An Aerodynamic CFD Analysis of Inlet Swirl in a Micro-Gas Turbine Combustor

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ABSTRACT

A combustor was designed for a 200N micro-gas turbine [1, 2] using the NREC preliminary combustor design method [1, 2, 3]. During the design process, there are various aspects where there are no definitive methodologies for specifying the design detail, such as the design of the hole-sets, and multiple options can be derived that can satisfy the required mass flow split and pressure drop for a particular hole-set.

Hole-set configurations were devised using the process provided in NREC [3] combined with the knowledge that the previous combustor used in the engine had a problem with the inner combustor liner burning away. It was suspected that part of the reason for this was a much lower air flow rate in the inner annulus than the outer annulus due to minimal holes in the inner liner wall. An alternative cause could also be due to annular flow irregularities in the inner annulus such as flow separation [4].

The original combustor design had the vaporizer tubes entering from the outer annulus. In order to approach the combustor development process systematically, it was decided that the first combustors to be developed from the new designs will retain the current vaporizer tube setup with the vaporizer tubes entering from the downstream liner wall fed from the outer annulus.

The first phase of design [1] focussed on correcting the airflow splits between the two annuli and focusing on achieving an improved Primary zone flow pattern that more closely resembles the recirculation in the theory [5, 6]. Multiple preliminary options were designed with a zero-degree inlet swirl condition assumed, and nine preliminary designs were chosen for CFD analysis and evaluation. These designs varied in terms of annular area split configuration, hole area splits and relative hole positions. The evaluation was broken up into the relevant aspects/features, namely, Recirculation zone (Rz), Outlet and Mixing. For each feature, the designs were subjectively evaluated relative to each other and given a rating/score using the method presented in [2]. In this previous study [2] two likely preferable designs were selected using the devised scoring method.

For this study, the effect of inlet (diffuser outlet) swirl on the internal aerodynamics of previously chosen two combustor designs was investigated using a RANS CFD analysis. For each of the two designs chosen in a previous study [2] a set of varying flow angles (0°, 10°, 20°, 25°, 30°, 33°, 35°, 37° and 40°) was applied at the inlet to the simulation domain. The effect on the establishment of the primary zone features is of specific

interest; however, the effects and consequences of the swirl throughout the combustor were investigated.

It was suspected that, although inlet swirl is potentially detrimental to the combustor aerodynamics, the temperature pattern factor at the outlet as well as causing an increased pressure drop and without necessarily enhancing mixing [6], the swirl could provide some improvement to the previously observed non-ideal outlet flow which demonstrated many multidirectional vortices on the outlet plane which is highly unfavorable for the functioning of the NGV and turbine.

For both designs, the vaporizer tubes are treated as one of the primary zone hole-sets. The major geometrical difference between the two designs was that Design C had the second primary zone hole-set on the outer liner wall in between the vaporizer tubes while Design G had the second primary zone hole-set on the inner liner wall in line with the vaporizer tubes.

The CFD data for the two designs at nine different inlet swirl angles resulted in 18 different runs being performed and the data were processed, analysed and interpreted. Some of the results such as mass flow splits and pressure drop are already quantitative in nature, however, the evaluation of the quality of the recirculation zone, mixing and outlet plane flow are of a more qualitative nature.

A scoring system was previously devised in order to apply a quantitative value to the qualitative aspects of the flow which are initially analysed subjectively. The evaluation was broken up into the relevant aspects/features, namely, Recirculation zone (Rz), Outlet and Mixing. For each feature, the designs were subjectively evaluated relative to each other and given a rating/score.

This scoring methodology for ranking different combustor designs previously, in this study, proved to be an effective method for evaluating the effect of inlet swirl on the flow features and behaviour of the chosen combustor designs and thus provide an indication of the likely performance changes to be expected. The methodology was able to indicate which of the two top designs was the better option when considering inlet swirl. however the potential for improvement was revealed when considering scoring in a global context.

The results indicate that increasing inlet swirl reduces the generation of vortices throughout the combustor liner with a higher influence in the reduction of the vortices generated on the cross-sectional planes of the combustor. The swirl entering the combustor is increased throughout the length of the combustor and thus a single directional swirling flow is dominant at the outlet plane. This is likely to result in a reduction of overall mixing but improves the general aerodynamic condition of the flow entering the nozzle guide vanes (NGV).

Further, it was noted that the swirling flow further exacerbated the tendency observed in the previous study for the air flow split between the inner and outer annuli to be biased towards the outer annulus.

Overall though, many negative aspects in the flow of the combustors without swirl were improved such as the removal of cross-sectional vortices and the condition of the outlet plane flow entering the NGV.

This study suggests that for this engine, the inlet swirl could allow for the negating of an NGV before the turbine since the flow is fairly well conditioned and “pre-turned” due to the swirling flow progressing to the outlet of the combustor. The removal of the traditional NGV allows for a reduction in NGV pressure losses which compensates for the increased combustor pressure loss experienced due to increased inlet swirl.

