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Response of a Store with Tunable Natural Frequencies in Compressible Cavity Flow

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Experiments in compressible cavity flows were performed to understand the fluid-structure interactions that occur during aircraft internal store carriage. A generic, aerodynamic store was installed in a rectangular cavity having a length-to-depth ratio of 7. Similar to previous studies using a cylindrical store, this aerodynamic store responded to the cavity flow at its natural structural frequencies, and it exhibited a directionally dependent response to cavity resonance. Specifically, cavity tones excited the store in the streamwise and wall-normal directions consistently, whereas the spanwise response was much more limited. The store had interchangeable components, which allowed its natural frequencies to be varied by about 10 – 400 Hz. With this ability to tune natural frequencies, cases where a prominent cavity tone frequency matched a structural natural frequency of the store, defined as mode matching, were explored. It was found that mode matching produced substantial increases in store vibrations, though the response of the store continued to scale linearly with the dynamic pressure or loading in the bay. Near mode matching frequencies, the response of the store was quite sensitive as changes in cavity tone frequency of 1% were found to alter store vibrations by as much as a factor of two.

I. Introduction

The flow over an open aircraft bay can result in intense structural vibrations caused by high levels of aeroacoustic loading. This loading has a large broadband component owing to turbulent fluctuations and under many conditions, cavity resonant tones are produced [1] with sound pressure levels *SPL* up to about 170 dB [2]. As summarized in several review articles [3-5], the aeroacoustic loading in cavity flows have motivated numerous studies over the last sixty years. In 'open' cavity flow [6, 7], the cavity acoustics and free shear layer interact to create a feedback loop resulting in cavity resonance. The resonant modes are longitudinal and in simple rectangular geometries their frequencies can be reasonably predicted by the semi-empirical relation of Rossiter [1, 8]. On the other hand, the mode shapes and amplitudes are less predictable as they are complex functions of flow conditions and cavity geometry [3, 4]. Moreover, the surface pressures in cavity flows are highly complex functions of time and position. For example, the dominant cavity mode can vary with time ('mode-switching' [9]) and surface pressures are highly three-dimensional [10]. In the case of internal carriage of a store within an aircraft bay, these spatial and temporal variations are then imparted onto a structure. Despite the potential for damaging vibrations [11], little work [12] had focused on store vibrations prior to release, until recently [13, 14].

Recent experiments by the present authors placed a simplified cylindrical store in an open rectangular cavity flow [13]. The resulting fluid structure interactions (FSI) were then directly measured using simultaneous cavity pressure and store vibration data. Perhaps not surprisingly, the broadband turbulence levels in the cavity were high

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enough to readily excite all of the store's natural frequencies. The response of the store to cavity resonant tones was more complex and exhibited a directional dependence. Specifically, cavity tones excited the store in the streamwise and wall-normal directions consistently, whereas a spanwise response was observed only occasionally. The streamwise and wall-normal responses were attributed to the longitudinal pressure waves and shear layer vortices known to occur during cavity resonance.

In the previous work, the store had fixed natural frequencies, though the cavity resonant tones could be varied by changing the cavity flow Mach number. In a select few cases, a store natural frequency matched a cavity tone, a condition which was defined as "mode matching." The largest store responses were measured in mode-matched cases. Quantifying the effects of mode matching, however, was difficult since the natural frequencies of the store were limited to fixed values and it was difficult to draw reliable conclusions by varying the cavity flow alone.

The current study seeks to further the understanding of fluid-structure interactions FSI in compressible cavity flows with an upgraded model store. In comparison to the previous studies, which used a simple cylindrical model, the current store is more aerodynamic and uses a generic nose cone and tail. Furthermore, the store has interchangeable components giving it variable natural frequencies. Mode-matching is investigated by holding the cavity Mach number (and therefore cavity resonant tones) constant while varying the store's natural frequencies. This provides a quantitative understanding of what is expected to be the worst-case-scenario, namely, when a structural natural frequency matches a cavity resonance tone.

II. Experimental Program

A. Trisonic Wind Tunnel (TWT) and Cavity Geometry

Experiments were conducted in the blowdown-to-atmosphere TWT. The facility uses air as the test gas and has a test section that is enclosed in a pressurized plenum. During a run, the stagnation temperature T_0 was held constant to about 321 K. The tunnel wall boundary layers develop naturally and were fully turbulent upon arrival at the test section. Previous PIV measurements have indicated that the 99% wall boundary layer thickness at the cavity entrance is about $0.5D$. The freestream Mach number M_∞ is measured with a static pressure tap in the tunnel wall at a location about 20 cm upstream of the cavity.

Supersonic tests were performed using a test section having a width of 305 mm and a height of 153 mm at a Mach numbers of 1.5 and at stagnation pressures P_0 ranging from 234 – 344 kPa. Subsonic tests were conducted in a 305 × 305 mm^2 test section at a Mach number of 0.9 and stagnation pressures ranging from 110 - 221 kPa. In subsonic tests, acoustic dampeners were placed in the walls opposite and orthogonal to the cavity to mitigate undesirable interactions of the cavity acoustics and the tunnel walls. This acoustical dampening configuration has been found to significantly reduce the acoustical contamination associated with the tunnel walls [15].

The experiments used a tunnel wall insert containing the rectangular cavity cutout and model store (discussed subsequently) shown in Fig. 1. The cavity had a length of 203 mm, a width of 102 mm, and a depth of 29 mm. With an L/D of 7, the cavity flow category is expected to be 'open' and resonate in subsonic [5] and supersonic flows [6].

