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Development of Curved Shape Diffuser-Duct for Aero-Engines With a Backend Centrifugal Compressor

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ABSTRACT

In the present study, a design of the curved shape diffuser-duct is proposed to apply to the compressor stage for aero-engines with a backend centrifugal compressor. For these configurations, the flow exiting radially from the centrifugal impeller needs to be changed from radial-to-axial direction to meet downstream combustion chamber requirements. Hence, the specially designed exit duct with a curved shape to manage the flow from the radial-to-axial direction was later diffused using the diffuser-shaped exit duct. This study aims to design and develop an efficient diffuser-duct for the adequate deceleration of flow in the exhaust diffuser and, as a result, a uniform and low-velocity flow at the exit. This configuration comprises a radial-to-axial turning annular passage at the centrifugal impeller exit. Then, the passage is directed to either a purely axial direction or is inclined to the axial direction by a slight angle. The results indicate a uniform total pressure at the stage exit with marginal variation along the span. It shows equivalent end wall effects near both the shroud and hub surfaces. This endwall effect may be occurring mainly due to the growth of the boundary layer across the diffuser passage.

Keywords: Curved shaped diffuser-duct; Aeroengine; Centrifugal compressor exit; Exit duct; Axial exit; End wall effects; Radial-to-axial turning

NOMENCLATURE

A	: Inclination angle
Ar	: Cross-sectional area
C	: Absolute velocity
Cp	: Coefficient of pressure
h	: Hub
IN	: Inlet
L	: Axial length
Lp_0	: Total pressure loss coefficient
OUT	: Exit
P	: Pressure
R	: Radius
Re	: Reynolds' number
s	: Shroud
m	: Meridional
mid	: Mid-span location
max	: Maximum dimension
$rotor$	: Centrifugal rotor
$stage$	: Centrifugal compressor stage
$turn$	: Radial-to-axial turning passage
0	: Total or stagnation state
θ	: Angular component

1. INTRODUCTION

Axial-centrifugal compressor configuration is typically employed in small and medium-sized gas tu rbine engines of aero applications. It has several axial-flow compressor stages with a backend centrifugal compressor stage. It exploits the advantage of both axial-flow compressors and centrifugal compressors. Here, the backend centrifugal compressor offers a higher pressure ratio within a limited available axial length, stall-free operation, and reduced engine weight with good efficiency, meeting the requirements for small aero engines. The centrifugal compressor stage consists of a centrifugal rotor with an exhaust diffuser. Centrifugal rotor generates high kinetic energy flow exiting radially outwards. This flow needs to be diffused and redirected with the objectives of suitable flow characteristics meeting the requirements of the downstream combustor.

The flow exiting the centrifugal rotor in the radial direction needs a dedicated passage segment to redirect the flow in the axial direction. This redirection necessitates the introduction of a curved flow passage turning the flow by about a 90° bend. The open literature extensively discusses the two-dimensional rectangular curved diffuser[1-6]. These studies give valuable insights into the fundamentals of flow physics in curved diffusers akin to the cascade studies of turbomachinery. However, a curved diffuser in turbomachinery applications would typically be an axisymmetric annular diffuser of three-dimensional shape[7-8]. Moreover, it may be subjected to highly non-uniform swirling flows. For example, the curved diffuser employed downstream of a centrifugal rotor is subjected to complex high kinetic energy flow entering radially. The resulting shape of this curved passage can be categorised as an annular conical curved diffuser in which flow enters the radial

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direction and exits in the axial direction. Hence, A diffusing arrangement employed in the centrifugal compressor stage typically consists of three segments: a radial passage, a radial-to-axial turning passage, and an axial passage[9].

The conventional arrangement of the centrifugal compressor stage provides several benefits, as discussed in the section above. However, it also poses some challenges in developing a functional and efficient flow-diffusing and redirecting system. Firstly, there is a penalty for the relatively higher overall frontal diameter of the compressor stage contributed by the centrifugal radial diffuser segment. Moreover, it consists of a radial-to-axial turning segment with the primary objective of redirecting the flow within a constrained space[13]. This passage may or may not diffuse highly non-uniform and swirling flow emanating from the centrifugal rotor. This passage could also contribute to increased losses associated with excessive flow turning within a highly constrained space. Furthermore, employing multiple arrangements like vanes, deswirlers, or pipe diffusers solves aerodynamic aspects such as flow diffusion and redirection[10-12,14]. However, these arrangements would have disadvantages of the increased number of parts, compounded losses due to proportionally increased 'wetted area,' increased weight, and increased design, manufacturing, and mechanical complexities. These disadvantages lead to raised gas turbine engine design, manufacturing, and operating costs.

A low-cost, lightweight, and compact vaneless diffuser-duct with flow diffusion and redirection functionality was proposed for low-speed, low-mass flow centrifugal compressor application[17-18]. It consists of two segments, i.e., a conical curved passage in radial-to-axial direction, followed by an axial conical passage for efficient pressure recovery. The first segment of the radial-to-axial passage replaces the conventional diffuser segments consisting of a long radial diffusing passage and the constrained curved turning passage. It has the benefits of reduced overall diameter with a marginally longer axial length. The axial passage segment was modified to a conical diffuser configuration for continuous pressure recovery throughout the whole length of the diffuser. It is designed and developed with the performance objectives of maximizing pressure recovery, minimizing total pressure losses, and removing flow distortion, resulting in an efficiently diffused uniform flow at the exit of the compressor stage. Hence, the following challenges have been addressed in this study.

- What must be the curvature of the curved-shaped diffuser-duct segment to connect the radial and axial ends?
- How to minimize the losses within the curved-shaped passage segment?
- What needs to be the shape of the axial passage segment of the diffuser-duct?
- How to decelerate the swirling flow going to the axial passage?

In the present study, the design approach to arriving at the baseline design of the curved diffuser is discussed. Subsequently, the numerical method was employed to finalize the diffuser geometry for the axial-centrifugal compressor stage. Following this, the numerical results are presented to evaluate the progression of development objectives. Lastly, the valuable conclusions drawn from this exercise are presented.

