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RTOP Interim Significant Result (RISR) Report

Relative Conservatism between Transient and Sine Sweep Test Methods

by M. J. Hine

The conservatism and overtest indices measured for multiple transient and SRS tests and a least favorable response test are compared to those of a swept-sine test for a typical spacecraft component. The absolute conservatism between a typical launch transient and the test environment responses was measured using, alternative characterizations previously used in shock testing. The characterizations include shock intensity, shock response spectrum, acceleration root mean square in both frequency and time domains, Fourier magnitude spectrum and ranked peaks. The sine sweep test response was characterized using ranked peaks, shock response spectrum, shock intensity and root mean square in time.

This report concerns experimental and analytical work representing an improvement over a prior report [1] detailing the absolute conservatism for three transient type test methods and a swept sine test method. One transient test was a replication of a flight transient waveform and termed a "transient"-test. The other transient was synthesized from decaying sinusoids to have the same shock response spectrum as the flight transient waveform and termed the "SRS "-test. The least favorable response (LFR) test method was described in reference [2].

improvements were made in the reproduction of the flight transient waveform following an investigation into the errors inherent with the HP 5841 C vibration controller used before [3]. Modifications to the vibration control system were made to better reproduce the transient signal levels required. A lower range shaker table amplifier was used and filters added to the vibration controller circuit.

The flight vibration transient has been better described and the transient tests have been repeated with multiple, instead of single, test waveform passes on the shaker table. Furthermore, the swept sine test response has been further characterized using ranked peaks, shock response spectrum, shock intensity and root mean square in time. This enabled a more direct comparison to be made between the sine sweep and transient test methods, whereas before only the "number of peaks exceeding" characterization was available.

These experimental and analytical advances did not affect the prior conclusions [1] significantly.

TESTING

The test article used for all tests was that used previously with the other transient test methods, namely the CI ?T-RTG [1], and it's free-end lateral response was characterized using the characterizations described in reference [4]. This test article represents a typical spacecraft component.

The transient and SRS testing was carried out, as before [1], with the CET-RTG mounted on a shaker table subjected to multiple (5) passes of the desired vibratory waveform. The test configuration of the CET-RTG is depicted in Figure 1, For the LFR test the results of prior work [1] were used.

ANALYSIS

'J'he index of conservatism (IOC) and the overtest factor (OTF) were calculated for each of the characterizations used relative to the expected flight transient waveform of Figure 2. An IOC of l was used for all the OTF calculations, which represents an 84.1 % probability of an overtest occurring. The test response level divided by the OTF value shows the amount by which the test input must be increased to obtain an 84.1% probability of an overtest. Since single test data points were used the coefficient of variation (k) was taken to be 0.15, as before [1]. All transient tests were analyzed with a time duration of 1,0 seconds. The digital sampling rate for al l test response measurements was 512 samples per second. This provided a reasonable compromise between the need to obtain frequency resolution up to 100 Hz. and the need for reasonable peak descriptions of the data, The test data was bandpass filtered between 10 and 100 Hz and corrected for DC offset before the characterizations were made.

FLIGHT RESPONSE

A revised flight response waveform (Figure. 2) was used, which better represents the flight vibration environment. This response was obtained from the predicted flight RTG base response (Figure 3), obtained from a coupled loads analysis, and the RTG frequency response function between the base and upper free end in the lateral direction (Figure 4). This frequency response function (stored in computer file "zavalaft") was obtained from a 3g amplitude sine sweep test of the RTG where the divided data was checked for coherence before performing the mathematics and then averaged. This process is depicted in Figure 5, where the frequency response function (transfer function) is multiplied by the. Fourier transform of the RTG base response (Figure 3) stored in a computer file " ftbase7", to obtain the RTG free end response stored in file " rtgfresp". The frequency response function, in file "zavalaft", used to obtain the flight response is now the same as that used previously to obtain the LFR response [2]. The prior work had used a frequency response function in computer file "trfunct" (Figure 6) that was not checked for coherence or derived from averaged data. It was taken from a transient test of the RTG on the shaker table. The current predicted RTG flight end response is compared to that previously used in Figure 7, where minor amplitude changes are apparent. All conservat ism indices quoted in this report were calculated with reference to this revised flight response (Figure 2).

TEST RESPONSE

The transient test was run with 5 separate shocks of the same nominal respective input, Figure

2, and the RTG test response amplitude averaged to obtain a representative test response. The same procedure was used for the SRS test. This process is depicted in Figure 8. The individual responses were first lined up manually before the averaging. No correction was applied for any DC shift in the data at this point. DC correction was performed in the computer code SHARPE used for the characterizations.

Base inputs: For the transient test method the vibration waveform applied to the shaker table by the vibration controller was that of Figure 2, the flight base motion. This transient test is referred to as the 2g transient test, since the maximum acceleration is -2 .0g. This distinguishes it from future transient tests wherein the amplitude and frequency spectrum have been manipulated away from the flight base transient waveform. The base of the RTG should therefore respond with a similar waveform with minor deviations due to controller errors [3]. The averaged RTG base test response is shown in Figure 9, and compared to the reference flight response in Figure 10. 'l'he achieved shaker table motion at the RTG base compares well with that specified. The variance error of the averaged table motion is 7.8% relative to the specified flight base motion [3]. The individual test variance. error varies between a minimum of 6.6% and a maximum of 9.6% with a corresponding standard deviation of 1.3%.

The averaged base response in the SRS test is shown in Figure 11 and the LFR test base response in Figure 12.

The base input for the sine sweep test was a 1.5g amplitude sine wave swept in frequency from 10 to 100 Hz at a sweep rate of 2 octaves pcr minute.

Free end responses: The averaged end response for the 2g transient test is shown in Figure 13 and is a fairly good reproduction of the flight response as shown in Figure 14. The differences between the two are discussed in attachment [1]. The averaged end response for the SRS test is shown in Figure 15, which understandably does not show good agreement with the flight response in the time domain, as shown in Figure 16. The LFR test response is reproduced here from earlier work [2] in Figure 17 and compared to the flight response in Figure 18.

The sine sweep test response is shown in Figure 19. 'l'he response shows a structural resonance in the RTG at 39 Hz. The frequency range included in the plot here varies from 10 Hz up to 116 Hz. Here, there is little to be gained from a direct comparison with the short duration flight response in the time domain. Clearly, the test specimen is subjected to vibration levels that are much higher in amplitude and longer in duration than those in the flight response. The upper sweep frequency of interest (100 Hz) is reached after 84 scc.ends of testing.

TEST PEAKS

The maximum peak amplitudes experienced during the tests arc shown below in Table 1. The LFR method produced the largest peak amplitude of all the test methods used. The maximum here is about 3.5 times the flight maximum. The maximum test level for the CET-RTG free-end is constrained to be 27 and 40 G's for flight acceptance and qualification respectively, at the natural frequency of 48 Hz. The LFR test method therefore comes closest to the test vibration constraints.

TABLE 1

Test Method	Maximum Peak (G)
Flight	4.7
Transient	3.3
SRS	4.8
Swept sine	12.6
1.l’R	16.6

PEAK RANKING

The test peaks, regardless of sign, were ranked in a descending order of magnitude as shown in Figure 20. As above, the LFR test method overtests at the higher peaks and undertests at the lower peaks. The sine sweep test overtests at all peak ranks. The peak ranking is not displayed after the 80th. ranked peak because the flight response only had 78 peaks in total, with a mean amplitude of 1.6 g. In contrast, the sine sweep test showed 1200 peaks with a mean amplitude of 4.1 g. Clearly the number of vibration cycles of high amplitude is excessive here compared to flight. ‘I’he corresponding conservatism is shown in Figure 21 and the OTF in Figure 22. “l’he SRS test only produces 49 peaks so the corresponding conservative indices stop at 49. The LFR test method clear] y produces a large undertest at the lower peaks (as does the SRS test method), and a high overtest at the higher peaks. The sine sweep test produces overtest at all peak ranks, which overtest grows larger as the peak rank increases. The smaller peaks are therefore grossly overtested necessitating the unusual logarithmic OTF scale. The size of the digitized sine sweep test computer files were large containing over 46,000 data points sampled at 512 samples per second. This required special techniques to process on the available personal computer and these are described in reference [5].

TRMS

The time domain root mean square characterization (’l’RMS) is shown in Figure 23, for all tests apart from the sine sweep test, which requires it’s own graph, Figure 24, due to it’s relatively excessive time duration. The large overtest of the LFR test method is clearly evident at the beginning of the test, The nature of this plot is better interpreted by referring to the overlay plot of the measured LFR response and flight waveforms of Figure 18. The length of the sine sweep test prevents a meaningful calculation of conservatism for this characterization, since the time duration exceeds that of the flight event, In essence after the initial 1 second of test response the sine sweep has infinite overtest. However, the terminal TRMS value around 2g is only about 30% over the 1.5g of the flight data. The IOC and OTF values are therefore shown in Figures 25 and 26 for the other test methods only. The excessive overtest in the LFR test method is clearly seen around 0.8 seconds. The SRS and transient test methods provide reasonable undertest for most of the time. Slight tailoring would be required to adjust the OTF for this characterization to a value of 1.0,

FRMS

The frequency domain root mean square characterization (FRMS) is shown in Figure 27 for all test methods apart from the sine sweep test. The sine sweep test could not be characterized by the FRMS characterization due to the computer program limitations in handling the enormous number of data points (46,000). Furthermore, the comparison of waveforms with the FRMS characterization requires the same anal ysis time duration. The sine sweep duration of 84 seconds far exceeds the 1 second duration of the other tests. The LFR test response shows a smooth amplitude change with frequency compared to the flight curve. This may be expected since the LFR waveform was not derived from the nature of the flight transient waveform but merel y it's energy. The large amplitude increase occurring around 40 Hz is due to the LFR waveform being obtained from the impulse response, which represents a resonant response of the CET-RTG . The LFR input therefore only has frequency content around the natural frequency. The corresponding IOC and OTF values arc shown in Figures 28 and 29. However, despite the above comments on frequency content the LFR test does not result in a severe overtest in terms of the FRMS. The OTF suggests an amplitude of only 83% of that used to obtain an IOC of 1.0. The LFR-test therefore provides a reasonable test at and above the fundamental natural frequency of the structure. How it behaves at any higher natural frequency has not been determined. Both the SRS and transient test provide undertest at all frequencies.

SRS

The shock response spectrum characterizations (SRS) are shown in Figure 30. The. manner in which the SRS was obtained for the sine sweep test response is detailed in reference [4]. The shock intensity (S1) values arc also indicated in this figure (see below). The corresponding IOC and OTF plots are shown in Figures 31 and 32. The sine sweep test provides excessive overtest throughout the frequency range. The LFR test method provides somewhat less undertest to the other methods at low frequencies. The transient and SRS test methods show slight undertest and therefore require amplification at the lower frequencies in order to obtain an IOC of 1.0.

s]

'he shock intensity (S1) characterization represents the area under the SRS curve (see above and [1]). The shock intensity (SI) values are indicated in Figure 38, and show how the energy in the sine sweep test response is about five times (5 X) the flight energy. If one defines the ratio of test/flight S1 as an overtest index then the values in Table 2 arc obtained. This shows that the transient test method undervests slightly by a factor of 0.83. The SRS test method shows no overtest with a factor of ().99 ≈ 1. The LFR test overtests by a factor of 2 and the sine sweep method by a factor of 5, FFT or FMS

'l'he FFT characterization was a requirement in the original RTOP but has not been used till now. The term FFT stands for "fast Fourier transform", which is the name for a computer code algorithm that rapidly calculates the "discrete Fourier transform" (DFT). The DFT is a zero order approximation 'to the Fourier transform divided by the sampling period of the data, or in equation form using displacement as the variable:

$$\overline{X(f)} \approx X(f)$$

where DT is the sampling period and $\overline{X(f)}$ is the discrete Fourier transform of $x(t)$. 'l'he sampling period used for all the work reported herein was 1/512 seconds, being the inverse of the data sampling rate. of512 samples per second. The Fourier transform however produces a spectrum with both real and imaginary frequency components. This amplitude versus frequency spectrum is termed the two-sided Fourier spectrum, containing both negative and positive frequencies. However to be realistic, the imaginary components are discarded and the positive frequency amplitudes doubled to form a spectrum with only a positive frequency axis,

This spectrum is therefore termed the one-sided Fourier magnitude spectrum [$F_x(f)$] , Specifically, for a one-sided spectrum defined only for non-negative frequencies:

$$F_x(f) = 2X(f) \; ; \; f > 0$$

For single channel analysis (as here) the phase portion of the Fourier transform is often ignored, and only the magnitude of the Fourier spectrum, $|F_x(f)|$, is displayed where:

$$|F_x(f)| = 2|X(f)|$$

Magnitude of 1-sided Fourier spectrum = 2 X Magnitude of 2-sided Fourier spectrum

The characterization used to display frequency content is therefore the one-sided Fourier magnitude spectrum, or FMS, instead of the FFT. The plot of $|F_x(f)|$ has the units of g-scc. versus frequency in Hz. The FMS of each test method response, apart from the sine sweep method, is shown in Figure 33. The transient and SRS tests provide spectra very similar to the flight except at frequencies above 50 Hz. The high frequency differences could be the result of the RTG interior components rattling around, The frequency response function used to obtain the flight response was however the same one used to derive the LFR response. It was found that the frequency response function measured for individual test shocks was different between the SRS and transient test methods. The corresponding IOC and OTF for the Fourier magnitude spectrum is shown in Figures 34 and 35. This characterization could not be used to measure the conservatism of the. sine sweep test due to the dissimilar test analysis times. A direct comparison would only be possible for a 90 second long analysis time which is outside the scope of the available computer programs. The Fourier magnitude spectrum provides a very sensitive measure of the response in the frequency domain. 'l'he spectrum frequency resolution was 1 Hz. for all test cases.

OTHER CHARACTERIZATIONS

The SIS characterization was used before [1] but has not been used here because of it's sensitive nature to small amplitude changes at the higher frequencies. It would not appear to add much information about the test response above that provided by the FRMS characterization. The 3D-SRS characterization is not suitable for conservatism calculations as described before [6]. A suitable alternative characterization, the 3D-PKA characterization [7] and the associated conservatism indices have been calculate-d for the. test methods and will be presented separately, due to time constraints.

SUMMARY COMPARISONS

The degree of conservatism achieved with each test method may conveniently be compared using average values of the OTF. For instance a linear average over the abscissa range of the characterizations may be used. Figure 36 shows such a comparison, for the sine sweep, transient, SRS and LFR test-methods. It is notable that all three transient type test methods produce a large overtest in terms of the FMS characterization. This is due to the nature of the FMS at the higher frequencies where differences of the characterization over a small frequency band arc plotted. At the present time the FMS dots not appear to work well for the tests conducted. The OTF values for the FMS characterization are 4.11, 5.7 and 12.0 for the transient, SRS and LFR test methods respective] y. The nature and source of the high frequency test data will be investigated in the future, The test method OTF's are therefore displayed in Figure 37 without the FMS characterization to gain a better insight into the test method performance. Some caution is advised in using the average OTF values since they do not describe the frequency or time dependenc y of the characterizations. For instance a test method exhibiting an ideal OTF of 1.0, say, may severely undertest at lower frequencies and severely overtest at higher frequencies.
The average OTF values for the different test methods and characterizations is shown in Table 2, without the FMS characterization values,

The transient test appears to best represent the flight conditions in a test environment for all the characterizations used, in both the time and frequency domains. It provides some degree of undertest in both the time and frequency domains. The average of the average OTF values for all four characterizations is 0.68 which suggests an increase in the shaker table input transient amplitude of 1.47 (1/0.68). The similar OTF values obtained for all characterizations suggests that this test method should be simple to tailor for specific conservatism in the time and frequency domains simultaneously.

TABLE 2 Average Overtest Factors

	Characterization				
Test	TRMS	FRMS	SRS	PKA	AVERAGE
Transient	**0.66**	0.65	0.68	0.73	0,68
SRS	**0.73**	0.59	0.81	0,19	0.58
LFR	**2.46**	0.85	1.66	0.27	1.31

The SRS test method is the next best test method, providing slightly more undertest than the transient test method above. The average of" the average OTF values for all four characterizations is 0.58 which suggests an increase in the SRS shaker table input amplitude of 1.72. (1/0.58). Apart from the PKA characterization this test method should also be simple to tailor for specific conservatism in the time and frequency domains simultaneously.

The LFR test method varies significantly in OTF between the characterizations, providing undertest with the PKA and FRMS characterizations, but overtest in the FRMS and TRMS characterizations. This test method would therefore appear to be difficult to tailor for specific conservatism in the time and frequency domains simultaneously.

The sine sweep test method provided extreme overtest in the time and frequency domain. The PKA overtest can be reduced by increasing (he sweep rate. The SRS characterization overtest could be reduced by an amplitude decrease. Tailoring this test method for specific conservatism could prove difficult in both the time and frequency domains simultaneously. The sweep rate factor of the sine sweep test method will be studied at a later date.

The IOC and OTF values vary significantly for the different characterizations. As noted before [1] the tester must decide therefore which aspect of the flight response waveform needs to be replicated. The appropriate characterization would then be used to adjust the input test amplitude and frequency content to obtain a desired IOC value.

CONCLUSIONS

The relative conservatism achieved between the flight transient, SRS, LFR and sine-sweep test methods has been compared using the PKA and SRS characterizations, The sine sweep test has been shown to provide excessive overtest relative to the response peak ranking characterization which is akin to the number of peaks exceeding specified levels, used before [1].

The relative conservatism achieved between the flight transient, SRS and LFR test methods has been compared using the following characterizations: time and frequency root mean square (TRMS and FRMS), shock response spectrum (SRS), shock intensity (S1), Fourier magnitude spectrum (FMS) and ranked peaks (PKA).

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2. M. J. Hine, "Dynamic Response Using the Least Favorable Response Test Method". RISR(16200-8), March 31, 1993.

3. M. J, Hine, "Vibration Controller Reproduction Error HP5841 CSystem". RISR(16200-12), August 5, 1993.

4. M. J. Hine, "Conservatism in Transient and Shock Response Test Methods". RISR(16200-7), January 7, 1993.

5. M. J, Hine, "Transient Characterizations Applied to Sine Sweep Test responses". RISR(16200-16), September 28, 1993.

6. M. J. Hine, "Transient Test Method Comparison Using the Three Dimensional Shock Response Spectrum". RISR(16200-10), July 1, 1993.

7. M. J. Hine, "Transient Test Method Comparison Using the Three Dimensional Peak Ranking Spectrum". RISR(16200-11) July 1, 1993.

