# SYNOPTIC: Analysis of Radar Return from Turbulent High-Altitude Rocket Exhaust Plumes,

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**Rocket Vehicle Aerodynamics, Plume Radar Backscatter**

### Theme

Describes character of radar backscatter from high-altitude launch vehicle plumes and proposes an approximate model based on scattering from the electron number density turbulence in the underdense (plasma frequency $\ll$ radar frequency) plume volume. Engine design, exhaust flow properties, combustion turbulence effects are included. Analysis is limited to the tail aspect geometry shown in Fig. 1.

### Content

Radar data of launch vehicle backscatter for altitudes > 100 km obtained from a HF (3-30MH$_3$) CW system are described. In these data are often seen: 1) an "enhanced skin echo" received from the vehicle and associated shock structures traveling at the vehicle that covers a narrow frequency range and 2) an "exhaust Doppler echo" Doppler shifted from the enhanced skin echo by ~3 km/sec covering a relatively broad frequency range and having a relatively sharp cutoff at the frequencies furthest removed from the enhanced skin echo.

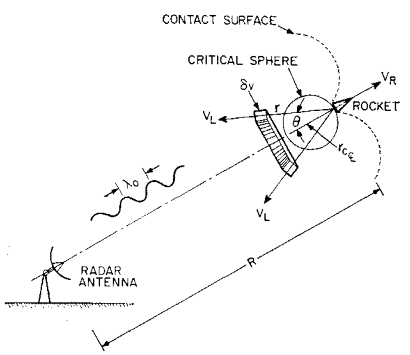


**Fig. 1 Radar backscatter geometry at tail aspect angle.**

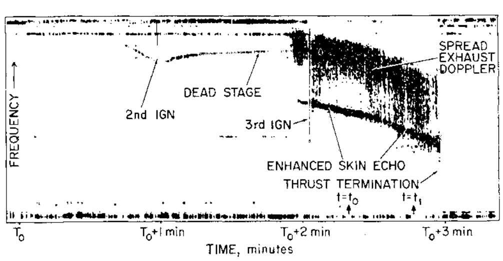


**Fig. 2 Radar backscatter history of launch with return frequency vs time into trajectory.**

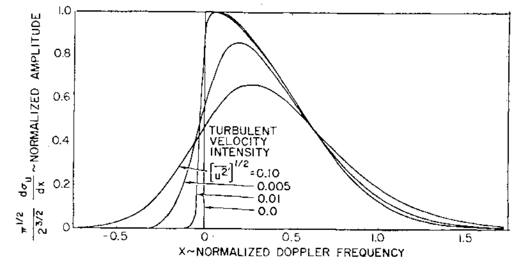


**Fig. 3 Variation of normalized Doppler spectra with turbulent intensity.**

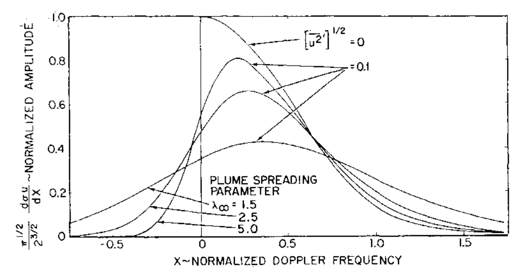


**Fig. 4 Variation of normalized Doppler spectra with plume spreading parameter.**

These structures are shown in the data of Fig. 2. As the gas limiting velocity is ~3 km/sec, the exhaust Doppler echo appears at higher altitudes where the plume scale is large (~3 km), and it appears for lower radar frequencies, the assumption is made that the exhaust Doppler echo is backscatter from the under dense electron densities turbulence downstream of the overdense region close to the engine exit. A model of this turbulence assuming frozen electron flow and allowing the far field velocity turbulence to be directly proportional to the combustion temperature turbulence is used. This model is used to derive an approximate integral expression for the exhaust Doppler echo frequency dependence, shown in Figs. 3 and 4. For $\gamma A_e/A^*$ small (plume spreading parameter $\lambda_\infty$ small) or $[\overline{u^{2\prime}}]^{1/2}$ large this frequency distribution becomes larger: $\gamma$ = ratio of specific heats, $A_e/A^*$ = engine area ratio, and $[\overline{u^{2\prime}}]^{1/2}$ = velocity turbulence intensity. Comparison of the model with the limited data available allows understanding of the exhaust Doppler echo features described previously. Backscattering from high-altitude local flows is suggested as the source of some features observed and the exhaust Doppler echo similarity with wake backscatter is discussed.