits (a leading 0 is present at speeds less than 100%), tip clearance set point in thousandths of an inch, labyrinth seal differential pressure (see sections 4.2 Backface Bleed and 7.3.2 Baseline Experimental Datasets) corrected mass flow rate, and stage total pressure. As an example, the file *inletFlowAngleSurvey_099Nc_13exitTC_0.5labSeal_11.44mdot_5.02TPR.csv* is stage inlet flow angle survey recorded at 99% corrected speed, an exducer exit clearance of 0.013-in, a labyrinth seal differential pressure of 0.5psid, corrected mass flow rate of 11.44-lbm/s, and a total pressure ratio of 5.02.

The data within each of the survey files is structured similarly to the previously discussed steady state data, and only a few small changes are incorporated to accommodate the inclusion of survey data. The relevant probe survey channels are outlined in Table 4 with additional details included in the *HECCvaned_metaData.csv* file, the structure of which is detailed in Section 6.3 Data.

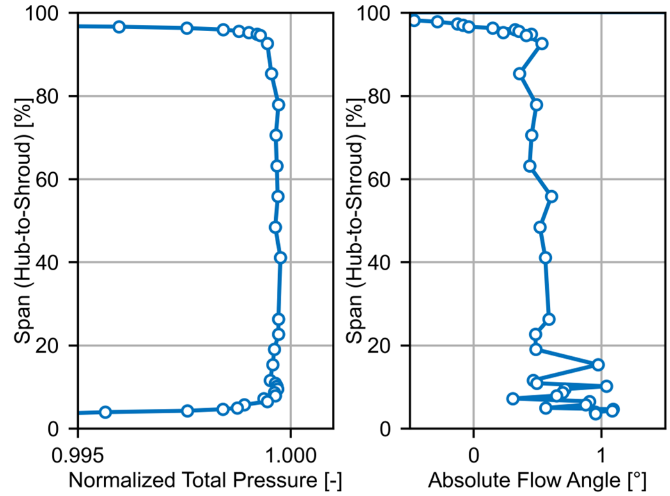


**FIGURE 4: HECC INLET SURVEY DATA AT 100% CORRECTED SPEED, 10.76-LBM/SEC INLET MASS FLOW RATE.**

**TABLE 4.** HECC VANED INLET SURVEY CHANNELS OVERVIEW (SEE METADATA FILE FOR DETAILS).

| Channel | Summary |
|---|---|
| `PROBESPAN` | Probe location in percent span from hub (0%) to shroud (100%) |
| `INLETPT` | Calculated value of total pressure from the inlet survey probe |
| `INLETALPHA` | Calculated value of inlet absolute flow angle from the inlet survey probe |

Each individual survey recording is identified by a unique reading number given in the survey data files. Generally, the location of the probe in the `PROBESPAN`, `INLETPT`, or `INLETALPHA` channels will change with each reading to build the survey of data across the span of the inlet duct. In addition to the unique reading numbers in the `RDG` column, a `MEAN` row is provided. The `MEAN` row is the average of the steady performance parameters recorded for each unique reading within the survey to give the average operating conditions over the entire survey acquisition process.

General notes on the survey data files:

- Any values for span data greater than 100% (PROBESPAN channel) indicate the probe is recessed within the shroud.
- The MEAN values are not applicable for the survey channels themselves, as the probe location changes throughout the survey.
- The processed flow angle data is obtained through the method given by Treaster and Yocum [10].

### 6.5 Models

A solid model of the HECC vaned diffuser stage is available in the *Models* directory in the form of a step file, *HECCvaned_AsManufacturedStage_cleanGeometry.stp*. The model is a simplified version of the original detailed model of the stage with extraneous features, such as instrumentation and components beyond the bounds of the stage, removed. The fillets on the blades of the impeller, vaned diffuser, and EGV are all included. Unfortunately, due to the complexity of the impeller model, the impeller often contains defects after exporting from various modelling packages. To help mitigate this issue, a separate impeller model is included in the *HECC_AsManufacturedImpeller_cleanGeometry.stp* file. Both models provide the As-Manufactured geometry of the compressor stage and components at cold, unloaded conditions.