Table 1. Diffuser-duct geometric parameters of baseline design

$\frac{R_{max(hub)}}{R_{IN}}$	1.150		
$\frac{R_{max(stage)}}{R_{IN}}$	1.300		
$\frac{L_{(turn)}}{L_{(rotor)}}$	1.317		
$\frac{L_{(stage)}}{L_{(rotor)}}$	2.454		
$A_{(hub)}$	5°		
Design planes	$\frac{R_{(hub)}}{R_{IN}}$	$\frac{L_{(hub)}}{L_{(rotor)}}$	$\frac{Ar}{Ar_{IN}}$
IN	1	1	1
I	1.055	1.016	0.983
II	1.102	1.071	0.965
III	1.134	1.159	0.946
IV	1.147	1.251	0.929
V	1.150	1.327	0.915

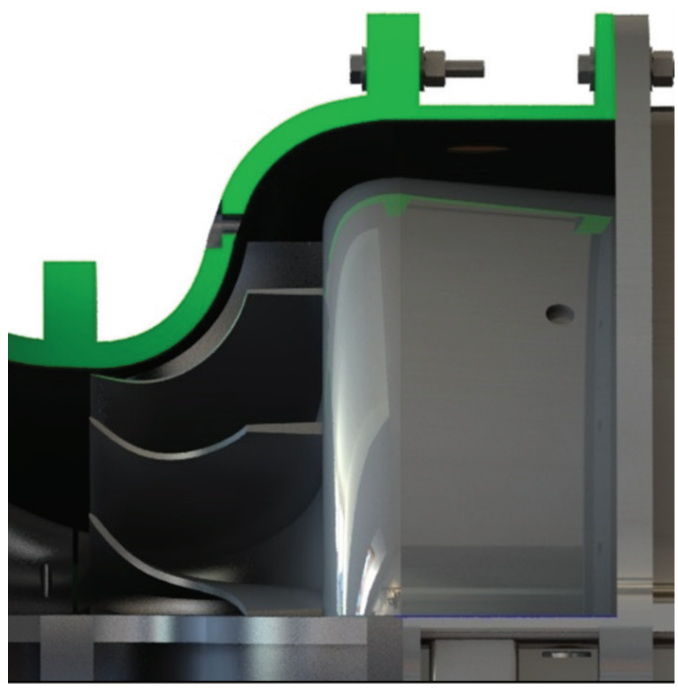

Figure 1. Cad preview of centrifugal stage developed for test rig facility.

2. DESIGN AND NUMERICAL METHODOLOGY

The proposed diffuser-duct is developed for the centrifugal compressor stage of the compressor test rig facility being developed, as shown in Fig. 1. The flow exiting from the centrifugal compressor rotor is three-dimensional, with very high kinetic energy. This kinetic energy needs to be converted to pressure energy using a special flow passage at the exit, and the flow needs to be redirected in the axial direction.

The diffuser-duct passage would be designed for adequate flow deceleration, hence a diffused flow at the stage's exit. A uniform total pressure at the stage's exit is to be achieved with minimized total pressure losses of the flow.

2.1 Design Description

There are few remarkable distinct geometrical features of diffuser-duct contrary to conventional diffuser employed in the centrifugal compressor, as shown in Fig. 2. First is the curved-shaped radial-to-axial turning passage at the exit of the centrifugal rotor. The flow exiting radially from the centrifugal rotor is directed in the axial direction with the help of this passage. This unconventional and innovative implementation is considered for minimizing the overall diameter to achieve a small and compact compressor configuration. The flow exiting the centrifugal rotor in conventional diffuser arrangements passes through a long radial diffuser passage segment. Afterward, a short curved-shaped turning passage segment is introduced to redirect flow from the radial to the axial direction. In the present study, a curved-shaped diffusing and redirecting passage is introduced directly at the exit of the centrifugal rotor. This modification would be longer marginally in the axial direction and would be reducing size in the radial direction significantly as compared to conventional diffuser arrangements.

This innovative design will allow diffusion and redirection of the flow gradually and recover the high kinetic energy of the flow exiting the centrifugal rotor. The second is a diffuser-shaped axial passage following the turning passage. This passage segment would further help diffuse the flow, hence a higher pressure recovery.

The outline of the diffuser-duct baseline design is shown in Fig. 2. The geometric parameters in this Fig. 2 are presented in Table 1. in normalized form. It can be observed that the maximum constrained diameter of the diffuser is 1.3 times the maximum centrifugal rotor diameter. Consequently, the radial-to-axial curved-shaped passage is confined within a maximum dimension of about 1.3 times the diameter and axial length of the centrifugal rotor. The overall axial length is about 2.5 times the centrifugal rotor's axial length. An inclination of 5° is given to the hub surface of the axial passage segment, forming an annular conical diffusing shape.

The curved-shaped passage is segmented with five spanwise design planes, numbered I to V, placed after the inlet, as shown in Fig. 3 (a). These planes form conical-shaped cross-sections, as shown in Fig. 3 (a). These uniformly varying planes in the cross-section area form the curved-shaped annular passage. The geometric description of the design planes is given in Table 1. It is interesting to observe that the area of design planes is reduced from the inlet to the last design plane at the end of the curved passage to about 0.9 times.

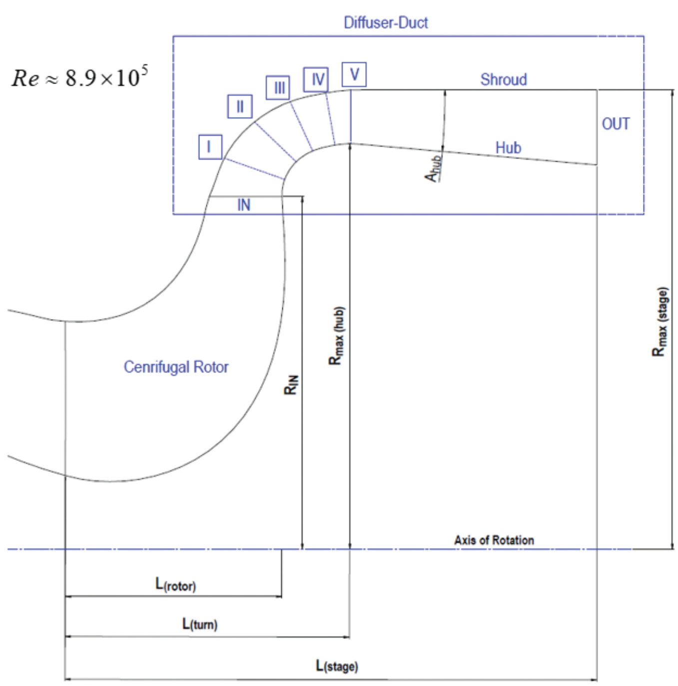

Figure 2. Outline with geometric parameter description of baseline design.

