Dynamic Stability Characteristics of HSP-CM at Mach 4

Presentation at

MATLAB EXPO India, 2017

20.04.2017

By,

Aaron Baptista, Sci/Engr

Akhtedar Abbas Khan, Sci/Engr

MD Jamal Nawaz Ansari, SCI/Engr

R Saravanan, Sci/Engr

VSSC, ISRO

Scope of the Project

- Dynamic stability is an important aspect of Crew Module (CM) design such that during reentry any disturbance will be damped out immediately.
- Amplitude of oscillation should be within limit and the CM should not tumble.
- Our objective is to characterize the aerodynamic damping and to determine whether the CM is dynamically stable or not.
- To quantify the aerodynamic damping characteristics, pitch damping coefficient is evaluated by obtaining the oscillation amplitude history of the CM at Mach 4.
- As damping is not constant throughout the amplitude range, hence it is defined over a number of ranges.

Problem Statement

- To quantify the aerodynamic damping of the CM one has to obtain the amplitude history of the oscillating CM in the wind tunnel.
- Of the various methods of Dynamic stability testing, Free oscillation technique is the most simplest and cost effective method, but the need to remove/model the structural damping due to oscillation amplitude measurement tools makes the technique equally complex as the other methods.
- Hence there is a need for devising a non-intrusive technique to obtain the oscillation amplitude history of the CM.

Model

- The 1:60 scaled model of the HSP-CM is used for this study.

  Model dia, D/d= 51.46

  Model length, l/d = 47.04
- The model is connected to sting through ball bearings, hence free to oscillate in vertical plane.
- Oscillation of the model is limited to ±10° with respect to sting axis.
- The sting diameter is 0.32 times of base diameter to minimize any wake alteration.

Assumptions

- Friction at the bearing is assumed to be negligible.

Experimental Set-up

- The experiment is carried out in hypersonic wind tunnel:

  Nozzle throat diameter $D_t/d = 77$

  Mach number = 4, AOA = 0 ^{o}
- Pressure readings are recorded to evaluate free stream conditions.

  Stagnation Pressure = 2 bar

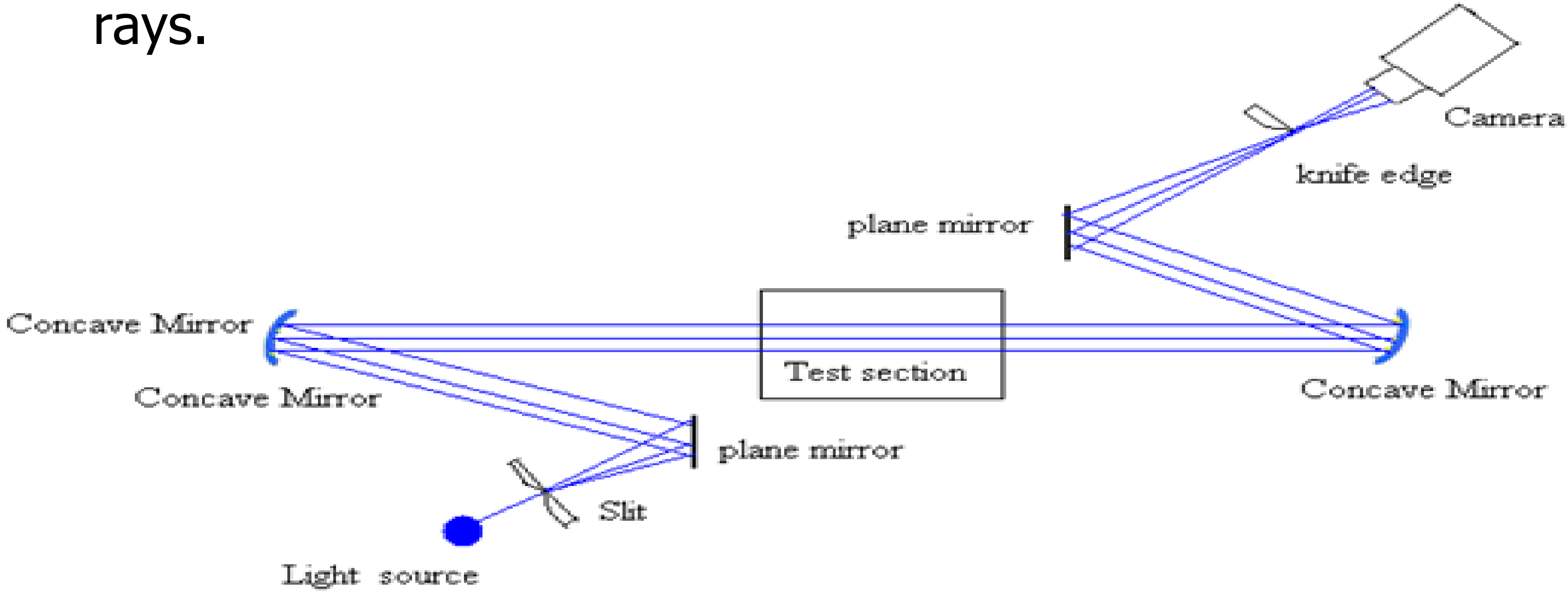
  Free stream velocity = 677.64 m/s
- Schlieren technique is used to visualize the flow over model.
- High speed camera is used to capture the video.

