2

CHARACTERISTICS OF A DEFLECTED-JET VTOL AIRCRAFT

By L. Stewart Rolls

Ames Research Center

INTRODUCTION

L1421

Of the VTOL vehicles available for study only one incorporates characteristics similar to those which are typical of high subsonic or supersonic speed aircraft. This vehicle is the Bell X-14 which derives its vertical take-off capabilities from the vectored direct thrust of turbojet engines. Flight tests of this machine are being conducted at the Ames Research Center. Results have been obtained which have general applicability to VTOL research as well as to the specific type. This paper summarizes these results.

DESCRIPTION AND TESTS

Figure 1 is a sketch of the X-14, built by the Bell Aircraft Corporation, illustrating its important features. Two side-by-side mounted Armstrong Siddeley Viper ASV. 8 turbojet engines provide the thrust. The exhaust from each engine passes through cascade-type diverters. These diverters are controlled by the pilot and enable him to select any direction of the thrust vector from vertical to horizontal. In airplane flight, conventional aerodynamic controls are used to control the airplane; in hovering, reaction jets at the wing tips and at the tail supply the control. The air for these reaction controls is bled from the compressors of the turbojet engines.

The flight experience gained with the X-14 showed that operation of a deflected-jet VTOL airplane is feasible. Transitions could be performed fairly easily. The transfer of control from reaction nozzle to aerodynamic control was smooth. These flight tests did, however, point out problems associated with the deflected-jet type of VTOL vehicle which should be corrected to improve its usefulness. These problems are height control, coupling of reaction control moment to engine thrust, and gyroscopic coupling. Even though the X-14 lacked sufficient control power because of the limited amount of bleed air available, it was possible to examine these problem areas.

RESULTS AND DISCUSSION

The first problem to be considered is the height control. Operation of a deflected-jet VTOL vehicle is complicated because of the negative ground effect or ground suction associated with the jet exiting in the center of a flat plate. This ground effect means that a vertical thrust in excess of the weight of the airplane is required to accomplish the initial lift-off. As pointed out in a previous paper by Robert O. Schade this extra thrust is proportional to the distance the exhausting jet is above the ground. For the X-14, the excess thrust required to break ground contact is on the order of 12 percent of the airplane gross weight. Once the airplane becomes airborne, the pilot must cope with the problem of reducing this excess thrust to zero if he plans to hover at a fixed altitude. During hover, the throttle performs as an acceleration command control and the pilot has difficulty in arriving at an exact balance between the thrust and weight. This problem of establishing equilibrium between weight and thrust usually results in a roller-coaster ride for the pilot on his first few hovering flights in the airplane. At present, no method of overcoming this negative ground effect by aircraft modification except moving the jet away from the center of the vehicle is known.

L1421

The second problem is that of varying control power with varying engine thrust. Where the reaction nozzles are supplied air directly from the compressors of the lifting engines, the amount of control power available to the pilot is a direct function of the compressor airflow. The amount of control-power reduction with reductions in engine speed for the X-14 is shown in figure 2. It will be noted that this reduction is very severe. As was pointed out in the discussion of height control, the airplane hovers out of ground effect at less than full throttle; hence, the pilot never has full reaction control available in this flight condition. Also, as the flight continues, the amount available becomes less, because of the reduction in thrust as fuel is consumed. Normal hovering engine speeds are of the order of 93 to 97 percent and, as a result, control powers of about 90 percent of the maximum are available. However, momentary reductions in engine speed as low as 90 percent have been experienced, and, as a result, control power of only 70 percent of maximum is available.

Some relief from this problem could be gained if variable bleed could be designed into the system to allow more bleed air at the lower engine speeds and thus minimize the loss of reaction control power with the reduction in engine speeds. Variable-geometry jet exits could also be used to allow the pilot to monitor thrust and operate the engines at full speed.

The third problem area associated with the operation of a deflected-jet VTOL can be gyroscopic coupling. This coupling on the X-14 is between the pitch and yaw axes because of the horizontal engine axis. On a VTOL design with vertically mounted lifting engines, the gyroscopic coupling would be between the pitch and roll axes. On the X-14 this gyroscopic moment is of sufficient magnitude that, at rates of yaw greater than 15° per second, the pilot is unable to hold the airplane level with the existing amount of longitudinal control. Reducing the gyroscopic moment by reducing engine speed does not minimize the problem because of the attendant loss of control power. In order to make a deflected jet operational, it will be necessary to overcome the gyroscopic coupling. An automatic stabilization system will eliminate this problem provided there is sufficient reaction control available for both the pilot and the stabilization system. A failure of the stabilization system, however, might leave the pilot with an unacceptable airplane. The gyroscopic coupling problem might be eliminated or reduced with engines similar to the Bristol Siddeley BE-53 which employs two spools rotating in opposite directions.

