PROJECT CARDS TECHNICAL INFORMATION RECORD

PARAMETRIC AND SENSITIVITY ANALYSIS AND DETERMINATION OF RESPONSE SPECTRA FOR HORIZONTAL, VERTICAL AND ROTATIONAL MOTION OF A RADIOACTIVE MATERIAL SHIPPING PACKAGE RELATIVE TO THE MOTION OF ITS SUPPORT (RAILCAR) (EAA)

Master

Hanford Engineering Development Laboratory

CARDS-TIR-80-4
Continuation of CARDS-TIR-80-3
(Preliminary)
S.R. Fields
November 1980

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Project CARDS Technical Information Record

PARAMETRIC AND SENSITIVITY ANALYSIS
AND
DETERMINATION OF RESPONSE SPECTRA FOR
HORIZONTAL, VERTICAL AND ROTATIONAL MOTION
OF A RADIOACTIVE MATERIAL SHIPPING PACKAGE
RELATIVE TO THE MOTION OF ITS SUPPORT (RAILCAR)

PART 2 - Continuation of CARDS-TIR-80-3
(Preliminary)

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November 26, 1980

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Richland, Washington

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SUMMARY

Frequency response spectra have been generated for the horizontal, vertical and rotational accelerations of a radioactive material shipping package (cask) relative to the accelerations of its support (rail car). Generation of the response spectra was coupled to a parametric and sensitivity analysis to assess the effects on the response spectra (and on selected response variables) of varying certain selected parameters.

The equivalent single-degree-of-freedom (1-DOF) equations of motion (EOMs) derived to generate the response spectra have forcing functions on the right hand side that are equivalent to the motion of a support (or shaker table in a testing facility). This support motion, and the 1-DOF EOMs, are derived from the equations of motion used in the CARDS (Cask Rail Car Dynamic Simulator) model. The relative accelerations, velocities and displacements in the 1-DOF EOMs are defined as the differences between the accelerations, velocities and displacements of the cask and rail car at their centers-of-gravity (cgs). However, there are higher relative vertical accelerations at other locations on the cask due to the pitching of both the cask and rail car. Earlier results from the CARDS model show that, for the centered cask case, the absolute relative vertical accelerations at the tiedown attachment points are almost 5 times greater than the corresponding accelerations at the cg.

Support accelerations and tiedown forces are presented as functions of time in Sections 4.2 and 4.3, respectively. The response spectra, i.e., the maximum absolute relative (MAR) accelerations (horizontal, vertical and rotational) as functions of frequency, are presented in Section 4.4. In Section 4.5, these spectra are concentrated on three plots, one for each of the three accelerations, to show how the various spectra lie within a band bounded by plus and minus 50% values of the corresponding base case spectra. Seven of the 23 cases considered fall outside the band for the vertical spectra, and ten cases fall outside the band for the rotational spectra. None of the cases fall outside the band for the horizontal spectra.

Results of the parametric and sensitivity analysis are presented in Section 4.1. and 5. In Section 5, the parameters are ranked according to how sensitive the response variables are to the parameter changes. It was found that the horizontal acceleration of the support and the MAR horizontal acceleration are relatively insensitive, while the corresponding vertical accelerations are highly sensitive to changes in 4 of the 13 parameters, and the corresponding rotational accelerations are highly sensitive to changes in 8 of the 13 parameters. The tiedown forces are moderately sensitive to changes in 3 of the parameters.

INTRODUCTION

This informal report has been prepared as a continuation of a previous informal report, CARDS-TIR-80-3, dated August 22, 1980.⁽¹⁾ The derivations of equations used and the technical discussion of CARDS-TIR-80-3 apply equally well to the present report. Additional applicable derivations and discussions are presented in Reference 2. Both CARDS-TIR-80-3 and the present report were prepared to present the results of a study to generate response spectra for the horizontal, vertical and rotational motion of a radioactive material shipping package relative to the motion of its support (rail car). The generation of the response spectra has been coupled to a limited parametric and sensitivity analysis to assess the effects on the response spectra, and on selected response variables, of varying certain selected parameters.

In CARDS-TIR-80-3, two sets of response spectra were generated. The first set is designated as "preliminary" because the response spectra were generated for various preliminary or exploratory cases, defined by conditions and parameter values used in the CARDS (Cask Rail Car Dynamic Simulator) and CARRS (Cask Rail Car Response Spectra Generator) models, prior to a request by Nuclear Regulatory Commission (NRC) personnel for a second set of response spectra (designated as "requested") based on specific conditions and parameter values. A total of 23 cases were requested. The results of the first 10 cases were presented in CARDS-TIR-80-3. The results of the remaining 13 cases are presented in this report.

METHODS, APPROACH AND DISCUSSION OF RESULTS

Construction of Response Spectra Generator

See Reference 1.

Generation of Response Spectra for Some Preliminary Cases

See Reference 1.

Generation of Response Spectra for Requested Cases, and Parametric and Sensitivity Analysis

The results of the first 10 cases requested by NRC have been presented and discussed in Reference 1. The results of the remaining 13 cases will be presented and discussed in this section. Although it may seem repetitious, for the sake of continuity and completeness, the results of the first 10 cases will also be presented here.

Reference 1 should be consulted for a discussion of the response variables selected, and definitions and discussions of influence coefficients and sensitivity.

The cask-rail car system simulated by CARDS is shown as a sketch in Section 1.1.

The 23 cases requested are defined in Sections 2.1 and 2.2 in terms of 13 parameters. The parameters have been divided into two groups. The first group consists of 5 parameters designated as "pure" parameters. The second group contains 8 parameters designated as "composite" parameters. The group of pure parameters includes individual parameters, but has been extended to include sets of parameters that are closely related. The two sets included in this group are $\{k_x\}$, a set of stiffness coefficients consisting of those for the horizontal components of the rear and front tiedowns and $\{k_y\}$, the set of stiffness coefficients consisting of those for the vertical components of the rear and front tiedowns. Composite parameters consist of unrelated parameters, or related parameters that are varied by differing amounts. For example, the composite parameter CP1 defined in Section 2.2

consists of the stiffness coefficients of both the horizontal and vertical components of the tiedowns. The stiffness coefficients of these components are considered to be unrelated because of their differences in orientation. Pure parameters and definitions of their cases are presented in Section 2.1. Composite parameters and definitions of their cases are presented in Section 2.2. The parameter values used in the various cases, and in the base case, are summarized in Section 3.1

The objective of the study was to determine acceleration response spectra, and to evaluate the effects on the spectra of varying the parameters. The parameters are varied in the CARDS model to produce "support" accelerations as functions of time. These time-varying support motions are then used in the single-degree-of-freedom (1-DOF) equations of motion (EOMs) of the CARRS model to generate the horizontal, vertical and rotational accelerations of the cask relative to the actual acceleration of the rail car. The actual rail car acceleration is not the same as the support acceleration. Detailed derivations of the horizontal, vertical and rotational accelerations of the support, along with derivations of the 1-DOF EOMs in terms of the corresponding relative accelerations, are presented in References 1, 2 and 3.

The results of this study are presented in several different forms in Sections 4 and 5. The horizontal, vertical and rotational accelerations of the "support" (not the actual rail car accelerations) are presented as functions of time, for all 23 cases and the base case, in Section 4.2. The forces in the horizontal and vertical components of the tiedowns at both the far and struck ends, for the same cases, are presented as functions of time in Section 4.3.