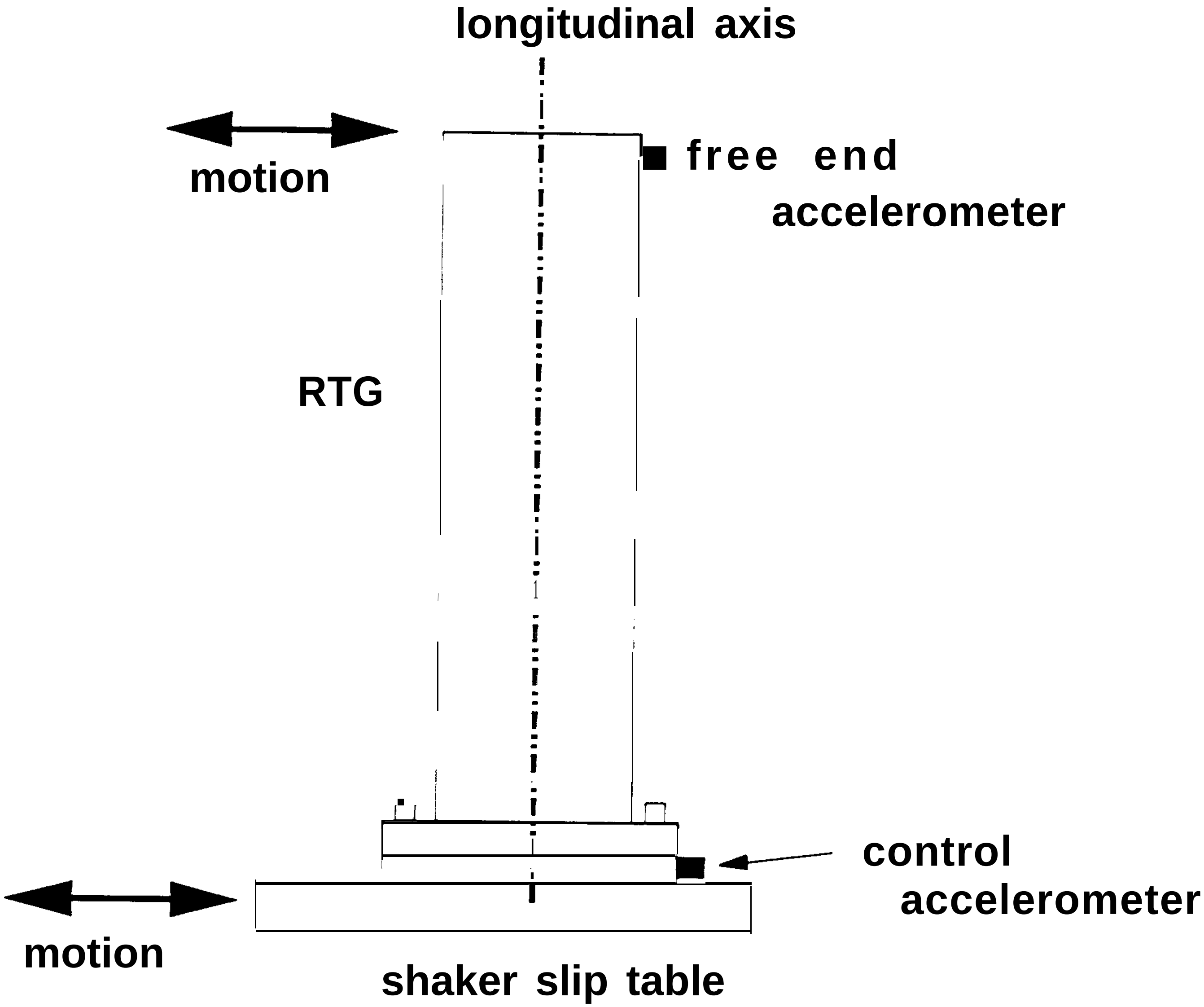

Figure 1 - CET RTG Installation on Shaker Slip Table

(ri9*01.drw)

RTG Flight End Response
Predicted

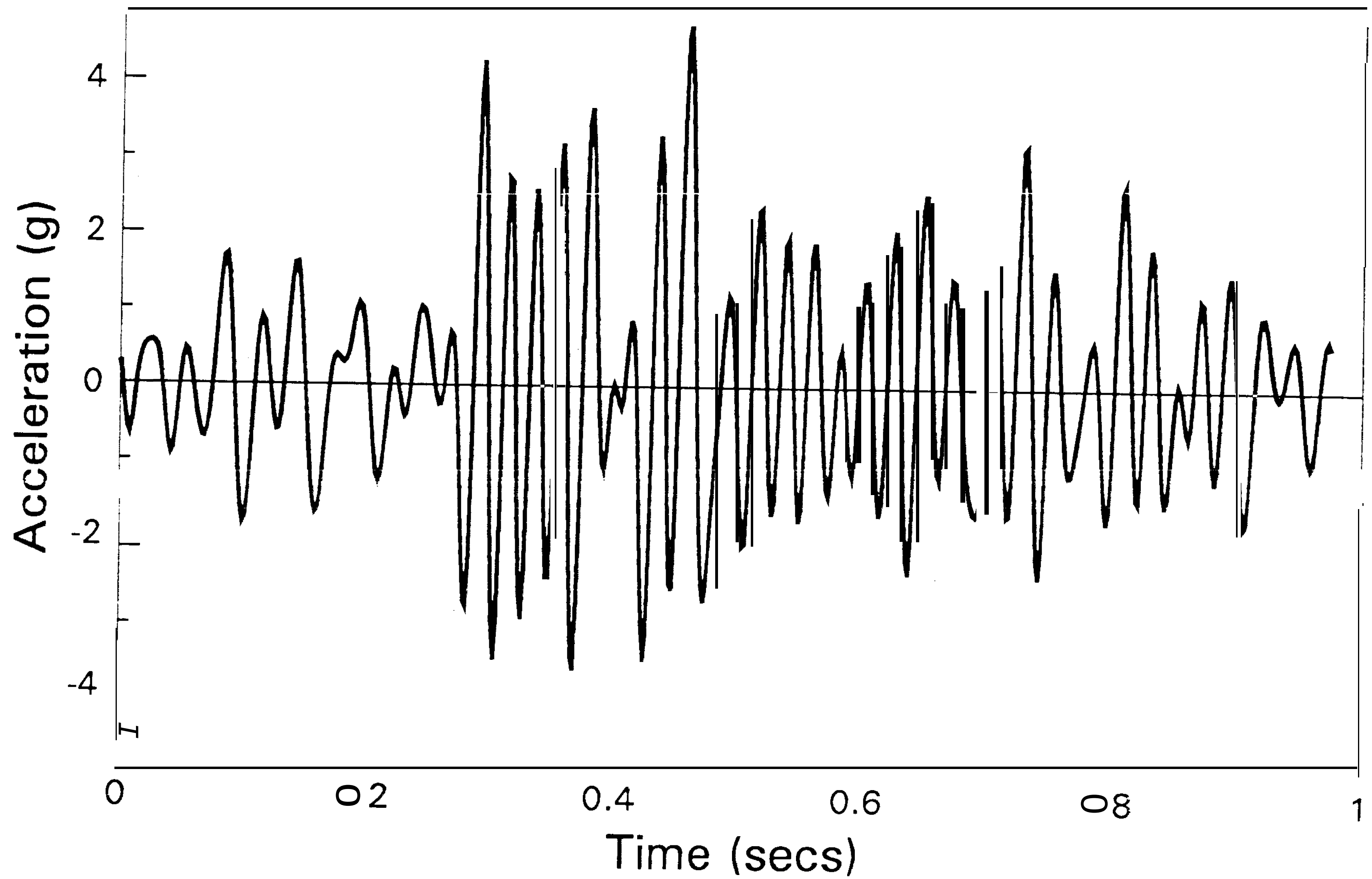

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Figure 2

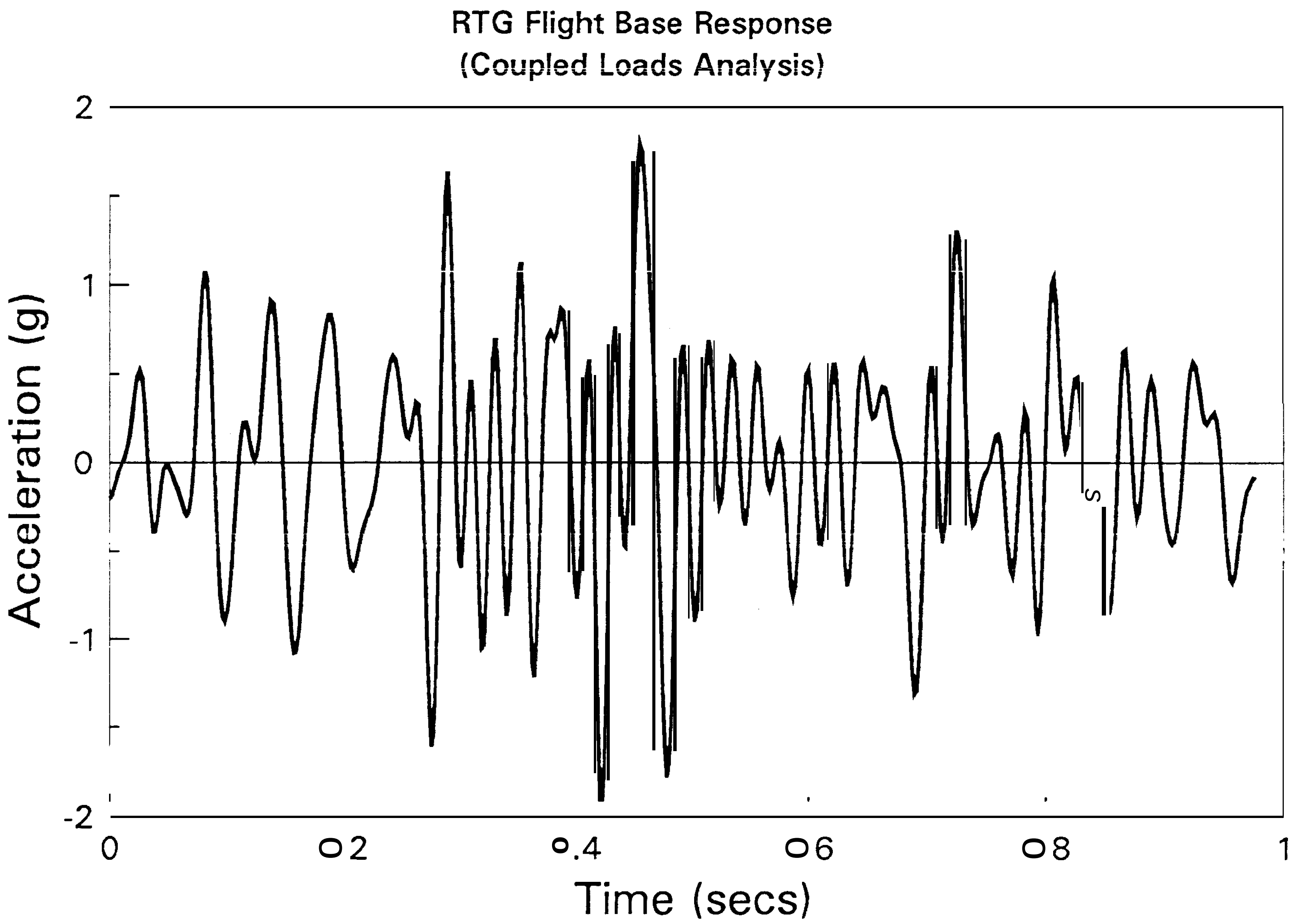

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Figure 3

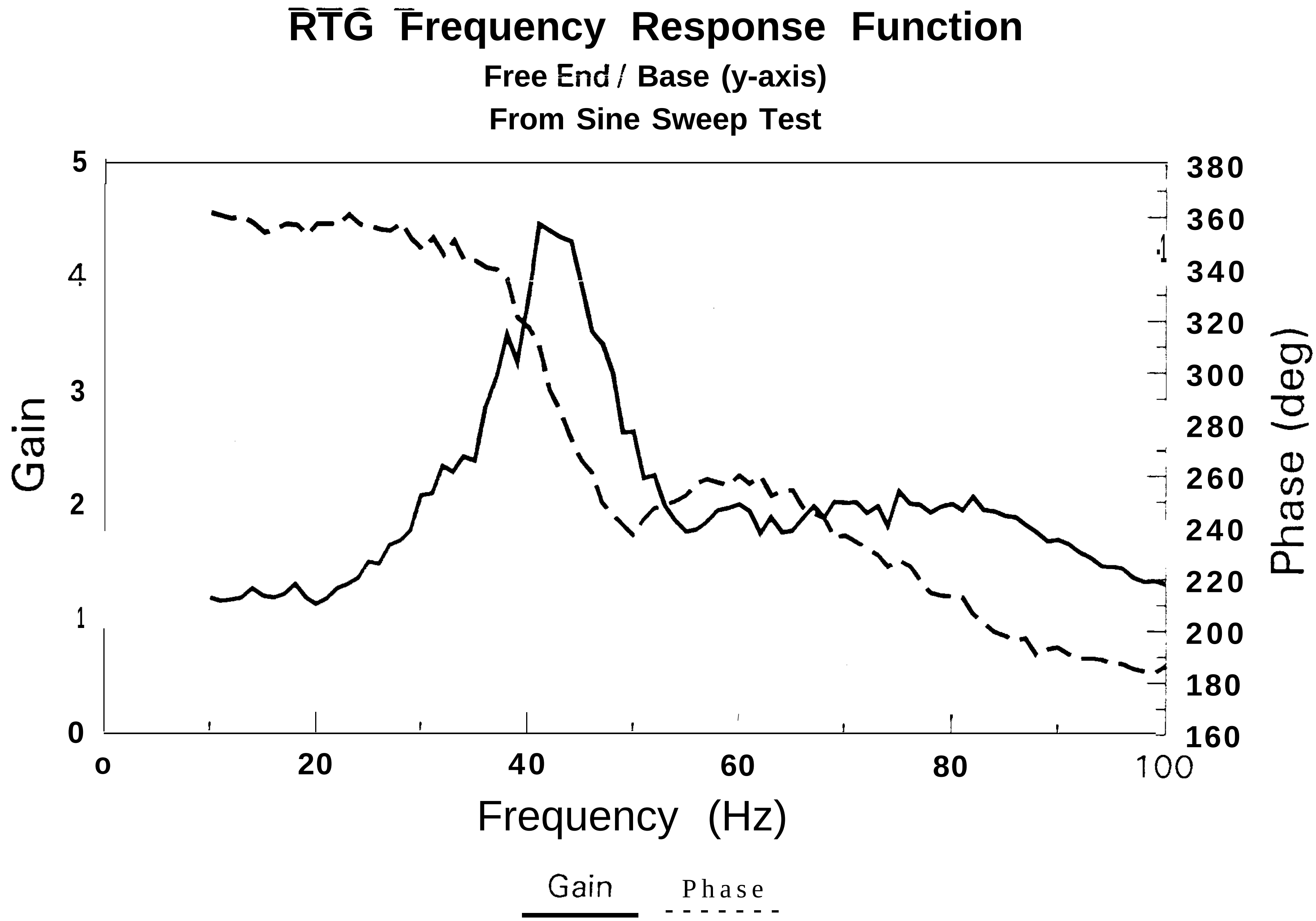

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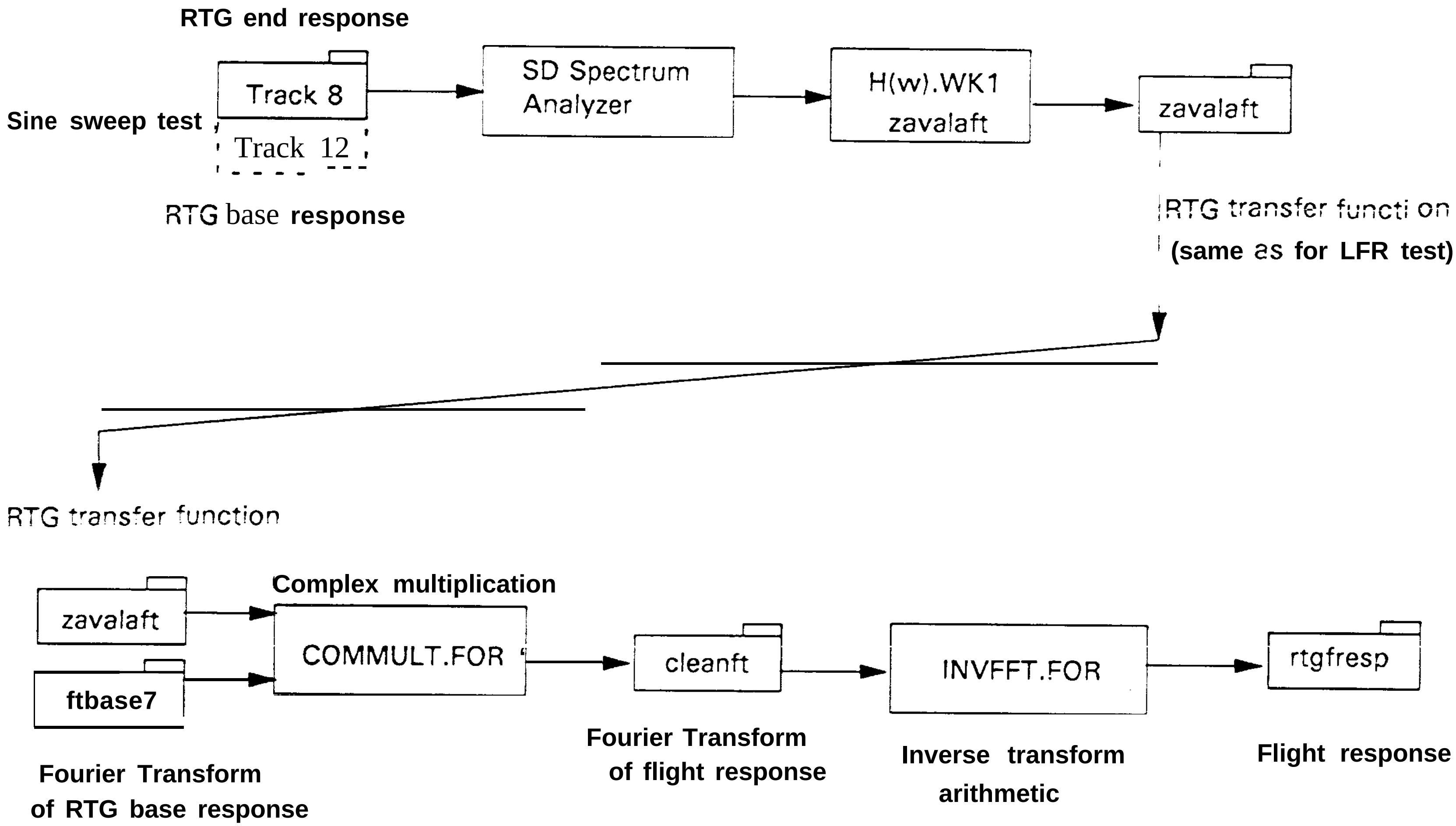
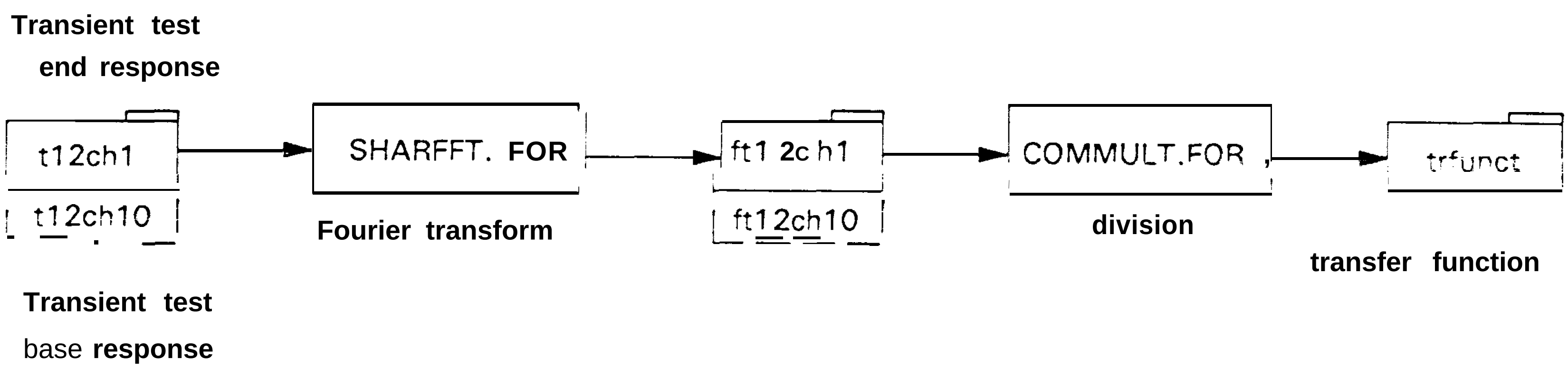
Figure 4

(flgtresp)



File Structure - Derivation of Flight RTG Response

Figure 5



Derivation of Frequency Response Function (trfunct)

(trfunct.drw)

