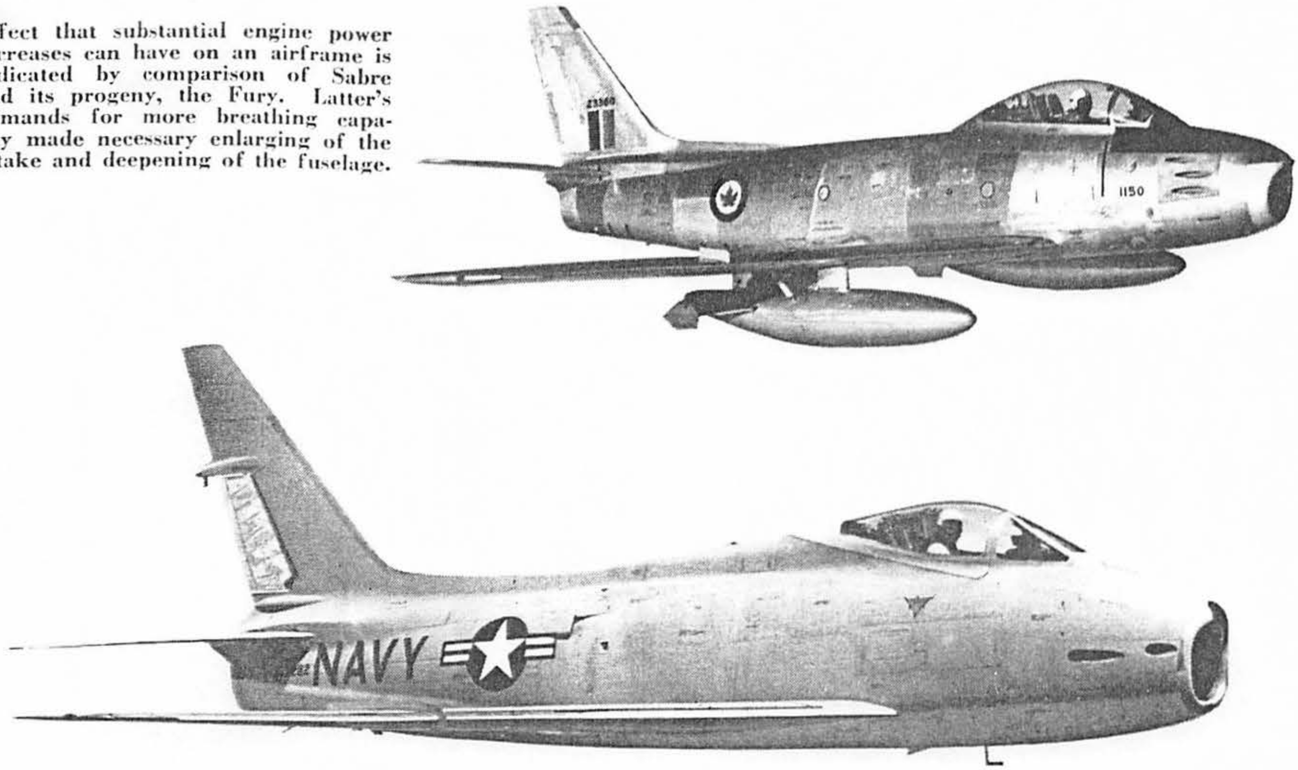
Effect that substantial engine power increases can have on an airframe is indicated by comparison of Sabre and its progeny, the Fury. Latter's demands for more breathing capacity made necessary enlarging of the intake and deepening of the fuselage.




# Jet Power and Progress

**By GROUP CAPTAIN H. R. FOOTTIT**

*"The turbojet and its aircraft are so interdependent, it is not possible to consider one without the other."*
*—Air Commodore F. R. Banks*

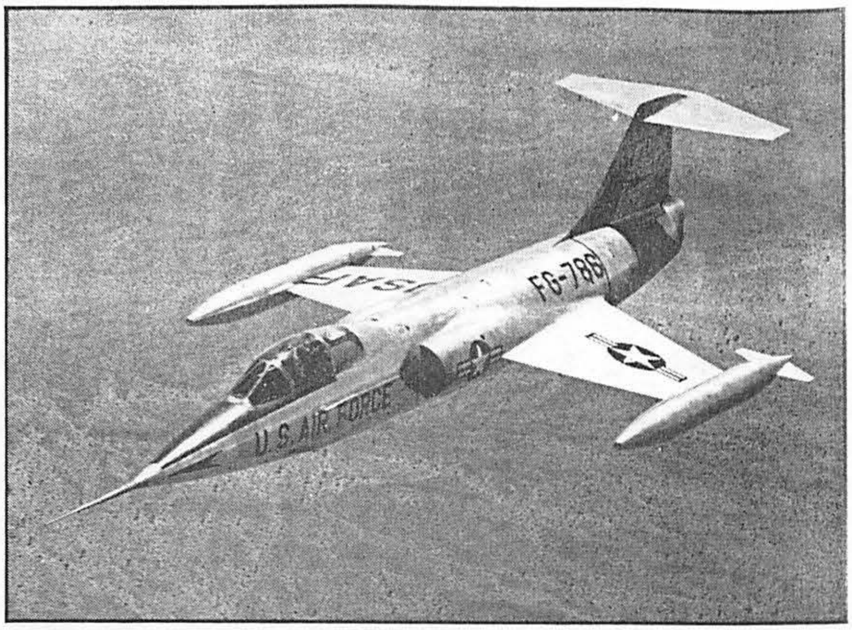
PLENTY OF PICTURES of the prototype had been published. And the controversey was soon underway. "I found a division of opinion on the operation of the so-called giant aircraft, such as the DC-4," reported the British engineer J. I. Waddinton, in the magazine *Flight* (September, 1939) after a trip through the United States. "Many people consider that any airline would be locking away a lot of capital in one machine, particularly as I'm told that two DC-3's carry more, and cost less to run, than one DC-4."