In Section 4.4, the maximum absolute relative (MAR) horizontal, vertical and rotational accelerations are presented as functions of frequency for all the cases and the base case. These latter plots are the acceleration response spectra for paired cases compared to the base case. In Section 4.5, these spectra are concentrated on three plots, one for each of the three MAR accelerations, to show how the various spectra lie within a band bounded by plus and minus 50 percent values of the base case spectra. The horizontal spectra are well behaved, that is, all of the spectra lie within the band;

however, the vertical and rotational spectra do not conform as well. Seven cases fall outside the band for the vertical spectra, and ten cases fall outside the band for the rotational spectra. These cases, and the parameters they represent, are:

Vertical Spectra		Rotational Spectra	
Case	Parameter	Case	Parameter
C	CP1	C	CP1
7	$\{k_y\}$	D	CP1
8	$\{k_y\}$	3	CP2
11	l_{OCR}	4	CP2
13	CP6	7	$\{k_y\}$
18	l_{OCR}	10	CP4
19	l_{OCR}	11	l_{OCR}
		13	CP6
		20	CP8
		21	CP8

These cases and their parameters are defined in Sections 2.1 and 2.2. It should be noted that, for the vertical spectra, the "pure" parameters $\{k_y\}$, l_{OCR} , l_{PR} and l_{PF} seem to be dominant since CP1 consists of $\{k_y\}$ and the less dominant $\{k_x\}$ while CP6 consists of l_{PR} and l_{PF} for a cask centered on the rail car. The same "pure" parameters appear to be dominant for the rotational spectra. The additional parameters affecting the rotational spectra are CP2, which consists of $\{k_y\}$ and the less dominant $\{k_x\}$ and W_p , CP4 which consists of the elements of $\{k_y\}$ varied individually, and CP8 which consists of $\{k_y\}$, $\{k_x\}$, W_p , and the stiffness coefficients of the horizontal and vertical components of the springs between the rail car and its trucks.

The sensitivities of selected response variables to parameter variations have been determined from a sensitivity analysis. Results of the sensitivity analysis are presented in Section 4.1 and Section 5. Section 4.1 presents a tabular summary of the results of the parametric and sensitivity analysis in

terms of the values of selected response variables at the base case and at the other 23 cases considered. This table also shows the differences between the values of the response variables at the base case and the values of the response variables at the other cases. These differences are also presented as a percent difference from the base case (%DFB). The response variables selected are:

- (1) The peak or maximum values of the absolute values of the accelerations of the support, $|\ddot{x}_S|_{\max}$, $|\ddot{y}_S|_{\max}$ and $|\ddot{\theta}_S|_{\max}$,
- (2) the peak or maximum values of the absolute values of the relative (MAR) accelerations (the cask relative to the rail car or support), $|\ddot{x}_d|_{\max}$, $|\ddot{y}_d|_{\max}$ and $|\ddot{\theta}_d|_{\max}$, and
- (3) the peak or maximum values of the forces in the horizontal tiedowns ($DUS1_{\max}$ and $DUS4_{\max}$) and in the vertical tiedowns ($DUS2_{\max}$ and $DUS3_{\max}$).

In Section 5, the parameters are ranked according to how sensitive the response variables are to the parameter changes. In Section 5.1, the parameters are ranked by sensitivity expressed as the absolute value of the percent difference from the base case, $|\%DFB|$, obtained from the table in Section 4.1. These rankings are graphically portrayed in bar charts, one for each of the response variables, in Section 5.1.1.

The results of Sections 4.1, 5.1 and 5.1.1 are expressed in terms of "sensitivity ranges" in the table in Section 5.1.2. In this table, the dividing point between "sensitive" and "insensitive" was arbitrarily selected as 40%DFB. The entire sensitivity range is divided into the following five subranges:

%DFB	Ranges	Subranges
80-100 Up 60-80 40-60	Sensitive	1. Response variable (RV) highly sensitive 2. RV sensitive 3. RV moderately sensitive
20-40 0-20	Insensitive	4. RV moderately insensitive 5. RV insensitive

The table in Section 5.1.2 shows that, when this sensitivity scale is applied, the horizontal accelerations $|\ddot{x}_s|_{\max}$ and $|\ddot{x}_d|_{\max}$ fall into the insensitive range, while the vertical accelerations $|\ddot{y}_s|_{\max}$ and $|\ddot{y}_d|_{\max}$ and the rotational accelerations $|\ddot{\theta}_s|_{\max}$ and $|\ddot{\theta}_d|_{\max}$ extend into the "highly sensitive" subrange. The tiedown forces extend no higher than the "moderately sensitive" subrange. The vertical accelerations are sensitive to the parameters $\{k_y\}$, ℓ_{OCR} , CP1 and CP6. The rotational accelerations are sensitive to the parameters $\{k_y\}$, CP1, CP2, CP8, ℓ_{OCR} , CP6, CP4 and CP3. These parameters and their cases are the same as those identified with the response spectra that fell outside the $\pm 50\%$ band on the response spectra plots in Section 4.5. They have been discussed earlier. It should be noted from the table in Section 5.1.2 that $|\ddot{\theta}_s|_{\max}$ is also moderately sensitive to W_p . The tiedown forces are moderately sensitive to the parameters CP2 and CP8. The vertical tiedown forces are also moderately sensitive to the vertical distance Z_p .

In Section 5.2, the "pure" parameters are ranked by influence coefficient and by sensitivity expressed as the contribution of each parameter to the total change in the response variable (see Reference 1, pages 23-26). The table in Section 5.2 shows that, for all the response variables except the vertical accelerations, the most influential "pure" parameter is the vertical distance Z_p . The parameter which has the most influence on the vertical accelerations is ℓ_{OCR} ,

the horizontal distance between the cg's of the cask and rail car. It should be noted that for the vertical accelerations λ_{OCR} is divided into two parameters, $\lambda_{OCR}(FE)$ when the cg of the cask is located on the far end side of the rail car cg, and $\lambda_{OCR}(SE)$ when the cg of the cask is located on the struck end side of the rail car cg. This was necessary since the slopes (rates of change of the vertical accelerations with respect to the λ_{OCR}) were nearly equal and opposite in sign. Influence coefficients derived from weighted averages of these slopes (see page 25 in Reference 1) would not have reflected the true influence of λ_{OCR} . The table in Section 5.2 also shows that the "pure" parameter which contributes the most to the total changes in the horizontal accelerations (i.e., the sensitivities) is W_p , the package weight. This table also reveals that the parameter which most affects the total changes in the vertical accelerations is λ_{OCR} , and the parameter causing the greatest changes in the rotational acceleration is $\{k_y\}$. The parameters which most affect the total changes in the tiedown forces $DUS1_{max}$, $DUS4_{max}$, $DUS2_{max}$ and $DUS3_{max}$ are W_p , $\{k_x\}$, Z_p and Z_p , respectively. It should be remembered that the ranges of the parameters used to arrive at the sensitivities were specified at the outset in the definition of the cases. More meaningful values of the sensitivities are obtained if these ranges represent the uncertainties in the parameters.

Nine of the thirteen parameters (both "pure" and "composite") varied were varied about the base case by applying a multiplying factor to the base case values. This multiplying factor is expressed in terms of a parameter ratio, ϕ , the ratio of the parameter value to the base case parameter value. Treating these parameter ratios as parameters, influence coefficients and sensitivities were obtained. These parameter ratio-based influence coefficients and sensitivities are presented in the table in Section 5.3. The sensitivities of each of the response variables to changes in the parameter ratios are illustrated in a series of plots in Section 5.3.1. The results in the table in Section 5.3 may be condensed as follows:

Response Variable	Most Influential Parameter (Parameter Ratio)	Response Variable Most Sensitive to (Parameter Ratio)
$ \ddot{x}_s _{\max}$	$\phi(\text{CP8})$	$\phi(\text{CP8})$
$ \ddot{y}_s _{\max}$	$\phi(\{k_y\})$	$\phi[\lambda_{\text{OCR}}(\text{SE})]$
$ \ddot{\theta}_s _{\max}$	$\phi(\text{CP2})$	$\phi(\text{CP2})$
$ \ddot{x}_d _{\max}$	$\phi(W_p)$	$\phi(W_p)$
$ \ddot{y}_d _{\max}$	$\phi(\{k_y\})$	$\phi[\lambda_{\text{OCR}}(\text{SE})]$
$ \ddot{\theta}_d _{\max}$	$\phi(\text{CP2})$	$\phi(\text{CP2})$

The sensitivities presented here are consistent with those presented in the table in Section 5.1.2.

