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Multidisciplinary Optimization of a Controlled Space Structure Using 150 Design Variables

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Abstract

A controls-structures interaction design method is presented. The method coordinates standard finite-element structural analysis, multivariable controls, and nonlinear programming codes and allows simultaneous optimization of the structure and control system of a spacecraft. Global sensitivity equations are used to account for coupling between the disciplines. Use of global sensitivity equations helps solve optimization problems that have a large number of design variables and a high degree of coupling between disciplines.

The preliminary design of a generic geostationary platform is used to demonstrate the multidisciplinary optimization method. Design problems using 15, 63, and 150 design variables to optimize truss member sizes and feedback gain values are solved and the results are presented. The goal is to reduce the total mass of the structure and the vibration control system while satisfying constraints on vibration decay rate. Incorporation of the non-negligible mass of actuators causes an essential coupling between structural design variables and control design variables.

Nomenclature

CEC	collocated elastic control
CSI	controls-structures interaction
$\left.\frac{\partial y}{\partial x}\right\|_G, \left.\frac{\partial y}{\partial x}\right\|_\ell$	partial derivative of y with respect to x, evaluated at the global level or the local level
EAL	Engineering Analysis Language
$\vec{G}_p$ $\vec{G}_r$	position- and rate-gain matrices used to define collocated elastic control law
GSE	global sensitivity equations
$\vec{g}$	vector of 12 design variables used to define $\vec{G}_p$ and $\vec{G}_r$ matrices
$\vec{I}$	Identity matrix
$\vec{J}$	spacecraft inertia matrix, kg-m^2
M_a	total mass of vibration suppression actuators, kg
M_s	total mass of truss structure, kg
M_t	$M_s + M_a$
n	number of modes used in reduced-order model of spacecraft

obj	objective function
$\vec{r}$	vector of design variables used to define radii of truss-element cross section, m
x	arbitrary design variable, $x \in \{\vec{r}, \vec{g}\}$
y	arbitrary constraint function
δ	required vibration decay rate
$\vec{\lambda}$	2n x 1 vector of closed-loop eigenvalues, rad^2/sec^2
$\vec{\phi}$	3 x n mode-slope matrix that contains rotational components of structural eigenvectors; superscript 0 indicates maneuver actuator location and superscripts 1 and 2 indicate first and second vibration-suppression-actuator locations
$\vec{\omega}^2$	n x 1 vector of natural eigenvalues of the structural model, rad^2/sec^2

Introduction

Vibrations of a space structure reduce the accuracy of precision instruments mounted on it. Future structures will be built with control systems to damp out any excited vibrations. Preliminary design of these structural systems is complicated by the coupling between the structure and the control system. Changes in either modify both the plant to be controlled and the expected excitation. Determining the trade-offs between structural design parameters and control design parameters is a fundamental problem facing control-structure analysts. Preliminary design of controlled space structures falls under NASA's Controls-Structures Interaction (CSI) Technology Program.[1]

One aspect of the CSI program is to exploit advances in structural analysis, multivariable control and multidisciplinary optimization in the preliminary design of large, flexible spacecraft. Recent work on the preliminary design process has seen the development of procedures to reduce surface distortion errors for large space antennas, tailor structures and control systems for reduced power consumption, and improve the fine-pointing performance of large space platforms while reducing mass.[2, 3, 4, 5]

Reference 6 introduces a general optimization-based design methodology concept that takes full advantage of opportunities to tailor the structure and control system as a single system. The design concept is to divide a coupled system engineering problem into subsystems and use the Global Sensitivity Equations (GSE) to provide for the coupling between the subsystems when calculating system sensitivity derivatives.[7, 8] The example used to demonstrate the concept was the preliminary design of the structure and the vibration suppression controller for a geostationary platform subjected to a slewing maneuver. The use of varying, non-negligible control actuator mass coupled the structural and controls analyses by influencing the structural dynamic characteristics of the model and the applied excitation maneuver. It also limited the maximum torque available for vibration suppression. The results showed that the method would work for small, academic type problems, as the entire structural model was represented by only three structural design variables.

This paper reports on the continuing development of the concept into a viable engineering tool. Brief discussions of the design methodology, the techniques used, and the example problem are presented. Typical results including computer execution times from several cases are presented and discussed.

Multidisciplinary Optimization Procedure

CSI Design Method Using Global Sensitivity Equations

Only a brief description of the method used is given below. A full description and comparisons to other methods is presented in reference 6.

The global system to be analyzed and optimized is broken into two subsystems, represented in Figure 1. The subsystems are coupled, e.g., outputs from one are inputs to the other. The subsystems analyses must iterate until the shared information converges to stable values. Figure 2 presents an approximation technique, based on structural derivatives, that was used to reduce the computer execution time required to achieve a converged solution.

Figure 3 is a block diagram of the method used to perform the preliminary design. Block 1 is the internally coupled system of Figure 1. The second block of Figure 3 indicates that after obtaining a converged solution, with all subsystem quantities shown inside the box in Figure 1 having known values, each subsystem calculates derivatives of its output responses with respect to its input quantities. At this stage, the subsystems were treated as independent, with subsystem coupling effects to be calculated later. The structural derivatives were calculated semi-analytically, while the controls derivatives were calculated by finite differences.

The GSE are represented by the third block of Figure 3. All uncoupled subsystem derivatives from the previous block are input to the GSE. The solution of the GSE gives the sensitivity derivatives of the system output responses with respect to the system design variables.

The baseline, converged solution calculated in block 1 and the system sensitivity derivatives calculated in block 3 are used in a linear extrapolation routine coupled with an optimizer to perform the optimization step in block 4. The optimization step is limited in the amount it can change the design variables to protect the validity of the information from the linear extrapolation. One pass through each of the blocks constitutes a cycle and the process continues to cycle until an optimal solution is found.

Structure and Structural Analysis

The geometry of the reference configuration is shown in Figure 4. The size and shape of the platform does not change during optimization. Its finite element model consists of 10 bays that are 3.0 meters long by 1.5 meters wide and high. Figure 5 indicates how beam elements are connected to form a bay. All beam elements are tubes with a constant wall thickness of 0.159 cm and the outside diameters are controlled by structural design variables through design variable linking, e.g., a design variable may specify the outer diameter of more than one beam element. The bays on each end of the bus include eight extra members to support the vibration suppression actuators located at the center of the bay. The actuators are modeled as point masses.

The flat, circular antennas with diameters of 7.5 and 15 meters are formed with 12 radial and 12 circumferential beam elements. These elements are also tubes with a constant wall thickness of 0.159 cm and outer diameters controlled by design variables.

The Engineering Analysis Language (EAL) computer code was used to perform the structural analysis. [9] Processors were written to transform the current structural design variables into beam section properties. EAL procedures were then used to calculate the structural mass, M_s, the inertia matrix, $\vec{J}$, and the first 20 elastic undamped vibration frequencies, $\vec{\omega}^2$, mode shapes and mode slopes, $\vec{\phi}$. Partial derivatives of these responses were calculated using semi-analytical techniques. [10, 11]

Controls Analysis

The control analysis determines the transient closed-loop response of the spacecraft to a reference maneuver and searches for the maximum vibration control torques and the times at which they occur. The maneuver represents a typical disturbance that might be encountered by a geostationary platform. However, the response is assumed to be linear and nonlinear coupling of rigid and elastic motion is not modeled.

The vibration suppression system uses collocated elastic control (CEC) with a single pair of actuators constrained such that their net torque output is zero. The robust dissipative control law used by CEC does not affect rigid body motion and guarantees stability despite unmodeled dynamics and parameter uncertainty. [12, 13, 14] The torque required by the CEC actuators is a function of the angular deformations and angular deformation rates at the actuator locations and the values of the 12 design variables, $\vec{g}$, which uniquely determine the position gain matrix, $\vec{G}_p$, and the rate gain matrix, $\vec{G}_r$.

The actuators are sized based on the peak torques required to suppress the elastic motion that remains after the reference maneuver. The mass of the actuators is determined from an assumed linear relationship between actuator mass and the maximum torque output. Outputs from the control analysis are the actuator mass, M_a, and the complex closed loop eigenvalues, $\vec{\lambda}$.