B. Store Apparatus

The primary goal of the current work is to understand better the fluid-structure interactions occurring in compressible cavity flows, particularly in the case where a cavity tone frequency matches a natural frequency of an internal store. The model store used to do so is shown installed in the cavity in Fig. 1 and dissembled in Fig. 2. The location of the store components within the cavity is shown in Fig. 3. The store has a length of 165.5 mm ($0.82L$) and a diameter of 17.5 mm ($0.60D$). The center-body of the store is a hollow stainless steel cylinder with an inner diameter of 9.5 mm. This center-body construction is very similar to the blunt cylindrical store used in [13]. Also similar, both flanges of the center-body serve as attachment points for triaxial accelerometers. Hollow steel rods having an outer diameter of 9.5 mm thread into the stainless steel store body and are secured with a thread locking compound. The rods are fixed to the aluminum cavity floor, which is 9.5 mm thick, using recessed nuts with smooth surfaces to minimize flow disturbances and the store is installed in the cavity such that the top of the cylindrical center-body is flush with the tunnel floor ($y = 0$). A generic nose cone having a length of 33.1 mm and a tail having a length of 14.5 mm attach to the flanges of the center-body. The tail fins extend to a diameter of 34.9 mm and are clocked 45-degrees with respect to the wall-normal axis here, though the store can be configured with a 0-degree clocking as well. To make variations in the natural frequencies of the store, three different materials are used for the nose and the tail, namely, aluminum, stainless steel, and tungsten. In addition, interchangeable fore- and aft-weights are also used for finer natural frequency adjustments, the specifics of which are detailed subsequently. Finally, the store's center-of-mass was at its axial center when all steel parts were used.

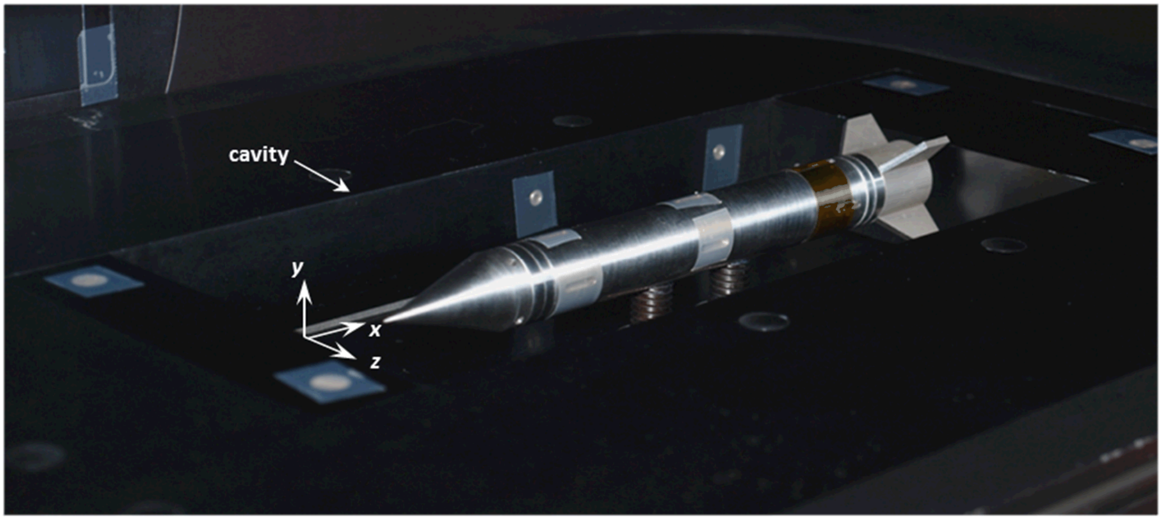

Fig. 1 Cavity with model store installed.

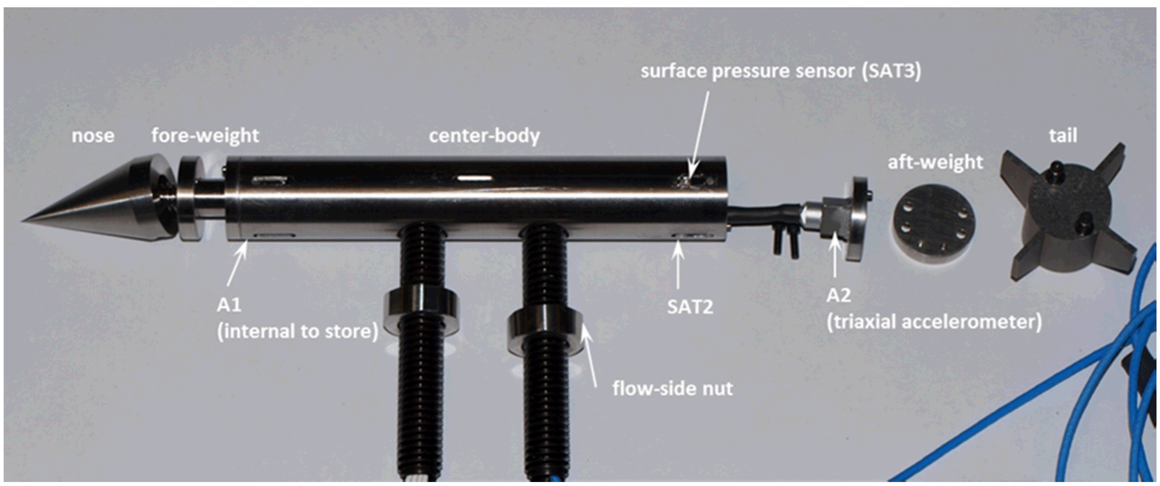

Fig. 2 Disassembled model store.

