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L^* Oscillations and a Pressure-Frequency Correlation for Solid Rocket Propellants

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IN the early 1960's experimenters[1,2] working with metallized double base propellants, reported a correlation between the mean pressure $\bar{p}$ and the frequency F, at which (L^*) oscillations occurred in solid propellant rocket motors or in special devices such as T burners and L^* burners. Combining their data, one finds that for 0.1 MPa (0 psig) $<\bar{p}<1.5$ MPa (200 psig) there is a more or less linear relation between the mean pressure and the frequency at which the oscillations take place. Price[3] points out that the mechanism that controls the frequency of L^* oscillations is not well understood and that the $\bar{p}-F$ correlation is not as distinct for composite propellants as for double base propellants. On the other hand, Strand,[4] working with metallized and nonmetallized composite propellants presents $\bar{p}-F$ correlations over a small interval, approximately 0.4 MPa (60 psi).

Other experimenters[5,6] in the early 1970's did not attempt to correlate the frequency of L^* oscillations to mean pressure. They used only composite propellants, such as JPL 540, A-13 and variations thereof. During recent experiments[7] with double base ARP propellant in two L^* burners of different size,[8] a well-defined relation was observed between the frequency and the mean pressure at which the oscillations took place. All experiments exhausted in the atmosphere (about 0.1 MPa), and the L^* varies between 0.25 and 1.75 m. ARP composition is as follows: cellulose nitrate (12.6%N) 49.9%, glycerol tri-nitrate 36.4%, triacetin 8%, additives 5.7%. Experimental results are shown in Fig. 1. We note the following:

1) There are two regions in which L^* oscillations occurred for ARP propellant: a low-pressure, high-frequency region (0.15 MPa$<\bar{p}<$0.7 MPa and 40 sec$^{-1}<F<$100 sec^{-1}), and a medium-pressure, low-frequency region (1.25 MPa$<\bar{p}<$4 MPa and 10 sec$^{-1}<F<$50 sec^{-1}). To the author's knowledge, the existence of two regions has not been reported before, and since no L^* oscillations were observed for 0.7 MPa$<\bar{p}<$1.25 MPa, it is not clear whether the regions are connected or not.

2) The medium pressure range in which a linear $\bar{p}-F$ correlation was observed is much larger than previously reported for L^* oscillations.

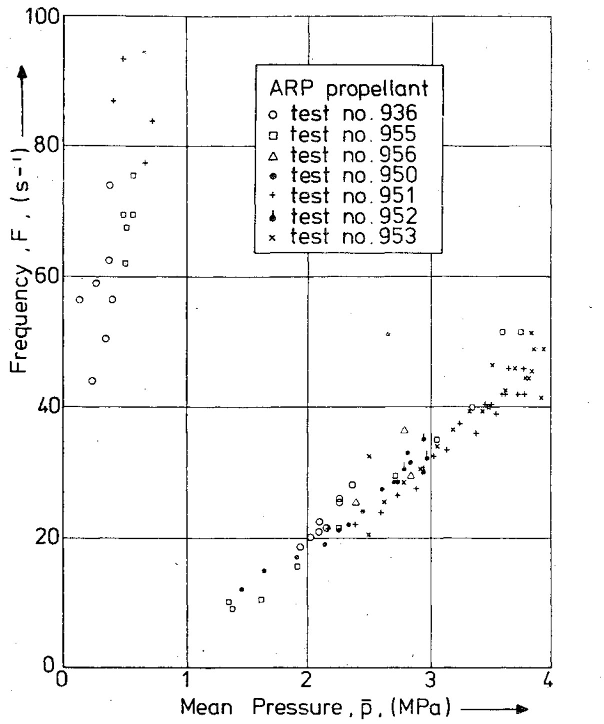

Fig. 1 Regions of linear mean pressure frequency relationship for L^* oscillations in 5-cm (open plotting symbols) and 10-cm L^* burners. (0.25 m$<L^*<$1.75 m.)

Figure 1 discriminates in the plotting symbols between the results of experiments carried out in L^* burners with 5 cm and with 10 cm i.d. Tests 936, 955, and 956 (open plotting symbols) were conducted in the 5-cm L^* burner, the other tests (closed plotting symbols) in the 10-cm L^* burner, and the $\bar{p}-F$ correlation is independent of the size of the L^* burner. Low-pressure, high-frequency oscillations are predominantly found in the 5-cm L^* burner tests, but test 951, conducted in the 10-cm L^* burner, is equally compatible with the other low-pressure, high-frequency data.

Earlier data by Eisel et al.[2] indicate for the L^* burner data, $dF/d\bar{p}\approx 4\times 10^{-6}$ m·sec·kg^{-1}. The medium-pressure, low-frequency data of Fig. 1 indicate $dF/d\bar{p}\approx 15\times 10^{-6}$ m·sec·kg^{-1}, which is of the same order of magnitude. However, the slope of the low-pressure, high-frequency data of Fig. 1 is much larger with $dF/d\bar{p}\approx 88\times 10^{-6}$ m·sec·kg^{-1}.