Global Sensitivity Equations

The GSE are determined by recognizing that the information needed for subsequent optimization is the sensitivities of the structural mass, the actuator mass and the closed loop eigenvalues to changes in the design variables. These sensitivities are the coefficients of the total differentials of the system outputs, i.e.

$$
\begin{aligned}
dM_S &= \left.\frac{\partial M_S}{\partial \vec{r}}\right|_G d\vec{r} + \left.\frac{\partial M_S}{\partial \vec{g}}\right|_G d\vec{g} \\
dM_a &= \left.\frac{\partial M_a}{\partial \vec{r}}\right|_G d\vec{r} + \left.\frac{\partial M_a}{\partial \vec{g}}\right|_G d\vec{g} \qquad (1) \\
d\vec{\lambda} &= \left.\frac{\partial \vec{\lambda}}{\partial \vec{r}}\right|_G d\vec{r} + \left.\frac{\partial \vec{\lambda}}{\partial \vec{g}}\right|_G d\vec{g}
\end{aligned}
$$

where G denotes that the derivatives are evaluated at the system, or global, level. Or, written in matrix form,

$$\begin{Bmatrix} dM_S \\ dM_a \\ d\vec{\lambda} \end{Bmatrix} = \begin{bmatrix} \left.\frac{\partial M_S}{\partial \vec{r}}\right|_G & \left.\frac{\partial M_S}{\partial \vec{g}}\right|_G \\ \left.\frac{\partial M_a}{\partial \vec{r}}\right|_G & \left.\frac{\partial M_a}{\partial \vec{g}}\right|_G \\ \left.\frac{\partial \vec{\lambda}}{\partial \vec{r}}\right|_G & \left.\frac{\partial \vec{\lambda}}{\partial \vec{g}}\right|_G \end{bmatrix} \begin{Bmatrix} d\vec{r} \\ d\vec{g} \end{Bmatrix} \tag{2}$$

These system derivatives include the coupling effects present in the system.

At a converged coupled analysis point, all inputs and outputs of the subsystems are known. This fact allows treating the subsystems independently for the calculation of the derivatives of the subsystem outputs at that point. These local derivatives do not include any coupling effects, and cannot be used to predict the system response.

To account for the system coupling using the information available, each subsystem's total differentials may be written,

$$\begin{aligned} dM_S &= \left.\frac{\partial M_S}{\partial \vec{r}}\right|_\ell d\vec{r} + \left.\frac{\partial M_S}{\partial M_a}\right|_\ell dM_a \\ d\vec{J} &= \left.\frac{\partial \vec{J}}{\partial \vec{r}}\right|_\ell d\vec{r} + \left.\frac{\partial \vec{J}}{\partial M_a}\right|_\ell dM_a \\ d\vec{\omega} &= \left.\frac{\partial \vec{\omega}}{\partial \vec{r}}\right|_\ell d\vec{r} + \left.\frac{\partial \vec{\omega}}{\partial M_a}\right|_\ell dM_a \\ d\vec{\phi} &= \left.\frac{\partial \vec{\phi}}{\partial \vec{r}}\right|_\ell d\vec{r} + \left.\frac{\partial \vec{\phi}}{\partial M_a}\right|_\ell dM_a \end{aligned} \tag{3}$$

and

$$\begin{aligned} dM_a &= \left.\frac{\partial M_a}{\partial \vec{J}}\right|_\ell d\vec{J} + \left.\frac{\partial M_a}{\partial \vec{\omega}}\right|_\ell d\vec{\omega} + \left.\frac{\partial M_a}{\partial \vec{\phi}}\right|_\ell d\vec{\phi} + \left.\frac{\partial M_a}{\partial \vec{g}}\right|_\ell d\vec{g} \\ d\vec{\lambda} &= \left.\frac{\partial \vec{\lambda}}{\partial \vec{J}}\right|_\ell d\vec{J} + \left.\frac{\partial \vec{\lambda}}{\partial \vec{\omega}}\right|_\ell d\vec{\omega} + \left.\frac{\partial \vec{\lambda}}{\partial \vec{\phi}}\right|_\ell d\vec{\phi} + \left.\frac{\partial \vec{\lambda}}{\partial \vec{g}}\right|_\ell d\vec{g} \end{aligned}$$

where ℓ denotes that the derivatives are evaluated at the subsystem, or local, level and do not include coupling effects. Upon examining eqns. (3), it can be noted that each differential is a differential of a subsystem output or a system input. The equations are rewritten to put the subsystem output differentials on the left hand side and the system input differentials on the right hand side, giving

$$
\begin{aligned}
dM_s - \left.\frac{\partial M_s}{\partial M_a}\right|_\ell dM_a &= \left.\frac{\partial M_s}{\partial \vec{r}}\right|_\ell d\vec{r} \\
d\vec{J} - \left.\frac{\partial \vec{J}}{\partial M_a}\right|_\ell dM_a &= \left.\frac{\partial \vec{J}}{\partial \vec{r}}\right|_\ell d\vec{r} \\
d\vec{\omega} - \left.\frac{\partial \vec{\omega}}{\partial M_a}\right|_\ell dM_a &= \left.\frac{\partial \vec{\omega}}{\partial \vec{r}}\right|_\ell d\vec{r} \\
d\vec{\phi} - \left.\frac{\partial \vec{\phi}}{\partial M_a}\right|_\ell dM_a &= \left.\frac{\partial \vec{\phi}}{\partial \vec{r}}\right|_\ell d\vec{r} \\
dM_a - \left.\frac{\partial M_a}{\partial \vec{J}}\right|_\ell d\vec{J} - \left.\frac{\partial M_a}{\partial \vec{\omega}}\right|_\ell d\vec{\omega} - \left.\frac{\partial M_a}{\partial \vec{\phi}}\right|_\ell d\vec{\phi} &= \left.\frac{\partial M_a}{\partial \vec{g}}\right|_\ell d\vec{g} \\
d\vec{\lambda} - \left.\frac{\partial \vec{\lambda}}{\partial \vec{J}}\right|_\ell d\vec{J} - \left.\frac{\partial \vec{\lambda}}{\partial \vec{\omega}}\right|_\ell d\vec{\omega} - \left.\frac{\partial \vec{\lambda}}{\partial \vec{\phi}}\right|_\ell d\vec{\phi} &= \left.\frac{\partial \vec{\lambda}}{\partial \vec{g}}\right|_\ell d\vec{g}
\end{aligned}
\tag{4}
$$

or, written in matrix form

$$
\begin{bmatrix}
\dot{I} & 0 & 0 & 0 & -\left.\frac{\partial M_s}{\partial M_a}\right|_\ell & 0 \\
0 & \dot{I} & 0 & 0 & -\left.\frac{\partial \vec{J}}{\partial M_a}\right|_\ell & 0 \\
0 & 0 & \dot{I} & 0 & -\left.\frac{\partial \vec{\omega}}{\partial M_a}\right|_\ell & 0 \\
0 & 0 & 0 & \dot{I} & -\left.\frac{\partial \vec{\phi}}{\partial M_a}\right|_\ell & 0 \\
0 & -\left.\frac{\partial M_a}{\partial \vec{J}}\right|_\ell & -\left.\frac{\partial M_a}{\partial \vec{\omega}}\right|_\ell & -\left.\frac{\partial M_a}{\partial \vec{\phi}}\right|_\ell & \dot{I} & 0 \\
0 & -\left.\frac{\partial \vec{\lambda}}{\partial \vec{J}}\right|_\ell & -\left.\frac{\partial \vec{\lambda}}{\partial \vec{\omega}}\right|_\ell & -\left.\frac{\partial \vec{\lambda}}{\partial \vec{\phi}}\right|_\ell & 0 & \dot{I}
\end{bmatrix}
\begin{Bmatrix} dM_s \\ d\vec{J} \\ d\vec{\omega} \\ d\vec{\phi} \\ dM_a \\ d\vec{\lambda} \end{Bmatrix}
=
\begin{bmatrix}
-\left.\frac{\partial M_s}{\partial \vec{r}}\right|_\ell & 0 \\
-\left.\frac{\partial \vec{J}}{\partial \vec{r}}\right|_\ell & 0 \\
-\left.\frac{\partial \vec{\omega}}{\partial \vec{r}}\right|_\ell & 0 \\
-\left.\frac{\partial \vec{\phi}}{\partial \vec{r}}\right|_\ell & 0 \\
0 & -\left.\frac{\partial M_a}{\partial \vec{g}}\right|_\ell \\
0 & -\left.\frac{\partial \vec{\lambda}}{\partial \vec{g}}\right|_\ell
\end{bmatrix}
\begin{Bmatrix} d\vec{r} \\ d\vec{g} \end{Bmatrix}
\tag{5}
$$

