Individual Modal Accelerations as the Result of a Shock Response Spectra Input to a Complex Structure

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ABSTRACT

An MSC/NASTRAN finite element model was developed and dynamic analysis was accomplished for a ring laser gyro guidance system designed to function on a steerable reentry warhead. This model contains approximately 1200 nodes, 6500 dof, using 44 ELAS2, 1017 QUADA, 667 BAR, 8 HEXA and 4 TRIA3 elements. Generalized dynamic reduction was used with the modified Givens technique to obtain 102 eigenvalues from DC to 3 KHz. Sixty-three (63) eigenvectors were calculated.

Ring laser gyros (RLG) are mechanically dithered to avoid laser lock-in. These gyros are dithered at 600 to 750 Hz with low power peizo-electric devices. It is important that no chassis resonance in this frequency range couple into the gyro dither frequency. Therefore, the chassis must be very stiff.

The RLG is sensitive to acceleration as a function of frequency because of internal resonances with high transmissibilities. For this reason, a unique DMAP "alter 1050" was developed to provide the resultant accelerations for each mode shape for the specified shock response spectra input. (SOL63)

INTRODUCTION

The Ring Laser Gyro Guidance System is suspended on 270Hz shock and vibration isolators. The chassis has resonant frequencies starting around 800Hz.

The Ring Laser Gyro (RLG) is fabricated with a low-damped ceramic block. As a result, the gyro body, or block, has transmissibilities at or above 100 at its' resonance frequencies. These resonances occur in the 2 to 3 KHz frequency range. That is, the RLG has shock sensitivity as a function of the frequency of the shock. (see Figure 1)

Because of the relatively high levels of shock input at the isolator and chassis resonances, the normal methods* yield accelerations too unacceptably high in the 2 to 3KHz range of the block sensitivity. (see Figure 1) The normal methods do not identify the actual accelerations at the specific frequencies of interest; in this case, the 2 to 3 KHz range.

Therefore, it was necessary to obtain the G level at each natural frequency of the structure to verify that no G level exceeded the levels identified by the gyro manufacturer.

* MSC/NASTRAN offers the absolute (ABS), or square root of the sum of the squares (SRSS) or the Naval Research Laboratories (NRL) methods to calculate a single value of acceleration is not exceeded over the frequency spectrum.

To obtain the g-level as a function of natural frequency required writing a Direct Matrix Abstract Program (DMAP) applied to the SRS module (SOL63). Mac Neal Schwendler Corporation was contracted to write the software. The application of the software is discussed below.

MODEL DESCRIPTION

The model includes a detailed model of the chassis with covers and simplified models of the inertial sensor assembly (ISA) and chassis electronics. The low voltage power supply (LVPS), high voltage power supply (HVPS), motherboard, harnesses and connectors are modelled as weights distributed at appropriate locations. AIMU isolators are modeled as triaxial springs.

Chassis

The chassis was modelled with quad plates and offset beams. The offset beams simulated the external and internal rib structure. The rib properties are delineated in the PBAR cards. The chassis material is 6061-T6 aluminum. The damping values are for modal damping. Eight percent damping is used for resonances below 300Hz, 6% to 600Hz, and 5% above 600Hz.

Model Description (contd)

Covers

The covers are fabricated using 6061T-6 metal matrix composite containing 35% to 40% silicon carbonide fiber. This material was chosen to provide cover resonances near or above 1000Hz. The covers have no ribs but are screwed to an internal chassis partition at two locations.

MODELING TECHNIQUE

Dynamic Analysis -

Solution 63 is a superelement program. The finite element model must use this solution to solve for response to shock spectra. A secondary benefit is that the superelement solutions are more efficient. For example, solution 24 and superelement solution 61 are both static solutions but 61 is faster than 24. No superelements are currently used in the AIMU model, therefore, the entire model is "residual structure" to a superelement program.

To provide dynamic input, MSC recommends the use of a large mass rigidly connected to the "missile side" of the shock isolator. Dummy nodes 9001 thru 9008 were located coincident with the corresponding isolator mounting nodes. The linear spring elements (CELAS2) tie the dummy nodes to the chassis in each of the three linear directions. The dummy nodes were then connected to the large dynamic mass via the rigid bar elements (RBE2).

Component numbers (123456) represent the three linear (123) and three rotational (456) degrees of freedom at each node. The "SUPORT" card defines which of the component numbers are to be considered in a given situation and which type of loading may be applied. That is, if the 456 component numbers are not present on the "SUPORT" card then no response will consider these rotations at the individual nodes. Likewise, no rotational input will be considered at any node within the model.

Shock Response Spectrum (SRS)

MSC NASTRAN provides acceleration response to Shock Response Spectra (SRS) in three methods as follows:

Absolute $\ddot{X} = \sum_{j=1}^{H} |x_j|$ Equation 1

SRSS $\ddot{X} = \left[\sum_{j=1}^{H} x_j^2 \right]^{1/2}$ Equation 2

NRL Method $\ddot{X} = \ddot{X}_1 + \left[\sum_{j=2}^{H} x_j^2 \right]^{1/2}$ Equation 3

Each of these methods yield one single value for acceleration. This value is independent of frequency. Figure 1 shows the G-level vs. frequency requirements for the Honeywell Ring Laser Gyros. The gyro block is a very low-damped material with a transmissibility of about 100 at resonance. The fundamental resonance of the block occurs in the range of 2 → 3 KHz. For this reason the gyro manufacturer reduced the maximum input allowed across this frequency spectrum from 420G, at 1100Hz, to 4G at 2 to 3 KHz.