## 7. HECC VANELESS DIFFUSER DATA SET

The *HECC Vaneless Configuration* directory contains the *Coordinates*, *Data - Baseline Metal Inlet*, *Data - Transition Duct Inlet*, and *Models* directories. While the inlet configuration and diffuser configuration are different from the vaned diffuser configuration, the impeller is unchanged. The convention for the dataset is given in Section 4.1 Convention, and the impeller blade number data are given in Table 1. A review of the vaneless diffuser performance is provided by Harrison, McNichols, and Blaha [8].

### 7.1 Coordinates

The *Vaneless Hub and Shroud - Baseline Metal Inlet (Hot)* directory contains the hot hub and shroud profiles of the vaneless diffuser configuration with the baseline metal inlet. The impeller is unchanged throughout the configurations, so the impeller blade sections are not repeated in the vaneless diffuser directory. However, they can be retrieved from the vaned configuration blade sections as documented in Section 6.1 Coordinates – .

### 7.2 Data – Baseline Metal Inlet

The *Data – Baseline Metal Inlet* directory is structured in the similar fashion to that of the vaned diffuser data directories. Critical to interpretation of the actual data is the *HECCvaneless_baselineMetalInlet_metaData.csv* which contains metadata associated with the instrumentation and calculated parameters of the experiment in comma delimited format. Excluding the single line header, each row is either instrumentation from the experiment or a calculated quantity. The single line column header has entries with data in each column as follows:

- CN: channel name corresponding to value in data files
- DESCRIPTION: description of the channel
- UNITS: units of the channel
  - DEG F: degrees Fahrenheit
  - DEG R: degrees Rankine
  - MIL: thousandths of an inch
  - PSIA: absolute pressure in lbf/in$^2$
  - PSID: differential pressure in lbf/in$^2$
  - RPM: rotations per minute
- CAT: category of the channel
  - AERO for aerodynamic instrumentation
  - CALC for calculated parameter
  - FLAG for noting data purpose or instrumentation configuration
- SCAT: subcategory for instrumentation type
  - DP: differential pressure
  - MISC: miscellaneous
  - PS: static pressure
  - PT: total pressure
  - RH: relative humidity
  - RPM: rotational speed
  - TC: tip clearance
  - TM: metal temperature
  - TT: total temperature
- R: radial coordinate of instrumentation in inches
- THETA: azimuthal coordinate of instrumentation in degrees (see section 6 for convention)
- Z: axial coordinate of instrumentation in inches (see section 6 for convention)
- SPAN: spanwise location of instrumentation in percent increasing from hub=0% to shroud=100%

**TABLE 5.** HECC VANELESS BASELINE METAL INLET **DFLAG** (DATA FLAG) INTERPRETATION.

| DFLAG Value | Meaning |
| --- | --- |
| 1 | Steady-state speedline recording |

**TABLE 6.** HECC VANELESS BASELINE METAL INLET **CLFAG** (CONFIGRUATION FLAG) INTERPRETATION.

| CLFAG Value | Meaning |
| --- | --- |
| 8 | Modular vane static pressure tap series installed (PMV3 and PMV4) |

- SETTINGANGLE: angle of the instrumentation relative to axial direction (only relevant to stage exit total pressure rakes)

Blank fields throughout the *HECCvaneless_baselineMetalInlet_metaData.csv* spreadsheet are generally not relevant to the associated parameter.

Of particular note in the meta data are the RDG, DFLAG, and CFLAG parameters. Each data entry has a unique identifier referred to as a reading number that is stored in the RDG column of the data spreadsheet. The DFLAG parameter is an integer flag identifier to signal the type of reading recorded. CFLAG is also an integer flag identifier used to note the configuration of the compressor at the time of the respective reading. For example, this may indicate the presence or absence of survey probes or modular instrumentation. For the vaneless diffuser, various types of modular instrumentation may be installed from the shroud via access ports. The options for modular instrumentation are actuated probes which can be traversed across the span, total pressure rakes, total temperature rakes, and a series of static pressure taps.

The integer values for the DFLAG and CFLAG used in the publicly available datasets hosted in the archive at the time of writing and their associated meanings are given in Table 5 and Table 6. For the different configurations indicated by CFLAG, the channels in the data files are unchanged. This results in cases where the channels exist, but do not contain valid data. For clarity, the channels which are not connected during testing but still exist in the file, the entries in the column are empty.