The coefficient matrix on the left hand side is the Global Sensitivity Matrix (GSM) and the off-diagonal terms represent the system coupling. Multiplying eqn. (5) by the inverse of the GSM and rearranging the rows and columns gives, after partitioning,

$$\begin{Bmatrix} dM_s \\ dM_a \\ d\vec{\lambda} \\ \cdots \\ d\vec{J} \\ d\vec{\omega} \\ d\vec{\phi} \end{Bmatrix} = \begin{bmatrix} \text{Matrix 1} \\ \cdots\cdots \\ \text{Matrix 2} \end{bmatrix} \begin{Bmatrix} d\vec{r} \\ d\vec{g} \end{Bmatrix} \tag{6}$$

By comparing eqn. (6) to eqn. (2), it can be seen that Matrix 1 is the matrix of derivatives evaluated at the global level.

Optimization

The optimization problem is to find the system design variable vector that minimizes the total mass of the platform while satisfying vibration decay requirements. The design variables used in this study were the 12 entries that uniquely defined the position and rate gain matrices and the radii that defined the beam elements. Several examples are given using design variable linking so that different numbers of radii are used to define the beam elements. The problem can be stated as

$$\text{minimize } M_T = M_s + M_a$$

subject to

$$Re(\lambda_i) \le \delta \qquad i = 1, 2, \ldots, 2n \tag{7}$$

where $Re(\lambda_i)$ is the real part of the complex eigenvalues, δ is the required decay rate and n is the number of modes used in the reduced order model of the spacecraft. The derivatives calculated using the GSE are used to provide linear approximations to the system responses that are used to calculate the objective function and the constraint functions as given below,

$obj(x) = M_T$

$$y_i = 1 - \mathrm{Re}(\lambda_i)/\delta \qquad i = 1, 2, \cdots, 2n \tag{8}$$

where $y_i \leq 0$ is a feasible constraint and the required decay rate, δ, is a negative number. The effect of changing an arbitrary design variable x_j by the amount Δx_j is approximated by

$$\mathrm{obj}(x_j + \Delta x_j) \approx Ms + \left.\frac{\partial Ms}{\partial x_j}\right|_G \Delta x_j + M_a + \left.\frac{\partial M_a}{\partial x_j}\right|_G \Delta x_j$$

$$y_i(x_j + \Delta x_j) \approx 1 - \left(\lambda_i + \left.\frac{\partial \lambda_i}{\partial x_j}\right|_G \Delta x_j\right)\Big/\delta \tag{9}$$

The solution of the optimization problem is accomplished by linking the linear approximation routine with the nonlinear programming code CONMIN (ref. 15).

Results and Discussion

Overview of the Test Cases

In each test case, the decay rate requirement is $\delta = -0.03$. The reference maneuver rotates the spacecraft 20° about each axis simultaneously in 10 seconds. The initial values of the 12 control design variables gave the following position and rate gain matrices

$$\vec{G}_p = \vec{G}_r = \begin{bmatrix} 5100 & 800 & 700 \\ 800 & 5000 & 7000 \\ 700 & 700 & 4900 \end{bmatrix} \tag{10}$$

Additionally, all design variables were constrained to a maximum of 10% change in each cycle.

Typical optimization results starting from an infeasible design show a rapid increase in the objective function until the constraints are satisfied. In each of the test cases below, the objective function is increased moderately until the constraints are satisfied. Previous results presented in Ref. 6 do show the characteristic rapid increase; therefore, the moderate increase is not a characteristic of the method, but possibly of the chosen starting points.

Test Case 1: 15 Global Design Variables

In addition to the 12 control matrix entries, three design variables were used to control the beam element sizes. One design variable controlled all members in the bus structure, one controlled all antenna members and one controlled all antenna support members. Results from this case are presented in figures 6 and 7.

The method was able to reach an optimum design in 22 cycles. The percentage of the total mass contributed by the control system increased from 0.8% to 7.5%.

Test Case 2: 63 Global Design Variables

An additional 51 design variables were used to size the beam elements. A separate design variable defined the radii of the members of each cross-section frame, the cross-section diagonal, the stringers in each bay and the diagonals in each bay. Also, a separate design variable controlled the sizes of the inner spokes, outer spokes and ring members of each antenna. The elements of the two antenna support groups were controlled by separate design variables. Figures 8 and 9 present the results for this case.

This case also needed 22 cycles to reach an optimum design. The control system mass increased from 0.8% to 8.2% of the total mass.

Test Case 3: 150 Global Design Variables

Each of the 135 individual beam elements in the bus structures was controlled by an individual design variable. All members in the antennas were controlled by one design variable as was the antenna support elements and the control actuator support elements. Results are presented in Figures 10 and 11.

An optimum design was found in 26 cycles. The mass contributed by the control system increased from 0.7% to 4.1% of the total mass.

Figure 12 shows the typical cycle history of three design variables. These design variables control members of the third cross sectional frame from the end with the large antenna. In this case, each design variable represented only a small fraction of the total system. Random changes in the design variables were expected, indicating that individual design variables were too insignificant to affect the optimization algorithm. The consistent changes in the design variable values show that the system sensitivities calculated by using the GSE had significant magnitudes and were not prone to numerical errors. These results were typical of all 135 structural design variables.

Computer Execution Times

The test cases were run on a Convex 220 computer. In all cases, the time required to perform the cycle's optimization step was less than 5 seconds. The 15 design variable case required an average of 1460 seconds to calculate the converged solution and global sensitivity derivatives. It is estimated that it would require 2210 seconds to calculate the same information by global finite differences. The 63 design variable case used an average 4610 seconds for the calculations, while an estimated 9540 seconds would be required by global finite differencing. Timing data was not available for the 150 design variable case.

The estimates for global finite differencing were obtained by adding the average times for a structural analysis and a controls analysis and multiplying by the number of design variables plus 1. The values calculated underestimate the actual values in that no estimate for the time required to obtain a converged baseline solution was included.

Concluding Remarks

This paper describes the development and implementation of a general optimization-based method for the design of large space platforms through integration of the disciplines of structural dynamics and controls. The method is especially appropriate for preliminary design problems in which the structural and control analyses are tightly coupled. The method is significant because it coordinates general-purpose structural analysis, multivariable control, and optimization codes and thus can be adapted to a variety of controls-structures integrated design (CSID) projects. The method uses the global sensitivity equations (GSE) approach.

To demonstrate its capabilities the method is used to minimize the total weight of a space platform while maintaining a specified vibration decay rate after slewing maneuvers. Although the structural model has many simplifying assumptions and the number and location of actuators are fixed, the number of design variables used in the example cases is representative of practical design problems. With the CSID procedure, the platform is redesigned so that the mass distribution and dynamic characteristics of the structure enhance the use of rate and position feedback by the control system. The CSID method must trade stiffness that adds structural weight for control effort that adds weight to the actuators. The procedure not only trades structural mass for control effort, but also satisfies the vibration decay rate constraints.

