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EMERGENCE OF ORDER FROM CHAOS IN TURBULENT SYSTEMS AND BOSE-EINSTEIN CONDENSATION

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Danger zone: Thermoacoustic instability can affect the guidance and control system of rockets and lead to mission failures, says R.I. Sujith.

An important phenomenon studied in aerospace engineering is the emergence of order from chaos in turbulent systems that leads to detrimental large amplitude fluctuations. Examples of this include aeroelastic flutter as observed in the wings of aircraft and thermoacoustic instabilities in rocket combustors, both of which can lead to the breaking down of the system. For this reason, it is important to be able to predict and understand such happenings and avoid them.

At R.I. Sujith’s lab in the Department of Aerospace Engineering of IIT Madras, this phenomenon has been studied for years. As he succinctly explains: Thermoacoustic instability, which comprises self-sustained large amplitude periodic oscillations, can overwhelm the thermal protection system in combustion chambers, cause damage to structural parts such as turbine blades, or even affect the guidance and control system of rockets and lead to mission failures.

An oft-quoted example of this is the failure during testing of the F-1 engine in the Apollo rocket. Initially, every time they tested the rocket, the engine would get into this instability and explode. They later introduced baffles that disrupted the interactions between the flames and that between the flames and the combustion chamber giving the engine the desired stability.

In a combination of theory and experiment, Prof. Sujith and his student Shruti Tandon have come up with an understanding of the emergence of order in chaotic systems by drawing an analogy with a phenomenon widely studied in quantum statistical physics – Bose-Einstein condensation (BEC). In BEC, Bosons, which are elementary particles having spins that take integer values, such as 0, 1 or 2, condense to the lowest energy level when temperature is taken to very low values. The group has shown an analogous condensation taking place in the case of order emerging from chaos in turbulent systems.

To understand this, take the concept of phase space – an dynamic imaginary space where a particle is represented by its position and momentum at every instant of time. The acoustic dynamics of the combustor is represented as a trajectory moving in this imaginary space.

During chaotic movement, there are several possible orbits, and so even as the trajectory moves towards one orbit, it is attracted to a different orbit, and therefore does not stick to any one orbit.

However, as the parameter is tuned and the system makes a transition towards order, the number of orbits is reduced and therefore, the trajectory gets caught in a few stable orbits. The researchers label this process a type of “condensation.”

“In the current work we have provided a novel perspective to study the transformation of the phase space structure with transition from chaos to order using analogy with Bose-Einstein Condensation,” says Ms Tandon, a dual degree student in the department.

“The next step would be to use statistics of Bosons, namely, tools from statistical mechanics that are used to study Boson particles and Bose-Einstein condensation, to quantify the transformations in the topology of the phase space," she adds.

The paper that draws out the analogy is published in the journal *Chaos.* "Using measures from cycle networks and using analogy with BEC we were able to develop 'early warning indicators' that identify the onset of intermittency and hence forewarn the occurrence of thermoacoustic instability in the combustor," says Prof Sujith, who is the D. Srinivasan Chair Professor in the department.

"In future, we would like to also analyse the spatio-temporal data from the perspective of BEC transition; thus, develop strategies to prevent the condensation transition and thus mitigate such instabilities," he adds.