#### *7.2.1 Tip Clearance*

Due to the eccentricity of the impeller relative to the shroud, the tip clearance at the impeller trailing edge varies around the circumference of the exducer in the same manner as the vaned diffuser testing. The details of the tip clearance measurement are given in Section 6.3.1 Tip Clearance. In brief summary, the parameter TCEXSET contains the intended value of tip clearance at the impeller exit.

#### *7.2.2 Experimental Data*

The experimental data is stored in separate files based on tip clearance setting. As noted in section 7.2.1 Tip Clearance, the tip clearance setting is the maximum tip clearance around the circumference and is stored in channel TCEXSET.

In the present revision, detailed experimental data at the design tip clearance is provided in the *HECCvanelessData_baselineMetalInlet_12MilExitClearance.csv* file, and the compressor map in Figure 5 gives an overview of the data contained therein. The channels and descriptions in the data are included in the previously described *HECCvaneless_baselineMetalInlet_metaData.csv* file.

Finally, as noted by Harrison [8], the total temperature rakes at the impeller exit failed before reaching high speeds in the vaneless diffuser test campaign. As such, there are no total temperature measurements available at the impeller trailing edge. However, the stage total temperature rakes were functional through the entire test campaign. Additionally, the impeller exit total temperature rakes were redesigned for the transition duct test, and that data was successfully acquired and recorded. The impeller exit total temperature data is available in the transition duct data files.

### 7.3 Data – Transition Duct Inlet

The *Data – Transition Duct Inlet* directory is structured in the similar fashion to that of the vaneless diffuser data directories. At the present revision, a single metadata file, *HECCvaneless_tDuct_metaData.csv*, provides the information for the instrumentation and calculated parameters in the experimental data. Excluding the single line header, each row is either instrumentation from the experiment or a calculated quantity. Each column has headers and entries as follows:

- CN: channel name corresponding to value in data files
- DESCRIPTION: description of the channel

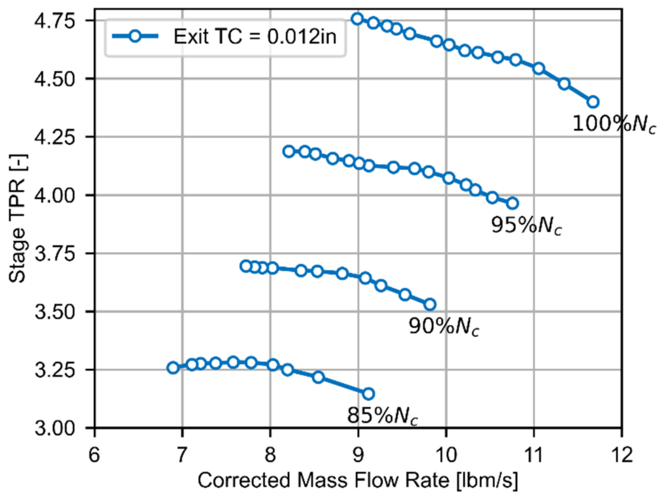


**FIGURE 5: HECC VANELESS DIFFUSER BLM CONFIGURATION COMPRESSOR MAP AT 0.012" IMPELLER TRAILING EDGE CLEARANCE.**

- `UNITS`: units of the channel
  - `DEG F`: degrees Fahrenheit
  - `DEG R`: degrees Rankine
  - `MIL`: thousandths of an inch
  - `PSIA`: absolute pressure in lbf/in$^2$
  - `PSID`: differential pressure in lbf/in$^2$
  - `RPM`: rotations per minute
- `CAT`: category of the channel
  - `AERO` for aerodynamic instrumentation
  - `CALC` for calculated parameter
  - `FLAG` for noting data purpose or instrumentation configuration
- `SCAT`: subcategory for instrumentation type
  - `DP`: differential pressure
  - `MISC`: miscellaneous
  - `PS`: static pressure
  - `PT`: total pressure
  - `RH`: relative humidity
  - `RPM`: rotational speed
  - `TC`: tip clearance
  - `TM`: metal temperature
  - `TT`: total temperature
- `R`: radial coordinate of instrumentation in inches
- `THETA`: azimuthal coordinate of instrumentation in degrees (see section 6 for convention)
- `Z`: axial coordinate of instrumentation in inches (see section 6 for convention)

