cidence than a comparable pure delta, due to the beneficial influence on the flow over the outer wing vortex which separates from the leading edge of the inner wing. The same effect is created by the strakes on some recently designed airplanes.

From the results of these studies the supersonic fighter J35 Draken (Fig. 3) was designed. It made its first flight in 1955 and has since been produced for the Swedish Air Force in four fighter versions with successively more powerful engines and improved weapons systems. There are also two-seat trainer and reconnaissance versions. For export a strike version has been developed with a takeoff weight twice as high as that of the first fighter version. With a top speed in excess of $M=2$ the J35 has good maneuverability and modest demands for runway length.

In the late 1950s the Swedish Air Force adopted a basic philosophy demanding that future aircraft should be able to operate from very short runways. As supersonic performance was still required, it was felt highly desirable to utilize the experience with the J35 and continue to use delta wings. For that reason a broad investigation into ways of improving their high lift capabilities was started.

A tailless delta, designed to be statically stable in pitch, cannot use trailing-edge flaps as a high lift device because an upward deflection of the flaps is needed to trim the airplane. As an unstable airplane was deemed unacceptable, wind-tunnel tests were made of combinations of the wing and a separate horizontal stabilizer. With the stabilizer behind the wing, it was found almost impossible to obtain satisfactory longitudinal stability due to the strong downwash from a delta wing at high incidence. A stabilizer in front of the wing has the advantage that the trim force on the stabilizer is added to the wing lift. In wind-tunnel tests it was found that, with a triangular stabilizer immediately in front of and slightly above the delta wing, a beneficial interference took place between the leading-edge vortices from the stabilizer and the wing. The interference increased both the lift at a given incidence and the range of incidence for acceptable longitudinal stability.

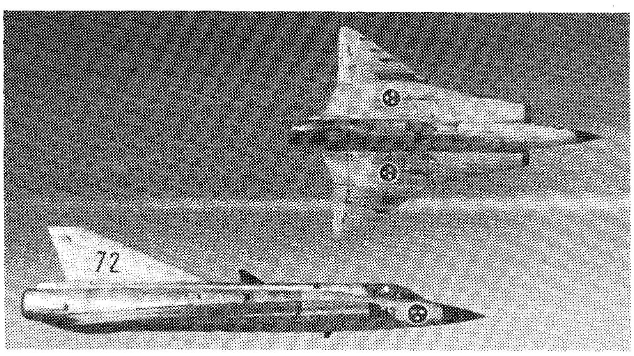

Fig. 3 The J35 single-seat supersonic interceptor fighter.

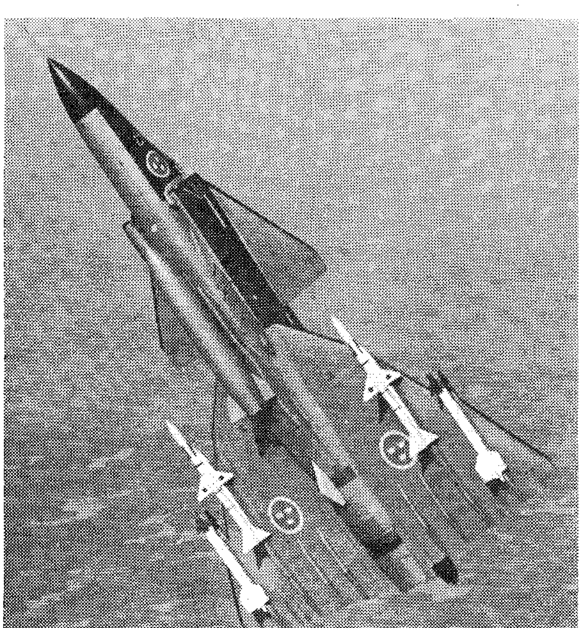
Fig. 4 The JA37 Viggen.