  Frame capture rate = 3000 fps

  Resolution = 768 x 640 pixels
- These images are processed using MATLAB image processing tools to get the oscillation amplitude variation over time.

Schlieren Technique

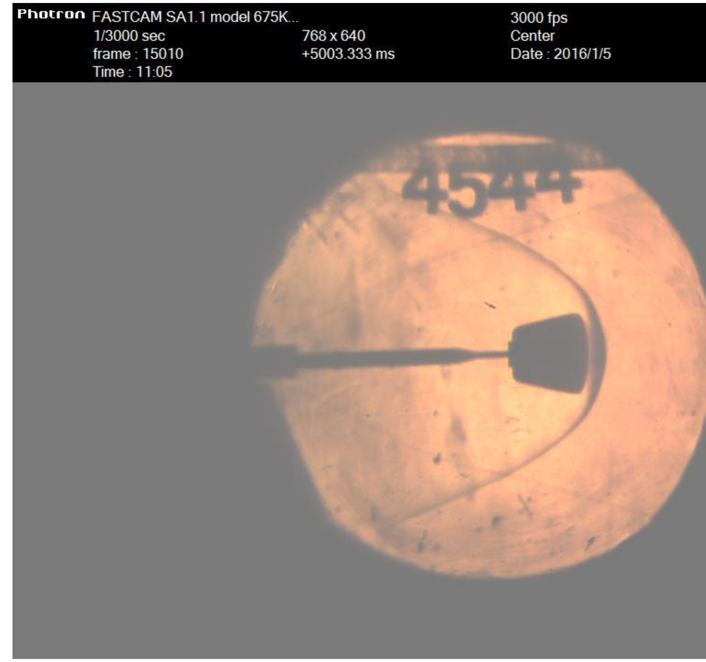
- The Schlieren technique of flow visualization is based on the principle that a collimated beam of light bends at the interface whenever they pass from a one medium to another having different densities.
- Beam must be parallel while passing over the test section to avoid any perspective illusion.
- Knife edge slit is used before camera to block the refracted rays.



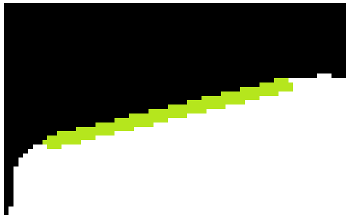
Dynamic Stability Characteristics of HSP-CM at Mach 4

