Stage Separation Dynamics Optimization to Avoid Collision During TSTO Separation by Aerodynamics and Flight Dynamics Simulation

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Abstract:

In this paper, we discuss the optimization of the stage separation sequence using aerodynamics and flight dynamics and evolutionary algorithms (EAs) for winged two-stage-to-orbit (TSTO)[1]. Figure. 1(a) showed the three-view of the model. In this TSTO model, the same vehicle geometry consisted of a main wing, V-tail wings, and fuselage is employed as a booster and an orbiter. This model launched vertically and TSTO is separated at 40.5 km altitude. The winged booster flies back to the runway. (Fig. 1(b).)

In this TSTO, each vehicle has a wing. Therefore, circulations of wings have interacted. For safer separation, flight control optimization is required in consideration of the aerodynamics in detail. Thus, we developed the flight-aerodynamic simulation. Then we optimize the flight at the separation phase. In this study, we considered two cases; one is that no joint is considered between two vehicles (Case1), and another is that joint force (Fig. 1(d)) by two pin-joints is considered. Each case considered the control by the jet (Case2).

An unstructured mesh-based computational fluid dynamics (CFD) was employed to collect aerodynamic data. The engine's plume was simulated. The stage separation dynamics were optimized by EA with simultaneous minimization of the total control moment and time apart from the shock wave interaction area.

Firstly, we investigated the flowfield around the TSTO and the aerodynamic forces. As a result of CFD, TSTO could not gain aerodynamic force enough to separate the booster and the orbiter when they were close to each other. Therefore, this TSTO concept required to be given appropriate control force to avoid the collision.

Lastly, we carried out the control optimizations for case1 and case2 by CNSGA-II which is one of the multi-objective EA. The time-series control of moment by jet is a design variable for each case. In addition, the aft pin-joint separation time is a design variable for case2. The objective functions are two; one is the separation completion time and the other is the total moment which means the fuel consumption. Figure 3(a) shows the non-dominated solutions which are the feasible solutions. As a result of optimization, TSTO can be successfully separated with designing control moment. Furthermore, better stage separation dynamics which could carry out could be obtained the total control moment amount and separation time by installing the separation mechanism as shown in Fig. 3(b). We will visualize and discuss the flowfield of the optimum solution in the final paper.

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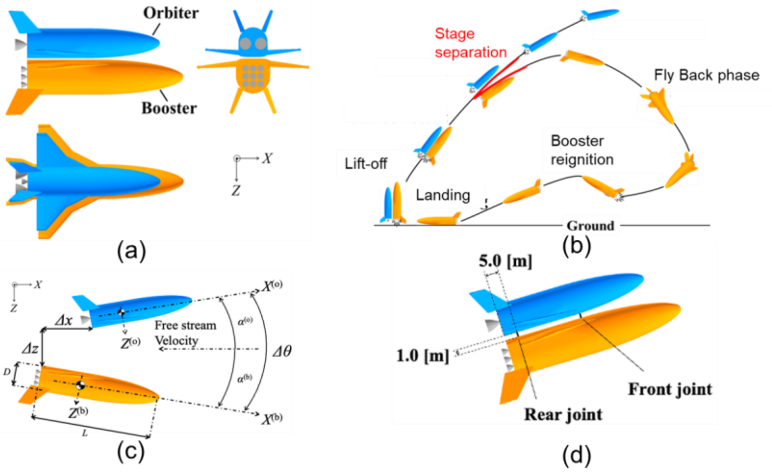
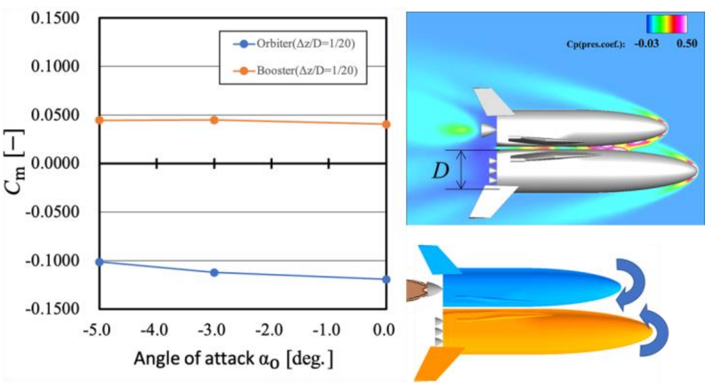
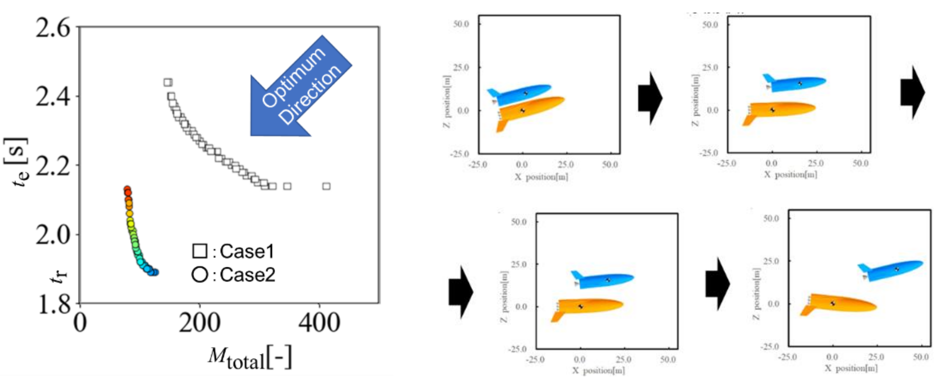


Fig. 1 TSTO concept. (a)Three-view of the TSTO, (b)Flight sequence, (c) Coordinate and parameters, and (d) Joint for the efficient separation.



(a) **(b)**

Fig. 2 Aerodynamic investigation by CFD. (a) Moment coefficient and (b)Flowfields at separation phase, and directions of the pitching moment at the separation phase.



(a) **(b)**

Fig. 3 Optimization results by CNSGA-II. (a)Solutions, and (b)The flight pass of the minimum M_{total} solution..