Figure 6

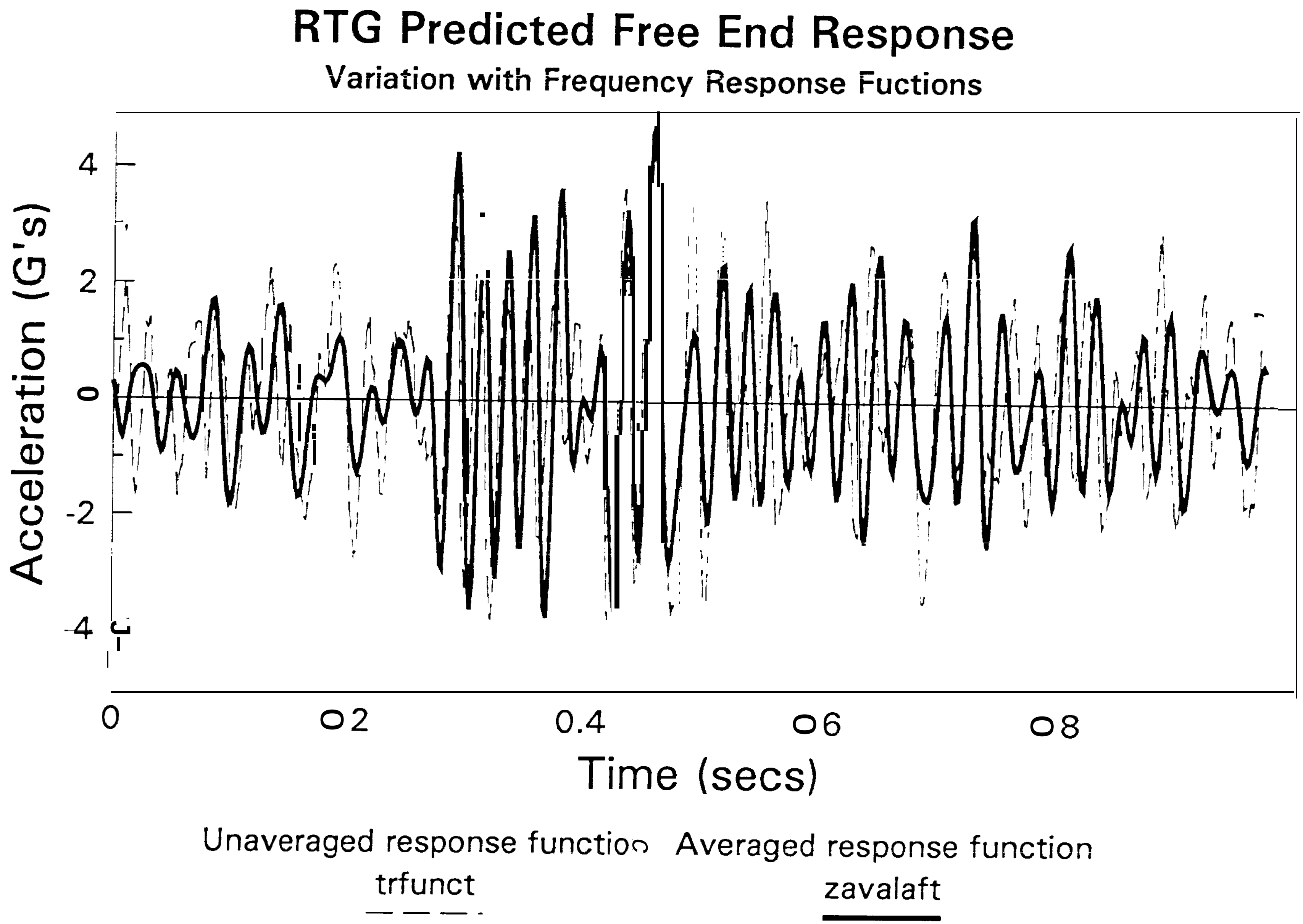


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Figure 7

Transient repeat tests 6/3/93

File names for met-aged-lined up time histories

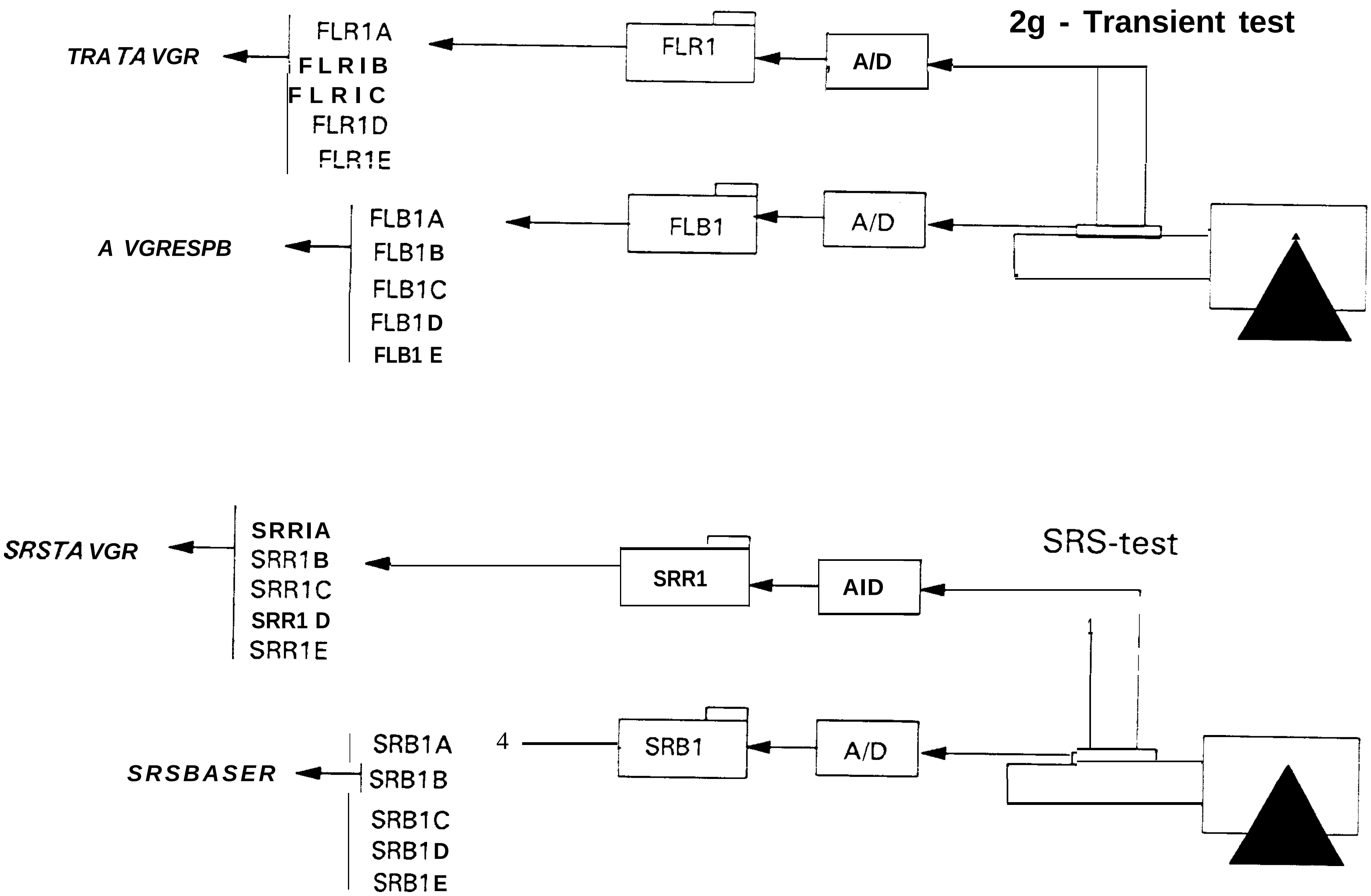

Figure 8 Transient test ***files***

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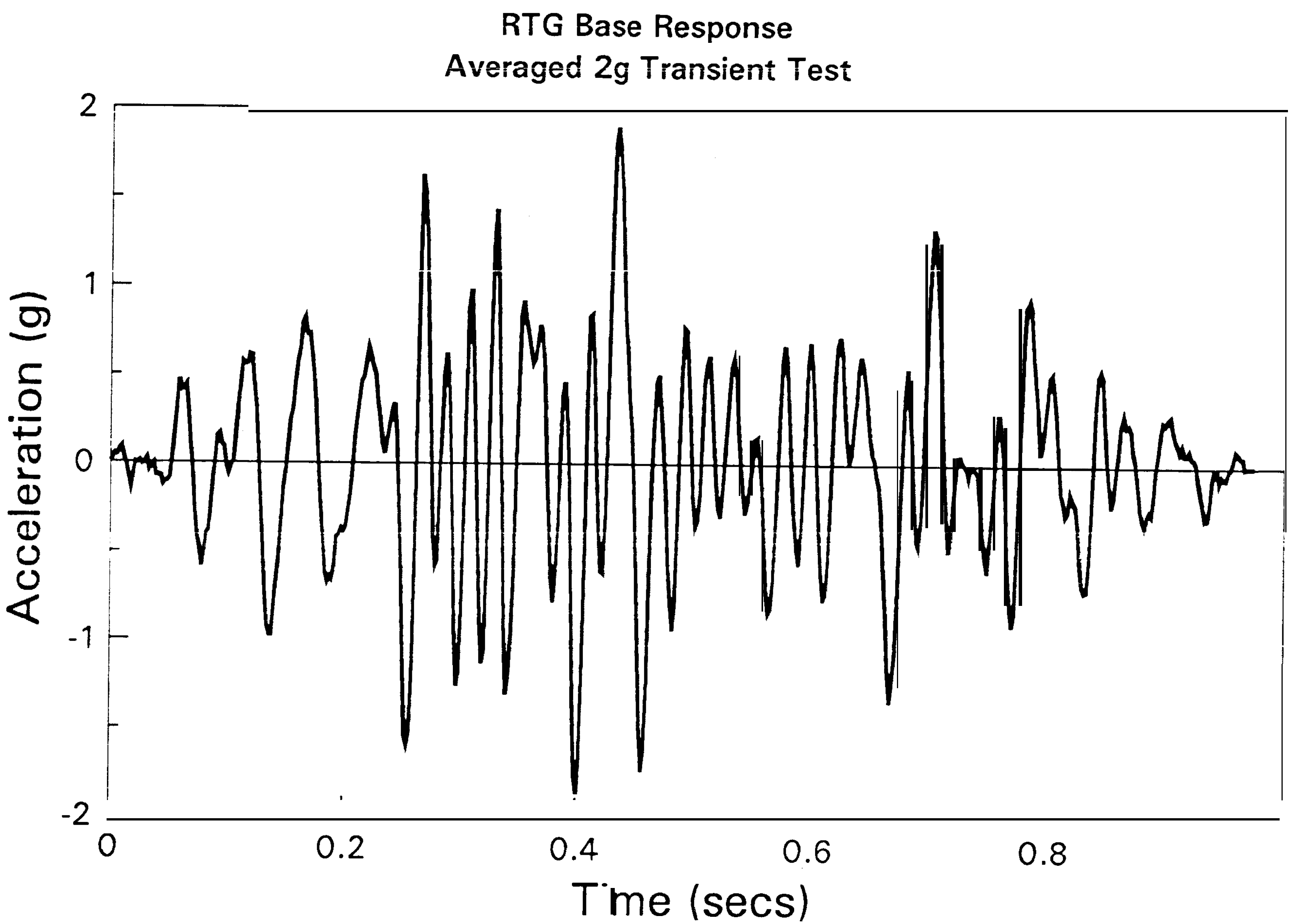

