APPLICATION of MSC/NASTRAN SENSITIVITY ANALYSIS at NISSAN MOTOR COMPANY

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Abstract

A pre-post processing system for MSC/NASTRAN sensitivity analysis has been developed. The effectiveness of the sensitivity analysis has been well recognized. However it is difficult for many designers to use it. This system creates MSC/NASTRAN design sensitivity data. With this system, the analytical results can be estimated easily. Some application examples are presented in this paper.

1. Introduction

In recent years, there has been a rapidly increasing demand for higher vehicle performance such as low noise and vibration levels. Therefore, from the early design stage, many structures must be studied in order to achieve the specifications required to provide high performance.

MSC/NASTRAN and other FEM programs are widely utilized as useful tools to accomplish this.

However,carrying out many different variable calculations with a large model involves several problems such as the CPU time and manpower needed to complete the job.

To solve these problems, a sensitivity analysis technique has been incorporated in MSC/NASTRAN. The term sensitivity analysis technique is used here as a technique to calculate the change(sensitivity coefficient) of the structure response (displacement, natural frequency, etc.) relative to the unit design variable change through structure re-analysis. Many design estimations can be done in a relatively short period of time using this technique.

However, for many designers , MSC/NASTRAN sensitivity analysis functions are difficult to use for the following reasons.

1. Element property IDs are used to define design variables. But the designers know only the element connectivity IDs. This means they have to inquire what the element property IDs are.
2. Since the analytical results are printed out in numerical form ,it is difficult to grasp the results intuitively

To promote easier use of sensitivity analysis functions, we developed a pre-post processing system called NSAS (Nissan Sensitivity Analysis System), which employs ordinary solution data (SoL 3, SoL 24) in creating sensitivity analysis data and graphic visualization of the analytical results. Both data creation and results visualization are performed interactively.

This paper outlines the features of NSAS and presents a number of application examples. One, in particular, demonstrates an expanded application of the system in optimizing the vehicle design to reduce the interior booming noise.

2.Outline of "NSAS"

The configuration of NSAS is illustrated in Fig.1..

A designer uses a TSS terminal or a CAD terminal to define the design variables and the design constraints.When a TSS terminal is used, he inputs the element connectivity ID, and the system then automatically searches the NASTRAN data for the corresponding element property (Fig. 2 and 3). When a CAD terminal is employed, he uses a mouse to select the element that he wants to define as a design variable or a design constraint.

The analytical results are sorted in the ascending order of the sensitivity coefficients and displayed on the CAD terminal screen in a contour (Fig. 4 and 8) Since the user input screen has a menu style, it is easy to add a new solution type.

3.Vehicle Structure Model Natural Frequency Sensitivity Analysis

The effectiveness of this system is first illustrated using a simple cantilever and shell model.

The first mode deformed shape, the elemental strain energy distribution, the elemental kinetic energy distribution and the element shell-thickness sensitivity coefficient distribution are shown in Fig.5 8, respectively.

The elements which have large strain energy have large positive sensitivity coefficients for a thickness increase and the elements of large kinetic energy have negative ones. It is easy for designers with this results to grasp which elements have a spring effect and which elements have a mass effect.

The system was then applied to a 2600 nodes vehicle model natural frequency sensitivity analysis. In order to control the 1st and 2nd bending modes of the vehicle, the sensitivity coefficient of the front and rear fender's Young ratio and joint stiffness at the pillar joint and some other parts were calculated. The total number of design variables was 571 and it took about 50 seconds to complete the calculations. By contrast,in one instance SOL63 took 380 seconds. This means that the design calculations for one example can be done about 4,000 times faster with sensitivity analysis than with SOL63.

4. Acoustic Sensitivity Analysis

Acoustic sensitivity analysis was employed to determine the sensitivity of structural changes relative to the sound pressure for a certain frequency at the measured point. There are two approaches that can be used in conducting a frequency response analysis. One is to conduct a direct frequency response analysis. The other is to conduct a modal frequency response analysis. Similar procedures can can be employed to conduct an acoustic frequency response sensitivity analysis.

