Proceedings of the 33rd European Safety and Reliability Conference (ESREL 2023)
Edited by Mário P. Brito, Terje Aven, Piero Baraldi, Marko Čepin and Enrico Zio

doi: 10.3850/978-981-18-8071-1_P074-cd

CFD Simulation and Experimental Study on Outgassing and Damage Characteristics of Multilayer Insulation During Ascent

Shouqing Huang

Beijing Institute of Spacecraft Environment Engineering, China. E-mail: hshouqing@163.com

Fangyong Li*

*Beijing Institute of Spacecraft Environment Engineering, China. *E-mail: fangyong_li@163.com*

Yue Liu

Beijing Information Science and Technology University, China. E-mail: yliu@bistu.edu.cn

Multilayer insulation (MLI) is widely used on the outer surface of spacecrafts. In the ascent stage, the air pressure outside the spacecraft decreases rapidly from 1 atmosphere to 100 Pa within approximate 120 seconds. Hence, the inert gas of the spacecraft expands and then releases rapidly through the MLI, which may result in the damage of MLI. In this paper, a simplified geometrical model of MLI is established, and computational fluid dynamics (CFD) method is applied to simulate the outgassing process, the pressure contour and aerodynamic force of each MLI layer during ascent are calculated. The results show the pressure decreases gradually from the inside to outside layers, and the flow induced force generally rises from the inside to outside layers. The maximum aerodynamic force and stress occur at approximately the intermediate moment of the depressurization process. In addition, a test rig is designed to simulate the rapid depressurization process during ascent. MLI damage phenomena are observed in some geometric and fixation conditions. It is interesting that all the damage occurs at the outer layers of MLI firstly, and the maximum differential pressure between the upstream and downstream of MLI occurs at intermediate moment of the rapid depressurization process. These findings agree with the CFD results. Besides, the influence of layer number, fashion of outgassing holes and fixation on damage characteristics are discussed.

Keywords: Multilayer insulation; Ascent stage; CFD; Outgassing; Damage characteristics.

1. Background

Multi-Layer Insulation (MLI) is one of the most commonly used passive thermal control components for spacecraft due to its lightweight and outstanding radiation insulation performance. Referring to Figure 1, MLI components are generally composed of alternating spacer layers and reflecting layers.

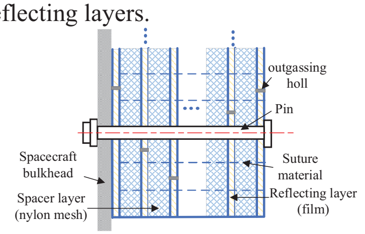


Fig. 1. Composition of MLI.

In the ascent stage of a flight, due to the rapid pressure decreasing, the gas inside the MLI components will rapidly discharge outward, which are prone to damage, tilting, or detachment of MLI. The damage of MLI components directly affects thermal control, optical imaging, etc.

The researches on MLI components during ascent stage mainly focuses on heat transfer characteristics. Johnson et al. (2012) applied a vacuum chamber to simulate the launch and ascent environment, the boil-off and thermal characteristics of a liquid methane tank are studied. Liu et al. (2016) investigated the thermal performances of MLI during the ascent and on-orbit process. Therefore, it is urgent to study the flow and damage characteristics of MLI components in ascent stage.

2. CFD Model and Typical Results

As shown in Fig. 2, a simplified CFD model with area of 18mm×18mm, contains 5 nylon mesh layers and 6 insulation film layers. The area size is far smaller than actual size to simply the calculation. The nylon mesh is 0.2 mm in diameter, and 0.1 mm in clearance from the adjacent films. The film is 10 μm in thickness with outgassing hole of 1mm in diameter. The grids have over 8 million elements in total with the least element size of 0.02mm. Transient-state model and SIMPLEC algorithm are applied.