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Figure 9

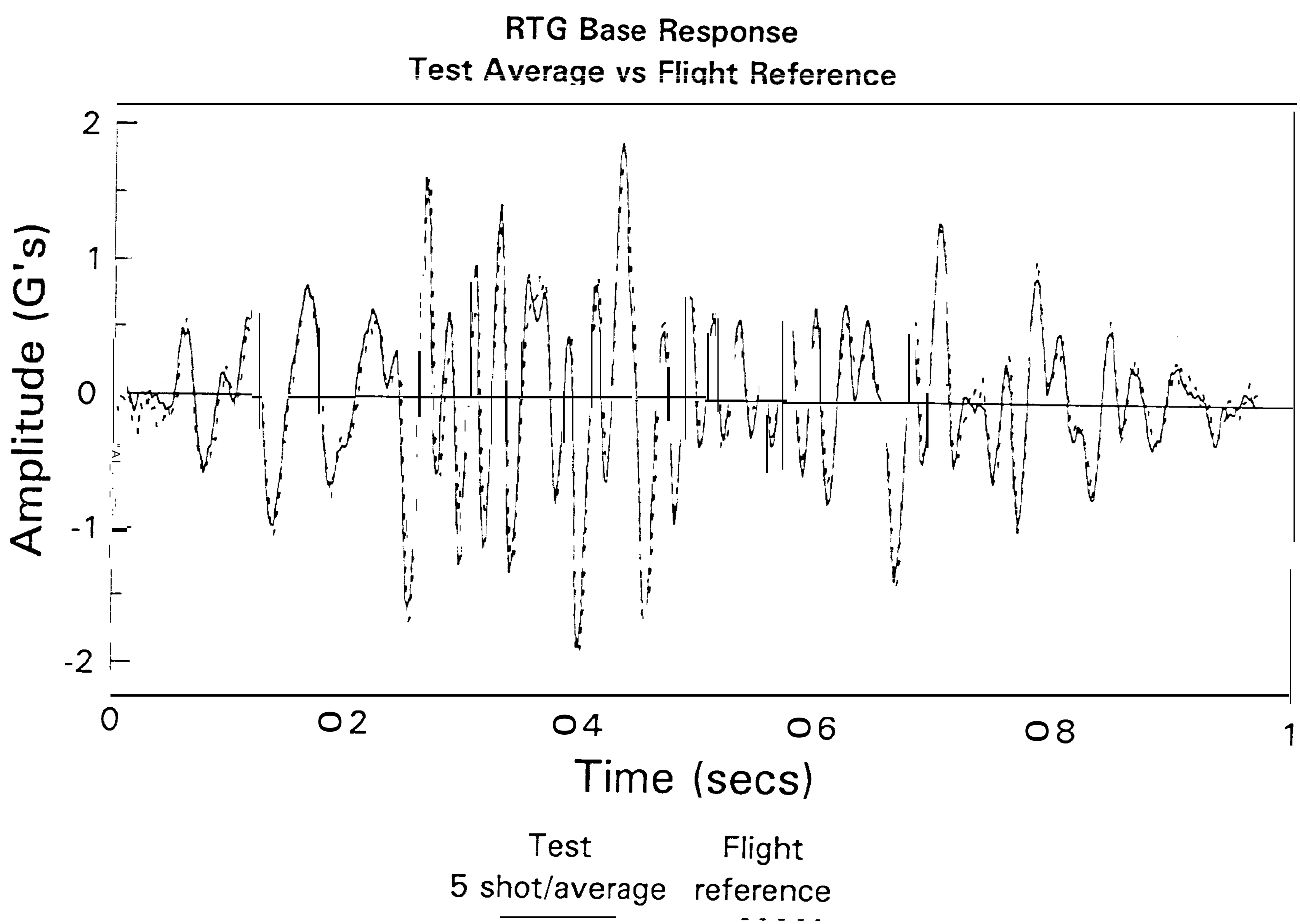

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Figure 10

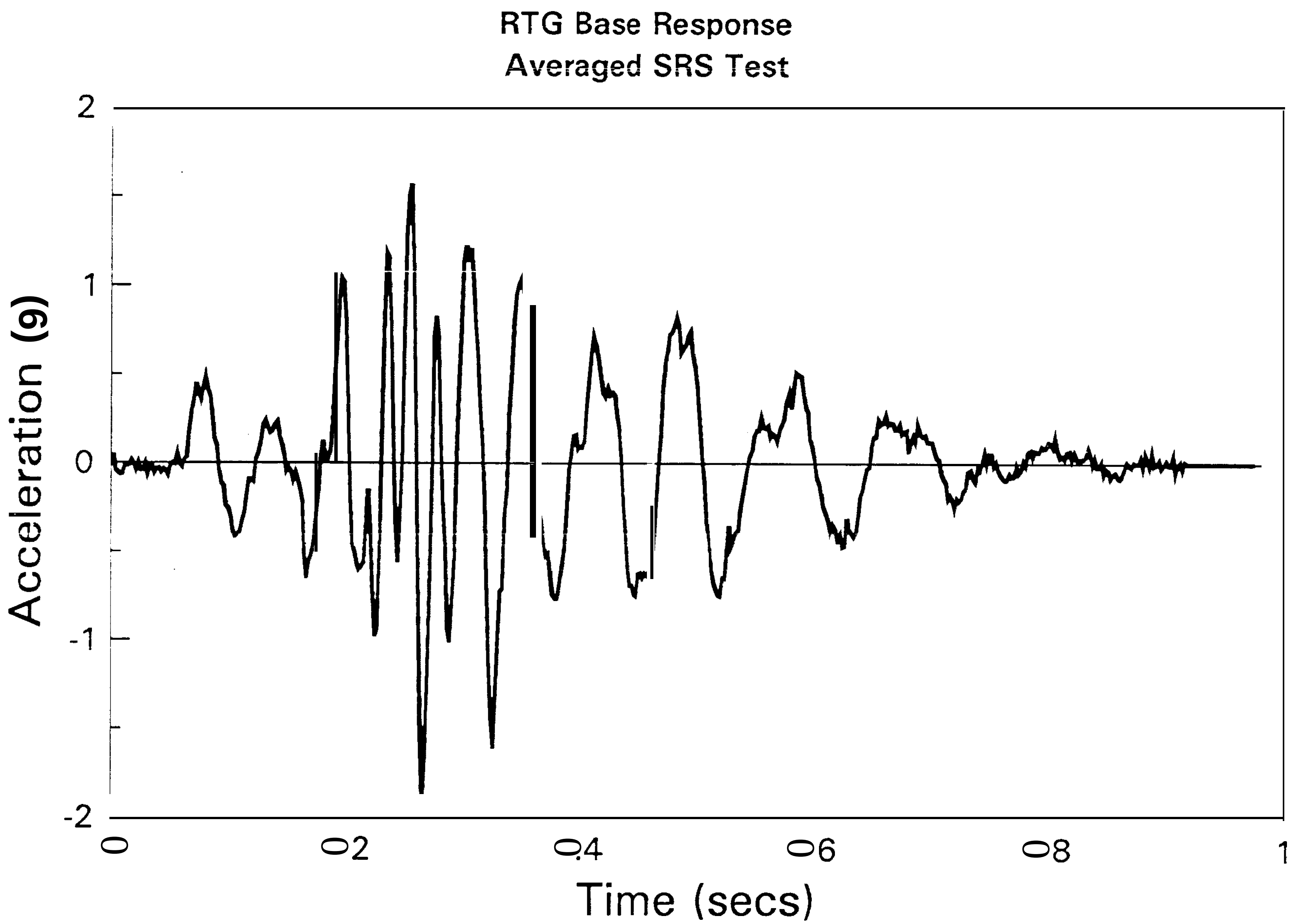

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Figure 11

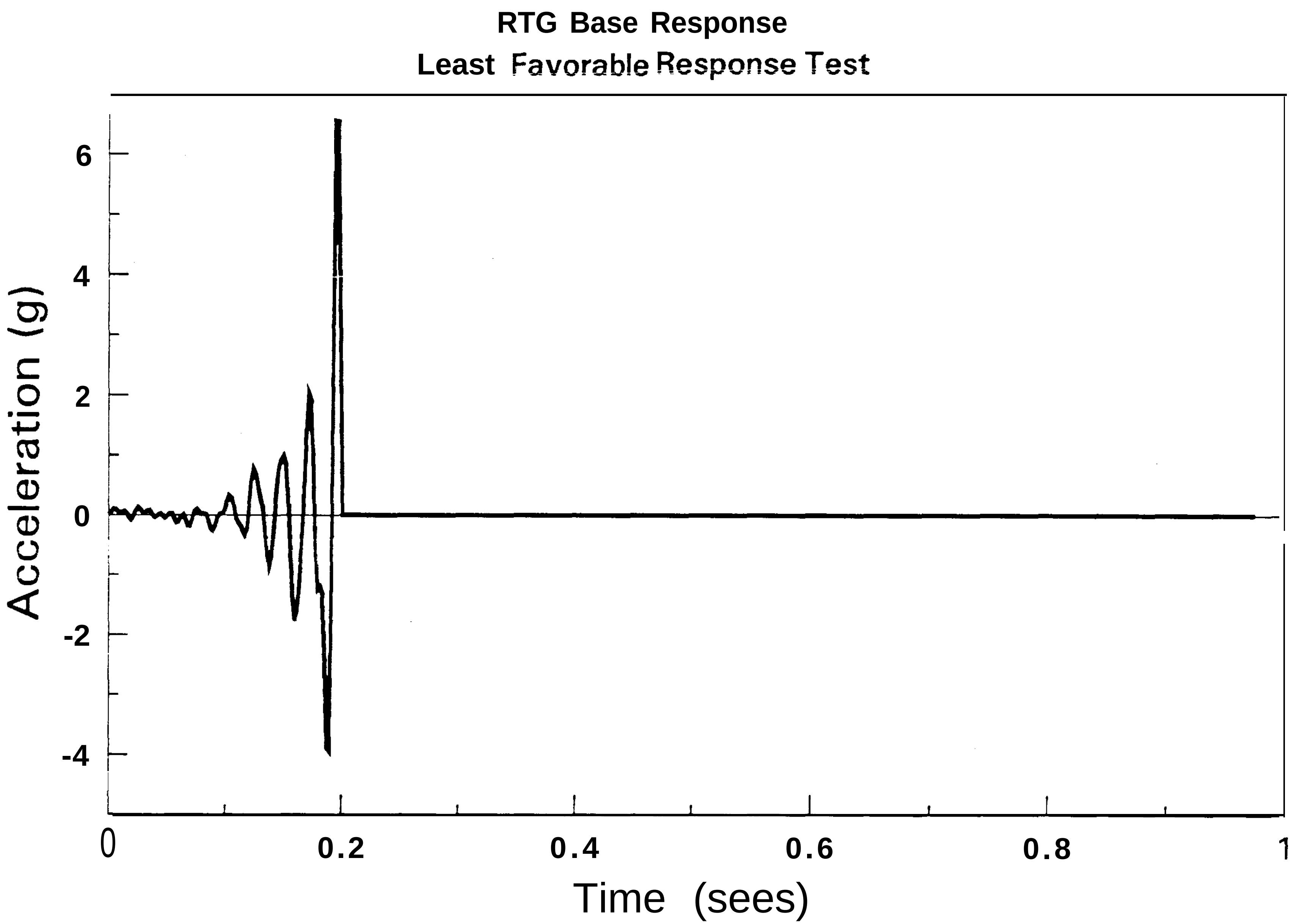

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Figure 72

RTG End Response
Averaged -2g Transient Test

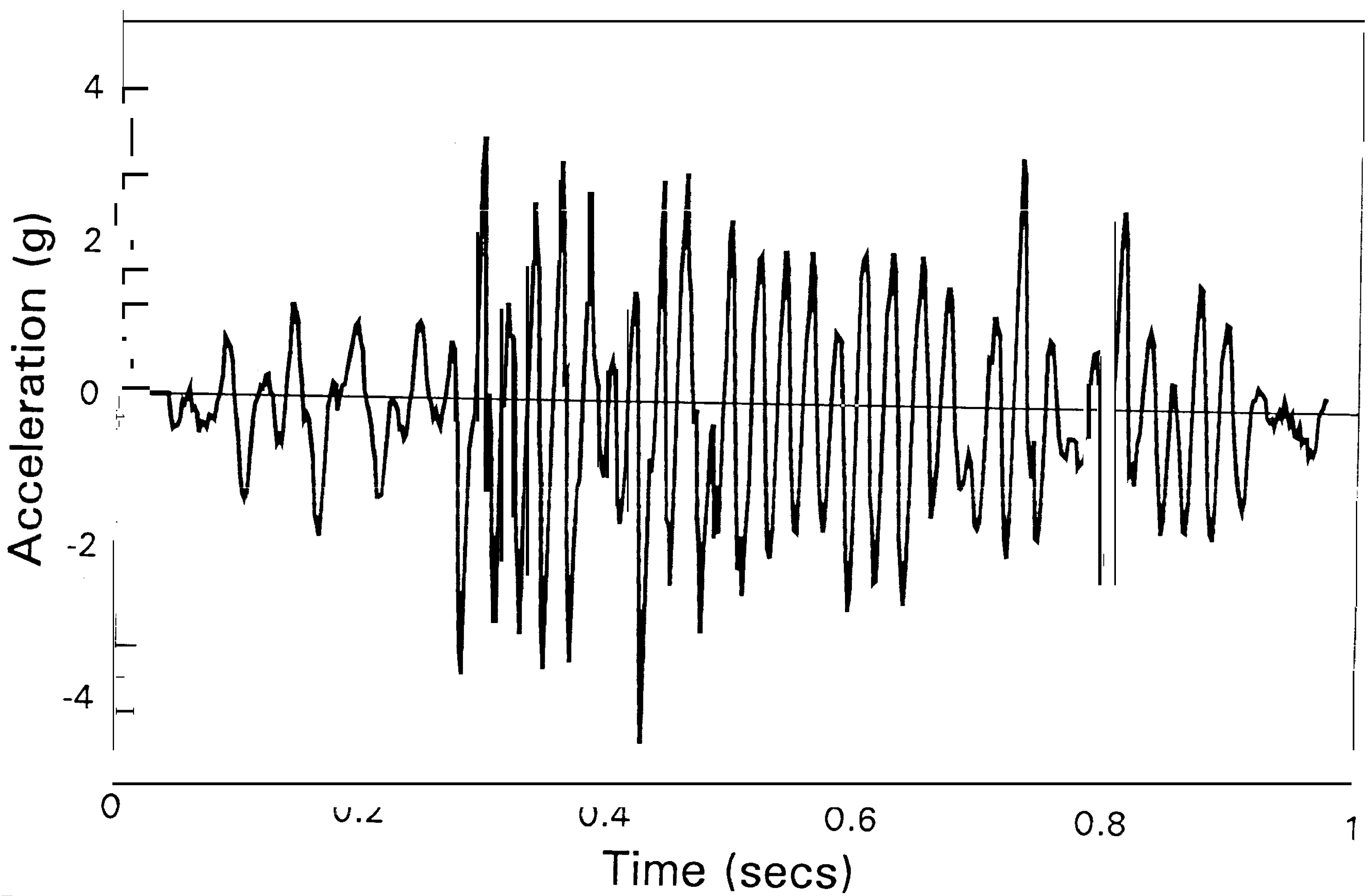

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Figure 13

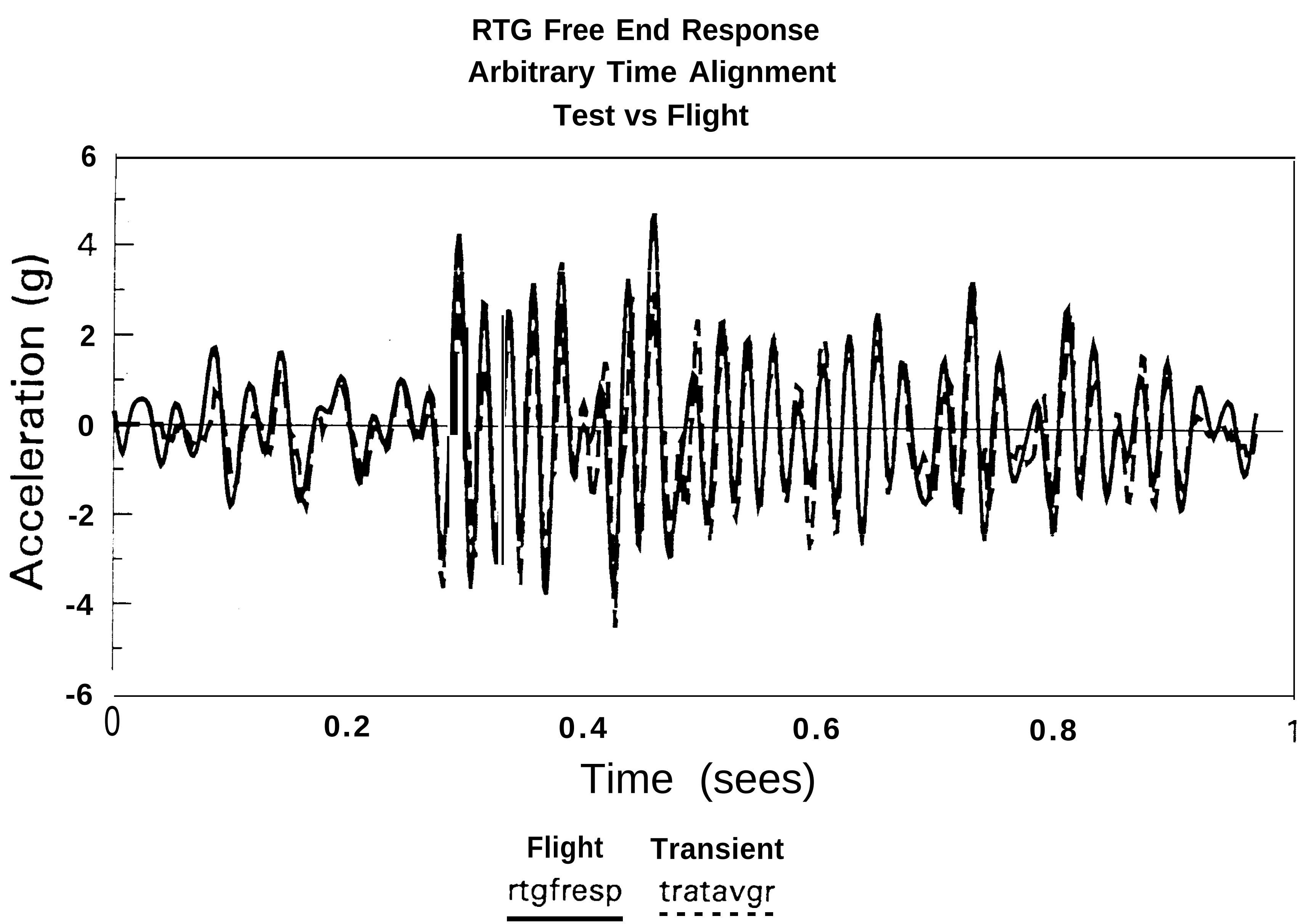

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Figure 14

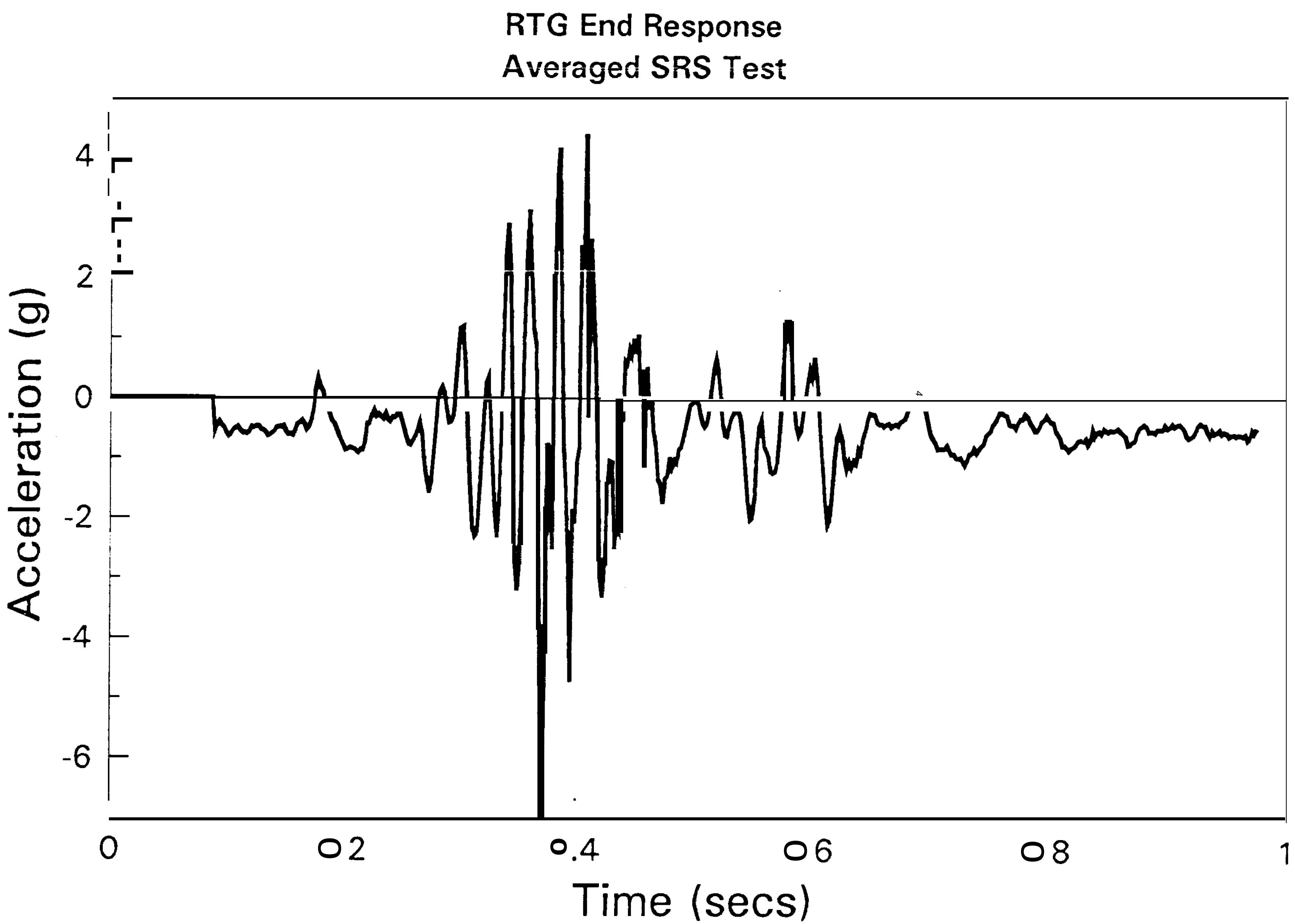

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Figure 15