The former approach, in which attention is focused on one frequency peak, was employed in this work. The reason for choosing this approach was that it was assumed that the noise reduction problem to be treated involved one peak frequency. The acoustic sensitivity coefficient was defined as indicated in Eq. (1).

$S_{ij} = \triangle P_i / \triangle D_j$ ----(1)

where,

S_{ij}: Sensitivity coefficient of the j-th design variable, D_j, relative to the sound pressure at joint i

$\triangle P_i$: Change in sound pressure resulting from a change in the j-th design variable, D_j, at joint i

$\triangle D_j$: Amount of change in the j-th design variable

A positive acoustic sensitivity coefficient indicates that the sound pressure rises due to an increase in the design variables, for example, the panel thickness.

Acoustic sensitivity analysis was combined with an optimization routine in an effort to determine the exact amount of modification that should be made so as to reduce interior noise to the target level. The basic idea adopted here was that the amount of modification should be kept as small as possible. Lagrangian multipliers were employed in determining the objective function, which represented the difference between the sound pressure generated by the present structure and the target level. The optimization routine is illustrated in Fig. 9.

This technique was used to analyze the booming noise of a vehicle. A sinusoidal force was applied to the engine mounts of the vehicle model illustrated in Fig. 10. The sound pressure at the ear level of the front seat occupant was found to have a peak of 47 Hz. The object was to reduce that peak sound pressure. The sensitivity distribution for the thickness of all the panel elements and for some of the area moments of inertia is shown in Fig. 11. Using these results, 16 design variables of high sensitivity coefficients were selected (Fig. 12). An example of the iteration history to obtain the ideal area moments of inertia and the results are illustrated in Fig. 13. The CPU running time required to perform this analysis is 145 seconds per iteration using an CRAY XMP.

The result confirms that acoustic sensitivity analysis used in combination with an optimization routine makes it possible to carry out structural modifications effective in reducing noise even in the case of a large-scale model like the vehicle body.

MSC/NASTRAN was employed in both the vibration and acoustic analyses. The sensitivity analysis procedure and optimization routine were written in a newly developed FORTRAN program.

5.Conclusion

A pre-post processing system NSAS has been developed which creates MSC/NASTRAN design sensitivity data. With this system, the analytical results can be estimated easily and many design evaluations can be performed with high efficiency. By applying sensitivity analysis,the vehicle booming noise can be reduced while suppressing weight increases .

References

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(2) Yashiro, H., Hagiwara, I., Suzuki, K., Arai, A., "Noise and Vibration Analysis of Vehicle Body and Application to the Floor Structure" (in Japanese), JSAE Paper No. 832046 (1983), p. 287.

(3) Hagiwara, I. and Nagabuchi, K., "Study of an Identification Analysis Procedure for Structures using Sensitivity Analysis" (in Japanese), Pre-print of the Journal of the Japan Society of Mechanical Engineers, 6th General Meeting, Paper No. 87-868A, (1988-3).

(4) Nakagiri, S. and Suzuki, K., "Shift Synthesis of Eigenvalue Problems using the Finite Element Method" (in Japanese), Journal of the Japan Society of Mechanical Engineers, 496-C, Paper No. 87-0103B, (1987).

