Chapter 5: Summary and Future Work

This chapter closes the main part of this work with a summary of the model and its results, followed by some recommendations as to its future development.

5.1. Summary

An unsteady model was developed for complete gas-turbine configurations, based on the fundamental governing equations for flows with non-equilibrium chemistry. A simple and fundamental approach was followed in the hope that it would allow the handling of problems not usually covered by more sophisticated CFD approaches due to their complexity and required computational resources.

The chosen approach was to solve the one-dimensional integral conservation equations for multi-species flows with chemical reactions. All the effects that could not be handled by the usual one-dimensional ideal-flow (Euler) equations (i.e., area-changes, friction) were included in source terms on the right-hand side of the system. The formulation of the source terms represent a non-trivial part of the modeling effort. A one-step chemistry sub-model has been adopted for the calculation of the species production terms. Standard approaches were chosen to calculate the fluxes and integrate the equations in time.

To accommodate domains with splits in flow-paths within a one-dimensional framework, special procedures had to be introduced. For straight-flow burners the main flow is split according to conservation of fluxes and user-given ratios of total pressure between the separate flow-paths. In the reverse-burner case (with open-inlet primary) a simplified two-dimensional approach is used at the flow-division location. In both configurations the primary- and annular-paths interact through bands of dilution holes, exchanging mass, momentum and energy.

The model can provide steady-state and dynamic results. For the first type the model was compared to a known analytical solution for a simple case (constantarea tube with friction) and to the results of an industrial code on a production burner. The results from the present method were satisfactory in both cases. The latter case, however, showed the limitations of any one-dimensional approach in that pressure losses that could not be modeled by simple fluid-dynamic effects had to be provided to the model. This is not considered as serious as it may appear. More sophisticated tools also have to be “calibrated” in order to give adequate agreement with known results. It is expected that once this calibration is obtained for one operating condition it can be held fixed for most other conditions. Finally, a generic reverse-flow burner was tested to verify that at least the calculations produced physically realistic results for this configuration.

For the unsteady part of the validation the main effect of finite-rate chemistry, i.e., blowout due to lean and rich mixtures, was tested. Results show that the model can predict blow-out outside certain limits which are functions of operating conditions. However some doubts remain as to its accuracy, as exemplified by the location of the “cusp” of the stability loop. The main effects of the blow-out phenomenon appear to be physically captured.

Finally, perturbations were introduced in boundary and operating conditions for the previously-mentioned reverse burner. The response of the model to these perturbations seems to be fundamentally correct.

5.2. Future Work

Based on the experience gained with the model, some recommendations can be made for its improvement:

- The robustness of the finite-rate model decreases notably with the Mach number. For Mach numbers between 0.01 and 0.001 in orders of magnitude convergence is somewhat difficult (particularly near or at blow-out). Below the latter limit it is almost impossible. This is due to the wide range of scales of the eigenvalues of the system (Withington et al. [1991]). This situation arises for low pressures and temperatures, or for locations with flow-reversal. A possible improvement could come from the use of pre-conditioning in order to scale all eigenvalues to the same order of magnitude (Godfrey, 1992).

- The treatment presented in this work of the flow-division makes the handling of complex configurations possible with a one-dimensional model. Unfortunately some problems arises within the context of the fully-implicit time-integration. The zonal boundary conditions used to converge to a solution (Appendix A) restricts the CFL number to a relatively modest value of 5.0. This might be linked to the previous point. A better procedure has to be developed.

- Not directly related to the model itself but rather to its computational implementation are the issues of spatial and temporal discretization. For the former it would be convenient to consider some form of adaptive grid, i.e., automatic re-discretization of the domain for better resolution of the gradients in physical properties. This would be specially useful to better capture the flame location in the primary flow and follow its evolution during dynamic events, while still using a reasonable number of control-volumes. As for time discretization the current approach requires the user to provide the CFL number as function of time. A better approach might be to adapt the CFL to time-gradients of flow properties, as in Garrard (1995).

- It would be desirable to install an ignition sub-model in order to study phenomena like starting from ground conditions and relight after blow-out.

- For convenience the domain was separated into calorically-perfect gas and reacting zones. For the sake of computational simplicity and to better capture processes like flow-reversal it would be convenient to use the same flow model throughout. This will impose some modifications in the flow-division models, but they should be feasible.

- To take full advantage of its dynamic capabilities, the present combustor model should be adapted to already-existing unsteady simulation codes (Garrard, 1995). The prescribed inlet and exit boundary conditions would be replaced by compressor and turbine models. This coupling would allow to study the interaction between all components in both stable and unstable operation.