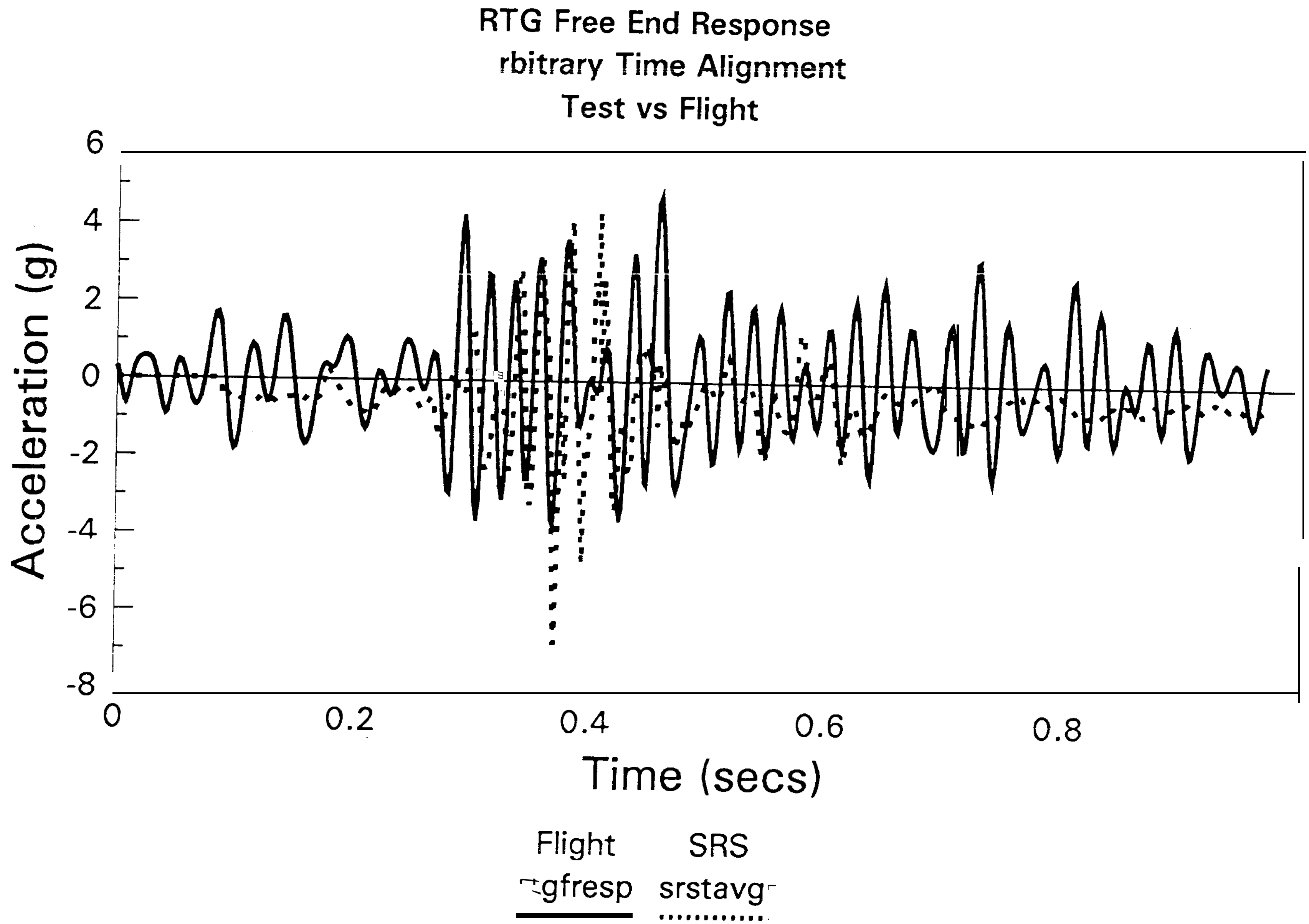

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Figure 16

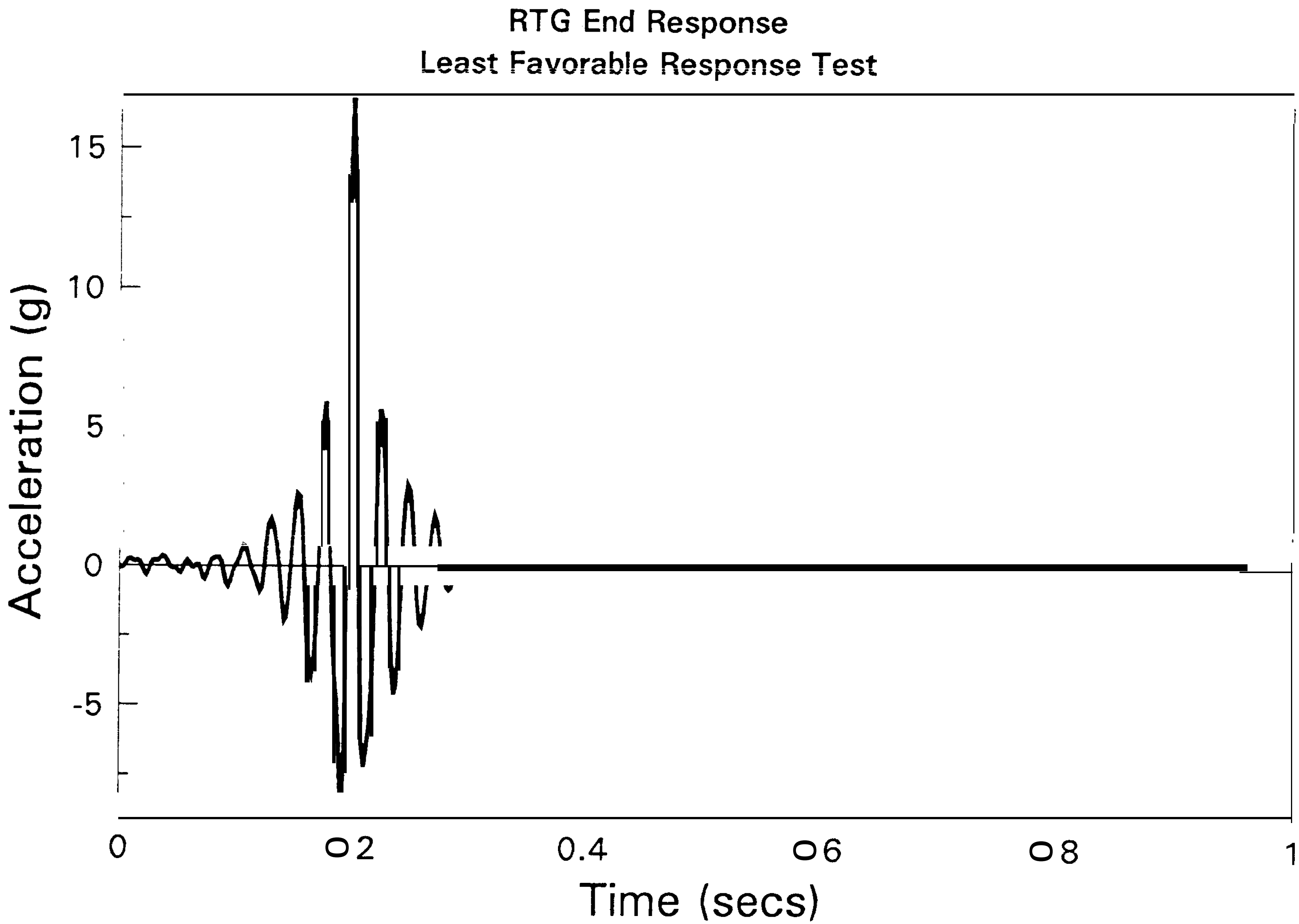

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Figure 17

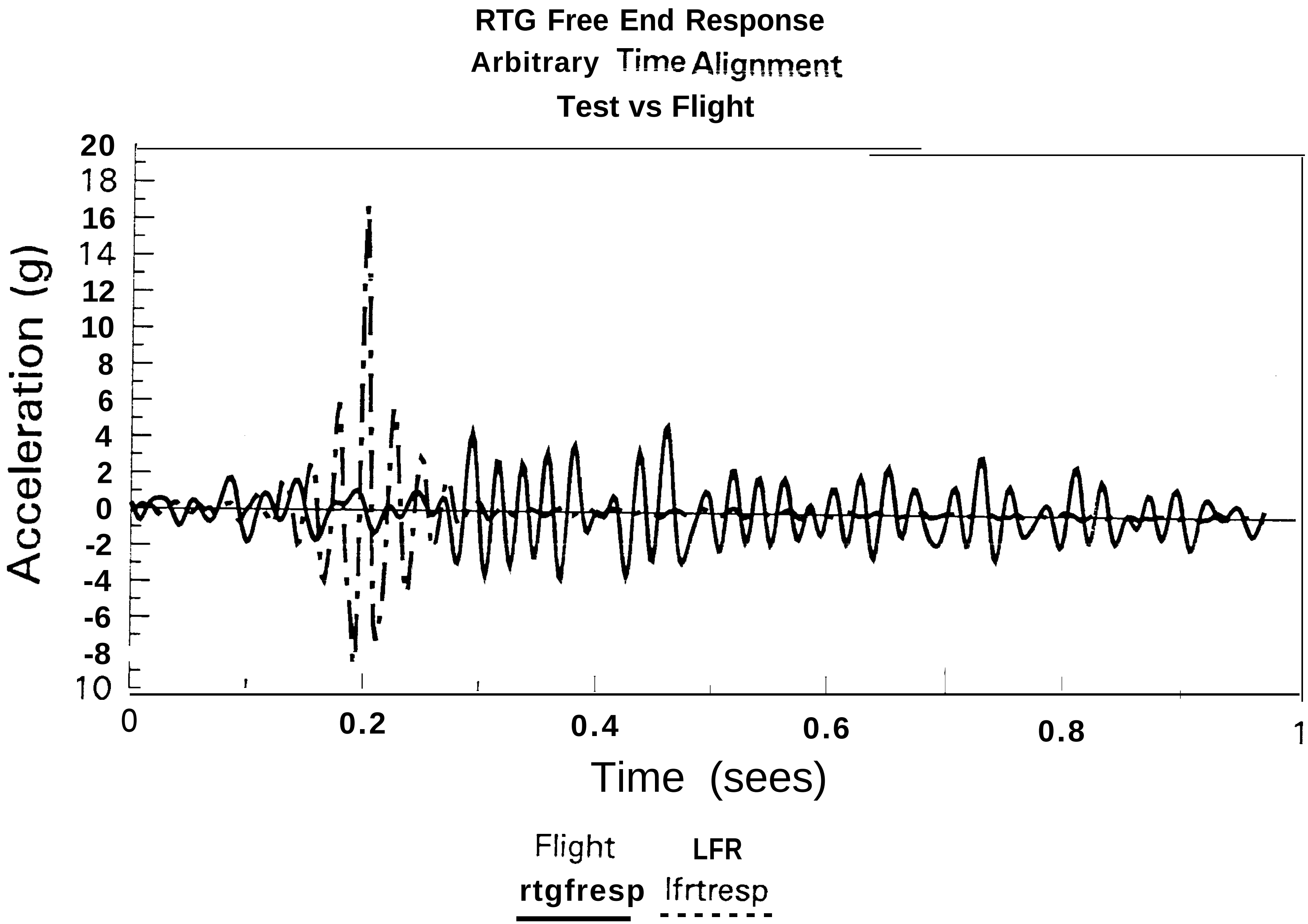

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Figure 78

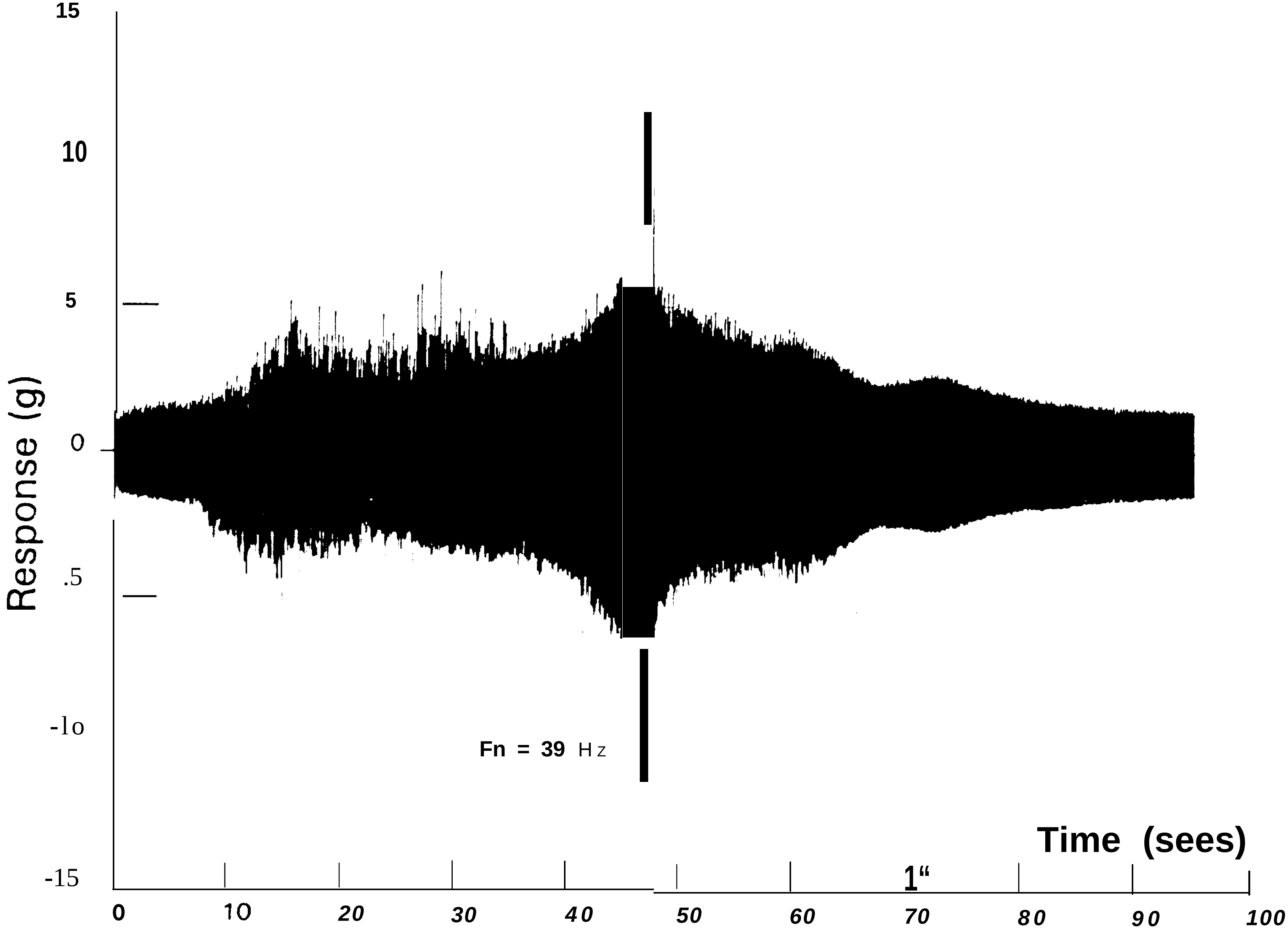
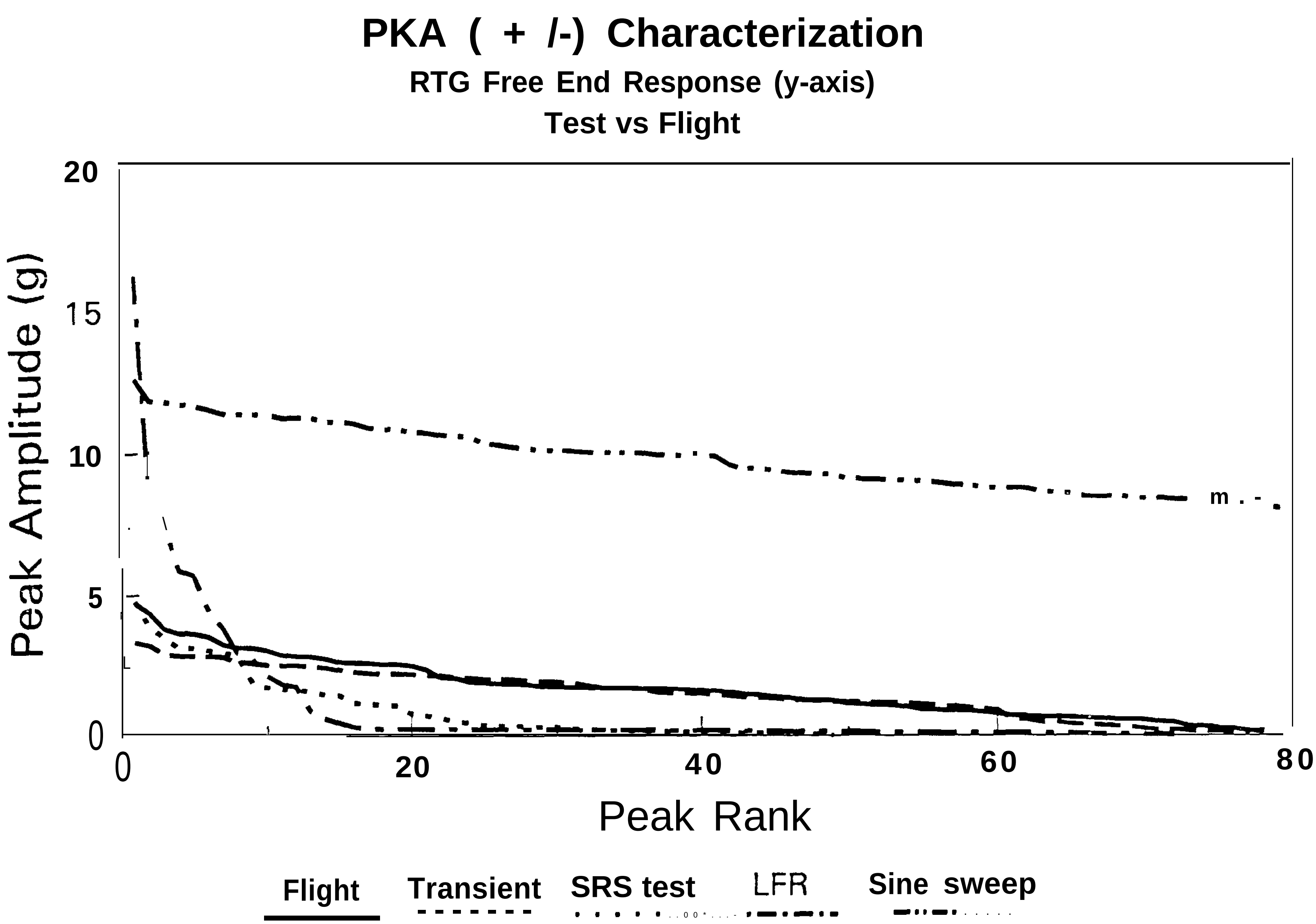


Figure 19 - Sine Sweep Response (2 Octave/rein.)



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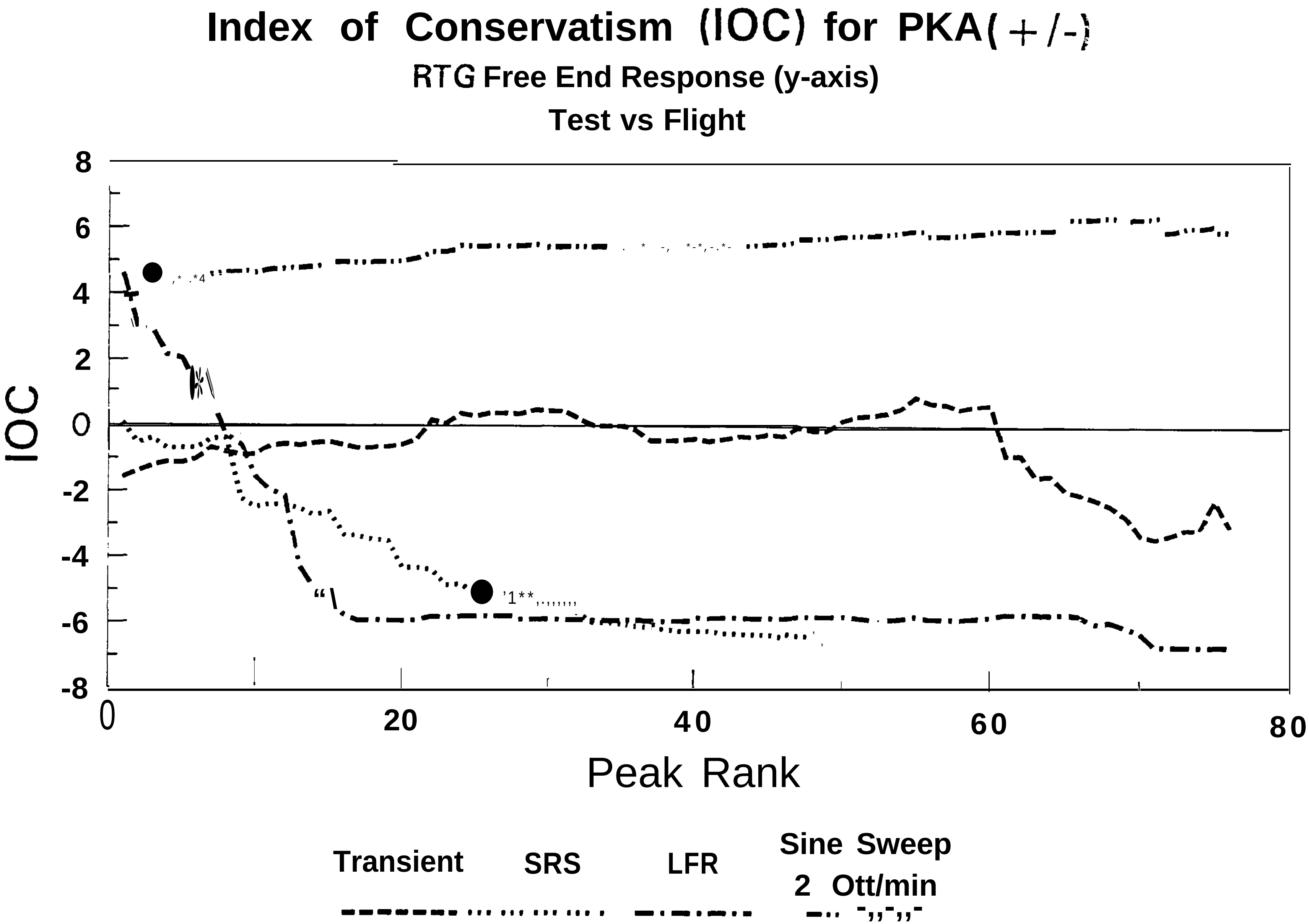
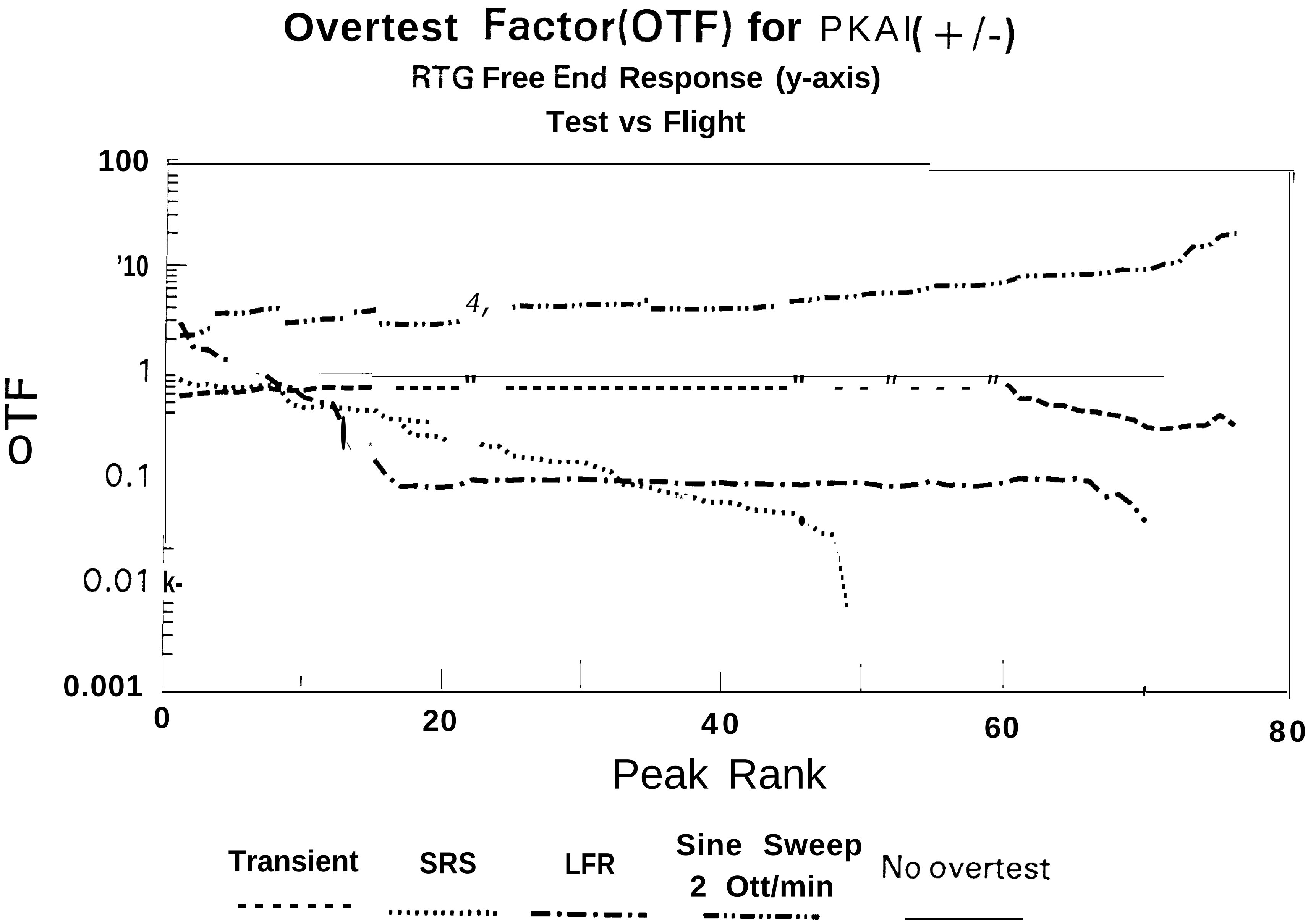
from c:\conserv\pks\conspka.wk1 *Figure 20* PKA Characterization



c:\conserv\pks\riocpka.drw
from c:\conserv\pks\conspka.wk1 *Figure 2 7 IOC for PKA Characterization*



