Space Exploration Technologies

C3-1 Dragon Interface Definition Document
Appendix: Dragon Cargo Flight Environments (only)

Approved Version	15.0
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6.0 DRAGON PAYLOAD ENVIRONMENTS

This section provides the maximum environments that cargo may be exposed for both launch and return missions and for pressurized and unpressurized cargo. Unless otherwise noted, the environments reported herein are applicable to all CRS missions. Once specific cargo is manifested on a particular mission, mission-specific analyses will be performed which will supersede the environments in this document. Mission-specific environments are reported in the Mission Resource Allocation Document (MRAD) and/or applicable ICDs.

6.1 Instrumentation Plan

Please refer to the separate Instrumentation Plan document, *C3-1 Dragon Instrumentation Plan*, specific to each mission.

6.2 Load Factors

Integrated end items shall be designed to accommodate the expected launch and re-entry loads for the Dragon capsule and Falcon 9 provided below.

6.3 Load Spectrums

Load spectrums that cover the expected loading events for one flight (launch, free-flight, berthing) are provided in +/-10% amplitude tiers at the cargo/payload interface (see **Error! Reference source not found.**).

Table 6-1: Falcon 9 Load Spectrum

Amplitude Tier	Cycle Count
100-90	7
90-80	12
80-70	24
70-60	59
60-50	115
50-40	199
40-30	641
30-20	3,120
20-10	3,405
10-0	125,537

6.3.1 Launch Loads – Pressurized and Unpressurized Cargo

All cargo shall withstand the design load factors for launch, shown in **Error! Reference source not found.** through Table 6-11.

The following notes apply to the quasi-static loads:

- Quasi-static loads based on Coupled Loads Analysis (CLA)
- Results shown are limit loads which include a Model Uncertainty Factor (MUF) of 1.25

Table 6-2: Design Load Factors – Launch (valid for CRS 1 and 2 missions only)

Location	Nx (g)	Ny (g)	Nz (g)	Rx (rad/sec^2)	Ry (rad/sec^2)	Rz (rad/sec^2)
Pressurized Cargo:						
Powered DMLE	+5.5/-1.2	±2.3		N/A	N/A	N/A
Aft	+5.3/-1.8	±2.6		N/A	N/A	N/A
Port	+5.3/-1.4	±2.8		N/A	N/A	N/A
Starboard	+5.2/-1.8	±2.3		N/A	N/A	N/A
Center	+5.2/-3.3	±4.8		N/A	N/A	N/A
Floor	+5.2/-1.9	±1.5		N/A	N/A	N/A
Lower Late Load	+5.9/-0.5	±5.1		N/A	N/A	N/A
Upper Late Load (+Y)	+5.3/-4.0	±3.2		N/A	N/A	N/A
Upper Late Load (center)	+5.2/-1.1	±2.7		N/A	N/A	N/A
Upper Late Load (-Y)	+5.4/-4.5	±6.3				
Pressurized Cargo Launch Envelope	**+5.9/-4.5**	**±6.3**		**N/A**	**N/A**	**N/A**
Unpressurized Cargo:						
Trunk	+5.3/-2.9	±4.07		N/A	N/A	N/A

Notes:
The reference frame for the load factors with respect to the directions of motion is as follows:

- X: The longitudinal axis of the vehicle. Positive x-axis extends from the base or bottom of the cargo vehicle to the nose of the cargo vehicle
- Z: Positive z-axis points directly away from the side hatch of the vehicle.
- Y: Y-axis completes the right-handed coordinate system, roughly aligned with the solar arrays.

Error! Reference source not found. through Table 6-11 provide preliminary quasi-static loads for the CRS 3 mission and beyond, which correspond to the upgraded Falcon 9 (Falcon 9 v1.1). These results are based on a design load cycle CLA of the CRS-3 mission. These tables will be updated in the next revision.

Table 6-3: Design Load Factors – GLACIER – Ascent and Re-entry (valid for CRS 3 missions and beyond)

		Glacier Rack NetCG (g)			
	Load Case	Axial Steady	Axial Dynamic	Lateral RSS Steady	Lateral RSS Dynamic
Ascent	SF	1.20	0.24	0.03	0.28
	LO	1.36	1.15	0.02	1.62
	MB_COMB	1.95	1.22	0.07	1.52
	TS_COMB	2.00	0.94	0.09	1.60
	MQ_COMB	2.14	0.96	0.09	1.82
	MECO_P99C90_V	5.14	0.32	0.05	0.95
	SES1_P99C90	0.83	1.32	0.00	0.53
	SECO1_P99C90	5.06	1.09	0.03	0.74
	ENVELOPE	**5.06**	**1.09**	**0.09**	**1.82**
Re-entry	Aero Reentry*	4.50	1.00	0.40	1.10
	Parachute Deployment	0.00	3.90	0.00	6.20
	Splashdown (2 Chutes)	9.69	4.81	6.90	0.24
	Splashdown (3 Chutes)	7.53	3.00	5.40	0.59
	ENVELOPE	9.69	4.81	6.90	6.20

* Aero Reentry loads are full Dragon capsule netCG accelerations. Individual rack loads to be completed.

Other notes:
The reference frame for the load factors with respect to the directions of motion is as follows:

- X: The longitudinal axis of the vehicle. Positive x-axis extends from the base or bottom of the cargo vehicle to the nose of the cargo vehicle
- Z: Positive z-axis points directly away from the side hatch of the vehicle.
- Y: Y-axis completes the right-handed coordinate system, roughly aligned with the solar arrays.

Table 6-4: Design Load Factors – PORT RACK – Ascent and Re-entry (valid for CRS 3 missions and beyond)

		Port Rack NetCG (g)			
	Load Case	Axial Steady	Axial Dynamic	Lateral RSS Steady	Lateral RSS Dynamic
Ascent	SF	1.20	0.26	0.03	0.21
	LO	1.36	0.77	0.02	1.50
	MB_COMB	1.95	0.48	0.07	1.03
	TS_COMB	2.00	0.49	0.09	1.07
	MQ_COMB	2.14	0.45	0.09	1.06
	MECO_P99C90_V	5.14	0.27	0.05	0.92
	SES1_P99C90	0.83	0.33	0.00	0.40
	SECO1_P99C90	5.05	0.56	0.03	0.56
	ENVELOPE	5.05	0.56	0.02	1.50
Re-entry	Aero Reentry*	4.50	1.00	0.40	1.10
	Parachute Deployment	0.00	3.90	0.00	5.20
	Splashdown (2 Chutes)	9.63	4.77	6.91	0.24
	Splashdown (3 Chutes)	7.48	2.98	5.41	0.59
	ENVELOPE	9.63	4.77	6.91	5.20

* Aero Reentry loads are full Dragon capsule netCG accelerations. Individual rack loads to be completed.

Other notes:
The reference frame for the load factors with respect to the directions of motion is as follows:

- X: The longitudinal axis of the vehicle. Positive x-axis extends from the base or bottom of the cargo vehicle to the nose of the cargo vehicle
- Z: Positive z-axis points directly away from the side hatch of the vehicle.
- Y: Y-axis completes the right-handed coordinate system, roughly aligned with the solar arrays.

Table 6-4: Design Load Factors – STARBOARD RACK – Ascent and Re-entry (valid for CRS 3 missions and beyond)

		Starboard Rack NetCG (g)			
	Load Case	Axial Steady	Axial Dynamic	Lateral RSS Steady	Lateral RSS Dynamic
Ascent	SF	1.20	0.22	0.03	0.33
	LO	1.36	0.96	0.02	1.43
	MB_COMB	1.95	0.51	0.07	1.13
	TS_COMB	2.00	0.50	0.09	1.25
	MQ_COMB	2.14	0.48	0.09	1.18
	MECO_P99C90_V	5.14	0.22	0.05	0.89
	SES1_P99C90	0.83	0.37	0.00	0.30
	SECO1_P99C90	5.05	0.63	0.03	0.53
	ENVELOPE	5.05	0.63	0.02	1.43
Re-entry	Aero Reentry*	4.50	1.00	0.40	1.10
	Parachute Deployment	0.00	2.50	0.00	5.40
	Splashdown (2 Chutes)	9.63	4.78	6.91	0.24
	Splashdown (3 Chutes)	7.49	2.98	5.40	0.59
	ENVELOPE	9.63	4.78	6.91	5.40

* Aero Reentry loads are full Dragon capsule netCG accelerations. Individual rack loads to be completed.

Other notes:
The reference frame for the load factors with respect to the directions of motion is as follows:

- X: The longitudinal axis of the vehicle. Positive x-axis extends from the base or bottom of the cargo vehicle to the nose of the cargo vehicle
- Z: Positive z-axis points directly away from the side hatch of the vehicle.
- Y: Y-axis completes the right-handed coordinate system, roughly aligned with the solar arrays.

Table 6-5: Design Load Factors – AFT RACK – Ascent and Re-entry (valid for CRS 3 missions and beyond)

		Aft Rack NetCG (g)			
	Load Case	Axial Steady	Axial Dynamic	Lateral RSS Steady	Lateral RSS Dynamic
Ascent	SF	1.20	0.26	0.02	0.25
	LO	1.36	0.99	0.02	1.39
	MB_COMB	1.95	0.69	0.07	1.04
	TS_COMB	2.00	0.69	0.09	1.14
	MQ_COMB	2.14	0.68	0.09	1.06
	MECO_P99C90_V	5.14	0.24	0.05	0.89
	SES1_P99C90	0.83	0.79	0.00	0.53
	SECO1_P99C90	5.05	1.11	0.03	0.84
	ENVELOPE	5.05	1.11	0.02	1.39
Re-entry	Aero Reentry*	4.50	1.00	0.40	1.10
	Parachute Deployment	0.00	4.20	0.00	4.50
	Splashdown (2 Chutes)	9.57	4.74	6.90	0.24
	Splashdown (3 Chutes)	7.44	2.96	5.40	0.59
	ENVELOPE	9.57	4.74	6.90	4.50

* Aero Reentry loads are full Dragon capsule netCG accelerations. Individual rack loads to be completed.

Other notes:
The reference frame for the load factors with respect to the directions of motion is as follows:

- X: The longitudinal axis of the vehicle. Positive x-axis extends from the base or bottom of the cargo vehicle to the nose of the cargo vehicle
- Z: Positive z-axis points directly away from the side hatch of the vehicle.
- Y: Y-axis completes the right-handed coordinate system, roughly aligned with the solar arrays.

Table 6-6: Design Load Factors – FLOOR RACK – Ascent and Re-entry (valid for CRS 3 missions and beyond)

		Floor Rack NetCG (g)			
	Load Case	Axial Steady	Axial Dynamic	Lateral RSS Steady	Lateral RSS Dynamic
Ascent	SF	1.20	0.23	0.20	0.97
	LO	1.36	1.02	0.96	0.21
	MB_COMB	1.95	0.51	0.97	0.91
	TS_COMB	2.00	0.54	0.94	0.88
	MQ_COMB	2.14	0.57	0.93	0.85
	MECO_P99C90_V	5.14	0.32	0.80	0.78
	SES1_P99C90	0.83	0.34	0.29	0.27
	SECO1_P99C90	5.05	0.60	0.39	0.38
	ENVELOPE	5.05	0.60	0.97	0.91
Re-entry	Aero Reentry*	4.50	1.00	0.40	1.10
	Parachute Deployment	0.00	2.20	0.00	2.50
	Splashdown (2 Chutes)	9.64	4.78	6.92	0.24
	Splashdown (3 Chutes)	7.49	2.98	5.42	0.59
	ENVELOPE	9.64	4.78	6.92	2.50

* Aero Reentry loads are full Dragon capsule netCG accelerations. Individual rack loads to be completed.

Other notes:
The reference frame for the load factors with respect to the directions of motion is as follows:

- X: The longitudinal axis of the vehicle. Positive x-axis extends from the base or bottom of the cargo vehicle to the nose of the cargo vehicle
- Z: Positive z-axis points directly away from the side hatch of the vehicle.
- Y: Y-axis completes the right-handed coordinate system, roughly aligned with the solar arrays.

Table 6-7: Design Load Factors – UPPER POWERED CARGO – Ascent and Re-entry (valid for CRS 3 missions and beyond)

		Upper Powered Cargo NetCG (g)			
	Load Case	Axial Steady	Axial Dynamic	Lateral RSS Steady	Lateral RSS Dynamic
Ascent	SF	1.20	0.43	0.03	0.42
	LO	1.36	3.42	0.02	3.64
	MB_COMB	1.95	0.68	0.07	1.27
	TS_COMB	2.00	0.63	0.09	1.26
	MQ_COMB	2.14	0.61	0.09	1.24
	MECO_P99C90_V	5.14	0.82	0.05	1.05
	SES1_P99C90	0.83	0.90	0.00	0.96
	SECO1_P99C90	5.05	1.02	0.03	1.39
	ENVELOPE	5.05	1.02	0.02	3.64
Re-entry	Aero Reentry*	4.50	1.00	0.40	1.10
	Parachute Deployment	0.00	6.80	0.00	6.20
	Splashdown (2 Chutes)	9.69	4.80	6.90	0.24
	Splashdown (3 Chutes)	7.53	2.99	5.39	0.59
	ENVELOPE	9.69	6.80	6.90	6.20

* Aero Reentry loads are full Dragon capsule netCG accelerations. Individual rack loads to be completed.

Other notes:
The reference frame for the load factors with respect to the directions of motion is as follows:

- X: The longitudinal axis of the vehicle. Positive x-axis extends from the base or bottom of the cargo vehicle to the nose of the cargo vehicle
- Z: Positive z-axis points directly away from the side hatch of the vehicle.
- Y: Y-axis completes the right-handed coordinate system, roughly aligned with the solar arrays.

Table 6-8: Design Load Factors – LOWER POWERED CARGO – Ascent and Re-entry (valid for CRS 3 missions and beyond)

		Lower Powered Cargo NetCG (g)			
	Load Case	Axial Steady	Axial Dynamic	Lateral RSS Steady	Lateral RSS Dynamic
Ascent	SF	1.20	0.31	0.03	0.38
	LO	1.36	0.93	0.02	1.71
	MB_COMB	1.95	0.80	0.07	1.39
	TS_COMB	2.00	0.85	0.09	1.50
	MQ_COMB	2.14	1.02	0.09	1.79
	MECO_P99C90_V	5.14	0.24	0.05	0.94
	SES1_P99C90	0.83	0.46	0.00	0.48
	SECO1_P99C90	5.06	0.72	0.03	0.59
	ENVELOPE	5.06	0.72	0.09	1.79
Re-entry	Aero Reentry*	4.50	1.00	0.40	1.10
	Parachute Deployment	0.00	6.00	0.00	4.40
	Splashdown (2 Chutes)	9.70	4.81	6.91	0.25
	Splashdown (3 Chutes)	7.53	3.00	5.41	0.59
	ENVELOPE	9.70	6.00	6.91	4.40

* Aero Reentry loads are full Dragon capsule netCG accelerations. Individual rack loads to be completed.

Other notes:
The reference frame for the load factors with respect to the directions of motion is as follows:

- X: The longitudinal axis of the vehicle. Positive x-axis extends from the base or bottom of the cargo vehicle to the nose of the cargo vehicle
- Z: Positive z-axis points directly away from the side hatch of the vehicle.
- Y: Y-axis completes the right-handed coordinate system, roughly aligned with the solar arrays.

Table 6-9: Design Load Factors – UPPER LATE LOAD +Y RACK – Ascent and Re-entry (valid for CRS 3 missions and beyond)

		Upper Late Load +Y Rack NetCG (g)			
	Load Case	Axial Steady	Axial Dynamic	Lateral RSS Steady	Lateral RSS Dynamic
Ascent	SF	1.20	0.25	0.03	0.27
	LO	1.36	1.09	0.02	1.30
	MB_COMB	1.95	0.81	0.07	1.58
	TS_COMB	2.00	0.80	0.09	1.64
	MQ_COMB	2.14	0.68	0.09	1.69
	MECO_P99C90_V	5.14	0.20	0.05	0.98
	SES1_P99C90	0.83	0.34	0.00	0.63
	SECO1_P99C90	5.06	0.71	0.03	0.84
	ENVELOPE	5.06	0.71	0.09	1.69
Re-entry	Aero Reentry*	4.50	1.00	0.40	1.10
	Parachute Deployment	0.00	4.50	0.00	5.30
	Splashdown (2 Chutes)	9.69	4.81	6.90	0.24
	Splashdown (3 Chutes)	7.53	3.00	5.40	0.59
	ENVELOPE	9.69	4.81	6.90	5.30

* Aero Reentry loads are full Dragon capsule netCG accelerations. Individual rack loads to be completed.

Other notes:
The reference frame for the load factors with respect to the directions of motion is as follows:

- X: The longitudinal axis of the vehicle. Positive x-axis extends from the base or bottom of the cargo vehicle to the nose of the cargo vehicle
- Z: Positive z-axis points directly away from the side hatch of the vehicle.
- Y: Y-axis completes the right-handed coordinate system, roughly aligned with the solar arrays.

Table 6-10: Design Load Factors – UPPER LATE LOAD –Y RACK – Ascent and Re-entry (valid for CRS 3 missions and beyond)

		Upper Late Load -Y Rack NetCG (g)			
	Load Case	Axial Steady	Axial Dynamic	Lateral RSS Steady	Lateral RSS Dynamic
Ascent	SF	1.20	0.25	0.03	0.23
	LO	1.36	1.10	0.02	1.99
	MB_COMB	1.95	0.65	0.07	1.56
	TS_COMB	2.00	0.64	0.09	2.24
	MQ_COMB	2.14	0.59	0.09	1.69
	MECO_P99C90_V	5.14	0.30	0.05	0.97
	SES1_P99C90	0.83	0.49	0.00	0.70
	SECO1_P99C90	5.05	1.19	0.03	1.66
	ENVELOPE	5.05	1.19	0.09	2.24
Re-entry	Aero Reentry*	4.50	1.00	0.40	1.10
	Parachute Deployment	0.00	3.60	0.00	5.20
	Splashdown (2 Chutes)	9.69	4.80	6.90	0.24
	Splashdown (3 Chutes)	7.53	2.99	5.40	0.59
	ENVELOPE	9.69	4.80	6.90	5.20

* Aero Reentry loads are full Dragon capsule netCG accelerations. Individual rack loads to be completed.

Other notes:
The reference frame for the load factors with respect to the directions of motion is as follows:

- X: The longitudinal axis of the vehicle. Positive x-axis extends from the base or bottom of the cargo vehicle to the nose of the cargo vehicle
- Z: Positive z-axis points directly away from the side hatch of the vehicle.
- Y: Y-axis completes the right-handed coordinate system, roughly aligned with the solar arrays.

Table 6-11: Design Load Factors – CENTER STACK CARGO – Ascent and Re-entry (valid for CRS 3 missions and beyond)

		Center Stack Cargo NetCG (g)			
	Load Case	Axial Steady	Axial Dynamic	Lateral RSS Steady	Lateral RSS Dynamic
Ascent	SF	1.20	0.25	0.02	0.26
	LO	1.36	0.85	0.02	1.61
	MB_COMB	1.95	0.39	0.07	1.10
	TS_COMB	2.00	0.39	0.09	1.19
	MQ_COMB	2.14	0.44	0.09	1.17
	MECO_P99C90_V	5.14	0.25	0.05	0.94
	SES1_P99C90	0.83	0.48	0.00	0.50
	SECO1_P99C90	5.05	0.54	0.03	0.80
	ENVELOPE	5.05	0.54	0.02	1.61
Re-entry	Aero Reentry*	4.50	1.00	0.40	1.10
	Parachute Deployment	0.00	2.90	0.00	4.20
	Splashdown (2 Chutes)	9.64	4.78	6.91	0.24
	Splashdown (3 Chutes)	7.49	2.98	5.41	0.59
	ENVELOPE	9.64	4.78	6.91	4.20

* Aero Reentry loads are full Dragon capsule netCG accelerations. Individual rack loads to be completed.

Other notes:
The reference frame for the load factors with respect to the directions of motion is as follows:

- X: The longitudinal axis of the vehicle. Positive x-axis extends from the base or bottom of the cargo vehicle to the nose of the cargo vehicle
- Z: Positive z-axis points directly away from the side hatch of the vehicle.
- Y: Y-axis completes the right-handed coordinate system, roughly aligned with the solar arrays.

