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Adaptive tracking control for air-breathing hypersonic vehicles with state constraints

Key words: Hypersonic vehicle; Constraints; Output redefinition; Barrier Lyapunov function

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Motivation

- For air-breathing hypersonic vehicles (AHV), the engine performance is very sensitive to the change of the angle of attack (AOA) due to the strong coupling between the engine and the AOA. Therefore, it is necessary to force the AOA to track a given reference trajectory to improve the performance of air-breathing engines. However, in the existing work, the AOA is viewed only as an intermediate variable and its main role is to guarantee the altitude tracking. As a consequence, the AOA tracking is difficult to achieve while ensuring altitude tracking.

Motivation (Cont'd)

- In addition, the strong coupling between the engine and the AOA determines that the AOA must be strictly within a given envelope; otherwise, air-breathing engines will unstart and this phenomenon is unacceptable. Thus, the control for AHVs with state constraints is of great importance. On the state-constrained control for AHVs, only a few results have been reported, which are still based on trial-and-error procedures, and thus the design procedures are very complicated.

Main idea

- By redefining the outputs, a novel indirect AOA tracking strategy is proposed which can ensure simultaneous tracking of the altitude and the AOA.
- The barrier Lyapunov function is used to solve the state-constrained control problem of AHV with the unknown control gain.

Method

1. Viewing the pitch angle as a new output and devising an appropriate pitch angle reference trajectory.
2. Based on the redefined outputs (i.e., the velocity, the altitude, and the pitch angle), a modified backstepping design is proposed where the controlled plant is divided into two functional subsystems: the velocity subsystem and the altitude subsystem and the barrier Lyapunov function is used to solve the state-constrained control problem with unknown control gain.

Major results

- The velocity has good tracking performance over the entire flight

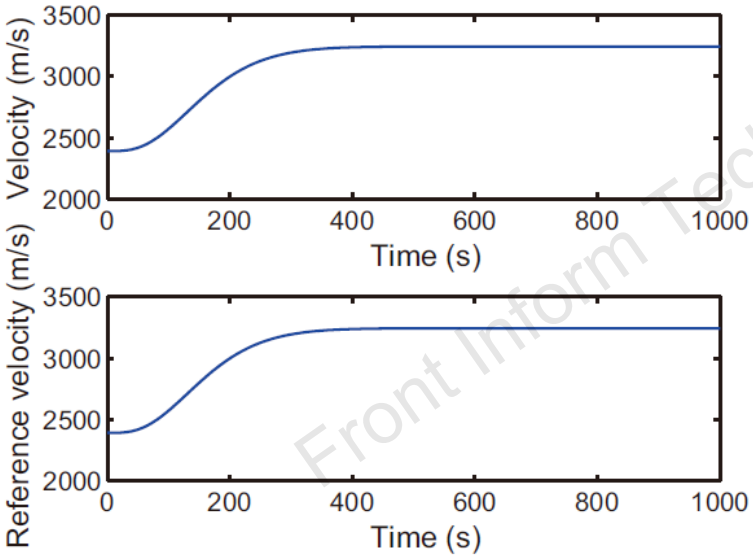

Fig. 2 Velocity tracking

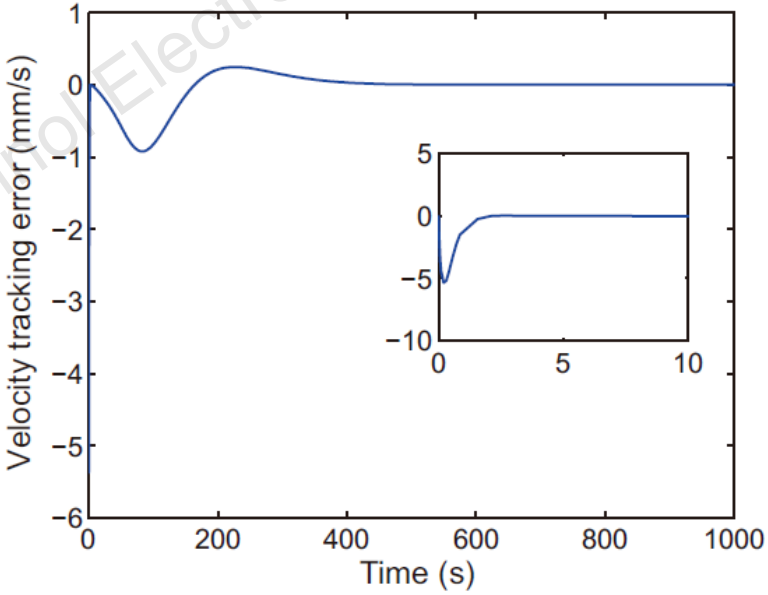

Fig. 3 Velocity tracking error

Major results (Cont'd)