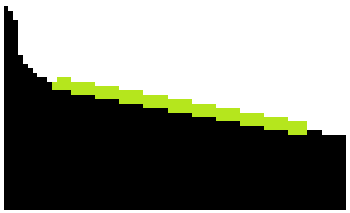
MATLAB Image Processing

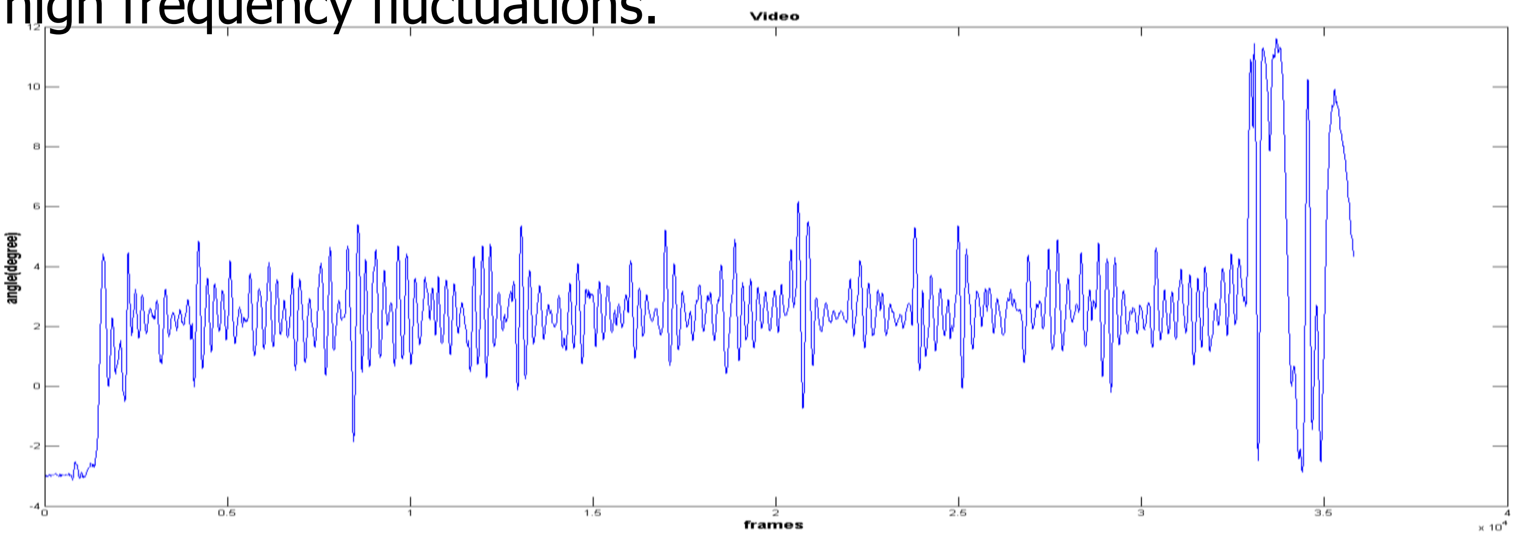
- Each frame is extracted from the video.
- The captured image is cropped for the region of interest.
- The cropped colour image is converted to black and white binary image such that the background appears black and oscillating body, white.
- A point is identified on the upper and lower edge of the body.
- The body edge is tracked from that point to a certain length (40 pixels).



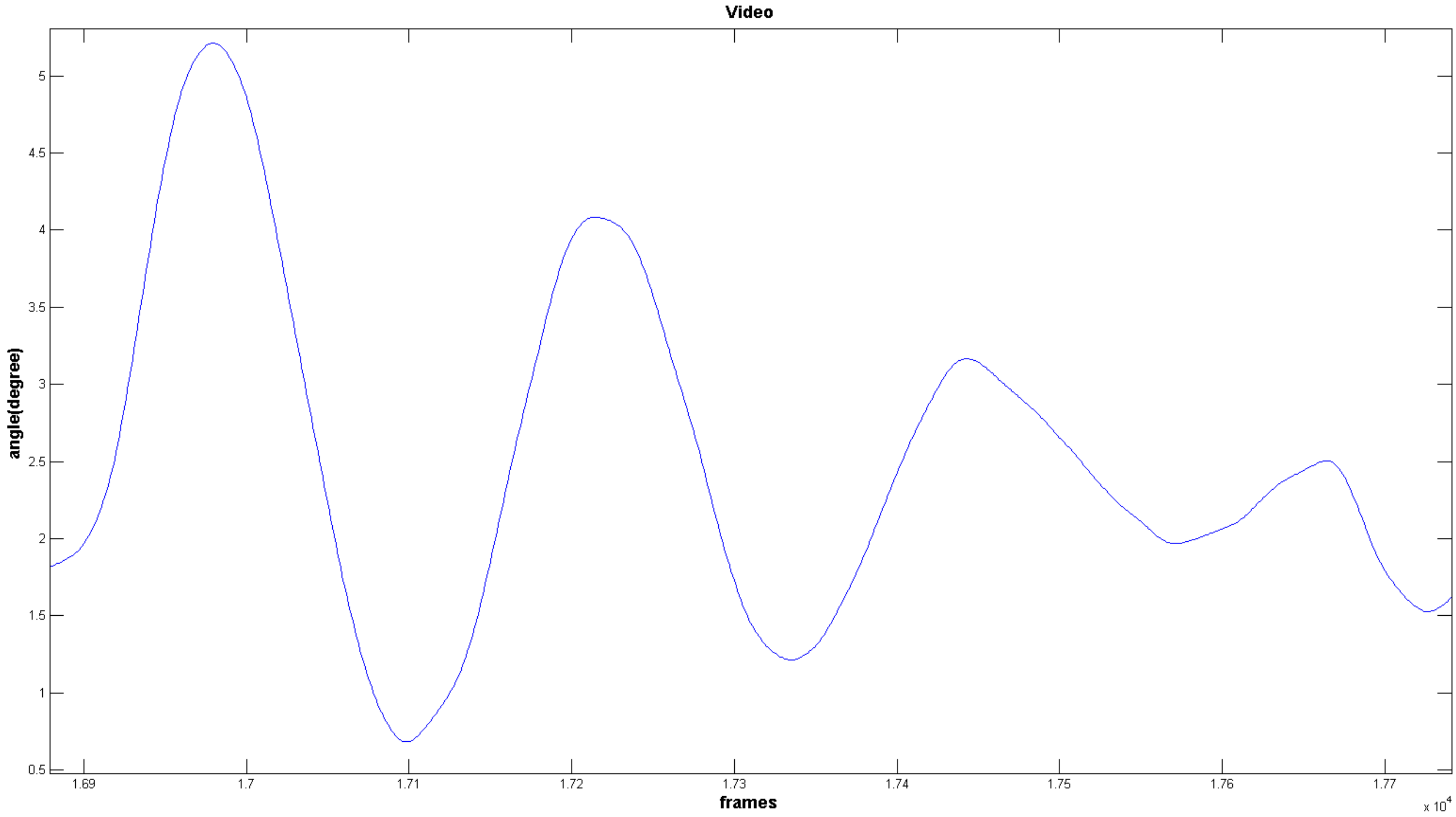
- As the boundary obtained is not a perfectly straight line due to limited resolution, linear curve fitting is applied to fit the 40 points obtained on the edge.
- After obtaining the equations of the lines, the angle for both the edges is obtained in degrees with respect to the sting axis in each frame.
- The pitching amplitude is taken as half of the difference between the two angles.
- With the complete data of all frames, the pitching amplitude (degrees) verses frame (frame number) graph is plotted. The plot is smoothened to remove high frequency fluctuations.







