Intelligent Control Systems Design for Flexible Aerospace Vehicles: Theoretical and Software Tools

Alexander I. Panferov, Sergey A. Brodsky, Alexander V. Nebylov

International Institute for Advanced Aerospace Technologies
of State University of Aerospace Instrumentation,
67, Bolshaya Morskaya, 190000, Saint-Petersburg, RUSSIA
(Tel: +7(812)4947016; e-mail: iiaat@aanet.ru)

Abstract: Possible approaches to the mathematical description of the dynamic properties of aerospace vehicles in the processes of flight in atmosphere are observed. This description includes different mathematical models such as: models of the construction flexibility, sloshing of the fuel and oxidant, rigid body flight in the variable gravitational field with variable distributed mass of the vehicle, integral and distributed aerodynamic in the big diapason velocities, aeroflexibility, models of different types of the rocket engines and so on. In the basis of these mathematical models the library of the program units were designed. This library was included in the special program, which allows automating the processes of simulation of arbitrary axisymmetrical aerospace constructions. The program allows calculating the general mathematical models in different forms, to simplify these models and to use for design the systems of stabilization.

Keywords: flight control, control design, simulation, control, flexible, vehicle dynamics, system synthesis

1. INTRODUCTION[1]

All stages of control systems design for new flexible aerospace vehicles are considered. First of all the construction of aerospace vehicle is designed and its mathematical description is developed. Approaches to the mathematical description of different types of flexible vehicles in view of oscillations of fluid in tanks and moving masses inside the vehicle are observed. Elastic bending of a body surface in interaction with a surrounding medium in a broad band of speed variation are taken into account. Then the problems of intelligent regulator's synthesis, damping of elastic oscillations, and also principles of construction of universal software for research of dynamic properties and simulations of elastic vehicles motion are considered. For implementation of suggested methods and algorithms the specialized program is designed. The software package is supplied with the program modules library. These modules are designed on the basis of mathematical models of the vehicle elements and control system, and also the significant physical phenomena such as flexibility, liquid oscillations, time lag of engines, local aerodynamic effects, etc. Functioning of the program is demonstrated and outcomes of calculations are presented.

Mass and aerodynamic characteristics are changing considerably during the flight of aerospace vehicles. From the point of view of control theory such vehicles are the typical non-linear and non-steady plants. The aim of designer is to create the light construction. For this reason such objects are deformed in flight, and their elastic properties appear. Elastic longitudinal and lateral oscillations of the complex form arise, which frequencies are changing during the flight. Elastic oscillations are usually described by differential partial equations or ordinary differential equations of the great dimension. Deformation of a body results in appearance of the local attack angles and slide angles. As a result of it, the local forces and moments of forces arise. These forces and moments are synchronized with the changes of local angles of attack and slide. The local forces and moments are the reasons of amplification or attenuation of elastic oscillations. This phenomenon is known as aeroflexibility. At excessive development of elastic oscillations the structural failure may take place. Paying attention to these effects has a great importance at control of space stations and space probes, airplanes and other mobile objects liable to the considerable dynamic loads.

Besides the flexibility and aeroflexibility, it is necessary to take into account the following factors in the mathematical models of aerospace vehicles:

1. Dependence of all parameters on time, velocity and altitude of flight, drift of CG, and so on.
2. Distributed and integral aerodynamic forces.
3. Oscillation of liquid in tanks (Sloshing).
4. Inertia of engines.
5. Errors of measuring instruments.

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6. Environment stochastic forces and moments of forces.

Mathematical descriptions of all these factors are complex and are based on different physical models. For research of elastic systems the special programs exist, for example, ANSYS, NASTRAN, Coventor, Femlab, Structural Dynamics Toolbox for use with MATLAB, etc.

In these programs the finite element method is used, which has been well recommended at calculation concerning the simple designs. For dynamic processes investigation and also for simulation of elastic oscillations of the flying vehicles, which consist of hundreds and thousand units of complex form, such approach is unsuitable. For calculation of distributed and integral aerodynamic forces can be used the program Fluent. The program Matlab allows to design of control or stabilization system. It is required to use all models simultaneous for analysis of interconnections and detection of possible resonances.

For with reason, the resulting mathematical model is very complex. There are no known programs to analyze and simulate such complex systems which include subsystems, which base on different physical principles.

The indicated reasons determine the necessity of development of the specialized program for simulating the motion of flexible objects of the composite form, the analysis of their dynamic properties and design of control systems

In the present paper other approach to modeling and control system design for flexible objects is observed. It is known that the flexible object is described by partial differential equations. The control theory of such objects is complex, bulky and presently is insufficiently designed analytically. There are numerical methods of calculation of the arbitrary quantity of harmonics of flexible vibrations and replacements of partial differential equations by ordinary differential equations of high dimension. For automation of analytical derivation of such mathematical models of flexible aerospace vehicle, for control law synthesis, for analysis and simulation of controlled flight, and also for representation of outcomes of modeling in the two-dimensional and three-dimensional space, the authors have developed the specialized software package.

2. METHODS OF THE PROBLEM SOLUTION

Authors propose new approach and special program to input construction of aerospace vehicles, to calculate mathematical model, to correct this model on the basis of separate experiments, to simplify separated models for any factors. The program allows using whatever experimental data about properties of the vehicle, presented in the most various formats. Hand-operated input and correction of separate values, and also the automated lead of large arrays of the information is provided. At absence or inaccessibility of a part of experimental data in the program, the models based on various theories or on generalization of experimental data of vehicles are used. The software for simulation of flexible essentially non-steady vehicle motion, synthesis of control systems for such a vehicle, research of dynamic properties by different methods in time and frequency domains, is developed and described in this paper. The basis of the program is the structure which allows analyzing the dynamic responses, simulation and visual information representation of the complex dynamic systems.

All stages of aerospace vehicles design are discussed, including the following problems:

- input of initial constructive data of the vehicle,
- determination of controllability and observability for the full and simplified model of a vehicle for real control inputs and arbitrary choice of measured signals,
- choice of flight program and control law,
- automatic linearization relatively to arbitrary trajectory,
- automate processes of mathematical models simplification for flexible vehicles and separate physical phenomena (oscillations of a liquid in cavities, time lag of engines, local aerodynamic loadings, etc.) and to control these simplifications,
- execute a system synthesis of control for elastic object in frequency domain with the given margin of stability on amplitude and a phase,
- control system synthesis for a vehicle with use of method of Kalman filtration and methods of optimal control,
- simulation of vehicle motion with nonlinear model and control law different complexity,
- investigation of local aerodynamic loads effect on elastic vibrations of a vehicle,
- determination eigenfrequencies of a liquid oscillations in tanks and computation of the local forces which affect on a vehicle body because of these oscillations,
- choice of sensors and actuators characteristics,
- computation charts of relations for any variables of state vector, both from a time, and from other variables of state vector,
- any frequency characteristics plots construction,
- choice of flight program and control law,
- determination of the elastic vibrations of a body and oscillation of liquid in tanks modes and to illustrate these oscillations as animations,
- study of control system sensitivity to vehicle parameters change.

3. MATHEMATICAL MODELS OF PHYSICAL PHENOMENA HAVING PLACE AT FLIGHT

3.1 Solid Dynamics

The rigid part of mathematical model of vehicle is allocated into the separate block, in which the system of differential non-linear equations of vehicle spatial motion is integrated. These equations in vector form in body-axes can be written as