- The altitude has also good tracking performance over the entire flight

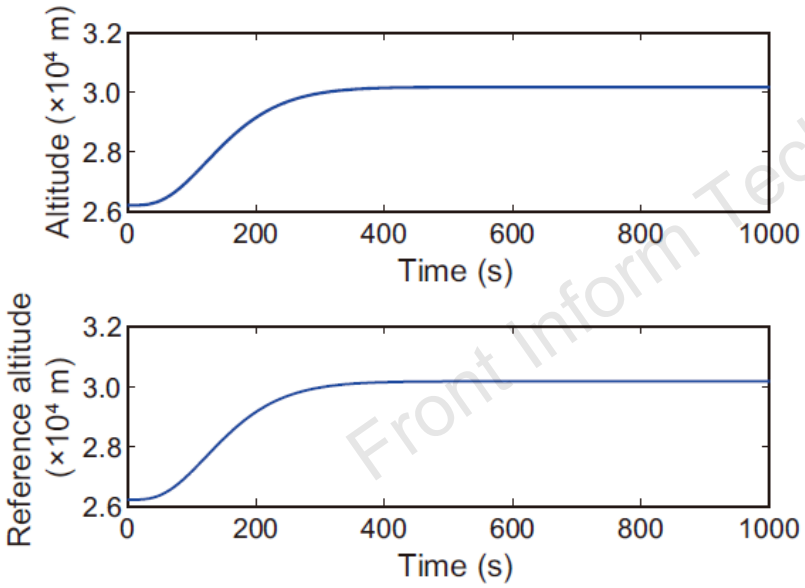

Fig. 4 Altitude tracking

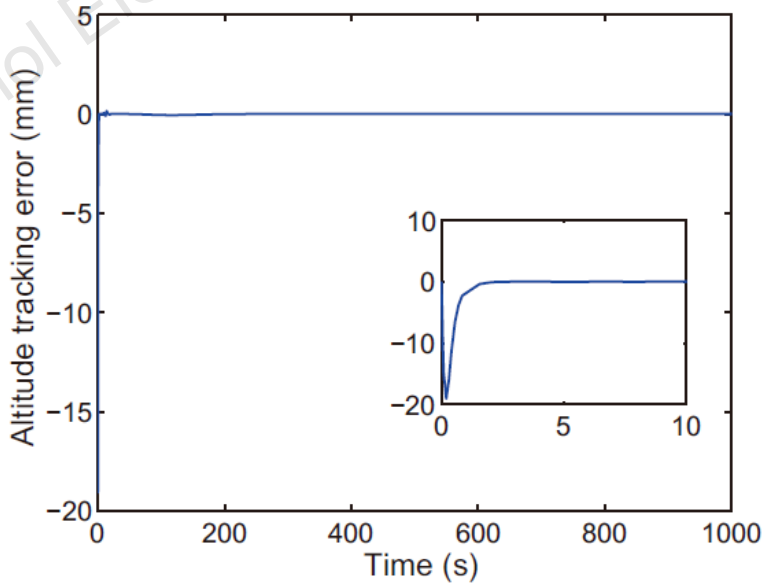

Fig. 5 Altitude tracking error

Major results (Cont'd)

- The AOA has also good tracking performance over the entire flight

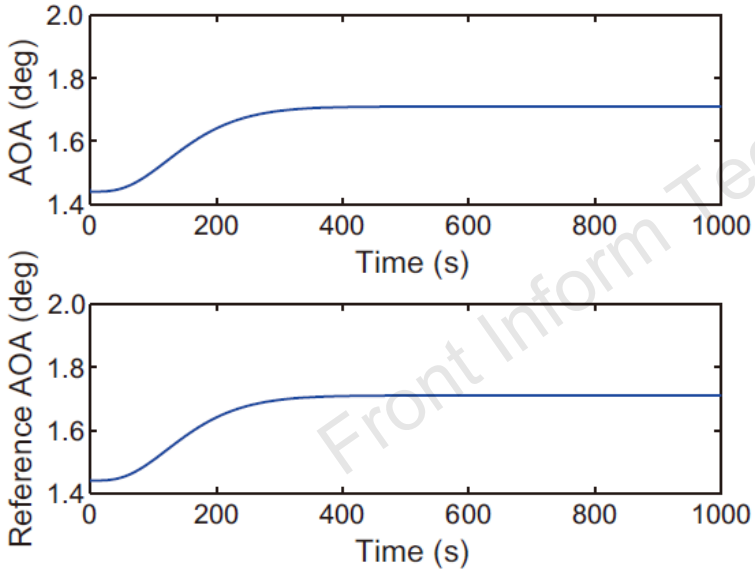

Fig. 6 AOA tracking

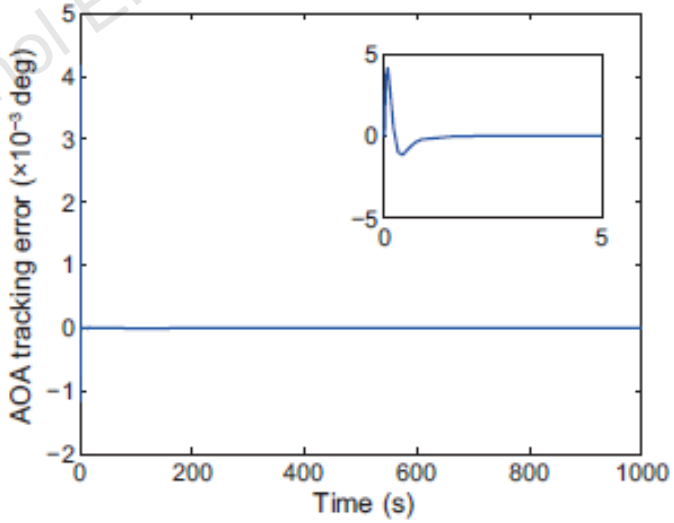

Fig. 7 AOA tracking error

Conclusions

- A novel adaptive tracking control approach is proposed which can not only ensure the simultaneous tracking of the velocity, the altitude and the AOA, but also guarantee that all the states always satisfy the given constraints.
- A set of simple and easily verified criteria has been provided, which guides the selection of reference trajectories and controller parameters.

Conclusions (Cont'd)

- The conventional barrier Lyapunov function has been used to solve the state-constrained control problem of the class of systems with unknown control gain, which considerably expands the scope of application of this method.
- Simulation results show the effectiveness of the approach.