On-Site WIM System Calibration; An Overview Of NCHRP Study 3-39(2)

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ABSTRACT

This paper offers a preview of NCHRP study 3-39(2), which deals with the calibration of weigh-in-motion (WIM) systems. The feasibility of two methods is explored, namely the use of a combination of test trucks and vehicle simulation models to account for the effect of axle dynamics, and the use of in-service vehicles equipped with automatic vehicle identification (AVI) systems to compare static and dynamic axle loads. The first method was tested through a field experiment involving three test trucks which were run repeatedly over three different types of WIM systems, namely a pressure-cell, a bending plate and a piezo-based system. Their dynamic behavior was modeled using the computer model VESYM. The models were calibrated through on-board acceleration measurements. The second method was tested using the AVI facilities developed for the Heavy Vehicle Electronic License Plate (HELP) project on the I-5 corridor. The static axle load of AVI-equipped vehicles was obtained from the Oregon DOT for two sites, namely Woodburn south-bound and Ashland north-bound. The WIM load data was obtained from Lockheed IMS for all the WIM systems on the I-5 corridor. The data was analyzed to sort-out AVI numbers, dates and times of weighing. Time limits for traveling between sites were established to ensure that trucks had no time to stop and load/unload cargo between sites. Errors were calculated as the percent difference between WIM and static loads for individual axles/axle groups. Calibration factors were derived to set the mean axle weight error to zero. Software was written to handle all calculations.

INTRODUCTION

Weigh-in-motion (WIM) technology has been extensively used in North America for vehicle data collection over the past thirty years. It provides an automated means of obtaining main-lane traffic stream data without interfering with vehicle movement. Typically, WIM data includes wheel/axle loads, axle spacing, vehicle classification, vehicle speed and so on. Various types of sensors are in use, including pressure cells, strain-gauged plates, piezoelectric sensors, capacitance mats and so on.

Traditionally, WIM accuracy in measuring loads is based on comparisons of the in-motion measurements to static load measurements of either axles/axle groups or gross vehicle weights. The WIM error thus defined is comprised by three components, namely:

1. error in measuring the static reference loads,
2. error in measuring the load applied by the in-motion axle to the sensor and,
3. error attributed to the difference between the static axle load and the load applied on the WIM sensor, when the in-motion axle is over the sensor.

The third error component is due to the dynamic interaction between vehicles and pavement and can be quite substantial. Experimental studies determined that the dynamic variation in axle loads depends on suspension type and increases exponentially with increasing vehicle speed and level of pavement roughness, (Gillespie et al, 1993). Typical values of the coefficient of variation of dynamic axle loads are in the 4% to 20% range, (Papagiannakis et al, 1990).

A considerable amount of effort has been spent in calibrating WIM systems and developing specifications for their accuracy, (ASTM Standard E 1318-90). To-date however, there is no widely acceptable evaluation/calibration method which accounts for the third component of error as described above. Nor, there is a method which can be automated to ensure the long-term accuracy of WIM systems. Study NCHRP 3-39(2) address these needs. Its scope is to develop procedures for the on-site evaluation/calibration of WIM systems.

Funding was provided by the National Academy of Sciences under NCHRP Study 3-39(2)

OBJECTIVES

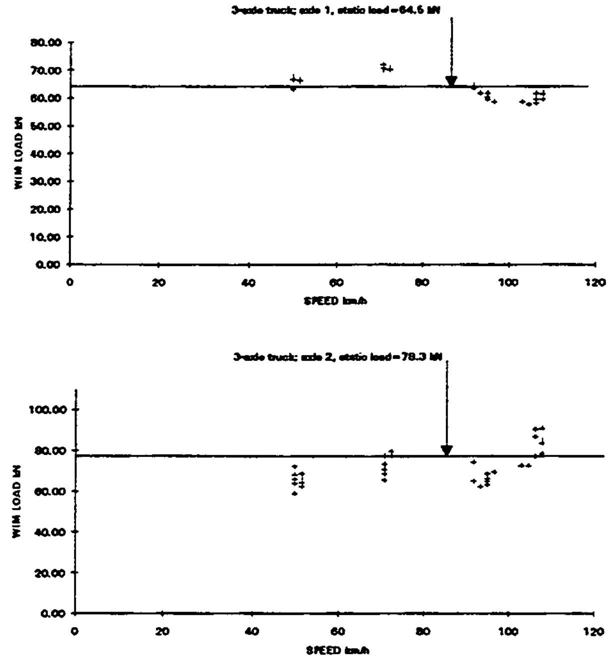
Two objectives were set forth by NCHRP Study 3-39(2):

- examine the feasibility of using a combination of test trucks and vehicle simulation models to evaluate/calibrate WIM systems and,
- examine the feasibility of using automated vehicle identification (AVI) the HELP infrastructure to evaluate/calibrate the WIM systems on the I-5 corridor.