2.2 Computational Tools and Technique

The numerical analysis was conducted on the whole compressor configuration with multiple flow domains for all blades and duct passages like diffuser-duct. The numerical methodology of the whole domain is covered in detail in the previous works[15,17-18]. The numerical study was performed using ANSYS CFX®. Only one passage of each domain was considered for analysis to reduce the computational power and

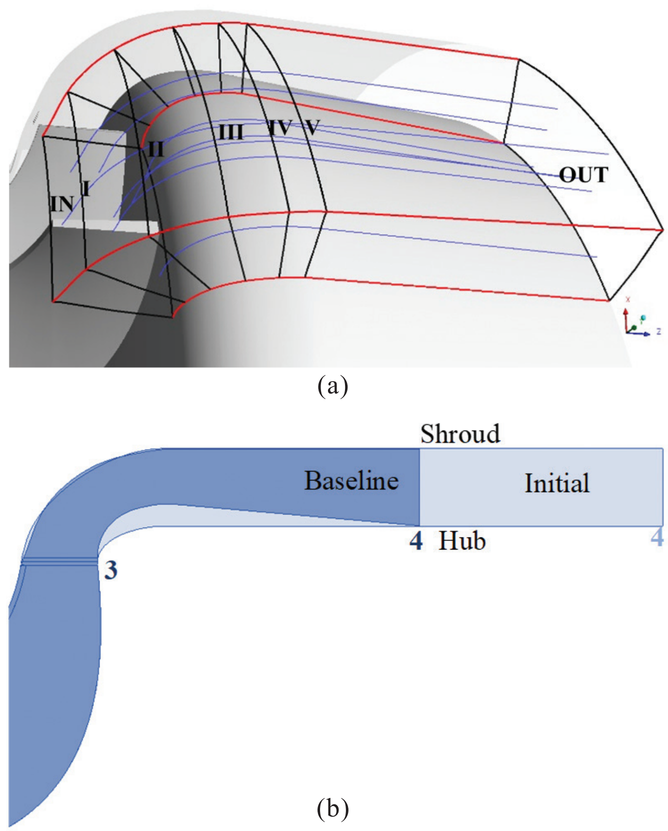

Figure 3. Geometry of radial-to-axial turn of diffuser-duct baseline and initial design, (a) Design planes shown for one rotor blade passage; and (b) Diffuser-duct baseline design configuration shown matched up to the initial design in the meridional view section.

time requirement. Periodic boundary conditions were applied accordingly. Mesh generation was performed independently with the help of ANSYS Turbogrid® using hexahedral elements. The domains between the rotors and diffuser-duct were connected using the Frozen rotor interface as the boundary condition. The shear stress transport model was used as a turbulence model.

2.3 Mesh

For mesh generation, A total of 0.65 million nodes of mesh optimum for accuracy and computational cost is generated for the diffuser-duct domain. The mesh expansion rate was selected to be 1.3. Boundary conditions assigned are total pressure at the inlet and mass flow at the outlet. Inlet turbulence intensity was taken at about 5%. The diffuser-duct domain was considered in the Stationary frame of reference. The stationary walls are modelled as smooth, non-slip walls. All residuals converged to at least 1.0e-04 level. Fine meshing is done near the hub and shroud boundary walls to adequately capture the boundary layer flow physics.

3. RESULTS AND DISCUSSION

3.1 Parameter Definitions

The parameters, total pressure loss coefficient, and coefficient of pressure were considered throughout the study for the flow characterization of the diffuser-duct. The total

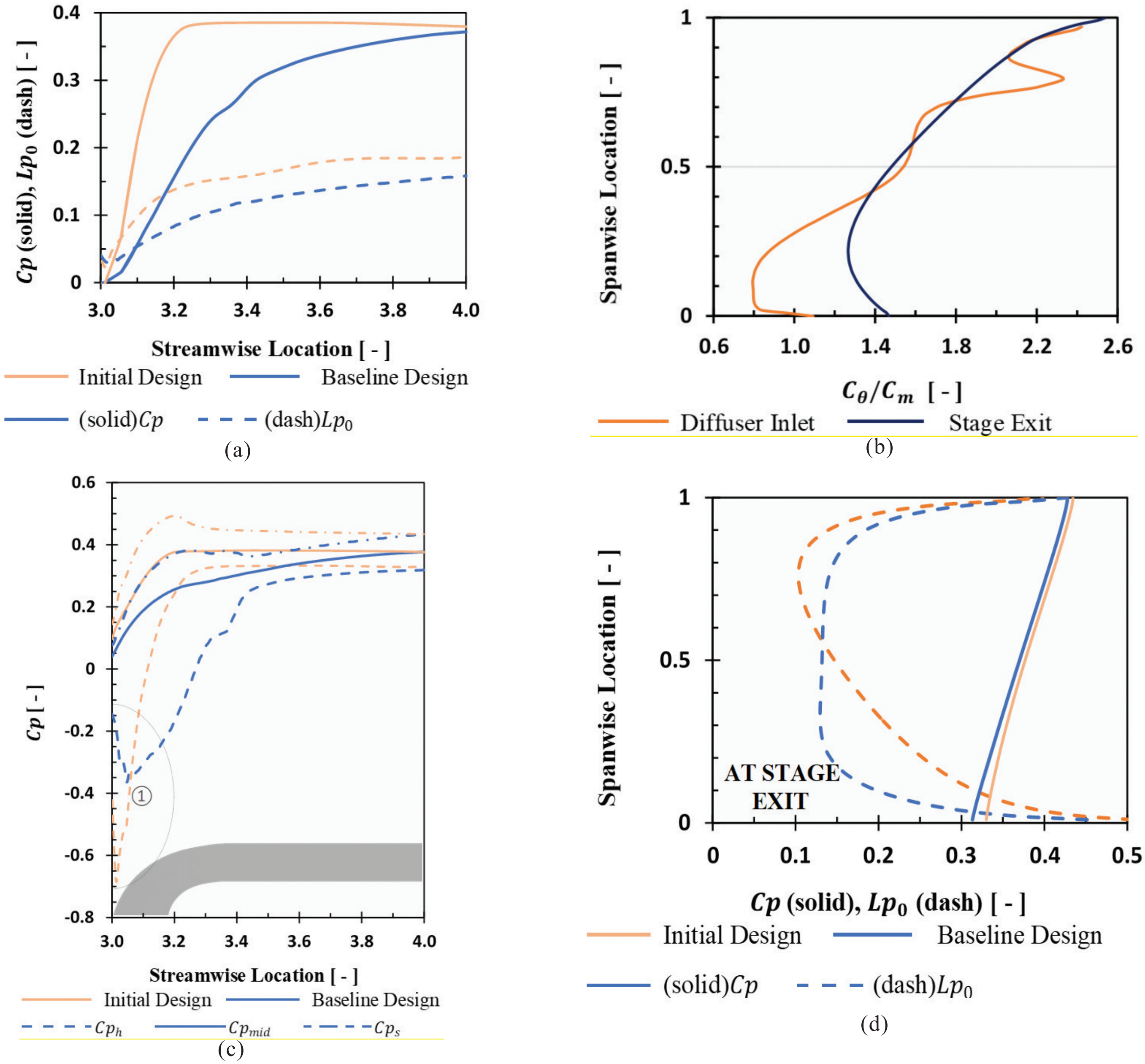

Figure 4. Performance parameters for initial and baseline design, (a) Streamwise Coef. of pressure, Cp and Total Pr. Loss Coef., Lp_0 of diffuser-duct configurations for initial design and baseline design; (b) Spanwise C_θ/C_m at diffuer inlet and stage exit for baseline design; (c) Streamwise Coef. of pressure, Cp of diffuser-duct configurations of initial design and baseline design at span locations hub, mid-span, and shroud; and (d) Spanwise Coef. of pressure, Cp and Total Pr. Loss Coef., Lp_0 of diffuser-duct configurations for initial design and baseline design at the stage exit.

