A Methodology for Optimizing Turbines powered by Rotating Detonation Combustors

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1. INTRODUCTION

- Design optimization can be defined as the process of determining the most desirable design given a set of constraints.
- The objective function is any sign of interest that must be minimized or maximized.
- This methodology utilizes a robust unsteady 1D Euler equations solver, a meanline performance analysis, and an optimization algorithm.

2. 1D EULER MODEL

The unsteady 3D-CFD simulations have very high computational cost and time. Therefore, reducing the order of the simulation can be highly beneficial. The compressible 1D-Euler equations are as follows.

$$\frac{\partial}{\partial t}\begin{pmatrix}\rho A\\ \rho V_x A\\ \rho E A\end{pmatrix} + \frac{\partial}{\partial x}\begin{pmatrix}\rho V_x A\\ \rho V_x^2 A + PA\\ V_x A(\rho E + P)\end{pmatrix} = \frac{\partial}{\partial x}\begin{pmatrix}\dot{m}_b\\ F_x + PA\\ W + \dot{m}_b h_{tb}\end{pmatrix}$$

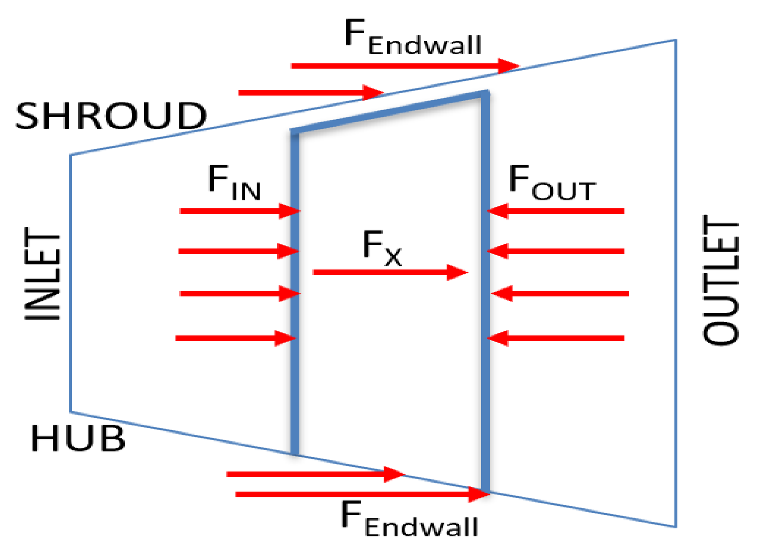
$$\dot{m}_b = 0$$

$$\Sigma F_x = \Delta(\dot{m} V_x)$$

$$\Sigma F_i = F_{in} - F_{out} + F_{endwall} + F_x$$

$$F_x = -F_{in} + F_{out} - F_{endwall} + \Delta(\dot{m} V_x)$$

$$W = (\dot{m} h_t)_{out} - (\dot{m} h_t)_{in}$$



MERIDIONAL VIEW AND FORCE BALANCE AROUND A TURBINE ROTOR BLADE.

The meanline method is executed to compute the source terms for a range of steady-state operating points. The boundary conditions includes total pressure and total temperature at the inlet and the static pressure at the outlet.

The baseline design for the current work is the high pressure turbine of the Energy Efficient Engine project by NASA.

3. OPTIMIZATION METHODOLOGY

3.1 Objective Function and Variables

The non-dimensional entropy is used as the objective function to be minimized. Non-dimensional entropy generation is computed by subtracting the corresponding values at the turbine outlet from the inlet. P_{ref} = 1Pa, T_{ref} = 1K.