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FIGURE 1. Spring-Mass Model of Cask-Rail Car System.

"PURE" PARAMETERS AND DEFINITIONS OF THEIR CASES

PARAMETER	CASE	DEFINITION
W_p	1	1. Cask weight W_p doubled.
	2	2. Cask weight W_p halved.
$\{k_x\}$	5	1. k_{s1} and k_{s4} doubled.
	6	2. k_{s1} and k_{s4} halved.
$\{k_y\}$	7	1. k_{s2} and k_{s3} doubled.
	8	2. k_{s2} and k_{s3} halved.
l_{CR}	11	1. $l_{CF} = 0$. This is equivalent to the tiedown attachment point on the cask at the struck end being located directly above the center or cg of the railcar, or $l_{CR} = l_{PF}$.
	18	2. $l_{CF} = l_{PF}$. This is equivalent to the cask being centered on the railcar, ie, the cg of the cask directly above the cg of the railcar, or $l_{CR} = 0$.
	19	3. $l_{CR} = 0$. This is equivalent to the tiedown attachment point on the cask at the Far end being located directly above the cg of the railcar, or $l_{CR} = -l_{PR}$.
Z_p	14	1. Z_p increased by 50%.
	15	2. Z_p reduced by 25%.

DEFINITIONS OF COMPOSITE PARAMETERS AND THEIR CASES

COMPOSITE PARAMETER	CASE	DEFINITION
CP1	C	1. k_{s1} , k_{s4} , k_{s2} and k_{s3} doubled.
	D	2. k_{s1} , k_{s4} , k_{s2} and k_{s3} halved.
CP2	3	1. W_p , k_{s1} , k_{s4} , k_{s2} and k_{s3} doubled.
	4	2. W_p , k_{s1} , k_{s4} , k_{s2} and k_{s3} halved.
CP3	9	k_{s2} halved and k_{s3} changed such that their sum remains constant.
CP4	10	k_{s3} halved and k_{s2} changed such that their sum remains constant.
CP5	12	L_{PR} and L_{PF} increased by 50%.
CP6	13	L_{PR} and L_{PF} increased by 50% with $L_{CR} = L_{CF}$ (cask centered on rail car).
CP7	16	1. $L_{CR} = 0$ and k_{s1} and k_{s4} doubled.
	17	2. $L_{CR} = 0$ and k_{s1} and k_{s4} halved. (cask centered on rail car when $L_{CR} = 0$)
CP8	20	1. W_p , k_{s1} , k_{s2} , k_{s3} , k_{s4} , k_{s5} , k_{s6} , k_{s7}
	21	and k_{s8} doubled. 2. W_p , k_{s1} , k_{s2} , k_{s3} , k_{s4} , k_{s5} , k_{s6} , k_{s7} and k_{s8} halved.

**PARAMETER VALUES USED IN CASES REQUESTED
FOR PARAMETRIC/SENSITIVITY ANALYSIS**

VARIABLE INPUT PARAMETER	BASE CASE	CASE 1, 2		CASE C, D		CASE 3, 4		CASE 5, 6		CASE 7, 8	
		2 CHANGE	1 CHANGE	D CHANGE	C CHANGE	4 CHANGE	3 CHANGE	6 CHANGE	5 CHANGE	8 CHANGE	7 CHANGE
w_p	8×10^4	4×10^4	1.6×10^5			4×10^4	1.6×10^5				
k_{S1} (Low)	5×10^4			2.5×10^4	1×10^5	2.5×10^4	1×10^5	2.5×10^4	1×10^5		
k_{S1} (High)	1×10^6			5×10^5	2×10^6	5×10^5	2×10^6	5×10^5	2×10^6		
k_{S4} (Low)	5×10^4			2.5×10^4	1×10^5	2.5×10^4	1×10^5	2.5×10^4	1×10^5		
k_{S4} (High)	1×10^6			5×10^5	2×10^6	5×10^5	2×10^6	5×10^5	2×10^6		
k_{S2}	5×10^6			2.5×10^6	1×10^7	2.5×10^6	1×10^7			2.5×10^6	1×10^7
k_{S3}	5×10^6			2.5×10^6	1×10^7	2.5×10^6	1×10^7			2.5×10^6	1×10^7

PARAMETER VALUES USED IN CASES FOR PARAMETRIC/SENSITIVITY ANALYSIS

VARIABLE INPUT PARAMETER	BASE CASE	CASE 9, 10		CASE 18		CASE 11, 19		CASE 12, 13		CASE 14, 15	
		10 CHANGE	9 CHANGE	18 CHANGE		19 CHANGE	11 CHANGE	13 CHANGE	12 CHANGE	15 CHANGE	14 CHANGE
W_p	8×10^4										
$k_{s1} (low)$	5×10^4										
$k_{s1} (high)$	1×10^6										
$k_{s4} (low)$	5×10^4										
$k_{s4} (high)$	1×10^6										
k_{s2}	5×10^6	7.5×10^6	2.5×10^6								
k_{s3}	5×10^6	2.5×10^6	7.5×10^6								
l_{CF}	151			102		204	0.	102			
l_{CR}	53			102		0.	204	102			
l_{PF}	102							153	153		
l_{PR}	102							153	153		
z_p	31									23.25	46.5
l_{OCR}	-49.			(0)*		(-102)	(102)	(51)	(2)		

VARIABLE INPUT PARAMETER	BASE CASE	CASE 16,17		CASE 20,21							
		17 CHANGE	16 CHANGE	21 CHANGE	20 CHANGE						
W_p	8×10^4			4×10^4	1.6×10^5						
$k_{s1} (low)$	5×10^4	2.5×10^4	1×10^5	2.5×10^4	1×10^5						
$k_{s1} (high)$	1×10^6	5×10^5	2×10^6	5×10^5	2×10^6						
$k_{s4} (low)$	5×10^4	2.5×10^4	1×10^5	2.5×10^4	1×10^5						
$k_{s4} (high)$	1×10^6	5×10^5	2×10^6	5×10^5	2×10^6						
k_{s2}	5×10^6			2.5×10^6	1×10^7						
k_{s3}	5×10^6			2.5×10^6	1×10^7						
L_{CF}	151										
L_{CR}	53										
L_{PF}	102										
L_{PR}	102										
Z_p	31										
$locr$	-49.	0	0								