pressure loss coefficient, Lp_0 is the ratio of total pressure loss ($P_{0,IN} - P_0$) to the dynamic pressure rise available at the stage inlet ($P_{0,IN} - P_{IN}$).

$$Lp_0 = \frac{P_{0,IN} - P_0}{P_{0,IN} - P_{IN}}$$

Similarly, the coefficient of pressure is defined as the ratio of static pressure recovery (P-P_{IN}) to the dynamic pressure rise available at the stage inlet ($P_{0,IN} - P_{IN}$).

$$Cp = \frac{P - P_{IN}}{P_{0,IN} - P_{IN}}$$

Here, the Total pressure, P_0, and static pressure, P, are the evaluated parameters of diffuser flow. $P_{0,IN}$ and P_{IN} are mass-averaged total pressure and static pressure at the inlet plane of the domain, respectively[16]. All parameters were considered in the stationary frame of reference. The mass averaging was also performed to Total pressure, P_0, and static pressure, P, for the streamwise averaged plots and contours, as discussed in the following section.

Several design iterations were performed, starting with an initial design to arriving at a baseline design. The evolution of the diffuser-duct for improved pressure recovery and reduced total pressure loss is shown in Fig. 3(b). The superior performance of baseline design to initial design is evident from mass circular-averaged streamwise plots (Fig. 4(a)). The coefficient of pressure for the baseline design is observed to be equivalent to the initial design. Moreover, total pressure loss is reduced remarkably for baseline design. Furthermore, the swirl indicated by the angular to meridional velocity ratio by C_θ/C_m is distributed more uniformly spanwise as flow progressed from diffuser inlet to exit, as shown in Fig. 4(b).

If the geometrical shape changing from the initial design to the baseline design is examined closely, two separate design modifications elevating the performance are observed. The first is the shape change of the radial-to-axial passage, and the second is the inclined hub surface of the axial passage. Some variations to the axial passage of the diffuser-duct will be discussed in the following section.

3.2 Curved-Shaped Passage Segment

The shape of the radial-to-axial curved passage is modified from equal width passage of the initial design to reducing area passage of baseline design (Fig. 3(b)). The spanwise distance between the hub and shroud is maintained equal from the radial inlet to the axial exit in the initial design. Whereas, for the baseline design, the curve joining along the hub and shroud of five span sections determined the shape of the baseline design.

The pressure recovery was examined through circular length averaged coefficient of pressure at hub, mid-span, and shroud locations, as shown in Fig. 4(c). The stark difference between the initial and baseline design is prominently visible in this Figure. The baseline design achieved remarkable pressure recovery compared to the initial design at the hub location (see region ① of Fig. 4(c)). A significant flow acceleration near the hub at the inlet of the diffuser-duct is noticed for the initial design. The modified shape of the baseline design increases the pressure recovery significantly near the hub. Near shroud and mid-span locations of the initial design have higher pressure recovery than baseline in radial-to-axial passage around the inlet of the diffuser-duct.

A sharp drop in pressure recovery was observed at the exit of the radial to-axial passage and inlet of the axial passage for the initial design. Following this, a stagnation in pressure recovery is observed due to constant area axial passage. However, the efficient design of the baseline configuration shows a steady rise in the pressure coefficient throughout the passage. That means pressure recovery is achieved continuously through the radial-to-axial turning passage and following axial passage. The initial design's pressure recovery level is matched efficiently to the baseline design. The pressure recovery of the baseline design is achieved with reduced total pressure losses, as mentioned in previous sections. Hence, an effective and efficient design of the diffuser-duct is achieved.

The spanwise performance at the stage exit demonstrates the superior performance of the baseline design, as shown in Fig. 4(d). A uniform flow characteristic with minimally varying static and total pressure distribution at the stage exit is achieved for baseline design. This uniformity resulted from

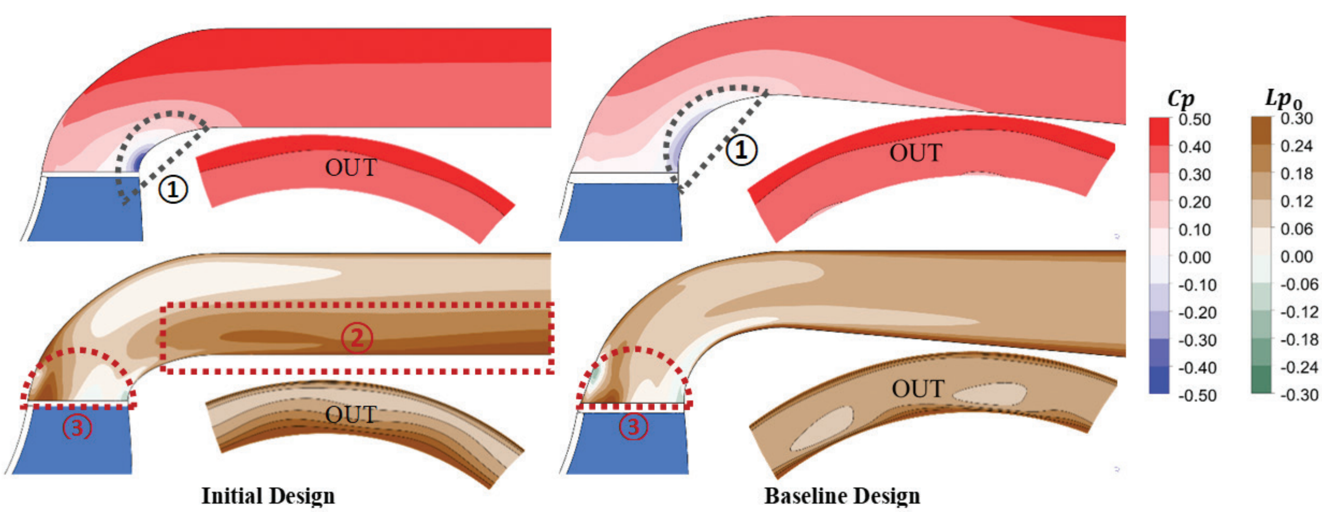

Figure 5. Coefficient of pressure, *Cp* and total pressure loss Coef., Lp_0 at Meridional Planes (Averaged) of initial and baseline design of diffuser-duct and stage exit planes (out).