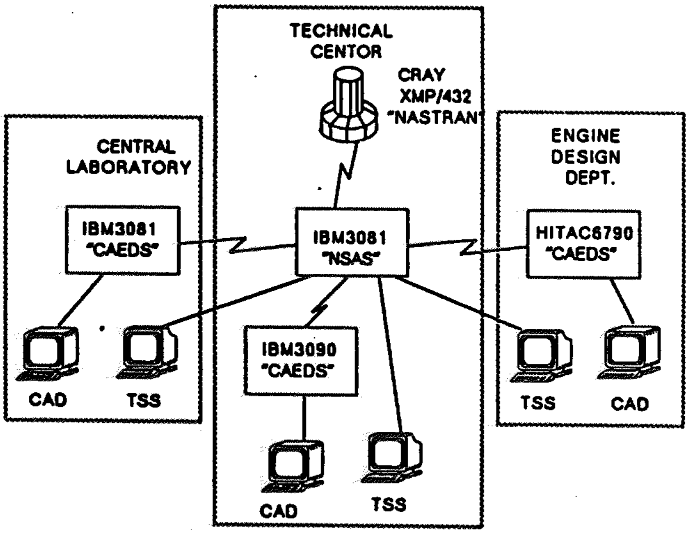
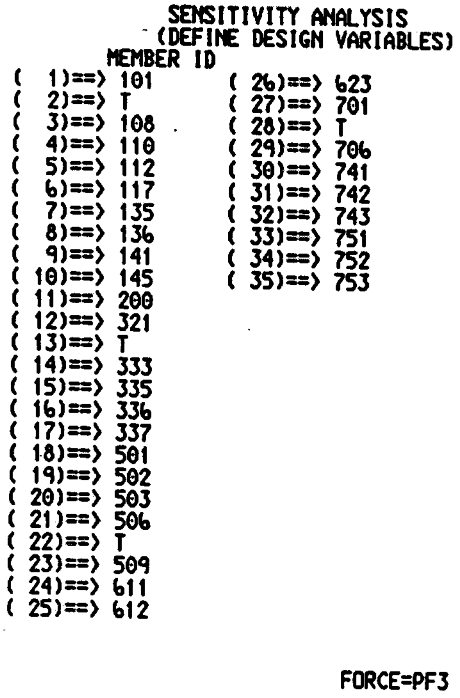


Fig. 1 SYSTEM CONFIGURATION of "NSAS"



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                (DEFINE DESIGN VARIABLES)
           MEMBER ID
(  1)==> 101          ( 26)==> 623
(  2)==> T            ( 27)==> 701
(  3)==> 108          ( 28)==> T
(  4)==> 110          ( 29)==> 706
(  5)==> 112          ( 30)==> 741
(  6)==> 117          ( 31)==> 742
(  7)==> 135          ( 32)==> 743
(  8)==> 136          ( 33)==> 751
(  9)==> 141          ( 34)==> 752
( 10)==> 145          ( 35)==> 753
( 11)==> 200
( 12)==> 321
( 13)==> T
( 14)==> 333
( 15)==> 335
( 16)==> 336
( 17)==> 337
( 18)==> 501
( 19)==> 502
( 20)==> 503
( 21)==> 506
( 22)==> T
( 23)==> 509
( 24)==> 611
( 25)==> 612

                         FORCE=PF3
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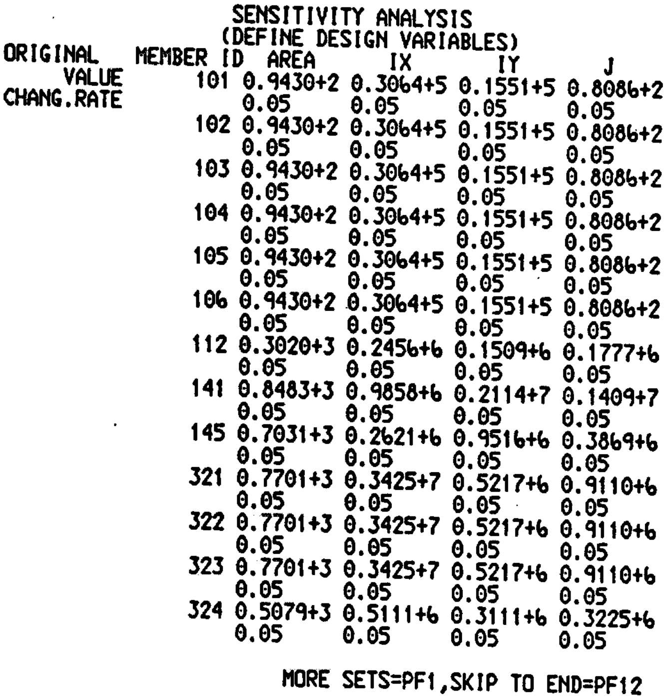
Fig. 2 DESIGN VARIABLE DEFINITION SCREEN



