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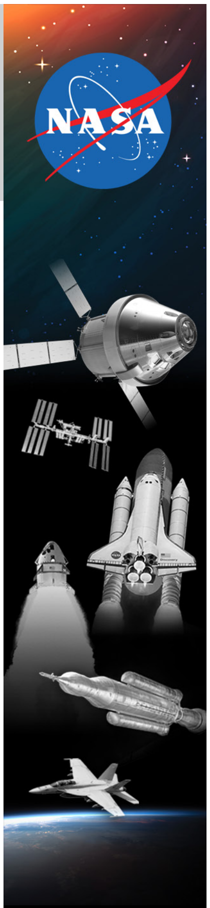

NESC tech bulletin

Detecting Flow-Induced Vibration in Bellows

The NESC performed testing to determine if high-speed video techniques can be used to predict the onset of flow-induced vibrations (FIV) in bellows. A comprehensive test matrix was established to determine if Motion Magnification (MM) and Digital Image Correlation (DIC) can be used to determine the onset of FIV in straight and gimbaled bellows. Several of the tests were intended to determine if MM and DIC can establish the resonant frequencies of the bellows with no a priori knowledge. The results of the MM and DIC were compared with data from strain gages and microphones. Although the testing was limited to one single-ply unshielded bellows, this effort provided the proof-of-concept that MM and DIC are feasible methods for determining the onset of FIV in bellows.

Background

Bellows (see Figure 1) are used to connect systems/components in rocket engines while allowing for expansion or contraction associated with temperature variations and articulation due to engine gimbaling. FIV are caused by resonance generated through the coupling of vortex shedding from bellows convolutions with the flexible line natural structural frequencies. FIV have caused the failure of bellows and flex hoses in several rocket engines [ref. 1]. Most NASA programs use analytical techniques instead of testing to predict the onset of FIV. However, these techniques do not account for bends in the bellows/flex hoses due to engine gimbaling [ref. 2]. In addition, the characterization of FIV through testing with strain gages is difficult for straight and gimbaled bellows (e.g., accessibility, durability, temperature range, etc.). Thus, FIV behavior during engine gimbal can only be estimated.

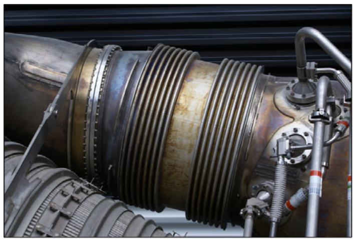

Figure 1: Example Rocket Engine Bellows

MM is the process by which small, imperceptible motions in an image series are visualized by manipulating each image in a digital video series [refs. 3-4]. MM works by decomposing each image in a time series into its local spatial amplitude and phase. By assessing how the local spatial phase changes from image to image within the series, and magnifying those small phase changes, the minute motions may be visualized and measured.

DIC is an optical, non-contacting method for extracting full-field displacements, full-field strains, velocities, and accelerations [refs. 5-6]. This technique requires a pair of digital cameras that are focused on the same area but viewing the structure from different angles. The surface of the structure is painted with a high-contrast (e.g., black/white) random speckle pattern. DIC uses pattern recognition on small subsets of the speckle pattern to determine the translations and distortions. A comparison is made of the position of the speckles in the deformed state to that of the undeformed state.

MM and DIC were chosen for this investigation because they are non-intrusive optical methods that produce significantly more information than a limited number of strain gages and/or microphones.

Testing

The testing was performed at the NASA Marshall Space Flight Center (MSFC) Component Development Area (CDA) water flow loop using a bellows from previous testing. This facility uses an electric motor-driven pump with a variable frequency drive and turbine flow meter to precisely establish and control the desired flow rate. More than 40 tests were performed to determine the ability of MM and DIC to predict the onset of FIV in bellows. Figures 2a, 2b, and 2c show strain gauge data, microphone data, and the results from MM for one of the tests. The three measurement techniques show the same dominant frequency for the onset of FIV. The difference in the amplitudes of the harmonics is due to the locations of the strain gage and microphone. The MM and DIC techniques produced similar accurate predictions for the onset of FIV in all test cases investigated.

References

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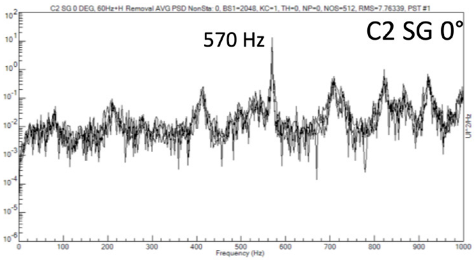

Figure 2a: Bellows Strain Gage Data

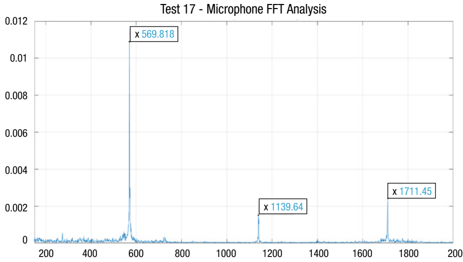

Figure 2b: Bellows Microphone Data

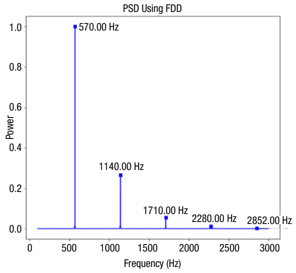

Figure 2c: Bellows MM Data

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