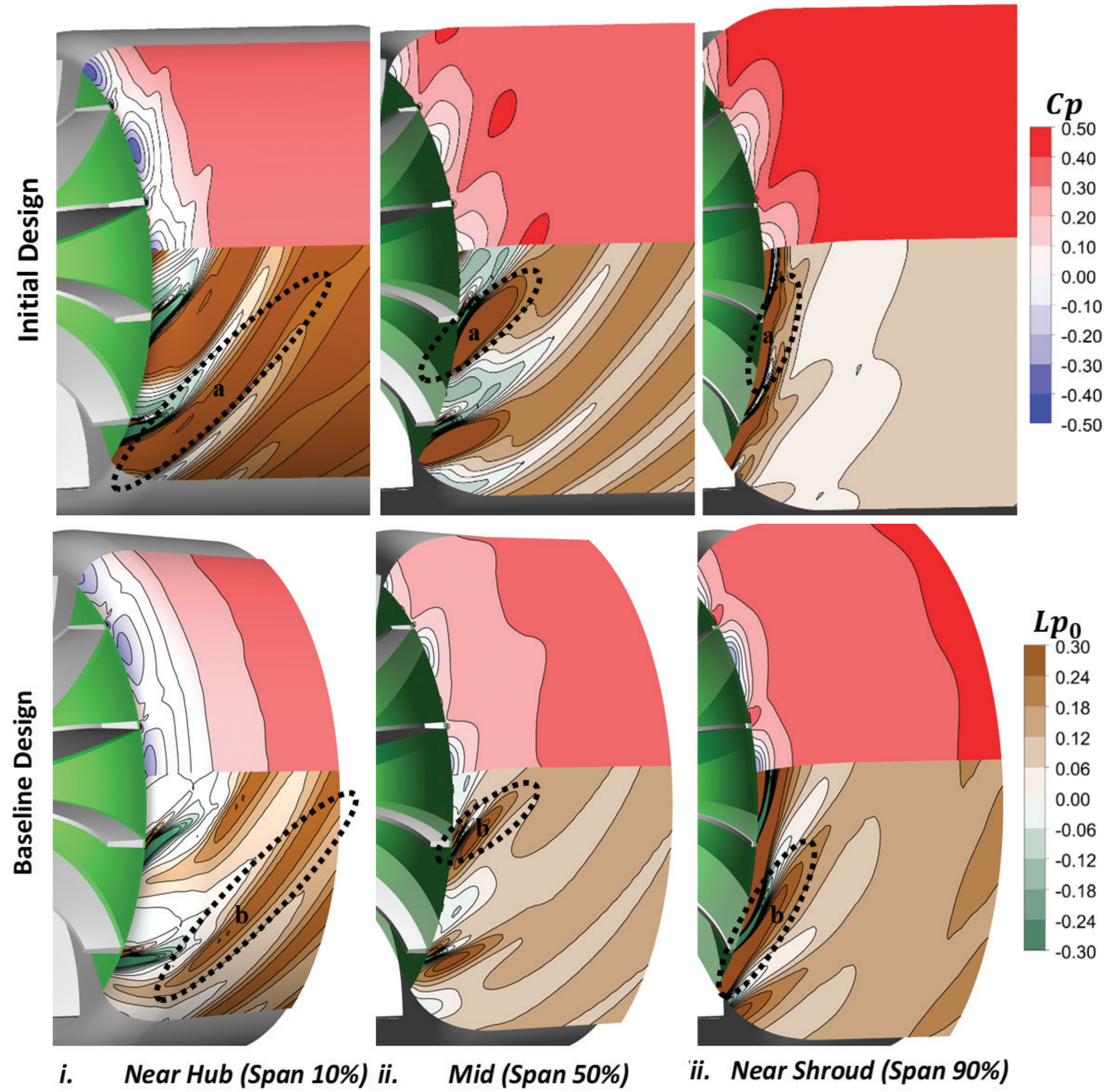

Figure 6. Streamwise coefficient of pressure, *Cp* and total pressure loss Coef., Lp_0 at the Span of 10 %, 50 %, and 90 % of the initial and baseline design of diffuser-duct.

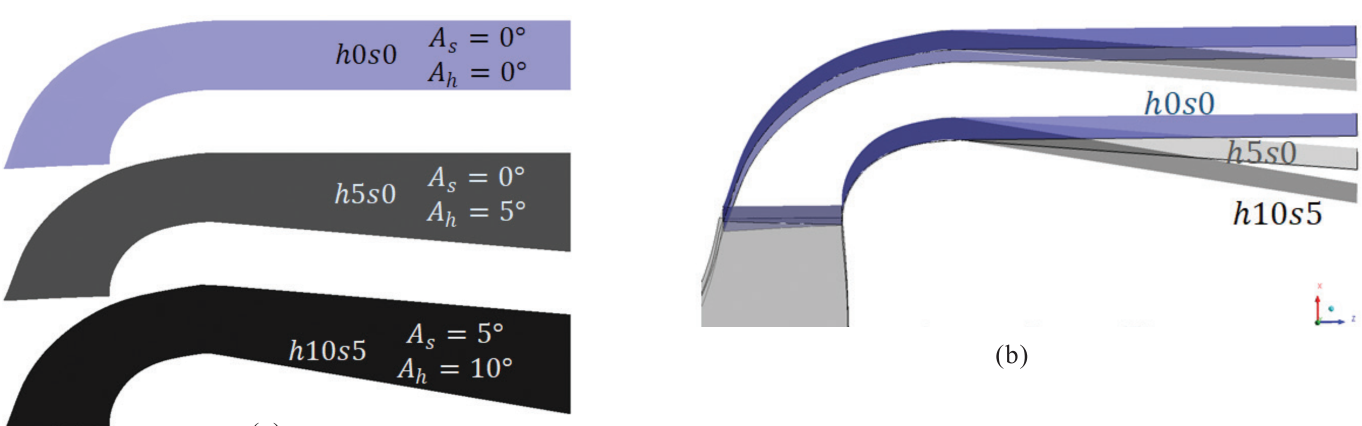

Figure 7. Diffuser-duct configurations of three different axial passage design geometry $h0s0$, $h5s0$ and $h10s5$, (a) Meridional view; and (b) Three-dimensional view.

improved flow characteristics, principally observed along the hub surface, from the initial to the baseline design. For example, the hub surface modification for the curved passage segment reduces the significant flow acceleration (see region ① of Fig. 5). Moreover, the total pressure losses occurring near the hub surface of the initial design are minimised successfully for baseline design (see region ② of Fig. 5). Hence, total pressure losses are contributed by mainly boundary layer effect near the hub and shroud walls. It is interesting to observe that a reduced total pressure variation and reduced total pressure loss are observed near the inlet of the diffuser-duct (see region ③ of Fig. 5). Hence, the baseline design diffuser-duct adds to significantly improved upstream total pressure characteristics.

