

# JET THRUST

BY L. A. SIMONOV

Academy of Sciences, U.S.S.R.

THE concept of the "engine thrust" is widely used, while in many cases it is impossible to differentiate thrust forces from the complexity of forces acting on the vehicle. This differentiation is but too conditional.

However, we need a correct conception of the thrust, as it should inspire the designer to create the best engine.

The report contains mainly the known examples and is of a methodical value.

1. Usually, when applying the momentum theorem to a jet passing through the engine, one obtains the engine thrust formula:

$$P = Q_a(V_j - V) + Q_f V_j + F(p - p_a) \quad (1)$$

When deriving this formula it is assumed, without proving, that

$$\left( \int p \, dF + V \, dQ \right)_1 - \left( \int p \, dF + V \, dQ \right)_2 = 0$$

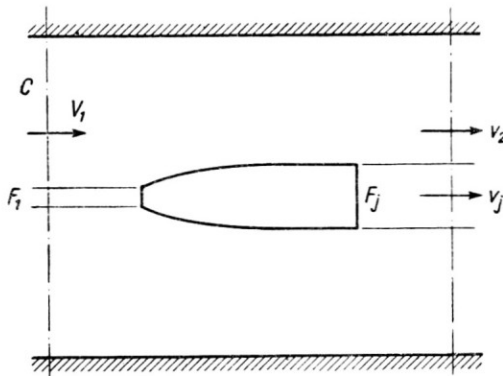


FIG. 1.

The strict proof for a subsonic flow requires consideration of the engine in a wind-tunnel, the area of which should then be extended to approach infinity (Fig. 1).

Then

$$P = Q(V - V_1) + S[(p_2 - p_1) + \rho_2 V_2(V_2 - V_1)] - Q(V_2 - V_1)$$

By expanding it in series with respect to  $\Delta V = V_2 - V_1$  one may show that

$$p_2 - p_1 + \rho_2 V_2 (V_2 - V_1) = 0(\Delta V)^2, \quad S = \frac{1}{0(\Delta V)}$$

Therefore the result for the limit is

$$|P|_{S \rightarrow \infty} = Q(V_c - V_1)$$

The thrust formula requires, even in the simplest case, a more explicit derivation.

2. For the case of a supersonic flight of a nacelle having a long cylindrical portion, where the atmospheric pressure may be assumed to be

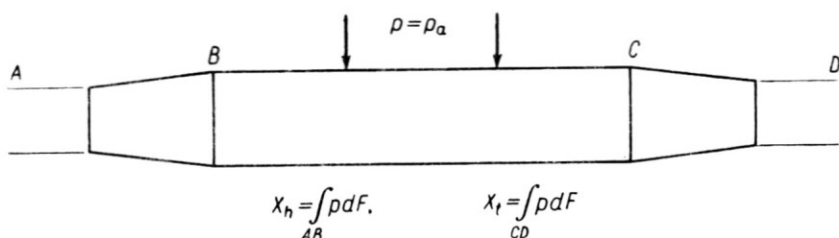


FIG. 2.

built-up (Fig. 2), one may differentiate rather precisely the forces acting on the nacelle, thrust, nose drag and tail drag. The last two forces present the integrals taken over the contour from the jet boundary on the infinity to the cylindrical portion.

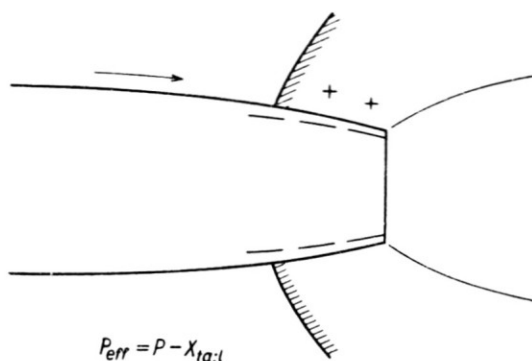


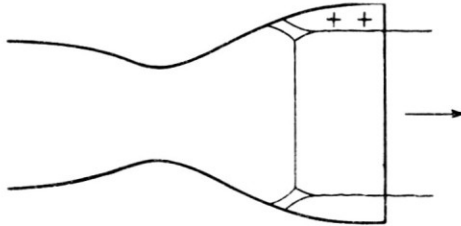
FIG. 3.

3. Using the underexpanded nozzle we shall obtain, conforming to (1), a certain loss in thrust. However in a supersonic flight the underexpanded jet sometimes induces a shock wave at the tail section of the nacelle, the increased pressure behind which to a great extent compensates

the loss in thrust. In this case the formula (1) gives a wrong presentation of the role of the nozzle underexpansion. In this case it is better to use the effective thrust equal to

