NASA HIGH EFFICIENCY CENTRIFUGAL COMPRESSOR DATA ARCHIVE

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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 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

2023/03/14	Initial publication of archive with HECC vaned diffuser, vaneless diffuser, and transition duct data at design tip clearance.

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
ρ	density
Φ	inlet flow coefficient
ψ	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.

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. [5] give a briefer review of the vaned diffuser configuration with less emphasis on the design process as well as additional aerodynamic data. A facility report to be 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.

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. The section headings correspond to directory names in the accompanying directory tree.

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. HECC VANED CONFIGURATION BLADE NUMBERS.

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

Table 1. The convention for the dataset is given in Section 4.1 Convention.

6.1 Coordinates – HECC Vaned Report 2016 (Hot)

The *HECC Vaned Report 2016 (Hot)* directory contains the 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 component defined by the files is explicitly included in each file name. The blade sections 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 6.3 Models. The coordinates account for the deflection and growth 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 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%
- 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)

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

DFLAG Value	Meaning
1	Steady-state speedline recording

TABLE 3. HECC VANED `CLFAG` (CONFIGRUATION FLAG) INTERPRETATION.

CLFAG Value	Meaning
1	Modular vane total pressure rakes installed at position 1 (MODVN1) and position 2 (MODVN2)

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.

6.2.1 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. 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. [5].

6.2.2 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.

6.3 Models

A solid model of the HECC vaned diffuser stage is available in the *Models* directory in the form of a step file, *HECCvaned_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.

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 [6].

7.1 Coordinates

The *Vaneless Hub and Shroud - Baseline Metal Inlet (Hot)* directory contains the hot hub and shroud profiles
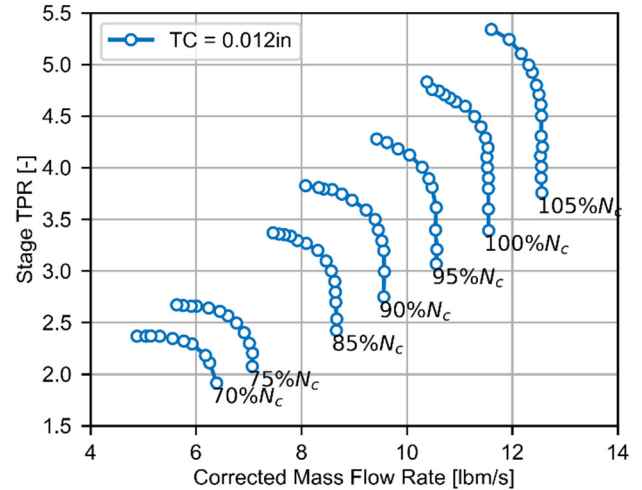

FIGURE 1: HECC VANED DIFFUSER CONFIGURATION COMPRESSOR MAP AT 0.012" IMPELLER TRAILING EDGE CLEARANCE.

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 – HECC Vaned Report 2016 (Hot).

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

- o `PSID`: differential pressure in lbf/in^2
  - o `RPM`: rotations per minute
- `CAT`: category of the channel
  - o `AERO` for aerodynamic instrumentation
  - o `CALC` for calculated parameter
  - o `FLAG` for noting data purpose or instrumentation configuration
- `SCAT`: subcategory for instrumentation type
  - o `DP`: differential pressure
  - o `MISC`: miscellaneous
  - o `PS`: static pressure
  - o `PT`: total pressure
  - o `RH`: relative humidity
  - o `RPM`: rotational speed
  - o `TC`: tip clearance
  - o `TM`: metal temperature
  - o `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%
- `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.

TABLE 4. HECC VANELESS BASELINE METAL INLET `DFLAG` (DATA FLAG) INTERPRETATION.

`DFLAG` Value	Meaning
1	Steady-state speedline recording

TABLE 5. HECC VANELESS BASELINE METAL INLET `CLFAG` (CONFIGRUATION FLAG) INTERPRETATION.

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

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 4 and Table 5. 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 6.2.1 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 2 gives an overview of the data contained therein. The channels and descriptions in the data are included in the previously
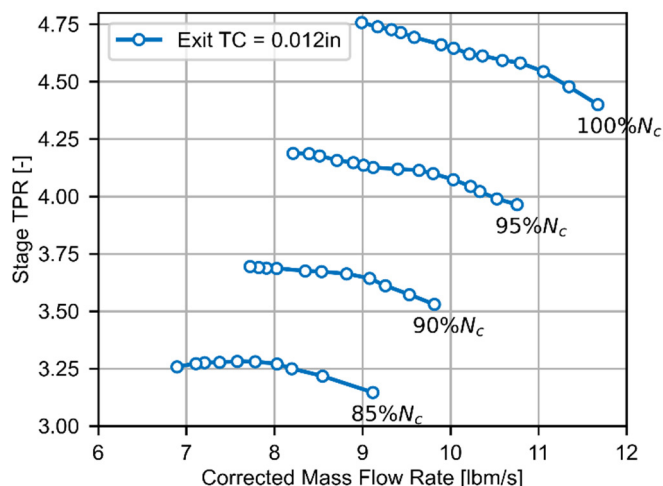
FIGURE 2: HECC VANELESS DIFFUSER BLM CONFIGURATION COMPRESSOR MAP AT 0.012" IMPELLER TRAILING EDGE CLEARANCE.

described

HECCvaneless_baselineMetalInlet_metaData.csv file.