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                      (DEFINE DESIGN VARIABLES)
ORIGINAL      MEMBER ID  AREA       IX         IY         J
    VALUE           101 0.9430+2 0.3064+5 0.1551+5 0.8086+2
CHANG.RATE              0.05     0.05     0.05     0.05
                    102 0.9430+2 0.3064+5 0.1551+5 0.8086+2
                        0.05     0.05     0.05     0.05
                    103 0.9430+2 0.3064+5 0.1551+5 0.8086+2
                        0.05     0.05     0.05     0.05
                    104 0.9430+2 0.3064+5 0.1551+5 0.8086+2
                        0.05     0.05     0.05     0.05
                    105 0.9430+2 0.3064+5 0.1551+5 0.8086+2
                        0.05     0.05     0.05     0.05
                    106 0.9430+2 0.3064+5 0.1551+5 0.8086+2
                        0.05     0.05     0.05     0.05
                    112 0.3020+3 0.2456+6 0.1509+6 0.1777+6
                        0.05     0.05     0.05     0.05
                    141 0.8483+3 0.9858+6 0.2114+7 0.1409+7
                        0.05     0.05     0.05     0.05
                    145 0.7031+3 0.2621+6 0.9516+6 0.3869+6
                        0.05     0.05     0.05     0.05
                    321 0.7701+3 0.3425+7 0.5217+6 0.9110+6
                        0.05     0.05     0.05     0.05
                    322 0.7701+3 0.3425+7 0.5217+6 0.9110+6
                        0.05     0.05     0.05     0.05
                    323 0.7701+3 0.3425+7 0.5217+6 0.9110+6
                        0.05     0.05     0.05     0.05
                    324 0.5079+3 0.5111+6 0.3111+6 0.3225+6
                        0.05     0.05     0.05     0.05

                          MORE SETS=PF1,SKIP TO END=PF12
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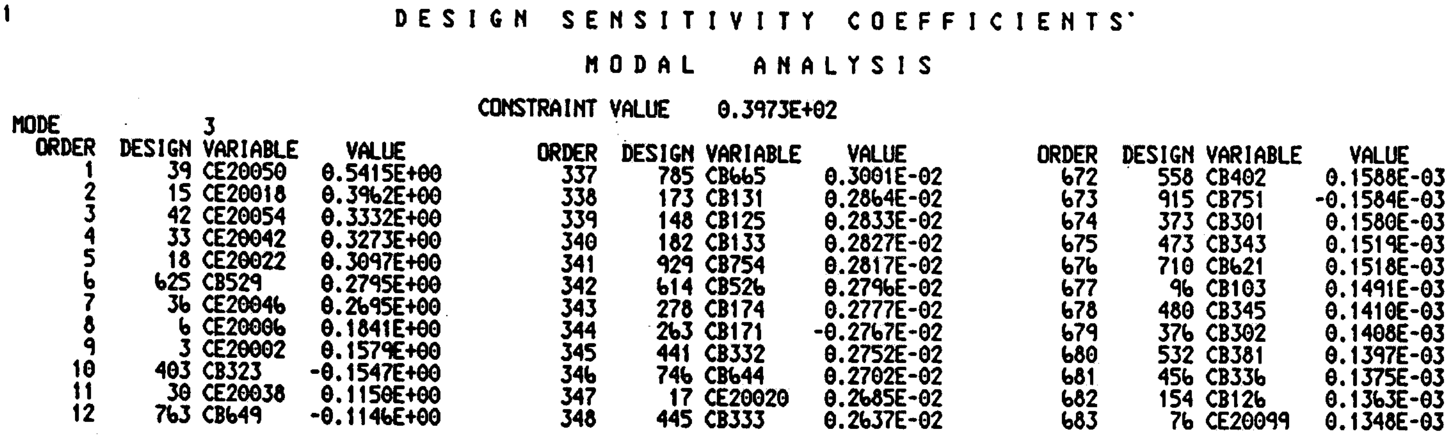
Fig. 3 ELEMENT PROPERTY LIST