C. Unsteady Pressure and Acceleration Measurements

Dynamic pressure sensors (Kulite XCQ-062-30A or similar) having a flat frequency response up until about 50 kHz were installed within the cavity (Fig. 3). Spanwise rows of sensors were placed in the cavity floor near the upstream end (FFP1 – FFP5), the downstream end (RFP1 – RFP5), and in the aft-wall near the wall-normal center (AWP1 – AWP5). A streamwise row of floor sensors was also placed in the upstream half of the cavity (C1 – C4) at equidistant spacing (C2 – C4 are under the store and not visible in the figure). Additionally, three surface pressure sensors (Kulite LQ-062-25A) were located on the store for a direct measurement of fluid forcing near the aft-end. SAT1 and SAT3 were at the spanwise-ends of the center-body (Fig. 2), while SAT2 was on the bottom-most portion of the center-body (Fig. 2). The wire leads for the surface sensors exited the store through the hollow rods. Data acquisition and processing of the pressure data was the same as that detailed in [16, 17].

Two miniature triaxial accelerometers (PCB 356A03) were attached to the inner sides of the center-body flanges with adhesive (Fig. 2). The sensors had flat frequency responses to about 5 kHz along the x-axis and to 8 kHz along the y and z axes. The accelerometers were located at the spanwise and wall-normal midpoints of center-body. The upstream accelerometer A1 had an axial location of $x = 0.36L$ and the downstream accelerometer A2 was at $x = 0.83L$. Data acquisition and processing of the acceleration data were the same as that detailed in [13].

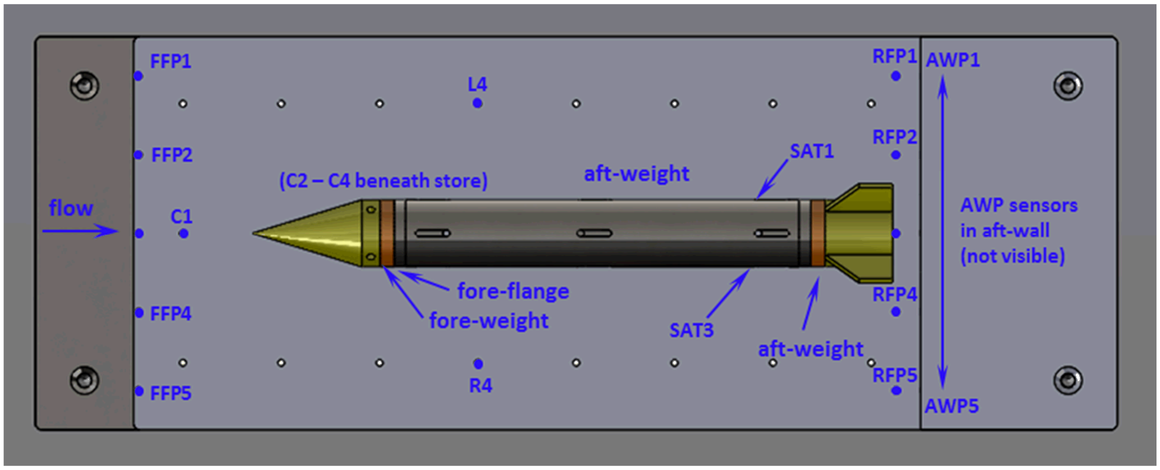

Fig. 3 Pressure sensor locations in cavity and on the surface of the store.

D. Store Natural Frequencies

Interpretation of the store vibration data during cavity FSI requires knowledge of the store's natural frequencies. To achieve this, similar to [13], impact hammer tests were performed to provide data for modal analysis. The triaxial accelerometers in the store were used to measure the response to a PCB (Model 086C01) impact hammer, whose force input was measured using an internal transducer. For each direction of vibration, the frequency response function (the ratio of the output acceleration to the input force as a function of frequency) was used to determine the store's natural frequency values. The responses were typically measured using a force input at the accelerometer location. Phase data from the accelerometers was then used to characterize the motions associated with each natural frequency. In some instances, accelerometers were also added to the cavity floor and additional locations along the store were forced to resolve the motions of more complex natural frequencies.

The motions associated with the natural frequencies are illustrated in Fig. 4 and are similar to those observed in [13] for a simple cylindrical store. The first mode, Z1, corresponds to a twisting of the posts about the wall-normal center axis of the model. Although the primary motion here is spanwise, this mode also involves smaller streamwise translations. The second mode, Z2 occurs with a spanwise rocking motion of the support posts that results in a nearly uniform translation of the entire cylindrical store. Although the primary motion is spanwise, there is also a small displacement component in the y direction. The third mode Y1 occurs with fore-aft (streamwise) motions of the posts that result in a simultaneous wall-normal pitching motion of the store. Unlike the other structural modes, Y1 occurs with large displacements along two axes. Y1 was observed to be excitable with either a streamwise or a wall-normal hammer input. Motions at Y2, on the other hand, are mostly associated with the first y-bending mode of the cylindrical store, although this mode is also associated with a bending of the cavity floor plate. The last mode listed, Z3, corresponds to the first z-bending mode of the cylindrical store. Finally, there were several other structural natural frequencies having more complex mode shapes than those described here. These modes typically involved a wall-normal coupling of the cavity floor (and possibly other tunnel hardware) with bending modes of the store and sometimes fore-aft motions of the store. Moreover, the vibrations associated with these modes tended to be small due to high damping. As a result, it is difficult to conclusively identify these natural frequencies in the FSI vibration spectra. Describing these modes further adds little value here, though their expected influence on the acceleration spectra will be noted where appropriate.

As listed in Table 1, a total of nine structural configurations were tested. The nose and tail in configurations 1 – 3, 4 – 6, and 7 – 9 were steel (S), aluminum (Al), and tungsten (W), respectively. Additionally, the fore- and aft-weights were varied for finer adjustment. The resulting natural frequencies ranged from 0.4 – 3.5 kHz. Changing the nose and tail material tends to vary the natural frequency by about 100 – 300 Hz, whereas, changes in the fore- and aft-weights result in variances of about 10 – 100 Hz. An exception to these generalities occurs at Z3 where larger variations in natural frequencies are observed between the configurations. This ability to tune the natural frequencies of the store to match cavity tone frequencies allows for cases of mode-matching to be investigated for a fixed cavity flow.