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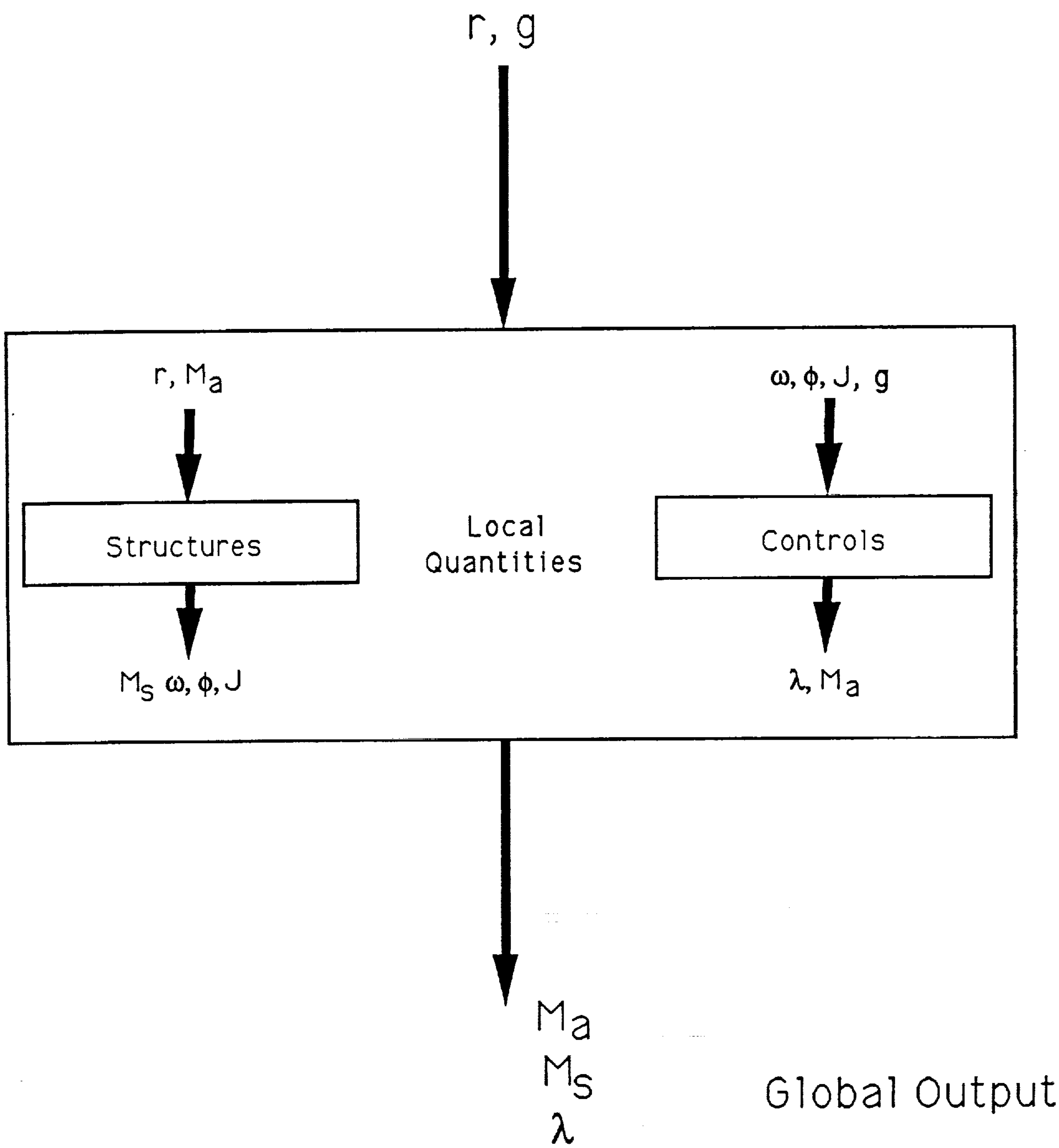


Figure 1: Input and output quantities for the system and subsystem.

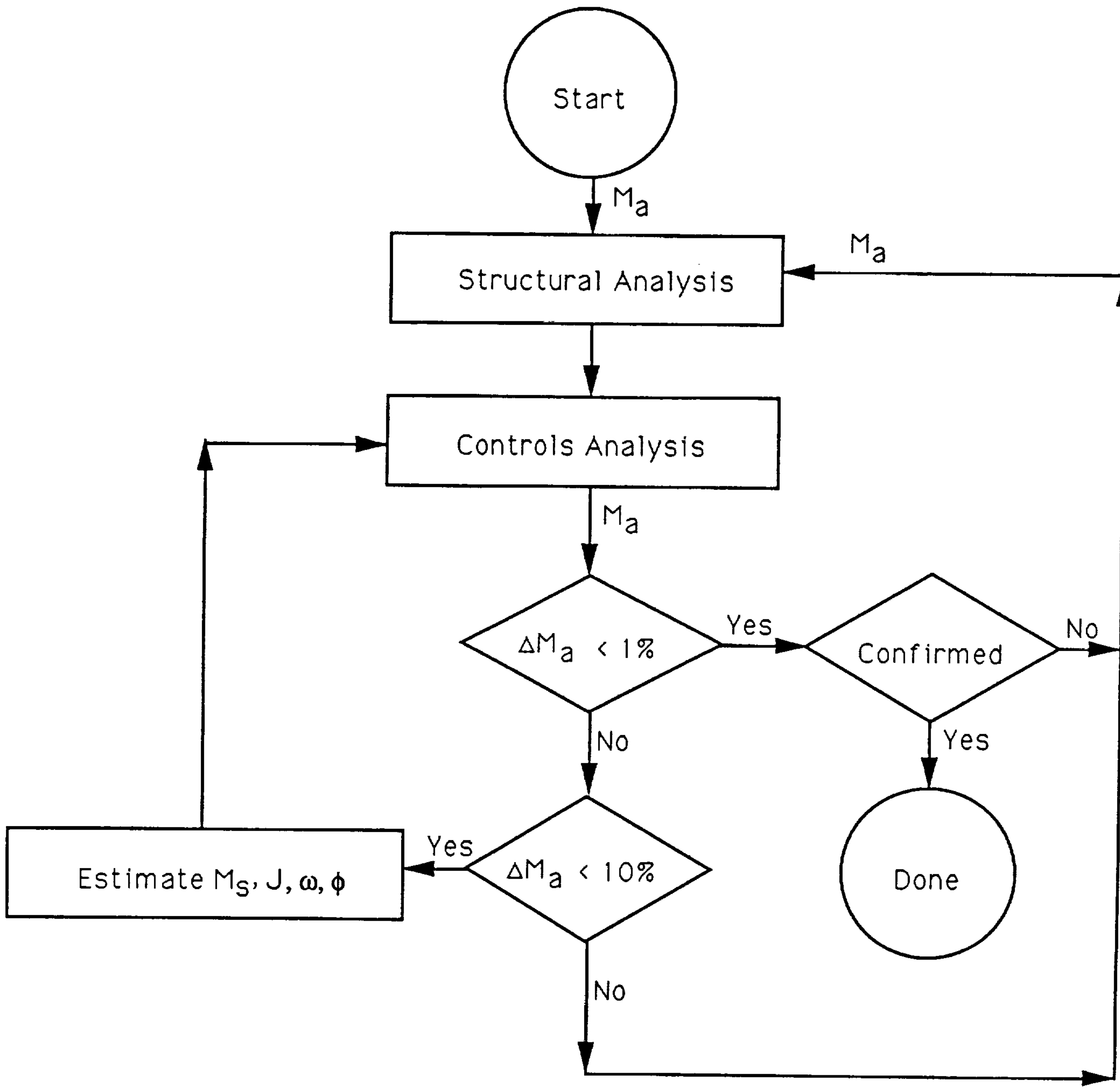


Figure 2: Flowchart of iterative procedure for coupled analysis.