**TABLE 7.** HECC VANELESS TRANSITION DUCT INLET **`TDFLAG`** (DATA FLAG) INTERPRETATION.

| `TDFLAG` Value | Meaning |
|---|---|
| 0 | Baseline inlet, additively manufactured ASA |
| 1 | Modified-hub inlet, additively manufactured ASA |

**TABLE 8.** HECC VANELESS TRANSITION DUCT **`DFLAG`** (DATA FLAG) INTERPRETATION.

| `DFLAG` Value | Meaning |
|---|---|
| 1 | Steady-state speedline reading |
| 5 | Impeller exit survey reading |

**TABLE 9.** HECC VANELESS TRANSITION DUCT **`CLFAG`** (CONFIGRUATION FLAG) INTERPRETATION.

| `CLFAG` Value | Meaning |
|---|---|
| 0 | Modular vane total pressure rakes are installed at impeller exit rating station (PMV1 and PMV2 series instrumentation) |
| 1 | 3-hole cobra style probes are installed at the impeller exit rating station (MV1C and MV2C series instrumentation) |
| 2 | Total temperature probes are installed at the impeller exit rating station (MV1TT and MV2TT) |

- `SPAN`: spanwise location of instrumentation in percent increasing from hub=0% to shroud=100%
- `SETTINGANGLE`: angle of the instrumentation relative to axial direction (only relevant to stage exit total pressure rakes)

Blank fields throughout the *HECCvaneless_tDuct_metaData.csv* spreadsheet are generally not relevant to the associated parameter.

Key meta data for the transition duct are the `RDG`, `DFLAG`, and `CFLAG` parameters, and though the information for each of the flags is quite similar to that in section 7.2 Data – Baseline Metal Inlet, the content is repeated here for convenience and clarity. Additionally, the transition duct data contains an additional flag, `TDFLAG`, which indicates the configuration of the additively manufactured transition duct inlet. All transition duct inlet configurations are manufactured from Stratasys acrylonitrile styrene acrylate (ASA). The values and meanings of `TDFLAG` are given in Table 7, and a detailed review of the transition duct configurations can be found in Harrison et al [8]. For the modified hub inlet (`TDFLAG` =1), some static pressure taps along the hub of the inlet flow path are lost. In the case where those channels are invalid, the entries in the column are empty.

Each data entry has a unique identifier referred to as a reading number that is stored in the `RDG` column of the data spreadsheet. The `DFLAG` parameter is an integer flag identifier to signal the type of reading recorded. `CFLAG` is also an integer flag identifier used to note the configuration of the compressor at the time of the respective reading. For example, this may indicate the presence or absence of survey probes or modular instrumentation. For the vaneless diffuser, various types of modular instrumentation may be installed from the shroud via access ports. The options for modular instrumentation are actuated probes which can be traversed across the span, total pressure rakes, total temperature rakes, and a series of static pressure taps.

The integer values for the `DFLAG` and `CFLAG` used in the publicly available datasets hosted in the archive at the time of writing and their associated meanings are given in Table 8 and

Table 9. For the different configurations indicated by `CFLAG`, the channels in the data files are unchanged. This results in cases where the channels exist, but do not contain valid data. For clarity, when the channels were not connected during testing but still exist in the file, the entries in the column are empty.

*7.3.1 Tip Clearance*

The eccentricity of the impeller relative to the shroud discussed in Section 6.3.1 Tip Clearance was improved in the transition duct testing. As such, the parameters `TCEX1` and `TCEXSET` are identical. Further details on the eccentricity of the tip clearance are given by Harrison et al [5].

