Analysis Technology for Spacecraft Aerodynamic Characteristics

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Abstract

Research and development of aircraft exploration on Mars has been conducted globally, resulting in the proposal of various types of aircraft, such as Mars airplanes and Mars helicopters. Meanwhile, the recent rise of electric vertical take-off and landing aircraft (eVTOL) has led to the exploration of various eVTOL configurations. Among these, convertible eVTOLs, which change the direction of propellers or wings depending on flight conditions, have become one of the representative eVTOL configulations. Shima et al. proposed a new type of convertible winged eVTOL, the Passive Pendulum Body (PPB) type eVTOL, aimed at achieving "simple mechanism and aerodynamically high-performance flight,". They have demonstrated its effectiveness through experiments [1]. Further research on the PPB type eVTOL using a Box-type wing, called as PPBB (Passive Pendulum Body with Box wing), has clarified the aerodynamic characteristics of Box wings [2].

In addition, Shima et al. have proposed a Loop-shaped propeller, "Looprop," which is characterized by its quietness and better transonic characteristics. They have demonstrated its effectiveness through experiments and numerical analysis [3].

This study aims to clarify the flow mechanisms around PPB type eVTOL, PPBB type eVTOL, and Looprop, which is difficult to measure experimentally, by employing numerical simulations. The objective is to acquire insights that will be useful for the design of future convertible eVTOL models

[1] Shima, E.,Tsutsumi, S.,Fujimoto, K.,Ito, H.,ANSS (2019) in Japanese.

[2] Shima, E.,Yonezawa, K., Nishida, R.,Sato, M.,Tsutsumi, S.,Fujimoto, K,, ANSS (2020).

[3] Shima, E., Tsutsumi, S., Fujimoto, K., 8th Asian/Australian Rotorcraft Forum (2019).

Reasons and benefits of using JAXA Supercomputer System

We need to conduct the large-scale simulations for the PPB-type eVTOL, PPBB-type eVTOL and Looprop using "rFlow3D" and "FaSTAR", which have been developed in JAXA.

Achievements of the Year

In the PPB-type eVTOL configuration, propellers are mounted in close proximity to the wing, both above and below the wing surface. The present analysis investigates the effect of the induced flow generated by the propellers on the aerodynamic characteristics of the wing, and how the presence of the wing affects the aerodynamic performance of the propellers. The numerical simulations were set based on the configuration of the PPB-type eVTOL as used in experiments. Here, simulations were performed using rFlow3D for both pre-stall and post-stall angles of attack. Figure 1 visualizes the flow field around the propeller-wing using iso-surfaces of the Q criterion for both pre-stall and post-stall angles of attack. In the pre-stall condition, wingtip vortices generated by each of the propellers mounted above and below the wing are clearly observed. On the other hand, in the post-stall condition, separation vortices from the leading edge interacting with the propellers are evident. From these simulations, the effects of propeller-induced flow on the aerodynamic characteristics of wing are clarifeid. In additon, the effects of the wing on th aerodynamic characteristics of propeller are also clarified.

Numerical simulations of the PPBB-type eVTOL were conducted using FaSTAR. While the computational model is based on the configuration of the PPBB-type eVTOL as in experiments, propellers were not considered in this analysis to elucidate the basic characteristics of the Box wing. Figure 2 shows the streamlines around the lower side of the Box wing, the upper side of the Box wing, and a rectangular wing under the same conditions. While a clear wingtip vortex is observed at the tip of the rectangular wing, such a vortex is not distinctly visible in the present visualization of the Box wing. This indicates that the Box wing can reduce the induced drag compared to a conventional rectangular wing.

In addition to the simulations related to eVTOL, numerical analysis of the Looprop, a Loop-shaped propeller, was performed using rFlow3D. Figure 3 depicts the flow field of a 3Looprop, which has three Loop-type blades. From the simulation results, it is clarified that the differences in aerodynamic characteristics between the front and rear blades, and the formation mechanism of wingtip vortices in Looprop.