PARAMETRIC AND SENSITIVITY ANALYSIS -
SENSITIVITY OF RESPONSE VARIABLES TO PARAMETER CHANGES

RESPONSE VARIABLE	BASE CASE	CASE 1, 2		CASE C , D		CASE 3, 4		CASE 5, 6		CASE 7, 8	
		2 CHANGE	1 CHANGE	D CHANGE	C CHANGE	4 CHANGE	3 CHANGE	6 CHANGE	5 CHANGE	8 CHANGE	7 CHANGE
$ \ddot{x}_s _{\max}$	4189	4663	3843	4544	3760	4874	3256	4535	3784	4204	4176
DIFF. FROM BASE	--	474	-346	355	-429	685	-933	346	-405	15	-13
% DIFF FROM BASE	--	11.3%	-8.3%	8.5%	-10.2%	16.4%	-22.3%	8.26%	-9.67%	0.36%	-0.31%
$ \ddot{y}_s _{\max}$	5626	6748	3883	2876	10400	3487	7302	5852	5142	2786	11369.7
DIFF. FROM BASE	--	1122	-1743	-2750	4774	-2139	1676	226	-484	-2840	5743.7
% DIFF. FROM BASE	--	19.9%	-30.98%	-48.9%	84.8%	-38.0%	29.8%	4.02%	8.6%	-50.5%	102.1%
$ \ddot{\theta}_s _{\max}$	306.1	181.2	437.3	163.9	554	96.5	791.7	316.8	281.8	157.96	603.2
DIFF. FROM BASE	--	-124.9	131.2	-142.2	247.9	-209.6	485.6	10.7	-24.3	-148.14	297.1
% DIFF. FROM BASE	--	-40.8%	42.9%	-46.4%	81.0%	-68.5%	158.6%	3.5%	-7.94%	-48.4%	97.1%
$ \ddot{x}_d _{\max}$	5406	4812	6662	5764	5995	4964	6158	5765	5965	5405	5399
DIFF. FROM BASE	--	-594	1256	358	589	-442	752	359	559	-1	-7
% DIFF. FROM BASE	--	-11.0%	23.2%	6.62%	10.9%	-8.2%	13.9%	6.64%	10.34%	-0.02%	-0.13%
$ \ddot{y}_d _{\max}$	4093	5009	2872	2069	7756	2488	5308	4218	3825	1970	8301
DIFF. FROM BASE	--	916	-1221	-2024	3663	-1605	1215	125	-268	-2123	4208
% DIFF. FROM BASE	--	22.4%	-29.8%	-49.5%	89.5%	-39.2%	29.7%	3.05%	-6.55%	-51.9%	102.8%
$ \ddot{\theta}_d _{\max}$	143.7	89.1	197.9	71.4	279.6	43.9	387.4	138	140.4	73.5	285.1
DIFF. FROM BASE	--	-54.6	54.2	-72.3	135.9	-99.8	243.7	-5.7	-3.3	-70.2	141.4
% DIFF. FROM BASE	--	-38.0%	37.7%	-50.3%	94.6%	-69.5%	169.6%	-3.97%	-2.3%	-48.9%	98.4%

RESPONSE VARIABLE	BASE CASE	CASE 9, 10		CASE 18		CASE 11, 19		CASE 12, 13		CASE 14, 15	
		10	9	18		19	11	13	12	15	14
		CHANGE	CHANGE	CHANGE		CHANGE	CHANGE	CHANGE	CHANGE	CHANGE	CHANGE
$ \ddot{x}_s _{\max}$	4189	4190	4195	4192		4178	4175	4139	4136	4141	4310
DIFF. FROM BASE	--	1	6	3		-11	-14	-50	-53	-48	121
% DIFF. FROM BASE	--	0.024%	0.143%	0.072%		-0.26%	-0.33%	-1.19%	-1.27%	-1.15%	2.9%
$ \ddot{y}_s _{\max}$	5626	5876	5500	62.3		11320.	11180.	52.2	4673	4898	7038
DIFF. FROM BASE	--	250	-126	-5564		5694	5554	-5574	-953	-728	1412
% DFB	--	4.44%	-2.24%	-98.9%		101.2%	98.7%	-99.1%	-16.9%	-12.9%	25.1%
$ \ddot{\theta}_s _{\max}$	306.1	461.9	158.2	237.2		368.7	81.6	107.1	194.2	266.2	384
DIFF. FROM BASE	--	155.8	-147.9	-68.9		62.6	-224.5	-199.	-111.9	-39.9	77.9
% DFB	--	50.9%	-48.3%	-22.5%		20.4%	-73.3%	-65.%	-36.6%	-13.%	25.4%
$ \ddot{x}_d _{\max}$	5406	5392	5413	5386		5465	5464	5486	5499	5489	5218
DIFF. FROM BASE	--	-14	7	-20		59	58	80	93	83	-188
% DFB	--	-0.26%	0.13%	-0.37%		1.09%	1.07%	1.48%	1.72%	1.54%	-3.48%
$ \ddot{y}_d _{\max}$	4093	4203	4117	73.4		8081	7932	61.99	3474	3593	5052
DIFF. FROM BASE	--	110	24	-4020		3988	3839	4031	-619	-500	959
% DFB	--	2.69%	0.59%	-98.2%		97.4%	93.8%	98.5%	-15.1%	-12.2%	23.4%
$ \ddot{\theta}_d _{\max}$	143.7	218.	75.	111.7		170.3	36.8	50.1	90.96	125.4	179.1
DIFF. FROM BASE	--	74.3	-68.7	-32.		26.6	-106.9	-93.6	-52.7	-18.3	35.4
% DFB	--	51.7%	-47.8%	-22.3%		18.5%	-74.4%	-65.1%	-36.7%	-12.7%	24.6%

RESPONSE VARIABLE	BASE CASE	CASE 16, 17		CASE 20, 21							
		17	16	21	20						
		CHANGE	CHANGE	CHANGE	CHANGE						
$ \ddot{x}_s _{\max}$	4189	4535	3784	5017	3118						
DIFF. FROM BASE	--	346	-405	828	-1071						
% DFB	--	8.26%	-9.67%	19.8%	-25.6%						
$ \ddot{y}_s _{\max}$	5626	5852	5144	4530	5350						
DIFF. FROM BASE	--	226	-482	-1096	-276						
% DFB	--	4.02%	-8.57%	-19.5%	-4.9%						
$ \ddot{e}_s _{\max}$	306.1	316.8	281.8	121.3	602						
DIFF. FROM BASE	--	10.7	-24.3	-184.8	295.9						
% DFB	--	3.5%	-7.9%	-60.4%	96.7%						
$ \ddot{x}_d _{\max}$	5406	5765	5965	5161	6052						
DIFF. FROM BASE	--	359	559	-245	646						
% DFB	--	6.64%	10.3%	-4.5%	12.0%						
$ \ddot{y}_d _{\max}$	4093	4218	3825	3167	4897						
DIFF. FROM BASE	--	125	-268	-926	804						
% DFB	--	3.05%	-6.55%	-22.6%	19.6%						
$ \ddot{e}_d _{\max}$	143.7	138.	140.4	53.	369.5						
DIFF. FROM BASE	--	-5.7	-3.3	-90.7	225.8						
% DFB	--	-3.97%	-2.3%	-63.1%	157.1%						

[illegible]

[illegible]

[illegible]

FIGURE 8.1. Horizontal Acceleration of the Support For An Equivalent Single-Degree-of-Freedom System (Requested Base Case and Cases 1 and 2)

FIGURE 8.2. Horizontal Acceleration of the Support For An Equivalent Single-Degree-of-Freedom System (Requested Base Case and Cases C and D)

FIGURE 8.3. Horizontal Acceleration of the Support For An Equivalent Single-Degree-of-Freedom System
(Requested Base Case and Cases 3 and 4)

FIGURE 8.4. Horizontal Acceleration of the Support For An Equivalent Single-Degree-of-Freedom System (Requested Base Case and Cases 5 and 6)

FIGURE 8.5. Horizontal Acceleration of the Support For An Equivalent Single-Degree-of-Freedom System (Requested Base Case and Cases 7 and 8)

FIGURE 9.1. Vertical Acceleration of the Support For An Equivalent Single-Degree-of-Freedom System (Requested Base Case and Cases 1 and 2)

FIGURE 9.2. Vertical Acceleration of the Support For An Equivalent Single-Degree-of-Freedom System (Requested Base Case and Cases C and D)

FIGURE 9.3. Vertical Acceleration of the Support For An Equivalent Single-Degree-of-Freedom System (Requested Base Case and Cases 3 and 4)

FIGURE 9.4. Vertical Acceleration of the Support For An Equivalent Single-Degree-of-Freedom System (Requested Base Case and Cases 5 and 6)

FIGURE 9.5. Vertical Acceleration of the Support For An Equivalent Single-Degree-of-Freedom System (Requested Base Case and Cases 7 and 8)

FIGURE 10.1. Rotational Acceleration of the Support For An Equivalent Single-Degree-of-Freedom System (Requested Base Case and Cases 1 and 2)

FIGURE 10.2. Rotational Acceleration of the Support For An Equivalent Single-Degree-of-Freedom System (Requested Base Case and Cases C and D)

FIGURE 10.3. Rotational Acceleration of the Support For An Equivalent Single-Degree-of-Freedom System (Requested Base Case and Cases 3 and 4)

