followed by a simple wave rarefaction represented by the fields 11, 12, 13, separated by C_+ characteristics. The free surface, ABC, is immediately accelerated at the incidence of $\mathscr{S}_+$ and a back-ward-facing rarefaction fan, $\mathscr{R}_-$, centered at B, is generated. The C_+ characteristics pass through the fan of the reflected rarefaction and each in turn is reflected from the free surface as shown. The map of the flow in the (p, u) plane is shown in Fig. 26 *b*).

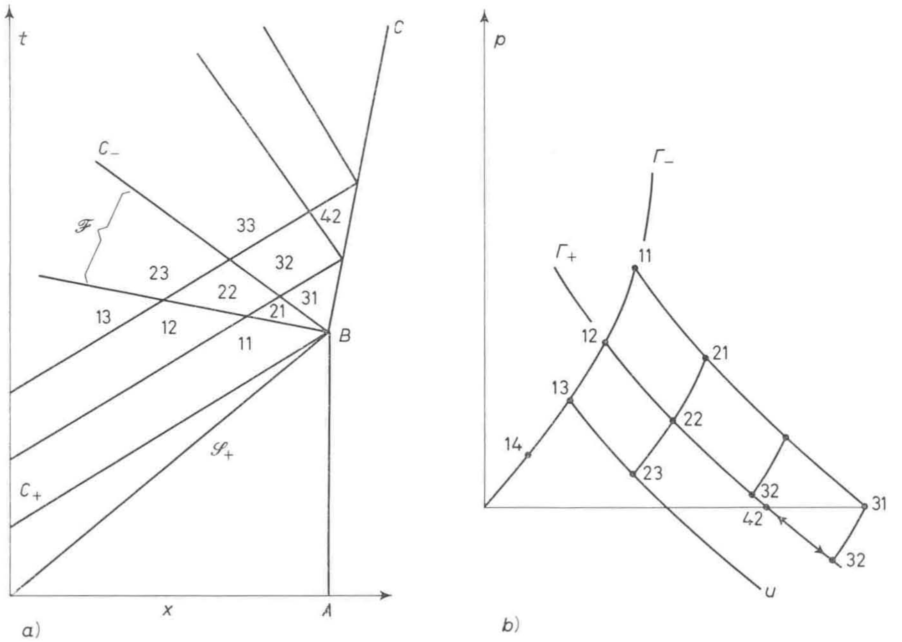

Fig. 26. – Reflection at a free surface. *a*) (x, t) plane; *b*) (p, u) plane.

The point to note here is that the transition from the field 12 to the free surface state takes place along a Γ_+ characteristic, and that the mapping goes into the negative pressure region and returns to the $p = 0$ state at 42. This is in qualitative agreement with the sketches of Fig. 25.

Whether or not a spall occurs depends upon the magnitude and duration of the stress. BREED, MADER and VENABLE have found [10] that spall occurs if the fracture stress, σ_f, satisfies the relation

$$\sigma_f = A + F(\Delta\sigma/z)^{\frac{1}{2}}, \tag{100}$$

where z is the distance from the free surface at which spall occurs, $\Delta\sigma = \sigma_f$, and $\Delta\sigma/z$ is the stress gradient. A and B are material constants. Equation (100) implies that fracture occurs when $\sigma\Delta t$ reaches a characteristic value.

BUTCHER, BARKER, MUNSON and LUNDERGAN have proposed a slightly more general relation which includes the above [11]; fracture occurs when

$$\Delta t \sigma^r = G\,, \tag{101}$$

where r and G depend on the material.

A still more general relation has been used by F. TULER [12] to describe experiments in 6061T6 Al; fracture occurs at time t_f defined by the relation

$$\int_0^{t_f} (\sigma_0 - \sigma)^r \, dt = G\,, \tag{102}$$

where $r = 2.02$, $G = 3.98 \cdot 10^{13}$, $\sigma_0 = -10^{10}$ dyn/cm². All of these rules apply to plane spall, described in Fig. 25 and 26. None have any particularly sound theoretical basis. Present efforts in this area are directed toward experiments which will provide information for nucleation and growth models similar to those discussed by MCCLINTOCK [13].

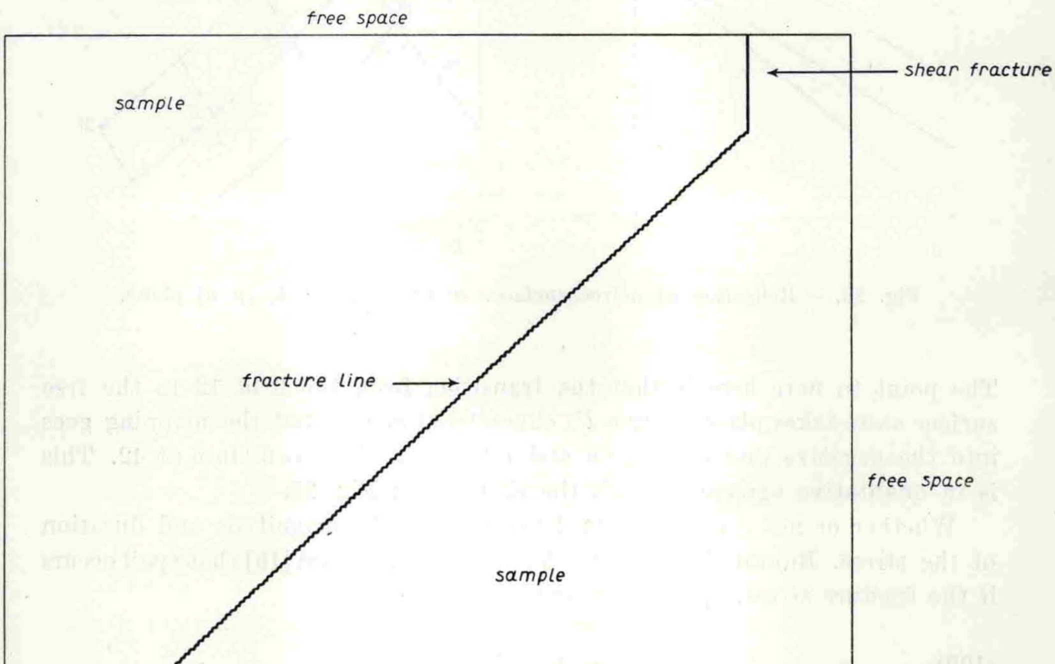

Fig. 27. – Ridge cut.