*7.3.2 Baseline Experimental Datasets*

The experimental data is stored in separate files based on tip clearance and inlet configuration. In the present revision, detailed experimental data at the design tip clearance for the baseline plastic inlet and modified hub

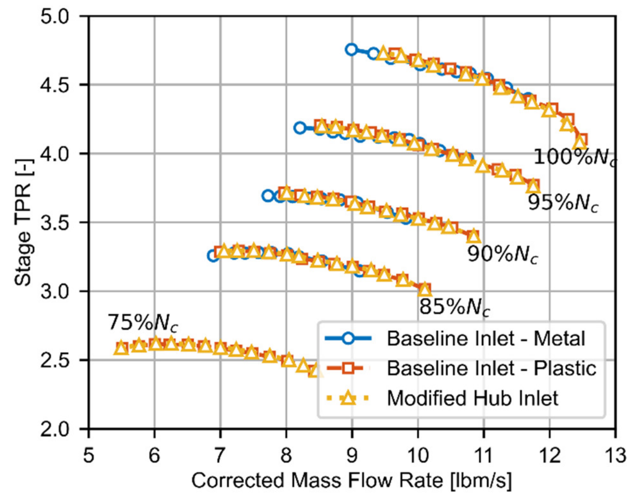


**FIGURE 6: HECC VANELESS DIFFUSER COMPRESSOR MAP AT 0.012" IMPELLER TRAILING EDGE CLEARANCE FOR EACH INLET CONFIGURATION.**

inlet are provided in the *HECCtductData_TD00_12MilExitClearance.csv* and *HECCtductData_TD01_12MilExitClearance.csv* files, respectively. The compressor map in Figure 6 shows the overall performance of the vaneless diffuser configuration with the baseline metal inlet (BLM), BLP, and MH inlet configurations. The difference in low and high mass flow rates recorded for the BLM an BLP/MH testing is due only to testing decisions and is not derived from the change in inlet configuration itself. The low mass flow rate was limited by the throttle during BLM testing. The throttle was then adjusted to accommodate larger mass flow rates during the BLP/MH testing which allowed the impeller to approach inducer choke at high speeds. Additionally, surge testing was conducted during the BLM test. To preserve the integrity of the plastic components, surge was avoided in the BLP/MH testing. The channels and descriptions in the data are included in the previously described *HECCtduct_metaData.csv* file.

Also included in the experimental data is the *HECCtductData_TD00_12MilExitClearance_CLSDP0.csv* file. This set of experimental data is recorded with the BLP inlet and vaneless diffuser, as well, but the compressor labyrinth seal differential pressure (`CLSDP`) has been set to 0-psid. The labyrinth seal allows for bleed flow to pass behind the backface of the impeller and exit through the secondary air flow system. In all previously discussed datasets, the labyrinth seal was set to 0.5-psid to provide

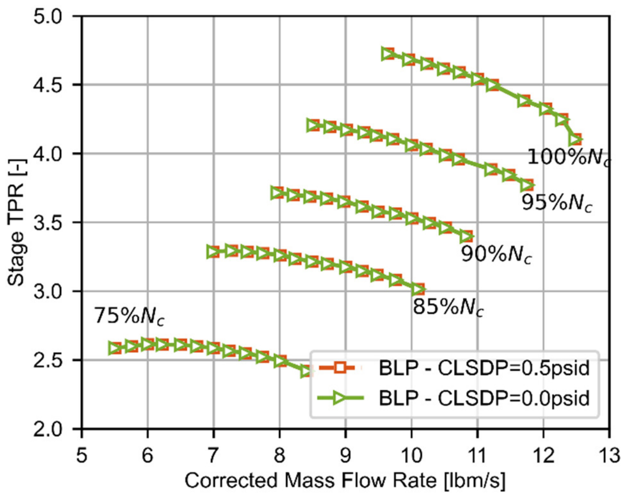


**FIGURE 7: HECC VANELESS DIFFUSER BLP CONFIGURATION COMPRESSOR MAP AT 0.012" IMPELLER TRAILING EDGE CLEARANCE FOR NOMINAL AND 0PSID LAB SEAL DIFFERENTIAL PRESSURE.**

