# Multiple Ducted Streams with a Periodic or a Steady Supersonic Driver Flow

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## Abstract

An experimental investigation of the operating characteristics of a two-dimensional planar, constant area, supersonic-subsonic ejector with a steady or a periodically pulsed continuous driver flow is presented. Improvements in ejector pressure recovery and entrainment capabilities resulted from the periodic driver for a limited range of operating conditions.

## Contents

The purpose of this study was to determine if periodic pulsation of the driver flow in an ejector would lead to improvements in ejector performance as a result of enhancing or exciting modes of flow interaction beyond those normally occurring in the ejector mixing duct. In particular, this investigation was concerned with pressure recovery applications in which the primary flow must pump the low pressure secondary to an appreciably higher pressure level. The approach taken to induce flow interaction was to periodically pulse the ejector driver flow with an efficient large scale fluidic oscillator developed for this purpose. This is similar to "wave energy exchanger" type ejectors[1-3] in which slugs of primary flow are discharged periodically into the mixing duct. In the current case, however, the driver flow is continuous.

A simple, one-dimensional inviscid control volume analysis, following that of Fabri and Siestrunk,[4,5] was used to predict ejector operating characteristics; the descriptive features of the analysis are useful for the present discussion. Three regimes of ejector operation are considered. The supersonic regime, SR, occurs when the primary flow expands against the secondary after entering the ejector mixing duct and the secondary flow chokes at an aerodynamic throat in the mixing duct; this is the situation depicted in Fig. 1. The saturated supersonic regime, SSR, occurs when the secondary static pressure equals or exceeds that of the primary flow at the ejector inlet and the secondary flow chokes at the inlet. The mixed regime, MR, occurs when the back pressure at the ejector exit plane is too high to allow choking of the secondary flow either in the mixing duct or at the inlet.

The solution surfaces of the analysis for the ejector configuration studied experimentally are shown in Fig. 2. $M_{S1}$ is the secondary flow Mach number at the inlet, $P_{S0}/P_{P0}$ is the secondary-to-primary stagnation pressure ratio, and $P_{M3}/P_{S0}$ is the compression ratio achieved across the ejector. The experiments in the present study were conducted for stagnation pressure ratios in the SR only, because pressure recovery in the SSR is poor. Attention was focused on the operating conditions separating the supersonic and mixed regimes. These "breakoff" conditions are the maximum compression ratios the ejector can achieve at given stagnation pressure ratios without the rapid decrease in the induced secondary mass flowrate as shown in Fig. 2 by the precipitous decrease in $M_{S1}$ in the mixed regime.

The ejector consisted of a uniform flow Mach 1.96 primary nozzle directed along the center of a constant area rectangular cross-section mixing duct interleaved between the two secondary streams (Fig. 1). The mixing duct measured 33.07 mm across the combined primary and secondary flows and was 15.24 mm deep. The secondary-to-primary area ratio was 2.0. Thus, the span across the primary nozzle and each of the two secondary passages at the inlet was approximately 11 mm. Three mixing duct lengths with length-to-width ratios of 9, 13, and 16.4 were used; the width is the span across the combined primary and secondary flows. Driver frequencies of 142 and 250 Hz were used.

The measured SR steady driver secondary-to-primary mass flowrate ratios, $W_S/W_P$, and inlet static pressure ratios closely followed the trends predicted by the analysis. Periodic driver data were similarly in agreement with results from a quasisteady version of the analysis. The steady driver compression ratios that caused the supersonic regime to break off into the mixed regime were approximately 25% lower than predicted. This is probably the result of neglecting viscous effects in the simple inviscid analysis.

The decrease in the mass flowrate ratio as the compression ratio exceeded the breakoff value and the breakoff value of the compression ratio were different for the steady, 142 Hz, and 250 Hz driver flows. The 250 Hz driver flow consistently broke off from SR to MR flow at slightly higher compression ratios than the other driver flows. Figure 3 shows the differences between the three drivers for a mean stagnation pressure ratio, $P_{S0}/P_{P0}=0.07$, in the $L/W=9$ mixing duct. The breakoff values of the mass flowrate ratio were approximately 0.079 for these data. The mass flowrate ratios were approximately 14% higher for the 250 Hz driver than for the steady driver at a given compression ratio after breaking off. The differences between the steady and 142 Hz driver results were noticeably smaller. These trends prevail at other stagnation pressure ratios, but the differences between the breakoff characteristics of the three drivers diminish substantially with increasing stagnation pressure ratio, so that at $P_{S0}/P_{P0}=0.13$ the differences in the mass flowrate ratios are only

