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INTEGRATED STRUCTURAL AND CONTROL OPTIMIZATION OF A LARGE SPACE STRUCTURE WITH A ROBOT ARM BY USING A SEMI-ANALYTICAL APPROACH

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Abstract

This paper focuses on the integrated structural and control optimization of a Low Earth orbit (LEO) large space structure (LSS) carrying a robot arm and subjected to the gravity-gradient torque In this paper the optimization process aims to obtain a minimum weight structure constrained to a prescribed first natural bending frequency greater than that of the initial given structure At the same time an optimal control index must be attained for the optimized structure The structure is assumed to be a long tubular beam containing a robot arm and the orbital motion is assumed to be planar. The attitude (pitch motion) and the elastic motion are confined to the orbital plane The finite element technique is combined with the Lagrangian formulation to derive the dynamic equations of motion The process optimization involves the evaluation of the sensitivity of the structure to changes in the constraint parameters, that is, the eigenvalue/eigenvector derivatives with respect to the design variables must be computed This evaluation through a pure numerical approach may become prohibitive because of the high computational time involved in the numerical calculation of the derivatives. For this reason a semi-analytical approach may become a good option. This approach is implemented in this paper. It consists of combining the analytic expressions for the gradients of the mass and stiffness matrices with the numerical solutions of the eigenvalues to obtain the eigenvalue derivatives with respect to the design variables. The first and second derivatives of the objective function are also done analytically In this way only the algebraic solution of the equations remains to be performed by the computer when performing the sensitivity analysis.

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Mechanical Tests For Low-Cost Microsatellite Programs

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Ground testing has been and is still a principal step in satellite projects In spite of the great improvements in the modeling, due to available computation power and time for longer and deeper analysis, the possibility to reproduce the flight conditions in a controlled environment is a basic asset in spacecraft program However, the goal of testing has to be carefully balanced with overall program targets and budget, as testing activities should result in a extremely time consuming task. This remark is especially true for the projects devoted to design and launch of microsatellites, where costs and time are usually limited

This paper is intended to present the experience developed at the University of Rome "la Sapienza" in the frame of the microsatellite UNISAT program Educational aim and limited budget dictated the conditions for all this program, which is strongly based on not previously qualified parts and architectures, both at component and subsystem level Most of the traditional satellite testing procedures cannot be applied to a low-cost microsatellite program

First of all, due to not previously qualified parts used, testing was fundamental in UNISAT program, in order to acquire a confidence on the subsystem behavior At the same time, a strong requirement for not overtesting any component was assessed, as several part were devoted to the launch model and were not spares

Another remark is that if a satellite has to be launched as an auxiliary passenger, as usual for microsatellites, testing activity can be planned quite late during the project development In effect, launcher selection is moved trough the end of the process, and therefore load spectra and launch environmental characteristics will be know really late

As typical of all microsatellites designed and built by University teams, testing activities had to be carried off-campus, due to lack of highly specialized facilities In the UNISAT case, tests have been carried on at Oerlikon-Contraves Space facilities in Rome, with use of electrodynamic shaker and performing software Oerlikon-Contraves contribution has been essential in the preparation and careful execution of the tests, as well as in data reduction At a later stage, acceptance test are foreseen at the Yuzhnoe facilities in Dnepropetrovsk (Ukraine)

This paper aims to carefully outline the entire mechanical test process carried on in the frame of the UNISAT microsatellite program, according to load spectra provided by the selected launcher, i.e the russian-ukrainian Dnepr The notching performed on the input spectra, according to the mechanical characteristics of the shaker, is considered Rationale followed for selecting the parts to be tested, and their order, so to save subsystems from unconsidered load factors, is discussed, as well as the positioning of the accelerometers permitted by the multiple channel instrument made available by Oerlikon-Contraves Tuning of the previously prepared numerical model, instrumental to maximize test effectiveness for configurations other than the tested one, or later changes in on board subsystem positioning, is presented A special attention is devoted to analyze the structure behavior in different points, with the aim to assess environmental conditions for devices to be placed onboard

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STRUCTURAL DEFORMATIONS CONTROL ACTIVITIES IN CNES (FRENCH SPACE AGENCY)

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The continuous increase of stability requirements for observation spacecrafts (earth, planets, asteroids missions) need to manage very accurately the direction of the instrument's optical axis, and the shape of the instruments