FIGURE 10.4. Rotational Acceleration of the Support For An Equivalent Single-Degree-of-Freedom System (Requested Base Case and Cases 5 and 6)

FIGURE 10.5. Rotational Acceleration of the Support For An Equivalent Single-Degree-of-Freedom System (Requested Base Case and Cases 7 and 8)

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FIGURE 11. Response Spectrum: Maximum Absolute Relative Horizontal Acceleration vs Frequency
(Requested Base Case and Cases 1 and 2)

FIGURE 12. Response Spectrum: Maximum Absolute Relative Vertical Acceleration vs Frequency
(Requested Base Case and Cases 1 and 2)

FIGURE 13. Response Spectrum: Maximum Absolute Relative Rotational Acceleration vs Frequency
(Requested Base Case and Cases 1 and 2)

FIGURE 14. Response Spectrum: Maximum Absolute Relative Horizontal Acceleration vs Frequency
(Requested Base Case and Cases C and D)

FIGURE 15. Response Spectrum: Maximum Absolute Relative Vertical Acceleration vs Frequency
(Requested Base Case and Cases C and D)

FIGURE 16. Response Spectrum: Maximum Absolute Relative Rotational Acceleration vs Frequency
(Requested Base Case and Cases C and D)

FIGURE 17. Response Spectrum: Maximum Absolute Relative Horizontal Acceleration vs Frequency
(Requested Base Case and Cases 3 and 4)

FIGURE 18. Response Spectrum: Maximum Absolute Relative Vertical Acceleration vs Frequency (Requested Base Case and Cases 3 and 4)

FIGURE 19. Response Spectrum: Maximum Absolute Relative Rotational Acceleration vs Frequency
(Requested Base Case and Cases 3 and 4)

FIGURE 20. Response Spectrum: Maximum Absolute Relative Horizontal Acceleration vs Frequency
(Requested Base Case and Cases 5 and 6)

FIGURE 21. Response Spectrum: Maximum Absolute Relative Vertical Acceleration vs Frequency
(Requested Base Case and Cases 5 and 6)

FIGURE 22. Response Spectrum: Maximum Absolute Relative Rotational Acceleration vs Frequency
(Requested Base Case and Cases 5 and 6)

FIGURE 23. Response Spectrum: Maximum Absolute Relative Horizontal Acceleration vs Frequency
(Requested Base Case and Cases 7 and 8)

FIGURE 24. Response Spectrum: Maximum Absolute Relative Vertical Acceleration vs Frequency
(Requested Base Case and Cases 7 and 8)

FIGURE 25. Response Spectrum: Maximum Absolute Relative Rotational Acceleration vs Frequency
(Requested Base Case and Cases 7 and 8)

PARAMETRIC AND SENSITIVITY ANALYSIS -
RANKING OF PARAMETERS BY ABSOLUTE PERCENT DIFFERENCE
OF RESPONSE VARIABLES FROM BASE CASE VALUES

RESPONSE VARIABLES (RV)	PARAMETERS (P)	CASES	ABSOLUTE PERCENT DIFFERENCE FROM BASE 100 DFB	PARAMETER RANKING BY 100 DFB	
$ \dot{x}_s _{max}$	W_p	1	8.3		
	"	2	11.3	3	
	CP1	C	10.2	4	
	"	D	8.5		
	CP2	3	22.3	2	
	"	4	16.4		
	$\{k_x\}$	5	9.67	5	
	"	6	8.26		
	$\{k_y\}$	7	0.31		
	"	8	0.36	9	
	CP3	9	0.143	11	
	CP4	10	0.024	12	
	locR	11	0.33	10	
	"	18	0.072		
	"	19	0.26		
	CP5	12	1.27	7	
	CP6	13	1.19	8	
	Z_p	14	2.9	6	
	"	15	1.15		
	CP7	16	9.67	5	
	"	17	8.26		
	CP8	20	25.6	1	
	"	21	19.8		
$ \ddot{y}_s _{max}$	W_p	1	30.98	6	
	"	2	19.9		
	CP1	C	84.8	4	
	"	D	48.9		
	CP2	3	29.8		
	"	4	38.	5	
	$\{k_x\}$	5	8.6	10	
	"	6	4.02		
	$\{k_y\}$	7	102.1	1	
	"	8	50.5		

RESPONSE VARIABLES (RV)	PARAMETERS (P)	CASES	ABSOLUTE PERCENT DIFFERENCE FROM BASE 100 DFB	PARAMETER RANKING BY 100 DFB	
$ \ddot{Y}_s _{max}$	CP3	9	2.24	13	
(CONT.)	CP4	10	4.44	12	
	locR	11	98.7		
	"	18	98.9		
	"	19	101.2	2	
	CP5	12	16.9	9	
	CP6	13	99.1	3	
	$\ddot{Z}_p$	14	25.1	7	
	"	15	12.9		
	CP7	16	4.02		
	"	17	8.57	11	
	CP8	20	4.9		
	"	21	19.5	8	
$ \ddot{\Theta}_s _{max}$	$\dot{W}_p$	1	42.9	9	
	"	2	40.8		
	CP1	C	81.	4	
	"	D	46.4		
	CP2	3	158.6	1	
	"	4	68.5		
	$\{K_x\}$	5	7.94	12	
	"	6	3.5		
	$\{K_y\}$	7	97.1	2	
	"	8	48.4		
	CP3	9	48.3	8	
	CP4	10	50.9	7	
	locR	11	73.3	5	
	"	18	22.5		
	"	19	20.4		
	CP5	12	36.6	10	
	CP6	13	65.	6	
	$\ddot{Z}_p$	14	25.4	11	
	"	15	13.		
	CP7	16	7.9	13	
	"	17	3.5		

RESPONSE VARIABLES (RV)	PARAMETERS (P)	CASES	ABSOLUTE PERCENT DIFFERENCE FROM BASE % DFB	PARAMETER RANKING BY % DFB	
$ \ddot{e}_s _{\max}$	CP8	20	96.7	3	
(CONT.)	"	21	60.4		
$ \ddot{x}_d _{\max}$	W_p	1	23.2	1	
	"	2	11.		
	CP1	C	10.9	4	
	"	D	6.62		
	CP2	3	13.9	2	
	"	4	8.2		
	$\{k_x\}$	5	10.34	5	
	"	6	6.64		
	$\{k_y\}$	7	0.13	12	
	"	8	0.02		
	CP3	9	0.13	12	
	CP4	10	0.26	11	
	δ_{CR}	11	1.07		
	"	18	0.37		
	"	19	1.09	10	
	CP5	12	1.72	8	
	CP6	13	1.48	9	
	Z_p	14	3.48	7	
	"	15	1.54		
	CP7	16	10.3	6	
	"	17	6.64		
	CP8	20	12.	3	
	"	21	4.5		
$ \ddot{y}_d _{\max}$	W_p	1	29.8	6	
	"	2	22.4		
	CP1	C	89.5	4	
	"	D	49.5		
	CP2	3	29.7		
	"	4	39.2	5	
	$\{k_x\}$	5	6.55	10	
	"	6	3.05		

RESPONSE VARIABLES (RV)	PARAMETERS (P)	CASES	ABSOLUTE PERCENT DIFFERENCE FROM BASE 10% DFB/	PARAMETER RANKING BY 10% DFB/	
$ \ddot{y}_d _{max}$	$\{k_y\}$	7	102.8	1	
(CONT.)	"	8	51.9		
	CP3	9	0.59	12	
	CP4	10	2.69	11	
	locR	11	93.8		
	"	18	98.2	3	
	"	19	97.4		
	CP5	12	15.1	9	
	CP6	13	98.5	2	
	Z_p	14	23.4	7	
	"	15	12.2		
	CP7	16	6.55	10	
	"	17	3.05		
	CP8	20	19.6		
	"	21	22.6	8	
$ \ddot{\theta}_d _{max}$	W_p	1	37.7		
	"	2	38.	9	
	CP1	C	94.6	4	
	"	D	50.3		
	CP2	3	169.6	1	
	"	4	69.5		
	$\{k_x\}$	5	2.3		
	"	6	3.97	12	
	$\{k_y\}$	7	98.4	3	
	"	8	48.9		
	CP3	9	47.8	8	
	CP4	10	51.7	7	
	locR	11	74.4	5	
	"	18	22.3		
	"	19	18.5		
	CP5	12	36.7	10	
	CP6	13	65.1	6	
	Z_p	14	24.6	11	
	"	15	12.7		