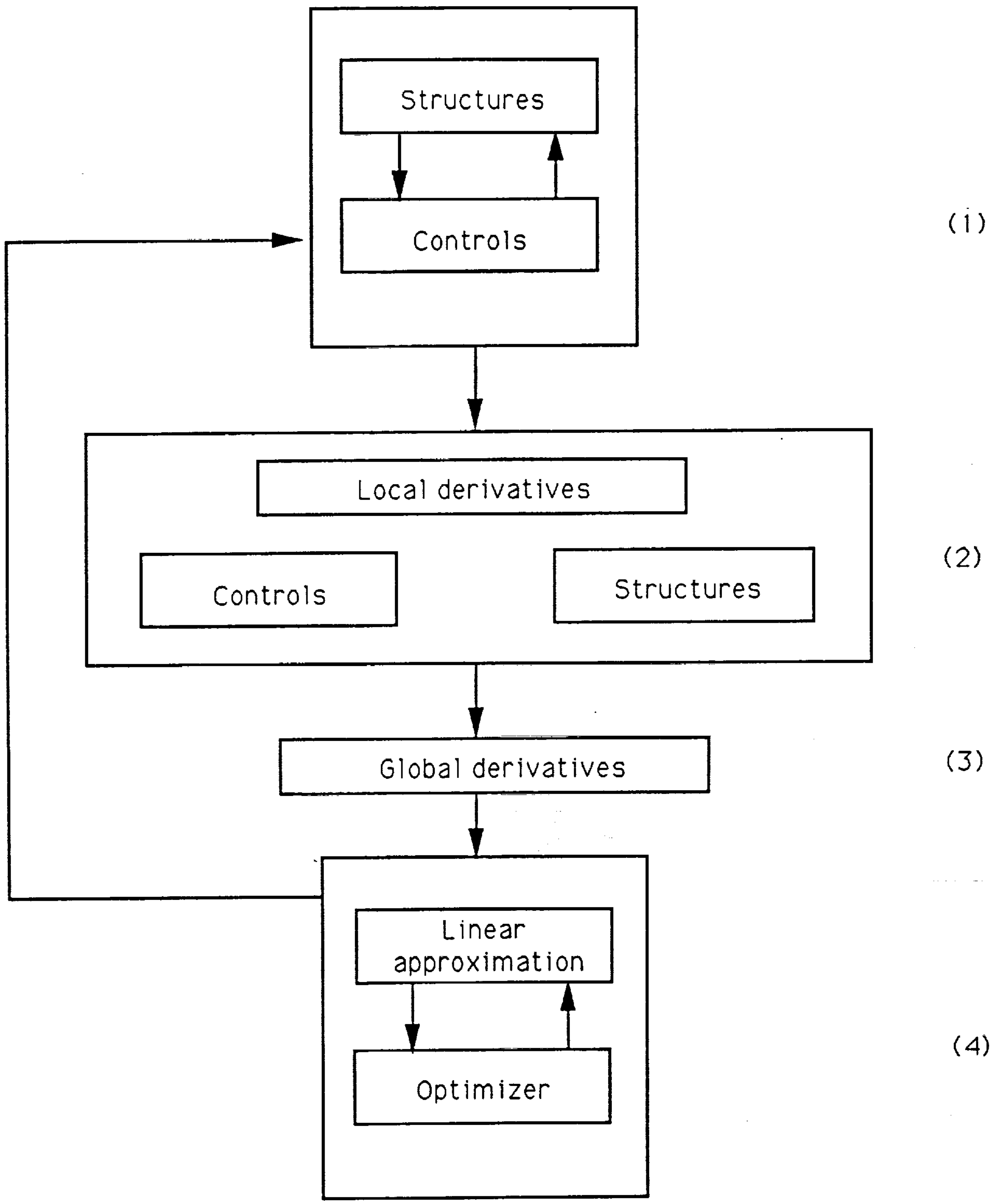


Figure 3: CSID procedure using global sensitivity equations.

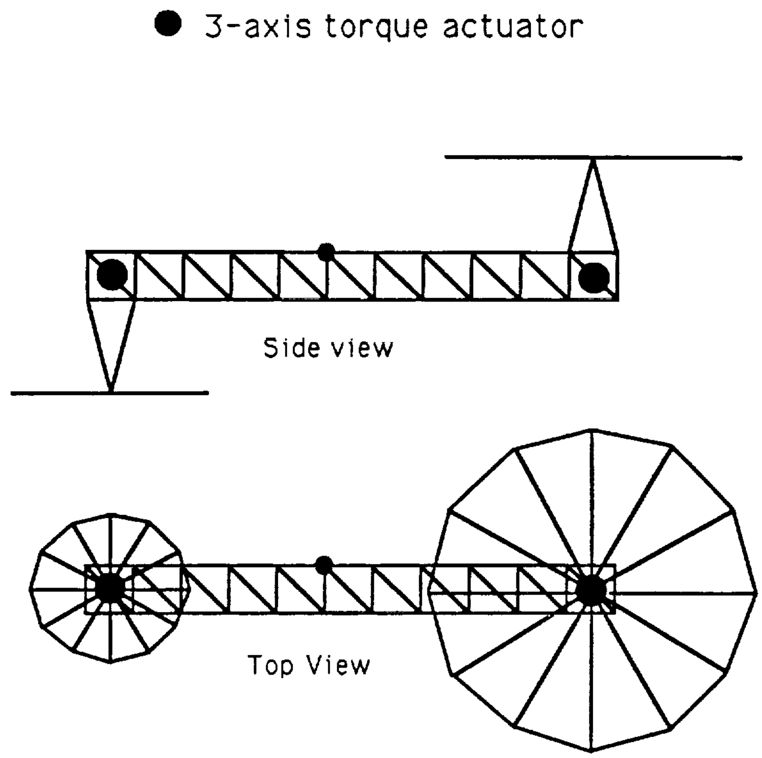


Fig. 4: Reference Configuration of Geostationary Platform with three-axis torque actuators.

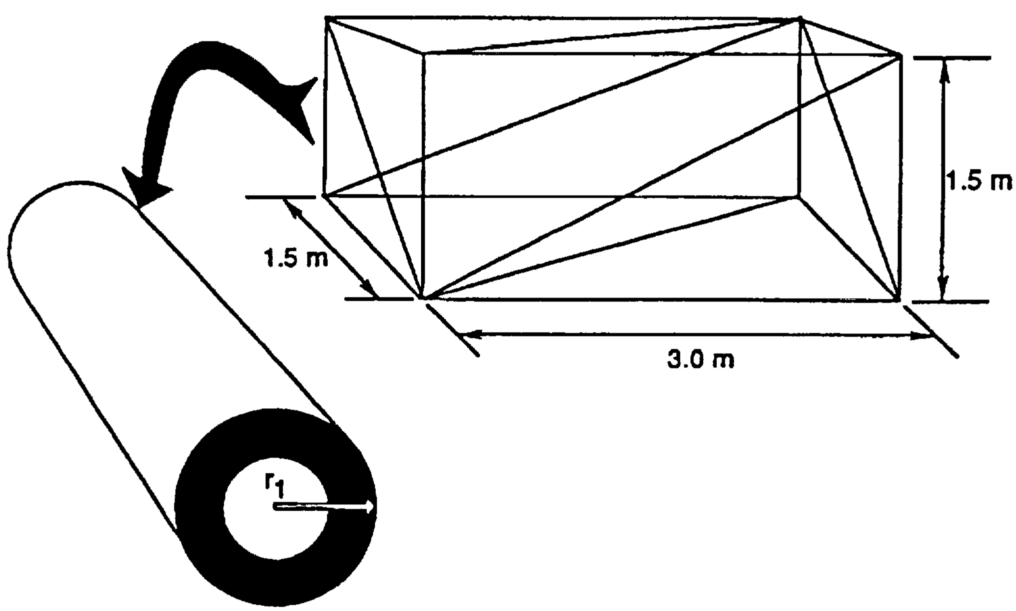


Fig. 5: Typical bay of truss structure for reference configuration.

