Flow Characteristics about Concave Conic Forebodies at $M_\infty = 5$

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Nomenclature

D	= model diameter
L	= tip length
ℓ	= length to shoulder
P_0	= stagnation pressure
R_f	= flare radius
R_n	= nose radius
R_s	= shoulder radius
Re_∞/ft	= freestream Reynolds number
T_0	= stagnation temperature
α	= angle of attack
θ_1	= tip angle
θ_2	= flare angle

Theme

AS an ablating nosetip progresses through its trajectory, its surface shape changes continuously. Among the myriad shapes it may assume, there are certain classes of shapes for which the flowfield is grossly unsteady, that is, the flowfield pulsates with a high frequency. Such shape induced flowfield instabilities may seriously compromise the realization of flight objectives. This paper describes the results of an experimental and analytical effort directed toward improving prediction procedures for identifying instability onset and the magnitude and frequency of the pressure fluctuations. A more complete discussion of this work is given in Ref. 1.

Contents

Prior to this study, there were experimental data[2,3] on such flowfield instabilities for idealized shapes, primarily flat faced cylinders and high angle cones with slender spikes. The data were adequate to define, at least roughly, the envelope of instability onset for the idealized shapes. There was no such data base for shapes characteristic of ablating nosetips. The objective of the current experimental program was to fill this void by providing a base on which a semi-empirical model could be constructed defining the envelope of instability onset for shapes of interest in ablating nosetip technology. An additional objective is to provide data which could be used to correlate pressure pulsation frequencies and magnitudes between ground test and flight configurations.

The experimental models were tested at the Naval Ordnance Lab., Silver Spring, Md., in tunnel number 8, at $M_\infty = 5$. The tips of the models were grit-blast roughened (1-2 mils) to ensure a turbulent boundary layer on the tip if the flow remained attached. Instrumentation included pressure, accelerometer, and photographic coverage.

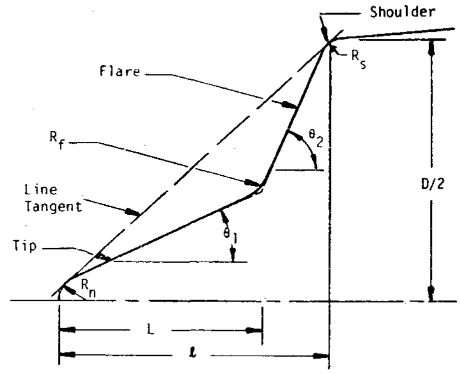

Fig. 1 Schematic of simplified model of nosetip.

A careful examination of low temperature ablator¶ data and shape change predictions led to the conclusion that the surface geometry can be adequately characterized by the model indicated in Fig. 1. By varying the parameters L/D, R_n/D, R_f/D, R_s/D, θ_1, and θ_2 through the range of interest determined by examining the low temperature ablator data and published experiments with pulsating flow on spiked bodies, the envelope of instability onset for realistic configurations was determined. With such a large number of parameters, it was unrealistic to test all possible combinations of interest. Therefore, nominal values of L/D, R_n/D, R_f/D, R_s/D, θ_1, and θ_2 were determined. The tests involved varying these parameters about their nominal values to determine the sensitivity of the onset and intensity of flowfield instability to departures from the nominal values. The test matrix, as run, is given in Table 1. This table also summarizes some of the test results obtained.

The following points represent a summary of the general findings of the experimental study: a) The shape variables θ_1, θ_2, and l/D are of primary importance in determining the limits of stability. b) The variable θ_l has significance in determining the stability limits. c) The fundamental frequency of the strong oscillations present was about 1100 cps which corresponds to a Strouhal number of about 0.20 which agrees with other data in the literature. d) Many of the MS type flows represent the most severe cases of pressure oscillations on the nosetip with the maximum pressure exceeding the mean by more than a factor of two. e) On an empirical/theoretical basis it was concluded that the stability limits are not strongly affected by freestream Mach numbers above $M_\infty = 5$. f) The effects of Reynolds number and tip radius have some influence on stability, but probably of a secondary nature. g) The effects of flare radius R_f and shoulder radius R_s upon stability limits are weak or negligible for the range of these variables tested. h) The effects of angle of attack are weak or negligible for the range tested.

The results of this study were correlated in the form of a volume of instability based upon the geometric parameters of interest. Figure 2 presents the results of this correlation. All points falling within the volume will be unstable.