This discovery formed the basis of the aerodynamic layout of the JA37 Viggen (Fig. 4) which combines a top speed in excess of $M=2$ and low gust sensibility at high speed and low altitude with a low touchdown speed at a moderate angle of attack. To fulfill the runway requirements, the engine has a thrust reverser and the undercarriage is designed for no flare (carrier-type) landings.

The airplane, which made its first flight in 1967 has been delivered to the Swedish Air Force in a strike and a reconnaissance version. A fighter version with a more powerful engine and modernized equipment is being delivered.

Viggen Thrust Reverser

AIAA 81-4163

Bengt Ahrén*
Saab-Scania AB, Linkoping, Sweden

ONE basic requirement for the A/C 37 Viggen was the capability to take off and land on 500 m runway strips. To achieve such a landing, the aircraft had to possess several specific features, the most important of which were: low approach speed, means to reduce touchdown scatter, and high rate of deceleration on the ground. The most efficient method of reducing speed quickly, even on icy runways, is thrust reversal. In 1962, when the Viggen program began, thrust reversers for afterburning engines were not available. In spite of this, it was decided to make the aircraft capable of thrust reversal and to start development of a reverser for the RM8 engine, the military version of the Pratt & Whitney (PWA) JT8D.

From the beginning, the reverser layout was based on a PWA concept consisting of a "blow-in-door" ejector, similar to the TF30 nozzle in the F-111, with a number of blocker doors for thrust reversal integrated into the ejector. In the Viggen, a single-engine aircraft, it was found advantageous to integrate the ejector nozzle into the rear fuselage instead of connecting it to the afterburner primary nozzle. Thus, because the ejector/reverser unit was an airframe component, Saab became responsible for its development and production.

After preliminary design and model testing, the original concept of the ejector/reverser layout was modified considerably and had the following main features. A fixed geometry ejector with a cylindrical inner shroud is connected

Received March 23, 1981.

*Head, Aircraft Technology, Design and Development Sector, Military Aircraft.

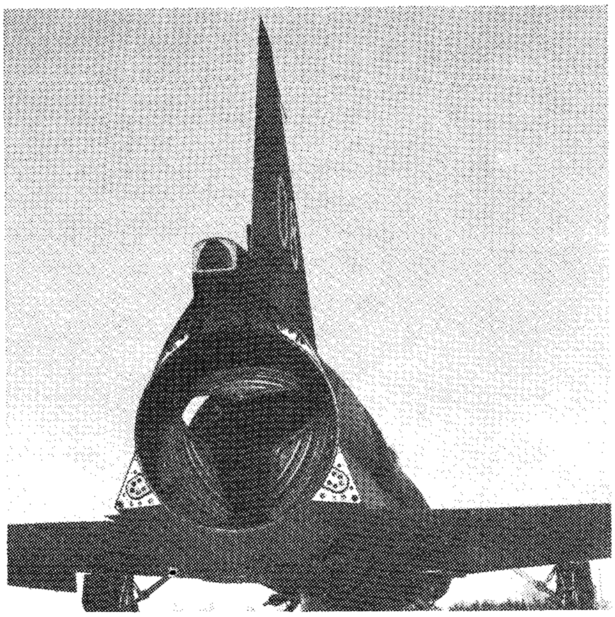

Fig. 1 Viggen thrust reverser in half-closed position.

to the afterbody by three supporting beams, one at each wing root and one below the fin. The slot between the afterbody and the leading edge of the ejector, divided into three parts by the beams, is the combined inlet for ambient air and nozzle for reverse exhaust gas. Instead of blow-in-doors, the slot has a translating sleeve which in the open position is retracted into the afterbody structure by hydraulic power. In the ejector shroud there are three blocker doors flush with the surface in the retracted position. When the reverser control is engaged, the doors are turned to their closed position by hydraulic actuators and the exhaust gas is deflected forward through the slot, forming one ground jet and two jets above the wing on either side of the fuselage. (See Fig. 1.) Thrust reversal can be preselected by the pilot in the air, and is then automatically initiated at touchdown of the main landing gear.