Fig. 6: Cycle History of the Objective Function : Case 1

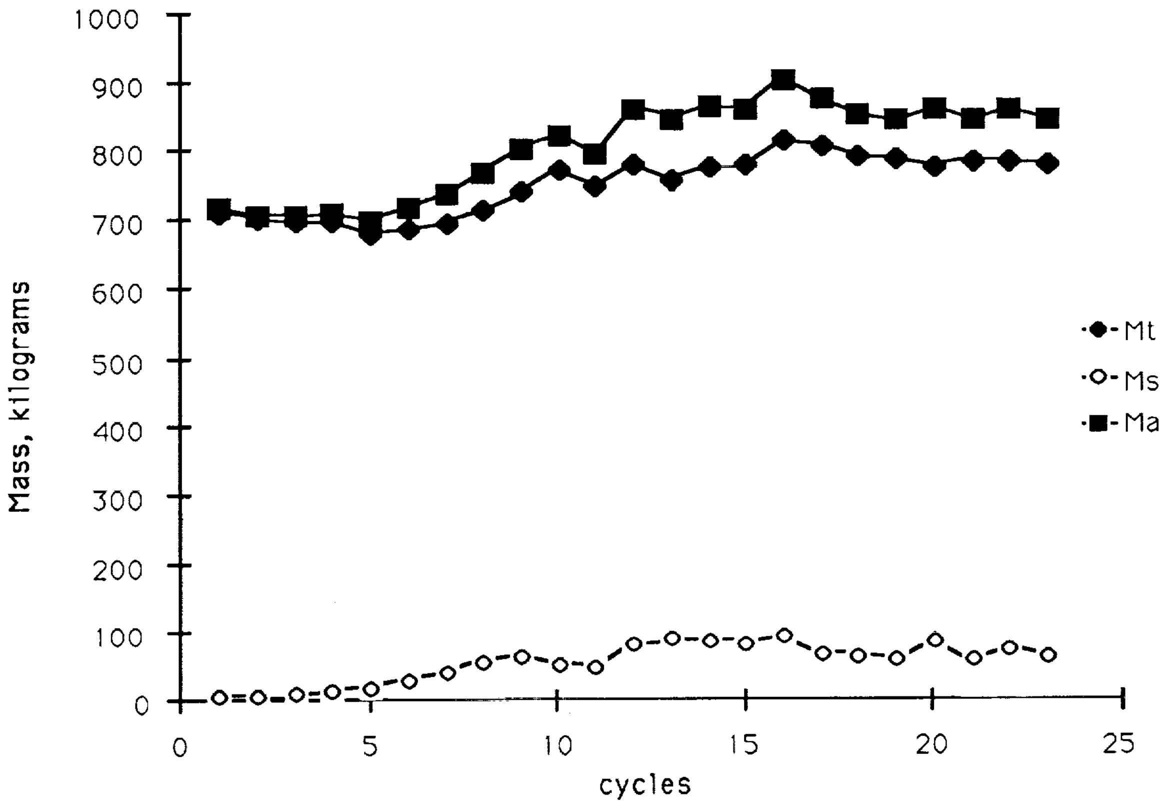


Fig. 7: Cycle History of the Maximum Closed-Loop Eigenvalue Compared to its Allowable Value: Case 1

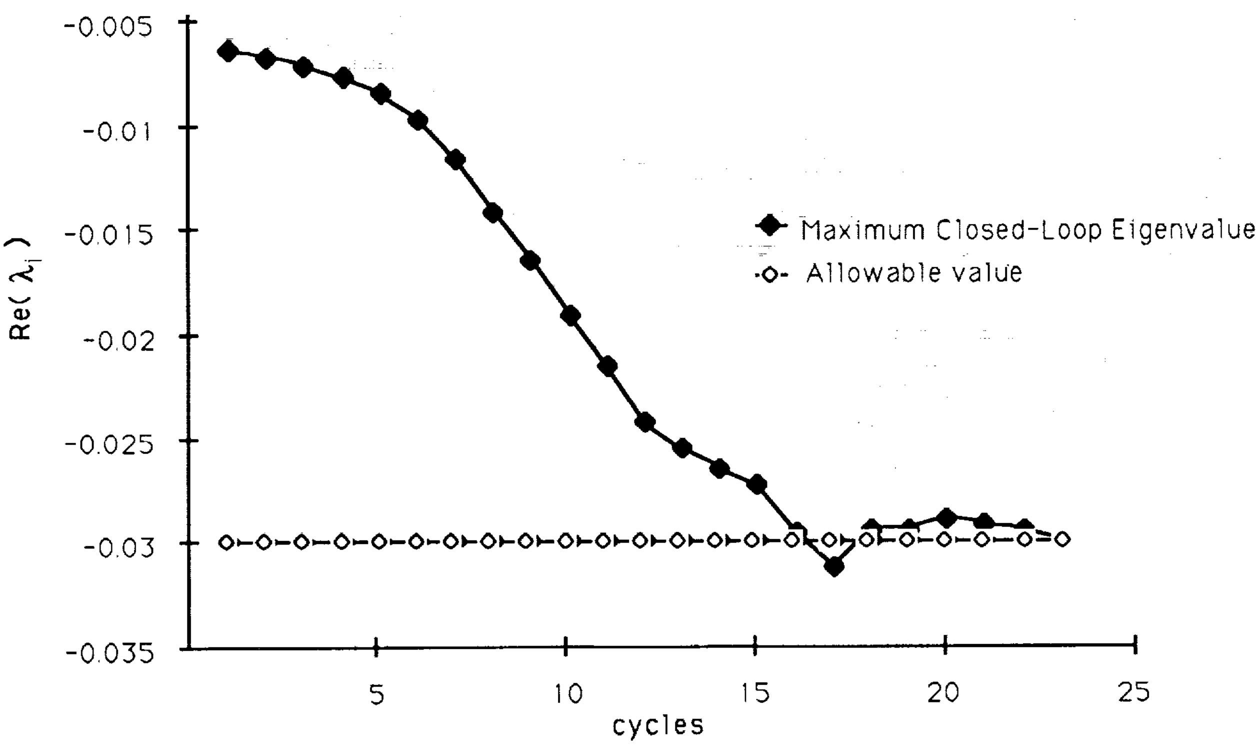


Fig. 8: Cycle History of the Objective Function: Case 2

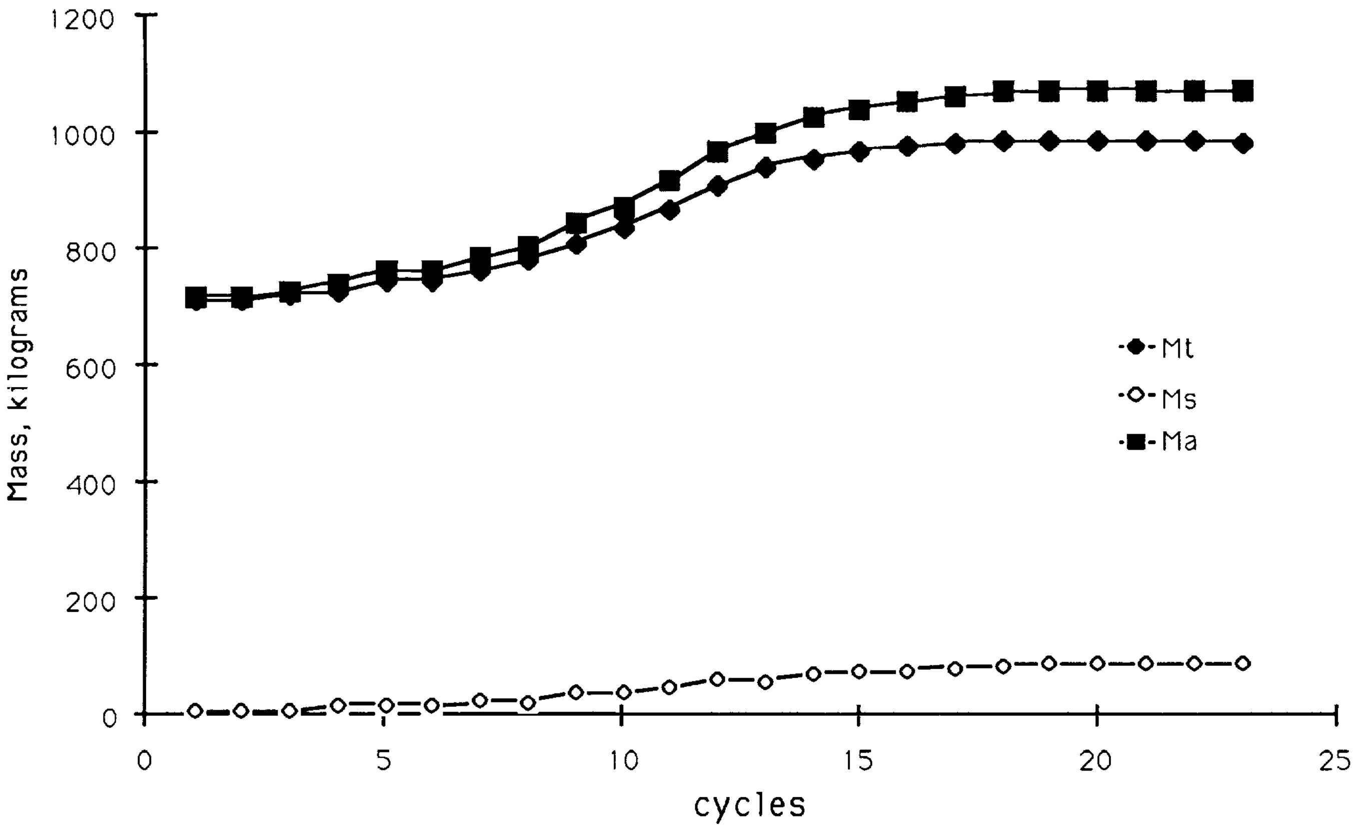


Fig. 9: Cycle History of the Maximum Closed-Loop Eigenvalue Compared to its Allowable Value: Case 2