Honeywell Florida contracted MSC to design Alter 1050 for the purpose of providing modal accelerations as a function of the normal modes.

To obtain the desired output, the normal mode executive deck (Sol 61) was changed by adding the alter 1050 (see Figure 2). The case control deck was changed by deleting the DYNRED, SEALL = ALL, and METHOD cards. The titles were changed and the SEMG = ALL card was added. The output desired was added. In this case, we have the SET (Output nodes), DISP (displacement), and ACCEL (accelerations) cards included. That is, we will get displacements and accelerations for the selected nodes. The DLOAD card is used to identify the SRS loading in the bulk data. The specified shock response spectra was as follows: 10G at 40Hz to 40G at 200Hz to 170G at 3000Hz then flat at 170G to 10KHz.

The bulk data deck includes the same chassis damping used in the random vibration model. The chassis damping is relatively unimportant in shock work because there is not sufficient time to dissipate energy on the first half cycle of response. The first half cycle is usually the maximum response, therefore, very little change in maximum response occurs as a result of damping.

The DTI,SPECSEL card identifies the SRS as an acceleration response and assigns structural damping. It also identifies the TABLED1 card. The TABLED1 card lists the response accelerations as a function of frequency. This allows the NASTRAN program to generate an internal set of decaying sinusoids with which to excite the model. PARAM, BYMODE, 1 and PARAM, SCRSPEC, 0 should be included in the bulk data deck.

RESULTS

A list of the real eigenvalues are not included in this report to conserve space. However, there are 51 natural frequencies between 524 Hz and 3KHz. The six additional resonant modes of the "rigid" chassis on the isolators and the six "rigid body" modes with zero generalized stiffness give a total of 63 eigenvalues below 3 KHz. All modes with shock acceleration levels in excess of 1G (386 in/sec^2) are plotted on Figure 1.

The accelerations plotted are the maximum linear acceleration found at any of the three locations where the gyros are mounted regardless of the direction of the acceleration. The highest accelerations occur at the shock and vibration isolator resonances (i.e., 235 336Hz). Until the mid frequencies are reached, none of the acceleration levels approach the limit imposed by the gyro manufacturer. The 1500 to 1800Hz range shows several modes at or near the roll-off limit. Above 2KHz the acceleration levels remain below the 4G limit.

Conclusions

Alter 1050 was crucial in allowing determination of the survivability of the ring laser gyro block in the dynamic environment imposed. In this case, the maximum shock acceleration allowable, near gyro block resonances, was 4G. External to the isolated chassis the SDOF shock environment was specified to range from 135G at 2KHz to 170G at 3KHz (i.e. definition of SRS). In addition, there was the uncertainty of potential amplification or re-amplification of the input accelerations in the complex multi-degree of freedom chassis.

With the accelerations at each normal mode, it is evident that the 4G limit above 2KHz was met. The isolator frequencies do not represent a threat to the gyro survivability. The RLG shock tolerance requirement in the 1500-1800Hz range needs to be re-examined. If the roll-off should be vertical at 2000Hz then the design is good. If the 20 30G accelerations effect the block resonances then additional work must be conducted to identify gyro block resonances more concisely.

Note that if the ABS, SRSS or NRL methods had been used we would have had a single number on the order of 100G's.