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from c:\conserv\pks\conspka.wk1

*Figure **22 OTF** for **PKA** Characterization*

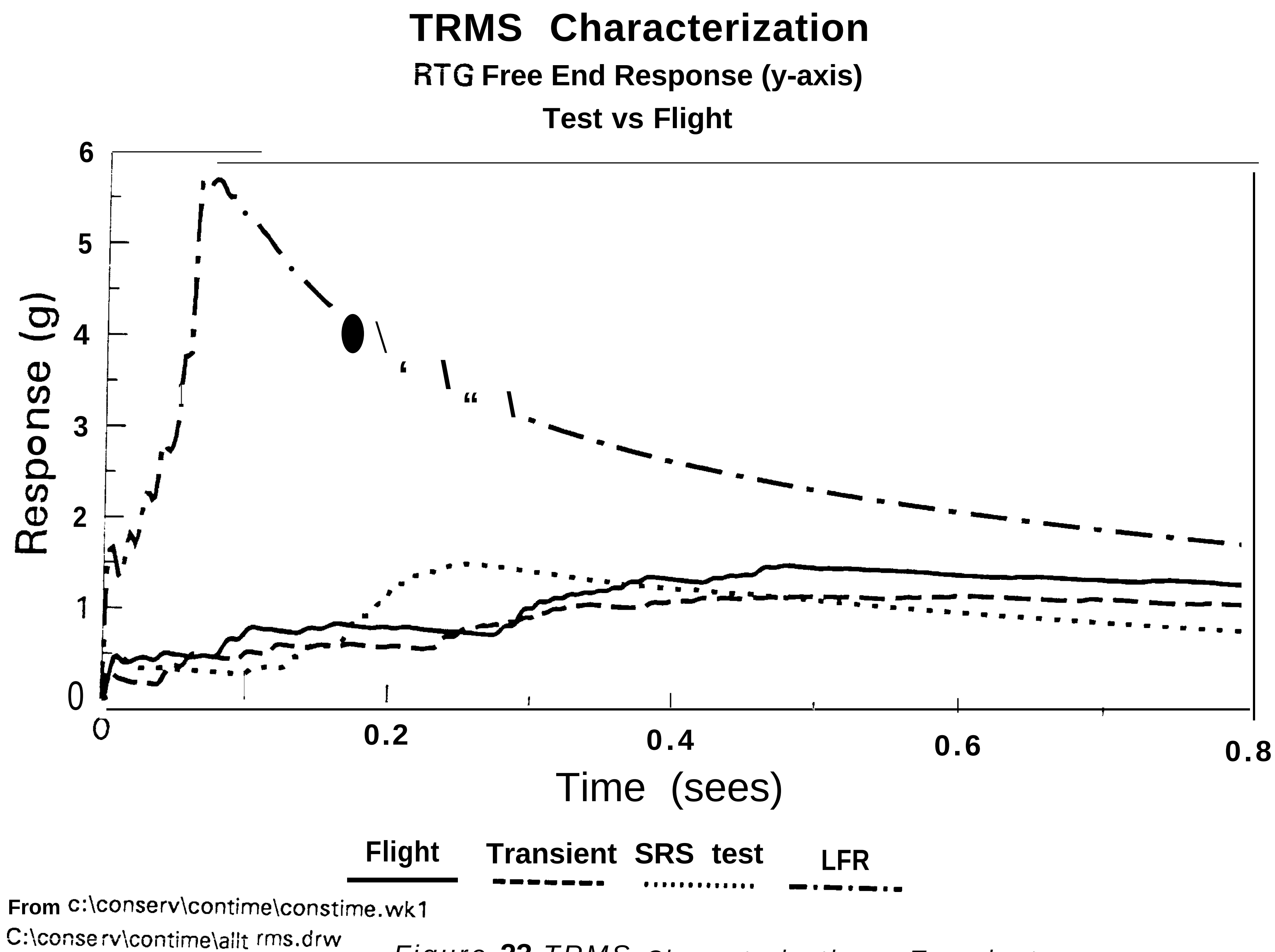
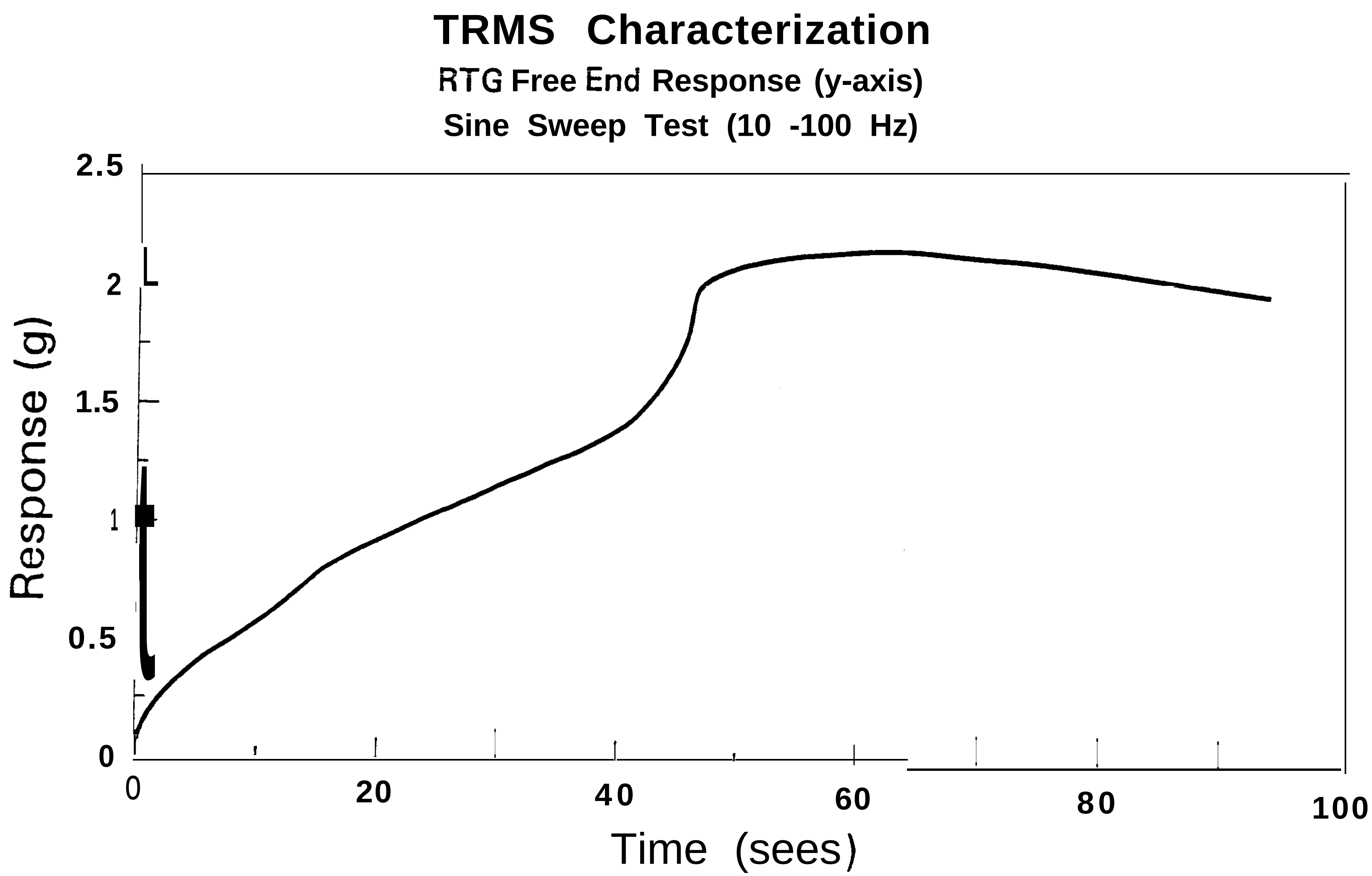


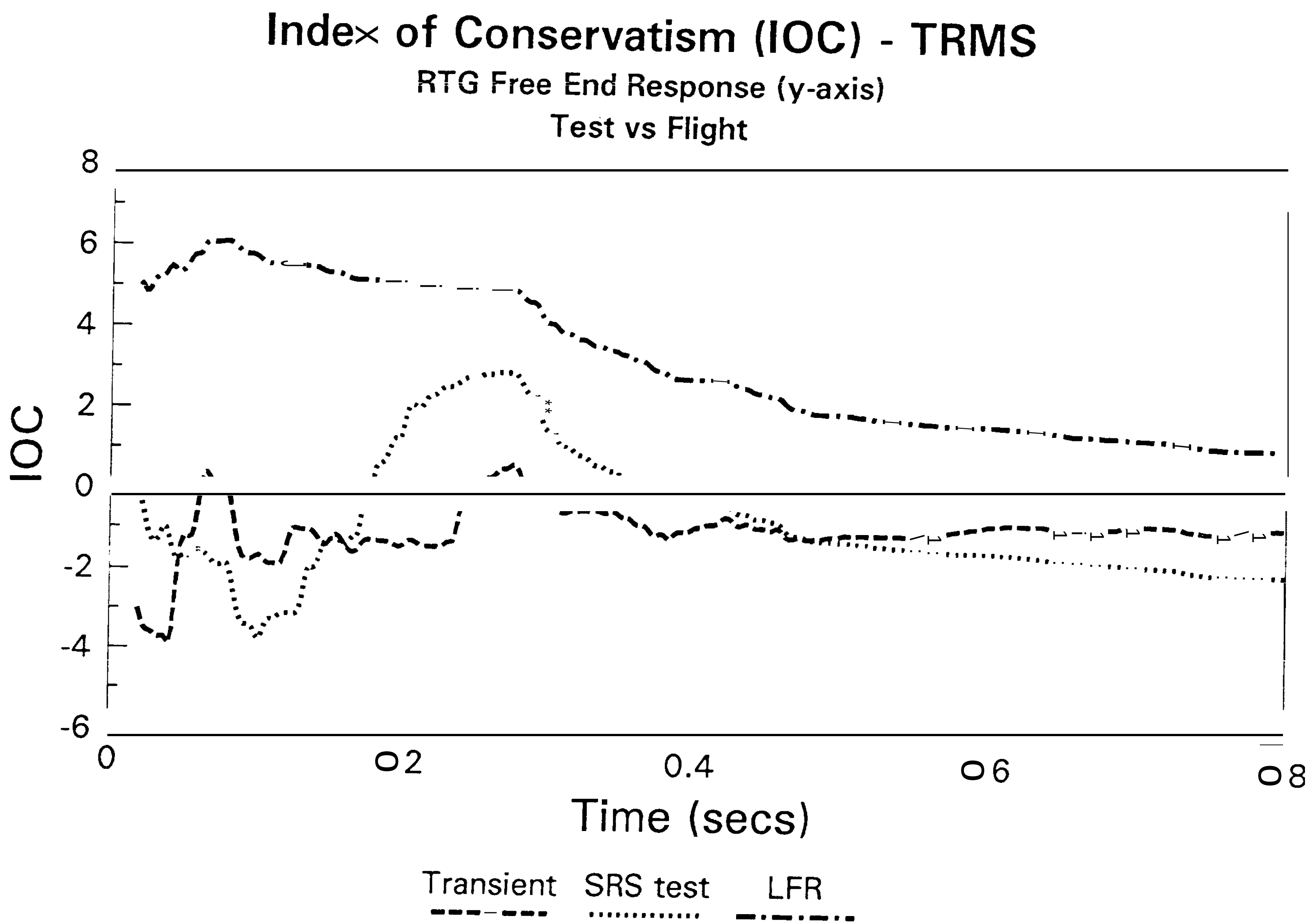
Figure **23** *TRMS Characterization - Transient tests*



Swept Sine 2 Ott/min

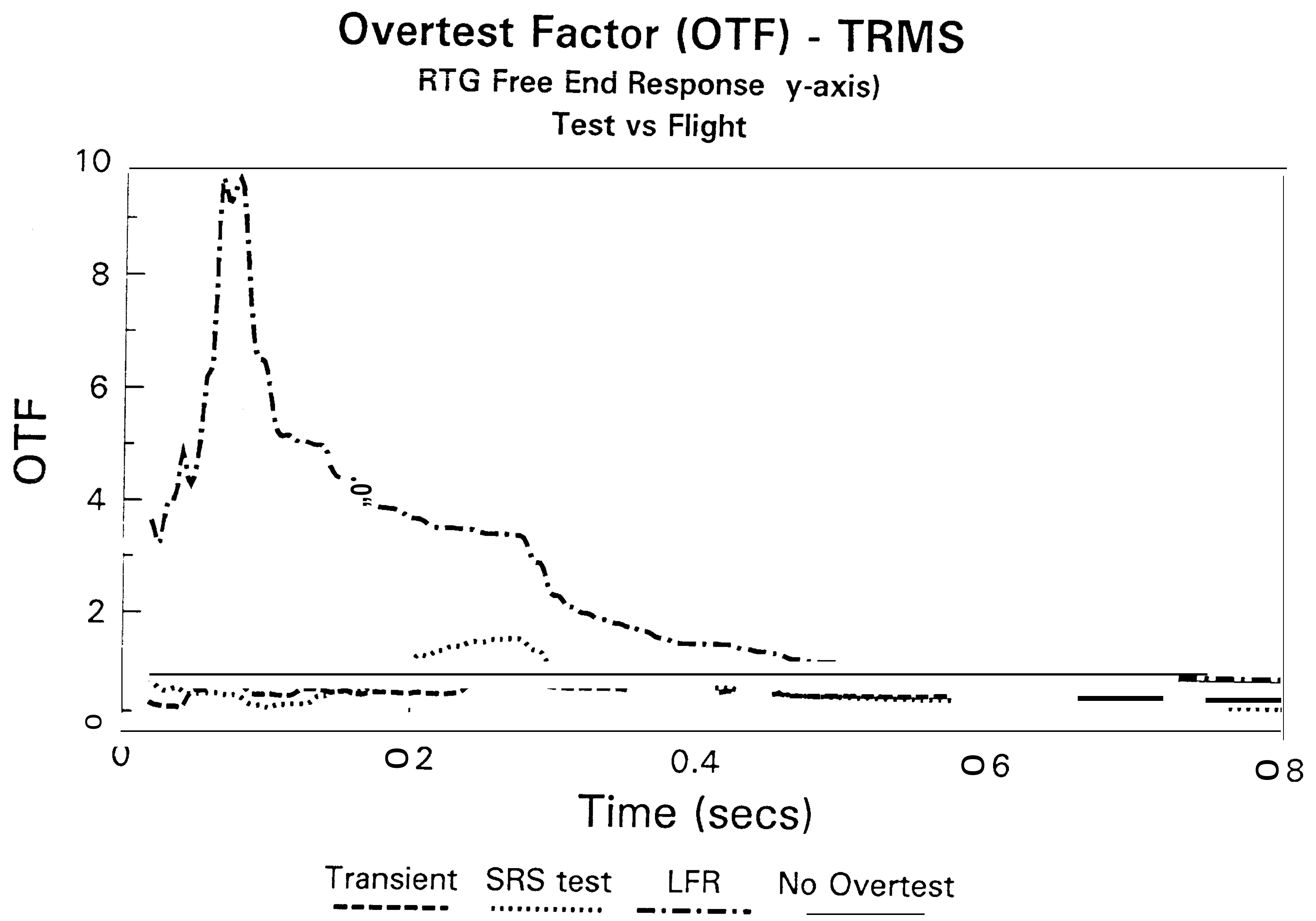
From c:\t-data\sinsweep\chopup\sw2trmst.prn
C:\t-data\sinsweep\chopup\sw2trms.drw