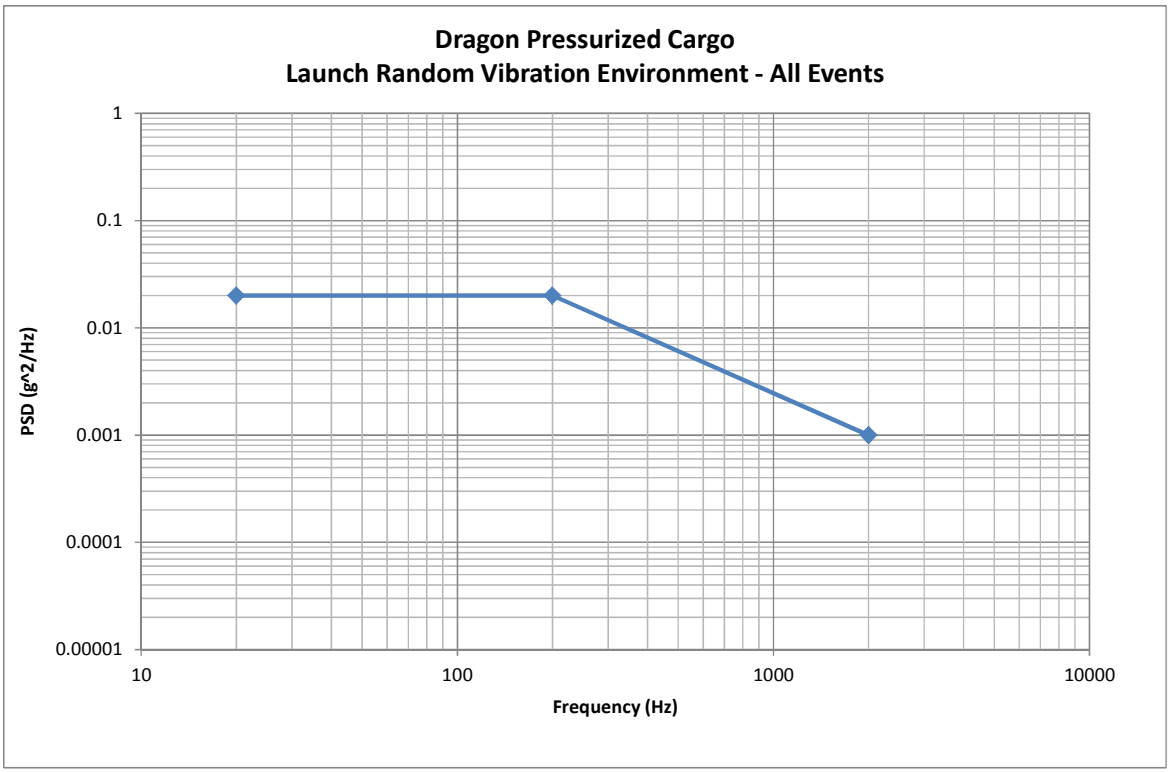
6.4 Pressurized Cargo Environments

6.4.1 Random Vibration – Launch and Return

Cargo items in the pressurized section shall meet the specified launch performance requirements after exposure to the maximum flight random vibration environment defined in figures in this section. This random vibration environment applies for items hard-mounted to the cargo racks or a powered rack. Cargo that is soft-mounted with straps and/or foam will have a lower random vibration environment.

The following notes apply to the random vibration environments:

- Based on F9-3 flight data
- Includes increase to cover v1.1 upgrade
- Environment presented is a Maximum Predicted Environment (MPE) which includes 4.9 dB margin for variability

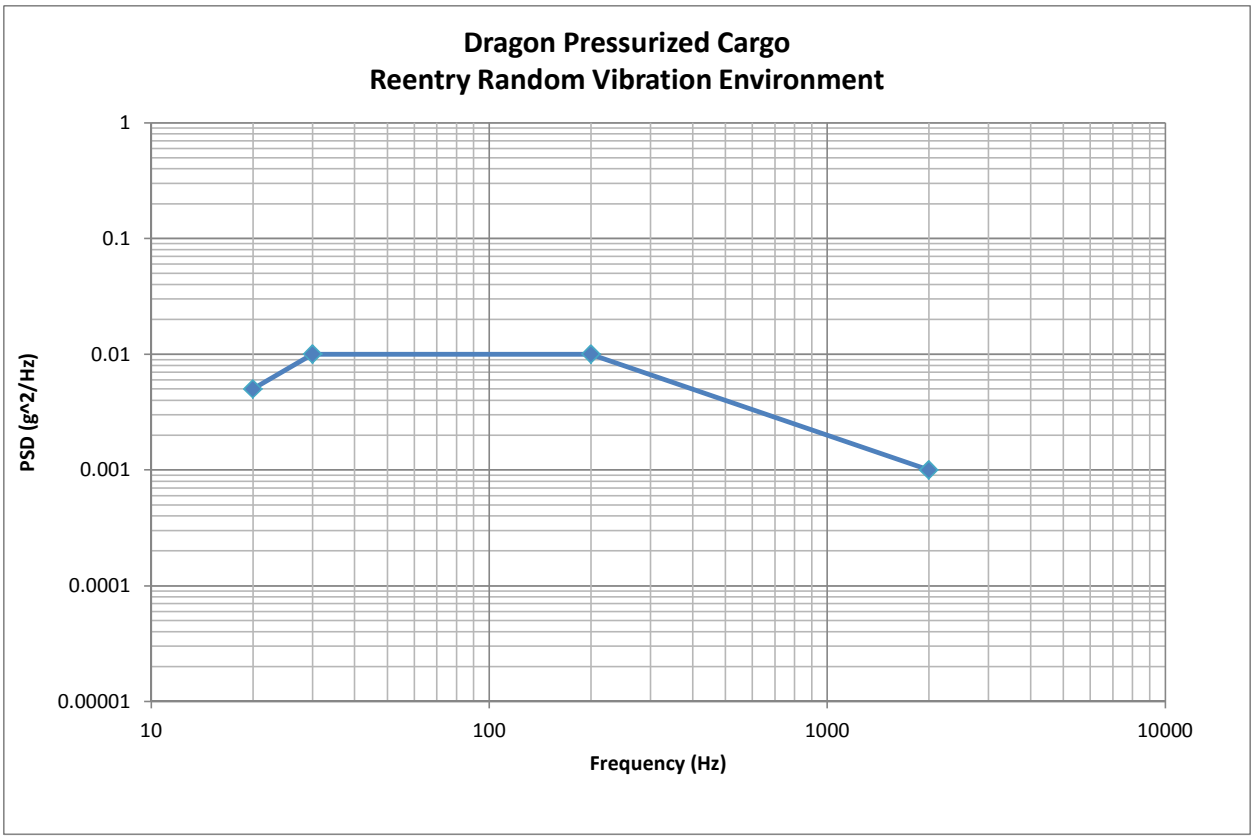


Frequency (Hz)	Dragon Pressurized Cargo Launch Vibration MPE - All Events (Rev11) - All Axes [g^2/Hz]
20	0.02
200	0.02
2000	0.001
GRMS	**3.2**
Duration	**60 sec/axis**

Figure 6-1 Random Vibration (LAUNCH – All Events)

Notes:

1. This random vibration environment applies for items hard-mounted to racks. Items soft-mounted with straps and/or foam will have a lower environment.
2. Duration covers liftoff, ascent, Mvac burn, and reentry (abort).



Frequency (Hz)	Dragon Pressurized Cargo Reentry Vibration MPE (Rev11) - All Axes [g^2/Hz]
20	0.005
30	0.01
200	0.01
2000	0.001
GRMS	**2.53**
Duration	**60 sec/axis**

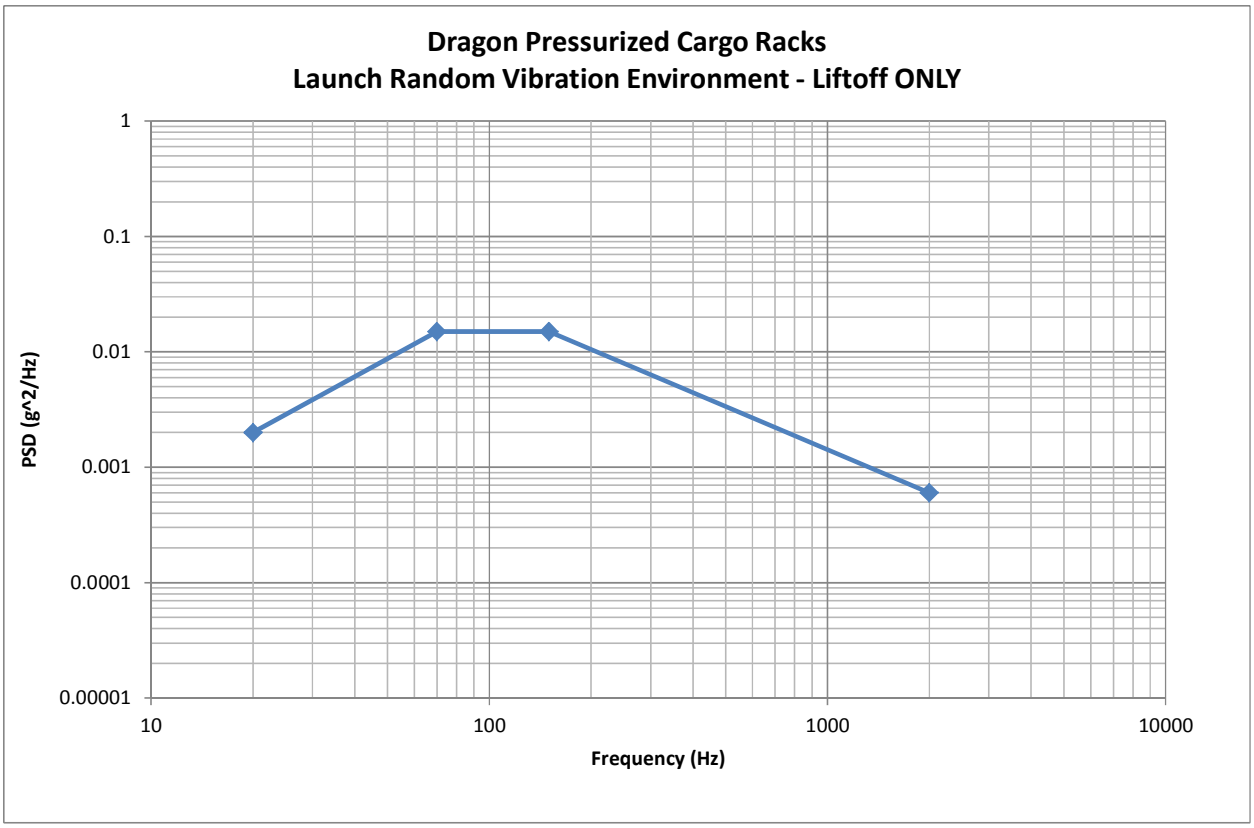
Figure 6-2 Random Vibration (RETURN)

Notes:

1. This random vibration environment applies for items hard-mounted to racks. Items soft-mounted with straps and/or foam will have a lower environment.
2. Duration covers the assumed 15 seconds for reentry aero-acoustic events.

6.4.2 Random Vibration for Combined Loads Analysis ONLY

Random vibration environments in this section are for combined loads analysis ONLY. Results exclude Coupled Loads Analysis results below 100 Hz.

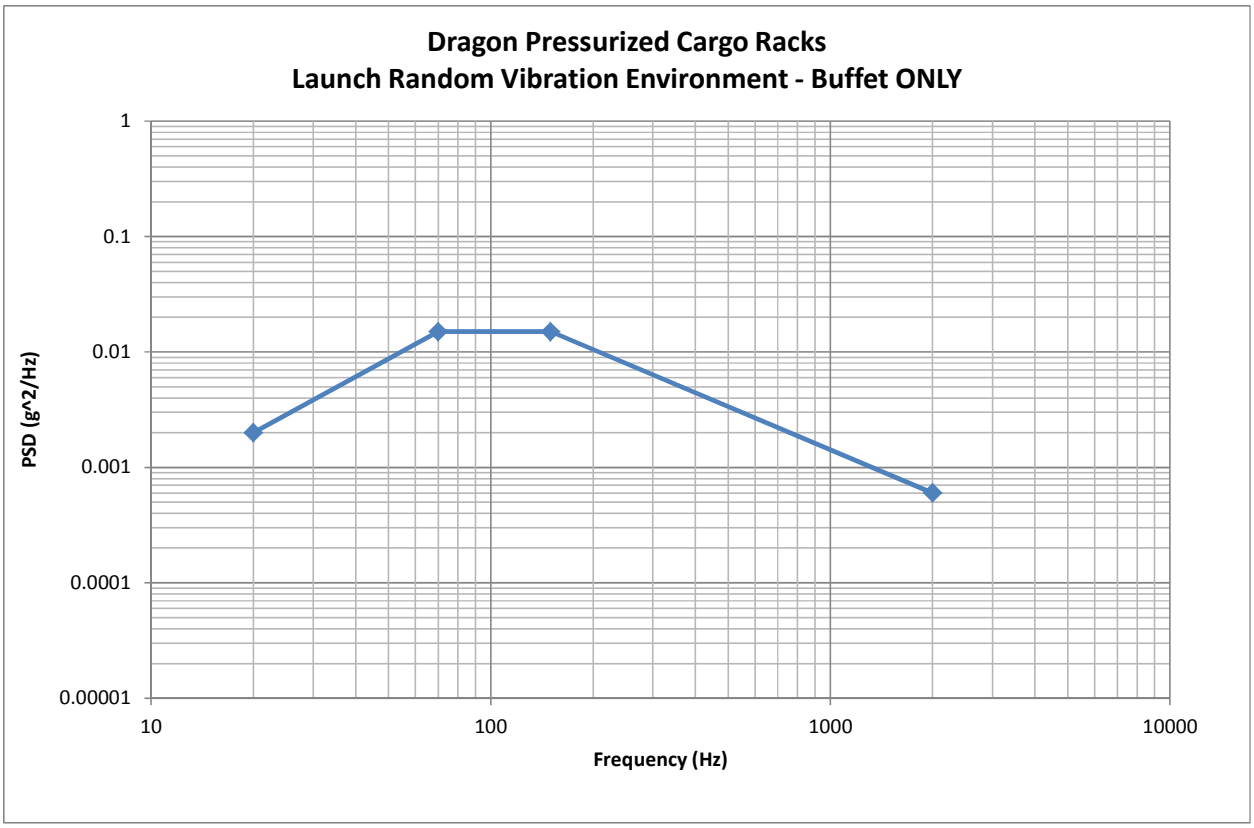


Frequency (Hz)	Dragon Pressurized Cargo Launch Vibration MPE - Liftoff ONLY (Rev11) - All Axes [g^2/Hz]
20	0.002
70	0.015
150	0.015
2000	0.0006
GRMS	**2.4**

Figure 6-3 Random Vibration (LAUNCH – Liftoff ONLY)

Notes:

1. This random vibration environment is for the combined loads analysis ONLY.

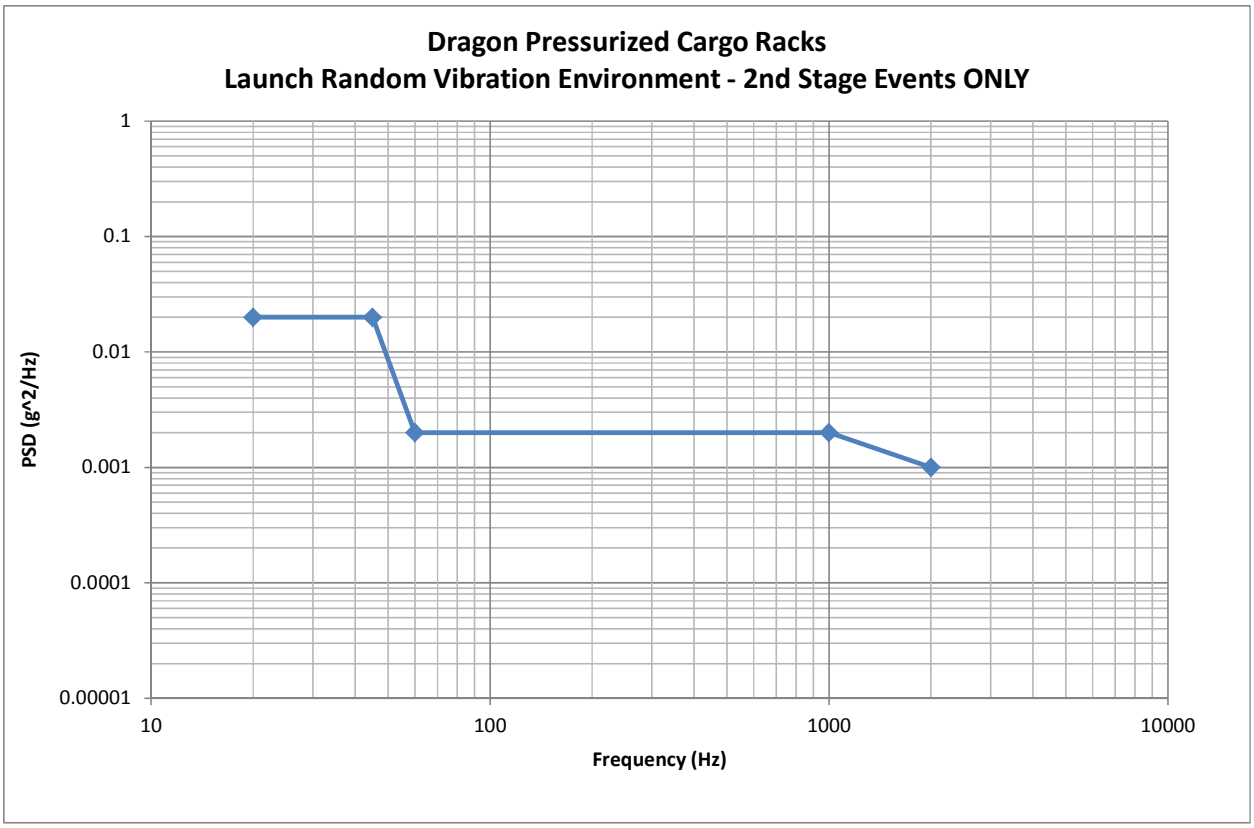


Frequency (Hz)	Dragon Pressurized Cargo Launch Vibration MPE - Buffet ONLY (Rev11) - All Axes [g^2/Hz]
20	0.002
70	0.015
150	0.015
2000	0.0006
GRMS	**2.4**

Figure 6-4 Random Vibration (LAUNCH – Buffet ONLY)

Notes:

1. This random vibration environment is for the combined loads analysis ONLY.
2. Results exclude buffet below 100 Hz.



Frequency (Hz)	Dragon Pressurized Cargo Launch Vibration MPE - 2nd Stage Events ONLY (Rev11) - All Axes [g^2/Hz]
20	0.02
45	0.02
60	0.002
1000	0.002
2000	0.001
GRMS	**2.0**

Figure 6-5 Random Vibration (LAUNCH – 2nd Stage Events ONLY)

Notes:

1. This random vibration environment is for the combined loads analysis ONLY.

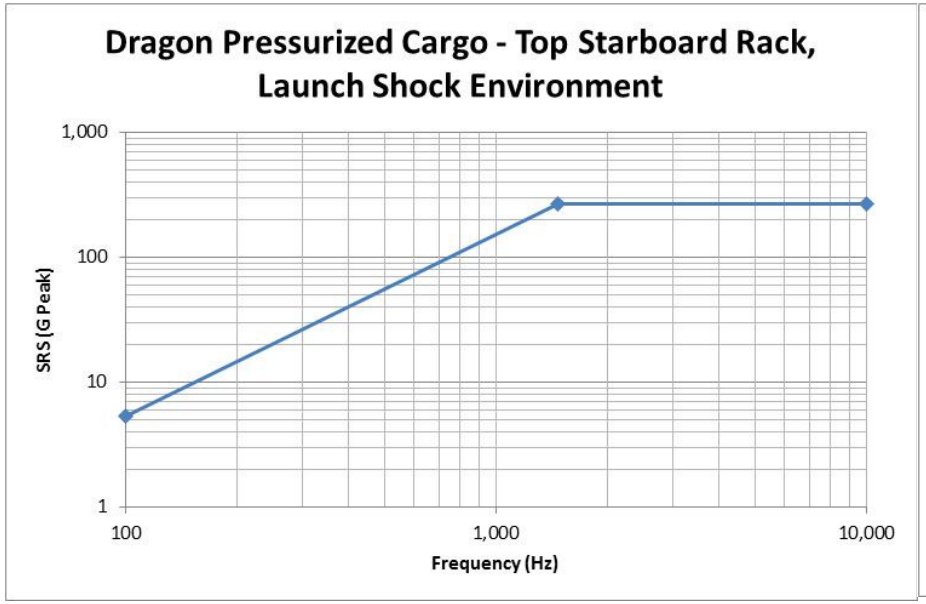
6.4.3 Shock – Launch and Return

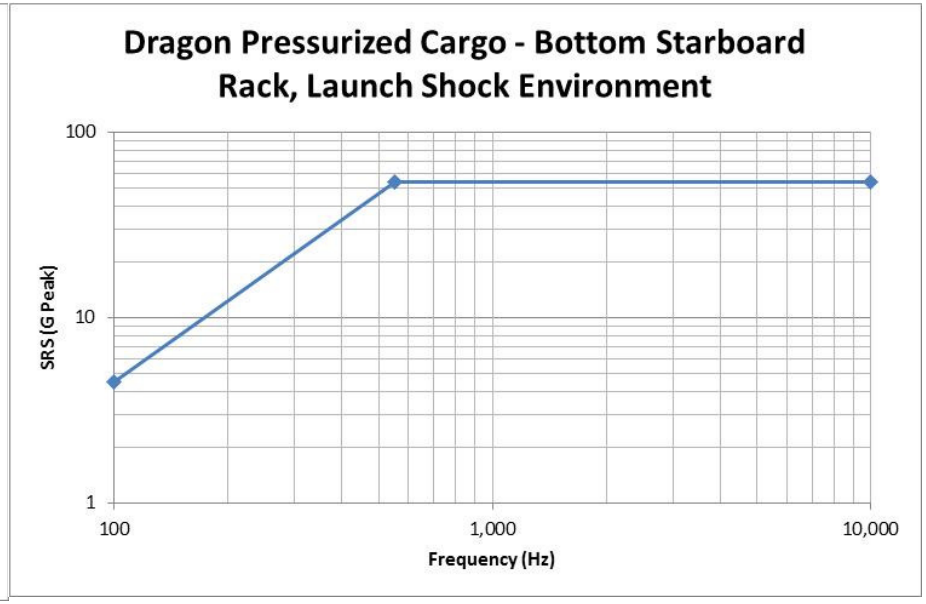
Cargo items shall meet the specified launch/return performance requirements when exposed to the maximum shock environment defined in the figures in this section. Note that this shock environment is based on a limited set of test data and analytical predictions.