The development work on the reverser system included a number of activities. Besides model testing in wind tunnels and rigs and full-scale testing on the engine test bed, a large number of test runs (including landings) were carried out in prototype aircraft for evaluation of the complete reverser system and for demonstration of roll distance and aircraft stability at thrust reversal.

During thousands of reverser operations in the flight test program, invaluable but also hard-earned experience was gained. The problems encountered were mainly due to influences on aircraft pitch and yaw stability. Owing to the aerodynamic ground interference from the lower jet of the deflected flow, a strong variation in pitching moment with forward speed and degree of reverse thrust occurred. The yaw stability problem was also caused by aerodynamic interference. With the upper jets close to the fin, small asymmetric disturbances in the jet boundaries could result in side forces and yawing moments too great to be controlled by the pilot. After extensive analysis, testing, and simulation, various means to improve the stability were introduced and, finally, the aircraft behavior was quite satisfactory at all actual conditions.

The experience of the Viggen thrust reverser system from many years of service in the Swedish Air Force has been most favorable and the reverser has become a useful tool for the pilots, not only to shorten the roll distance but also in handling the aircraft during taxiing and parking. The mechanical functioning and durability of the reverser have been quite good and, in addition, a considerable savings of tires and brakes has been gained.

AIAA 81-4164

Minimum Fuel Paths for a Subsonic Aircraft

E. Large*
Marconi Space & Defence Systems Ltd.
Stanmore, England

Nomenclature

A	= aspect ratio
C_{D0}	= zero incidence drag coefficient
C_L	= lift coefficient
$C_{L\alpha}$	= slope of lift coefficient, per rad
C_l	= speed of sound, m/s
c	= equivalent jet exhaust velocity, m/s = 3600 g/sfc
D	= drag, N
$E(y)$	= ratio of density at altitude to sea level
F	= function to be maximized
g	= acceleration due to gravity, m/s^2
H	= Hamiltonian
H_0	= reference altitude below tropopause ($T_0/l = 44.3$ km)
H_2	= scale height of isothermal atmosphere above tropopause (6343.2 m)
k	= shape parameter for induced drag
K	= $kC_{L\alpha}/\pi A$
l	= lapse rate of temperature (6.5°C/km)
L	= lift, N
M	= mass, kg
M_f	= final mass, kg
N	= $\frac{1}{2}\rho_0 S C_{L\alpha}$, kg/m
D_0	= $\frac{1}{2}\rho_0 S C_{D0}$, kg/m
R	= gas constant (287.423)
S	= wing reference area, m^2
T	= temperature, K
T_0	= sea level temperature (288 K)
T_2	= temperature above tropopause (216.5 K)
sfc	= specific fuel consumption, kg/h/kg thrust
t	= time, s
V	= velocity, m/s
x	= horizontal distance, m
y	= altitude, m
α	= incidence, rad
γ	= climb angle, rad
Γ	= ratio of specific heats of air ($C_p/C_v = 1.4$)
ρ	= air density, kg/m^3
ρ_0	= sea-level air density, kg/m^3
μ	= Mach number = V/C_l

Introduction

THE theory of optimal flight paths for winged or unwinged, supersonic rockets or aircraft has now reached a fairly complete stage. The history of optimal flight paths goes back to 1951, when Tsien and Evans[1] found the optimum thrust program for a vertically ascending sounding rocket. In 1952 Hibbs found the optimum burning program for horizontal flight of a winged supersonic rocket.[2]

Recently, the problem of the optimal climb path of a ballistic rocket away from the vertical has been shown in Ref. 4 to have a simple analytical solution. The problem of a winged, supersonic rocket, assuming the thrust acts along the flight path, has been solved in Ref. 5. The solution for a vectored, variable-thrust aircraft or missile has been given in Ref. 6. All of the solutions gave optimal flight paths which

Received Nov. 17, 1980.

*Principal Engineer.