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Optimal transient growth behind distributed roughness elements on a spherical re-entry capsule

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In this work we investigate the optimal disturbance growth behind an array of rectangular, subcritical distributed roughness elements on a spherical re-entry capsule at cold hypersonic flow conditions. The boundary layer on this capsule does not feature modally amplified perturbations at typical wind-tunnel conditions[1]. However, transitional surface heating has been observed in experiments where the model was coated with an infrared paint at a surface mean roughness height of 10 μm[1]. The onset of laminar to turbulent transition in the experiment could be caused by roughness induced disturbance growth.

The intent of this work is to clarify the impact of distributed roughness on the optimal transient growth characteristics. An adjoint-based optimization algorithm is applied to determine the maximum disturbance growth behind five streamwise aligned squared elements, exploiting the intrinsic parabolic nature of the governing equations. The direct PSE-3D are used to march an initial solution in a plane in the streamwise direction from $\xi = \xi_0$ to $\xi = \xi_1$, followed by a backward adjoint PSE-3D integration. Optimality conditions at ξ_0 and ξ_1 are used to obtain the initial condition for the subsequent PSE-3D and adjoint PSE-3D march, respectively.

The influence of different optimization interval lengths ($[\xi_0, \xi_1]$) and objective functions (mean energy gain vs. maximum energy gain at ξ_1) on the maximum disturbance growth will be presented and compared to the smooth wall case without roughness elements. Furthermore, the relevant frequency range of the optimal perturbations will also be identified.

REFERENCES

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