The following notes apply to the shock environments:

- Shock environment is a Maximum Predicted Environment (MPE) which includes 4.9 dB margin for variability

6.4.3.1 Shock (LAUNCH) – Starboard Rack





Frequency (Hz)	Top Starboard Rack Launch Shock MPE (Rev2) (g-peak)
100	5
1463	270
10000	270

Frequency (Hz)	Bottom Starboard Rack Launch Shock MPE (Rev2) (g-peak)
100	5
550	54
10000	54

Below 50inches/second

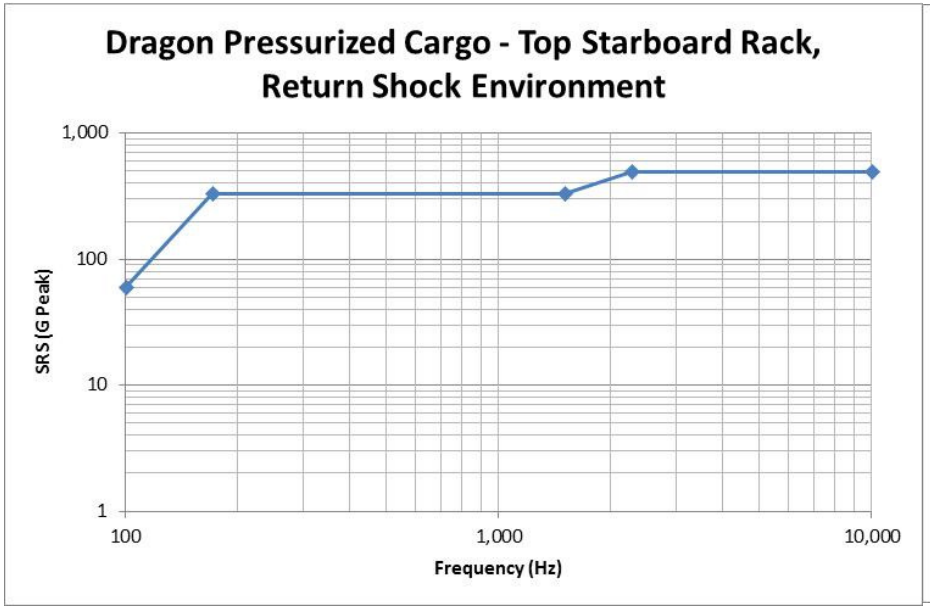
Figure 6-7 Shock (LAUNCH) – Starboard Rack

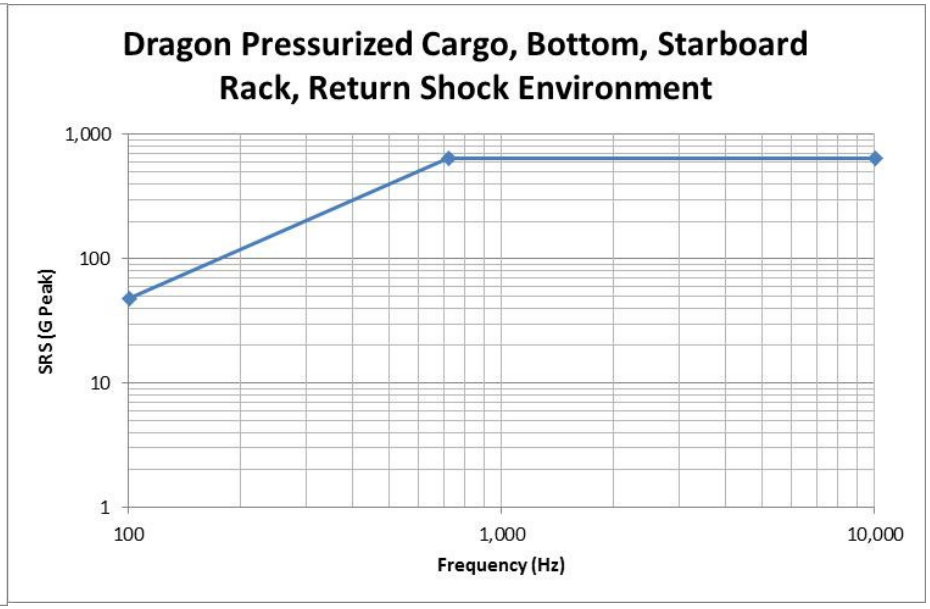
Below 50inches/second
Covered by Random Vibration Test

Notes:

1. This shock environment applies for items hard-mounted to racks. Items soft-mounted with straps and/or foam will have a lower environment.

6.4.3.2 Shock (RETURN) – Starboard Rack





Frequency (Hz)	Top Starboard Rack Return Shock MPE (Rev2) (g-peak)
100	59
171	328
1500	328
2273	489
10000	489

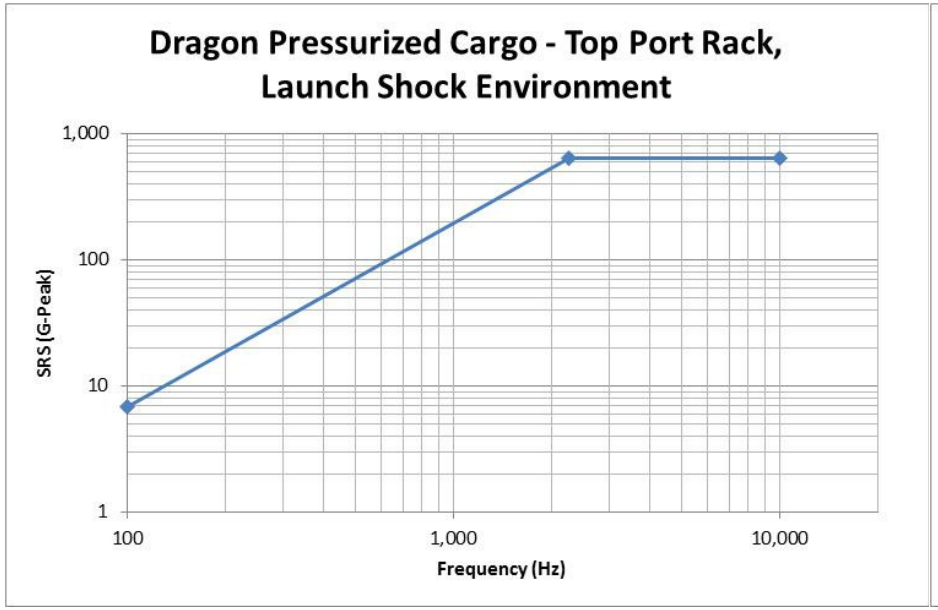
Frequency (Hz)	Bottom Starboard Rack Return Shock MPE (Rev2) (g-peak)
100	48
718	645
10000	645

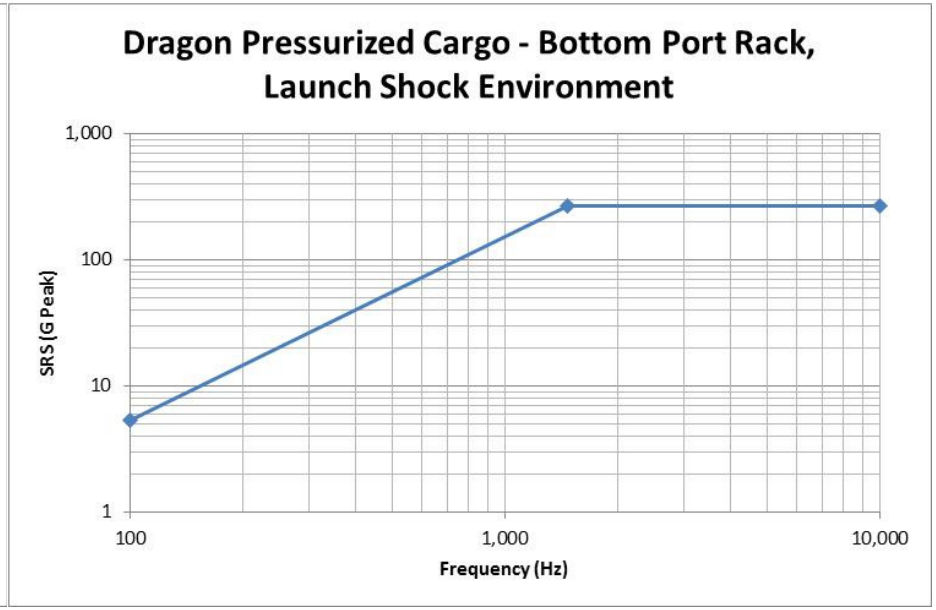
Figure 6-8 Shock (RETURN) – Starboard Rack

Notes:

1. This shock environment applies for items hard-mounted to racks. Items soft-mounted with straps and/or foam will have a lower environment.

6.4.3.3 Shock (LAUNCH) – Port Rack





Frequency (Hz)	Top Port Rack Launch Shock MPE (Rev2) (g-peak)
100	7
2254	648
10000	648

Below 50inches/second

Frequency (Hz)	Bottom Port Rack Launch Shock MPE (Rev2) (g-peak)
100	5
1463	270
10000	270

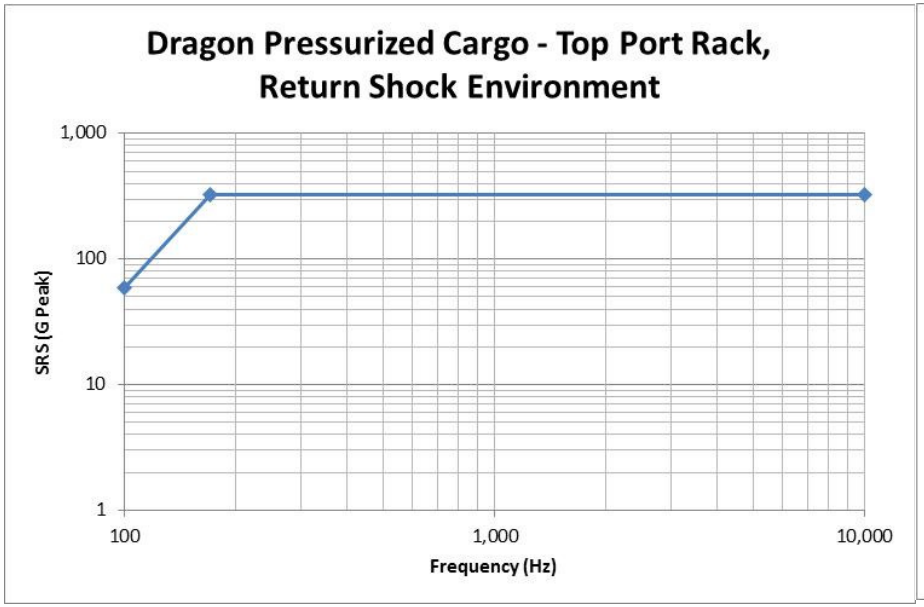
Below 50inches/second

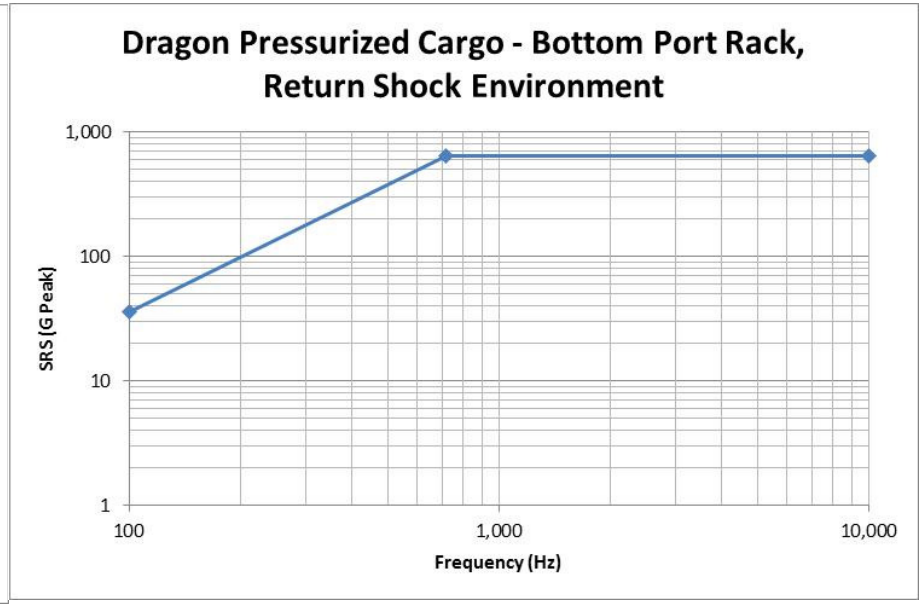
Figure 6-9 Shock (LAUNCH) – Port Rack

Notes:

1. This shock environment applies for items hard-mounted to racks. Items soft-mounted with straps and/or foam will have a lower environment.

6.4.3.4 Shock (RETURN) – Port Rack





Frequency (Hz)	Top Port Rack Return Shock MPE (Rev2) (g-peak)
100	59
171	326
10000	326

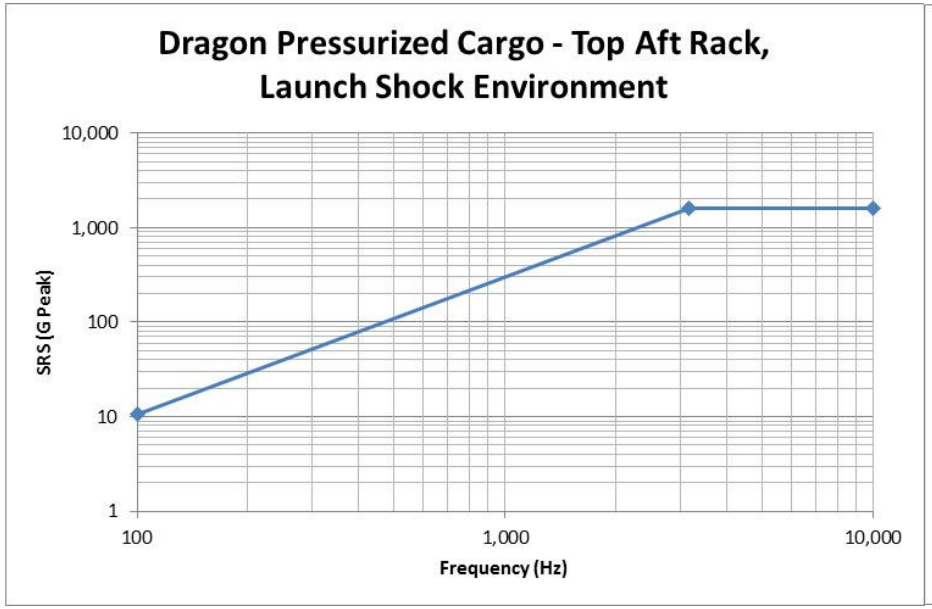
Frequency (Hz)	Bottom Port Rack Return Shock MPE (Rev2) (g-peak)
100	36
718	645
10000	645

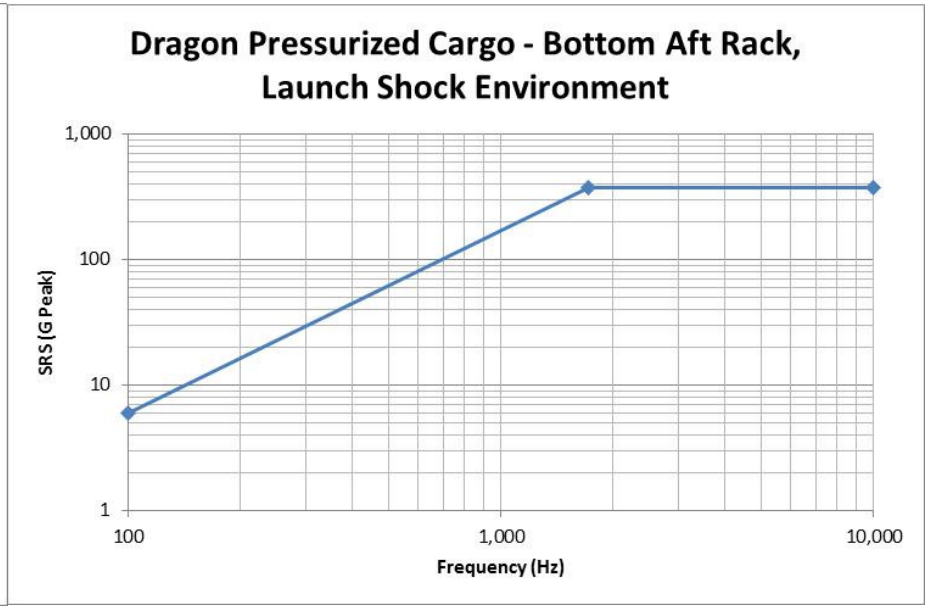
Figure 6-10 Shock (RETURN) – Port Rack

Notes:

1. This shock environment applies for items hard-mounted to racks. Items soft-mounted with straps and/or foam will have a lower environment.

6.4.3.5 Shock (LAUNCH) – Aft Rack





Frequency (Hz)	Top Aft Rack Launch Shock MPE (Rev2) (g-peak)
100	11
3169	1620
10000	1620

Frequency (Hz)	Bottom Aft Rack Launch Shock MPE (Rev2) (g-peak)
100	6
1714	378
10000	378

Below 50inches/second

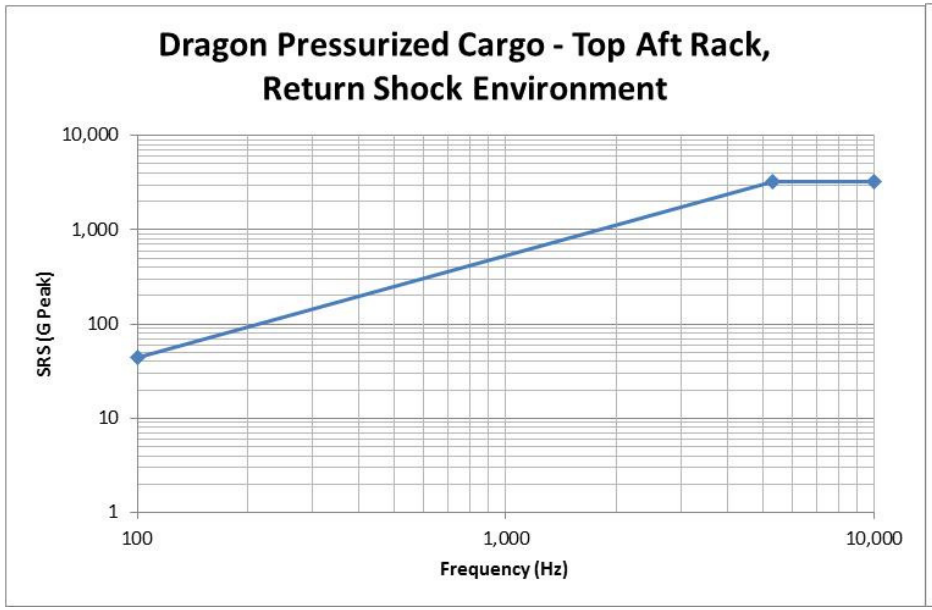
Figure 6-11 Shock (LAUNCH) – Aft Rack

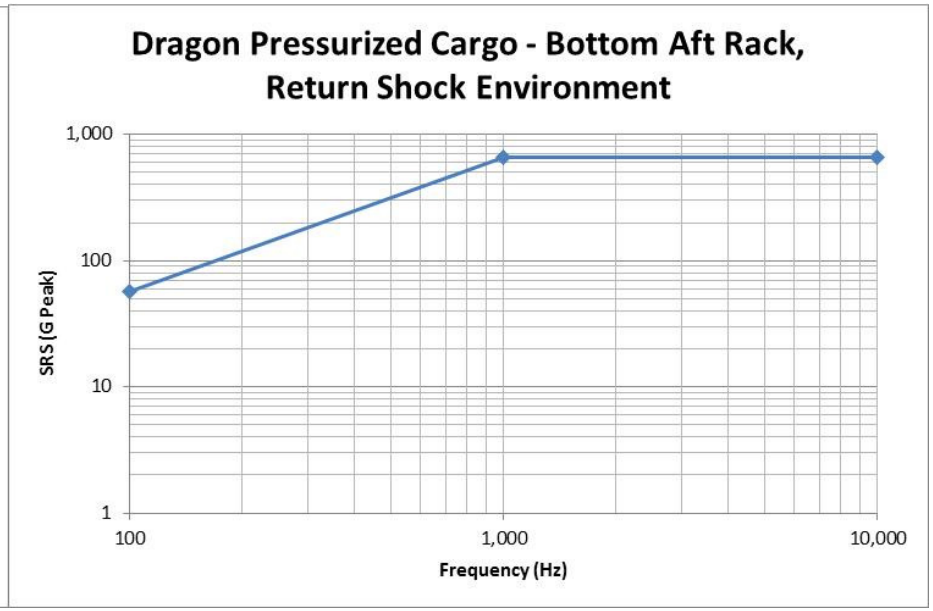
Below 50inches/second

Notes:

1. This shock environment applies for items hard-mounted to racks. Items soft-mounted with straps and/or foam will have a lower environment.