Figure 24



From c:\conserv\contime\constime.wk1
C:\conserv\contime\ioctrms.drw

Figure 25 IOC for TRMS Characterization



From c:\conserv\contime\constime.wk1
C:\conserv\contime\otftrms.drw

Figure 26 OTF for TRMS Characterization

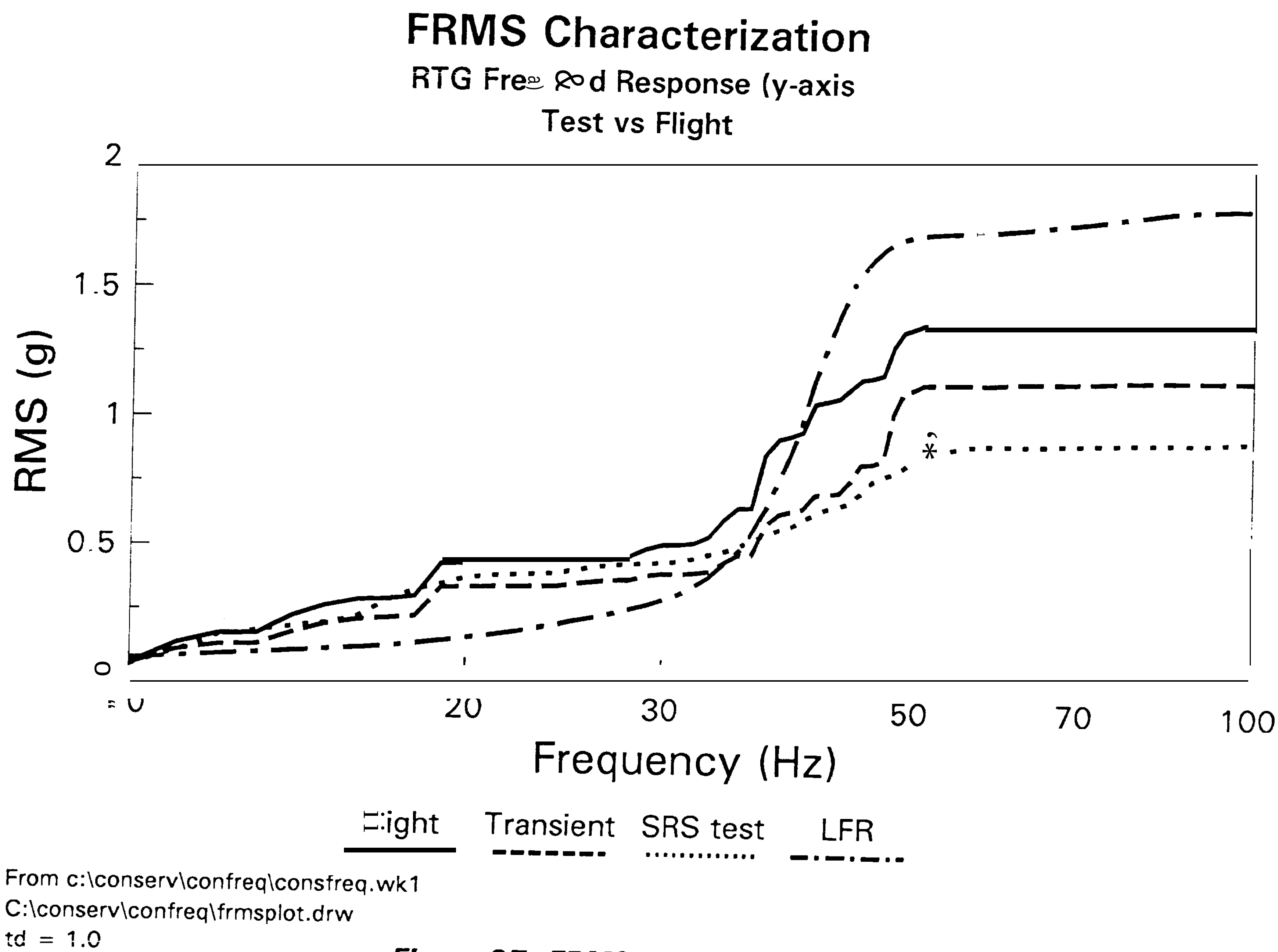
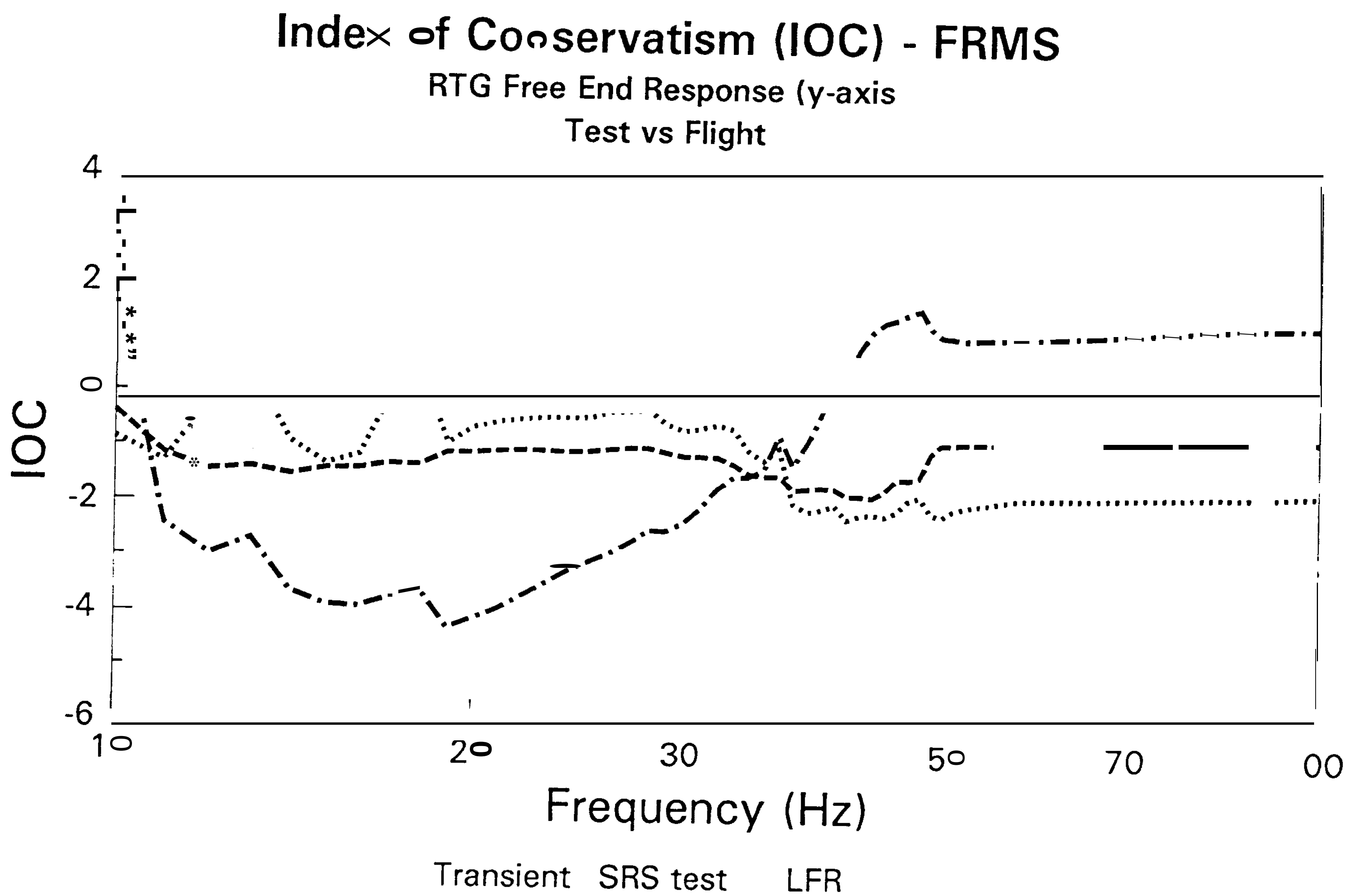


Figure 27 FRMS Characterization



From c:\conserv\confreq\consfreq.wk1
C:\conserv\confreq\iocfrms.drw
td = 1.0

Figure 28 IOC for FRMS Characterization

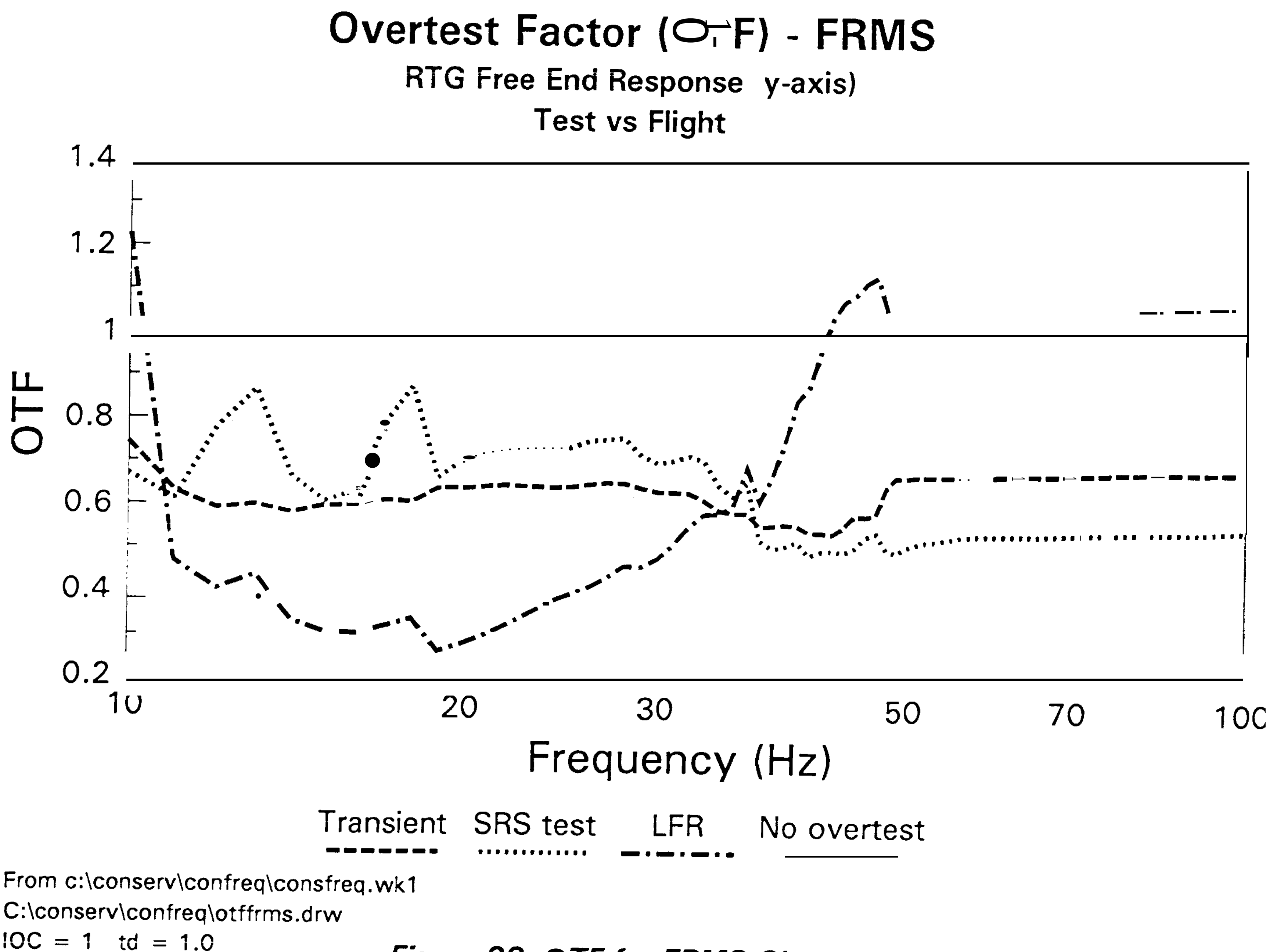
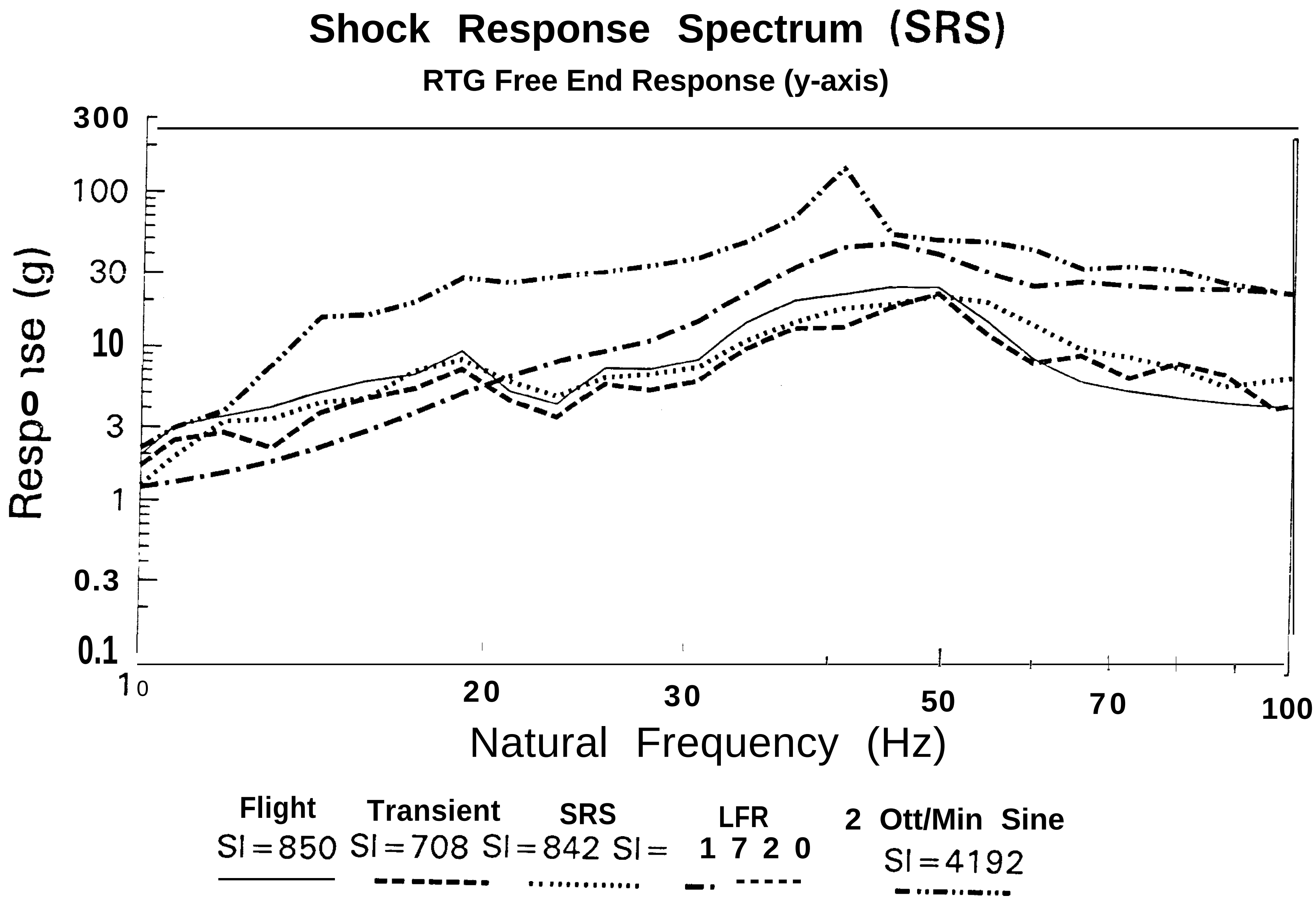
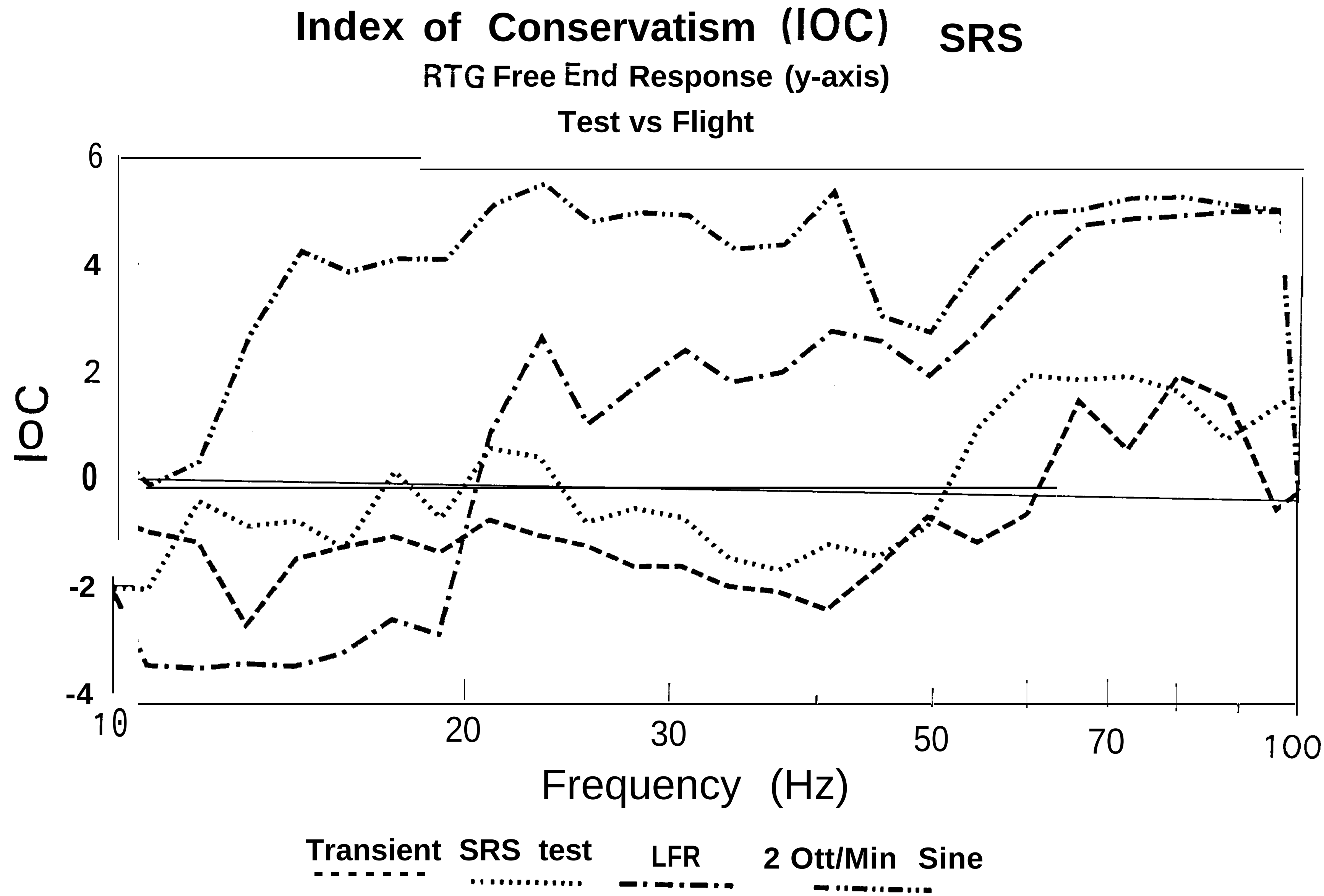


Figure 29 OTF for FRMS Characterization



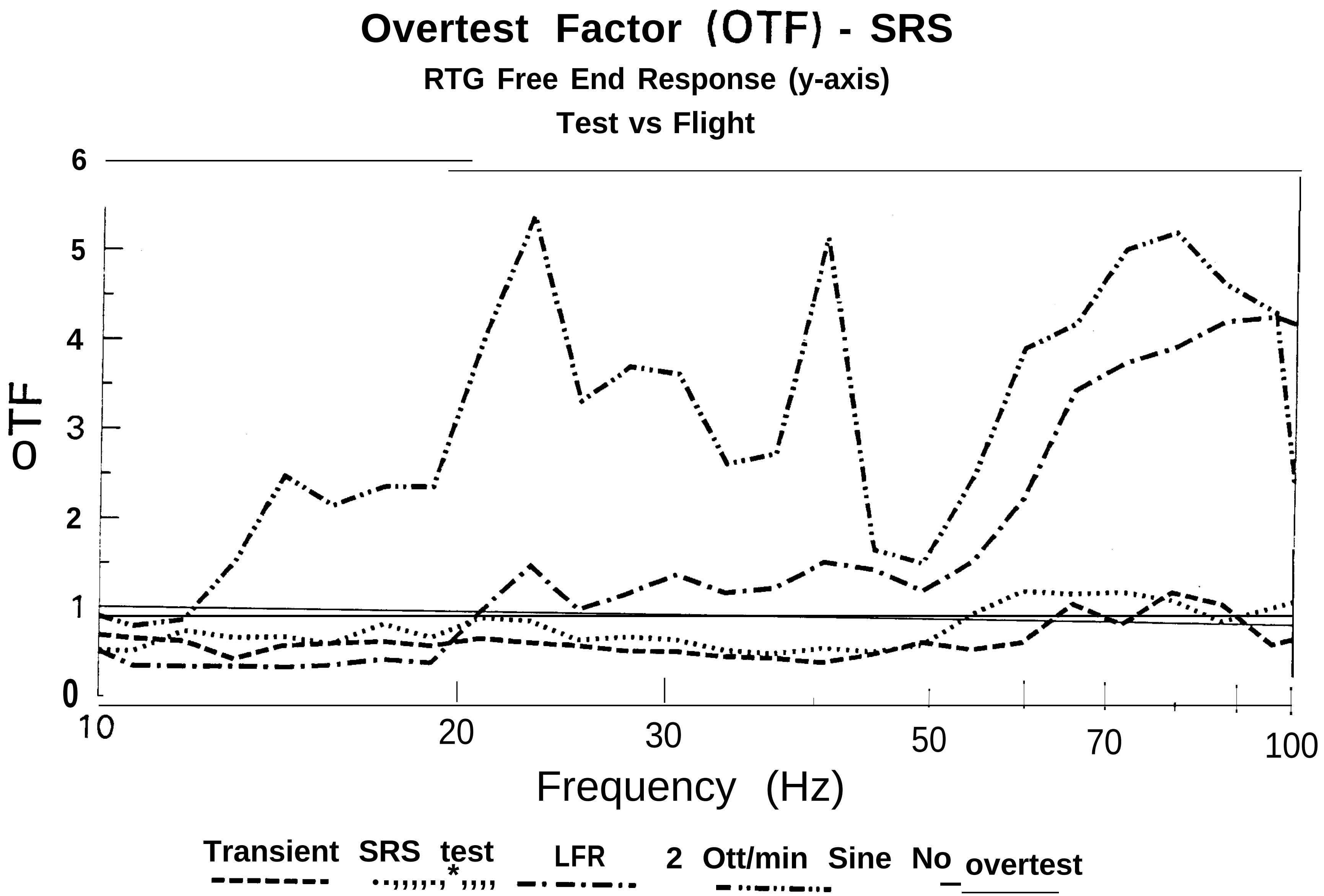
From c:\conserv\confreq\consrs.wk1
c:\conserv\confreq\srsplot.drw
damping ratio = 0.03