To determine whether composite propellants also yield a significant $\bar{p}-F$ correlation, older data[5,6] were reconsidered. Schöyer,[5] using A-13 propellant provided by the Naval Weapons Center, China Lake, presents tables listing $\bar{p}$ and the angular frequency ω. No $\bar{p}-F$ correlation could be traced from these data. Kumar and McNamara,[6] using CIT-2, Ã-13, CIT-3, and CIT-4 propellants, produced at JPL, present $\bar{p}$, but the frequency F must be deduced from other data.

No $\bar{p}-F$ correlation could be traced for CIT-2 propellant. The experiments with Ã-13 propellant yield a clear correlation, as is shown in Fig. 2. Around $\bar{p}=0.4$ MPa the frequency is at a minimum and the figure suggests that the right branch of the curve may continue as a medium-pressure, low-frequency correlation, while the left branch may become the low-pressure, high-frequency correlation. A correlation

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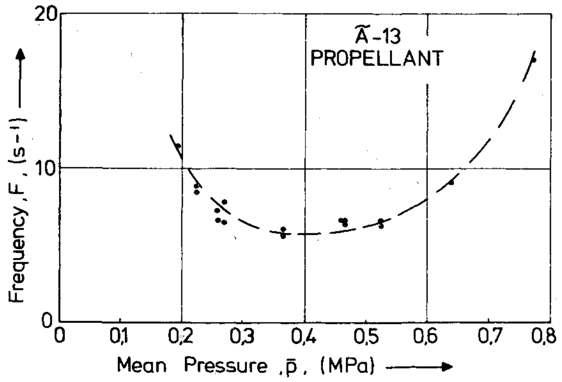

Fig. 2 Nonlinear correlation between mean pressure and frequency for L^* oscillations. (Data from Kumar and McNamara.[6])

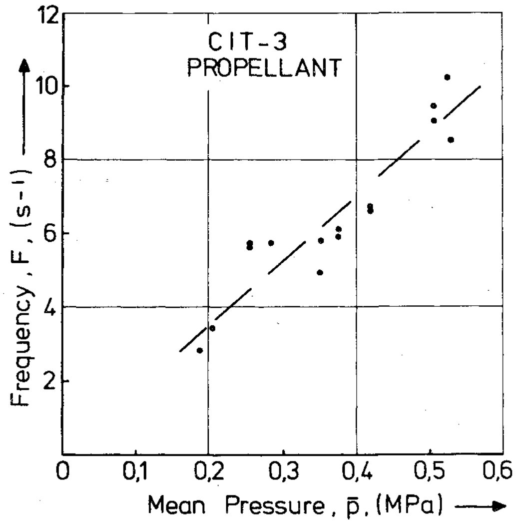

Fig. 3 Linear correlation between mean pressure and frequency for L^* oscillations. (Data from Kumar and McNamara.[6])

similar to that shown in Fig. 2 for a composite propellant may be the missing link between the low- and medium-pressure data in Fig. 1, which applies for a double base propellant.

Data from experiments with CIT-3 propellant, shown in Fig. 3, yield a linear relation between $\bar{p}$ and F, with $dF/d\bar{p} \approx 2 \times 10^{-6}$ m·sec·kg^{-1}. The difference between Ã-13 and CIT-3 formulations is the large oxidizer particle size of the latter (175 μm vs 39.5 μm). In this respect, it should be noted that slight changes in the propellant may seriously affect the results of L^* experiments. For example, data from experiments with NWC A-13[5] do not yield a $\bar{p}-F$ correlation, and oscillation frequencies vary between 20 and 90 sec^{-1}, while experiments with JPL-processed Ã-13 produce a distinct $\bar{p}-F$ correlation, with oscillations varying between 6 and 20 sec^{-1}. The pressure range of experiments with CIT-4 propellant is too small for $\bar{p}-F$ analysis.

Price's remarks[3] about oscillatory combustion in L^* burners and rocket motors are still generally applicable. The newly observed relations between oscillation frequency and mean pressure appear to be much more prevalent than previously noted and may contribute to a better understanding of L^* oscillations.

Conclusions

1) Both double base and composite propellants, which are sensitive to L^* oscillations, may exhibit a distinct $\bar{p}-F$ correlation.

2) For ARP double base propellant, there exist two regions in which L^* oscillations may occur: a low-pressure, high-frequency region and a medium-pressure, low-frequency region. In these regions, the frequency increases linearly with the mean pressure.

3) The pressure-frequency relation of L^* oscillations is not affected by the size of the L^* burner.

4) The oxidizer particle size of composite propellants clearly affects the linear burning rate, the frequency at which the oscillations occur, and the $\bar{p}-F$ correlation.

Acknowledgment

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Surface Pressure Fluctuation Generated by a Jet Impinging on a Curved Plate

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Introduction

THIS work deals with a turbulent jet impinging on a solid boundary. The study of this problem is motivated by the use of the blown flap in STOL airplanes. Experiments related

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