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1                       D E S I G N   S E N S I T I V I T Y   C O E F F I C I E N T S

                                        M O D A L   A N A L Y S I S

                               CONSTRAINT VALUE    0.3973E+02
MODE            3
  ORDER  DESIGN VARIABLE     VALUE          ORDER  DESIGN VARIABLE     VALUE           ORDER  DESIGN VARIABLE     VALUE
      1      39 CE20050   0.5415E+00          337     785 CB665     0.3001E-02           672     558 CB402     0.1588E-03
      2      15 CE20018   0.3962E+00          338     173 CB131     0.2864E-02           673     915 CB751    -0.1584E-03
      3      42 CE20054   0.3332E+00          339     148 CB125     0.2833E-02           674     373 CB301     0.1580E-03
      4      33 CE20042   0.3273E+00          340     182 CB133     0.2827E-02           675     473 CB343     0.1519E-03
      5      18 CE20022   0.3097E+00          341     929 CB754     0.2817E-02           676     710 CB621     0.1518E-03
      6     625 CB529     0.2795E+00          342     614 CB526     0.2796E-02           677      96 CB103     0.1491E-03
      7      36 CE20046   0.2695E+00          343     278 CB174     0.2777E-02           678     480 CB345     0.1410E-03
      8       6 CE20006   0.1841E+00          344     263 CB171    -0.2767E-02           679     376 CB302     0.1408E-03
      9       3 CE20002   0.1579E+00          345     441 CB332     0.2752E-02           680     532 CB381     0.1397E-03
     10     403 CB323    -0.1547E+00          346     746 CB644     0.2702E-02           681     456 CB336     0.1375E-03
     11      30 CE20038   0.1150E+00          347      17 CE20020   0.2685E-02           682     154 CB126     0.1363E-03
     12     763 CB649    -0.1146E+00          348     445 CB333     0.2637E-02           683      76 CE20099    0.1348E-03
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Fig. 4 ANALYTICAL RESULT LIST

