Technical Paper

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Feasibility of artificial muscle for mars airplane

Abstract

An airplane for Mars exploration is under being developed by Japanese researchers. This airplane requires lightweight and powerful actuators to fly in rare Martian atmosphere. A dielectric elastomer (DE) actuator is one of the candidates of the actuator for Mars airplane because it has high power, high efficiency, and high energy density. This research investigates a feasibility of the DE actuator for this application of the Mars airplane. As a first step, a structural model of a wing, a control surface, a DE actuator, and a linkage was built and a generated torque around a hinge of a control surface was measured. A result shows that the DE actuator can actuate the control surface under the wind speed of 65 m/s on Martian atmosphere. Therefore it is feasible to use the DE actuator for the actuation of the control surface of the Mars airplane.

Keywords: dielectric elastomer, Mars airplane, unmanned aerial vehicle

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Introduction

A dielectric elastomer (DE) is a relatively new transducer technology that uses rubberlike polymers (elastomers) as actuator materials.[1, 2] The basic element of DE is a very simple structure comprised of a thin elastomer sandwiched by soft electrodes. When a voltage difference is applied between the electrodes, they are attracted to each other by Coulomb forces leading to a thickness-wise contraction and plane-wise expansion of the elastomer. At the material level, DE actuator has fast speed of response (over 100kHz), with a high strain rate (up to 600%), high pressure (up to 8MPa), and power density of 1W/g.[3] DE actuator having only 0.1 g of DE can lift the weight of 2kg easily using carbon system electrodes.[3]

Recently, world leaders are seriously planning to explore Mars. Airplanes are payed attention as a new platform for Mars exploration.[4] The airplane can obtain detailed data than satellite and can observe larger area than rovers. One of the unique capabilities of the Mars airplane is to observe a geologic stratum at canyon. The satellite cannot see the geologic stratum from the sky, and the rovers cannot approach to the canyon. The Mars airplane has a possibility to achieve unique scientific efforts. The Mars airplane must be lightweight to fly using aerodynamic forces in the rarefied Martian atmosphere. Therefore light-weight and high-power actuators are required for the Mars airplane. The advantages of the DE actuators shown above are beneficial for the Mars airplane. The DE actuators have a possibility to be used as actuators for control surfaces (i.e. ailerons, rudder, elevator, and flap) and a propeller of the Mars airplane. This research investigates a feasibility of the application of the DE actuators to the Mars airplane. As a preliminary examination, a mechanical system was tested. A structural model of a wing and a control surface with a DE actuator was built. A torque generated around a control surface hinge was measured and compared with the external aerodynamic torque at Mars flight condition.

Methods

Experimental set-up

Figure 1 shows an experimental set-up. The dimensions of the wing and the control surface are described in Figure 2. The wing was mounted on a base. The control surface was connected to the wing using a hinge. A force sensor (IMADA Co., LTD., ZTS-20N) was set on the control surface to calculate the generated torque around the hinge axis.[5] A diaphragm type DE actuator (Wits Inc.) was used (Figure 3). Its outer and inner diameters were 80mm and 50mm, respectively. The mass of the elastomer was 0.1g. A bias voltage of 2.7kV was supplied from a high voltage power supply.[6] The DE actuator was connected to the control surface using a linkage. Figure 4 shows a schematic illustration of the dimensions of the linkage.

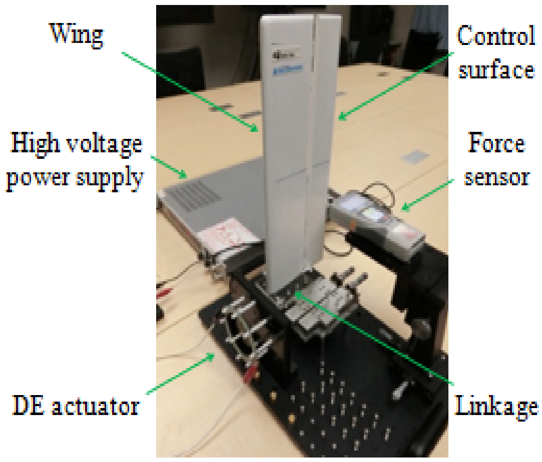

Figure 1 Experimental set-up.