6.4.3.6 Shock (RETURN) – Aft Rack





Frequency (Hz)	Top Aft Rack Return Shock MPE (Rev2) (g-peak)
100	45
5313	3262
10000	3262

Frequency (Hz)	Bottom Aft Rack Return Shock MPE (Rev2) (g-peak)
100	57
1000	652
10000	652

Below 50inches/second

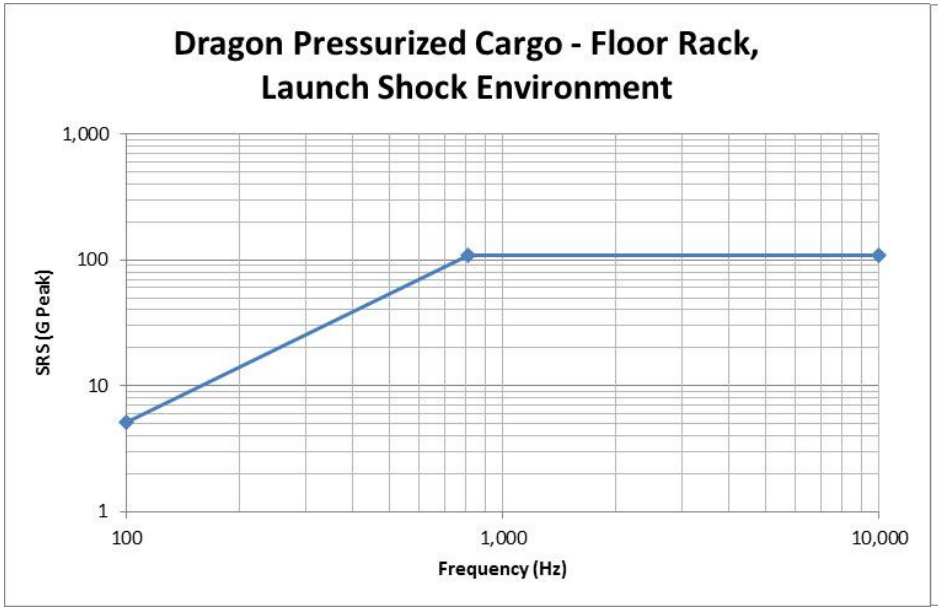
Below 50inches/second

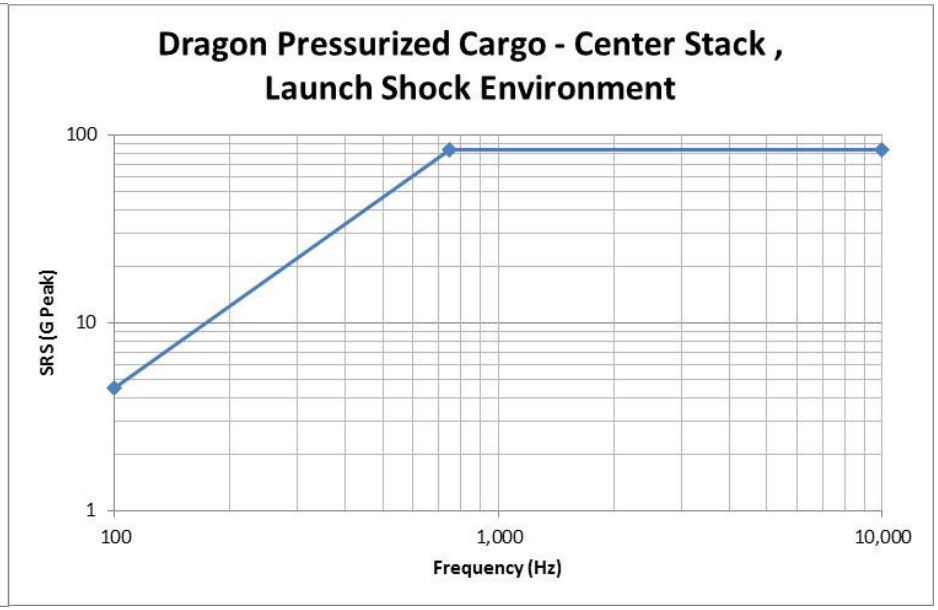
Figure 6-12 Shock (RETURN) – Aft Rack

Notes:

1. This shock environment applies for items hard-mounted to racks. Items soft-mounted with straps and/or foam will have a lower environment.

6.4.3.7 Shock (LAUNCH) – Floor Lockers and Center Stack





Frequency (Hz)	Pressurized Cargo Floor Rack Launch Shock MPE (Rev2) (g-peak)
100	5
812	108
10000	108

Below 50inches/second

Frequency (Hz)	Pressurized Cargo Center Stack Launch Shock MPE (Rev2) (g-peak)
100	5
746	84
10000	84

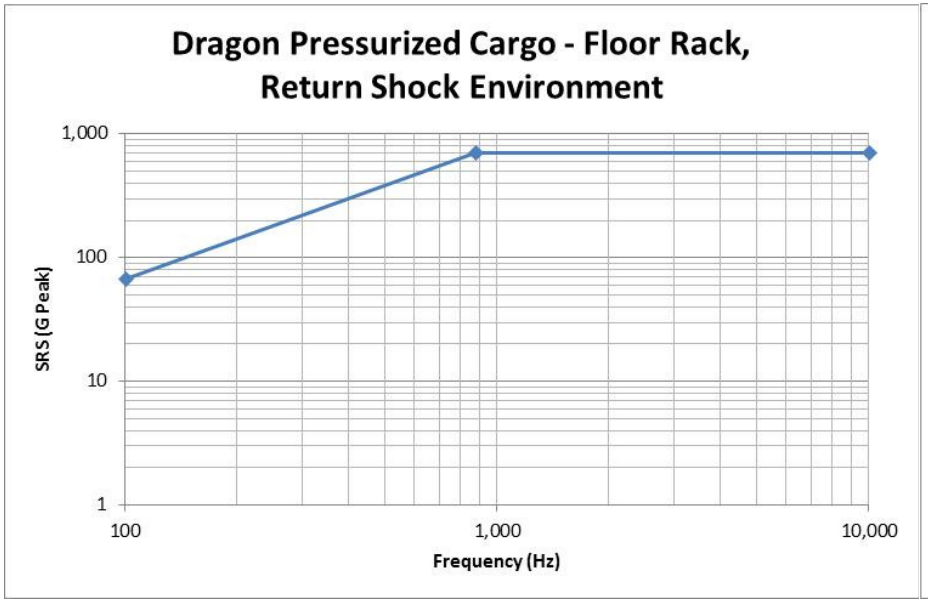
Below 50inches/second

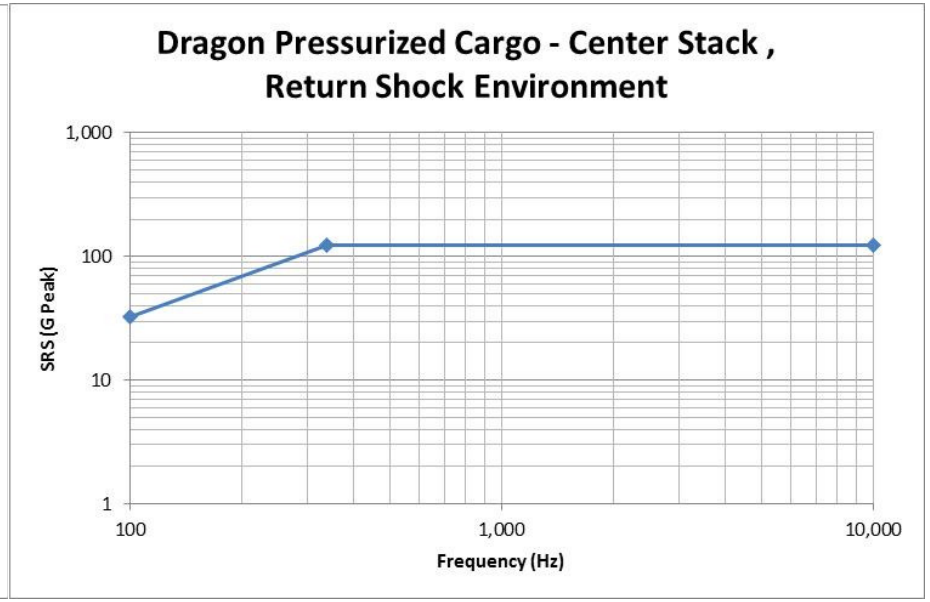
Figure 6-13 Shock (LAUNCH) – Floor Lockers and Center Stack

Notes:

1. This shock environment applies for items hard-mounted to racks. Items soft-mounted with straps and/or foam will have a lower environment.

6.4.3.8 Shock (RETURN) – Floor Lockers and Center Stack





Frequency (Hz)	Pressurized Cargo Floor Rack Return Shock MPE (Rev2) (g-peak)
100	68
876	707
10000	707

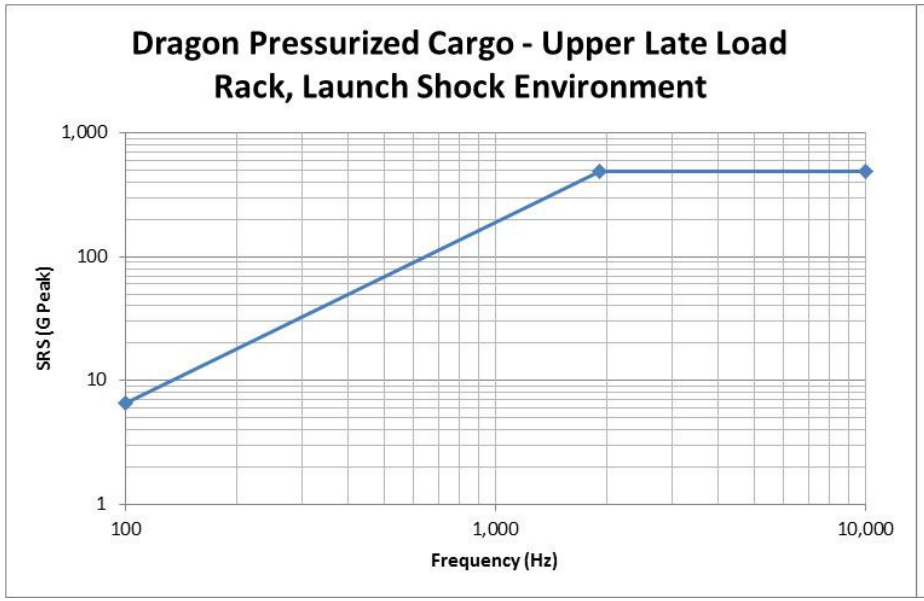
Below 50inches/second

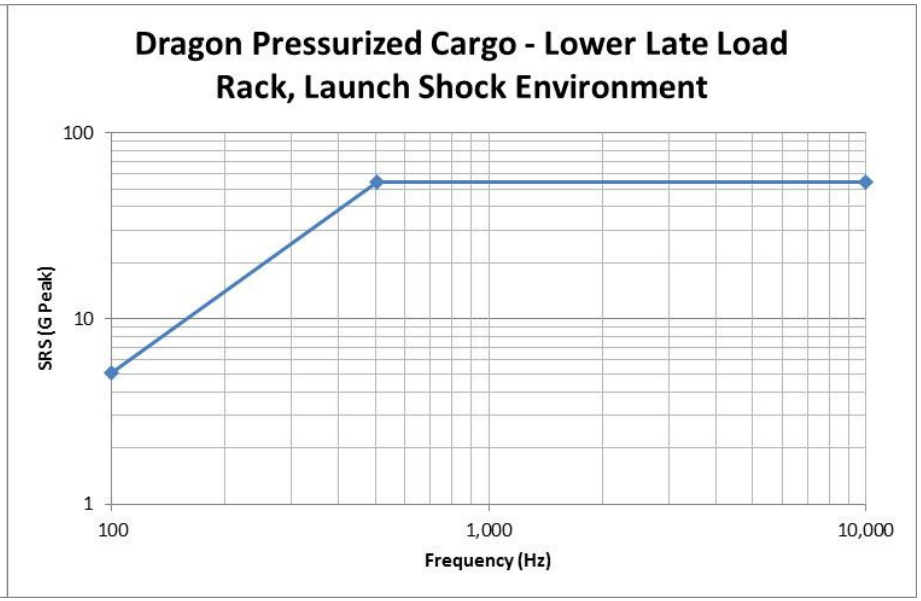
Frequency (Hz)	Pressurized Cargo Center Stack Rack Return Shock MPE (Rev2) (g-peak)
100	32
339	123
10000	123

Below 50inches/second

Figure 6-14 Shock (RETURN) – Floor Lockers and Center Stack

6.4.3.9 Shock (LAUNCH) – Upper and Lower Late Load Rack





Frequency (Hz)	Pressurized Cargo Upper Late Load Rack Launch Shock MPE (Rev2) (g-peak)
100	7
1908	486
10000	486

Below 50inches/second

Frequency (Hz)	Pressurized Cargo Lower Late Load Rack Launch Shock MPE (Rev2) (g-peak)
100	5
505	54
10000	54

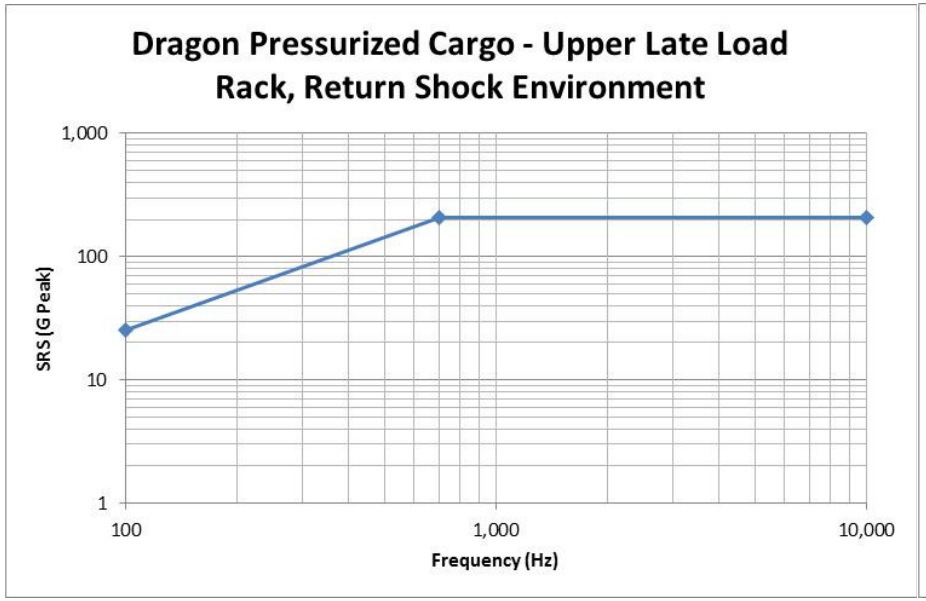
Below 50inches/second
Covered by Random Vibration Test

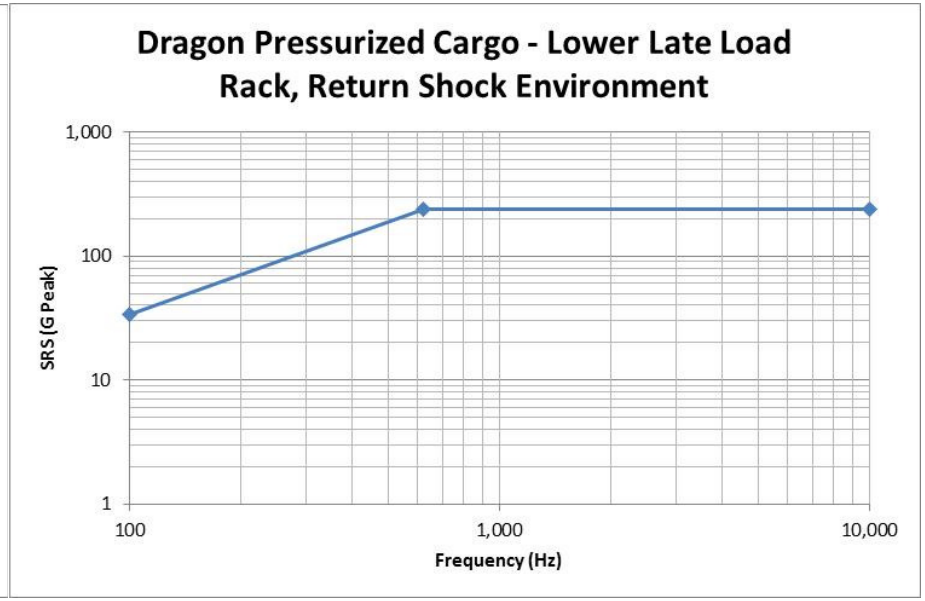
Figure 6-15 Shock (LAUNCH) – Upper and Lower Late Load Rack

Notes:

1. This shock environment applies for items hard-mounted to racks. Items soft-mounted with straps and/or foam will have a lower environment.

6.4.3.10 Shock (RETURN) – Upper Late and Lower Load Rack





Frequency (Hz)	Pressurized Cargo Upper Late Load Rack Return Shock MPE (Rev2) (g-peak)
100	26
700	208
10000	208

Below 50inches/second

Frequency (Hz)	Pressurized Cargo Lower Late Load Rack Return Shock MPE (Rev2) (g-peak)
100	34
624	238
10000	238

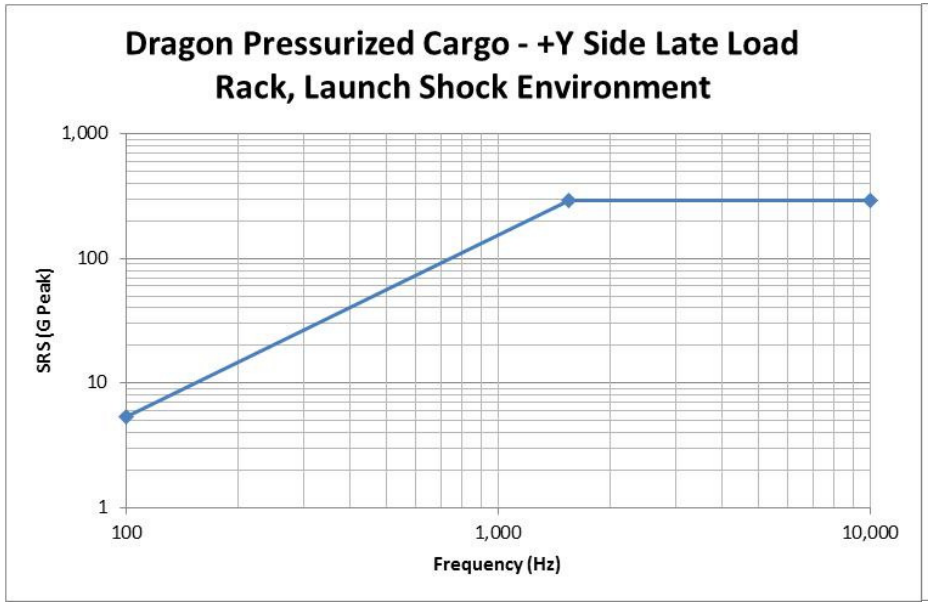
Below 50inches/second

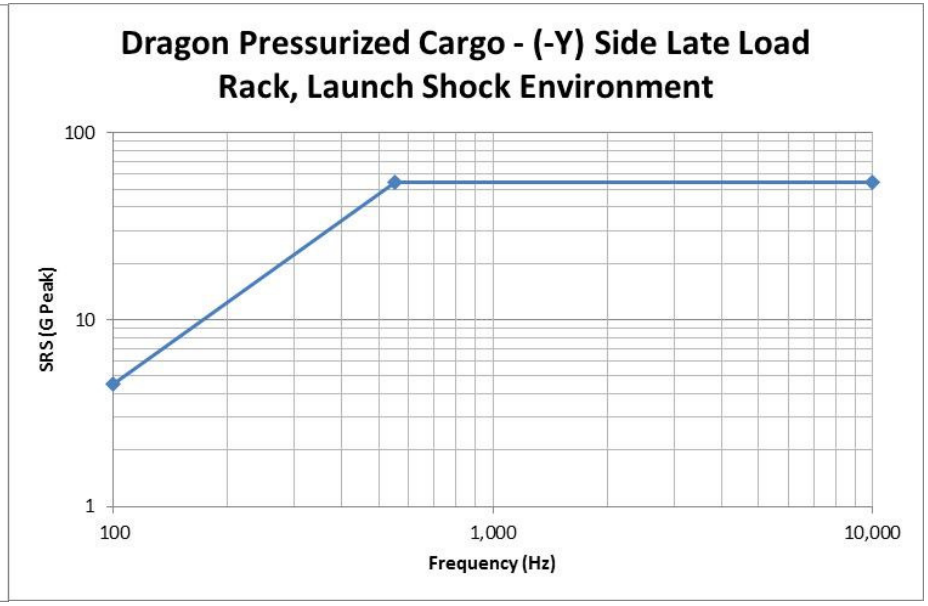
Figure 6-16 Shock (RETURN) – Upper and Lower Late Load Rack

Notes:

1. This shock environment applies for items hard-mounted to racks. Items soft-mounted with straps and/or foam will have a lower environment.

