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Extreme sensitivity in Thermoacoustics

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In rocket engines and gas turbines, fluctuations in the heat release rate can lock in to acoustic oscillations and grow catastrophically. Nine decades of engine development have shown that these oscillations are difficult to predict but can usually be eliminated with small ad hoc design changes. The difficulty in prediction arises because the oscillations' growth rate is exceedingly sensitive to parameters that cannot always be measured or simulated reliably, which introduces severe systematic error into thermoacoustic models of engines. Passive control strategies then have to be devised through full scale engine tests, which can be ruinously expensive. For the Apollo F1 engine, for example, 2000 full-scale tests were required. Even today, thermoacoustic oscillations often re-appear unexpectedly at full engine test stage.

Although the physics is well known, a novel approach to design is required. In this presentation, the parameters of a thermoacoustic model are inferred from many thousand automated experiments using inverse uncertainty quantification. The adjoint of this model is used to obtain cheaply the gradients of every unstable mode with respect to the model parameters. This gradient information is then used in an optimization algorithm to stabilize every thermoacoustic mode by subtly changing the geometry of the model.