CENTRE NATIONAL D'ÉTUDES SPATIALES

Centres de Compétence Technique

Control of Re-entry Space Vehicle

September, 26th 2006

CNES - Paris

This seminary is organized by the CCT Automatique Pilotage and the subject is « Control of re-entry space vehicle ».

In the aerospace scientific literature, the control issue for re-entry vehicle is not a major area of publication. The aim of this meeting is to create a communication between the European entity involved in control for re-entry space vehicle.

Adress: Centre National d'Etudes Spatiales, 2 place Maurice Quention 75001 Paris

Program

9h30	welcome
10h00	PRE-X Program: overview – P. Baiocco - CNES
10h30	Control of re-entry vehicles : modelisation and control methods - N. Fezans, D. Alazard, N. Imbert – ONERA
11h00	PRE-X Attitude Flight Control System – H. Strauch, W. Gockel - Astrium Space Transportation
11h30	ARD like attitude control applied to lifting body – M. Ganet, Astrium Space Transportation
12h00	Lunch Breack
14h00	Nonlinear robust model predictive control for lifting body re-entry flight - R. Van Oort, Q.P. Chu and J.A. Mulder – Delft University
14h30	Flatness-based Hypersonic Reentry Guidance of a Lifting-body Vehicle - V. Morio, F. Cazaurang, P. Vernis - LAPS-CNRS and Astrium Space Transportation
15h00	Future Control Challenges for Re-entry Vehicles – S. Bennani & C. Philippe – European Space Agency
16h00	Round table

DETAILED PROGRAM

PRE-X Program: overview

Paolo Baiocco - CNES

Control of re-entry vehicles : modelisation and control methods

N. Fezans, D. Alazard, N. Imbert – ONERA

Since the earliest flights to space, more than 100 Reusable Launch Vehicles systems have been studied. On one hand very few of them became reality and on the other hand not all Reusable Launch Vehicle must reenter into atmosphere. The aim of our study is to develop generic models for atmospheric reentry control and the associated control laws design methodologies.

The presentation will be divided into two parts:

- RLV concepts
  - Mission profile based classification
  - Multi-stages RLVs with atmospheric reentry
  - Realized RLVs

- Control during atmospheric reentry
  - Our Study and GN&C structure
  - Flight control simulation and design models
  - Study achievement
  - Future work

PRE-X Attitude Flight Control System

Hans Strauch, Wilhelm Gockel (Astrium Space Transportation)

PRE-X is a re-entry vehicle designed for flight test demonstration of essential re-entry technologies and measurement techniques. The flight test is scheduled for 2010, using a VEGA rocket to transport PRE-X into low orbit to establish the initial conditions for the re-entry flight. Governed by the vehicles lift to drag ratio, the atmospheric re-entry flight will be steered in the classical way by bank angle control for a fixed angle of attack profile. The free flight is terminated by parachute recovery initiated at supersonic speed. The desired attitude along the flight path will be realized by the flight control system, which commands the available control effectors of the vehicle, namely a reaction control system and aerodynamic flaps.

The presentation will be dedicated to the attitude flight control system and describe the current status of the system in the running phase B of the PRE-X project. The topics that will be covered are:

- Overview vehicle and control effectors (vehicle shape, flight control system computational design constraints, RCS thruster architecture, two bodyflaps attached to the rear, …)
- Flight control system concept (overview of the major flight control system modules: navigation data processing, orbital control module, setpoint generation, feedforward control, feedback control, control selector, …)
- Flying strategy (use of control effectors for trim and maneuver)
- Transition from orbital to atmospheric flight (strategy to change from RCS to aerodynamic control as dynamic pressure increases along the re-entry)
- Design criteria (criteria for attitude tracking performance and robust stability)
- Feedback gain design approach (design based on representative linearized models along the reference trajectory entailing gain scheduling, consideration of worst case uncertainty combinations, sensitivity to closed loop computation delay, …)

ARD like attitude control applied to lifting body control

Martine GANET, H. CHARBONNEL (Astrium Space Transportation - Les Mureaux)

Atmospheric Re-entry Demonstrator (ARD) was an unmanned capsule like initiated by ESA to develop and consolidate flight-proven know-how in the field of re-entry technologies. ARD mission was successfully carried out in 1998. Hypersonic control law is based on feedforward gyroscopic torque compensation plus an observer and state feedback structure with analytical on board gain computation. This control law could easily be extended to lifting body hypersonic re-entry.

The main advantages of this method are the direct on board gain computation without gain scheduling or interpolation and the access to an estimated state that can be used for post-flight analysis. In the frame of internal research studies, it was successfully applied to PRE-X re-entry vehicle control. Additional analysis tools were also developed to perform worst case analysis and insure robust stability.

Nonlinear robust model predictive control for lifting body re-entry flight'

R. Van Oort, Q.P. Chu and J.A. Mulder – Delft University

The dynamics of re-entry vehicles are time varying and notoriously nonlinear due to the large variation of Mach number and dynamic pressure, nonlinear aerodynamic flow phenomena at large aerodynamic flow angles and rotation rates, and the need for significant manoeuvring. The accuracy of the guidance and control of the re-entry vehicle along a predefined nominal trajectory is crucial because of operational and safety considerations, which stimulates research into advanced high performance nonlinear controllers.