Aerodynamic torque estimation

A flow over the wing and control surface generates an external aerodynamic torque on the control surface hinge. This torque H can be calculated by the following equation.[7]

$$H = qS_e C_e C_h \quad (1)$$

where S_e and C_e are an area and a mean aerodynamic chord of the control surface, respectively. C_h is a hinge moment coefficient. The value of the hinge moment coefficient of this structural model is 0.30, assuming that the angle of attack and the deflection angle are 5 and 20 degrees respectively.[7] q is a dynamic pressure. The definition of the dynamic pressure is as follows:

$$q \equiv \rho V^2 / 2 \quad (2)$$

where ρ is an atmospheric density. The atmospheric density at Martian surface is around 0.015kg/m^3. V is flow velocity. Therefore, the external aerodynamic torque can be obtained as a function of the flow velocity.

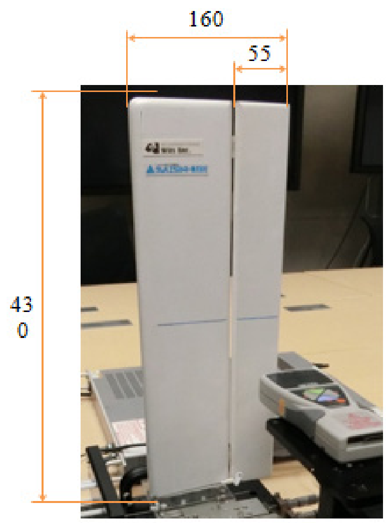

Figure 2 Wing.

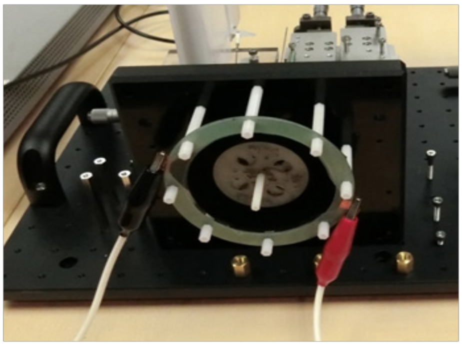

Figure 3 DE actuator.

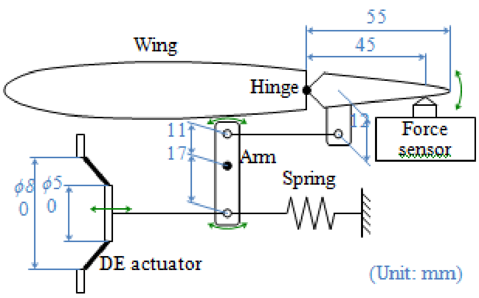

Figure 4 Schematic illustration of dimensions of linkage.

Results and discussion

As a result, a generated force at the force sensor position was 28gf. Because a distance between the hinge axis and the force-application point was 45mm, the generated torque was 0.13kgf·cm. Figure 5 shows a comparison of the generated torque and the aerodynamic torque with various dynamic pressure and flow velocity conditions. The generated torque was equal to the aerodynamic torque at dynamic pressure of 32Pa. It was same condition to the flow velocity of 65m/s at Martian surface. This result indicates that the DE actuator can be used for the Mars airplane.

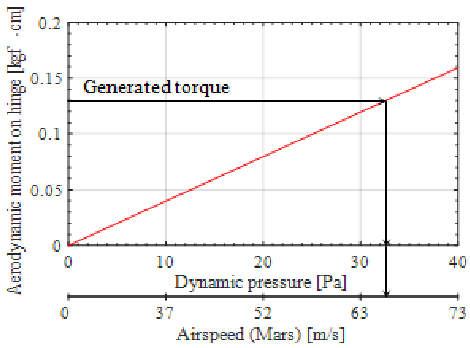

Figure 5 Comparison of generated torque and aerodynamic torque.

Conclusion

The structural model of a DE-actuator-installed wing was built and the torque generated by DE actuator was measured to consider the feasibility of usage of the DE actuator for the airplane for Mars exploration. A chord length of the wing was 160mm, including the control surface of 55mm. A ϕ80mm, diaphragm-shaped DE of 0.1g was used with a bias voltage of 2.7kV. The DE actuator generated a torque of 0.13kgf·cm on the hinge of the control surface through a linkage. This torque balances the external aerodynamic force at flow velocity (≈ flight velocity) of 65m/s at Mars condition. This result suggests that it is feasible to use the DE actuators for the Mars airplane.

Future works include the following tasks:

a. Wind tunnel test with more realistic shape

b. Mechanical property tests such as movable range, allowable torque, and responsiveness

c. Space resistance property tests such as cosmic ray, low pressure, and low temperature

d. Consideration of the usage of DE actuator for propeller motor and other mechanisms

e. Conceptual design of the DE-actuator-installed Mars airplane and comparison with conventional-actuator design

These tasks will finally bring us the innovative and unique Mars airplane.

Acknowledgements

None.

Conflict of interest

The author declares that there is no conflict of interest.

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