The results of this study to-date are discussed next.

CALIBRATION BASED ON TRUCK SIMULATIONS

This method relies on vehicle dynamic simulations to predict the third component of error defined above. The computer model VESYM is used for these simulations, (Hedrick et al, 1989). Three test trucks were used to field test this approach, namely a 2-axle single unit, a 3-axle single unit and a 5-axle semitrailer. Testing was carried out on three WIM systems, a pressure cell, a bending plate and a piezo, respectively. At each WIM site, 40 runs were performed by each vehicle, (i.e., 10 runs at each of speeds of 50, 70, 90 and 110 km/h). The WIM measurements were plotted for each axle as a function of vehicle speed as measured by the WIM system. Examples of the results are shown for the 3-axle truck for the pressure cell and the piezo system, (Fig., 1 and 2, resp.). Note that the effect of axle dynamics repeats itself in vehicle runs conducted at the same speed. This is in agreement with experimental evidence, which suggests that replicate vehicle runs yield dynamic axle load waveforms repetitive in-space, (Papagiannakis et al, 1990). The remainder of the analysis in this area will focus on comparisons of the average difference of the WIM measurements at a given speed to the VESYM simulation output.



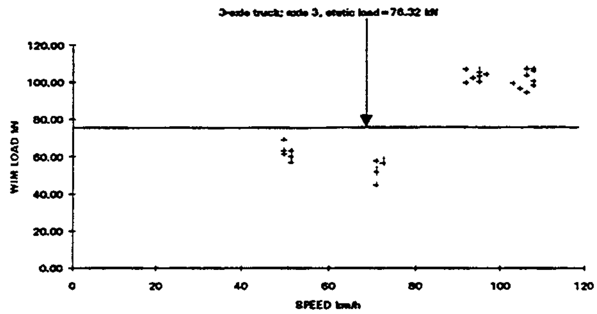


Figure 1: Pressure-Cell WIM Measurements for 3-Axle Truck.

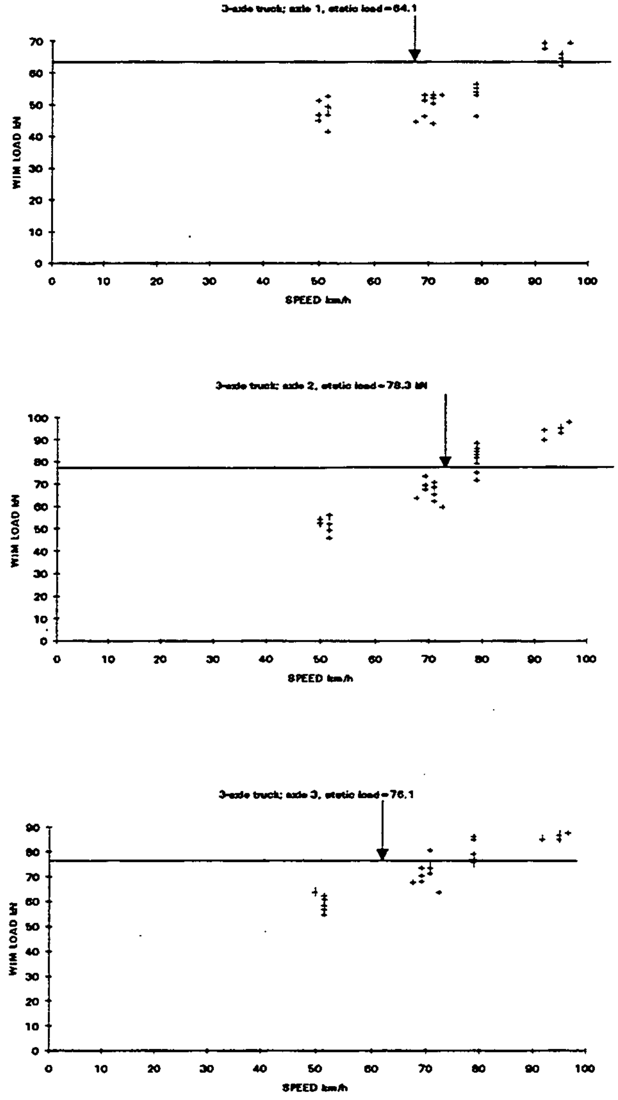


Figure 2: Piezo WIM Measurements for 3-Axle Truck.

