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Author: Dr. Takahiro Fujikawa
Tokyo University of Science, Japan

Prof. Koichi Yonemoto
Tokyo University of Science, Japan

APPLICATION OF MULTIDISCIPLINARY DESIGN OPTIMIZATION TO THE DEVELOPMENT OF AN UNMANNED SUBORBITAL SPACEPLANE BY INDUSTRY-GOVERNMENT-ACADEMIA COLLABORATION

Abstract

Development of a series of suborbital spaceplanes with LOX/LNG rocket engines is in progress under the industry-government-academia collaboration with the initiative of a Tokyo University of Science's start-up, SPACEWALKER Inc. This paper presents the past progress and the current result of the preliminary design of an unmanned suborbital spaceplane called FuJin. It performs vertical take-off and horizontal landing, and its mission is to transport 100 kg payload up to 120 km altitude for micro-gravity experiments, upper-atmosphere observations, or ground surveillance.

In the preliminary design of FuJin, MDO (Multidisciplinary Design Optimization) techniques have been utilized. Detail design analysis models for propulsion, structure, and electrical/mechanical equipment are developed and updated by industries, and the integrated optimization of vehicle design and the trajectory design are conducted using MDO. It makes it possible to obtain the design with the minimum lift-off mass while taking complicated design constraints into account.

After the preliminary design started in April 2019, system-level design has been revised 24 times according to the updates of the analysis models. Especially, the vehicle size and aerodynamic planform have changed considerably. Since the structure mass estimated at the beginning of the preliminary design was too small, the first design (revision NC: No Change) had the total length of 9.3 m and the lift-off mass of 7.8 t, while the current design (revision X-5) has the total length of 13.4 m and the lift-off mass of 18.6 t. Because the estimated position of the center of mass has moved backward as the preliminary design proceeded, the aerodynamic planform has been modified in order to satisfy the longitudinal trim and static stability throughout the mission trajectory.

In the current design, FuJin is propelled by three LOX/LNG engines with 79 kN thrust at sea level per each, and the engines are cut off at the Mach number of 3.7 and the altitude of 44 km. After the subsequent coasting flight with the apogee altitude of 120 km, the vehicle performs the re-entry. During the re-entry, the maximum angle of attack is 40 deg, the maximum normal load factor is 6 G, and the maximum dynamic pressure is 30 kPa. FuJin flies directly back to a runway at the launch site, with the approach speed of 91 m/s and the touch-down speed of 77 m/s. The FAR (Federal Aviation Regulations) balanced field length for landing is estimated less than 1500 m.