At present the general consensus[2,3] is that the flow oscillations are related to changes in the effective geometry of the body due to growth of the separation bubble. The bubble is thought to grow to some critical state at which time further

Presented as Paper 75-153 at the AIAA 13th Aerospace Sciences Meeting, Pasadena, Calif., January 20-22, 1975; synoptic received April 28, 1975; revision received July 18, 1975. Full paper available from AIAA Library, 750 Third Avenue, New York, N. Y. 10017. Price: Microfiche, $1.50; hard copy $5.00. **Order must be accompanied by remittance.**

Index categories: Nonsteady Aerodynamics; Supersonic and Hypersonic Flow.

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¶Camphor models which sublime at hypersonic wind tunnel conditions.

Table 1 Test matrix

Run No.	θ_1 (deg)	θ_2 (deg)	ℓ/D	L/D	R_n/D	R_f/D	R_s/D	α (deg)	Re_∞/ft $\times 10^{-6}$	Nominal Chamber Conditions T_0 (°F)	P_0 (atm)	Type[a] Flow
25	20	70	0.540	0.4	0.025	0.10	0.05	0,2-1/2,5	20	300	45	MS
17			0.547			0.0		0	20		45	SS
15						0.05						SS
16												SS
18			0.534			0.20						SS
19			0.547		0.0	0.1						MS
20			0.534		0.05							SS
26			0.367	0.2	0.025			0,2-1/2,5	20		45	MS
22			0.360		0.0			0				FP
23			0.362		0.05							SS
47	30		0.507	0.4	0.025							CS
24			0.341	0.2								FP
21			0.277	0.1								CS
27	20	70	0.526	0.4	0.025	0.1	0.0		20		45	SS
28									10		22	MS
29									5		11	....
30												FP
31									2.5		6	....
35		70	0.554				0.10		20		45	SS
37		70	0.597				0.20					SS
5	20	80	0.674	0.6	0.025	0.1	0.05					MS
6												MS
7												MS
1			0.480	0.4					10		22	FP
2									20		45	FP
3			0.290	0.2								CS
4												CS
8			0.480	0.4		0.0						FP
9			0.484			0.05						FP
10			0.480			0.2						FP
11	20	60	0.612	0.4	0.025	0.1	0.05					SS
12			0.454	0.2								SS
13	30		0.559	0.4								CS
14			0.421	0.2								SS
42	20	90	0.420	0.4	0.025	0.1	0.05	0,2-1/2,5	20		45	FP
43								0,2-1/2,5	10		22	FP
44								0	5		11	FP
45									2.5		6	....
39	30		0.424						20		45	CS
40	40		0.316	0.3								CS
41			0.212	0.2								CS
46			0.423	0.4								CS
32	20	70	0.367	0.2	0.025	0.1	0.0					MS
33									10		22	MS
34									5		11	MS
36		70					0.10		20		45	MS
38		70					0.20					MS

[a] SS Steady Separated, CS Completely Steady, FP Fully pulsating, MS Metastable.

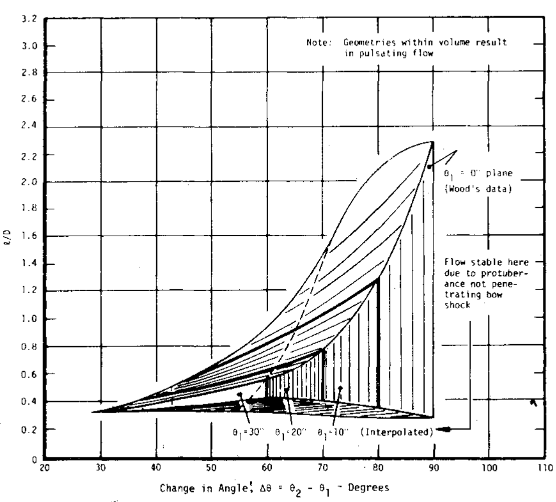

Fig. 2 Correlation of instability limits based upon NOL-8 series tests and data of Wood.

growth cannot be sustained, and the bubble suffers a collapse due to outflow near the shoulder. The exact mechanism of bubble growth and collapse is presently a matter of speculation.

It is hypothesized that when conditions for attached flow on the face are violated that a readjustment occurs resulting in either steady or quasi-pulsating reattachment at the shoulder, or the flow will become completely oscillatory. The present flow model consists of a mechanism for flow separation (either free-interaction or forced separation), a free shear flow analysis of the separated zone based upon the theory of Korst, and reattachment turning conditions given by oblique shock theory.

References

[1] Abbett, M. J., Cooper, L., Dahm, T. J., and Jackson, M. D., "Flow Characteristics About Concave Conic Forebodies at High Mach Number," AIAA Paper 75-153, Pasadena, Calif., 1975.

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