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Simulation of Instability Onset in a Gas Turbine

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Abstract

This is a design document for the next stage of the GasTurbnLab project. The goal is to incrementally build a simulator of gas turbines that exhibits the onset of instability in the gas flow (stall). The simulator will have a minimal number (perhaps 16 to 48) of compressor blades in the compressor and one combustor. These physical components will be represented by computational agents in the simulation; perhaps 50 to 150 will be required.

1 OVERVIEW

The goal is to have a gas turbine simulation that exhibits stall and that is as simple as practical. Since cylindrical symmetry precludes stall, there must be at least one row of rotor blades, one row of stators and a combustor. Currently, we can simulate combination of one rotor blade, one stator blade and a combustor. We will increase the number of blades incrementally until we have a simulation that exhibits stall. There are three principal challenges in this project: (1) To develop interface conditions between blades in the same row and then to create mediator agents that handle them, (2) To develop ways to partition a combustor into multiple pieces each simulated independently by KIVA. This again involves developing interface conditions and associated mediators, and (3) To manage the computations efficiently on our parallel computers.

The design is presented in two parts. First is the gas turbine configurations to be considered and the development of the interface conditions to be satisfied among the components. Second is the creation of the mediator agents and the management of the computation. This work is based on the designs and analysis in the references given at the end.

2 GAS TURBINE CONFIGURATION

2.1 Multiple Blades

The physical layout or multiple blades is illustrated in Figure 1 for two rows rotors and two rows of stators, each with three blades. These rows form a cylindrical band around the axis of

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the turbine so using three blades is unrealistic, but it illustrates some issues to be considered:

* *Interfaces between rotating and stationary blades.* We have already handled this and expect this new situation to be handled in the same way.

* *Interfaces between adjacent rotors and adjacent stators.* The interface conditions and associated mediators need to be checked to assume that they are correct, especially for the slanted domain boundaries.
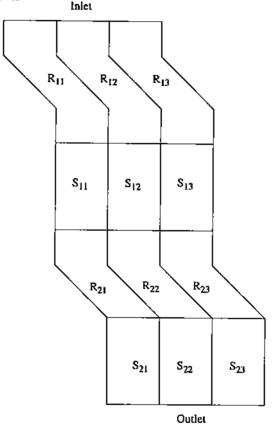

Figure 1. Outside-in view of the configuration of domains for two rows of six rotors (R_{11}, R_{12}, R_{13}, R_{21}, R_{22}, R_{23}) and six stators (S_{11}, S_{12}, S_{13}, S_{21}, S_{22}, S_{23}). Note that (a) the stators are fixed and the rotors rotate, (b) the physical blades are inside the domains indicated with flowing gas between them, and (c) the rows have periodic conditions, e.g., the right side of R_{13} is adjacent to the left side of R_{11}.

2.2 Combustor Partitioning

The physical layout of the combustor and the blades is shown in Figure 2 with an outside-in view. Figure 3 shows a cross section of the combustor perpendicular to Figure 2. It is obvious that the combustor is a much larger and more complex object than the individual blades. Further, the

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time steps required in simulating the combustor are smaller than those of the compressor. Thus, to balance the computational load, the combustor must be partitioned into separate zones. This has not been done before, but is feasible if done carefully.

First, the combustor is partitioned along radial planes into 1 or 2 times the number of blades. Then each of these slices is partitioned as shown in Figure 4. One of the primary tasks in the computation is to select this partitioning so as to approximately balance the computational loads. Furthermore, the interface conditions between zones must be determined; it is important that the direction of the flow be known across each interface.

2.3   Final Configuration

The final configuration will join the compressor rows and the combustor to create a complete gas turbine. Simplistic configurations (e.g., 1 row of 3 rotors, 1 row of 3 stators, plus a combustor with $3 \times 4 = 12$ partitions) will be used to test the computational procedures. Then the complexity of the configuration will be increased until reasonably realistic gas turbine behavior is observed. Finally, the operating conditions will be changed until the onset of instability is observed. Note that we must first observe "normal" turbine behavior before looking for the instable behavior, as we would not know whether the instability is due to simplification in the model or represents actual physical behavior.
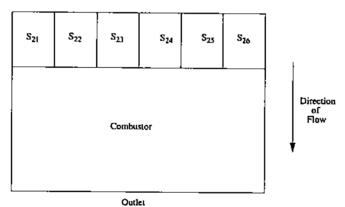

Figure 2. Outside-in view of the last row of stators and the combustor. The inner details of the combustor are not shown, but note that it wraps all the way around the turbine.
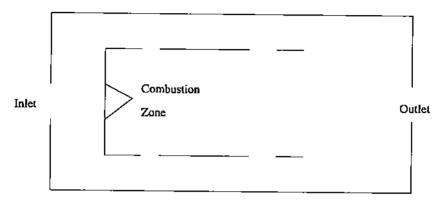
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Figure 3. Cross section of the combustor perpendicular to the cylindrical symmetry. The rectangular design here is not representative of real combustors, but has been used by others to simplify the computational complexity due to the geometry.
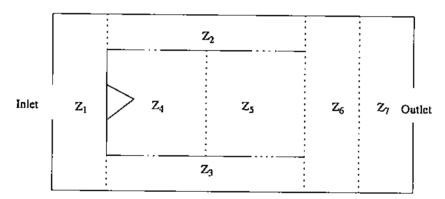

Figure 4. Partitioning of a slice of the combustor into seven zones ($Z_1, ..., Z_7$). All the zone interfaces are parallel to one of the sides of the combustor.

References

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