Flight Control Stability of Multi-Hierarchy Dynamic Inversion for Winged Rocket

Hiroshi Yamasaki,[1] Koichi Yonemoto,[1] Takahiro Fujikawa,[1] Kento Shirakata,[1]
and Hayato Tobiyama[1]
[1]*Kyushu Institute of Technology, Japan*
n344156h@mail.kyutech.jp

Keyword : Winged Rocket, Nonlinear Dynamics, Autonomous Control, Dynamic Inversion

Recently, reusable space transportation vehicles have become an active area of development all over the world. Falcon 9 developed by Space X has launched some commercial satellites. Its booster vehicle also succeeded in vertically landing on the ground, and demonstrated the possibility of future reusability. If the vehicle can be reused, it is expected to reduce the operation cost further.
Kyushu Institute of Technology are developing an experimental winged rocket called WInged REusable Sounding rocket (WIRES) as reusable space transportation system since 2005. This paper will describe the development of the control system for the winged rocket.
Dynamics of such vehicle must possess good stability performance in a wide range of flight conditions. Due to higher nonlinearity of flight environment compared to aircraft, nonlinear control system is indispensable. The authors adopted Dynamic Inversion (DI) method [1] for constructing the nonlinear control system. DI enables linearization from control input to output. However, when the relative degree of the nonlinear control system is high, its formulation and implementation become highly complicated. Therefore, Menon has proposed the methodology using Time-scale Separation (TS) [2]. TS method, whose idea is based on the singular perturbation method, separates the states for each time constant or frequency. If a system can have artificiality time constant using a feedback control law, the system can be separated by TS method. The resulting control system has hierarchy structure. TS method has a problem that the control gain of each hierarchy cannot reflect the effect of other hierarchies [3]. In addition, the control gain must be designed by experience, and its evaluation has to rely on the numerical simulation [4]. Summarizing the above, the design of control gain using TS method takes a burden to control engineers.
In order to solve foregoing drawbacks, the authors assume that the dynamics of the aircraft can be replaced by the block strict-block feedback system, which is a subset of affine system. When the dynamics can be represented by the strict-block feedback system, the model of the controlled system using the DI method can be separated into the linear terms and non-linear terms in each hierarchy. The advantage of this proposed method is that the control gain can be determined using linear terms, given that the effect of non-linear terms is small or stable. In this paper, the effect of the non-linear terms in the dynamics of aircraft is assessed, and the validity of the proposed method is demonstrated.

References

[1] A. Ishidori, Nonlinear Control System, 145/172, Springer-Verlag Berlin, Heidelberg (1995)
[2] P.K.A. Menon, et al., Nonlinear Flight Test Trajectory Controllers for Aircraft, Journal of Guidance, Control, and Dynamics, **10**-1(1987), 67/72
[3] J. Kawaguchi, Y. Miyazawa, T. Ninomiya, Flight Control Law Design with Hierarchy-Structured Dynamic Inversion Approach, Proceeding of the AIAA Guidance, Navigation, and Control Conference, 2008-6959, Honolulu, Hawaii, August (2008)
[4] S. Sunasawa, H. Ohta, Reentry Vehicle Using Inverse Dynamics Transformation, Journal of the Japan Society for Aeronautical and Space Sciences, **45**-516(1997), 52/61 (in Japanese)

	Dynamic Inversion	Multi-Hierarchy Dynamic Inversion Using TS	Multi-Hierarchy Dynamic Inversion Using block strict-block feedback system
Time Response	Any time	Depend on nonlinear system	Depend on nonlinear system
Gain Tunning	Depend on Time Response	Experience of designer	Analysis of linearised approximation Model