Keywords: Combustor; Computational Fluid Dynamics; Evaluation, Inlet Swirl

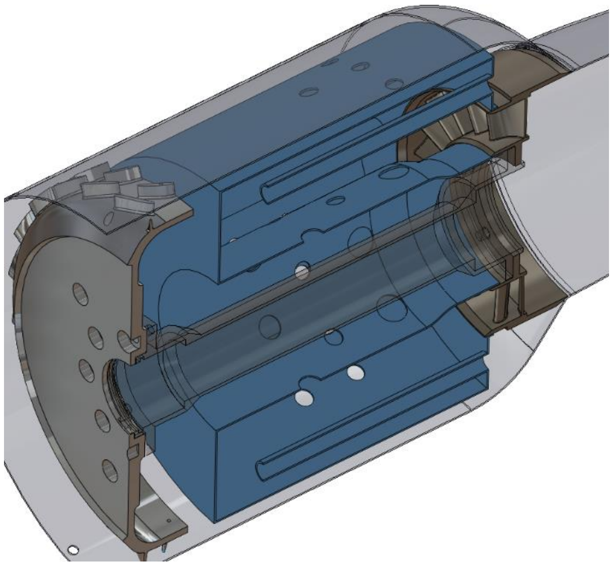

Figure 1: Perspective, cross-sectional view of the installed combustors for Design G showing the Installed NGV at the combustor outlet

<u>Best</u>

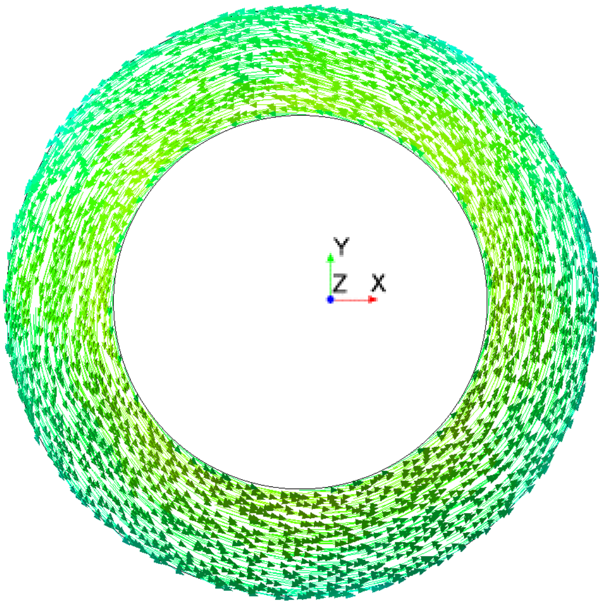

Figure 2: Design C @ 25° - outlet plane velocity vectors showing relatively fewer vortices. Score 6/10

<u>Worst</u>

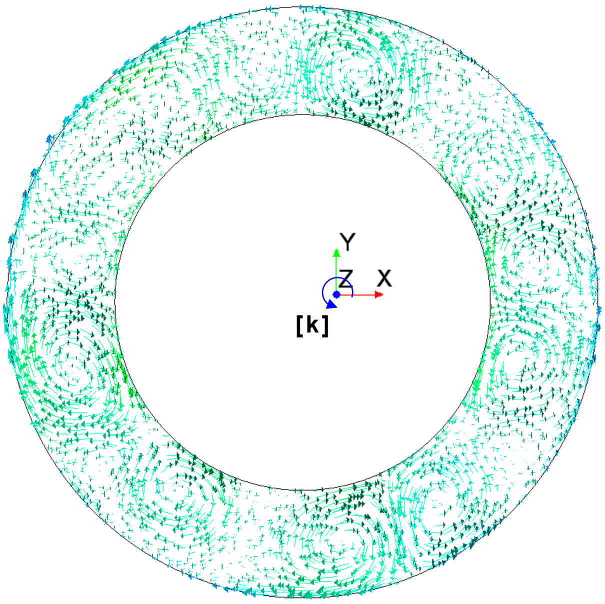

Figure 3: Design G @ 0° - outlet plane velocity vectors showing a large number of vortices. Score 1/10.

NOMENCLATURE

alt	Altitude
An	Annulus
C/S	Cross section
CFD	Computational Fluid Dynamic
Dz	Dilution zone
Dzi	Inner dilution zone hole-set
Dzo	Outer dilution zone hole-set
Eff	Efficiency
NGV	nozzle guide vanes
NREC	Northern Research and Engineering Corporation
Pz	Primary zone
Pzi,	Inner primary zone hole-set
Pzo	Outer primary zone hole-set
PzV	Primary hole-set that are vaporiser tubes
RST	Reynolds stress turbulence
Rz	Recirculation zone
SL	Sea Level
SST	Shear Stress Transport
Sz	Secondary zone
Szi	Inner secondary zone hole-set
Szo	Outer secondary zone hole-set
trac	Tracers
Vec	Vectors
Vort	Vortices

Symbols

ΔP	Pressure drop
$\dot{m}$	Mass flow rate
d	Liner diameter
D	Casing Diameter
p	Static pressure
P	Total pressure
T	Temperature
x	Horizontal co-ordinate
x	The fraction of total air required in the outer annulus
y	Vertical co-ordinate
z	Axial co-ordinate

Subscripts

3	Station at the inlet to the combustor
4	Station at the outlet to the combustor
f	Fuel
i	Inner
o	Outer

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