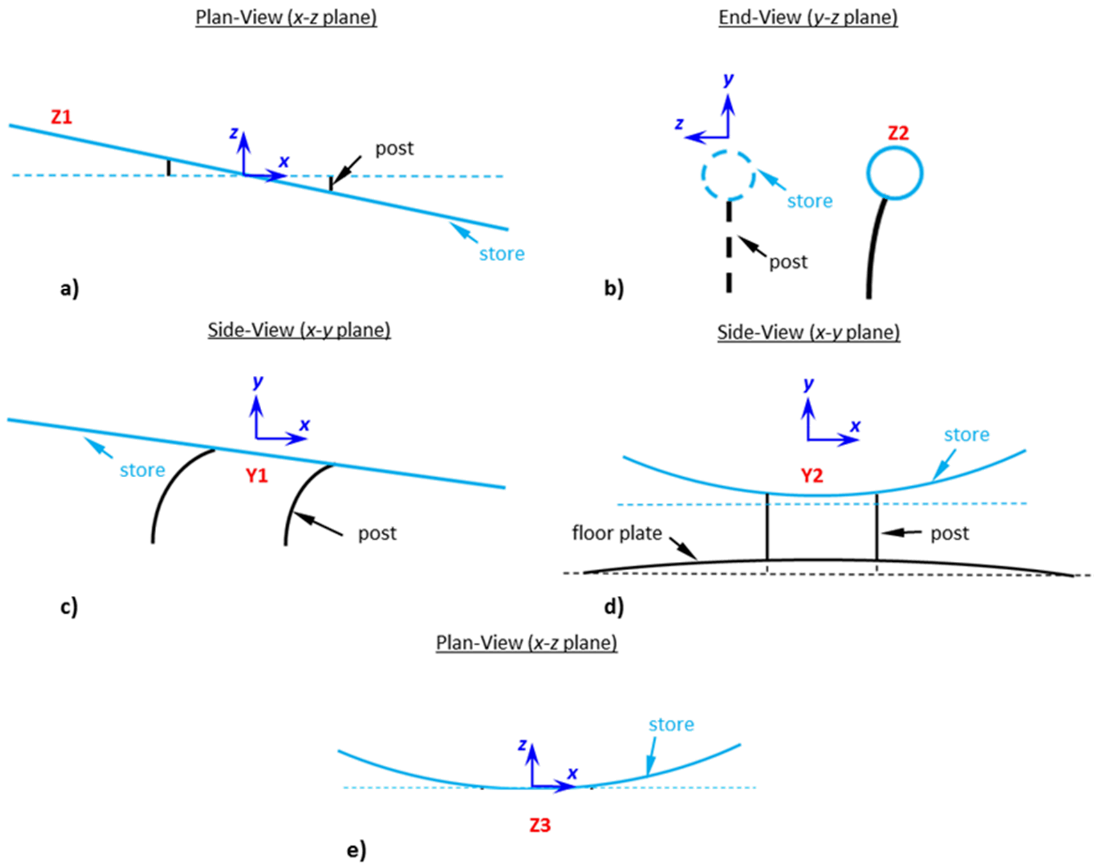

Fig. 4 Motions occurring with natural frequencies: a) Z1, b) Z2, c), Y1, d) Y2, and e) Z3.

Table 1: Natural frequencies and damping coefficient ζ for nine store configurations.

#	Nose/ Tail	Weights	Z1 *f*, kHz	Z1 ζ, %	Z2 *f*, kHz	Z2 ζ, %	Y1 *f*, kHz	Y1 ζ, %	Y2 *f*, kHz	Y2 ζ, %	Z3 *f*, kHz	Z3 ζ, %
1	S	S	0.64	0.56	0.80	0.58	0.94	0.80	1.65	1.20	2.69	1.85
2	S	Al	0.65	0.51	0.81	0.62	0.97	0.73	1.65	1.25	2.63	1.78
3	S	W	0.61	0.49	0.77	0.60	0.91	0.81	1.65	0.96	2.66	1.65
4	Al	S	0.78	0.50	0.87	0.56	1.11	0.64	1.71	1.26	3.46	1.93
5	Al	Al	0.81	0.42	0.89	0.60	1.15	0.71	1.72	1.35	2.97	2.25
6	Al	W	0.73	0.47	0.84	0.63	1.05	0.61	1.70	1.25	3.20	2.52
7	W	S	0.51	0.51	0.70	0.51	0.76	0.62	1.49	0.96	2.23	1.34
8	W	Al	0.41	0.59	0.71	0.49	0.78	0.64	1.49	0.95	2.05	1.73
9	W	W	0.49	0.54	0.68	0.50	0.74	0.60	1.59	2.26	2.13	1.78

III. Results and Discussion

A. Cavity Acoustics With and Without a Captive Store

Pressure measurements in the empty cavity at supersonic and subsonic Mach numbers were discussed in detail in Casper et al. [16, 17] and are only briefly summarized here. In general, the measured cavity tone frequencies were found to be in reasonable agreement with those predicted by Rossiter [1, 8]. Moreover, the expected trend of increasing pressure with increasing streamwise distance was observed and the flow exhibited symmetry across the cavity span.