A considerable amount of effort has been made to calibrate the VESYM simulation models for these three test vehicles.

This was done using instrumentation on-board these vehicles measuring acceleration of the sprung and unsprung masses, (e.g., Fig. 3 and 4). Calibration was effected by selecting mechanical constants so the estimated accelerations compare with the measured accelerations.

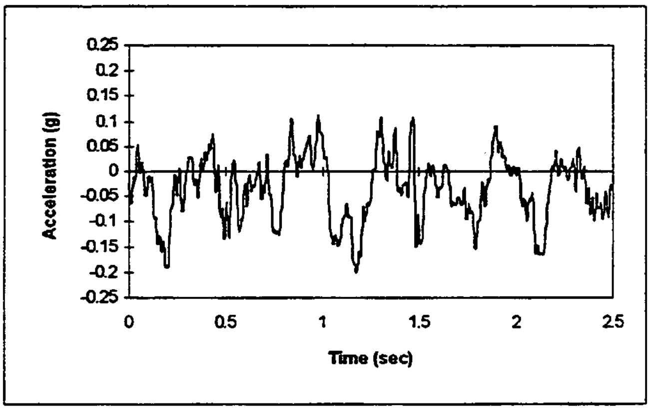


Figure 3: Sprung Mass Acceleration; 3-Axle Truck; Front Passenger Side

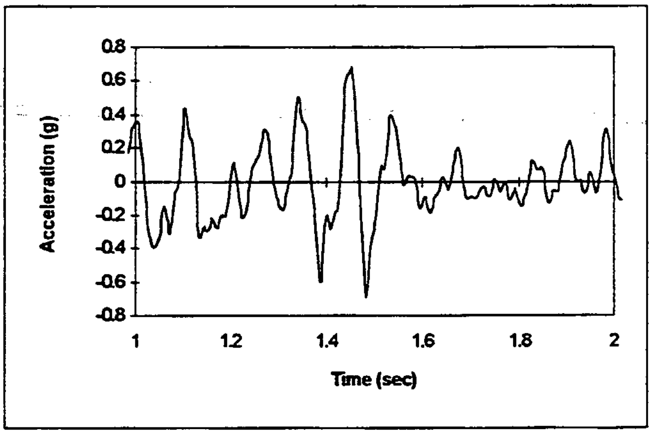


Figure 4: Axle Acceleration; 3-Axle Truck; Steering Front Axle; Passenger Side

AVI-BASED CALIBRATION

This method relies on in-service vehicles equipped with AVI transponders for comparing WIM and static axle loads. The AVI infrastructure of the Heavy Vehicle Electronic License Plate (HELP) program on the I-5 corridor were used for this purpose, (Figure 5). Approximately 5,000 AVI transponder-equipped trucks are currently operating on this system.