Transition with the X-14 airplane presents no great problems. As with any fixed-wing VTOL airplane, as the wing approaches the stall angle of attack, some control difficulties may occur. With the X-14 the speed at which the wing stalls can be restricted to a speed where the dynamic pressure is low; thus, no large airplane motions result. If the pilot has sensitive airspeed, rate-of-climb, and angle-of-attack indicators, he is able to perform transition without difficulties and is able to avoid the stall region.

As a support to the general investigation of the handling-qualities requirements for operational V/STOL aircraft, it was felt that a variable-stability V/STOL airplane would be of great value. The X-14 possessed the unique feature that the reaction nozzles exert a pure moment on the airframe; hence, a variable-stability vehicle controlled with reaction nozzles would not be influenced by possible cross-coupling effects such as would result with aerodynamic controls. Also the loading and unloading of the fixed wing would afford an opportunity to investigate transition and STOL-type operations. The conversion of the X-14 to a variable-stability-and-control airplane was possible because of the greater bleed-air capabilities of the General Electric J85-5 engines. The J85-5 engines also furnished greater thrust at less weight than the Viper ASV. 8 engines originally installed in the X-14 and were adaptable to the existing diverter system.

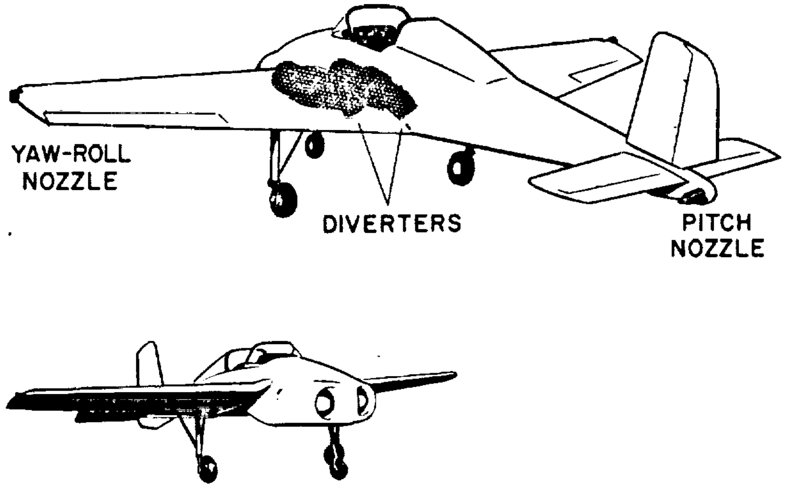
The X-14 is shown in figure 3 as it will operate as a variable-stability-and-control airplane; only one engine is shown for clarity. The original reaction nozzles have been retained for the pilot's control and a parallel set of nozzles were installed to supply the variable-stability moments. This parallel arrangement of nozzles was used to provide an effective margin of safety. Since the pilot's control nozzles supply a greater amount of bleed air than the variable-stability nozzles, the pilot has a direct mechanical overriding capability.

The variable-stability reaction nozzles are driven by servomotors which are controlled by a signal combining six possible airplane functions. The pilot is furnished a selector which enables him to vary the magnitude and sign of these input signals. The moments from these nozzles can be applied in the same direction as the pilot control moments to investigate increases in control power or applied in the direction to oppose airplane motion to investigate additional damping.

L
1
4
2
1

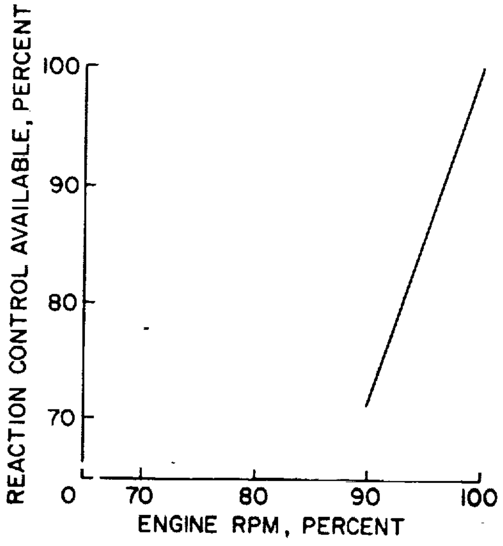
The ranges of damping and control power available with the modified X-14 airplane using both reaction-nozzle systems are illustrated in figure 4. In this figure, the shaded areas indicate the conditions of control power and damping which can be obtained when the available bleed air is divided among the axes on the basis of 55 percent for roll, 28 percent for pitch, and 17 percent for yaw. The solid curves indicate the control-power-damping characteristics which could be investigated if the maximum bleed air were used on only one axis, sufficient air being used on the other axes only to maintain approximately the same control as that of the original airplane. The boundaries for satisfactory, unsatisfactory, and unacceptable control characteristics discussed in a paper by Alan E. Faye, Jr., are shown in this figure for reference. The data points represent the original X-14 airplane. It will be noted that with the X-14 it will be possible to investigate ranges of characteristics from satisfactory to unacceptable in pitch and roll; however, in yaw its capabilities are somewhat less because of the higher moment of inertia about that axis. These reaction-control power and damping capabilities can also be imposed upon the airplane characteristics during transition. It will, for example, be possible at 40 knots (which is a speed approximately halfway through the transition) to change the airplane damping from zero to twice the aerodynamic damping available at that speed. Since the aerodynamic damping in roll and yaw is low, areas of control power and damping similar to those shown for hovering can be investigated through the transition.