Power spectral densities (PSDs) with and without [16] a captive store are compared in Fig. 5a, where $M_\infty = 1.5$. All spectra herein are normalized by the freestream dynamic pressure q. The presence of the store results in significant reduction of the cavity tone amplitudes upstream (FFP2) and downstream (AWP3), though the broadband fluctuations increase. Near the cavity center (C4), the amplitudes of the first five cavity tones (M1 – M5) are also decreased, whereas the amplitude of the seventh and eighth tones increases substantially with the store. Similar to the previous cavity FSI work by the authors [13], the presence of the store results in an overall decrease in the cavity tone frequencies; however, the differences are less pronounced here. The presence of a store in the previous study modified the distribution of cavity tones. For example, in some instances the store changed which mode was dominant. In contrast, however, the store did not result in the overall decrease in tonal amplitudes seen Fig. 5a. The size of the store with respect to the cavity diameter and its location within the free shear layer are si milar between the studies. The explanation for this difference may be related to the fact that the L/D in the previous study was 3.3, compared to 7.0 here. The tones may be more susceptible to interruption by a captive store in the case of the current cavity, since cavity resonance tends to decrease with increasing length-to-depth ratio [6, 7]. This lowering of cavity resonance with a store present in the free shear layer is not without precedent. For example, in an $L/D = 6.8$ study, Shaw et al. [18] made similar observations. Finally, experiments were run where the tail was replaced with a cylinder having no fins and where the nose cone was removed resulting in a blunt upstream end. These permutations had very little effect on the cavity acoustics. Thus, it seems the primary mechanism for lowering the cavity resonance is the interruption of the shear layer feedback mechanism caused by the store.

Comparisons of PSDs at various cavity locations with the store installed are given in Fig. 5b. Unless noted, the spectra correspond to a run using configuration 1 at a dynamic pressure of 123 kPa. Comparisons across the upstream (FFP1 and FFP5) and downstream (AWP1 and AWP5) spans of the cavity show the expected symmetry (the data at L4 and R4 also exhibited symmetry, but are omitted from the figure for clarity). Moreover, the comparison at AWP3 to a separate run with a dynamic pressure of 150 kPa demonstrates the appropriate scaling with q [6, 19]. Most importantly though, comparison of the centerline pressure at C4 to that given using configuration 7 shows the spectra are essentially identical. Similar agreement in spectra was observed at all other cavity locations and for all of the nine store configurations tested. Thus, as intended, the cavity flow characteristics can be fixed while the store's natural frequencies are varied. This also indicates that the store vibrations do not result in flow modifications, indicating the FSI here is one-way-coupled.

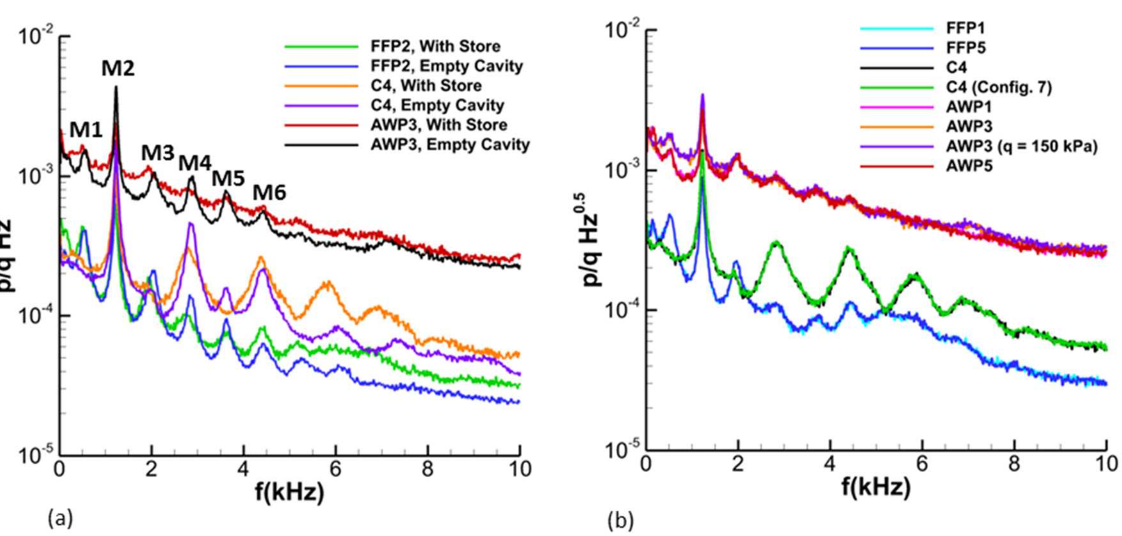

Fig. 5 Pressure power spectral densities at Mach 1.5: a) comparison of empty cavity pressures to those with a store, and b) comparison of at various cavity locations with a store present.

B. Simultaneous Store Vibration and Cavity Pressures

Acceleration spectra from both accelerometers are compared to pressure data at two sensors, one located on the aft-end of the store at the same axial location as A2 (SAT2), and the other located in the cavity floor upstream of the store (FFP2) in Fig. 6. The figure shows the response of the store using configuration1 in the streamwise, wall-normal, and spanwise directions to the Mach 1.5 cavity flow. Peaks are labeled in the vibration spectra corresponding to natural frequencies of the store and responses to cavity tones. Unless otherwise specified, similar observations were made using the other eight store configurations.

Inspection of the streamwise vibration spectra (Fig. 6a) reveals many peaks at both cavity tones and structural natural frequencies. A response to cavity tones M2 – M5 is seen in both vibration spectra, which is likely explained by the fact that there are pressure differences between the fore and aft ends of the store to produce a streamwise force during cavity resonance. Note that a structural mode involving higher order wall-normal bending and fore-aft pitching of the store was measured at frequencies near M3 during the impact hammer tests. The proximity of this natural frequency to the cavity tone most likely influences the relatively pronounced amplitude of M3. For each configuration a response to cavity tones M2 and M5 was observed. A response at M3 was not measured for store configurations 7 – 9. Moreover, the store did not respond to M4 in configurations 4 – 6.