$$P_{\text{eff}} = P - X_{\text{tail}}$$

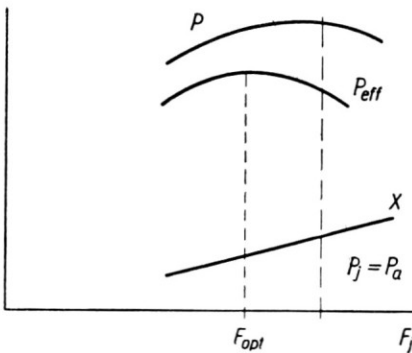
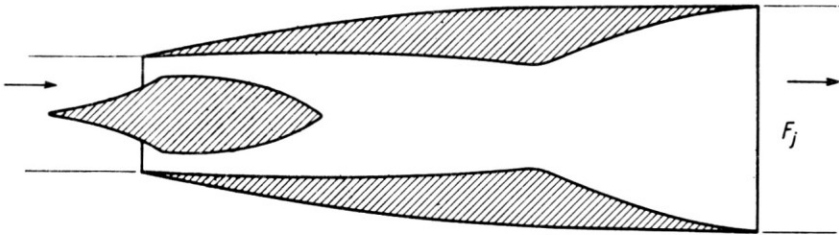
4. In the overexpanded nozzle the jet separation may occur, which will lead to a decrease in the thrust losses (Fig. 4). The formula (1) in this case also gives a wrong presentation as to the role of the nozzle exit area  $F_c$ .



$$P_{\text{exp}} > P_{\text{theory}}$$

FIG. 4.

5. In order to obtain the maximum thrust as defined by the formula (1), we shall construct the air intake so that the pressure losses are minimum.



$$P_{\text{eff}} = P - X_{\text{nacelle}}$$

FIG. 5.

Having gained somewhat in thrust, we may lose much because of the increased drag of the nacelle nose outline. To get a correct estimate of the air intake one should again use the effective thrust:  $P_{\text{eff}} = P - X_{\text{nose}}$ .

6. In order to obtain maximum thrust as defined by the formula (1), we must select the nozzle, so that  $P_c = P_a$ . But this may lead to the increase in the external drag of the nacelle (sharply expanded at the outlet) exceeding the gain which is obtained when using a fully expanded nozzle (Fig. 5).

In the cases discussed the correct solution is implied not by the concept of the engine thrust, but the concept of the engine nacelle effective thrust, i.e. by the difference between thrust and external drag of the nacelle.

7. The concept of the thrust becomes still less convincing in complex aircraft arrangements where the power plant is located not in a distinctly presented nacelle, but is interwoven organically in the air-frame structure.

The supersonic wing develops wave drag in the narrowing section due to the rarefaction caused by the flow acceleration.

The engine nacelle, as a rule expanded at its tail, develops the wave drag because of the flow deceleration. If the nacelle is connected to the wing by means of a pylon, then the two drags will exist. If we connect the nacelle to the wing organically, then we may exclude a certain part of the wing-and-nacelle drag, i.e. may obtain a positive interference (Fig. 6).

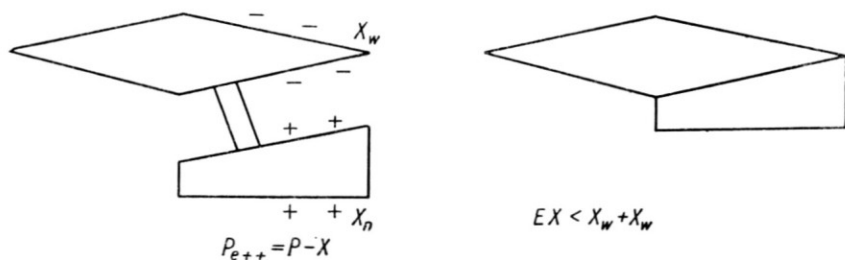


FIG. 6.

8. The power plant may be placed downstream of the body (Fig. 7) so that it would swallow the flow decelerated by the body. In this case one cannot use the usual concepts of the body drag and the engine thrust. The phenomena may be considered only as a unity.

The fuselage drag as if vanished, but the engine operates with considerable losses at the inlet.

In case of the engines utilizing a gas propellant such a combination is not profitable, as decreasing losses due to the kinetic energy of the jet stream, it increases losses due to the thermal energy of jet stream.

For the case of propulsion in water one may create in principle a device which will develop neither a wake moved forward, nor a jet engine moved back. If one considers the efficiency with respect to the kinetic energy losses downstream of the moving device, then such an efficiency may be equal to unity.

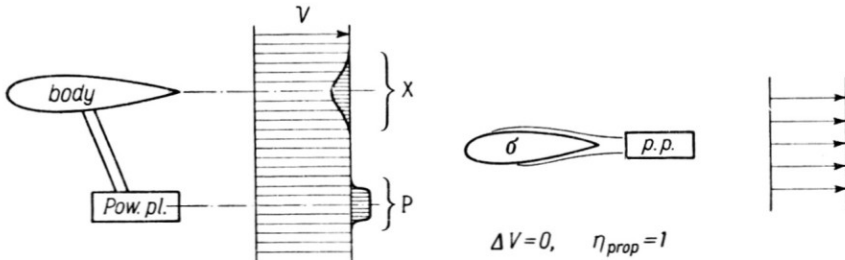


FIG. 7.

9. Even for the cases of space electric jet engines, where the thrust seemed to be just equal to  $QV_c$ , there may occur electric interactions between the aircraft and the substance ejected, but not yet neutralized, which complicate the concept of a thrust.

The thrust concept arose at the time when the engine and the air-frame were distinctly separated. Nowadays, the engine and the frame are becoming more and more a total complex arrangement rendering the old concept of a thrust rather conditional.

In each particular case it should be replaced by an appropriate concept of the effective thrust ( $P_{eff} = P - X$ ) involving a part of external forces which depend on the power plant, and inspiring a designer to create a really optimum engine design or a really optimum design of the aircraft as a whole.