For an in-depth understanding of the flow field, the contour plots at the exit of the rotor are explored, as shown in Fig. 6. The curved passage segment is subjected to highly non-uniform complex flow around the inlet region. A considerable variation in static and total pressure is observed, as shown in Fig. 6. This variation is due to various complex flow phenomena such as tip leakage flow, blade wakes, endwall boundary layer effect, and other secondary flows originating due to strong passage curvature of the centrifugal rotor and curved passage segment, all interacting around the inlet region of the curved diffuser. Nevertheless, the baseline design is modifying the flow field to the benefit of reduced total pressure losses, as shown in regions (a) and (b) of Fig. 6.

This improved design also provides a uniform pressure recovery by eliminating circumferential pressure variations. A higher and more uniform pressure recovery was observed than the initial design for all span locations. These improved performances are also contributed by diffusing shape axial passage segments. Hence, three variations to the axial passage of the diffuser-duct will be discussed comparatively in the following section.

3.3 Axial Passage Segment Configurations

The diffuser-duct axial passage is conFig.d to provide a diffusing passage for three configurations, as shown in Fig. 7. The initial configuration of a purely axial hub and shroud surfaces is modified to two configurations inclined at a slight angle. The initial configuration, *h*0*s*0 of the axial hub A_h=0° and axial shroud A_s=0°, i.e., parallel and axial surfaces form an equal area passage.

The second configuration, *h*5*s*0 of hub inclined at an angle A_h=5° and axial shroud A_s=0°, is forming progressively increasing area conical passage (Fig. 7(b)). Thus, a diffusing-shaped duct is formed for this configuration. Lastly, the third configuration, *h*10*s*5 of hub inclined at an angle A_h=10° and shroud inclined at an angle A_s=5° also forms an increasing area passage of diffusing shape. Moreover, these configurations are also being explored to evaluate the effect of modifications on the upstream flow physics of the immediate radial-to-axial duct.

The pressure recovery of the diffuser-duct is represented by the coefficient of pressure in the streamwise direction, as shown in Fig. 8(a). This parameter gives a measure of performance indicating recovery of the kinetic energy to pressure. The exact figure is also showing total pressure loss

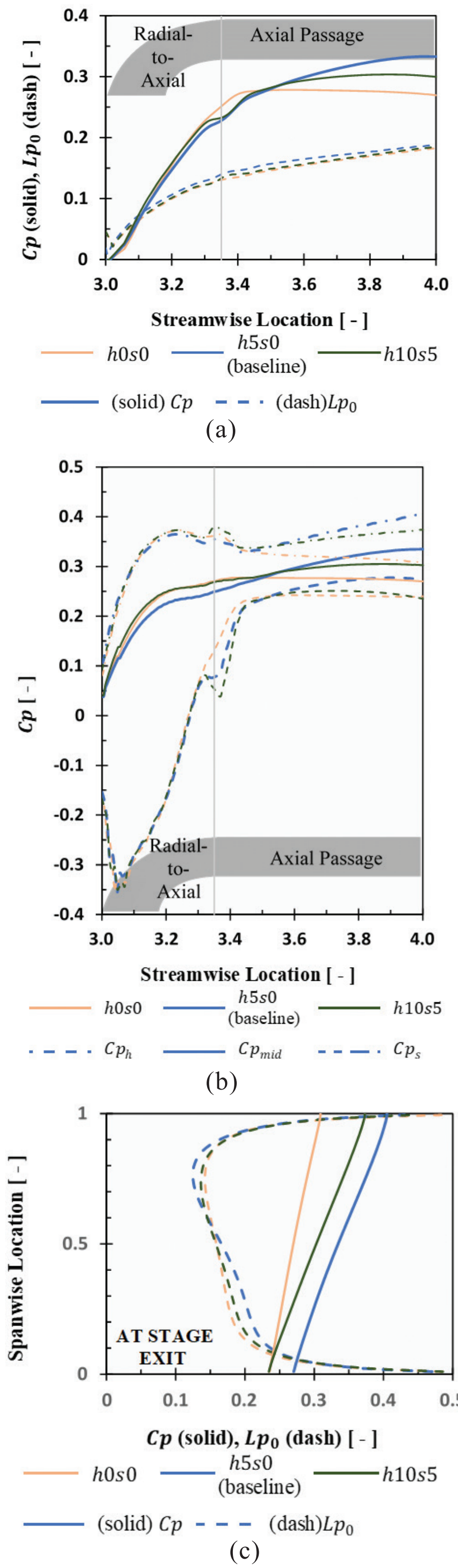

Figure 8. Performance parameters for modified diffuser-duct configurations, (a) Streamwise Coef. of Pressure, Cp, and Total Pr. Loss Coef., Lp_0 of Diffuser-Duct Configurations *h*0*s*0, *h*5*s*0 and *h*10*s*5; (b) Streamwise Coef. of Pressure, Cp of Diffuser-Duct Configurations *h*0*s*0, *h*5*s*0 and *h*10*s*5 at Span Locations Hub, Mid-Span, and Shroud; and (c) Spanwise Coef. of pressure, Cp, and Total Pr. Loss Coef., Lp_0 of diffuser-duct configurations *h*0*s*0, *h*5*s*0 and *h*10*s*5 at stage exit.

coef. in the streamwise direction of the diffuser-duct. This parameter estimates the process's efficacy by evaluating the flow's total pressure loss. The configuration *h*5*s*0 shows improved performance and is producing the most significant pressure recovery of the flow. Total pressure loss is almost equivalent for all three configurations throughout the passage. Hence, these modifications to the diffuser duct do not significantly influence the process's efficacy.