RESPONSE VARIABLES (RV)	PARAMETERS (P)	CASES	ABSOLUTE PERCENT DIFFERENCE FROM BASE % DFB	PARAMETER RANKING BY % DFB	
$ \ddot{\theta}_d _{max}$	CP7	16	2.3		
(CONT.)	"	17	3.97	12	
	CP8	20	157.1	2	
	"	21	63.1		
$DUS _{max}$	W_p	1	29.2		
	"	2	32.2	3	
	CP1	C	12.31		
	"	D	16.75	6	
	CP2	3	45.3	1	
	"	4	42.9		
	$\{k_x\}$	5	12.17		
	"	6	16.76	5	
	$\{k_y\}$	7	0.		
	"	8	0.243	11	
	CP3	9	0.15	12	
	CP4	10	0.12	13	
	$locr$	11	0.395	10	
	"	18	0.12		
	"	19	0.335		
	CP5	12	1.16	8	
	CP6	13	1.06	9	
	Z_p	14	2.22	7	
	"	15	0.943		
	CP7	16	12.17		
	"	17	16.8	4	
	CP8	20	41.9	2	
	"	21	40.9		
$DUS4_{max}$	W_p	1	29.23		
	"	2	31.4	3	
	CP1	C	12.35		
	"	D	16.76	4	
	CP2	3	45.27	1	
	"	4	42.86		

RESPONSE VARIABLES (RV)	PARAMETERS (P)	CASES	ABSOLUTE PERCENT DIFFERENCE FROM BASE 10%DFB	PARAMETER RANKING BY 10%DFB	
DUS4 _{max}	{k _x }	5	12.18		
(CONT.)	"	6	16.76	4	
	{k _y }	7	0.		
	"	8	0.23	9	
	CP3	9	0.13	10	
	CP4	10	0.13	10	
	locR	11	0.4	8	
	"	18	0.13		
	"	19	0.368		
	CP5	12	1.14	6	
	CP6	13	1.07	7	
	Z _p	14	2.2	5	
	"	15	0.937		
	CP7	16	12.18		
	"	17	16.76	4	
	CP8	20	41.9	2	
	"	21	40.9		
DUS2 _{max}	W _p	1	30.35	5	
	"	2	30.21		
	CP1	C	8.095	11	
	"	D	6.38		
	CP2	3	42.9	2	
	"	4	31.5		
	{k _x }	5	16.19	8	
	"	6	14.61		
	{k _y }	7	2.95		
	"	8	13.92	10	
	CP3	9	15.1	9	
	CP4	10	3.67	12	
	locR	11	20.2	7	
	"	18	8.82		
	"	19	10.66		
	CP5	12	30.27	6	
	CP6	13	37.2	4	

RESPONSE VARIABLES (RV)	PARAMETERS (P)	CASES	ABSOLUTE PERCENT DIFFERENCE FROM BASE 10%DFB/	PARAMETER RANKING BY 10%DFB/	
DUS2 max	Zp	14	47.38	1	
(CONT.)	"	15	24.6		
	CP7	16	16.19	8	
	"	17	14.6		
	CP8	20	41.07	3	
	"	21	30.9		
DUS3 max	Wp	1	27.3		
	"	2	27.8	6	
	CP1	C	2.8		
	"	D	10.52	8	
	CP2	3	28.1		
	"	4	29.2	4	
	{kx}	5	4.43		
	"	6	8.9	9	
	{ky}	7	0.34		
	"	8	4.2	11	
	CP3	9	2.8	12	
	CP4	10	7.38	10	
	LocR	11	27.9	5	
	"	18	6.1		
	"	19	7.25		
	CP5	12	31.9	3	
	CP6	13	26.6	7	
	Zp	14	48.6	1	
	"	15	24.8		
	CP7	16	4.43		
	"	17	8.9	9	
	CP8	20	36.15	2	
	"	21	30.2		

RESPONSE VARIABLE : $ \ddot{x}_s _{max}$			ABSOLUTE PERCENT DIFFERENCE FROM BASE CASE					
PARAMETER	CASES	RANK	0	10	20	30	40	50
CP8	20	1						
	21							
CP2	3	2						
	4							
Wp	1	3						
	2							
CP1	C	4						
	D							
CP9	16	5						
	17							
{k _x }	5	5						
	6							
Zp	14	6						
	15							
CP5	12	7						
CP6	13	8						
{k _y }	7	9						
	8							
h _{ocr}	11	10						
	18							
CP3	19	11						
	9							
CP4	10	12						

RESPONSE VARIABLE : $\ddot{y}_s / \max$

PARAMETER	CASES	RANK	ABSOLUTE PERCENT DIFFERENCE FROM BASE CASE							
			0	20	40	60	80	100	120	
{k _y }	7	1								
	8									
LoCR	11									
	18									
	19	2								
CP6	13	3								
CP1	C	4								
	D									
CP2	3									
	4	5								
W _p	1	6								
	2									
Z _p	14	7								
	15									
CP8	20									
	21	8								
CP5	12	9								
{k _x }	5	10								
	6									
CP7	16									
	17	11								
CP4	10	12								
CP3	9	13								

RESPONSE VARIABLE : $|\ddot{\theta}_s|_{\max}$

PARAMETER	CASES	RANK	ABSOLUTE PERCENT DIFFERENCE FROM BASE CASE					
			0	50	100	150	200	250
CP2	3	1
	4							
{k _y }	7	2
	8							
CP8	20	3
	21							
CP1	C	4
	D							
Loer	11	5
	18							
	19							
CP6	13	6
CP4	10	7
CP3	9	8
W _P	1	9
	2							
CP5	12	10
Z _P	14	11
	15							
{k _x }	5	12
	6							
CP7	16	13
	17							

RESPONSE VARIABLE : $\ddot{x}_d / \max$

PARAMETER	CASES	RANK	ABSOLUTE PERCENT DIFFERENCE FROM BASE CASE					
			0	10	20	30	40	50
W_p	1	1						
	2							
CP2	3	2						
	4							
CP8	20	3						
	21							
CP1	C	4						
	D							
$\{k_x\}$	5	5						
	6							
CP7	16	6						
	17							
Z_p	14	7						
	15							
CP5	12	8						
CP6	13	9						
L_{ocr}	11							
	18							
CP4	19	10						
	10	11						
$\{k_y\}$	7	12						
	8							
CP3	9	12						

RESPONSE VARIABLE : $|\ddot{y}_d|_{max}$

RESPONSE VARIABLE : $\ddot{\theta}_d / \max$

PARAMETER	CASES	RANK	ABSOLUTE PERCENT DIFFERENCE FROM BASE CASE					
			0	50	100	150	200	250
CP2	3	1
	4							
CP8	20	2
	21							
{k _y }	7	3
	8							
CP1	C	4
	D							
Loer	11	5
	18							
	19							
CP6	13	6
CP4	10	7
CP3	9	8
W _p	1	9
	2							
CP5	12	10
	13							
Z _p	14	11
	15							
{k _x }	5	12
	6							
CP7	16	13
	17							

RESPONSE VARIABLE : DUST _{max}

PARAMETER	CASES	RANK	ABSOLUTE PERCENT DIFFERENCE FROM BASE CASE					
			0	10	20	30	40	50
CP2	3	1						
	4							
CP8	20	2						
	21							
Wp	1	3						
	2							
CP7	16	4						
	17							
{K _x }	5	5						
	6							
CP1	C	6						
	D							
Zp	14	7						
	15							
CP5	12	8						
CP6	13	9						
LocR	11	10						
	18							
	19							
{K _y }	7	11						
	8							
CP3	9	12						
CP4	10	13						