6.4.3.11 Shock (LAUNCH) – (+/-Y) Late Load Rack





Frequency (Hz)	Pressurized Cargo +Y Side Late Load Rack Launch Shock MPE (Rev2) (g-peak)
100	5
1542	292
10000	292

Below 50inches/second

Frequency (Hz)	Pressurized Cargo -Y Side Late Load Rack Launch Shock MPE (Rev2) (g-peak)
100	5
550	54
10000	54

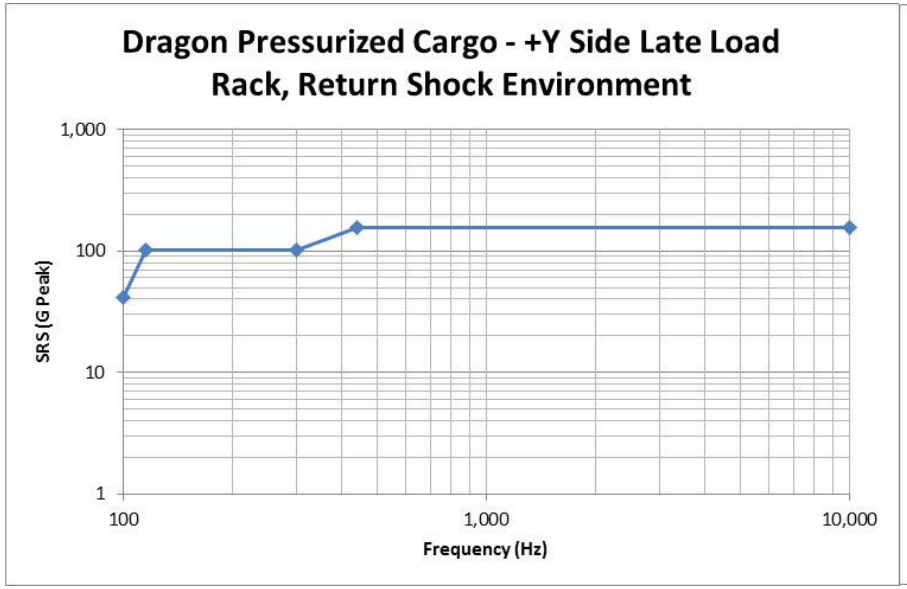
Below 50inches/second
Covered by Random Vibration Test

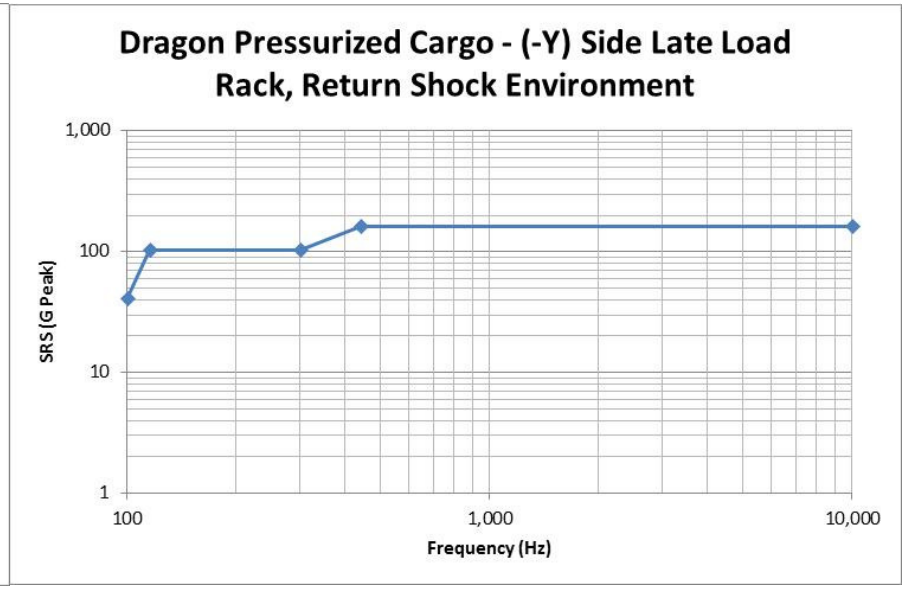
Figure 6-17 Shock (LAUNCH) – (+/-Y) Late Load Rack

Notes:

1. This shock environment applies for items hard-mounted to racks. Items soft-mounted with straps and/or foam will have a lower environment.

6.4.3.12 Shock (RETURN) – (+/-Y) Late Load Rack





Frequency (Hz)	Pressurized Cargo +Y Side Late Load Rack Return Shock MPE (Rev2) (g-peak)
100	41
115	102
300	102
441	156
10000	156

Below 50inches/second

Frequency (Hz)	Pressurized Cargo -Y Side Late Load Rack Return Shock MPE (Rev2) (g-peak)
100	41
115	102
300	102
439	163
10000	163

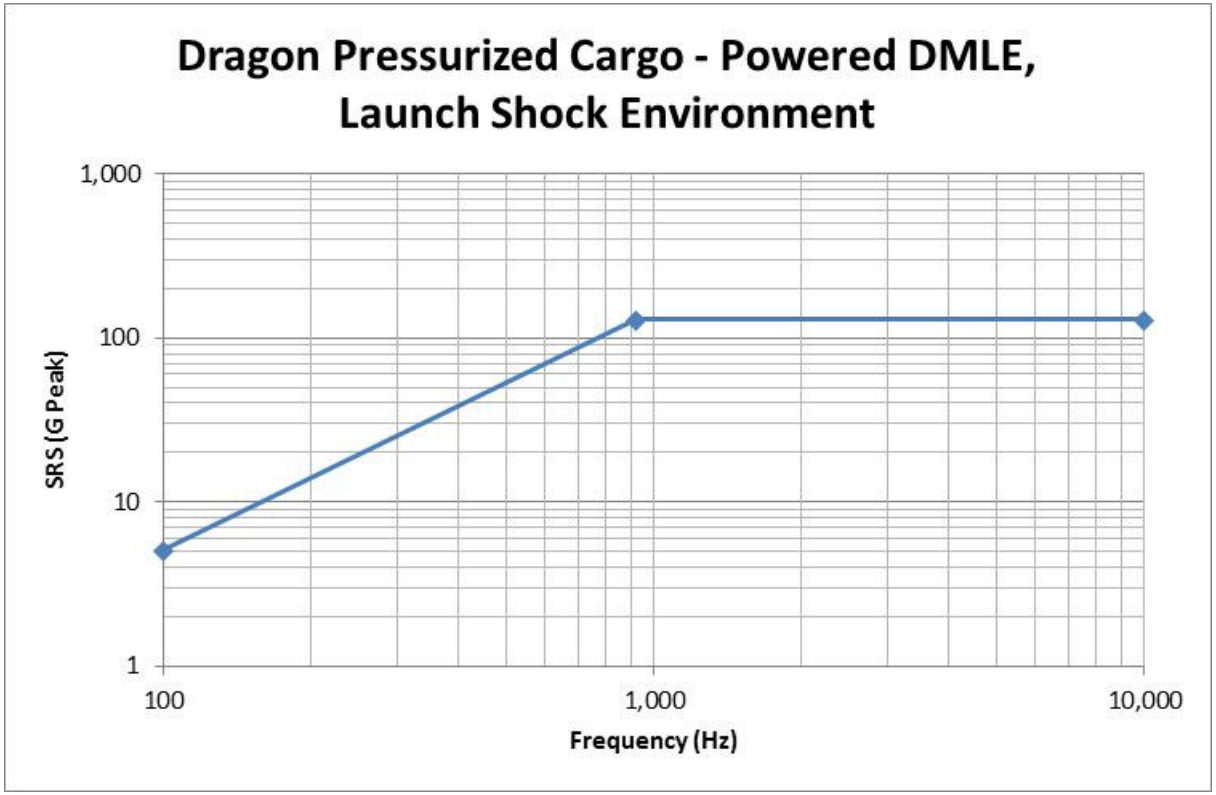
Below 50inches/second

Figure 6-18 Shock (RETURN) – (+/-Y) Late Load Rack

Notes:

1. This shock environment applies for items hard-mounted to racks. Items soft-mounted with straps and/or foam will have a lower environment.

6.4.3.13 Shock (LAUNCH) – Powered DMLE



Frequency (Hz)	Powered DMLE Launch Shock MPE, Rev2 (g-peak)
100	5
920	130
10000	130

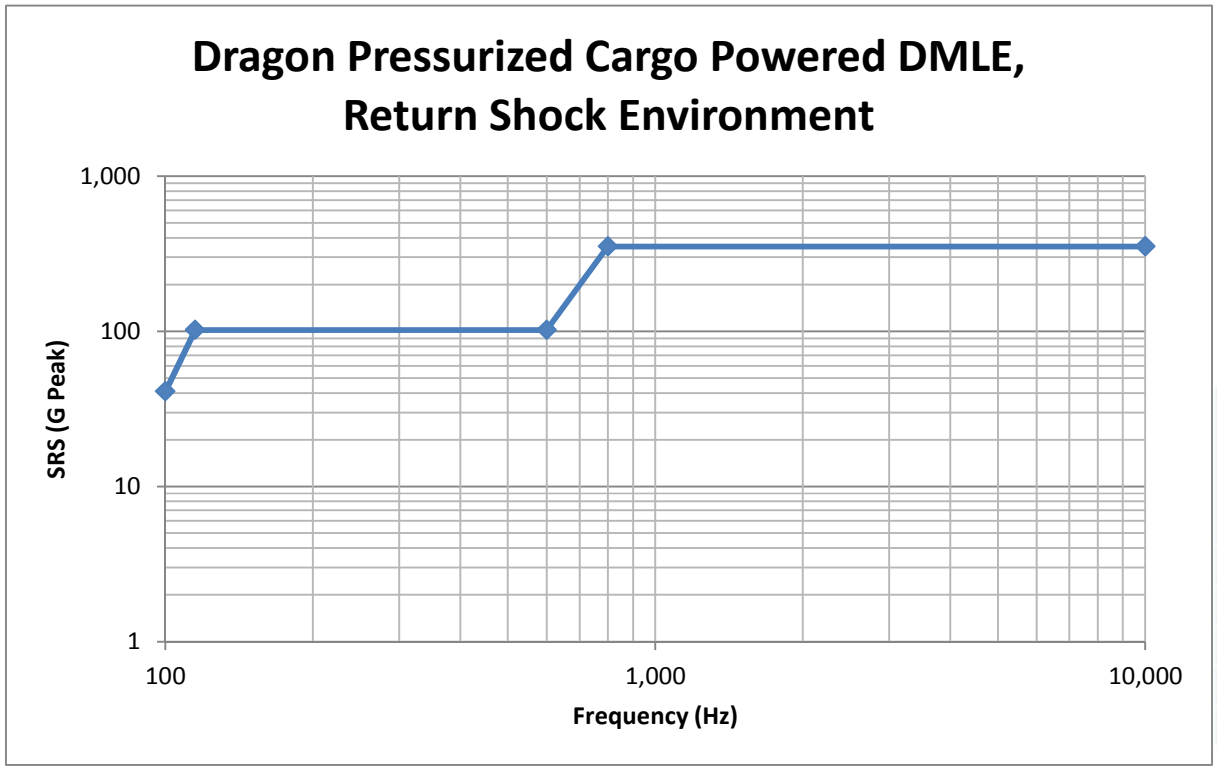
Below 50inches/second

Figure 6-19 Shock (LAUNCH) – Powered DMLE

Notes:

1. This shock environment applies for items hard-mounted to racks. Items soft-mounted with straps and/or foam will have a lower environment.

6.4.3.14 Shock (RETURN) – Powered DMLE



Frequency (Hz)	Powered DMLE Return Shock MPE (Rev. 11) (g-peak)
100	41
115	102
600	102
800	352
10000	352

Below 50inches/second

Figure 6-20 Shock (RETURN) – Powered DMLE

Notes:

1. This shock environment applies for items hard-mounted to racks. Items soft-mounted with straps and/or foam will have a lower environment.

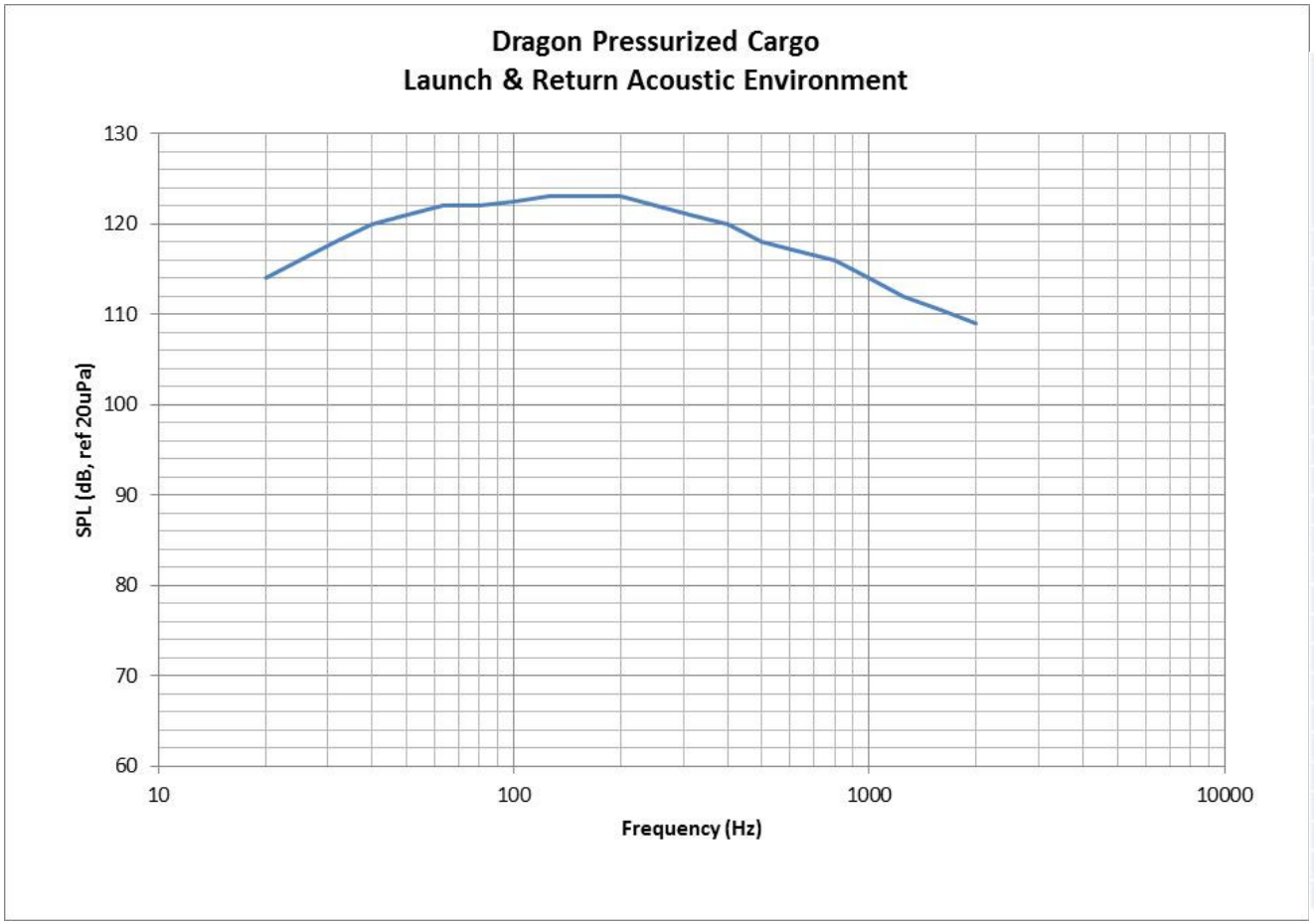
6.4.4 Acoustics – Launch and Return

Cargo items shall meet the specified launch performance requirements when exposed to the maximum launch/return acoustic environment defined figures in this section.

The following notes apply to the acoustic environments:

- Acoustics based on F9-3 (Demo C2) mission flight data
- Includes increase to cover v1.1 upgrade
- Acoustic environment is a Maximum Predicted Environment (MPE) which includes 4.9 dB margin for variability

6.4.4.1 Acoustics (LAUNCH and RETURN)



Frequency (Hz)	Dragon Pressurized Cargo Launch & Return Acoustic MPE (Rev11) (dB)
20	114
25	116
31.5	118
40	120
50	121
63	122
80	122
100	122.5
125	123
160	123
200	123
250	122
315	121
400	120
500	118
630	117
800	116
1000	114
1250	112
1600	110.5
2000	109
OASPL	133.1
Duration	5sec/flight

Figure 6-21 Acoustics (LAUNCH and Return) – Pressurized Cargo

6.4.5 Pressure

Cargo items must maintain positive margins of safety when pressure effects (operational and pressurization/depressurization environments) are combined, when applicable, with induced dynamic and thermal loads. Pressure effects are applicable for both launch and re-entry.

- The nominal pressure environment for cargo is 13.9 psia to 14.9 psia for all mission phases.
- Cargo items shall maintain positive margins of safety and not induce a hazard during or after exposure when exposed to a depressurization rate 0.890 kPa/s (7.75 psi/min).
- Cargo items shall maintain positive margins of safety and not induce a hazard during or after exposure when exposed to a repressurization rate of 0.800 kPa/s (6.96 psi/min).

6.4.6 Thermal

Cargo items shall maintain positive margins of safety when thermal effects are combined, when applicable, with induced dynamic and pressure loads.

For launch (launch to hatch open) and return (hatch closed to hatch open) mission phases, the nominal air supplied temperature of the pressurized section is +18.3°C (+65°F) to +30.0°C (85°F).

For attached operations (hatch open to the ISS):

- During nominal operating conditions the air the nominal air supplied temperature of the pressurized section is +18.3°C (+65°F) to +30.0°C (85°F).
- During periods of both high solar beta angle (β=+75°) and high Node 2 Intermodule Ventilation input temperature (≥73°F) the nominal air supplied temperature of the pressurized section is +18.3°C (+65°F) to +34.0°C (93.2°F).

For all mission phases air is supplied at 36 cubic feet per minute (CFM).

6.4.7 Gas Release

During flight and ground processing, the Dragon Environmental Control System (ECS) allows for the unplanned, non-explosive release of up to 400 standard liters of inert gas from the cargo. After the unplanned, non-explosive release of 400 standard liters of gas from the cargo, the Dragon ECS allows for the additional release of inert and/or non-explosive gas from the cargo at a rate not to exceed 8.5 standard cubic feet per minute (240 standard liters per minute).

6.4.8 Relative Humidity

The relative humidity will be 25% to 75% RH for all mission phases.

6.5 Unpressurized (External) Cargo Environments

6.5.1 Interface Definition

Unless otherwise noted, all environments for FRAM-based cargo are defined at the cargo side of the PFRAM Adapter Plate. For non-standard external cargo, all environments are defined at the cargo side of the trunk cargo rack, unless otherwise noted in the cargo-specific ICD.

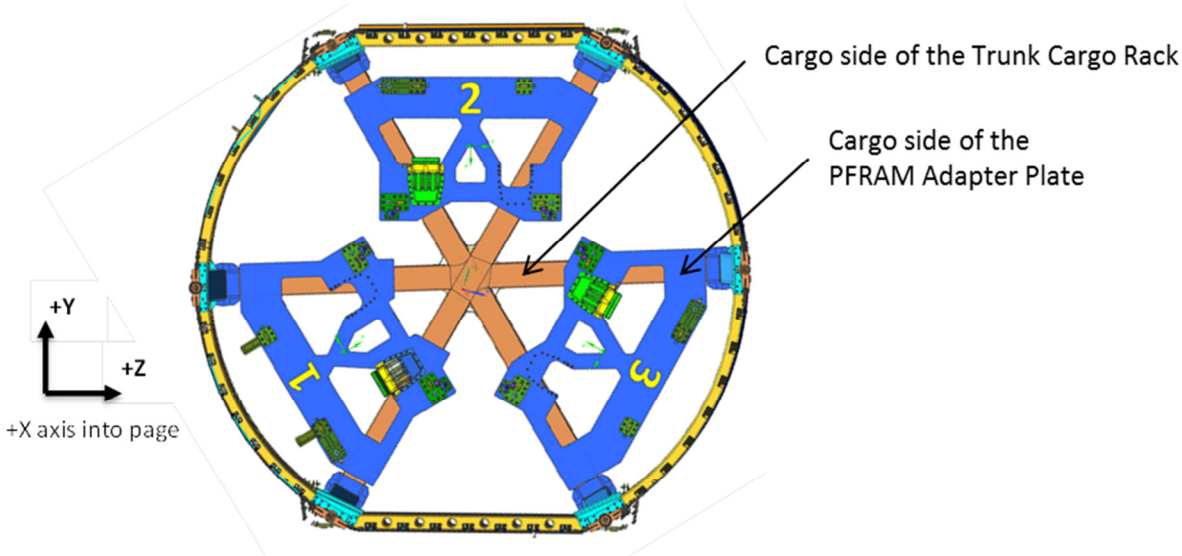


Figure 6-22 Interface Definition of Provided Environments (Dragon Capsule in +X direction)

The environments input definition is show in Figure 6-23 and Figure 6-24.