Finally, as noted by Harrison [6], 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
- 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%
- 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 6, and a detailed review of the transition duct configurations can be found in Harrison et al [6]. For the modified hub inlet

Revision Date: April 14, 2023

(`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 7 and

Table 8. 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 6.2.1 Tip Clearance was improved in the transition duct testing. As such, the parameters `TCEX1` and `TCEXSET` are identical.

7.3.2 Experimental Data

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 inlet are provided in the *HECCtductData_TD00_12MilExitClearance.csv* and *HECCtductData_TD01_12MilExitClearance.csv* files, respectively. The compressor map in Figure 3 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

TABLE 6. 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 7. HECC VANELESS TRANSITION DUCT **`DFLAG`** (DATA FLAG) INTERPRETATION.

`DFLAG` Value	Meaning
1	Steady-state speedline recording

TABLE 8. HECC VANELESS TRANSITION DUCT **`CLFAG`** (CONFIGRUATION FLAG) INTERPRETATION.

`CLFAG` Value	Meaning
0	Modular vane total pressure rakes installed at impeller exit rating station (PMV1 and PMV2 series instrumentation)

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, during 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 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
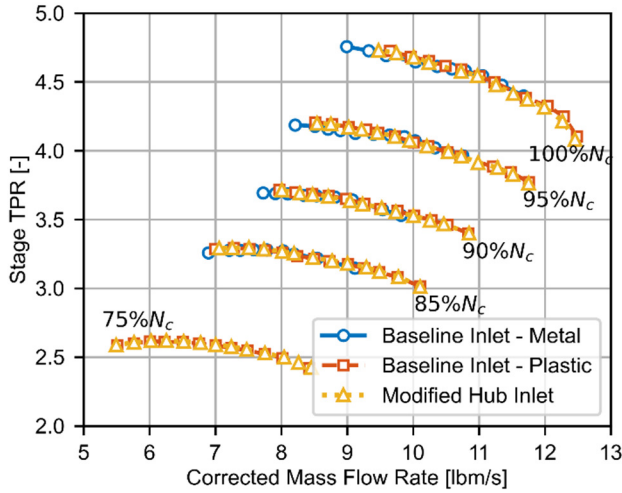
FIGURE 3: HECC VANELESS DIFFUSER COMPRESSOR MAP AT 0.012" IMPELLER TRAILING EDGE CLEARANCE FOR EACH INLET CONFIGURATION.
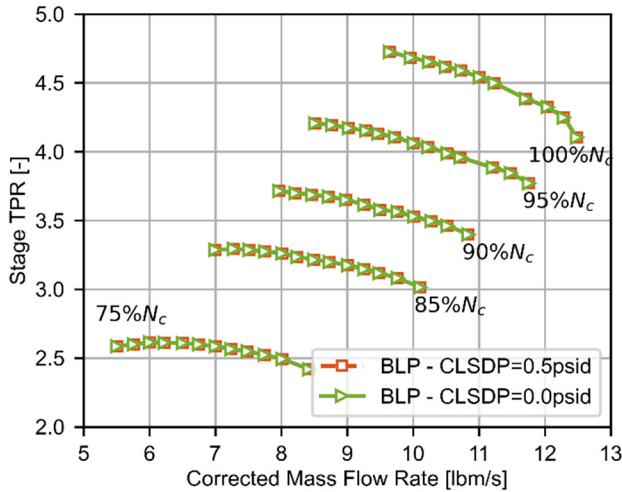

FIGURE 4: HECC VANELESS DIFFUSER BLP CONFIGURATION COMPRESSOR MAP AT 0.012" IMPELLER TRAILING EDGE CLEARANCE FOR NOMINAL AND 0PSID LAB SEAL DIFFERENTIAL PRESSURE.

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
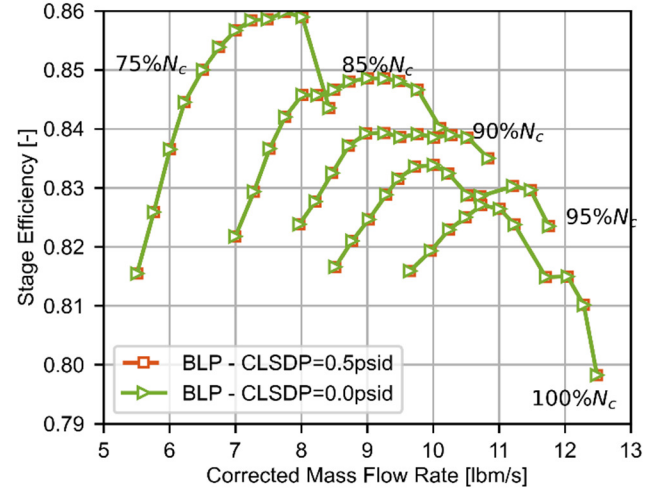

FIGURE 5: HECC VANELESS DIFFUSER BLP CONFIGURATION EFFICIENCY MAP AT 0.012" IMPELLER TRAILING EDGE CLEARANCE FOR NOMINAL AND 0PSID LAB SEAL DIFFERENTIAL PRESSURE.

observed in Figure 4, 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 5.

7.4 Models

In the present revision (dated April 14, 2023), the *Models* directory has not yet been updated to include the vaneless diffuser solid model.

8. ACKNOWLEDGEMENTS

9. REFERENCES

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