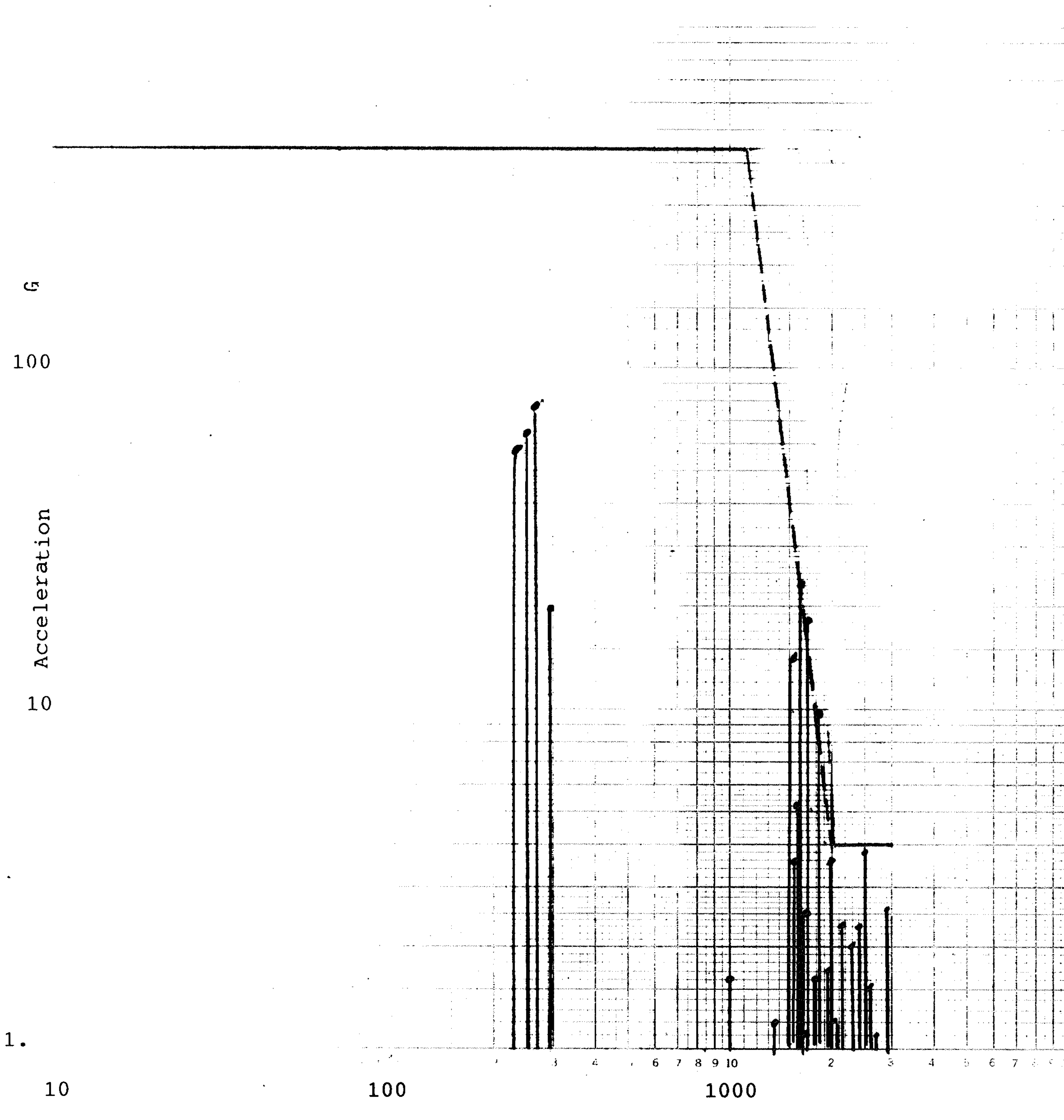

Figure 1 - RLG Shock Tolerance Profile with AIMU Modal Responses

```
$ TYPE ALTER1050.DAT
alter 1050 $ alter to perform data recovery by mode
param //nop/v,y,bymode=-1 $ set parameter BYMODE to -1 if not input
cond notmode,bymode $ if BYMODE=-1, then skip recovery by mode
  param //nop/v,n,modeno=0 $ set mode counter to 0
  file modeno=save $ keep this parameter - needed for looping
  paraml uhvr//c,n,trailer/1/v,n,ncol $ no of columns in UHVR
  paraml uhvr//c,n,trailer/2/v,n,nrow $ no. of rows in UHVR = no. of modes
  label bymodes $ top of loop to perform data recovery by mode
  param //add/v,n,modeno/v,n,modeno/1 $ increment mode counter
  param //sub/v,n,giveup/nrow/modeno $ giveup=nmodes-mode no.
 cond alldon,giveup $ if giveup<0 then done
   param //sub/v,n,modm1/modeno/1 $ prepare for partitioning vectors
   param //sub/v,n,left/nrow/modeno $ prepare for partitioning vectors
   matgen ,/modpart/6/nrow/modm1/1/left $ partitioning vector
   matgen ,/colpart/6/ncol/ncol $ partitioning vector
   partn uhvr,,modpart/tempz,modval,,/1 $ partition out current mode resul
   add tempz,/tempz0/(0.,0.)/ $ create zero matrix for other modes
   merge tempz0,modval,,,colpart,modpart/uhvnew/1//2 $ create new
$                       UHVR(UHVNEW) with only terms for current mode
  prtparm //0/c,n,modeno $ print mode number on output
$           ************************************************************
$       NOTE: modeno is the mode counter of selected modes for output
$                 if any modes (for example zero frequency)are left out,
$                 they aren't included in the counter
$           ************************************************************
   ddrmm casexx,uhvnew,,iphig1,iqg1,ies1,ief1,xycdbdr/
         oupvm,oqpm,doesm,doefm, $ perform data recovery for selected mode
   ofp oupvm,oqpm,doesm,doefm//s,n,cardno $ print out results
   rept bymodes,1000 $ bottom of loop
  label alldon $ label jumped to when finished with data recovery by mode
  param //add/v,n,allmodes/nrow/0 $ set print flag for output with all mod
  prtparm //0/c,n,allmodes $ print almodes label for output using all mode
label notmode $ label jumped to if not doing data recovery by mode
CEND
$ LO
  FCUTTING      logged out at 23-NOV-1988 09:05:14.63
```

Figure 2 - Alter 1050

(1) Created by Ted Rose at MSC under Honeywell contract. This alter is available to all MSC NASTRAN users.