French Space Agency (CNES) manages several activities, in order to help projects to solve this problem A first direction for these activities concerns the low frequency deformations compensation. These deformations come from

- vacuum (hygroelasticity) research concerns resins used for Carbone composite (CFRP) preparation which do not absorb water on ground and so do not loose this water into space, and so do not change their shape.
- Launch vibrations these mechanical solicitations can lead to modifications of the instrument geometry.
- Thermal cycling these fluctuations are generally associated to orbital cycle or equipment on/off cycles To suppress the effects of such variations we can control the instrument temperature with a very high accuracy or use zero expansion materials such as MCMM or C/C
- Gravity : this parameter is important for very large instruments (like HUBBLE for instance) The trend in France is more to increase the instrument performances and reduce its size for a given mission specification.
- Life duration : we select very stable materials in space environment (vacuum, radiations etc.).

The second direction for our activities concerns the higher frequencies perturbations

- a first parameter to be identified concerns the variations of damping factors between ground and space (air/vacuum, gravity...) several experiments have been conducted to identify these variations (PASTEC/SPOT4, CASTOR/TREILLIS)
- another parameter concerns the way of combining all perturbations in order to obtain the best estimation of the error on the instrument line of sight.
- If damping is necessary, we can use either passive systems (fluids, elastomers) or active systems (piezoelectric) In flight experiment have been conducted, and results wil be presented

We will present in the paper the activities now on going in these domains, and results obtained.

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ADVANCING DAMAGE AND PARAMETER IDENTIFICATION IN MODULAR AEROSPACE STRUCTURES BY STRUCTURAL MODIFICATIONS

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Modern space structures are constructed using a modular approach that facilitates transport and assembly in space and leads to increasingly large and complex structures. Ensuring the safety of these structures demands rapid advances in parameter and non-destructive damage identification techniques

The key problem with current damage detection technology is the lack of data available for the analysis Extending the amount of data available for a given structure is of very high significance to all vibration based damage assessment methods. Improvement in experimental techniques is unlikely to yield the necessary data so a theoretical approach is required In this paper an innovative method for generating the additional data is proposed This method generates modified structures and integrates the new information for these structures into the damage detection formulation for the original structure

The proposed method has the potential to dramatically enhance structural damage detectability from simple vibration measurements The method requires measurements of only a few of the lowest natural frequencies of a structure and not its modes, as required by many other modern techniques. Increase in the sensitivity of vibration based damage identification is achieved by use of the 'twin' structures concept, in particular, "twins" generated by submerging an original structure in a larger structure by adding another section(s) with known properties Very often, twins are naturally generated during scheduled procedures. For example, a twin for the International Space Station is obtained after docking with a space vehicle, like Space Shuttle, Hope or X-33 With this study it will be possible to use all such scheduled events for advancing the damage assessment of the structure

To illustrate the main idea of the method, two groups of numeric experiments are presented In group "A", a few cases of damage were simulated in an eight bay cantilevered truss structure and the natural frequencies of their vibrations were compared

In group "B", the original structure was modified by 'docking' four bay segments to it In this case, when the same damage as for group "A" was used, there were more "accessible" frequencies. Changes in natural frequencies in the order of 0.5-3 Hz were recorded for the damaged and undamaged configurations of modified structures These large frequency changes, which can be easily monitored, and such a significant extension of the information field (registered number of frequency changes due to the damage), in contrast to that in group "A", can constitute a basis for effective damage detection. It is important to note that in both cases, simulated vibration noise was superimposed on the data

For the cases where structural reconfigurations are not feasible, two alternative methods for generating "twins" are proposed and studied.

- A shape alloy element/module with modifiable properties is imbedded into the structure Changing this smart module's properties will change the vibrational properties of the whole structure
- The original system is "submerged" in a liquid of known properties (this could be used, for example, for damage assessment of space antennae prior to launch)

A computer program was designed to implement the proposed damage assessment techniques This program has been successfully used to locate and quantify damage in modular 3D structures The method performed well for multiple damage cases and for a wide range of damage types characterised by changes in mass/stiffness properties ranging from 10% to 70%

The structural modification technique and computer program can also be used for parameter identification of the system In this case, guessed parameters of the system and desired corrections to the guessed parameters are treated as original parameters of the "undamaged" structure and "damages" in the damage identification task respectively