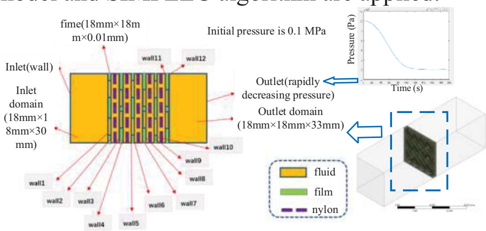
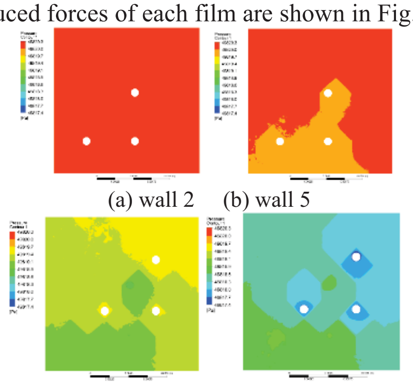


Fig. 2. CFD model.

The pressure results of typical interfaces at 58s when has the fastest outlet pressure decreasing rate are listed in Fig. 3. The calculated flow induced forces of each film are shown in Fig. 4.



(a) wall 2 (b) wall 5

(c) wall 8 (d) wall 11

Fig. 3. Pressure contour at various interfaces.

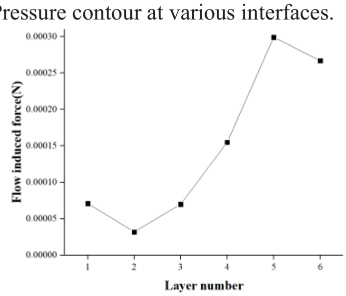


Fig. 4. Flow induced forces of each film.

As shown, the pressure decreases from the inside to outside layers. The pressure gradient near the outgassing holes is relatively large, indicating that the leakage through these holes is the main reason for pressure drop. Besides, the flow induced force of each layer generally rises from inside to outside, except for some fluctuations at both innermost and outermost layers. Hence the damage is more likely to occur at outer layers

3. Test Rig and Typical Results

As shown in Fig. 5, the test rig can simulate the rapid depressurization outside of the MLI. The MLI specimen is 240 mm in diameter. The differential pressure can be up to 70 kPa. Various number of layers, fashion of outgassing holes and fixation conditions are tested comparatively.

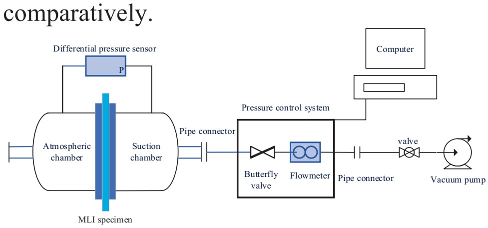


Fig. 5. Test rig and connections.

As shown in Fig. 6, the damage occurs at the outer layers of MLI, where has the larger aerodynamic force and stress than inner layers. The phenomenon agrees with the CFD results.

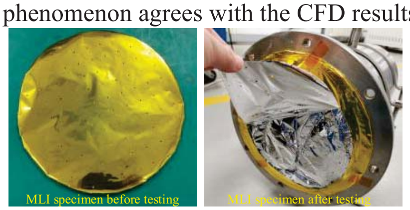


Fig. 6. Damage phenomenon of a 5-layer MLI.

4. Conclusions

The pressure of MLI decreases from the inside to outside layers. Besides, the flow induced force generally rises from the inside to outside layers in general. In addition, a test rig is designed to simulate the rapid depressurization process during ascent. MLI damage phenomena are observed in some conditions. All the damage occurs at the outside layers of MLI firstly, which agree with the CFD results.

Acknowledgement

Thanks to the funding support from the National Natural Science Foundation of China (No. 52075043).

References

Johnson, W. L., J. M. Jurns, H. H. Bamberger, D.W. Plachta (2012). Launch ascent testing of a representative Altair ascent stage methane tank, *Cryogenics*, 52: 278-282.

Liu, Z., Y. Li, F. Xie, et al (2016). Thermal performance of foam/MLI for cryogenic liquid hydrogen tank during the ascent and on orbit period. *Applied Thermal Engineering*, 98: 430-439.