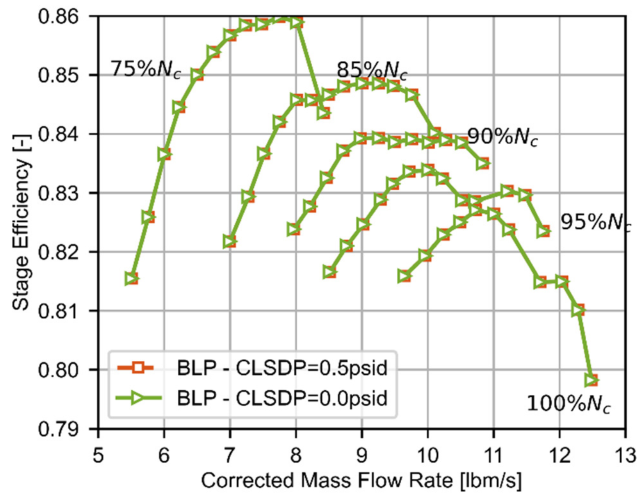


**FIGURE 8: HECC VANELESS DIFFUSER BLP CONFIGURATION EFFICIENCY MAP AT 0.012" IMPELLER TRAILING EDGE CLEARANCE FOR NOMINAL AND 0PSID LAB SEAL DIFFERENTIAL PRESSURE.**

air flow for cooling the backface region of the compressor stage: high pressure air at the impeller trailing edge passes across the backface and exits through the labyrinth seal at positive values for `CLSDP`. The *HECCtductData_TD00_12MilExitClearance_CLSDP0.csv* dataset was recorded with the value for the labyrinth seal set to 0-psid such that there should be no flow out of the stage through the backface leak path. It is provided to give simplified operating conditions in which there is minimal secondary flow into or out of the stage. As can be observed in Figure 7, the labyrinth seal bleed has a negligible impact on the stage compressor map, though there is a small deviation in efficiency at low speeds, Figure 8.

### 7.4 Data - Tip Clearance

The tip clearance dataset is also contained in the *Data – Transition Duct Inlet* directory since the associated data were acquired with baseline additively manufactured inlet configuration. Metadata associated with the tip clearance dataset are the exact same as that given in the *HECCvaneless_tDuct_metaData.csv* file. As such, users of the archive are directed to Section 7.3 Data – Transition Duct Inlet for details on the configuration metadata.

Both steady state speedline and impeller exit survey data were collected at tip clearance values of 0.012-in, 0.018-in, 0.024-in, and 0.030-in. The steady state data are contained in the *HECCtductData_TD00_allClearance.csv* file. A compressor map utilizing the tip clearance dataset is given in Figure 10 for reference. As previously stated, the experimental data were acquired from near-choke to near-stall conditions. Instability was avoided to preserve the integrity of the plastic inlet components.

Impeller exit surveys of flow angle and total temperature were also acquired at each tip clearance condition. The details for interpretation of the impeller exit surveys are provided in Section 7.5 Data - Impeller Exit Surveys.

### 7.5 Data - Impeller Exit Surveys

Impeller exit surveys of flow angle, total pressure, and total temperature were acquired at numerous operating conditions throughout the operating range of the compressor, Figure 9. The surveys were obtained by traversing probes across the span of the vaneless diffuser at the impeller exit rating plane, and the compressor was maintained at the same operating condition throughout the survey. Examples of processed survey data can be found in reference [5].

The *Data – Transition Duct Inlet* directory contains the *Impeller Exit Surveys* directory which in turn contains the *Flow Angle* and *Total Temperature* directories. As their names indicate, *Flow Angle* and *Total Temperature* directories contain impeller exit surveys of flow angle and temperature data across the span at the impeller exit rating station.

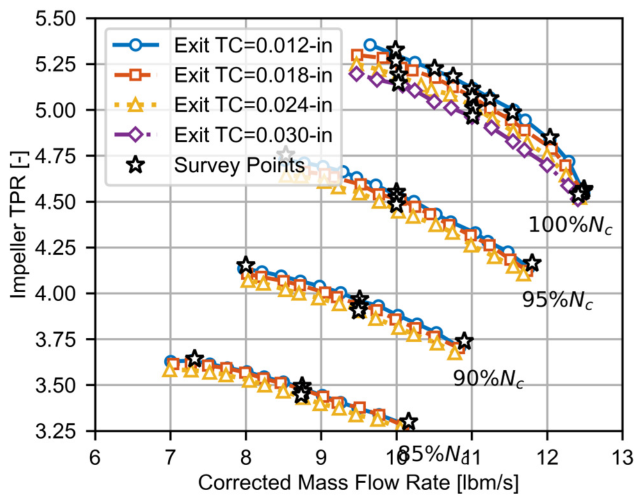


**FIGURE 9: HECC IMPELLER MAP WITH OPERATING CONDITIONS AT WHICH IMPELLER EXIT FLOW ANGLE SURVEYS WERE COLLECTED INDICATED BY STARS.**