Figure 30 ***SRS*** *Characterization*



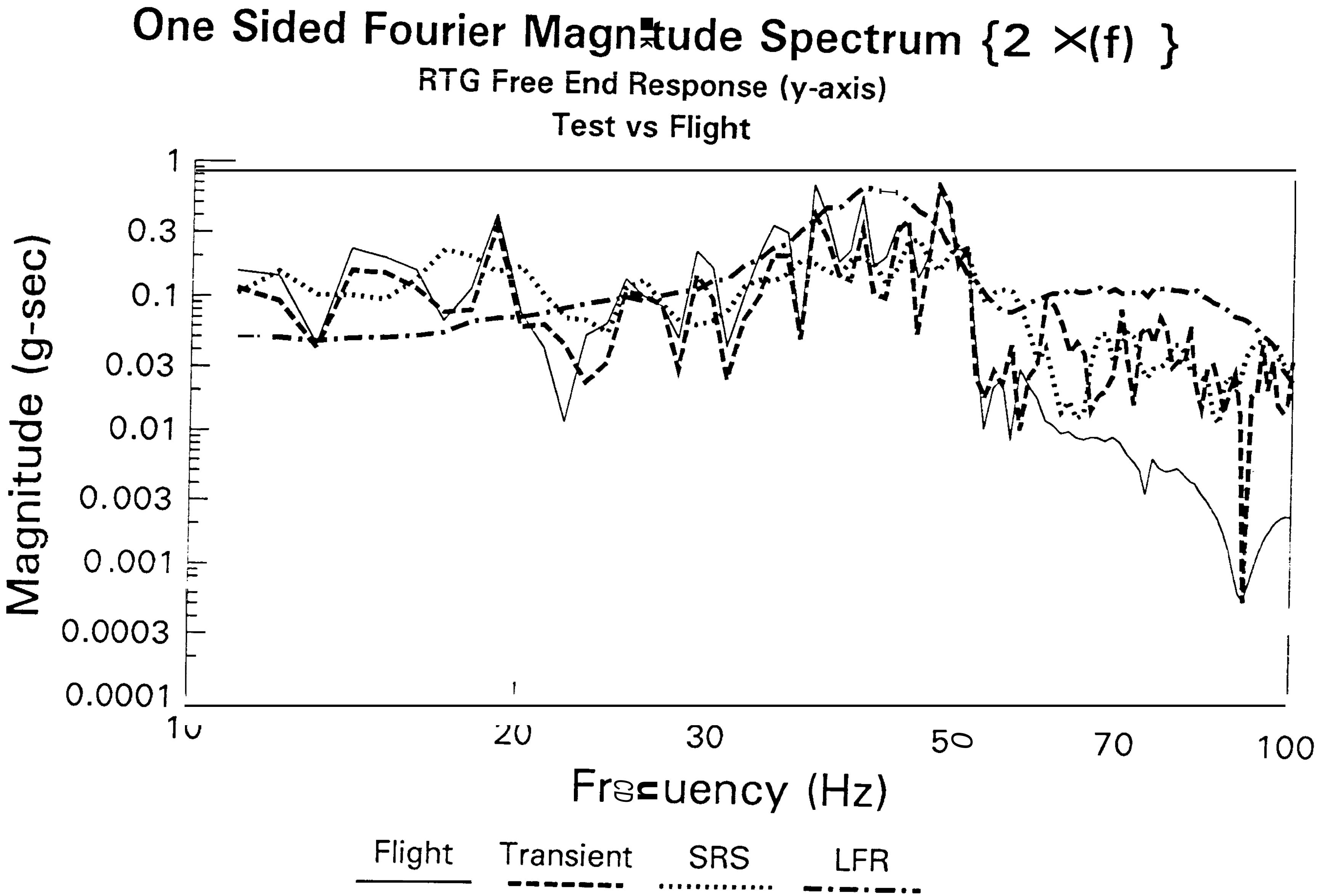
From c:\conserv\confreq\consfreq.wk1
C:\conserv\confreq\iocsrs.drw
td = 1.0 damping = 0.03

*Figure 37 **IOC** for SRS Characterization*



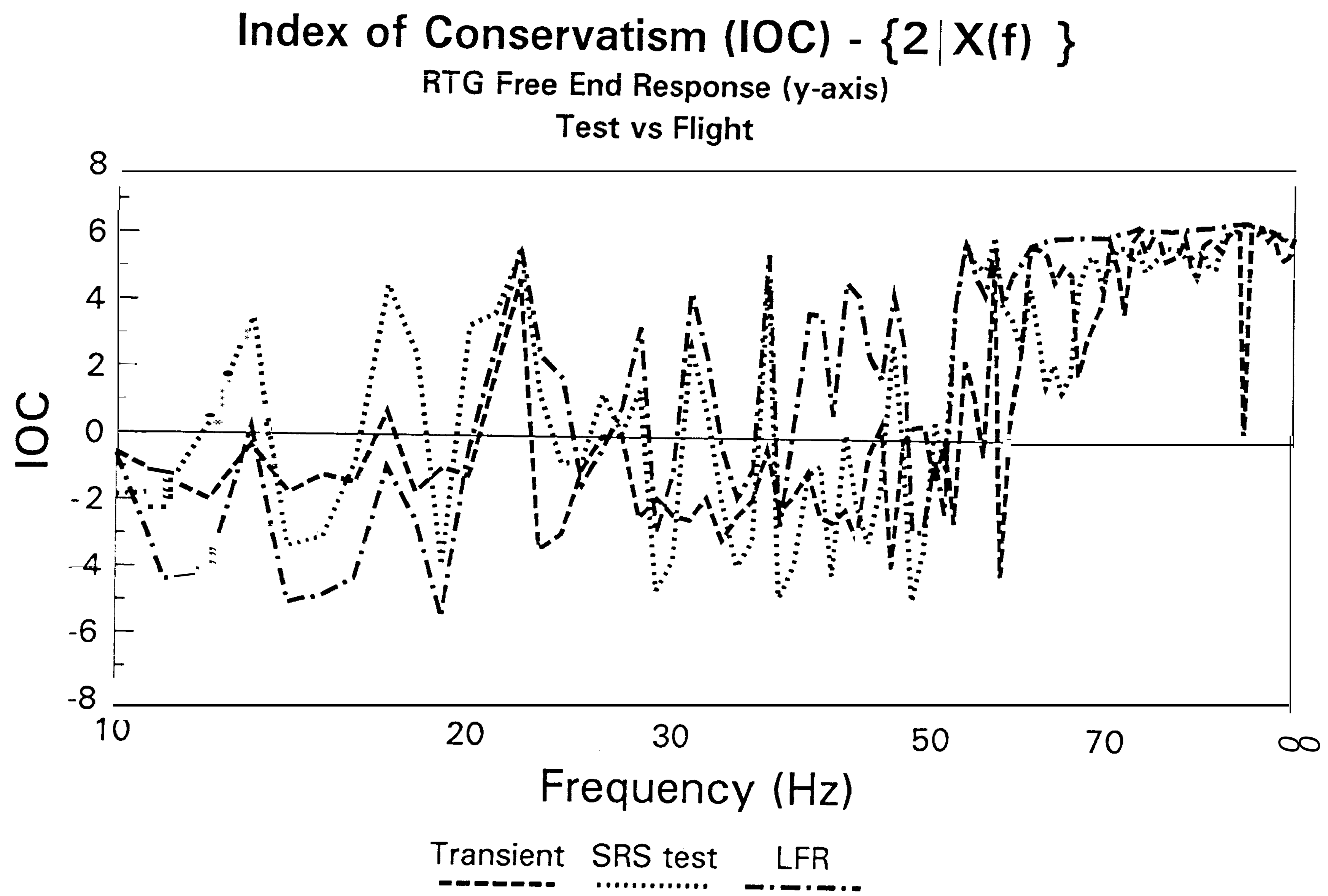
From c:\conserv\confreq\consfreq.wk1
C:\conserv\conf req\otfsrs.drw
IOC = 1 td = 1.0 damping = 0.02

Figure* 32 0 *TF *for SRS Characterization*



From c:\conserv\confreq\consfreq.wk1
c:\conserv\confreq\fftplot.drw
td = 1.0

Figure 33 FMS Characterization



From c:\conserv\confreq\consfreq.wk1
C:\conserv\confreq\iocfft.drw
td = 1.0

Figure 34 IOC for FMS Characterization

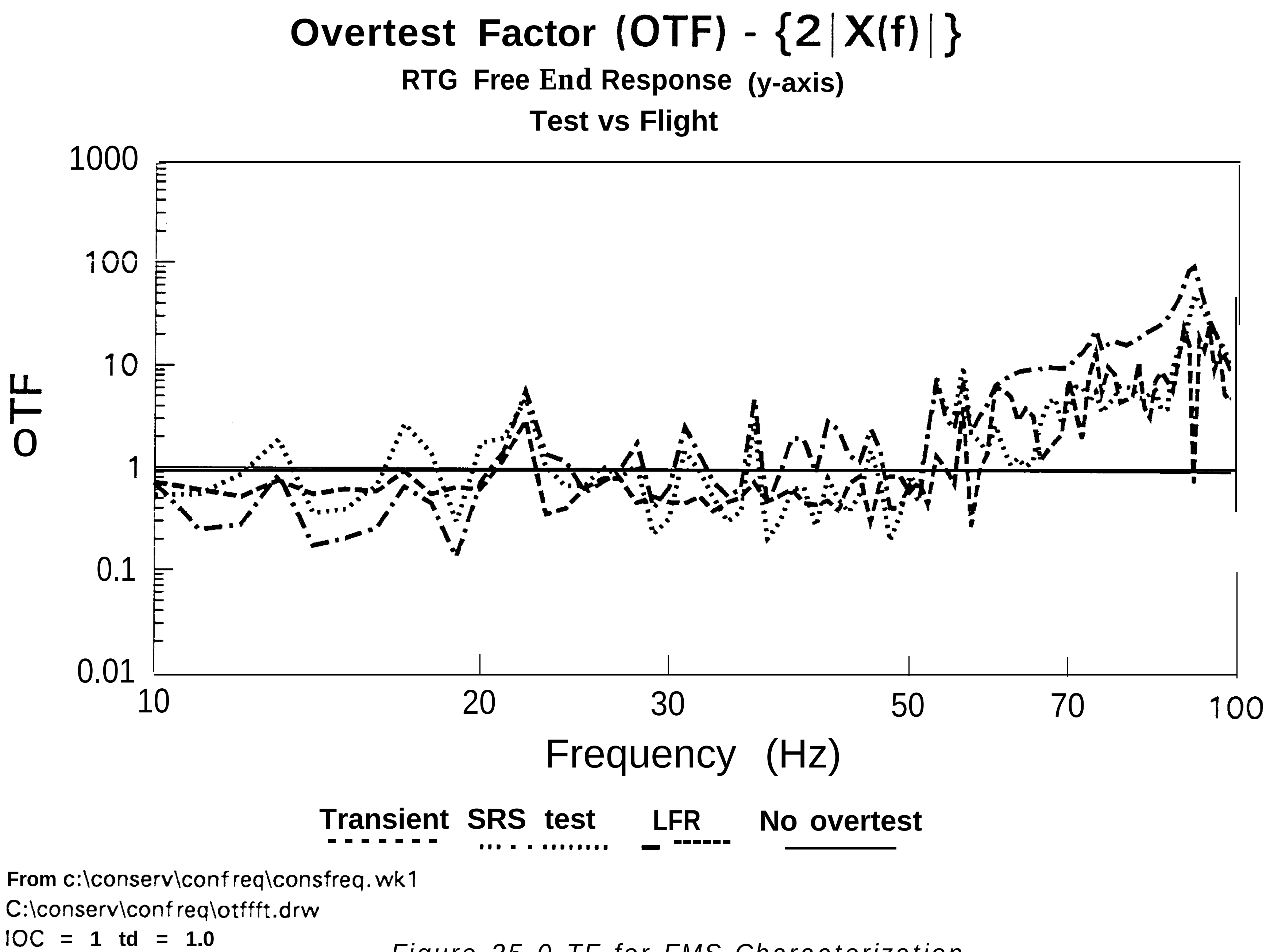
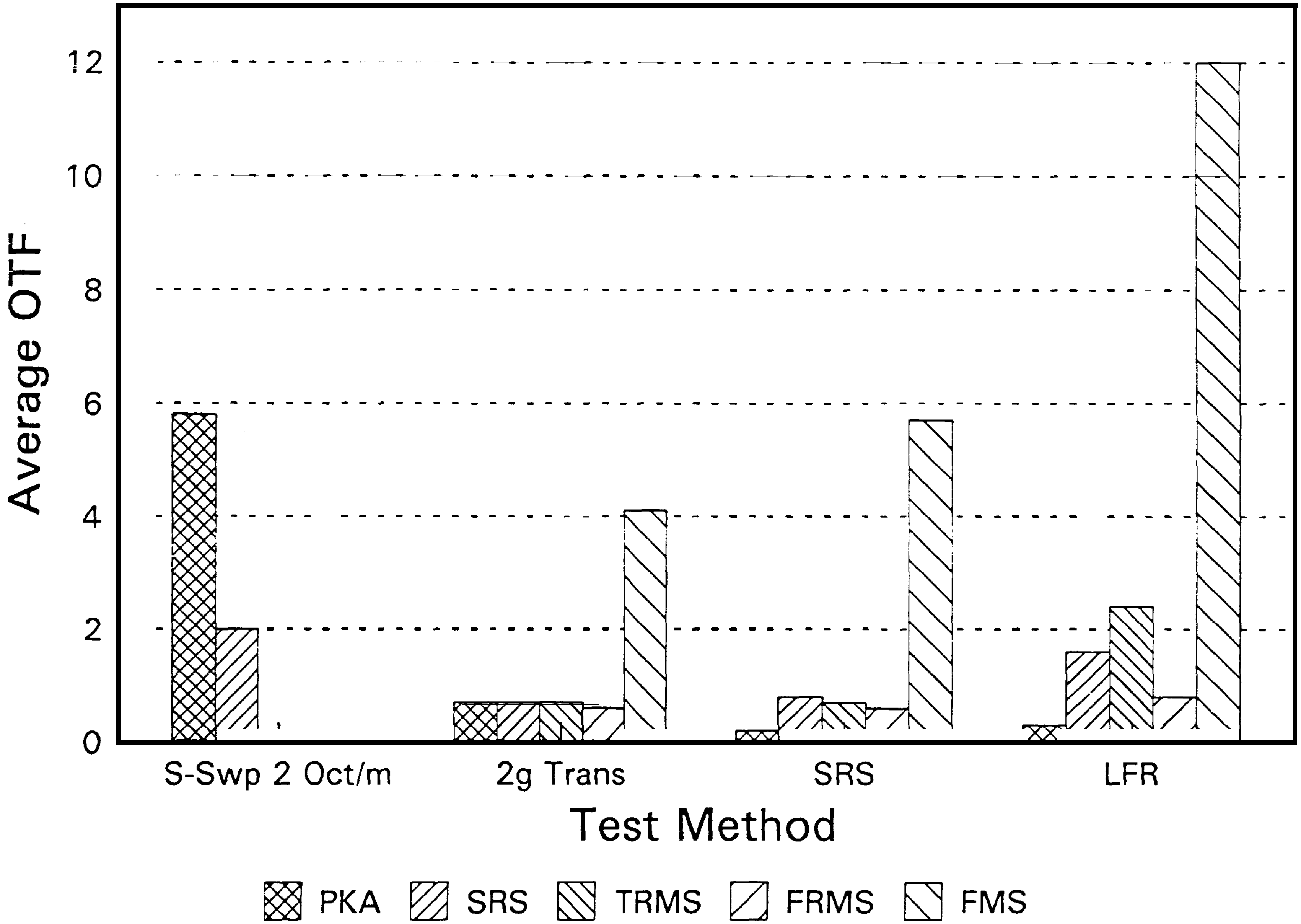
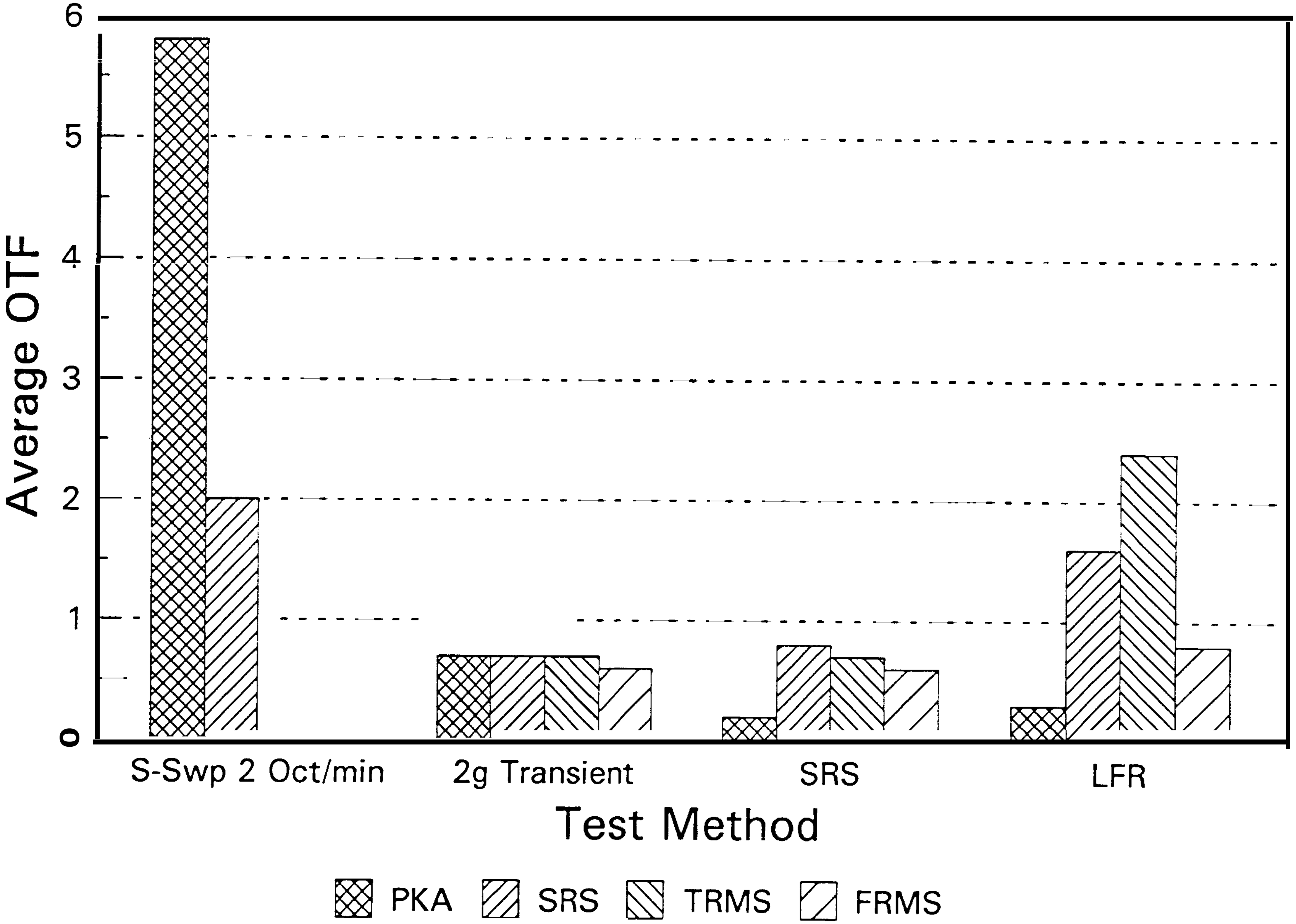


Figure 35 0 TF for FMS Characterization



from c:\conserv\pks\consvall.wk1
c:\conserv\pks\consvnal.drw

Figure 36 Average OTF vs Characterization / Test Method



from c:\conserv\pks\consvall.wk1
c:\conserv\pks\sconvnal.drw

Figure 37 Average OTF vs Characterization / Test Method