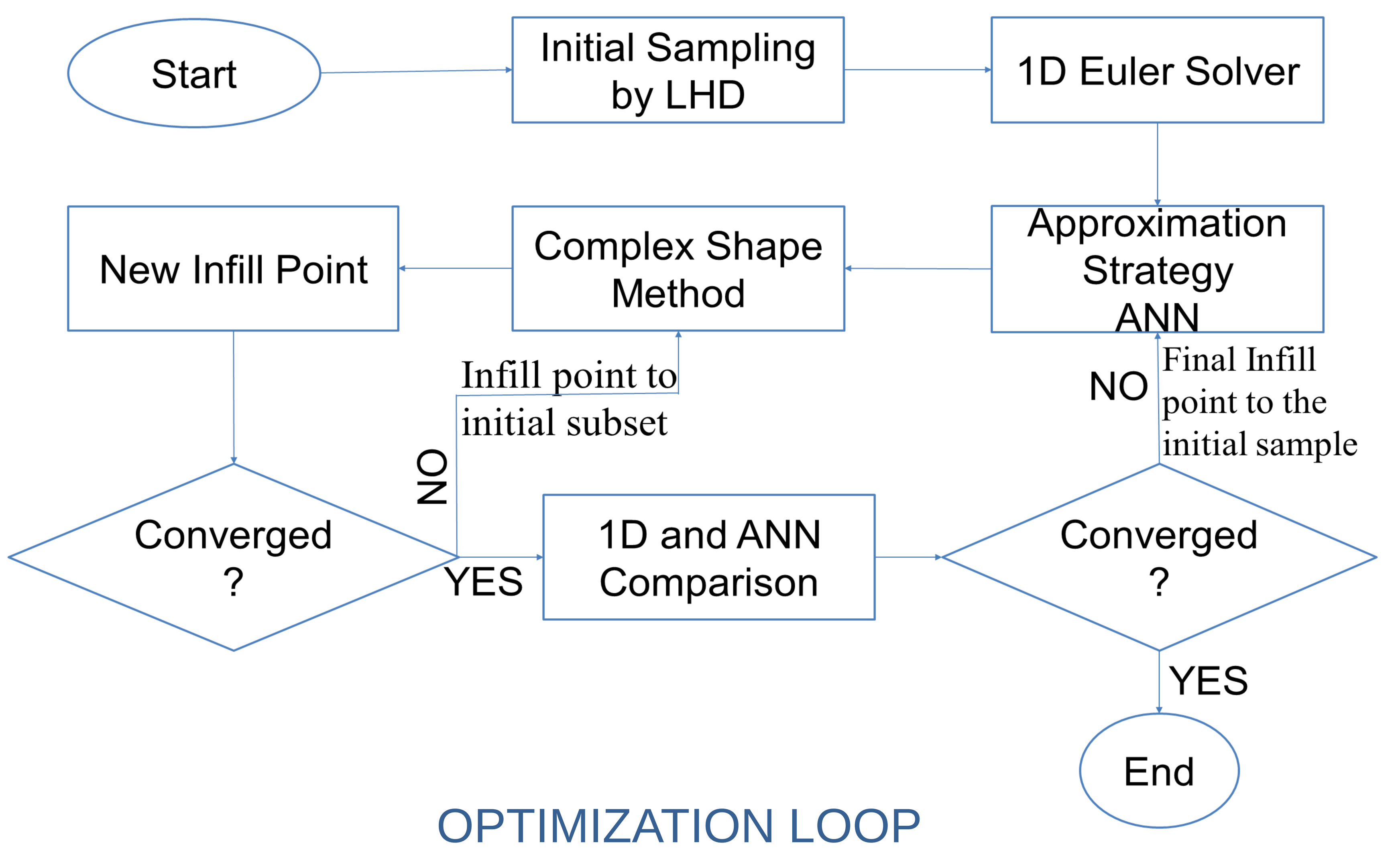
$$S = \left[\frac{T}{T_{ref}}\right]^{\gamma/\gamma-1} \left[\frac{P}{P_{ref}}\right]^{-1}$$

Variable	NB_{v1}	NB_{r1}	NB_{v2}	NB_{r2}
Base Value	46	76	48	70
Bounds	29-116	54-198	29-116	54-116