The pressure recovery is equivalent approximately for the radial-to-axial passage of all three configurations apart from some discrepancies near this passage exit (Fig. 8(a)). Since this passage is geometrically identical for all three configurations, flow characteristics undergo minute variations that do not significantly affect overall performance. However, discrepancies near this passage exit are due to inclined hub and shroud surfaces modifying passage geometries. Inclined surfaces introduce a drop of pressure recovery around the inlet of the axial passage. The configuration *h*10*s*5 pressure recovery has sharply dropped and risen, showing unfavourable pressure recovery characteristics. Contour plots, as shown in Fig. 9, better demonstrate this. However, a uniform rise of pressure recovery has resulted in configuration *h*5*s*0. Furthermore, this configuration's diffusing-shaped axial passage produces superior pressure recovery. Hence, the configuration *h*5*s*0 demonstrates a superior performance characteristic.

The pressure recovery characteristic is further examined by evaluating the circular length averaged of the parameter Cp for the hub surface, mid-span, and shroud surface, as shown in Fig. 8(b). The pressure recovery developing along the streamwise locations is influenced directly by the axial duct geometry of three different configurations. For example, the discrepancies at the exit of the radial-to-axial duct and inlet of the axial duct are influenced by changing hub and shroud surfaces of these configurations. The mid-span pressure recovery has smoothly transitioned from the radial-to-axial to the axial duct. In contrast, hub and shroud pressure recoveries show irregularities responsible for discrepancies around this transitioning location.

The configuration h5s0 shows a superior pressure recovery for all three span locations, as shown in Fig. 8(b). The identical shape radial-to-axial duct shows nearly equivalent pressure recovery for all three configurations. However, the axial duct of configuration h5s0 has produced remarkable pressure recovery for all three span locations, i.e., hub, mid-span, and shroud. This result further establishes the superior performance characteristics of the configuration h5s0.

The spanwise performance is shown in Fig. 8(c) for all three different configurations. The higher pressure recovery of the configuration h5s0 is visible distinctly at the stage exit. The pressure near the shroud is higher than the hub. These trends are further elaborated with various contour plots in the following sections.

The configuration h5s0 performs superior at the stage exit, as shown in Fig. 9. with circular averaged Cp and Lp_0 contours on meridional plane views. It maximizes pressure recovery (Fig. 9 (1)) and minimizes total pressure losses (Fig. 9 (2)), resulting in a uniform flow characteristic. The pressure recovery characteristics remain almost identical in

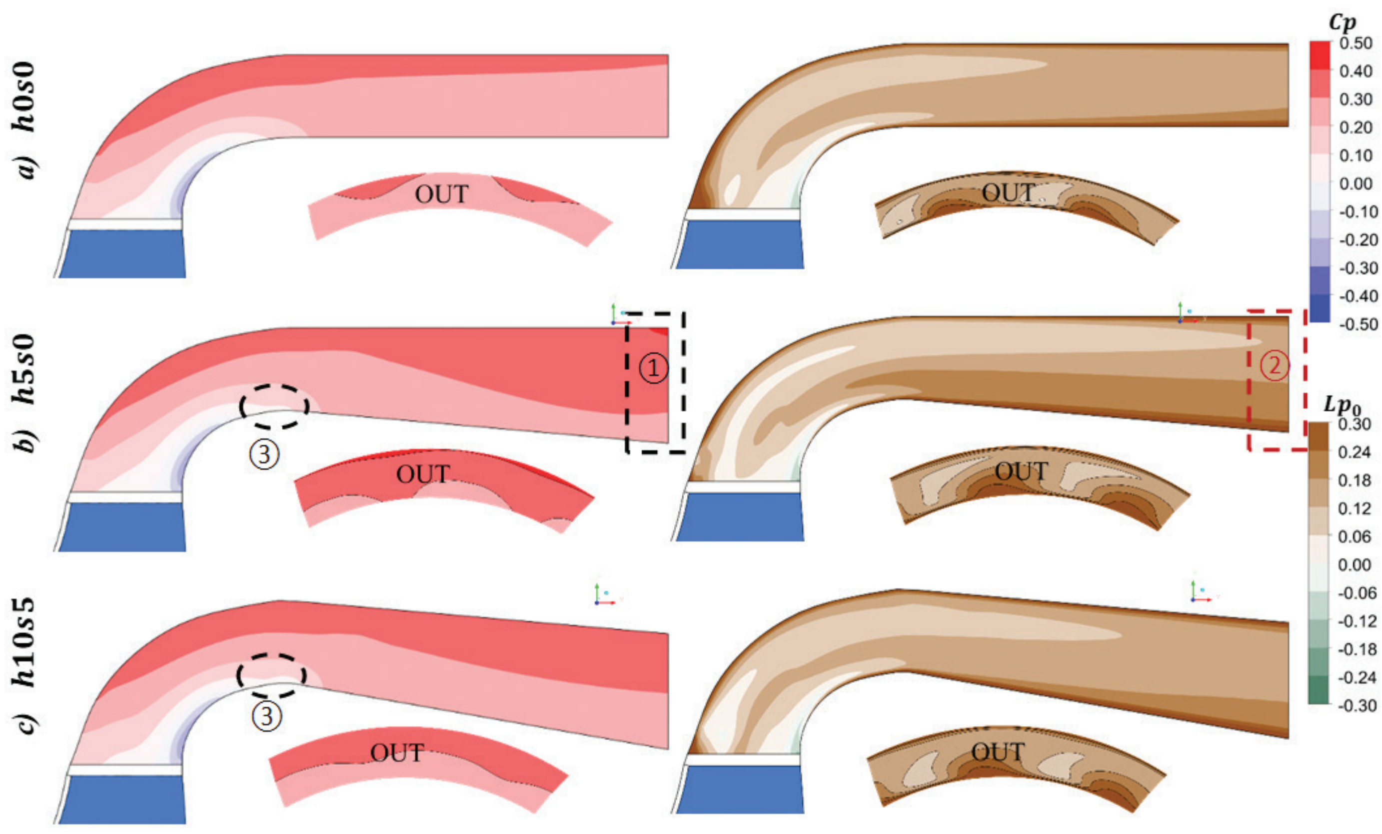

Figure 9. Coefficient of pressure, Cp and Total Pressure Loss Coef., Lp_0 at Meridional Planes (Averaged) of axial passage configurations of diffuser-duct and stage exit planes(out).