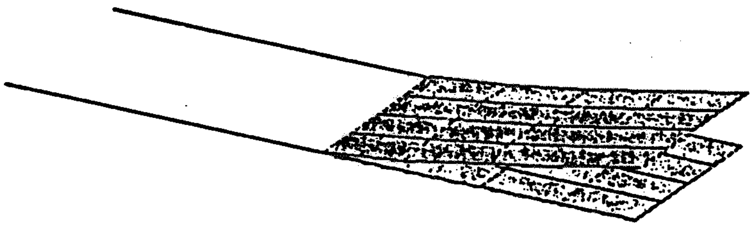


Fig. 5 ANALYTICAL MODEL and ITS FIRST EIGEN MODE

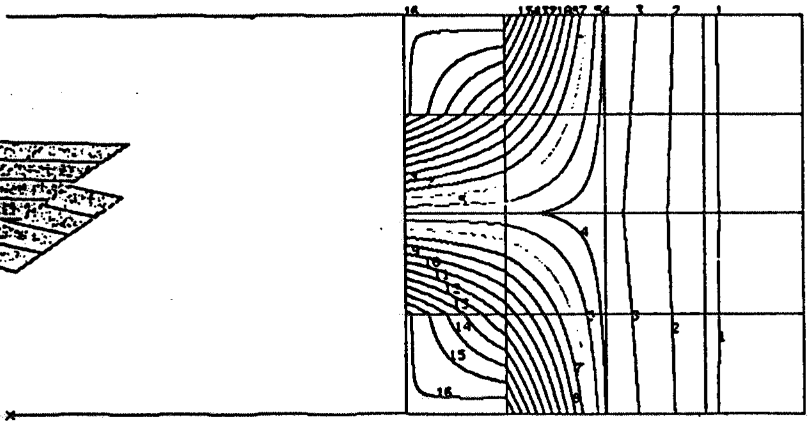


Fig. 8 ELEMENT SHELL THICKNESS SENSITIVITY COEFFICIENT DISTRIBUTIO

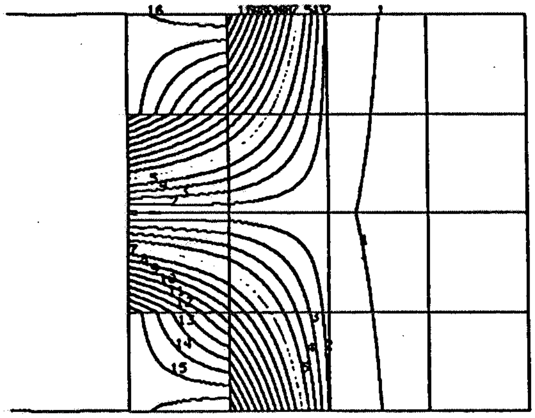


Fig. 6 ELEMENTAL STRAIN ENERGY DISTRIBUTION

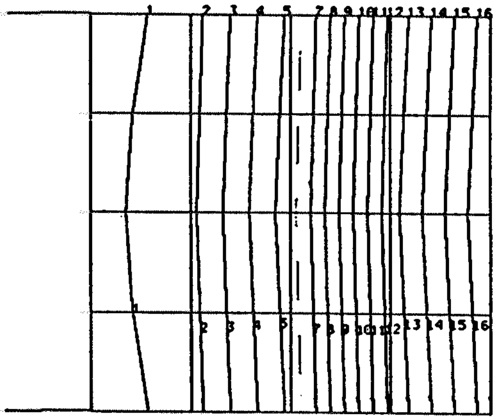


Fig. 7 ELEMENTAL KINETIC ENERGY DISTRIBUTION

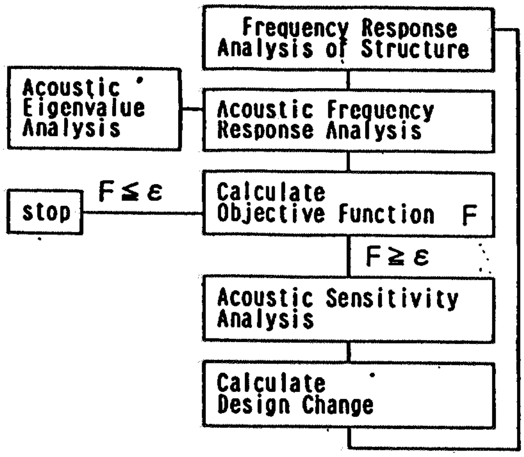