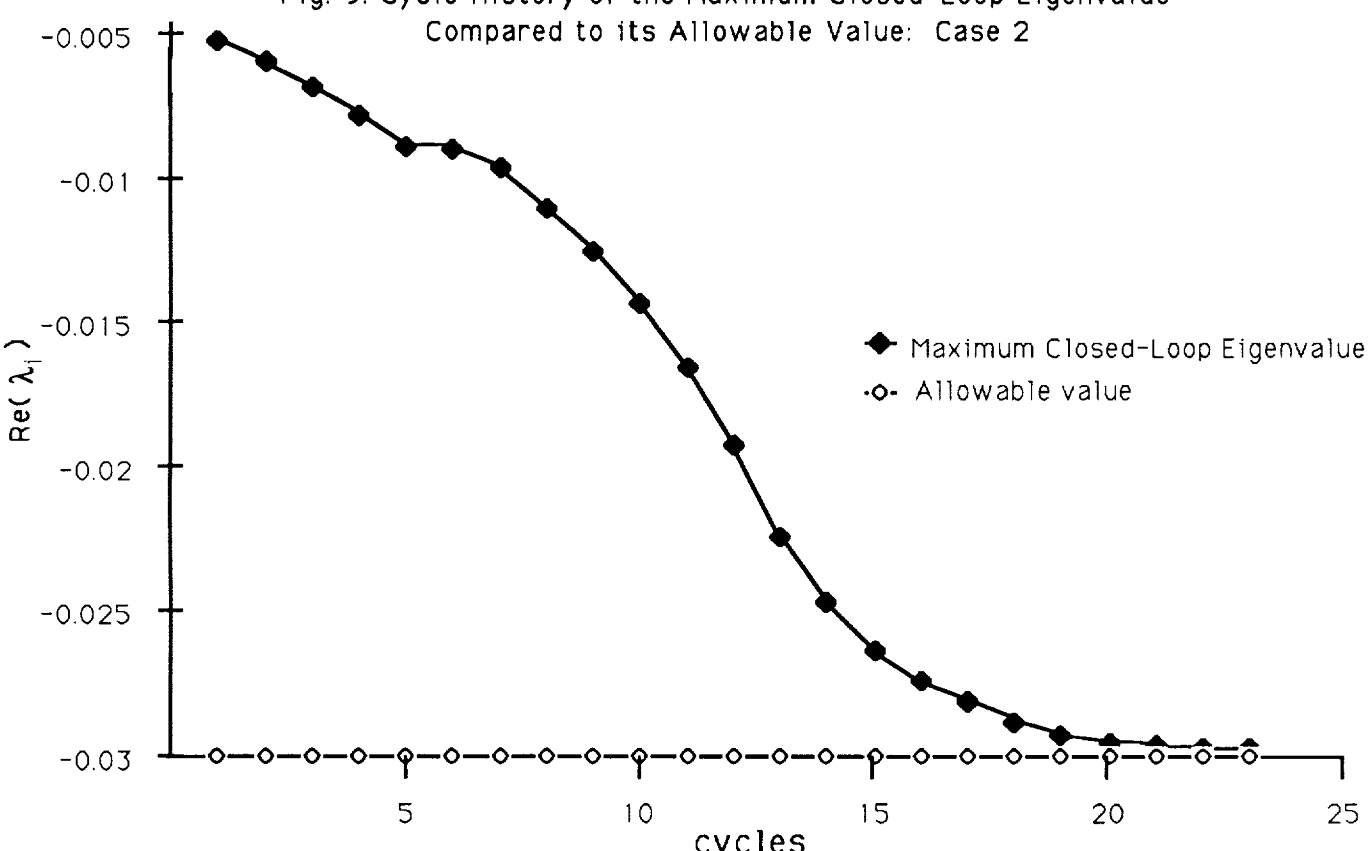


Fig. 10: Cycle History of the Objective Function: Case 3

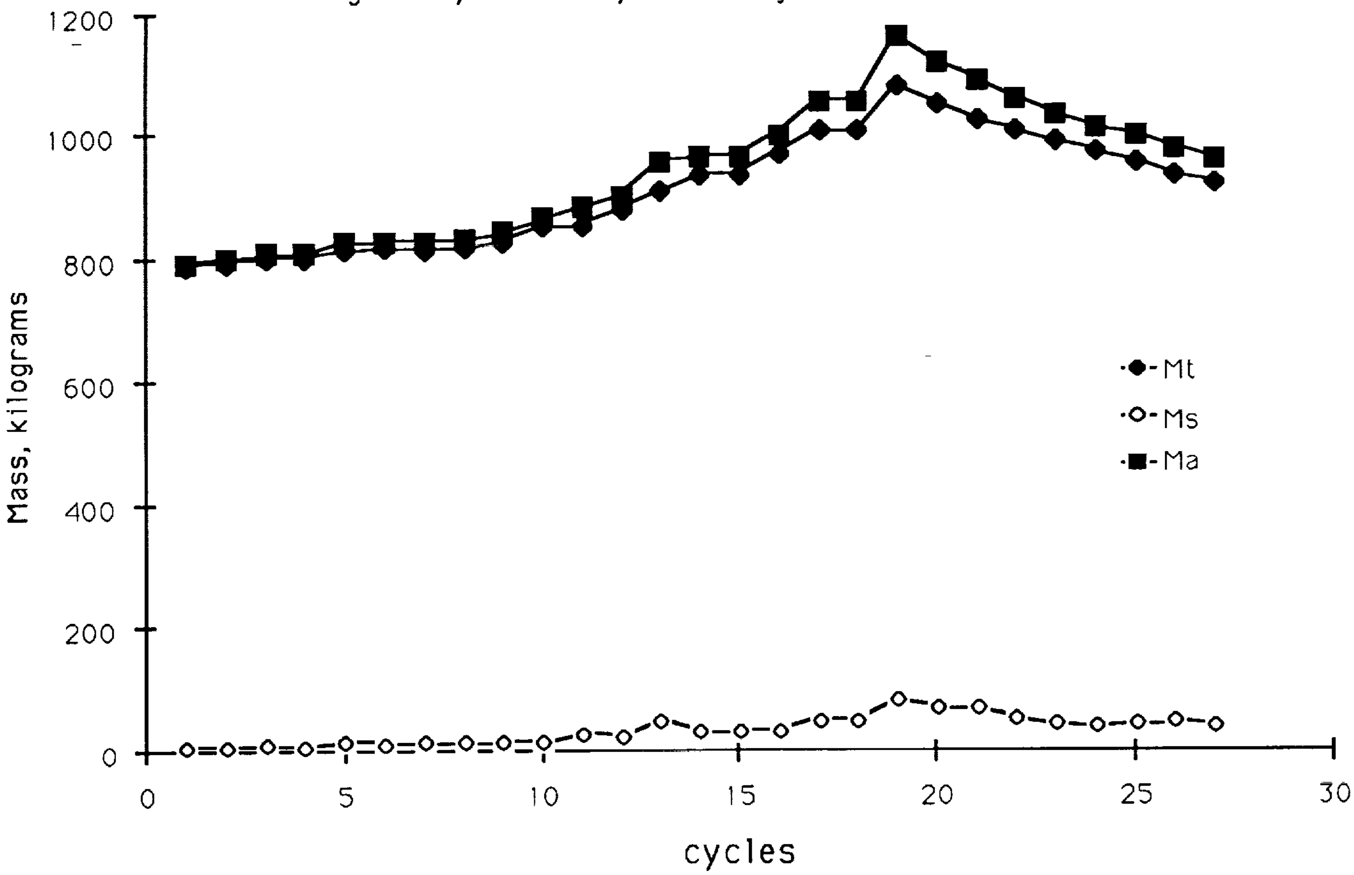


Fig. 11: Cycle History of the Maximum Closed-Loop Eigenvalue Compared to its Allowable Value: Case 3