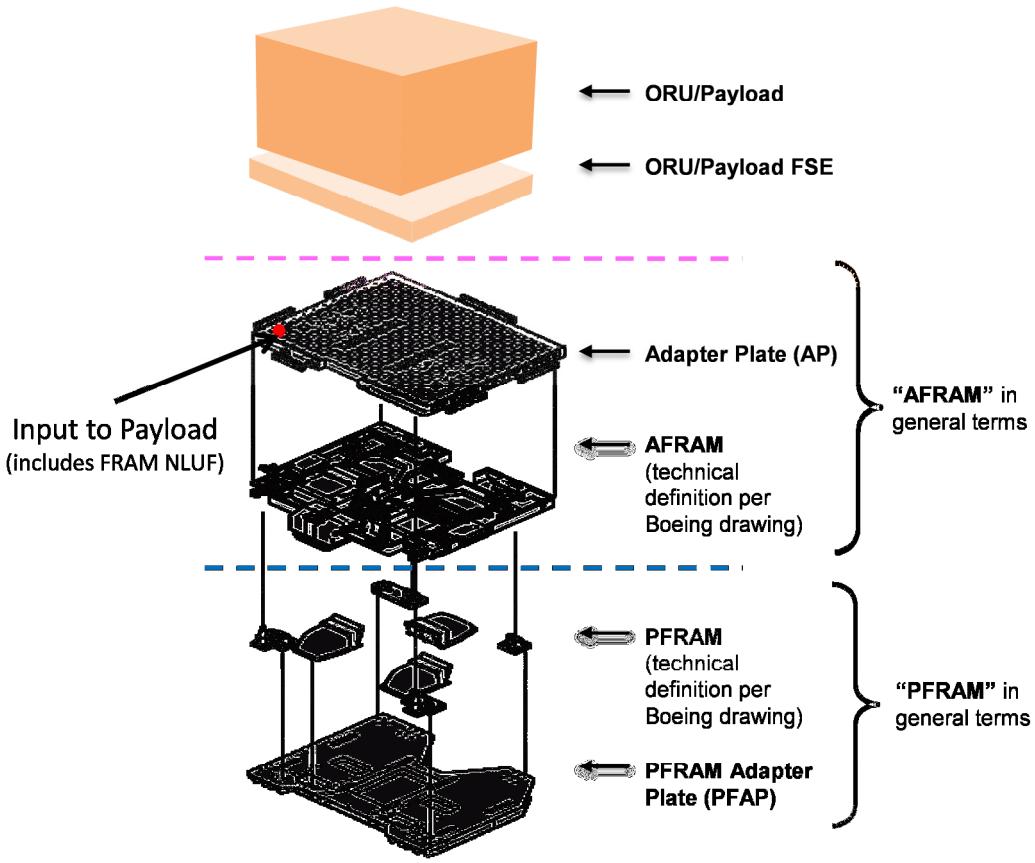


Figure 6-23 Input to payload

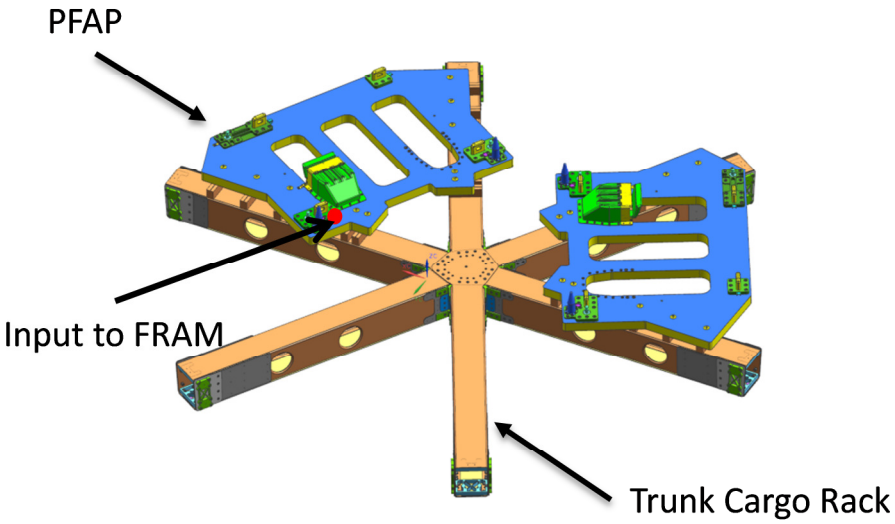
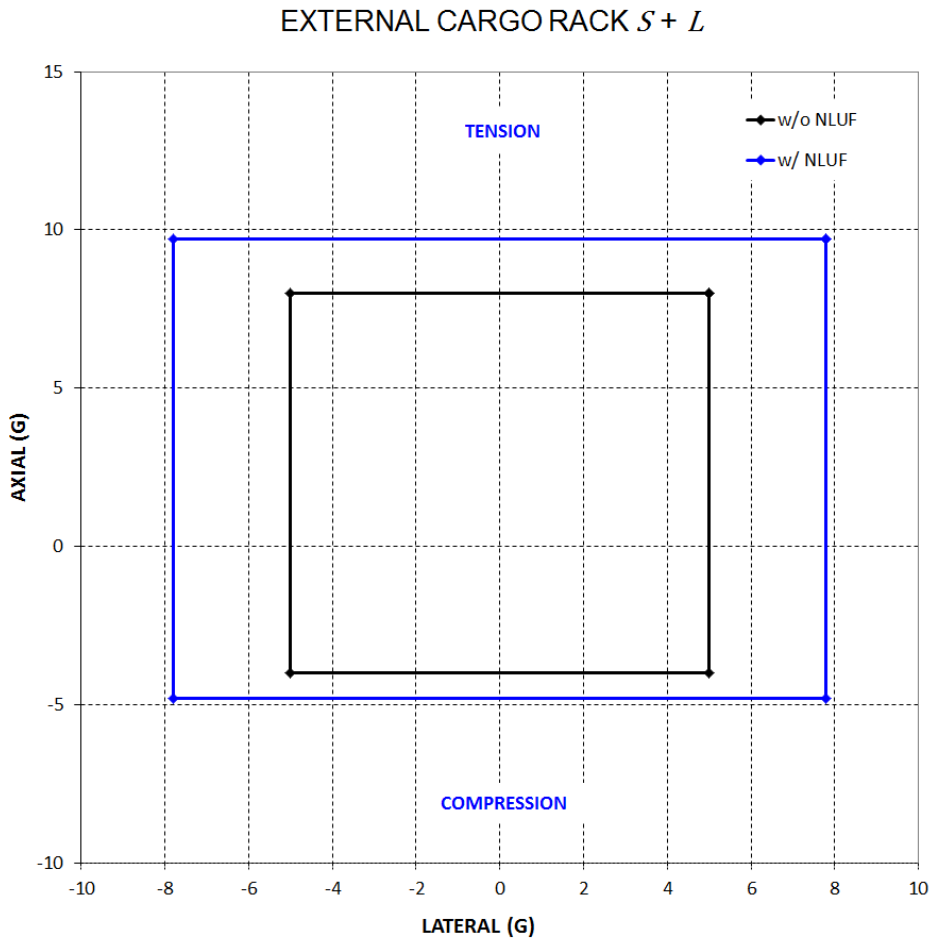


Figure 6-24 Input to FRAM

6.5.2 Loads and FRAM Non-linearity

Coupled loads analysis performed as part determining environments for FRAM-based cargo will include non-linearity uncertainty factors. The following uncertainty factors will be applied to all components above the Trunk Cargo Rack, including the Passive FRAM Adapter Plate (PFAP), the Passive FRAM assembly (PFRAM), and the payload Integrated Assembly (the Active FRAM assembly, adapter plate, and the payload):

Nonlinear Uncertainty Factor (NLUF) for translational acceleration: 1.5625
Nonlinear Uncertainty Factor (NLUF) for rotational acceleration: 2.0
Ax: 1.5625
Ay: 1.5625
Az: 1.5625
Rx: 2.0
Ry: 2.0
Rz: 2.0



	Unpressurized Cargo NetCG (g)		
	Axial Maximum	Axial Minimum	Lateral RSS
W/out NLUF	+8.0	-4.0	+/- 5.0
W/ NLUF	+9.7	-4.8	+/- 7.8

Figure 6-25 Design Load Factors – UNPRESSURIZED CARGO – Ascent only (valid for CRS 3 missions and beyond)

Notes:
The reference frame for the load factors with respect to the directions of motion is as follows:

- Loads are combined steady-state (*S*) and low-frequency (*L*) load factors
- X: The longitudinal axis of the vehicle. Positive x-axis extends from the base or bottom of the cargo vehicle to the nose of the cargo vehicle
- Z: Positive z-axis points directly away from the side hatch of the vehicle.
- Y: Y-axis completes the right-handed coordinate system, roughly aligned with the solar arrays.
- Positive design load factors induce tension at payload interface

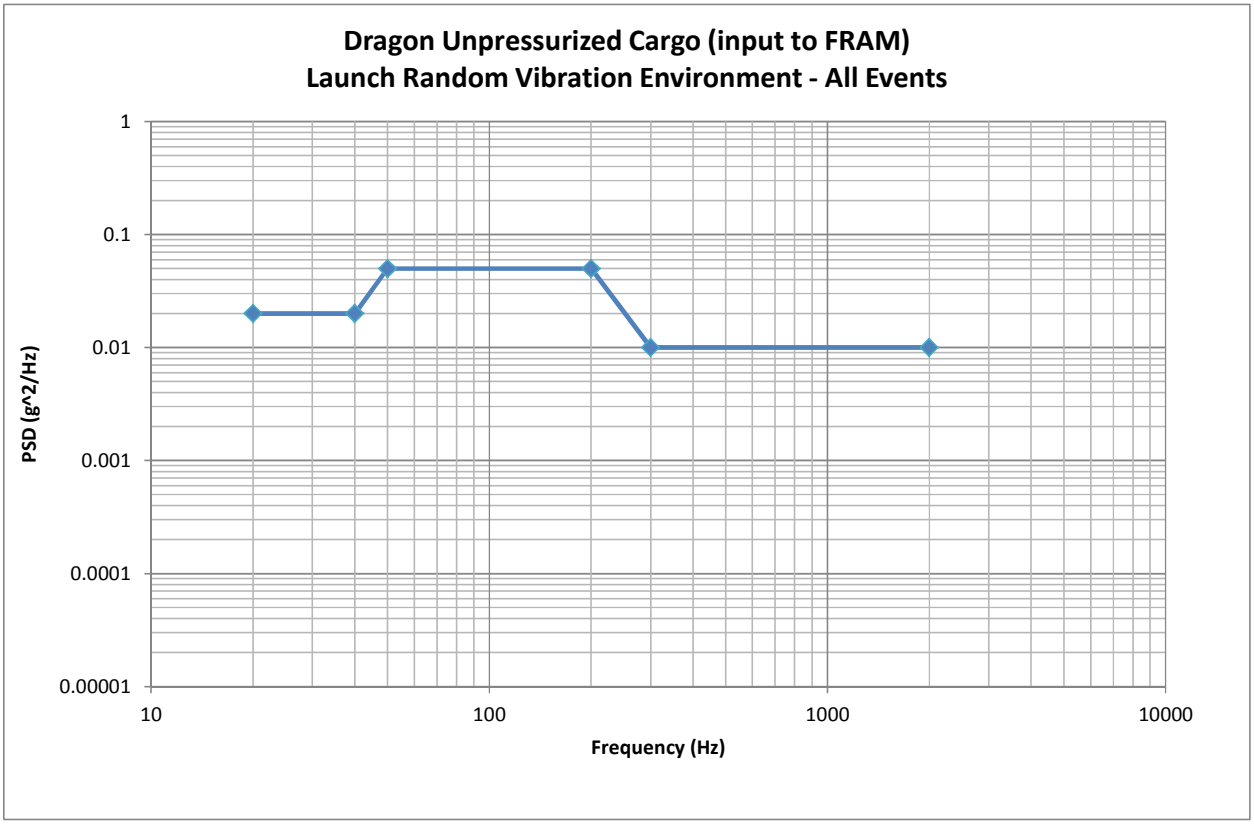
6.5.3 Random Vibration

Cargo items in the unpressurized section shall meet the specified launch performance requirements after exposure to the maximum flight random vibration environment defined in figures in this section. Note that this random vibration environment is based on a limited set of analytical predictions of various cargo configurations. This environment will be verified and updated, if necessary, after additional test and flight data is received.

The following notes apply to the random vibration environments:

- Based on Coupled Loads Analysis (CLA) ascent results below 100 Hz
- Based on trunk acoustic test results above 100 Hz
- Acoustic input/forcing functions based on F9-001 and F9-002 flight data
- Includes increase to cover v1.1 upgrade
- Environment presented is a Maximum Predicted Environment (MPE) which includes 4.9 dB margin for variability

6.5.3.1 Random Vibration (LAUNCH-All Events) – Unpressurized Cargo (input to FRAM)



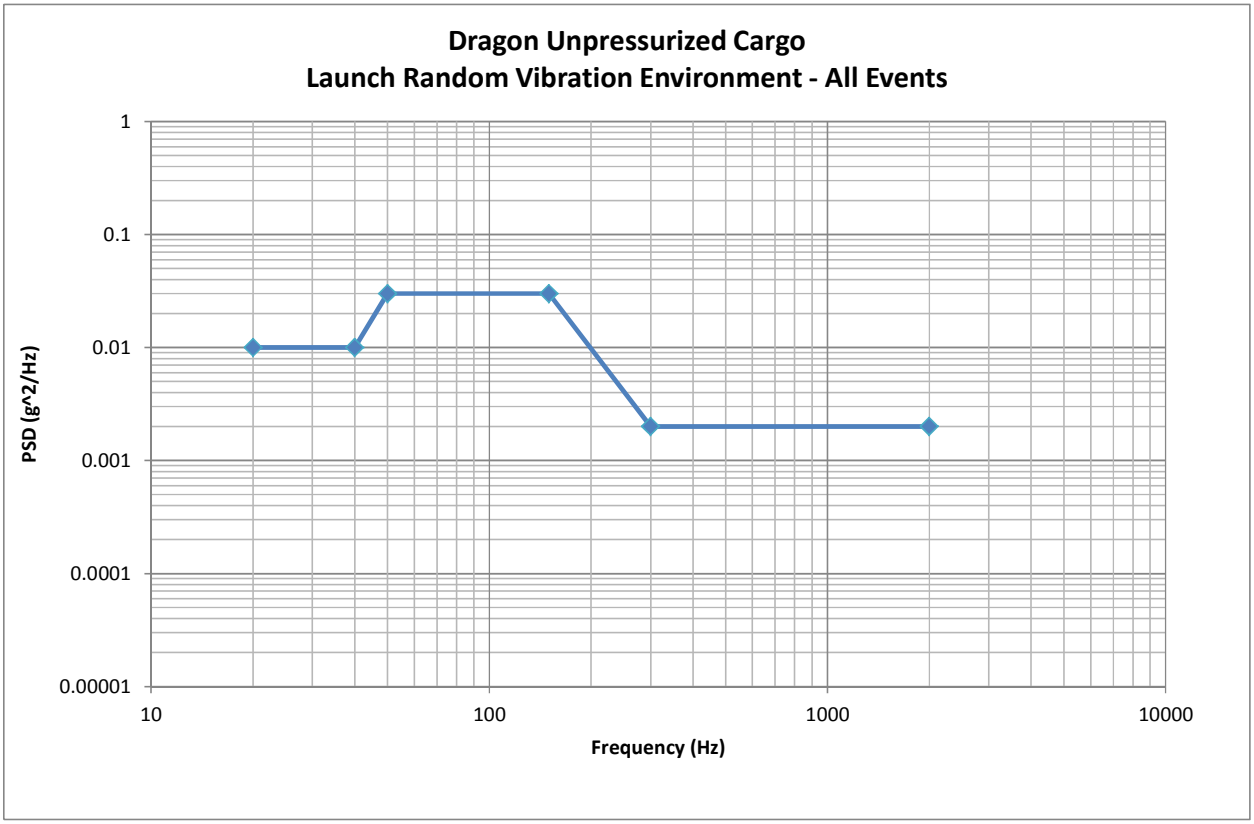
Frequency (Hz)	Dragon Unpressurized Cargo (input to FRAM) Launch Vibration MPE - All Events (Rev11) - All Axes [g^2/Hz]
20	0.02
40	0.02
50	0.05
200	0.05
300	0.01
2000	0.01
Grms	**5.25**
Duration	**60 sec/axis**

Figure 6-26 Random Vibration (LAUNCH – All Events) – Unpressurized Cargo (input to FRAM)

Notes:

1. Duration covers liftoff, ascent, Mvac burn, and reentry (abort)

6.5.3.2 Random Vibration (LAUNCH-All Events) – Unpressurized Cargo (input to payload)



Frequency (Hz)	Dragon Unpressurized Cargo (input to payload) Launch Vibration MPE - All Events (Rev11) - All Axes [g^2/Hz]
20	0.01
40	0.01
50	0.03
150	0.03
300	0.002
2000	0.002
Grms	**2.85**
Duration	**60 sec/axis**

Figure 6-27 Random Vibration (LAUNCH – All Events) – Unpressurized Cargo (input to payload)

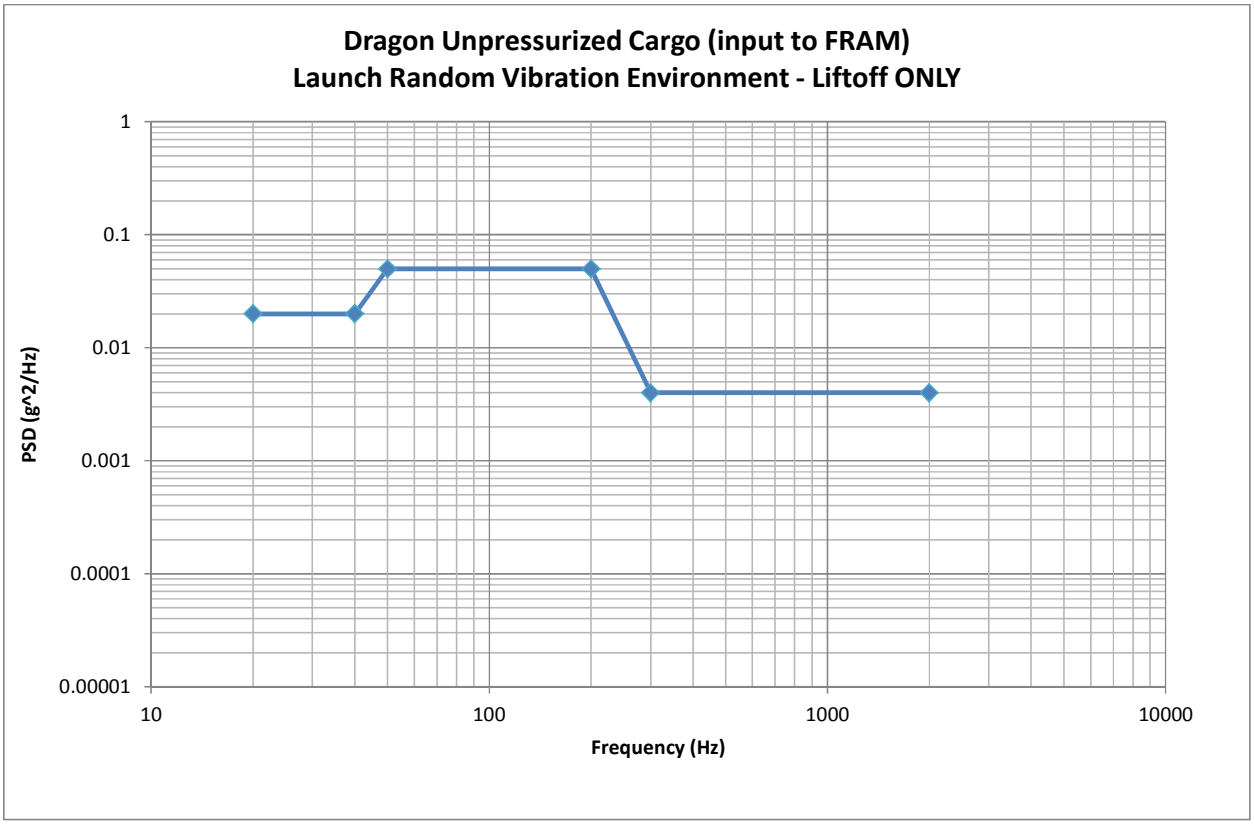
Notes:

1. Duration covers liftoff, ascent, Mvac burn, and reentry (abort)

6.5.4 Random Vibration for Combined Loads Analysis ONLY

Random vibration environments in this section are for combined loads analysis ONLY. Results exclude Coupled Loads Analysis results below 100 Hz.