OPTIMIZATION VARIABLES

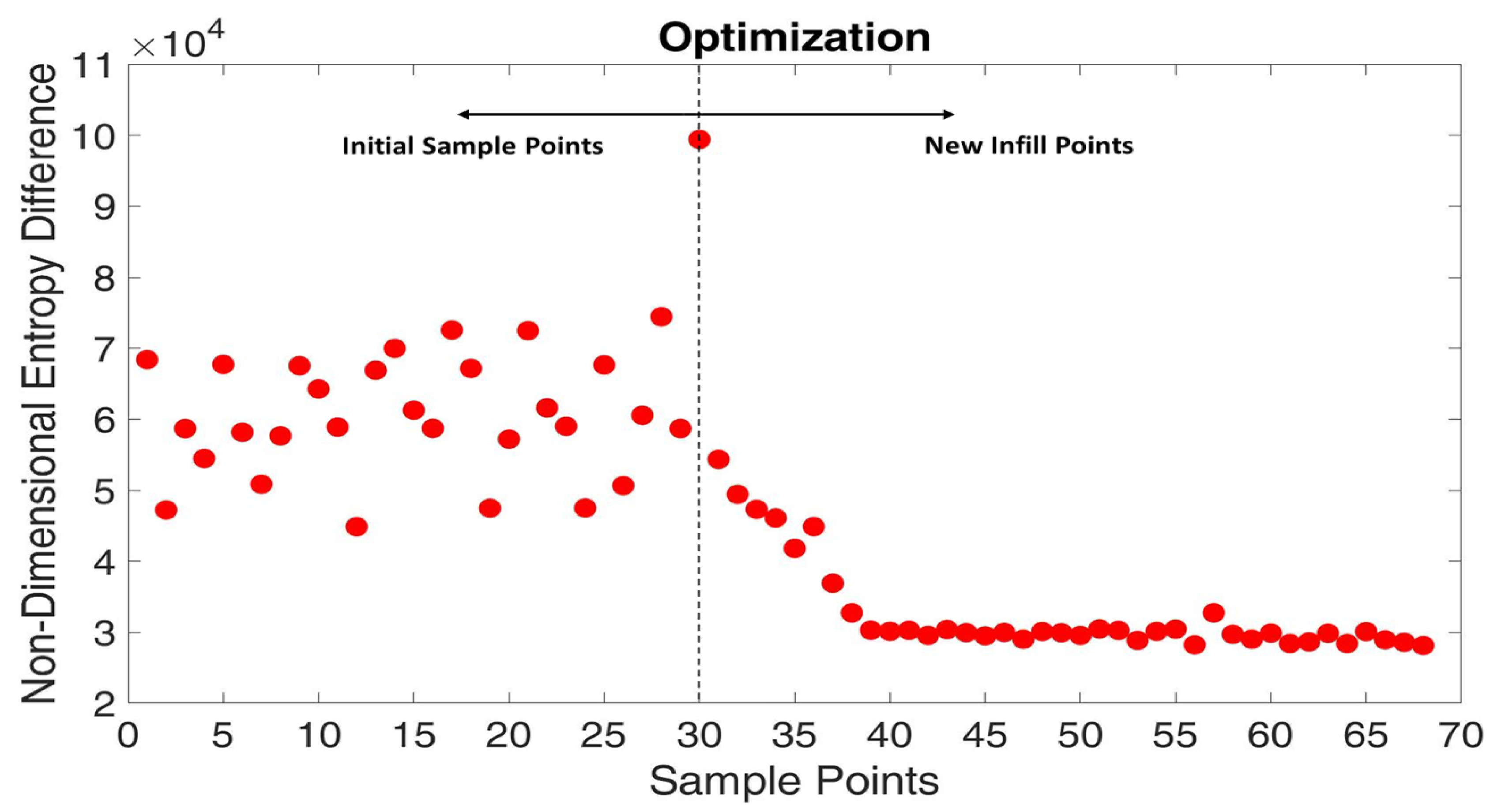
3.2 Optimization Procedure

- For the optimization process, we use Artificial Neural Network (ANN) for approximation and Complex Shape Method (CSM) to get the new infill points. The detailed procedure of CSM is explained in [1].
- The new infill point from the CSM operations replaces the worst sample point. Then the iteration continues. By using these operations, the replacement points are constantly approaching the optimal solution.