- From each plot, samples are selected where the effective damping is observed.



- Peaks of the sample are obtained and the pitch damping coefficient is calculated.
- Analysing each sample individually, after obtaining peak pitching amplitudes, the Logarithmic Decrement (δ) is calculated as

$$\boldsymbol{\delta = \ln (a_{i+1}/a_i)}$$

Where,

'ai' is amplitude at a peak

'ai+1' is amplitude at next successive peak.

- Geometrical details of model are as follows :

  Moment of Inertia about Center of rotation,

  $I = 26.8547e\text{-}6\ kgm^2$

  Reference Area, $S/(\pi d^2/4)=0.002648$

  Major Diameter, $D/d=0.05146$

- Pitch damping coefficient is calculated as follows

  $$= -\,(4/\pi)\,(\omega D/2V)\,(I/\,\rho_\infty S D^3)\delta$$

  Where,

  $\omega = 2\pi f$

  f – Frequency of oscillation (20 Hz)

  ρ_∞ - Free stream density (0.064 kg/m^3)

  V - Free stream velocity (677.64 m/s)

Dynamic Stability Characteristics of HSP-CM at Mach 4

Results

Range	Pitching amplitude	Logarithmic decrement	Pitch damping coefficient	Average value
$2.0 < \theta$	**2.8762**	**0.31337**	**-2.8185**	**-2.726205**
	2.5106	**0.29283**	**-2.6338**	
$1.6 < \theta \leq 2.0$	**1.7859**	**0.32960**	**-2.9644**	**-2.59695**
	1.7142	**0.24787**	**-2.2294**	
$1.25 < \theta \leq 1.6$	**1.537**	**0.19678**	**-1.7699**	**-1.69**
	1.261	**0.35928**	**-1.6101**	
$\theta \leq 1.25$ (approx.)	**1.082**	**0.094159247**	**-0.84689**	**-0.74323**
	0.9569	**0.086550492**	**-0.77845**	
	0.7234	0.067197008	-0.60438	

Results

- Pitch damping coefficient is computed for a range of pitching amplitudes and is found to be decreasing with amplitudes with a nonlinear trend.
- The pitching amplitudes are divided into different ranges and average value of pitch damping coefficient is defined over these ranges.
- Negative value of damping coefficient indicates that the vehicle is dynamically stable.
- It is also observed that the model is continuously being disturbed after damping of initial oscillations due to alumina particle impingement.
- Hence only specific samples were selected where these disturbances were minimal.

Conclusion

- It has been found that HSP-CM is dynamically stable at Mach 4. and the CM model was found to be oscillating within ± 5 degree.
- Higher damping is observed at higher amplitudes and as the amplitude of oscillation decays, the damping coefficient also decreases.
- The result is found to be satisfactory except irregular observations at some instances due to alumina particle impingement.
- The same code can be used in future for similar tests requiring image processing and data analysis.

Thank you