Fig. 9 OPTIMIZATION ROUTINE

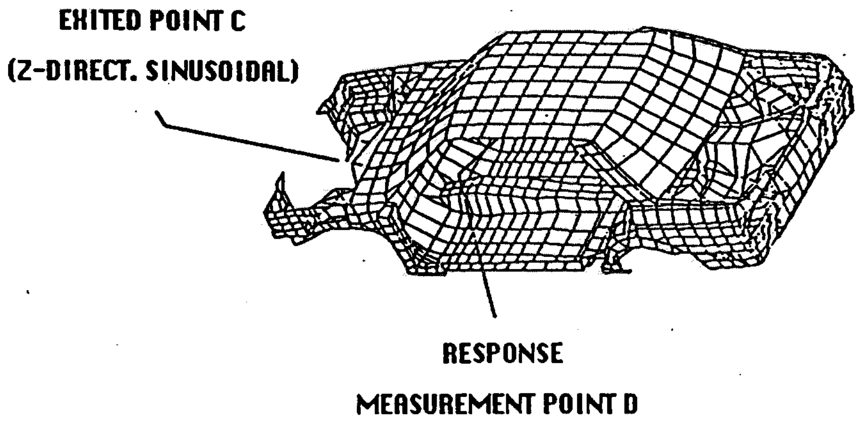
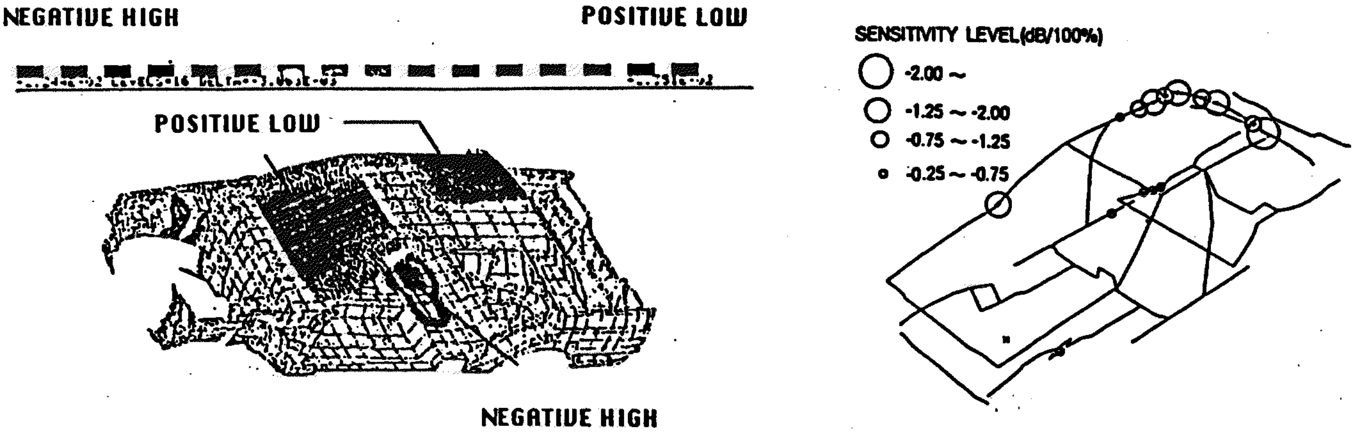


Fig. 10 VEHICLE MODEL



DESIGN VARIABLE : SHELL THICKNESS

DESIGN VARIABLE : BAR AREA MOMENT OF INERTIA

Fig. 11 SENSITIVITY COEFFICIENT DISTRIBUTION

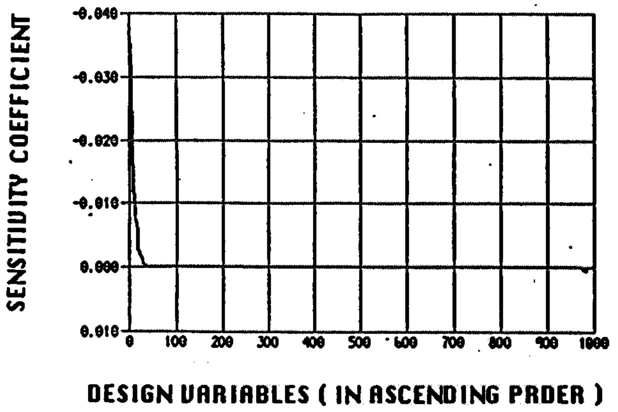


Fig. 12 SENSITIVITY COEFFICIENT DISTRIBUTION

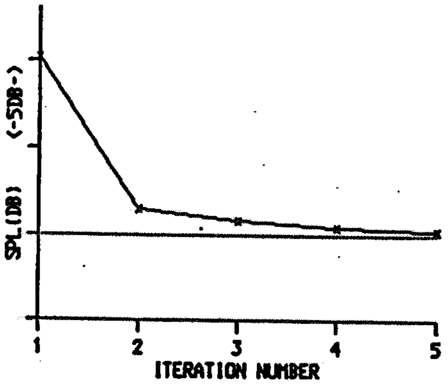


Fig. 13 EXAMPLE of ITERATION HISTORY