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CALTECH/AFOSR WORKSHOP ON DYNAMICS AND CONTROL OF COMBUSTION INSTABILITIES IN PROPULSION AND POWER SYSTEMS

NOVEMBER 20-22, 1997
CALIFORNIA INSTITUTE OF TECHNOLOGY

Chairmen: J. Marsden, R. Murray, F.E.C. Culick

The workshop reinforced the idea that a combination of analysis, simulation, and experiment continues to be a feasible approach to the problem of combustion instabilities. Control of these instabilities is very important to industry and provides a challenge to theory and simulation.

Some of the areas needing more development and in which there are research opportunities are as follows.

1. Modeling.
An understanding of nonlinear processes is critical to advancements in the area. For example, the importance of combustion versus gas dynamics is still an area needing much more investigation from a fundamental point of view. Some areas, such as flame sheets, have seen some progress, but in general, there is much that is not understood. Advances in this area should ultimately lead to better control strategies.

Effective modeling of nonlinear processes must combine observations from experiments as well as models derived from basic principles. Due to the complicated nature of both the gas and combustion dynamics in propulsion applications, it is unlikely that a model based completely on first principles will be both tractable and capture all of the details of the system. Therefore, reduced-order models which capture the essential features must be developed. This has been started, for example, in the context of laminar flame dynamics.

2. Modeling tools.
The development and improvement of several modeling approaches should continue. These methods include combination of hierarchical methods based on the mechanics, physics, and chemistry of the processes involved; the proper orthogonal decomposition; and dynamical systems methods to get low-order models (including data analysis, attractors, etc.). In addition, many of the situations reported (such as the combustor studied by Siemens) show that symmetry plays an important role in some problems.

3. Chemistry.
The complex chemical kinetics that is involved is one of the reasons modeling is so hard. However, it is possible that the use of techniques of averaging, the proper orthogonal decomposition, invariant manifolds, the use of numerics, and the modeling tools already mentioned can help here.

4. Control.
Recent success with the compressor problem suggests that progress is possible in combustion too, but combustion lags behind in the required modeling because of the higher complexity of the problem, as we have mentioned. However, industry has shown that control is possible in some circumstances, such as with the modulation of a secondary fuel supply.

Although there have been several successful demonstrations of active control on industrial engines and test rigs, many of these demonstrations are not accompanied by any formal analysis indicating how the control is affecting the stability or what basic mechanisms are involved. Without this analysis, it will be very difficult to scale up to full-scale engines or to do design modifications without a lot of tuning on the hardware, which can be very expensive. The UTRC efforts in modeling appear to be the most advanced, but no results were given about how the control laws were derived or analyzed. Hence, this remains an area that requires much more work from the research community.

5. Industry.

As we mentioned, control of combustion instabilities is very important to industry. Generally, industrial projects benefit greatly from interactions with universities and research labs. For example, the links between Siemens and the Technical University of Munich showed this. Some of the control strategies presented by them were interesting and the ABB method of using swirl to reduce NOX levels was quite impressive, as was the control of afterburners by Rolls Royce. Scalability is always an important issue in such cooperative ventures. However, the proprietary nature of many results can be a problem.