RESPONSE VARIABLE: $DLSH_{max}$

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RESPONSE VARIABLE : $DUSZ_{max}$								
PARAMETER	CASES	RANK	ABSOLUTE PERCENT DIFFERENCE FROM BASE CASE					
			0	10	20	30	40	50
Z_p	14	1						
	15							
CP2	3	2						
	4							
CP8	20	3						
	21							
CP6	13	4						
W_p	1	5						
	2							
CP5	12	6						
ρ_{CR}	11	7						
	18							
	19							
$[A_x]$	5	8						
	6							
CP7	16	9						
	17							
CP3	9	10						
$[A_y]$	7	11						
	8							
CP1	C	12						
	D							
CP4	10	13						

RESPONSE VARIABLE : DUS3 max

RANGE OF % DFB →	← INSENSITIVE	←	←	SENSITIVE	→
	0 - 20	20.01 - 40	40.01 - 60	60.01 - 80.	80.01 - 100 UP
RESPONSE VARIABLE (RV)	RV INSENSITIVE	RV MODERATELY INSENSITIVE	RV MODERATELY SENSITIVE	RV SENSITIVE	RV HIGHLY SENSITIVE
$ \ddot{x}_s _{\max}$	W_p	CP8			
	CP1	CP2			
	CP7				
	$\{k_x\}$				
	Z_p				
	CP5				
	CP6				
	$\{k_y\}$				
	locR				
	CP3				
	CP4				
$ \ddot{y}_s _{\max}$	CP8	CP2			$\{k_y\}$
	CP5	W_p			locR
	$\{k_x\}$	Z_p			CP6
	CP7				CP1
	CP4				
	CP3				
$ \ddot{\theta}_s _{\max}$	$\{k_x\}$	CP5	CP4	locR	CP2
	CP7	Z_p	CP3	CP6	$\{k_y\}$
			W_p		CP8
					CP1
$ \ddot{x}_d _{\max}$	CP2	W_p			
	CP8				
	CP1				
	$\{k_x\}$				
	CP7				
	Z_p				
	CP5				
	CP6				
	locR				
	CP4				

RANGE OF % DFB →	← INSENSITIVE → 0 - 20	20.01 - 40	← → 40.01 - 60	SENSITIVE 60.01 - 80.	← → 80.01 - 100 UF
RESPONSE VARIABLE (RV)	RV INSENSITIVE	RV MODERATELY INSENSITIVE	RV MODERATELY SENSITIVE	RV SENSITIVE	RV HIGHLY SENSITIVE
$ \ddot{x}_d _{max}$ (CONT.)	{k _y } CP3				
$ \ddot{y}_d _{max}$	CP5 {k _x } CP7 CP4 CP3	CP2 W _p Z _p CP8			{k _y } CP6 locR CP1
$ \ddot{\theta}_d _{max}$	{k _x } CP7	W _p CP5 Z _p	CP4 CP3	locR CP6	CP2 CP8 {k _y } CP1
DUS/max	CP7 {k _x } CP1 Z _p CP5 CP6 locR {k _y } CP3 CP4	W _p	CP2 CP8		
DUS4 max	{k _x } CP1 CP7 Z _p CP5 CP6 locR {k _y } CP3	W _p	CP2 CP8		

RANGE OF % DFB →	← INSENSITIVE →		← SENSITIVE →		80.01 - 100 UP
	0 - 20	20.01 - 40	40.01 - 60	60.01 - 80.	
RESPONSE VARIABLE (RV)	RV INSENSITIVE	RV MODERATELY INSENSITIVE	RV MODERATELY SENSITIVE	RV SENSITIVE	RV HIGHLY SENSITIVE
DUS4 max	CP4				
(CONT.)					
DUS2 max	{kx}	CP6	Zp		
	CP7	Wp	CP2		
	CP3	CP5	CP8		
	{ky}	locR			
	CP1				
	CP4				
DUS3 max	CP1	CP8	Zp		
	{kx}	CP5			
	CP7	CP2			
	CP4	locR			
	{ky}	Wp			
	CP3	CP6			

PARAMETRIC AND SENSITIVITY ANALYSIS -
RANKING OF "PURE" PARAMETERS BY INFLUENCE
COEFFICIENT AND SENSITIVITY

RESPONSE VARIABLES (RV)	PARAMETERS (P)	INFLUENCE COEFFICIENTS $\frac{\partial(RV)}{\partial(P)}$	SENSITIVITY $\frac{\partial(RV)}{\partial(P)} \Delta(P)$	PARAMETER RANKING BY INFLUENCE COEFFICIENT	PARAMETER RANKING BY SENSITIVITY
$ \ddot{x}_s _{\max}$	W_p	-6.833×10^{-3}	-820.	3	1
	$\{k_x\}^*$	-4.768×10^{-4}	-751.	4	2
	$\{k_y\}^{**}$	-3.733×10^{-6}	-28.	5	4
	$\ddot{z}_p$	7.3	169.7	1	3
	locr	-0.0147	-3.	2	5
$ \ddot{y}_s _{\max}$	W_p	-0.02388	-2865.	4	4
	$\{k_x\}$	-4.508×10^{-4}	-710.	6	6
	$\{k_y\}$	-1.144×10^{-3}	8580.	5	3
	$\ddot{z}_p$	92.04	2140.	3	5
	*** locr (FE)	109.	11118.	2	2
	locr (SE)	-110.	-11220.	1	1
$ \ddot{\theta}_s _{\max}$	W_p	2.134×10^{-3}	256.	3	3
	$\{k_x\}$	-2.222×10^{-5}	-35.	5	5
	$\{k_y\}$	5.937×10^{-5}	445.	4	1
	$\ddot{z}_p$	5.067	117.8	1	4
	locr	-1.407	-287.	2	2
$ \ddot{x}_d _{\max}$	W_p	0.01542	1850.	2	1
	$\{k_x\}$	1.2698×10^{-4}	200.	4	3
	$\{k_y\}$	-8.0×10^{-7}	-6.	5	4
	$\ddot{z}_p$	-11.66	-271.	1	2
	locr	-0.0049	-1.	3	5
$ \ddot{y}_d _{\max}$	W_p	-0.01781	-2137.	4	4
	$\{k_x\}$	-2.495×10^{-4}	-393.	6	6
	$\{k_y\}$	8.441×10^{-4}	6331.	5	3
	$\ddot{z}_p$	62.75	1459.	3	5
	locr (FE)	77	7854	2	2
	locr (SE)	-78.5	-8007.	1	1

RESPONSE VARIABLES (RV)	PARAMETERS (P)	INFLUENCE COEFFICIENTS $\frac{\partial(RV)}{\partial(P)}$	SENSITIVITY $\frac{\partial(RV)\Delta(P)}{\partial(P)}$	PARAMETER RANKING BY INFLUENCE COEFFICIENT	PARAMETER RANKING BY SENSITIVITY
$ \ddot{\theta} _{max}$	W_p	9.07×10^{-4}	109.	3	3
	$\{k_x\}$	1.524×10^{-6}	2.4	5	5
	$\{k_y\}$	2.821×10^{-5}	212.	4	1
	Z_p	2.31	53.7	1	4
	ρ_{CR}	-0.6544	-133.5	2	2
DUS1 max	W_p	1.68	201600.	2	1
	$\{k_x\}$	0.0604	95130.	4	2
	$\{k_y\}$	1.067×10^{-4}	800.	5	4
	Z_p	-447.3	-10400.	1	3
	ρ_{CR}	0.9804	200.	3	5
DUS4 max	W_p	0.51	61200.	2	2
	$\{k_x\}$	0.0549	86468.	4	1
	$\{k_y\}$	9.33×10^{-5}	700.	5	4
	Z_p	-404.3	-9400.	1	3
	ρ_{CR}	0.4902	100.	3	5
DUS2 max	W_p	0.51	61200.	3	2
	$\{k_x\}$	0.0198	31185.	4	4
	$\{k_y\}$	-2.279×10^{-3}	-17092.	5	5
	Z_p	3138.	72959.	1	1
	ρ_{CR}	-153.4	31294.	2	3
DUS3 max	W_p	-0.407	-48840.	3	2
	$\{k_x\}$	-0.00749	-11797.	4	4
	$\{k_y\}$	4.56×10^{-4}	3420.	5	5
	Z_p	-2796.	-65007.	1	1
	ρ_{CR}	-152.6	-31130.	2	3

- * Set of stiffness coefficients of the horizontal components of the tiedowns.
- ** Set of stiffness coefficients of the vertical components of the tiedowns.
- *** l_{ocr} divided into two parameters, $l_{ocr}(FE)$ when the cg of the cask is on the far end of the rail car cg, and $l_{ocr}(SE)$ when the cg of the cask is on the struck end of the rail car cg.