6.5.4.1 Random Vibration (LAUNCH-Liftoff ONLY) – Unpressurized Cargo (input to FRAM)



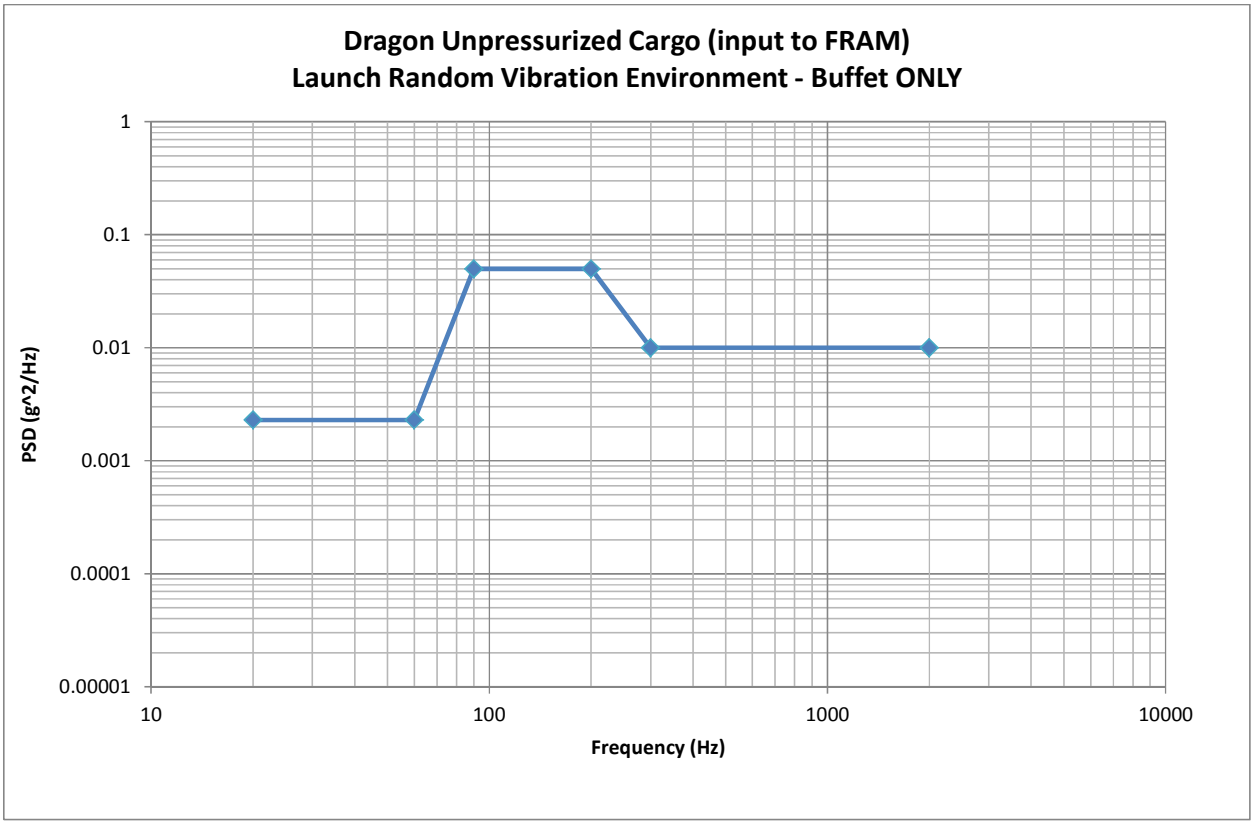
Frequency (Hz)	Dragon Unpressurized Cargo (input to FRAM) Launch Vibration MPE - Liftoff ONLY (Rev11) - All Axes [g^2/Hz]
20	0.02
40	0.02
50	0.05
200	0.05
300	0.004
2000	0.004
Grms	**4.09**

Figure 6-28 Random Vibration (LAUNCH – Liftoff ONLY) – Unpressurized Cargo (input to FRAM)

Notes:

1. This random vibration environment is for the combined loads analysis ONLY.

6.5.4.2 Random Vibration (LAUNCH-Buffet ONLY) – Unpressurized Cargo (input to FRAM)



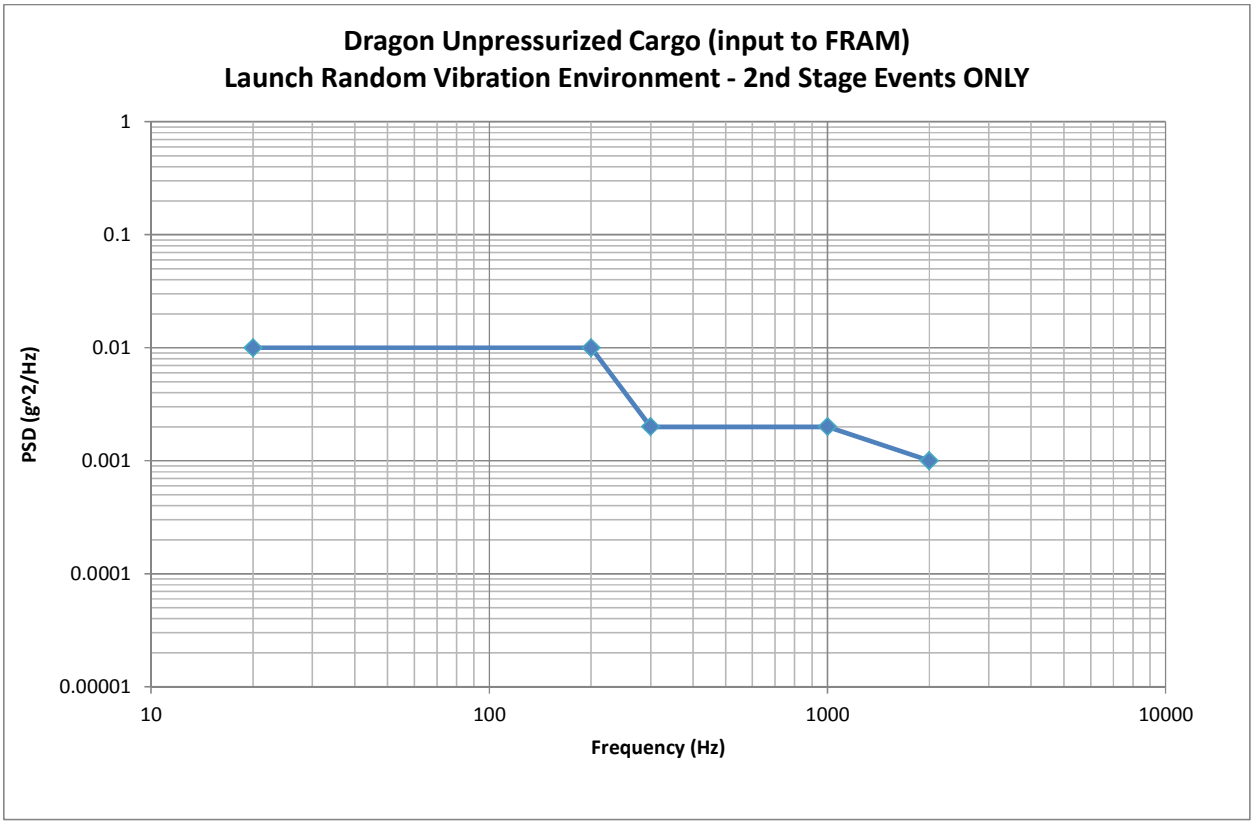
Frequency (Hz)	Dragon Unpressurized Cargo (input to FRAM) Launch Vibration MPE - Buffet ONLY (Rev11) - All Axes [g^2/Hz]
20	0.0023
60	0.0023
90	0.05
200	0.05
300	0.01
2000	0.01
Grms	**5.05**

Figure 6-29 Random Vibration (LAUNCH – Buffet ONLY) – Unpressurized Cargo (input to FRAM)

Notes:

1. This random vibration environment is for the combined loads analysis ONLY.
2. Results exclude buffet below 100 Hz.

6.5.4.3 Random Vibration (LAUNCH-2nd Stage Events ONLY) – Unpressurized Cargo (input to FRAM)



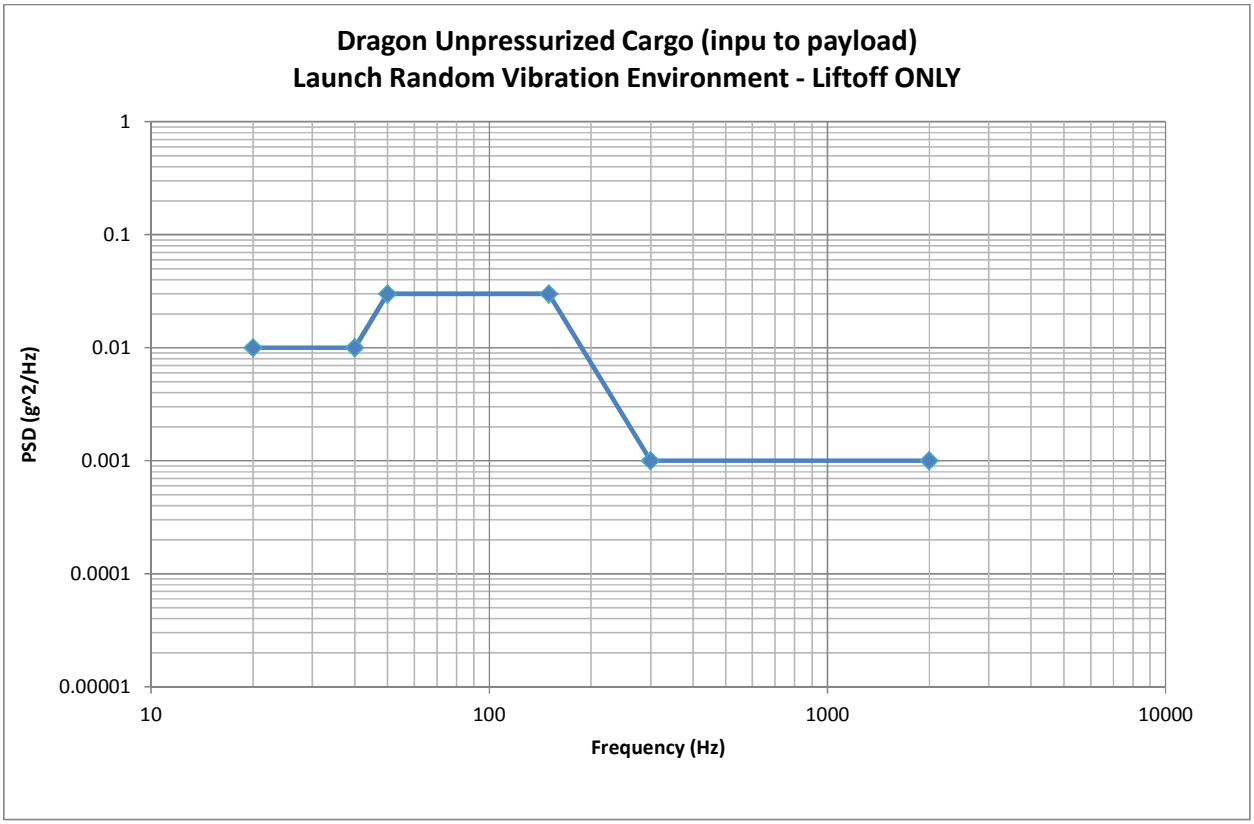
Frequency (Hz)	Dragon Unpressurized Cargo (input to FRAM) Launch Vibration MPE - 2nd Stage Events ONLY (Rev11) - All Axes [g^2/Hz]
20	0.01
200	0.01
300	0.002
1000	0.002
2000	0.001
GRMS	**2.3**

Figure 6-30 Random Vibration (LAUNCH – 2nd Stage Events ONLY) – Unpressurized Cargo (input to FRAM)

Notes:

1. This random vibration environment is for the combined loads analysis ONLY.

6.5.4.4 Random Vibration (LAUNCH-Liftoff ONLY) – Unpressurized Cargo (input to payload)



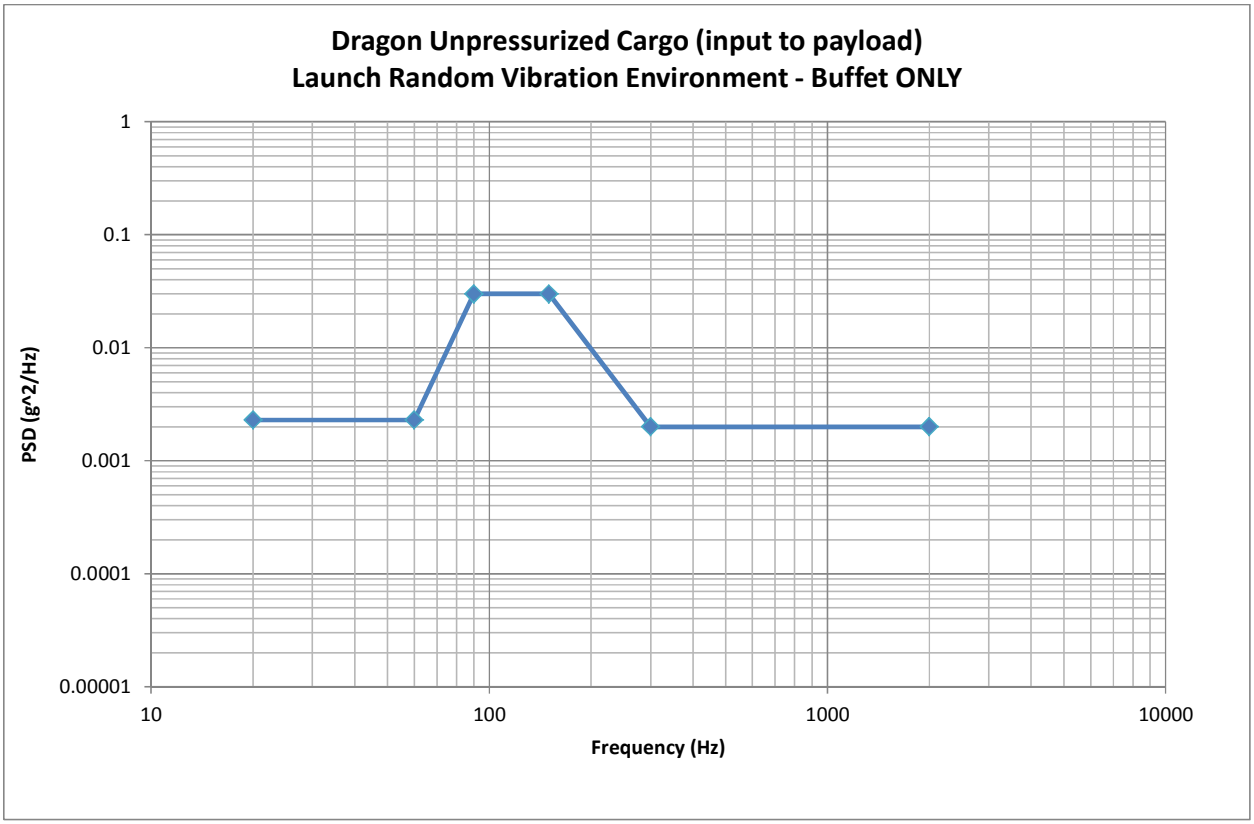
Frequency (Hz)	Dragon Unpressurized Cargo (input to payload) Launch Vibration MPE - Liftoff ONLY (Rev11) - All Axes [g^2/Hz]
20	0.01
40	0.01
50	0.03
150	0.03
300	0.001
2000	0.001
Grms	**2.48**

Figure 6-31 Random Vibration (LAUNCH – Liftoff ONLY) – Unpressurized Cargo (input to payload)

Notes:

1. This random vibration environment is for the combined loads analysis ONLY.

6.5.4.5 Random Vibration (LAUNCH-Buffet ONLY) – Unpressurized Cargo (input to payload)



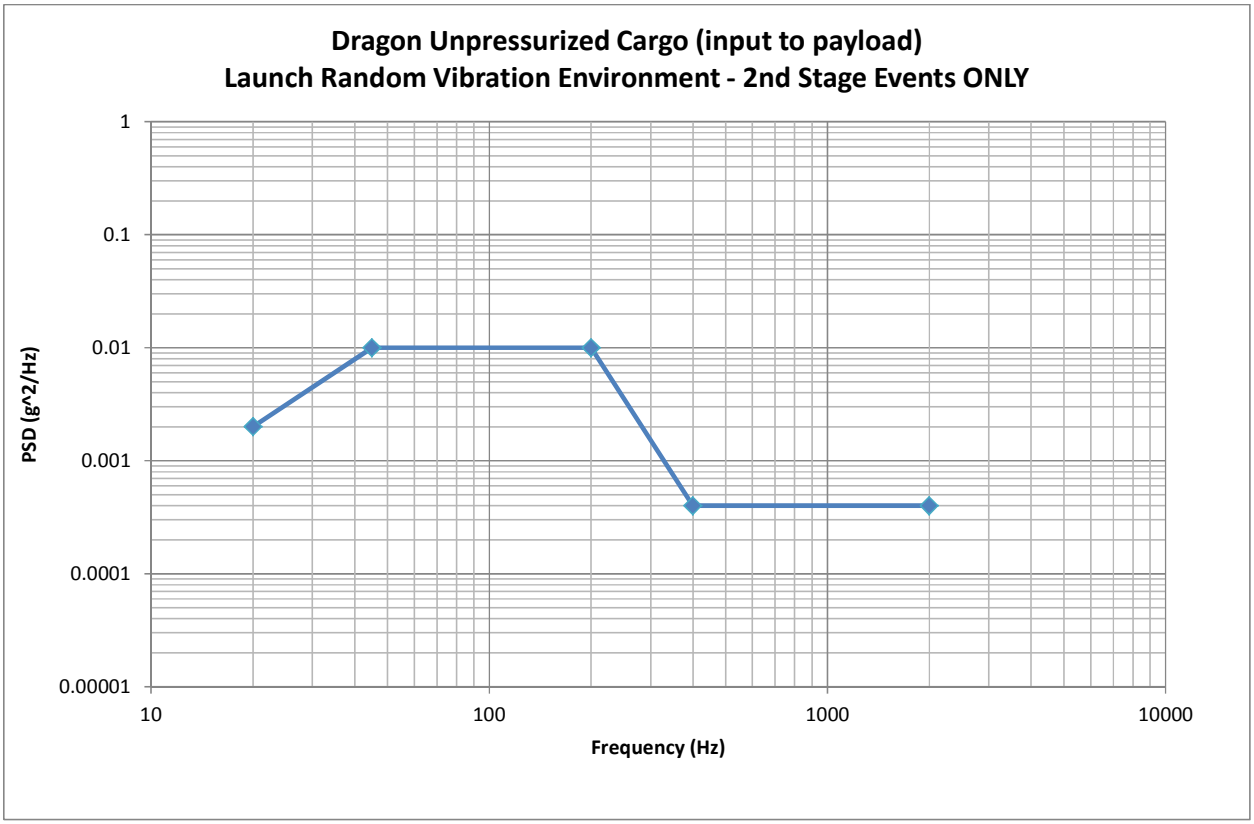
Frequency (Hz)	Dragon Unpressurized Cargo (input to payload) Launch Vibration MPE – Buffet ONLY (Rev11) - All Axes [g^2/Hz]
20	0.0023
60	0.0023
90	0.03
150	0.03
300	0.002
2000	0.002
Grms	**2.64**

Figure 6-32 Random Vibration (LAUNCH – Buffet ONLY) – Unpressurized Cargo (input to payload)

Notes:

1. This random vibration environment is for the combined loads analysis ONLY.
2. Results exclude buffet below 100 Hz.

6.5.4.6 Random Vibration (LAUNCH-2nd Stage Events ONLY) – Unpressurized Cargo (input to payload)



Frequency (Hz)	Dragon Unpressurized Cargo (input to payload) Launch Vibration MPE - 2nd Stage Events ONLY (Rev11) - All Axes [g^2/Hz]
20	0.002
45	0.01
200	0.01
400	0.0004
2000	0.0004
GRMS	**1.7**

Figure 6-33 Random Vibration (LAUNCH – 2nd Stage Events ONLY) – Unpressurized Cargo (input to payload)

Notes:

1. This random vibration environment is for the combined loads analysis ONLY.

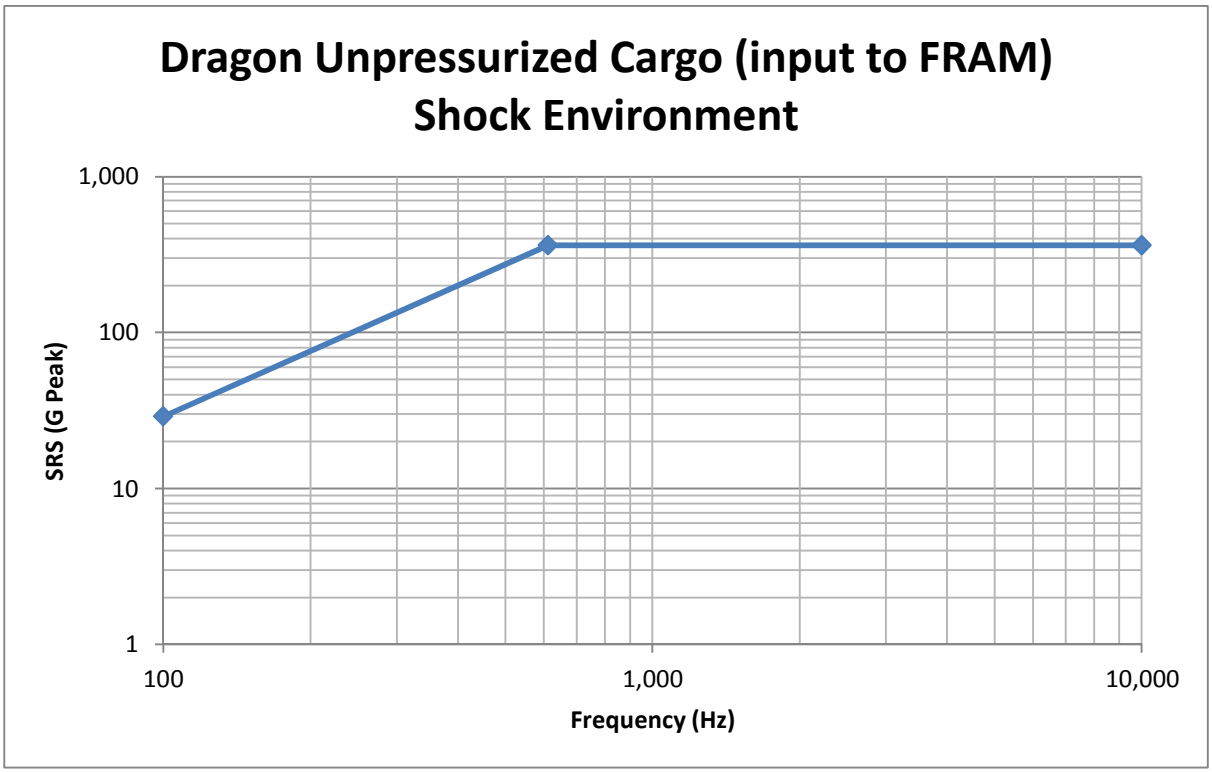
6.5.5 Shock

Cargo items shall meet the specified launch/return performance requirements when exposed to the maximum shock environment defined in the figures in this section. These environments do not include shock due to the payload separation system which may induce higher shock to the cargo. Additional, cargo-specific shock environments will be included in the mission-specific interface documents.

Note that this shock environment is based on a limited set of test data and analytical predictions.