OPTIMIZATION LOOP

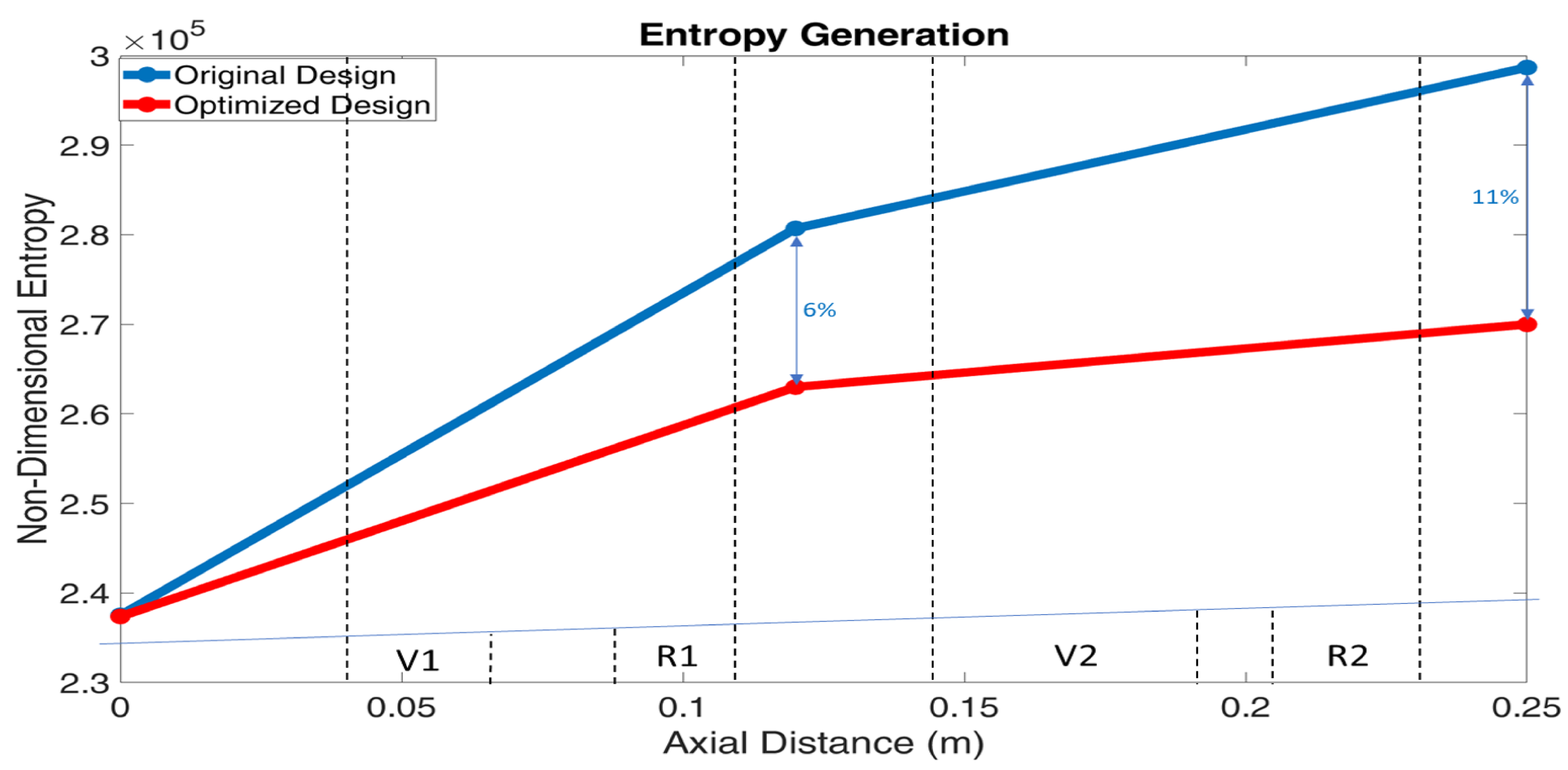
4. RESULTS AND CONCLUSION



CONVERGENCE TREND OF THE OPTIMIZATION PROCESS

Variable	ΔS	NB_{v1}	NB_{r1}	NB_{v2}	NB_{r2}
Base	61173.48	46	76	48	70
Optimized	28144.90	116	136	30	67

OPTIMIZATION RESULTS



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5. FUTURE WORK

- Perform 3D-CFD simulation for both original and optimized design.
- Introduce the bleed flow into the 1D Euler model, in order to simulate the flow with the turbine blade cooling.

6. ACKNOWLEDGEMENT

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