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TEST OUTLINE FOR FLUTTER ANALYSIS OF RECTANGULAR PANELS IN RAREFIED FLOW CONDITIONS

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ABSTRACT

Jet plume impingement forces acting on large flexible space structures may precipitate dynamically unstable behavior during space flights. Typical operating conditions in space involve rarefied gas flow regimes which are intrinsically distinct from continuum gas flow and are normally modeled using the kinetic theory of gas flow. Docking and undocking operations of the Space Shuttle with the Russian Mir space laboratory represent a scenario in which the stability boundaries of solar panels may be of interest. Extensive literature review of research work on the dynamic stability of rectangular panels in rarefied gas flow conditions indicated the lack of published reports dealing with this phenomenon.

A recently completed preliminary study for NASA JSC dealing with the mathematical analysis of the stability of two-degree-of-freedom elastically-supported rigid panels under the effect of rarefied gas flow was reviewed. A test plan outline is prepared for the purpose of conducting a series of experiments on four rectangular rigid test articles in a vacuum chamber under the effect of continuous and pulsating Nitrogen jet plumes. The purpose of the test plan is to gather enough data related to a number of key parameters to allow the validation of the two-degree-of-freedom mathematical model. The hardware required careful design to select a very lightweight material while satisfying rigidity and frequency requirements within the constraints of the test environment. The data to be obtained from the vacuum chamber tests can be compared with the predicted behavior of the theoretical two-degree-of-freedom model. Using the data obtained in this study, further research can identify the limitations of the mathematical model. In addition modifications to the mathematical model can be made, if warranted, to accurately predict the behavior of rigid panels under rarefied gas flow regimes.

INTRODUCTION

This study is a step toward the development of an engineering tool capable of predicting the stability boundaries of solar panels while taking into consideration their unique structural characteristics. Although research on flutter analysis of structures in continuum gas flow regimes is well documented in the published literature, work on flutter analysis of structures in rarefied gas flow is virtually non-existent. In recent years, scientists and engineers at NASA JSC and elsewhere conducted a number of investigations to study the physics of jet plumes and their impingement loads on stationary rigid objects in vacuum chambers and in space (1, 2, 3, 4, 5).

Literature review of the jet plume impingement forces and the dynamic stability of rectangular panels in rarefied gas flow conditions was undertaken. The review focused on a recently completed study dealing with the theoretical analysis of the flutter of a two degree-of-freedom rigid body model (6,7). A brief test outline is given for the purpose of investigating the experimental behavior of rectangular panels in a vacuum chamber under the effect of continuous and pulsating Nitrogen jet plume. Three of the four test articles will be attached to a flexible element which will allow torsional and bending vibrations, and one test article is stationary. Validation of the stability boundaries predicted by the theoretical rigid body model is the primary objective of the test plan.

TEST OVERVIEW

Tests on a total of four rectangular panels of 40" by 20" are outlined. The first test article (TA-I) consists of a rigid metal panel mounted on a rigid support. The second and third test articles (TA-II and TA-III) are elastically-supported rigid panels. The fourth test article (TA-IV) is an elastically-supported flexible panel. The tests will be conducted in Vacuum Chamber B at NASA JSC to study the dynamic stability of rectangular panels when subjected to rarefied gas continuous and pulsating flow in vacuum conditions. A number of key parameters will be varied to study the phenomenon of dynamic stability of these panels under different conditions.

TEST SETUP

The test setup is referenced to a global set of axes (XYZ) whose origin (0,0,0) is located at the center of the floor of Vacuum Chamber B. The XY plane is parallel to the floor. The X-axis is oriented to the geographic east and the Y-axis is oriented toward the geographic north. The Z-axis is vertically upward for positive direction.

The gas nozzle will be located at (0, 0, 10 ft). The longitudinal axis of the nozzle will be parallel to the X-Y plane. The nozzle will be mounted on a turning table which will allow orientation of the nozzle axis to be at an angle θ of 0° for TA-I, 90° for TA-II, 180° for TA-III and 270° for TA-IV, where the angle θ is measured positive counterclockwise with respect to the positive X-axis.

All the test articles (rigid or flexible) will be oriented with their transverse axis parallel to the Z-axis. The orientation of the longitudinal axis of the test articles (angle of attack) will vary during the tests. The longitudinal axis of the jet nozzle will be passing through the geometric center of the test articles during testing. Test article TA-I will be stationary during the tests. Test articles TA-II, TA-III and TA-IV will be supported along the transverse axis to provide the specified torsional frequency of 1 Hz for the test articles/support system while restricting the bending frequency of the system to at least 10 Hz.