The first tests conducted with the variable-stability-and-control system will be to investigate the control-power-damping requirements for satisfactory pilot opinion; this investigation is similar to that conducted by Alan E. Faye, Jr., on a moving-base simulator. In this investigation the reaction nozzles will be positioned by signals from rate gyros and control motions by the pilots.



X-14 VTOL TEST VEHICLE

Figure 1



CONTROL POWER-ENGINE RPM RELATION

Figure 2

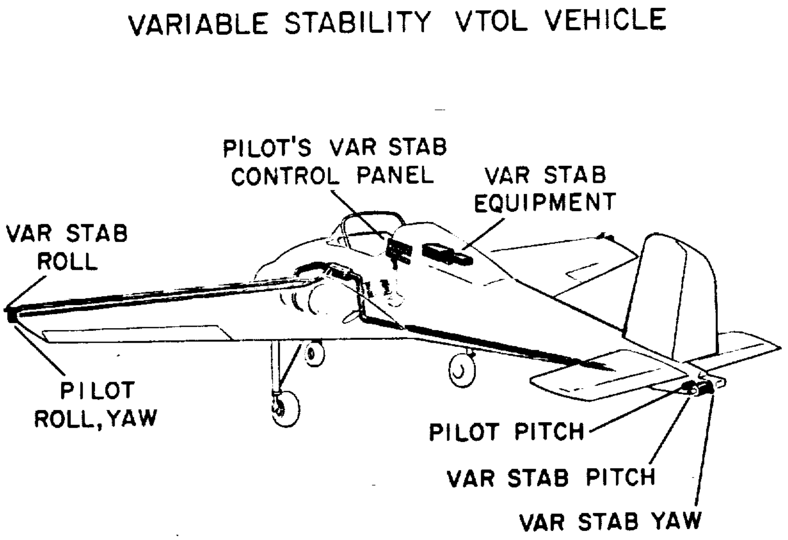


Figure 3

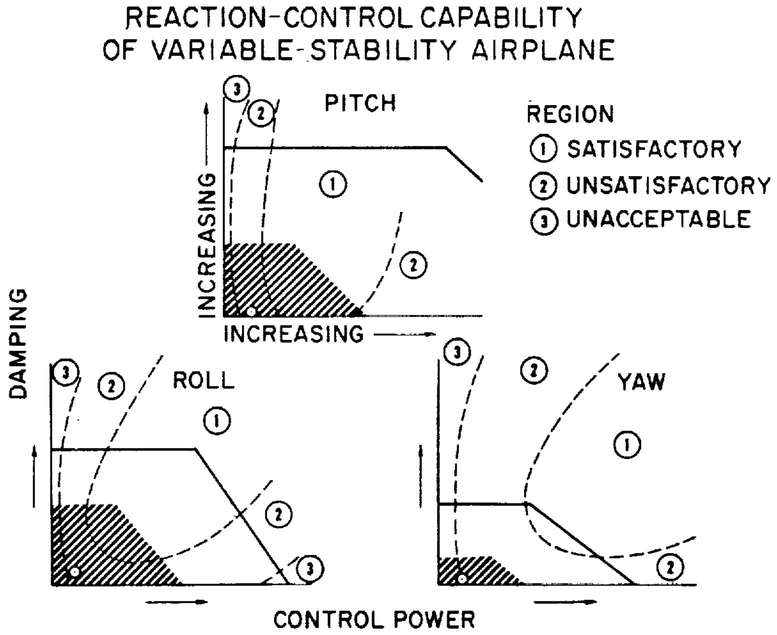


Figure 4