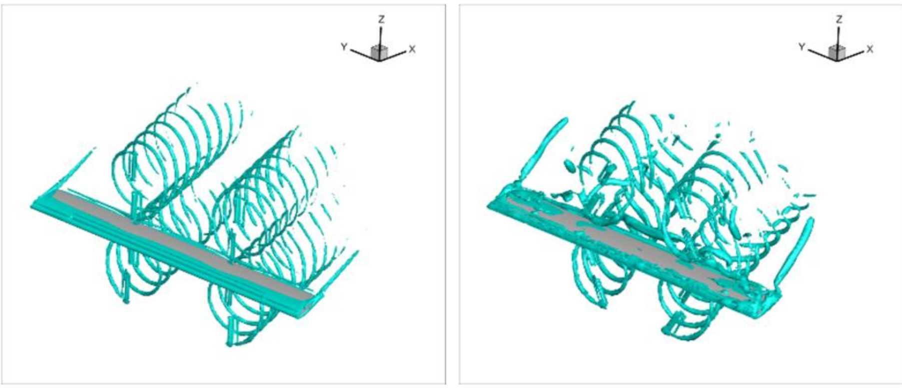

Fig. 1: Flow fields of interaction between propeller and wing for PPBtype eVTOL (left:pre-stall angle, right:post-stall angle)

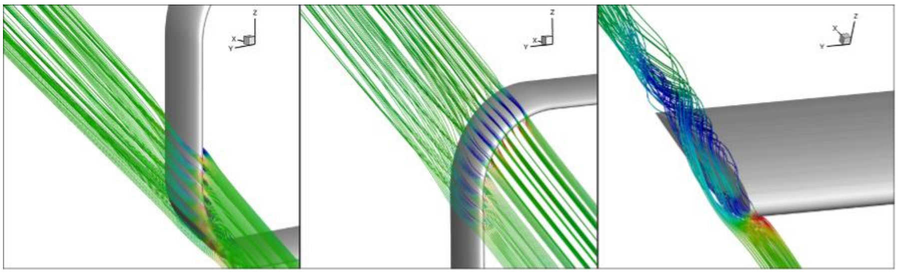

Fig. 2: Tip vortex for Box wing and rectangular wing

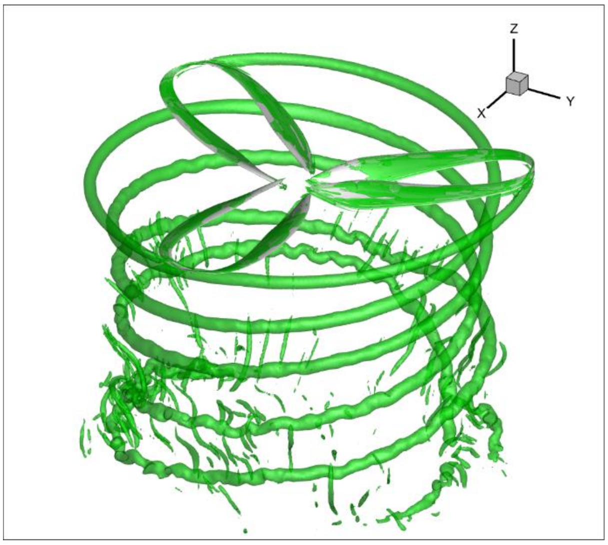

Fig. 3: Flow fields of 3Looprop

Publications

N/A

Usage of JSS

- **Computational Information**

Process Parallelization Methods	N/A
Thread Parallelization Methods	OpenMP
Number of Processes	1
Elapsed Time per Case	480 Hour(s)

- **JSS3 Resources Used**

Fraction of Usage in Total Resources[*1](%): 0.04

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage[*2](%)
TOKI-SORA	902,075.99	0.04
TOKI-ST	10,690.72	0.01
TOKI-GP	0.00	0.00
TOKI-XM	0.00	0.00
TOKI-LM	0.00	0.00
TOKI-TST	3.17	0.00
TOKI-TGP	0.00	0.00
TOKI-TLM	0.00	0.00

File System Resources		
File System Name	Storage Assigned (GiB)	Fraction of Usage[*2] (%)
/home	580.08	0.48
/data and /data2	65,078.46	0.40
/ssd	5,406.15	0.51

Archiver Resources		
Archiver Name	Storage Used (TiB)	Fraction of Usage[*2] (%)
J-SPACE	2.67	0.01

[*1]: Fraction of Usage in Total Resources: Weighted average of three resource types (Computing, File System, and Archiver).

[*2]: Fraction of Usage：Percentage of usage relative to each resource used in one year.

- **ISV Software Licenses Used**

ISV Software Licenses Resources		
	ISV Software Licenses Used (Hours)	Fraction of Usage[*2] (%)
ISV Software Licenses (Total)	514.88	0.23

[*2]: Fraction of Usage：Percentage of usage relative to each resource used in one year.