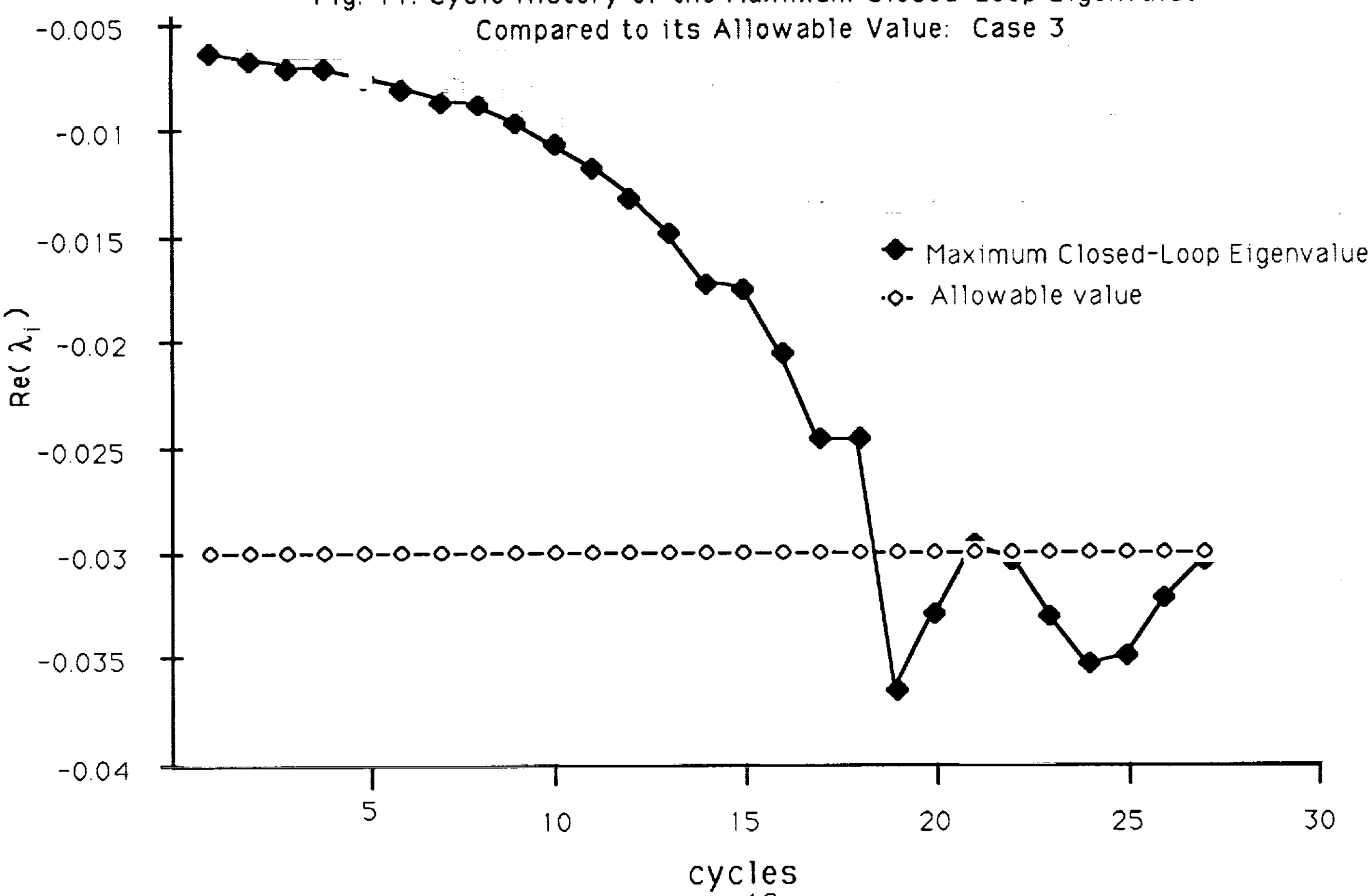
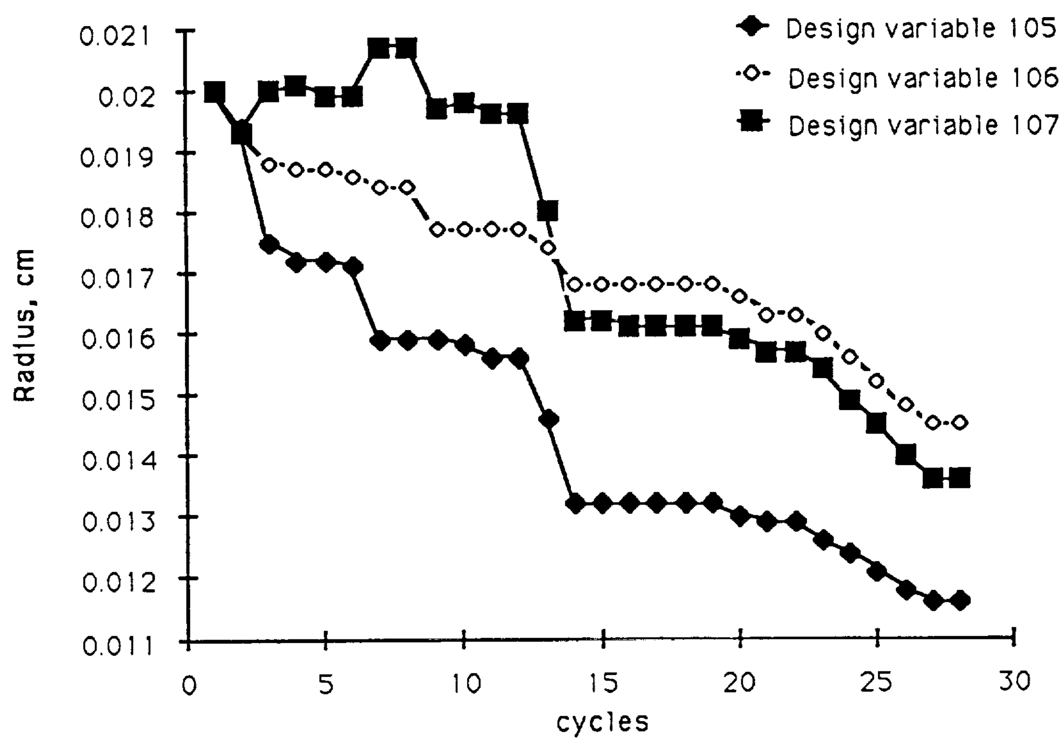


Fig. 12: Cycle History of Selected Structural Design Variables: Case 3



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13. ABSTRACT *(Maximum 200 words)*
A controls-structures interaction design method is presented. The method coordinates standard finite-element structural analysis, multivariable controls, and nonlinear programming codes and allows simultaneous optimization of the structure and control system of a spacecraft. Global sensitivity equations are used to account for coupling between the disciplines. Use of global sensitivity equations helps solve optimization problems that have a large number of design variables and a high degree of coupling between disciplines.
The preliminary design of a generic geostationary platform is used to demonstrate the multidisciplinary optimization method. Design problems using 15, 63, and 150 design variables to optimize truss member sizes and feedback gain values are solved and the results are presented. The goal is to reduce the total mass of the structure and the vibration control system while satisfying constraints on vibration decay rate. Incorporation of the nonnegligible mass of actuators causes an essential coupling between structural design variables and control design variables.

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