The largest streamwise response is at structural frequency Y1, which occurs with simultaneous fore-aft rocking and wall-normal pitching of the store. In contrast, little response is observed at Y2, though streamwise motions associated with natural frequency are minimal in comparison to Y1 (Fig. 4). Moreover, the mode shape of Y1 happens to result in little motion at the accelerometer locations, making it difficult to discern in the FSI vibration spectra. The upstream accelerometer shows a clear response to the spanwise natural frequencies Z1 and Z2, whereas the response at the downstream accelerometer is much more limited. This stark variation in response at Z1 and Z2 may be related to the way the ends of the store attach to the center-body. For instance, the nose has internal threads for attachment, while the tail bolts to the center-body. Finally, a peak at Z3 also appears in the downstream acceleration spectrum.

Similar to the streamwise data, the wall-normal acceleration spectra (Fig. 6b) are a maximum at the lightly damped natural frequency Y1. A peak occurs within about 70 Hz of Y2 (determined with the impact hammer) is also observed. It is possible that Y2 shifted during the tunnel run to a new frequency corresponding to this peak. Clear responses in the downstream acceleration spectrum occur at each spanwise natural frequency Z1 – Z3, whereas, the response to these spanwise modes is more limited upstream. Peaks appear in the wall-normal spectra corresponding to the strongest cavity mode M2. The wall-normal response at other cavity tones, however, is more limited. The relatively small responses near M3 and M4 are likely related to wall-normal structural natural frequencies associated with a coupling of the store and the cavity floor and not a strong forcing by the cavity flow. This is supported by inspection of the wall-normal vibration spectra corresponding to configurations 4 – 9, which showed little response to M3 and M4.

In comparison to the x and y directions, the spanwise response (Fig. 6c) is far simpler. As expected, three prominent peaks appear at the spanwise natural frequencies Z1 – Z3. On the other hand, there is very little response at frequencies corresponding to the other natural frequencies or to cavity tones.

The response of the aerodynamic store exhibits many similarities to that of the simpler cylindrical store used in previous work [13]. For instance, the store responds at each of its natural frequencies. Moreover, as evidenced by peaks in all three directions at Z1 and Z2, a triaxial coupling more complicated than that suggested by the impact hammer tests alone (Fig. 4) occurs during these spanwise modes. Additionally, the store responds to cavity tones in the streamwise and wall-normal directions, which is likely attributable to the longitudinal pressure waves and shear layer vortices known to occur during cavity resonance. Furthermore, also similar to [13], the streamwise vibration levels are quite similar for most frequencies (with the exception of natural frequencies Z1 – Z3), likely due to the relatively high rigidity of the store in the x direction. On the other hand, the spanwise and wall-normal vibrations are greater downstream, likely owing to increased turbulence and a lower structural rigidity in y and z compared to x.

There are also some differences in comparison to the response of the simple store. In the case of the simple store, the response to cavity tones in the wall-normal direction was roughly the same as in the streamwise direction. Here, however, the store tends to have a stronger response in x than in y. In addition, stark differences in the store's response at natural frequencies, such as those seen at Z1 and Z2 in Fig. 6a, were not observed during FSI using the simple store.

A goal of the current work is to vary the natural frequencies of the store while holding the cavity resonance constant to avoid ambiguities associated with changing the flow. An example of this is given in Fig. 7, where the streamwise response for all nine configurations is displayed at Mach 1.5. Unless otherwise specified, all spectra were obtained with a dynamic pressure of 123 kPa. Also shown in the figure is the pressure PSD obtained on the store at SAT2. The configuration 1 spectrum corresponding to 150 kPa demonstrates that the store vibrations also scale with q, as was observed in [13]. As the tail and noise of the store are varied from tungsten (Configurations 7-9) to aluminum (Configurations 4-6) the accelerations increase. This is likely because the mass of the structure is decreased, but the forcing caused by the cavity flow remains constant.