The far end of the support for test articles TA-II, TA-III and TA-IV will be secured to a mounting rig at or near the Vacuum Chamber floor such that translations and rotations about the X, Y, and Z axes are restrained. The mounting rig for TA-II shall be attached to a slider which will allow the distance between the test article and the nozzle exit to be varied within ± 1 ft. The mounting rigs for all four test articles will also provide the facility to change the angle of attack of the test articles by rotating them about the Z-axis.

A video camera, laser targets and a number of transducers will be set up on and around the test article. Data acquisition will be setup outside the Chamber for data A/D conversion and collection.

JET PLUME

Type:	Nitrogen
Nozzle:	Dia. = 0.0065 in ±0.0005 in single orifice.
Flow:	Continuous until plume collapse
Pulsating flow:	two scenarios: periodic square and periodic half-sine waves.
	Pulse duration $t_o = 0.1$ sec
	Pulse separation $\Delta t = 0.2$ sec.

TEST ARTICLES

Test Article I (TA-I)

TA-1 consists of a 40" by 20" rigid aluminum panel of uniform thickness with a Kapton thin film bonded to the front side. The panel will be supported by brackets, or other type of support, which will restrain the plate during the tests. The thickness of the aluminum plate is governed by the distance needed to accommodate the pressure transducers to be attached to the test article. Three pressure transducers will be used to measure the dynamic pressure. Six thermocouples will used to measure the temperature of the plate surface.

Test Article II (TA-II)

TA-II consists of a 40" by 20" panel. The panel is made of a framework of 1/4" composite tubes. A three mill Kapton film will cover the front side of the panel. A pretension force will be applied to the Kapton film during fabrication. The Kapton film is then secured to the back side of the outer composite tubes. The test article will be mounted on a slider which will allow the distance between the nozzle exit and the front of TA-II to vary from 3 ft to 5 ft. The mass moment of inertia of the test article/support system about the Z-axis, I, is equal to 60 $lbm.in^2$. The torsional natural frequency of the test article/support system, f_z, is equal to 1 Hz.

Test Article III (TA-III)

TA-III also consists of a 40" by 20" panel to be made of a honeycomb paper with two triangular cutout areas. A two mill Kapton (or mylar) film covers the front and back sides of the panel. An adhesive film of 5.5 mil will be used to glue the films to the panel. The mass moment of inertia of the test article/support system about the Z-axis, I, is equal to 60 $lbm.in^2$. The torsional natural frequency of the test article/support system, f_z, is equal to 1 Hz.

Test Article IV (TA-IV)

TA-IV consists of a 40" by 20" flexible metal panel such that the bending frequency of the panel itself about its transverse axis (Z-axis) is 2 Hz. The mass moment of inertia about the Z-axis, I, is equal to 60 $lbm.in^2$. The torsional natural frequency of the test article/support system, f_z, is equal to 1 Hz.

REFERENCES

[1] Fitzgerald, S.M., Bouslog, S.A. and Hughes, J.R.," Model for Predicting Orbiter PRCS Plume Impingement Loads," NASA JSC Report #26507, Rev. A, June 1995.

[2] Bouslog, S.A., Fitzgerald, S.M. and Machin, R.A.," Instrument Characterization Tests in a Nitrogen Free Jet," NASA JSC Report #26706, March 1995.

[3] Fitzgerald, S.M., and Hughes, J.R.," Orbiter PRCS Plume Impingement Tollkit," NASA JSC Report #26583, March 1995.

[4] Fitzgerald, S.M., Bouslog, S.A. and Hughes, J.R.," Model for Predicting Orbiter PRCS Plume Impingement Loads," NASA JSC Report #26507, January 1994.

[5] Machin, R.A., et al, "Shuttle Plume Impingement Flight Experiment (SPIFEX) Data Reduction," NASA JSC Report #27030, Vol. I.

[6] Storch, J.A., " Flutter of Solar Arrays Subjected to Rarefied Plume Impingement," Draper Laboratory Reports, September 1994 and January 1995.

[7] Storch, J.A., " Solar Array Flutter in Pulsed Rarefied Flow," Draper Laboratory Report, June 1995.