A New Integrated-Aerodynamic-Design Program of Multistage Axial Compressor MACADS ver.1.2

Part 2 : 3D Design and Analysis

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Objectives

- Demonstrate a new design process of multistage axial compressors using MACADS ver.1.2.
  - As Part 2 with a sample design of a 10-stage highly-loaded axial-flow compressor for PR = 23
  - Evaluate each-row 3D blade design, done by BLADE3DR ver.5.1, through the built-in 3D Multistage CFD Effective.
  - Only at the initial design iteration (Rev.1)

- Demonstrate a new flow analysis code for a multistage design process of turbomachinery.
  - Named Multistage 3D CFD Effective
  - 3D RANS solver with viscous stress terms replaced by those of turbulent loss correlations
  - No tip leakage flows
  - Density-based time marching with artificial dampings
  - Mixing plane interface
  - Multi-grid acceleration
  - Fast and reliable solutions serving multistage design purposes
  - Intended for replacing traditional throughflow analysis programs of streamline curvature methods
Multistage 3D Design

Last page of Part 1 Study

- Initial 3D geometry from Throughflow Design
- 3D geometry changes in Multistage 3D Design
  - by calling BLADE3DR ver.5.1
Multistage 3D Design

When each-row 3D blade geometry was updated by BLADE3DR, and ready for analysis using Multistage 3D CFD Effective

Last page of Part 1 study
Multistage 3D Analysis

Input options

- Multistage 3D Design: Bring each geometry from Multistage 3D Design to Multistage 3D Analysis folder
- Multistage 3D Analysis: Stay in Multistage 3D Analysis folder
Multistage 3D CFD Effective – Input

### Grid Generation
- **US units**
  - Grid count in spanwise direction (max. 46)
  - Grid count in circumferential direction (max. 37)
  - Streamwise direction
  - Grid count on each blade (from LE to TE)
  - Grid count upstream (or downstream) of internal blades
  - Grid count upstream of the 1st-row blade LE
  - Grid count downstream of the last-row blade TE

### Operating Conditions
- **Total-to-static pressure ratio**
- **Inlet total pressure**
- **Inlet total temperature**
- **Gas specific heat ratio**
- **Gas constant**
- **Rotational speed (+ve in +ve Theta)**

### Inlet Boundary Conditions
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#### Notes:
- (1) Smaller spacing with the value closer to 1.0 (usually 1.2)
- (2) Smaller spacing with a higher value from 1.0 (usually 1.1)
- (3) Normalized span from the hub (in an ascending order)
- (4) Target mass flow rate through whole circumferential sectors
- (5) Based on R1 tip chord, if unknown you can put 0 there
- (6) Mass flow option is not recommended in general

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(©) Current version does not support interstage bleed flows

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TurboAeroDesign.com
In the current 10-stage case, total grid size was,
- 667 in the streamwise direction
- 28 in the spanwise direction
- 19 in the circumferential direction

For 2,000 iterations it took about 15 min. on the i7 laptops
Current sample design is shooting for 85% isentropic efficiency at PR = 23 in a 10-stage axial.

My meanline design predicted 82% efficiency max. with only 10 stages.

First design of Rev.1 shows now 79% efficiency from 3D CFD Effective, which implies there must be many design issues to fix.
Multistage 3D CFD Effective

Solution Convergency
Multistage 3D CFD Effective

New plot screens of CFD updated when run is complete

Two groups of screen
Multistage 3D CFD Effective

Computational mesh in the meridional plane

Zoomed view
Multistage 3D CFD Effective

Computational mesh in the blade-to-blade plane

Zoomed view
Multistage 3D CFD Effective

Stage 2 PR is down
Stage 1,2,10 ETA are down
Too highly-loaded Mid-stages

Higher shock losses at R1 tip
 Shock is positioned upfront in R2

Higher shock losses at R2 tip

Higher DF at R2 tip
Multistage 3D CFD Effective

Shock is positioned upfront in R2

Highly-skewed at S3 shroud
Hub incidence to be optimized
Multistage 3D CFD Effective

Flow separation on suction side

R2 needs shock position controls.

R2 needs incidence controls.
Incidence control breakdown at S1 shroud.

S2 needs deviation controls accordingly.
Mid-block rotors need loading controls. Incidence control required. Too high DF at R5 tip.
Mid-block stators need loading controls.

Incidence control required

Too high DF at SS shroud
Rear-block rotors need loading controls.

"Too high DF at R5 endwalls"

"Incidence control required"
Rear-block stators need loading controls.

Incidence control required.

Too high DF
Multistage 3D CFD Effective

Trend of blockage developments in the flowpath
Summary

- In Part 1 and Part 2 of this study, the first single loop of multistage aerodynamic design process was demonstrated, prior to the so-called CFD, for a sample 10-stage highly-loaded axial-flow compressor.

- Starting with design specifications given, Design of Rev.1 went through,
  - Meanline Design
  - Meanline Analysis
  - Compressor Map Generation
  - Effects of interstage bleed and VIGV/VSV reset schedule on compressor map
  - Throughflow Design
  - Blade 3D geometry design of each row using BLADE3DR ver.5.1
  - Multistage 3D Design
  - Multistage 3D Analysis using Multistage 3D CFD Effective

- All of design issues, detected by Multistage 3D Analysis, will be addressed through so many numbers of design loop, to be ready for more accurate state-of-the-art CFD analysis before finalized.

- MACADS will serve as a new powerful, reliable and effective design suite for the complicated and otherwise-time-consuming design loop.
In Part 3, the followings will be covered:

- **Block-CFD Module:**
  - It is planned to add to MACADS ver.1.2 to enhance flow analysis of a few blade rows as a block analysis.
  - 3D RANS CFD with an algebraic turbulence model
  - Rotor tip leakage flows included
  - Several design improvements of the sample case will be demonstrated.