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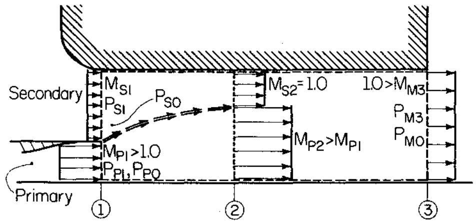


**Fig. 1 Nomenclature and flowfield for constant area supersonic-subsonic ejector. (Conditions at 2 valid only for SR operation.)**

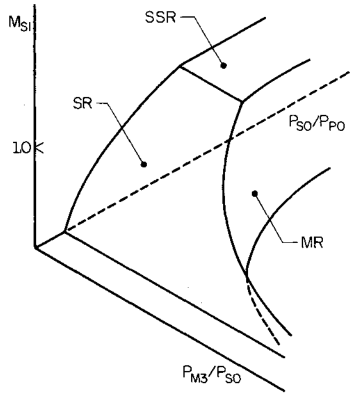


**Fig. 2 Solution surfaces from the one-dimensional analysis of the ejector configuration investigated.**

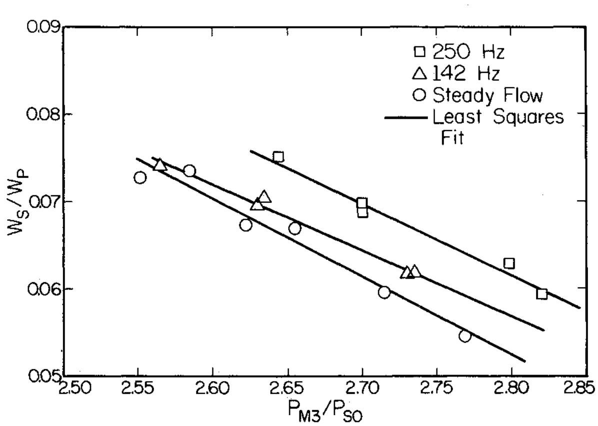


**Fig. 3 Mass flowrate ratio breakoff characteristics for all three driver flows, $L/W=9.0$, $P_{S0}/P_{P0}=0.07$.**

2-3%. The maximum stagnation pressure ratio examined was $P_{S0}/P_{P0}=0.18$.

The decrease in the effect of the periodic driver with increasing stagnation pressure ratio is due to the changing slope of the SR to MR breakoff curve in Fig. 2. Periodic pulsation of the driver moves the ejector operating point back and forth on the solution surfaces in a plane parallel to the $(P_{S0}/P_{P0}, M_{S1})$ plane. It can be seen that at higher values of $P_{S0}/P_{P0}$ the operating point moves nearly parallel to the breakoff curve, whereas at the lower $P_{S0}/P_{P0}$ values the operating point moves nearly normal to the breakoff curve. In the latter case, the ejector operating point is always moving toward or away from a different regime of operation than the current one; as a result, the potential changes in the ejector flowfield are large. In the former case, the ejector operating point tends to stay a fixed distance from the breakoff curve; thus flowfield conditions remain more nearly the same.

Transient static pressures were recorded with high frequency response instrumentation for a variety of flow conditions to determine the effects of pulsation of the driver flow on the ejector flowfield. These measurements demonstrated that driver pulsation changed the operating conditions of the ejector so that the length of the supersonic core at the center of the mixing duct periodically grows and diminishes. The shock wave structure is also pulsed periodically and changes in form and strength in doing so. The extent of flowfield disturbance depends on the magnitude of the changes in the ejector operating conditions and is most significant at the lowest stagnation pressure ratios. Surprisingly, the ejector flowfield with a steady driver was also found to be unsteady, but shock wave motion was limited and the induced secondary flow was relatively quiescent. In contast, the disturbances in the ejector flowfield with a periodic driver were sustained and vigorous at the lower stagnation pressure ratios compared to those of the steady driver, but the differences did diminish, as expected, at higher stagnation pressure ratios.

Although the fluidic oscillator used provided an efficient means of pulsing the primary flow, more substantial improvements over a broader range of operating conditions would require both larger amplitude and higher frequency pulsations. The differences between the breakoff behavior of the 142 and 250 Hz flows shown in Fig. 3 suggest that further increases in driver frequency would be beneficial. An entrained fluid element traverses the entire length of the mixing duct in a fraction of the 250 Hz driver cycle. A driver frequency of 1000 Hz or greater would ensure that the entrained flow experiences the full range of pulsation in the mixing duct.

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