RESPONSE VARIABLES (RV)	PARAMETERS (P)	INFLUENCE COEFFICIENTS $\frac{\partial(RV)}{\partial(P)}$	SENSITIVITY $\frac{\partial(RV)\Delta(P)}{\partial(P)}$	PARAMETER RANKING BY INFLUENCE COEFFICIENT	PARAMETER RANKING BY SENSITIVITY
$ \ddot{x}_s _{max}$	$\phi(CP8)$	-1266.	-1899.	1	1
	$\phi(CP2)$	-1078.7	-1618.	2	2
	$\phi(W_p)$	-546.7	-820.	3	3
	$\phi(CP1)$	-522.7	-784.	4	4
	$\phi(\{k_x\})$	-500.7	-751.	5	5
	$\phi(CP7)$	-500.7	-751.	5	5
	$\phi(Z_p)$	225.3	169.	6	6
	$\phi(\{k_y\})$	-18.7	-28.	7	7
	$\phi(\rho_{ocr})$	0.72	3.	8	8
$ \ddot{y}_s _{max}$	$\phi(CP8)$	546.7	820.	8	8
	$\phi(CP2)$	2543.3	3815.	6	5
	$\phi(W_p)$	-1910.	-2865.	7	6
	$\phi(CP1)$	5016.	7524.	4	4
	$\phi(\{k_x\})$	-473.3	-710.	9	9
	$\phi(CP7)$	-472.	-708.	10	10
	$\phi(Z_p)$	2853.3	2140.	5	7
	$\phi(\{k_y\})$	5722.5	8584.	1	3
	$\phi[\rho_{ocr}(FE)]$	-5341.	11118.	3	2
$\phi[\rho_{ocr}(SE)]$	5409.	-11258.	2	1	
$ \ddot{\theta}_s _{max}$	$\phi(CP8)$	320.5	481.	2	2
	$\phi(CP2)$	463.5	695.	1	1
	$\phi(W_p)$	170.7	256.	5	6
	$\phi(CP1)$	260.1	390.1	4	4
	$\phi(\{k_x\})$	-23.3	-35.	8	8
	$\phi(CP7)$	-23.3	-35.	8	8
	$\phi(Z_p)$	157.1	117.8	6	7
	$\phi(\{k_y\})$	296.8	445.2	3	3
	$\phi(\rho_{ocr})$	68.95	287.1	7	5

RESPONSE VARIABLES (RV)	PARAMETERS (P)	INFLUENCE COEFFICIENTS $\frac{\partial(RV)}{\partial(P)}$	SENSITIVITY $\frac{\partial(RV)}{\partial(P)} \Delta(P)$	PARAMETER RANKING BY INFLUENCE COEFFICIENT	PARAMETER RANKING BY SENSITIVITY
$ \ddot{x}_d _{max}$	$\phi(CP8)$	594.	891.	3	3
	$\phi(CP2)$	796.	1194.	2	2
	$\phi(Wp)$	1233.	1850.	1	1
	$\phi(CP1)$	154.	231.	5	5
	$\phi(\{k_x\})$	133.3	200.	6	6
	$\phi(CP7)$	133.3	200.	6	6
	$\phi(Zp)$	-361.3	-271.	4	4
	$\phi(\{k_y\})$	-4.	-6.	7	7
	$\phi(l_{ocr})$	0.24	1.	8	8
$ \ddot{y}_d _{max}$	$\phi(CP8)$	1153.3	1730.	8	7
	$\phi(CP2)$	1880.	2820.	6	5
	$\phi(Wp)$	-1424.7	-2137.	7	6
	$\phi(CP1)$	3791.	5687.	3	4
	$\phi(\{k_x\})$	-262.	-393.	9	9
	$\phi(CP7)$	-262.	-393.	9	9
	$\phi(Zp)$	1945.3	1459.	5	8
	$\phi(\{k_y\})$	4220.7	6331.	1	3
	$\phi[l_{ocr}(FE)]$	-3775.	7858.	4	2
$ \ddot{\theta}_d _{max}$	$\phi[l_{ocr}(SE)]$	3847.	-8008.	2	1
	$\phi(CP8)$	211.	317.	2	2
	$\phi(CP2)$	229.	344.	1	1
	$\phi(Wp)$	72.5	108.8	5	6
	$\phi(CP1)$	138.8	208.2	4	4
	$\phi(\{k_x\})$	1.6	2.4	8	8
	$\phi(CP7)$	1.6	2.4	8	8
	$\phi(Zp)$	71.6	53.7	6	7
	$\phi(\{k_y\})$	141.1	211.6	3	3
$ \ddot{z}_d _{max}$	$\phi(l_{ocr})$	32.1	133.5	7	5
$ \ddot{w}_d _{max}$					
$ \ddot{v}_d _{max}$

FIGURE 26. Sensitivity of Absolute Peak Support Accelerations to Changes in Cask Weight (Requested Base Case and Cases 1 and 2)

FIGURE 31. Sensitivity of Maximax Absolute Relative Accelerations to Changes in Cask Weight (Base Case and Cases 1 and 2)

FIGURE 29. Sensitivity of Absolute Peak Support Accelerations to Simultaneous Changes in the Stiffness Coefficients of Both the Horizontal and Vertical Components of the Tiedowns (Requested Base Case and Cases C and D)

FIGURE 34. Sensitivity of Maximax Absolute Relative Accelerations to Simultaneous Changes in the Stiffness Coefficients of the Horizontal and Vertical Components of the Tiedowns (Base Case and Cases C and D)

FIGURE 30. Sensitivity of Absolute Peak Support Accelerations to Simultaneous Changes in the Cask Weight and the Stiffness Coefficients of the Horizontal and Vertical Components of the Tiedowns (Requested Base Case and Cases 3 and 4)

FIGURE 35. Sensitivity of Maximax Absolute Relative Accelerations to Simultaneous Changes in the Cask Weight and the Stiffness Coefficients of the Horizontal and Vertical Components of the Tiedowns (Base Case and Cases 3 and 4)

FIGURE 27. Sensitivity of Absolute Peak Support Accelerations to Changes in the Stiffness Coefficients of the Horizontal Components of the Tiedowns (Requested Base Case and Cases 5 and 6)

FIGURE 32. Sensitivity of Maximax Absolute Relative Accelerations to Changes in the Stiffness Coefficients of the Horizontal Components of the Tiedowns (Base Case and Cases 5 and 6)

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FIGURE 28. Sensitivity of Absolute Peak Support Accelerations to Changes in the Stiffness Coefficients of the Vertical Components of the Tiedowns
(Requested Base Case and Cases 7 and 8)

FIGURE 33. Sensitivity of Maximax Absolute Relative Accelerations to Changes in the Stiffness Coefficients of the Vertical Components of the Tiedowns (Base Case and Cases 7 and 8)