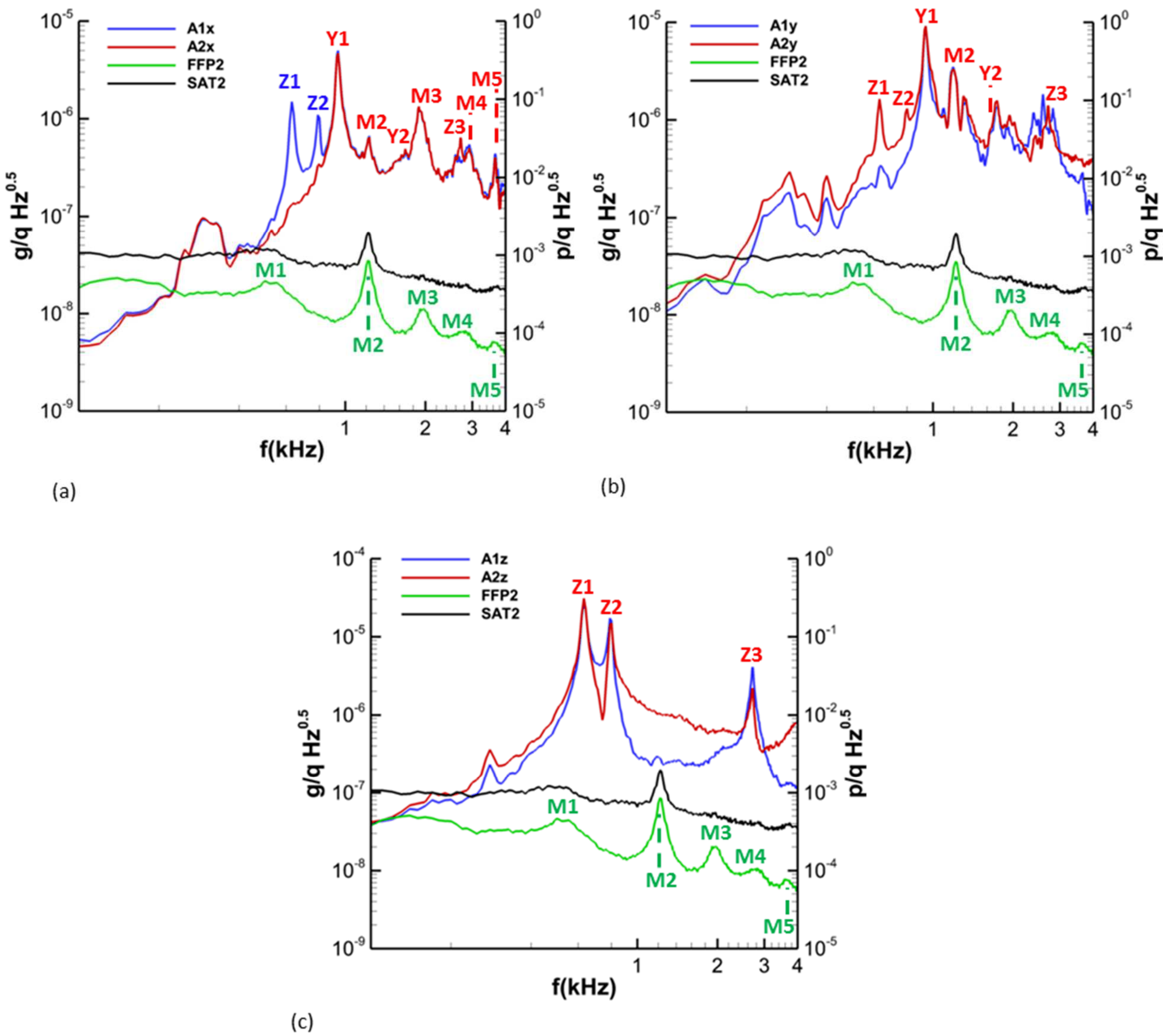

Fig. 6 Simultaneous pressure and acceleration power spectral densities at Mach 1.5 using configuration 1: a) streamwise (*x*), and b) wall-normal (*y*), and c) spanwise (*z*) directions.

Of primary interest here is the response of the store during mode matching. In particular, matching a strong cavity tone with a lightly damped natural frequency such as Y1would help quantify this expected worst-case-scenario for vibrations. As shown in Fig. 7, the Y1 frequency in configuration 9 comes close to the strongest cavity tone M2, resulting in a side peak; however, mode-matching between these prominent flow and structural modes is not achieved at this Mach number.

In contrast, a case where structural mode Y1 matches the dominant cavity tone, M2, occurs at $M_\infty = 0.94$ (Fig. 8). Unless specified otherwise, the dynamic pressure was held to 39 kPa. In configuration 1, Y1 and M2 have essentially identical frequencies of 0.94 kHz. As a result, the wall-normal vibrations are roughly five times those of the other structural configurations. Similar observations were made using the upstream accelerometer and in the streamwise spectra. These results clearly demonstrate that mode matching results in significantly increased vibrations. Furthermore, when the dynamic pressure is doubled to 78 kPa, the accelerations continue to scale with q. Thus, even in a case of mode matching, the response of the store scales linearly with loading, a result it would seem consistent with one-way coupling.

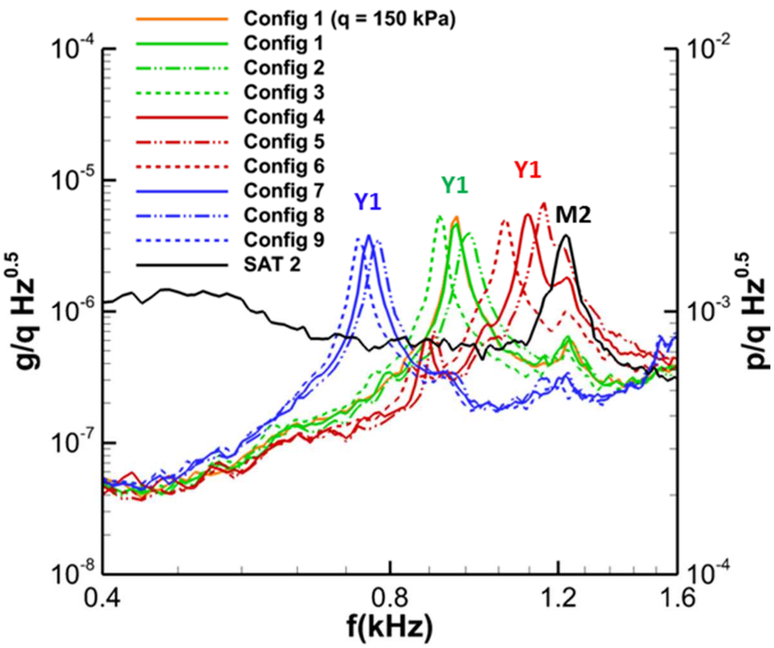

Fig. 7 Mach 1.5 streamwise acceleration spectra in the vicinity of natural frequency Y1 for all nine configurations at A2 simultaneous with pressure PSD at SAT2. Unless specified q = 123 kPa.