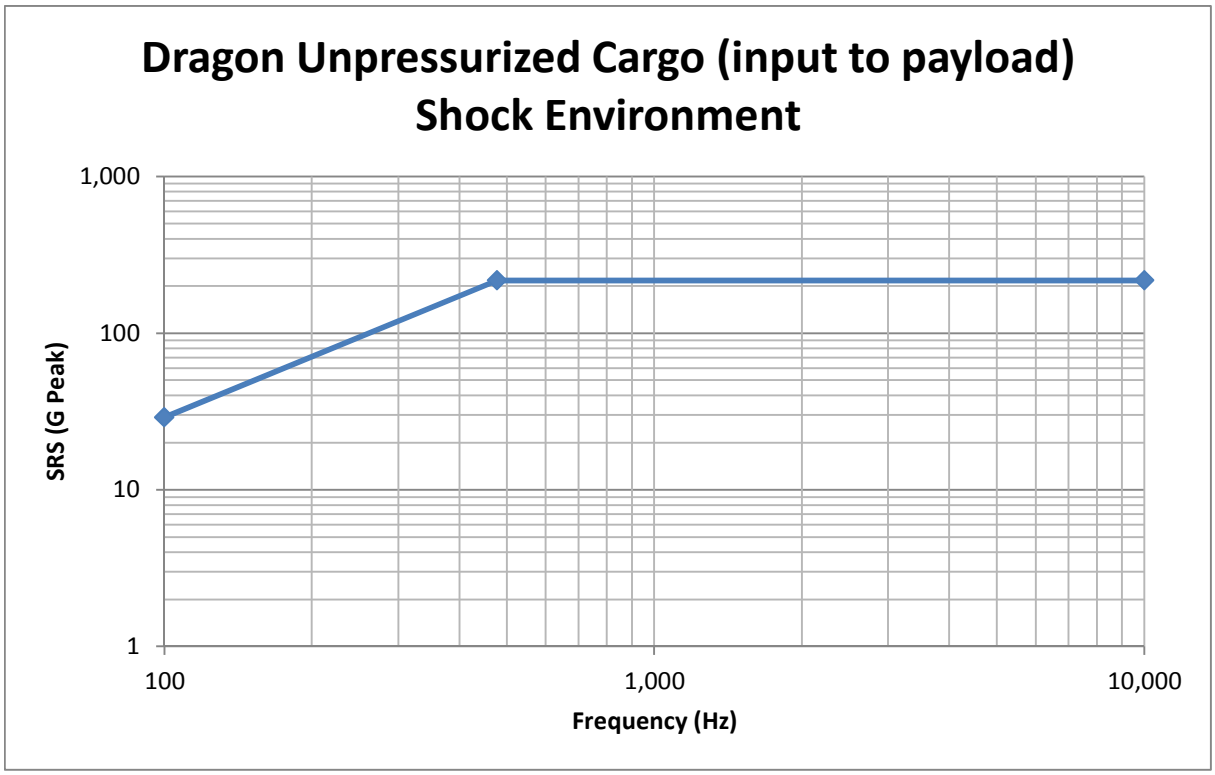
The following notes apply to the shock environments:

- Shock environment is a Maximum Predicted Environment (MPE) which includes 4.9 dB margin for variability



Frequency (Hz)	Unpressurized Cargo (input to FRAM) Shock MPE (Rev10) (g-peak)
100	29
611	362
10000	362

Figure 6-34 Shock (LAUNCH) – Unpressurized Cargo (input to FRAM)



Frequency (Hz)	Unpressurized Cargo (input to payload) Shock MPE (Rev10) (g-peak)
100	29
477	217
10000	217

Figure 6-35 Shock (LAUNCH) – Unpressurized Cargo (input to payload)

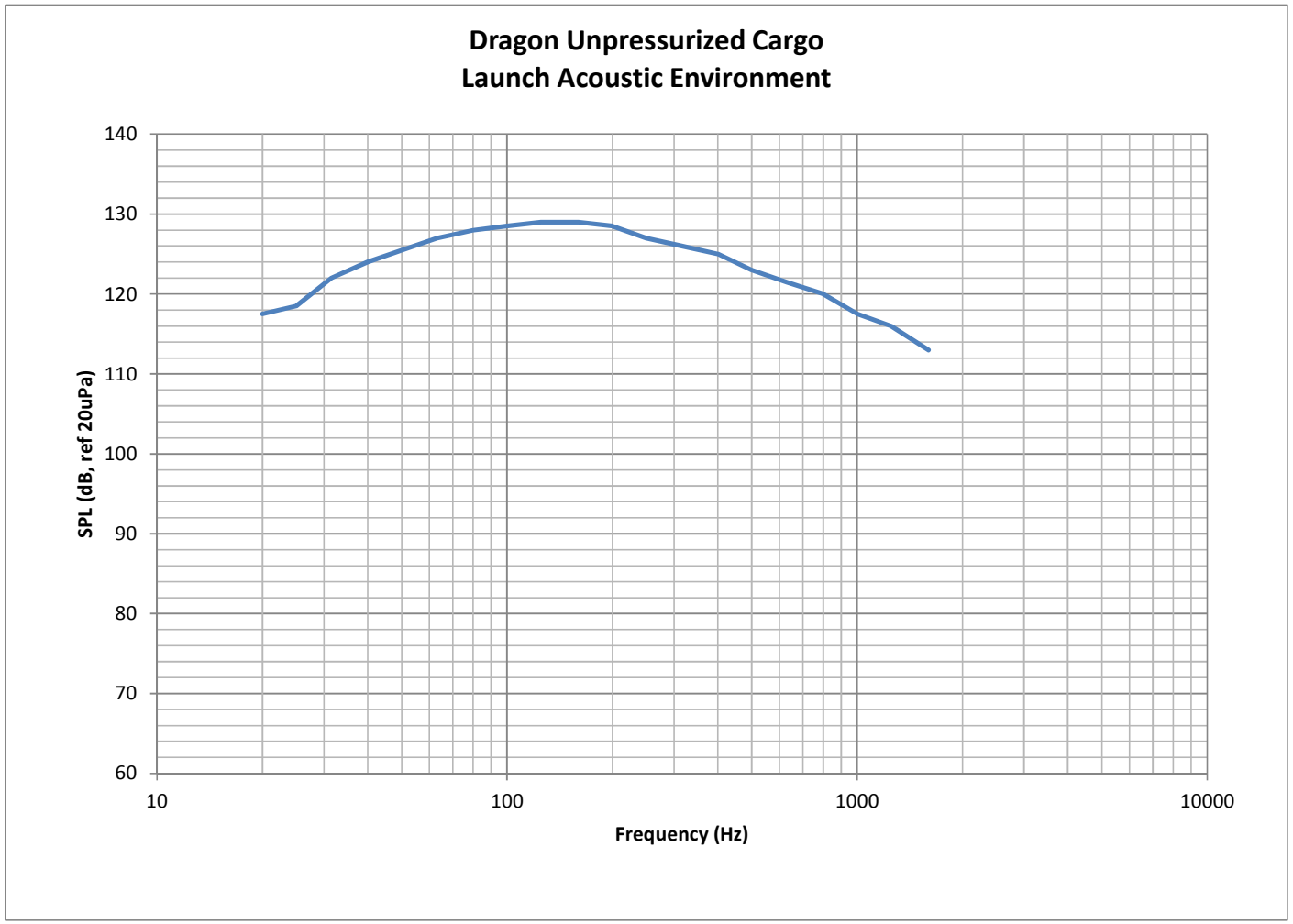
6.5.6 Acoustics

Cargo items shall meet the specified launch performance requirements when exposed to the maximum launch/return acoustic environment defined figures in this section. Note that this acoustic environment is based on a limited set of test data and analytical predictions. This environment will be verified and updated, if necessary, after flight data is received.

The following notes apply to the acoustic environments:

- Acoustics based on SEA and F9-001 and F9-002 flight data
- Includes increase to cover v1.1 upgrade
- Includes a worst-case fill factor in the trunk
- Acoustic environment is a Maximum Predicted Environment (MPE) which includes 4.9 dB margin for variability

6.5.6.1 Acoustics (LAUNCH)



Frequency (Hz)	Dragon Unpressurized Cargo Launch Acoustic MPE (Rev11) (dB)
20	117.5
25	118.5
31.5	122.0
40	124.0
50	125.5
63	127.0
80	128.0
100	128.5
125	129.0
160	129.0
200	128.5
250	127.0
315	126.0
400	125.0
500	123.0
630	121.5
800	120.0
1000	117.5
1250	116.0
1600	113.0
OASPL	138.3
Duration	5sec/flight

Figure 6-36 Acoustics (LAUNCH) – Unpressurized Cargo

6.5.7 Pressure Decay Rate

The pressure decay rate will not exceed 0.3 psi/s except for a brief period of time near transonic speeds where it will not exceed 1 psi/s. The duration of the transonic speed spike should not exceed 7.5 seconds.

6.5.8 Thermal

6.5.8.1 Thermal Environment

The temperature of the air in the trunk pre-launch while the launch vehicle is on the pad will be maintained from 10°C (+50°F) to +35°C (+95°F).

6.5.8.2 Thermal Environment – All Mission Phases Post-Liftoff

For flight operation, the trunk internal thermal environment is radiation dominated. The temperature inside the trunk can be extreme. The inside of the trunk has a low emissivity surface, partially connected to the trunk skin that sees thermally harsh environments. In addition, the trunk can act as a solar trap when, due to spacecraft attitude, it is pointed directly at the sun. Payload temperatures and thermal behavior are highly dependent on the payload's specific properties and on coupling with the trunk surfaces and other payloads. Therefore, thermal environments are cargo and mission specific and best derived from joint, integrated thermal analyses.

SpaceX and NASA have developed a joint approach to allow payload developers to best understand and plan for trunk thermal environments. Payload developers will be provided with a Dragon Thermal Assessment Package. This package will include a non-proprietary Dragon thermal model, mission parameters, and thermal assessment guidelines. This package will allow payload developers to evaluate and iteratively design their payload thermal systems (e.g. heater power, surface coatings, MLI, etc.).

This approach will be accomplished in three parts: On-Orbit Solo Flight analyses (performed by payload developer), Berthed to ISS analyses (performed by payload developer), and Mission Specific Integrated Analysis (performed by SpaceX). During this process analysis results will be reviewed and mitigation options discussed as needed.

6.5.9 Relative Humidity

The relative humidity of the air in the trunk pre-launch while the launch vehicle is on the pad will be maintained at 40% to 70% RH.

6.5.10 Maximum RF Environment

Launch vehicle intentional and spurious radiated emissions seen by external cargo are expected to be below the values show in figure and table below.

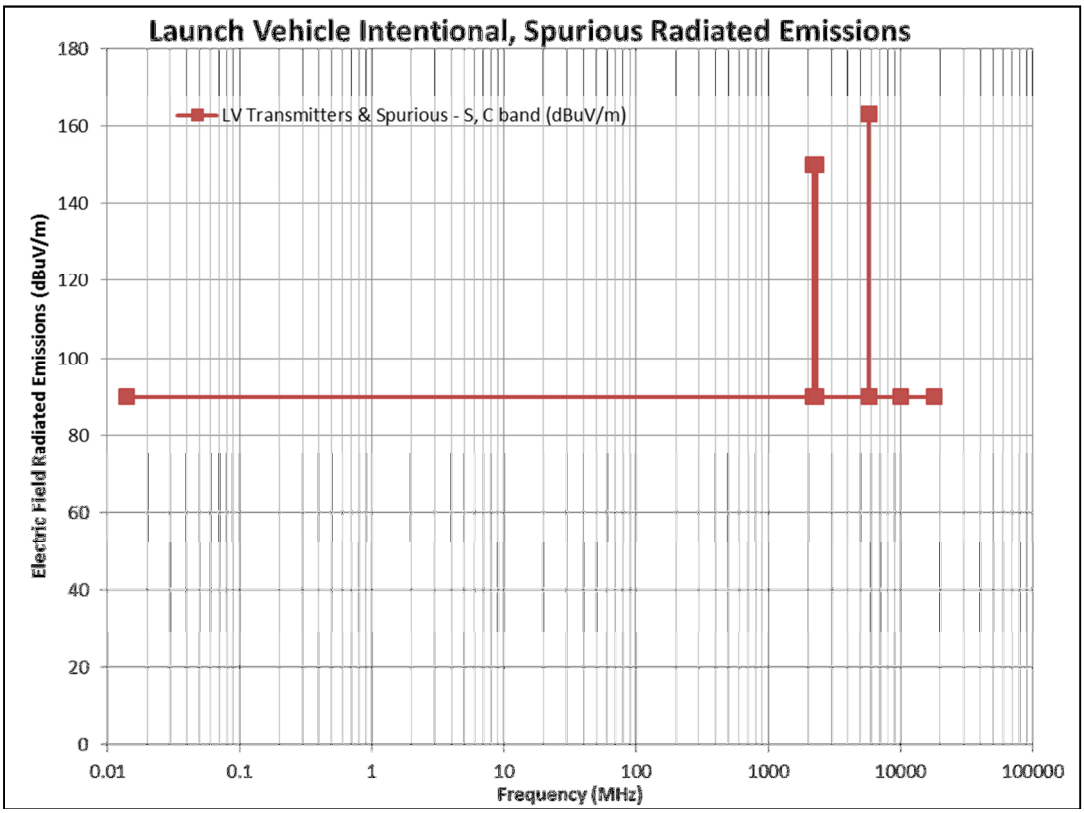


Figure 6-37 Maximum RF Environment

Table 6-4 Maximum RF Environment

Frequency Range (MHz)	Electric Field Limit (dBuV/m)
0.014	90
2200	90
2200	150
2300	150
2300	90
5755	90
5755	163
5775	163
5775	90
10000	90
18000	90

6.5.11 Outgassing Environment

Best efforts are made to select low outgassing processes and materials per ASTM E595 for trunk production, and the trunk is expected to be a relatively low outgassing environment. The potential contamination through deposition on cargo surfaces is highly dependent on payload properties, view factors, surface temperatures, and the other payloads present in the trunk. Specific contamination requirements and concerns will be addressed on a mission and cargo specific basis. If needed, NASA may provide an integrated contamination analysis based on the specific mission and cargo manifest (TBC).

6.5.12 Disposal External Cargo

After departure from ISS to just before trunk jettison, disposal cargo environments should be enveloped by launch environments. Trunk-to-capsule separation shock may exceed launch and on-orbit shock environments, however, it should be low risk to mission success.

APPENDIX A: PAYLOAD MODEL REQUIREMENTS

A.1 Dynamic Math Model Requirements

Below are requirements for customer models of cargo to be included in SpaceX Coupled Loads Analysis (CLA). Dynamic math models can either be provided as bulk data or as a Craig-Bampton model.

Cargo models shall be representative of the fully integrated payload and Flight Support Equipment assembly, all in the final, launch-ready configuration. As applicable to the type of model, this should account for all FSE including blankets, shielding, handles, etc. For example, in the case of FRAM-based cargo, the model should include the final payload itself, the complete Active FRAM assembly and adaptor plate, all handles, and any other associated hardware and Flight Support Equipment.

Craig-Bampton Models

The customer provided dynamic model should include mass, stiffness, response transformation matrices, definition of modal damping and any uncertainty factor to be applied to the modal responses, and specific requests for results.

Dynamic model should be a fixed-interface modal model (Craig-Bampton formatted) with the interface to the vehicle remaining physical. The frequency content of the model should be 150 Hz, as a minimum. The units used (SI or English) as well as the model coordinate system(s) relative to the vehicle should also be defined. The model should consist of mass and stiffness matrices and acceleration, displacement, and/or load transformation matrices (ATM, DTM, and LTM) to recover desired responses. The definition of the rows/columns of the matrices should also be provided to facilitate coupling of the provided model to vehicle model. It is requested that labels for the rows of the ATM, DTM, and/or LTM also be provided for inclusion in results tables.

Models should be in formatted ASCII OUTPUT4 Nastran files.

Bulk Data

If bulk data is provided all nodes, elements, and coordinate systems must be numbered between 10,500,001 and 10,600,000. All requested outputs should be included in the documentation. If requested, SpaceX can provide nodal accelerations, component NetCG responses, element forces, and relative displacements.

Damping Definition

Damping should also be defined. Typically, diagonal modal damping is defined as a percent of critical (and may vary from mode to mode) unless there is firm rationale why full matrix damping should be exercised. This rationale would be the existence of an internal highly damped isolation system with known physical characteristics.

Uncertainty Factor

SpaceX, as a standard practice, will apply a modal uncertainty factor to all responses that reflects launch vehicle maturity. However, if the customer desires the application of a larger modal uncertainty factor, this should be specifically requested. Under no circumstance will the modal uncertainty factor be less than that used in SpaceX standard practice.

Documentation

SpaceX requested that the dynamic model be accompanied documentation that includes:

- Definition of units used (SI or English)
- Definition of coordinate system
- A list of all the frequencies
- Pictures of the first few mode shapes (including the three fundamental modes in X, Y, and Z)
- Definition of damping
- Definition of the modal response (dynamic) uncertainty factor
- Definition of response recovery (excel file with rows and descriptions)

The above list is not all inclusive and the customer may provide additional information that will assist SpaceX in processing the dynamic model for CLA.

Results Transmittal

The following results will be provided to the customer:

- Maximum/Minimum summary tables for all flight events analyzed.
- Results tables enveloping all analyzed flight events.

Other results may be available. Requests for other results need to be made sufficiently in advance and are pending agreement between SpaceX and NASA. These include but may not be limited to shock response spectra, power spectral densities, and/or time histories of specific response recovery items.

A.2 Thermal Model Requirements

Overview

SpaceX will perform an integrated thermal analysis. This analysis will couple the SpaceX external payload compartment (Dragon trunk) thermal model with the payload thermal models from the payload providers, and analyze the combined models for three phases:

- Ground operations
- On pad operations
- Flight operations (launch to Dragon rendezvous with the ISS , through Dragon berthing, and up to cargo deployment from Dragon Trunk)

Cargo models shall be representative of the fully integrated payload and Flight Support Equipment assembly, all in the final, launch-ready configuration. As applicable to the type of model, this should account for all FSE including blankets, shielding, handles, etc. For example, in the case of FRAM-based cargo, the model should include the final payload itself, the complete Active FRAM assembly and adaptor plate, all handles, and any other associated hardware and Flight Support Equipment.

Payload Model Requirements

- Thermal math models in Thermal Desktop (TD), SINDA-G, SINDA/FLUINT compatible formats
- Geometric math models in TRASYS, TSS, or Thermal Desktop compatible formats
- Maximum of 500 thermal model nodes and 500 geometry model surfaces. Up to 50 additional thermal model nodes and 50 additional geometry model surfaces for mechanical interfaces, such as FRAM, Flight Support Equipment, and external fixtures. [For initial models on the CRS 3 (SpaceX 3) mission, there will be flexibility on the node count for mechanical interfaces. NASA is working toward providing reduced models in Thermal Desktop format for NASA-provided hardware for future analyses.]
- Internal and external convection nodes added.
- List of critical nodes and associated temperature limits for stowage (non-operational survival) and all operational modes.
- Other important model information and variable settings, such as power or heater settings for each of the mission phases to be analyzed, etc.
- Documentation/model comments for user inputs and variable settings for all operational modes and mission phases, such as heater power and/or operational power settings.
- Model delivery to include checkout case.
- SI units or English units are acceptable if the thermal math model files are delivered in Thermal Desktop format. In any other format, the thermal math model delivered to SpaceX shall be delivered in SI units. Models delivered in SI units shall be documented/commented such as to make models readily convertible to the English units required for ISS vehicle integration. [NASA and SpaceX will coordinate on a case by case basis on the best approach for existing hardware models, e.g. ISS ORU and FSE assemblies, which may not be easily provided in SI units.]
- The geometry model shall be delivered with only the external surfaces active. Payload surfaces that see only other payload surfaces shall be made inactive. Radiation conductors from cavity models shall be delivered as part of the conductor block. Convection in hermetically sealed cavities shall be treated the same way. Internal radiation conductors (RADK) and convection conductors shall be pre-defined and fixed.
- A cargo identifying prefix based on the payload name should be used for all cargo specific submodel names, optical properties, register data, other global user data, etc. Cargo providers are encouraged to

confirm with SpaceX early in the analysis process that their naming scheme will be compatible. For example (where "XXX" is an example payload identifier):

- Sub-model name: XXXnam10
- Optical property: XXX_blackpaint
- Material property: XXX_aluminum

Output Delivered to Customer

SpaceX assessment will include external convection heat transfer modes for the expected air temperature in the trunk during appropriate mission phases, integration of the Dragon and payload mounting interface, and analysis of the integrated thermal models in a simulated launch campaign. Outputs to the payload owner include:

- Documentation of assumptions for the Dragon/ISS flight attitudes, natural environments, and solar beta angle range.
- Minimum and maximum temperatures of critical, pre-defined payload nodes during each mission phase up to removal from trunk.
- Time-temperature profiles for critical pre-defined payload nodes or a representative list if results are similar.
- Table of payload thermal limit violations, if any.

A.3 CAD Model Requirements

SpaceX requests a computer-aided design (CAD) model of the payload from the payload provider. The SpaceX structures department will integrate the CAD model with our Dragon and Falcon 9 vehicle models, as applicable, for visualization, integration, clearance check, and operations development purposes.

Cargo models shall be representative of the fully integrated payload and Flight Support Equipment assembly, all in the final, launch-ready configuration. As applicable to the type of model, this should account for all FSE including blankets, shielding, handles, etc. For example, in the case of FRAM-based cargo, the model should include the final payload itself, the complete Active FRAM assembly and adaptor plate, all handles, and any other associated hardware and Flight Support Equipment.

SpaceX uses NX7.5 (formerly known as Unigraphics), and prefers models delivered in the Parasolid (.x_t) native format of NX. Customers may also provide models in STEP format. While no explicit limitations are placed on file size or complexity, customers are asked to provide simplified models focusing primarily on outer mold line and interface fidelity, and which avoid including detailed models of every piece part. For example, interior parts and all fasteners which do not specifically affect the outer mold line should be removed before model export. All CAD models should be delivered with a mass properties report for the component which lists the mass and inertial properties of the cargo, the location of the center of gravity, and specifically defines the coordinate systems and units used.

Images files (such as JPG, PNG, etc.) showing various views of the solid model should be provided. SpaceX will use these to verify that the model has transferred and loaded correctly.