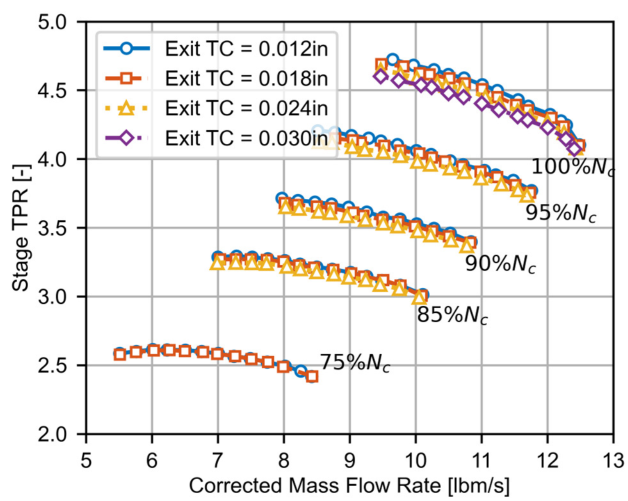


**FIGURE 10: HECC VANELESS DIFFUSER BLP CONFIGURATION COMPRESSOR MAP FOR ALL ACQUIRED CLEARANCE CONDITIONS.**

The filenames within each of the subdirectories indicate the operating condition at which the surveys were collected and are in the following format:

- *impellerExitFlowAngleSurvey_TDX_XXXNc_XXexitTC_X.XlabSeal_X.XXmdot_X.XXTPR.csv*
- *impellerExitTtSurvey_TDX_XXXNc_XXexitTC_X.XlabSeal_X.XXmdot_X.XXTPR.csv*

Each series of characters between the underscores gives a specification of the operating conditions, and each X character is a numeric character giving values for each of the performance parameters within the name. The type of survey is initially given, followed by the transition duct configuration (see Table 7), percent corrected speed in three digits (a leading 0 is present at speeds less than 100%), tip clearance set point in thousandths of an inch, labyrinth seal differential pressure (see sections 4.2 Backface Bleed and 7.3.2 Baseline Experimental Datasets) corrected mass flow rate, and stage total pressure. As an example, the file *impellerExitFlowAngleSurvey_TD0_085Nc_18exitTC_0.5labSeal_8.76mdot_3.47TPR.csv* is an impeller exit flow angle survey recorded with the baseline plastic transition duct configuration at 85% corrected speed, an exducer exit clearance of 0.018-in, a labyrinth seal differential pressure of 0.5psid, corrected mass flow rate of 8.76-lbm/s, and a total pressure ratio of 3.47.

**TABLE 10.** HECC VANELESS TRANSITION DUCT SURVEY CHANNELS OVERVIEW (SEE METADATA FILE FOR DETAILS).

| Channel | Summary |
|---|---|
| `PAC01`, `PAC03` | Raw survey probe actuator angular position, measured in degrees relative to radial direction |
| `PAC02`, `PAC04` | Raw survey probe actuator linear position measured in percent span with shroud and hub corresponding to 0% and 100% span, respectively |
| `MV1CC`, `MV1CL`, `MV1CR`, `MV2CC`, `MV2CL`, `MV2CR` | Raw pressure data measured with each cobra style 3-hole probe measured at the modular vane 1 and 2 locations |
| `MV1TT`, `MV1TT` | Raw total temperature data measured with each cobra style 3-hole probe measured at the modular vane 1 and 2 locations |
| `MV1PANGLE`, `MV1PT`, `MV2PANGLE`, `MV2PT`, `MV1ALPHA`, `MV2ALPHA`, `MV1SPAN`, `MV2SPAN`, | Processed 3-hole probe and/or total temperature probe data |

The data within each of the survey files is structured similarly to the previously discussed steady state data, and only a few small changes are incorporated to accommodate the inclusion of survey data. The relevant probe survey channels are outlined in Table 10 with additional details included in the *HECCvaneless_tDuct_metaData.csv* file, the structure of which is detailed in Section 7.3 Data – Transition Duct Inlet.