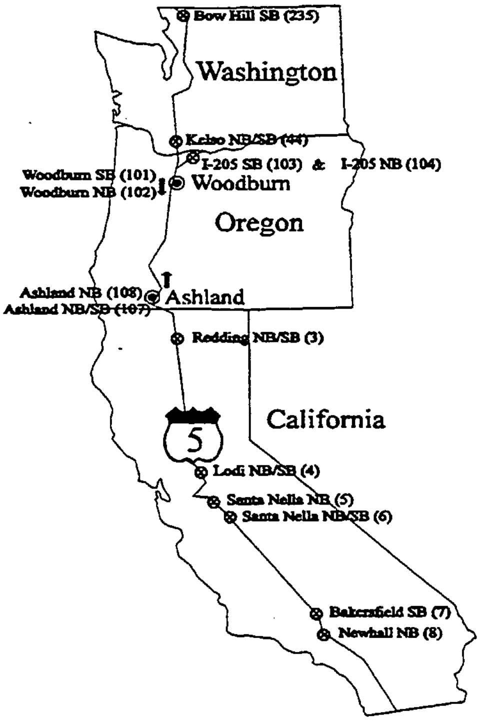


Figure 5: The WIM/AVI and Static Locations on I-5

The database containing the WIM data of the HELP program is being maintained by Lockheed IMS. The data obtained from them covers a period of six months, (i.e., 1/1/94 to 5/31/94). The static axle load data was extracted from a database maintained by Oregon DOT for two locations on the I-5 corridor, namely Woodburn southbound (SB) and Ashland northbound (NB). These are load enforcement scales operating downstream from WIM sorting scales, hence most of the trucks weighed statically at these locations are likely to be heavily loaded. WIM and static data was input into two separate relational databases. Each database, contains in addition to AVI number and load, data on the date, time, vehicle class and axle spacing. The load data in the static database is for axles/axle groups, (i.e., tandems and tridems). The largest percentage of the AVI-equipped vehicles belonged to FHWA class 9, (i.e., 5-axle semi-trailers).

The accuracy of the WIM systems on the I-5 corridor was analyzed using the two databases described earlier. Direct comparisons between WIM and static axle loads were effected by matching the AVI numbers of transponder-equipped vehicles at static and WIM weighing locations and then by cross-checking the date and the driving time between them. Preliminary observation of the data indicated that the WIM load database was not complete. For some locations there was no WIM data whatsoever, e.g., Bow Hill, WA, northbound and southbound and Woodburn, OR, northbound, (i.e., HELP sites 235 and 108). There were also WIM locations where WIM data was not available for particular vehicles, despite the fact that data for these vehicles was available for the same date at adjacent WIM sites.

The data was screened in two stages, first to compare dates and second to compare the driving time between locations. For the latter, the relative travel time between weighing locations was sufficient for identifying vehicles that may have stopped long enough for loading/unloading.

The analysis in the first stage was carried out through a FORTRAN algorithm, which identified particular vehicles that were weighed with both a static and a WIM scale in the same day. The algorithm did not screen out data obtained in consecutive days, to allow for vehicles that drove overnight between weighing locations. Furthermore, it did not screen out data obtained in the transition between months. This was accomplished by identifying all matching AVI numbers obtained in a day of the month involving the number 1, (e.g., static weighing on 1/31/94 and WIM weighing on 2/1/94, or static weighing on 2/28/94 and WIM weighing on 3/1/94 and so on).

The second stage of the analysis was carried out through another FORTRAN algorithm, which screened the reduced database to further eliminate data corresponding to driving times between weighing locations exceeding prescribed maximum values. For each pair of weighing locations, the maximum acceptable driving time was established on the basis of the minimum recorded time plus an allowance for stopping of half-an-hour for every four hours of driving. The minimum travel time was used instead of the actual time difference between weighing locations to eliminate possible discrepancies in the clock settings of the various systems. The time allowance was calculated from the actual distance between locations assuming a driving speed of 60 mph.

The results of the two stages of data screening are shown in Table 1. It should be noted that the number of successful comparisons with respect to date, (i.e., after the first screening) may be higher than the sample size of the WIM load data in a particular location, because of multiple passes of a given vehicle over this site. For example, a particular truck was weighed statically twice on the 5th of February and by a WIM system twice on the 4th of February, three-times on the 5th of February and twice the 6th of February. The total number of possible successful static-WIM load comparisons after the first screening would be 14, (i.e., 2x[2+3+2]).

It is also evident that the second screening with respect to the driving time between weighing locations was fairly restrictive and produced a small number of successful static and WIM load comparisons. Clearly, the further away the WIM location was from one of the two static weighing scales, (i.e., Woodburn SB and Ashland NB), the smaller was the number of successful static and WIM load comparisons.