The present paper presents the design of a nonlinear attitude controller for the attitude of the re-entry vehicle based on a robust version of a Model Based Predictive Controller (MBPC). MBPC controllers are very attractive for re-entry flight applications as state and input constraints can readily be implemented in principle, safeguarding the vehicle from entering forbidden parts of the flight envelope. MBPC controllers require the solution of an optimisation problem to generate the control input needed to track the reference trajectory and to provide input and state constraint handling. In the present case an efficient Linear Matrix Inequalities (LMI) algorithm was used to solve this optimisation problem. Even then, however, the disadvantage of MBPC controllers remains that they are notoriously computation time intensive, in particular in cases of nonlinear system dynamics. In the present design approach, this problem is handled by applying Feedback Linearization (FBL) to map the nonlinear system dynamics to linear system dynamics. The re-entry vehicle model can not be assumed to be known perfectly well, however, and consequently FBL will not fully linearise the system. This is the argument behind the development of a robust version of the MBPC controller. Uncertainty is modelled as perturbations of the aerodynamic parameters within a given percentage of their nominal value. A first version of the MBPC controller containing a polytopic uncertainty model still turned out to be prohibitively computer time intensive, only allowing for a zero time prediction horizon. The present paper presents a next, more efficient version of the MBPC controller allowing a finite prediction horizon. This version includes a Linear Fractional Transformation (LFT) uncertainty model representation rather than the simpler polytopic one.

The newly designed controller was tested using the GESARED simulation toolbox developed by the Faculty of Aerospace Engineering, Delft University of Technology for entry and re-entry vehicle simulations. The results show an excellent performance of in particular the latest version of the MBPC controller, the vehicle remaining within its state and input constraints, and the robustness of the controller to variations in the aerodynamic parameters to be significantly better compared to that of a nominal non-robust controller suffering from the same uncertainties.

Flatness-based Hypersonic Reentry Guidance of a Lifting-body Vehicle

V. Morio, F. Cazaurang, P. Vernis - LAPS-CNRS and Astrium Space Transportation

This paper deals with the design of a guidance algorithm based on nonlinear dynamic inversion by flatness approach and a classical PID controller for a lifting body vehicle. The aerodynamics shape of the vehicle considered in this work is quite similar from those of potential reentry experimental vehicles which are candidate to become the final Intermediate Experimental Vehicle (IXV) of ESA Future Launchers Preparatory Program (FLPP). To maintain and improve the European expertise in strategic and critical reentry technologies, the main objectives of FLPP project are to develop and in-flight validate the related technical disciplines such as aero-thermodynamics, thermal protection shields, and new guidance, navigation and control strategies. The guidance strategy suggested in this paper and that could be a candidate within the frame of preparatory studies to FLPP, uses a Nonlinear Dynamic Inversion (NDI) due to the large flight envelope that characterizes the reentry of the wingless lifting-body vehicle. Flatness theory focuses on the choice of specific outputs to ensure input to state space linearization. In this way, the guidance algorithm uses alternative tracking outputs. Using altitude and curvilinear abscissa, the longitudinal model is dynamically inverted to provide the nominal input trajectories. A PID corrective term is then added to circumvent uncertainties and parameters dispersions. Eventually, a Monte Carlo analysis is performed on a nonlinear simulation tool designed by EADS ST to assess robustness and performances of the considered reentry guidance scheme in the case of initial kinematics dispersions, atmospherics and aerodynamics uncertainties. Recent works aimed at extending the capabilities of such a hypersonic reentry guidance algorithm to the Terminal Area Management Phase (TAEM) have clearly proved the flatness property of coupled in-plane and out-of-plane nonlinear dynamics, using bank angle, angle-of-attack and airbrake deflexion as control inputs. Preliminary results obtained with ARES-H winged-body vehicle disclose interesting capabilities.

Future Control Challenges for Re-entry Vehicles

Samir Bennani & Christian Philippe – European Space Agency

This presentation starts by highlighting a selection of demanding control issues related to the design of future re-entry vehicles. The flight control law development process for re-entry space vehicles shall be presented in the view of increasing performance and robustness demands at reduced development costs. The various process elements, design activities and associated tools in the iterative development process shall be discussed and characterized. Some potential future research directions shall be given in the area of the vehicle modelling, disturbance and uncertainty modelling, control system design, control system validation to improve the current process and to set out not yet existing design guidelines that can be used for the further developments of re-entry systems. We shall stress on the multidisciplinary role and character of flight control and address issues coming from flight mechanics, aero-thermo dynamics, guidance navigation and control, including flight testing. In this view we shall investigate some possible research directions.

Various ESA programmes shall be reviewed and some ongoing and future work in the field of control will be presented.

Round table about the issue

The discussions of the day will be summarise in collective approach

How to participate

Participation is free.

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