Each individual survey recording is identified by a unique reading number given in the survey data files. Generally, the location of the probe in the `PACXX`, `MVXPANGLE`, or `MVXSPAN` channels will change with each reading to build the survey of data across the span at the impeller exit rating station. In addition to the unique reading numbers in the `RDG` column, a `MEAN` row is provided. The `MEAN` row is the average of the steady performance parameters recorded for each unique reading within the survey to give the average operating conditions over the entire survey acquisition process.

General notes on the survey data files:

- Any values for span data less than 0% (`PACXX` channels) or greater than 100% (`MVXSPAN` channels) indicate the probe is recessed within the shroud.
- The `MEAN` values are not applicable for the survey channels themselves, as the probe location changes throughout the survey.
- The processed flow angle data is obtained through the method given by Treaster and Yocum [10].

### 7.6 Models

The solid model of the HECC vaneless diffuser is provided in the *HECCvaneless_cleanGeometry.stp* file. As with other solid models in the Data Archive, the geometry is provided at cold, unloaded conditions.

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## 9. REFERENCES

[1] Medic, G., Sharma, O. P., Jongwook, J., Hardin, L. W., McCormick, D. C., Cousins, W. T., Lurie, E. A., Shabbir, A., Holley, B. M., and Van Slooten, P. R., 2017, *High Efficiency Centrifugal Compressor for Rotorcraft Applications*, E-18856-1.

[2] Lemmon, E. W., Bell, I. H., Huber, M. L., and McLinden, M. O., 2018, “NIST Standard Reference Database 23: Reference Fluid Thermodynamic and Transport Properties-REFPROP, Version 10.0, National Institute of Standards and Technology.”

[3] Berdanier, R. A., Smith, N. R., Fabian, J. C., and Key, N. L., 2015, “Humidity Effects on Experimental Compressor Performance—Corrected Conditions for Real Gases,” J. Turbomach, **137**(3), p. 031011.

[4] Lou, F., Fabian, J., and Key, N. L., 2014, “The Effect of Gas Models on Compressor Efficiency Including Uncertainty,” Journal of Engineering for Gas Turbines and Power, **136**(1), p. 012601.

[5] Harrison, H. M., Nguyen-Huynh, T., and Mathison, R., 2024, “NASA HECC Geometry and Performance Review Part 3: A Numerical And Experimental Investigation of Tip Clearance Effects on the Vaneless Diffuser Configuration,” American Society of Mechanical Engineers Digital Collection, London, England.

[6] Robles Vega, G., Bosshart, A. J., Ni, M., Ni, R.-H., Harrison, H. M., and Nguyen-Huynh, T., 2024, “NASA HECC Geometry and Performance Review Part 2: Geometric Differences Between the As-Manufactured and Design-Intent Impeller Geometry and Their Effects on the Vaneless Diffuser Configuration Performance,” American Society of Mechanical Engineers Digital Collection, London, England.

[7] Braunscheidel, E. P. W., Welch, G. E., Skoch, G. J., Medic, G., and Sharma, O. P., 2015, “Aerodynamic

Performance of a Compact, High Work-Factor Centrifugal Compressor at the Stage and Subcomponent Level," AIAA, Cleveland, OH, United States.

[8] Harrison, H. M., McNichols, E. O., and Blaha, M. R., 2023, "NASA Small Engine Components Compressor Test Facility: High Efficiency Centrifugal Compressor Vaneless Diffuser and Transition Duct Configurations," *Boston, MA*, American Society of Mechanical Engineers Digital Collection.

[9] Robles Vega, G., Bosshart, A. J., Ni, M., Ni, R.-H., Harrison, H. M., and Nguyen-Huynh, T., 2024, "NASA HECC Geometry and Performance Review Part 1: Validation of a Computational Model for the Vaneless Diffuser Configuration with As-Manufactured Impeller Geometry," American Society of Mechanical Engineers Digital Collection, London, England.

[10] Treaster, A. L., and Yocum, A. M., 1978, *The Calibration and Application of Five-Hole Probes*, PENNSYLVANIA STATE UNIV UNIVERSITY PARK APPLIED RESEARCH LAB.