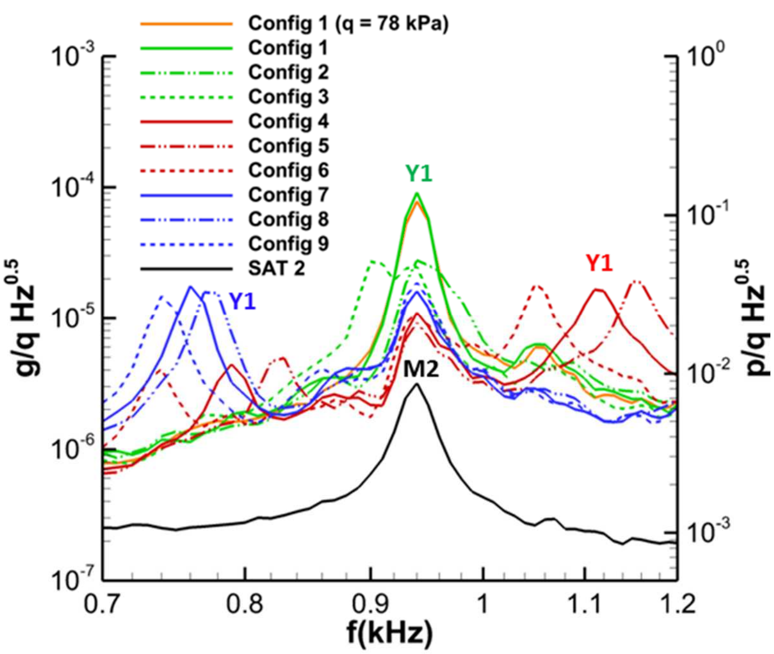

Fig. 8 Mach 0.94 wall-normal acceleration spectra in the vicinity of natural frequency Y1 for all nine configurations at A2 showing a case of mode matching. Unless specified q = 39 kPa.

Additional experiments were conducted where M_∞ was varied in small steps to make incremental alterations in the frequency of cavity tone M2 (f_2). The dash-dot curves in Fig. 9 show four different runs where f_2 was varied from 0.92 – 0.95 kHz. The mode-matched case (replicated from Fig. 8) occurs when f_2 = 0.94 kHz. Lowering the M2 frequency by 10 Hz does little to alter the store response. Raising it by 10 Hz, however, lowers the wall-normal store response by about a factor of two. Therefore, near mode matching, the response of the store is quite sensitive to the cavity tone frequency. Small changes of about 1% can result in pronounced response variations.

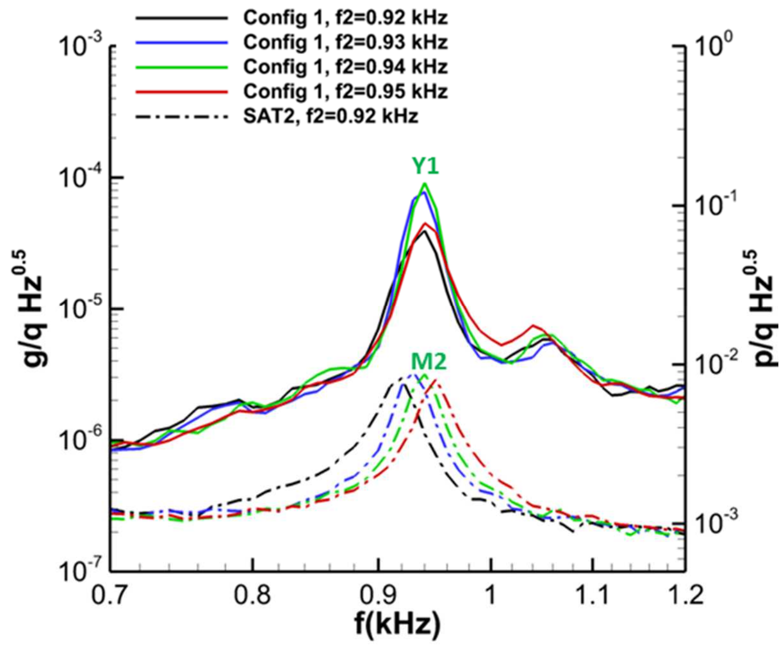

Fig. 9 Comparison of the wall-normal store response at A2 with the frequency of cavity tone M2 varied from 0.92 – 0.95 kHz about the mode-matched value 0.94 kHz (green curves). The dash-dot lines of the same color correspond to the simultaneous pressure PSDs at SAT2.

IV. Conclusions

Experiments were performed to understand the fluid-structure interactions that occur during aircraft internal store carriage. To do so, a generic, aerodynamic store was installed in a resonating rectangular cavity having a length-to-depth ratio of 7. The store had interchangeable components, which allowed its natural frequencies to be varied from about 10 – 400 Hz. Mach numbers of 0.9 and 1.5 were tested and the incoming boundary layer was turbulent. Fast-response pressure measurements provided aeroacoustic loading in the cavity and on the store, while triaxial accelerometers provided simultaneous store response. Despite occupying only a small portion of the cavity volume, the store significantly altered the cavity acoustics, reducing cavity resonance. Similar to previous studies using a simplified cylindrical store, the aerodynamic store responded to the cavity flow at its natural structural frequencies, and it exhibited a directionally dependent response to cavity resonance. Specifically, cavity tones excited the store in the streamwise and wall-normal directions consistently, whereas a spanwise response was observed only occasionally. The streamwise and wall-normal responses were attributed to the longitudinal pressure waves and shear layer vortices known to occur during cavity resonance. With the tunable natural frequencies of the store, cases where a prominent cavity tone frequency matched a structural natural frequency were explored. It was found that mode matched cases produced substantial increases in store vibrations, though the response of the store scaled linearly with the dynamic pressure or the pressure loading in the bay. The response of the store to cavity tones having frequencies near mode-matched values was quite sensitive. Specifically, changes in cavity tone frequency of about 1% were found to alter the store vibrations by as much as a factor of two.

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