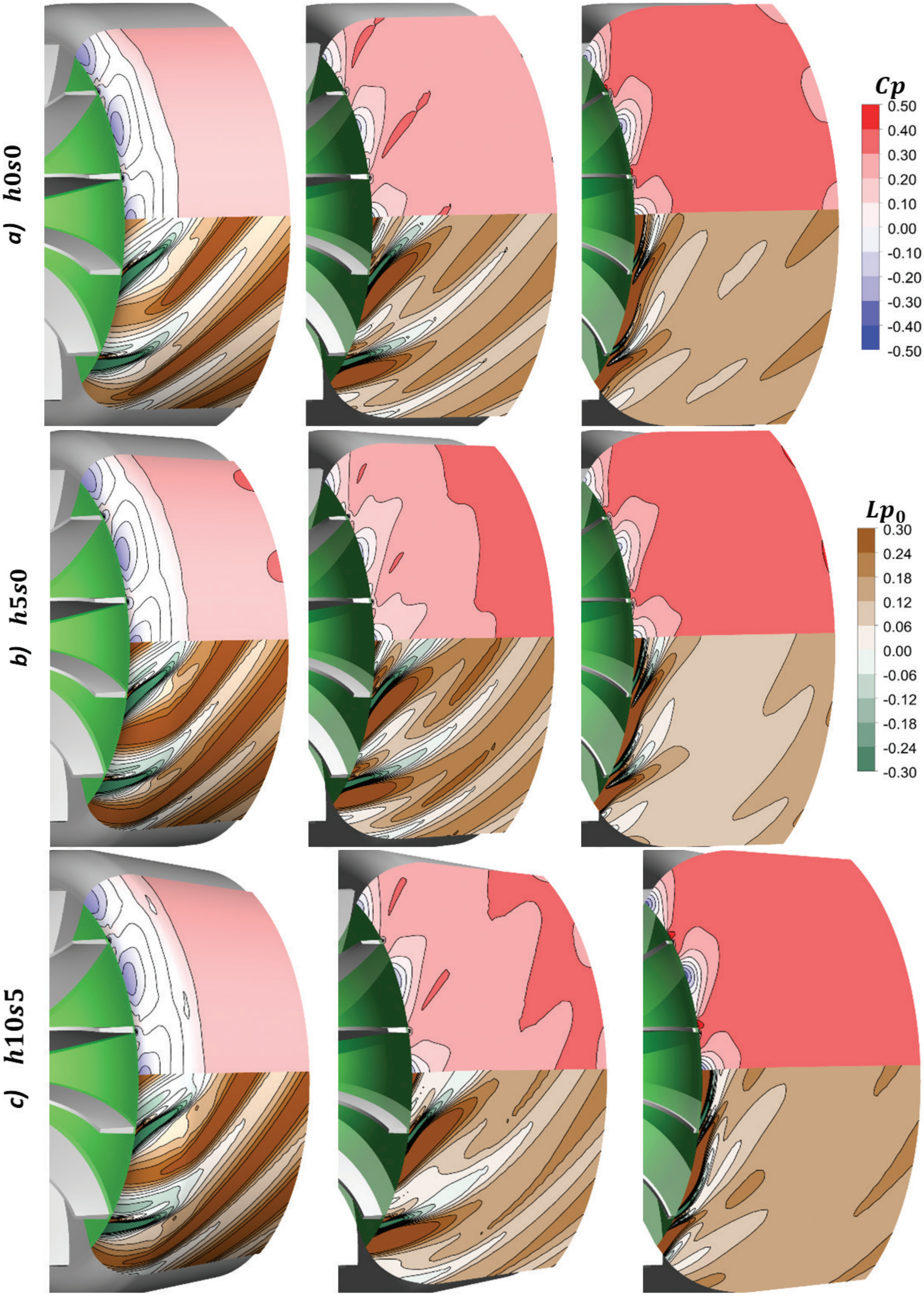

Figure 10. Streamwise coefficient of pressure, C_p and Total pressure loss Coef., Lp_0 at span 10 %, 50 %, and 90 % of axial passage configurations of diffuser-duct.

curved passage segments for all configurations. However, the conical diffusing shape of h5s0 has significantly improved the axial passage segment. However, this configuration has a marginally higher total pressure loss near the hub surface. Nonetheless, it is overall compensated with lower total pressure loss near the shroud. At the beginning of the axial passage segment, the inclined hub surfaces of h5s0 and h10s5 have produced a discrepancy of drop in pressure recovery, as shown in region (3) of Fig. 9. This discrepancy could be because the change in flow direction introduced due to the inclined hub surfaces may introduce deviation of the flow, and it is not receiving proper guidance. This characteristic could be similar to 'flow slip' occurring in centrifugal rotors. As discussed in the previous paragraph, this is reflected as streamwise hub pressure recovery discrepancies. However, it influences only small regions without affecting the overall effectiveness of the configurations.

All three axial passage configurations have marginal variation for streamwise total pressure loss coefficient, as shown in constant span streamwise locations in Fig. 10. It indicates that all three configurations are equally effective in minimizing total pressure losses. However, pressure recovery characteristics are better for h5s0 with maximum static pressure at the stage exit. The pressure is highest near the shroud region and least near the hub -region for all configurations. The considerable circumferential pressure variation near the inlet is resolved to uniformly distributed circumferential pressure as the flow progresses downstream. This variation exists for only curved passage segments. Axial passage segments have uniformly distributed circumferential pressure for all span locations.≈

4. CONCLUSIONS

A low-cost, lightweight, and compact diffuser-duct developed with the functionality of flow diffusion and redirection could be integrated into small gas turbine engines for aero applications. Numerical studies have been conducted at $Re \approx 8.9 \times 10^5$ to arrive at an efficient diffuser-duct geometry to maximize pressure recovery and minimize total pressure losses with the uniform flow at the stage exit.

The diffuser-duct developed for a centrifugal compressor stage has novel and innovative features.

- It consists of two segments:1. Annular conical curved-shape passage in Radial-to-axial direction, and 2 Annular axial conical passage
- The curved-shaped segment has the benefits of the reduced overall diameter of the stage with a marginally longer axial length than a conventional centrifugal diffuser configuration
- The axial conical passage has a diffusing shape geometry for continuous pressure recovery.

Valuable conclusions were drawn from this extensive exercise in developing the curved-shaped diffuser-duct. Development of curved-shape passage segment

- This segment is iteratively evolved from the initial design with equal passage width to a sophisticated baseline design generated with five intermediate design planes.
- Principally, geometry's visible hub surface modification significantly reduced total pressure losses with a gradually increasing pressure recovery throughout the passage.

Evaluation of different configurations of axial passage segment

- Three axial passage segment configurations were studied, namely, h0s0, h5s0, and h10s5. These are modified by changing the inclination of the hub and the shroud surfaces at small angles.
- The total pressure losses are almost equivalent for all three configurations. However, configuration h5s0 shows a superior pressure recovery characteristic.

The configuration featuring a curved-shaped segment and axial passage configuration h5s0 with inclined hub A=5° would be suitable for the baseline design configuration of the centrifugal compressor stage.

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