Table 1:

Sample Size of Databases and of Successful Static and WIM Load Comparisons per Site

NB **Site Location**	**Sample Size WIM Data**	**First Screening (Comparing Dates)**	**Second Screening (Comparing Times)**
Bow Hill, WA	0	0	0
Kelso, WA	234	72	3
I-205, OR	930	159	7
Ashland, OR	640	953	9
Ashland , OR	0	-	-
Redding, CA	345	406	63
Lodi, CA	1292	1199	82
Santa Nella, CA	1113	1187	49
Santa Nella, CA	626	741	16
Newhall, CA	321	316	29
Totals	5501	5033	258

SB **Location**	**Sample Size WIM Data**	**First Screening (Comparing Dates)**	**Second Screening (Comparing Times)**
Bow Hill, WA	0	0	0
Kelso, WA	855	207	46
I-205, OR	1040	223	21
Woodburn, OR	58	31	4
Redding, CA	1227	156	3
Lodi, CA	339	46	2
Santa Nella, CA	449	37	1
Bakersfield, CA	1009	70	1
Totals	4977	770	78

The error analysis focused on 5-axle semi-trailers only and considered errors of steering axles, first tandem axle group, (i.e., drive axles) and second tandem axle group, (i.e., trailer axles). WIM errors were defined as the percent of the arithmetic difference between WIM and static axle load measurements with respect to the static axle load. Frequency distributions of errors were plotted only for WIM systems, where eight or more successful comparisons were made. An example of such frequency distribution is shown in Figure 6 for WIM site 44.

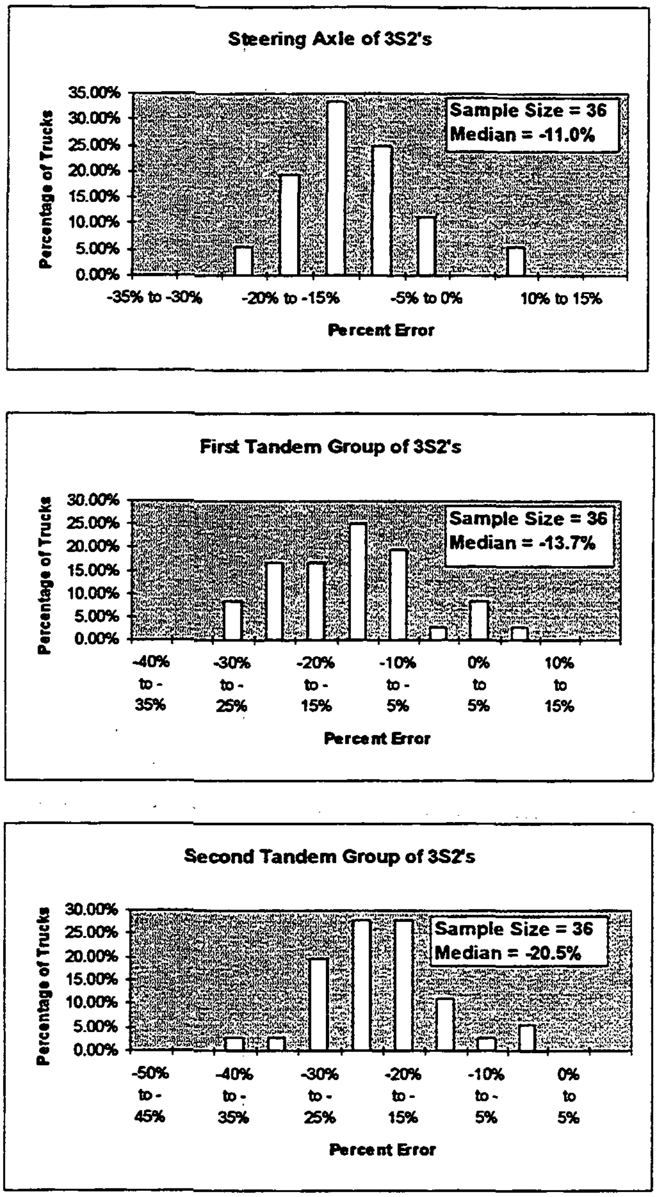


Figure 6: Percent WIM Errors for WIM Site 44 Southbound.

A summary of the median of the WIM errors for each site is shown in Table 2. It can be seen that with a few exceptions the median errors calculated were all negative and had substantial magnitudes.

Table 2:
Median Arithmetic Errors for 5-Axle Semitrailer Trucks

NB WIM Site Name	Median of	Arithmetic	Error %
	Axle 1	Group 1	Group 2
Kelso, WA	-10.64	-2.98	-6.44
I-205 OR	-17.89	-21.86	-20.24
Ashland OR	-2.50	3.69	10.10
Redding, CA	-7.60	-8.98	-10.62
Lodi, CA	0.00	-1.76	-0.54
Santa Nella, CA	-1.73	1.16	-1.68
Santa Nella, CA	0.88	-6.22	2.14
Newhall, CA	-6.50	-0.75	-0.97

SB WIM Site Name	Median of	Arithmetic	Error %
	Axle 1	Group 1	Group 2
Bow Hill, WA	-	-	-
Kelso, WA	-11.01	-13.70	-20.47
I-205 OR	-11.83	-20.19	-26.26
Woodburn OR	4.20	-2.40	2.10
Redding, CA	-51.67	-49.84	-51.48
Lodi, CA	-1.74	-0.61	-11.01
Santa Nella, CA	12.62	-9.38	-6.29
Bakersfield, CA	10.68	-8.21	2.10

Calibration factors were developed through regression, considering the static load as the dependent and the WIM load as the independent variable. Simple linear regression expressions were fitted with no intercept, hence the slope of the line is the calibration factor. One expression was fitted per axle, (i.e., steering, first tandem group and second tandem group) and for each WIM location. In addition, the data from all the axles/axle groups were grouped together and a single regression equation was fitted for each site.
The results are shown in Table 3.

Table 3:
WIM Calibration Relationships

Site 44 SB Axle	Equation x = WIM Load y = Static Load	Correlation (x,y)
Steering	y = 1.1062x	0.592
1st Tandem	y = 1.1320x	0.877
2nd Tandem	y = 1.2412x	0.929
All	y = 1.1751x	0.965

Site 103 SB **Axle**	**Equation** **x = WIM Load** **y = Static Load**	**Correlation (x,y)**
Steering	$y = 1.1665x$	0.609
1st Tandem	$y = 1.2433x$	0.838
2nd Tandem	$y = 1.2889x$	0.935
All	$y = 1.2553x$	0.955

Site 107 NB **Axle**	**Equation** **x = WIM Load** **y = Static Load**	**Correlation (x,y)**
Steering	$y = 0.9839x$	0.751
1st Tandem	$y = 0.9346x$	0.743
2nd Tandem	$y = 0.9119x$	0.701
All	$y = 0.9293x$	0.882

Site 3 NB **Axle**	**Equation** **x = WIM Load** **y = Static Load**	**Correlation (x,y)**
Steering	$y = 1.1258x$	0.221
1st Tandem	$y = 1.1193x$	0.685
2nd Tandem	$y = 1.1209x$	0.722
All	$y = 1.1204x$	0.869

Site 4 NB **Axle**	**Equation** **x = WIM Load** **y = Static Load**	**Correlation (x,y)**
Steering	$y = 1.0050x$	0.370
1st Tandem	$y = 1.0114x$	0.937
2nd Tandem	$y = 1.0116x$	0.918
All	$y = 1.0110x$	0.967

Site 5 NB **Axle**	**Equation** **x = WIM Load** **y = Static Load**	**Correlation (x,y)**
Steering	$y = 1.0154x$	0.336
1st Tandem	$y = 0.9978x$	0.935
2nd Tandem	$y = 1.0208x$	0.936
All	$y = 1.0086x$	0.979

Site 6 NB **Axle**	**Equation** **x = WIM Load** **y = Static Load**	**Correlation (x,y)**
Steering	$y = 1.0025x$	0.691
1st Tandem	$y = 1.0618x$	0.985
2nd Tandem	$y = 0.9764x$	0.979
All	$y = 1.0169x$	0.984

Site 8 NB **Axle**	**Equation** **x = WIM Load** **y = Static Load**	**Correlation (x,y)**
Steering	$y = 1.0766x$	0.352
1st Tandem	$y = 1.0323x$	0.538
2nd Tandem	$y = 0.9956x$	0.633
All	$y = 1.0201x$	0.913

CONCLUSIONS

The feasibility of two methods for WIM calibration is explored, one using of a combination of test trucks and vehicle simulation models to account for the effect of axle dynamics, and the other using of in-service vehicles equipped with automatic vehicle identification (AVI) systems to compare static and dynamic axle loads. The first method was tested through a field experiment involving three test trucks which were run repeatedly over three different types of WIM systems, namely a pressure-cell, a bending plate and a piezo-based system. Their dynamic behavior was modeled using the computer model VESYM. The models were calibrated through on-board acceleration measurements.

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