Seventeen years have slipped by since this statement. Yet those who are adverse to jet airliners still run out similar reasons when they argue with the advocates. But before the debate can be decided, if at all, one specific transport, with one specific engine, must be weighed against another. For even from the early design stage, the aircraft manufacturer is prepared to deliver an airplane with any one of two or more different engine installations, to suit the customer's choice. Trans-Canada Air Lines, for example, ordered the Douglas DC-8 jet transport with Rolls-Royce "Conway" engines, while other U.S. airlines stayed with the Pratt & Whitney J-75 jet.

**Flexibility Fading:** As transport aircraft have gone into service in the past, there has been a well established tendency to build the aircraft with even a wider selection of engine installations. But this day of flexibility in engine selection is slowly passing. Jet power and progress are sweeping it away. The supersonic era may well see it gone for good. "The rules change," said R. J. Woods, U.S. design consultant to Bell Aircraft, two years ago. "Subsonic design techniques and procedures need careful scrutiny, and basic concepts need change."

In the piston period we changed engine installations with seemingly reckless abandon. The Avro Anson, the RCAF's twin-engined trainer of the war era, went from the original Armstrong Siddeley "Cheetah" through the Jacobs L6MB, a Wright installation, and finally the Pratt & Whitney Wasp of the Anson V. In the transport field, there were similar transformations. In 1938, after a potent publicity campaign, the Douglas Aircraft Company wheeled out its "giant airliner" from a small hangar at Clover Field, Santa Monica, California. This was the 60,000 lb., four engined DC-4. It had been designed to the joint requirements of Pan-American, Eastern, TWA, United, and American Airlines. In 1937, Douglas had been confidentially forecasting that this new denizen of the skies would sell at \$250,000, in production — about twice the price of a jet trainer today!

Incidentally, it was not the DC-4 as we know it now. It featured two innovations that caught the operator's eye: a triple vertical tail, and a tricycle landing gear. This particular triple-tailed DC-4 prototype soon dropped from view. When World War II broke over the world in 1939 and finally inundated the U.S. in late 1941, a production line of larger DC-4's, with single vertical tails, was just starting to roll. This was when the U.S. Army Air Force stepped in. The airplanes were quickly assigned to USAAF use. And the war saw numerous C-54 "Sky-




**Supersonic aircraft like Lockheed's F-104A (XF-104 shown) are tailored to their powerplants, and vice versa, and are not amenable to engine switches.**

masters" lugging the big military loads from one continent to another.

The work of these Skymasters quickly evaporated all the eruptions of pre-war days on the efficiency of "giant airliners". No one would deny that they were here to stay. In fact, according to the publicity reports, Douglas had commercial orders for 40 DC-4's almost a year before the war ended.

**North Star Seed:** About this same time, the RCAF and TCA began thinking of big transport craft. The C-54 Skymaster design, with thousands of hours flying behind it, filled the bill. At the same time the Rolls-Royce "Merlin" engine had a similar military flying record. Why not knit the two together? By replacing the Pratt & Whitney 1450 hp. engine of the C-54 with the Rolls-Royce Merlin at 1750 hp., a better, faster "North Star" was born. To the credit of Canadair Ltd. in Montreal the change was accomplished. By 1948, the North Stars were flying the airways under TCA and RCAF markings. And the following year British Overseas Airways introduced the type to the other side of the Atlantic.

About the time these North Stars were establishing their way in the air world the pattern of progress was showing its first signs of change. The jet age had arrived. Engineers were now paying more attention than ever before to matching the airframe and the power plant. In Toronto, in the early postwar years, the Gas Turbine Division of A. V. Roe Canada Ltd., (now Orenda Engines Ltd.) had started on the design of a small gas turbine, the Chinook. But as the Airframe Division (now Avro Aircraft Ltd.) worked overtime on the design of the CF-100 fighter for the RCAF, the engine company made a proposal to match a new powerplant to the airframe. The result was the now famous Orenda engine which powers all our various marks of CF-100, as well as the later marks of F-86 Sabres in the RCAF and South African Air Force.

In 1950, however, the first two CF-100's that lifted their wheels from Malton Airport were powered with Rolls-Royce "Avon" engines of 6,000 lbs. static thrust. I asked Winnett Boyd, who was chief designer on the Orenda at the time, and who is now president of Winnett Boyd Ltd., and chief mechanical engineer for C. D. Howe Ltd., about the basic concept of the Orenda relative to the Avon. "The Orenda was originally conceived," he said, "as an engine that would be interchangeable with the Rolls-Royce Avon so that the development of the CF-100 could proceed independently of the Orenda development."

**The Price:** This course of action led Boyd and his design team into some difficulty. The Avon had an odd mounting arrangement. By trying to keep to the interchangeability tenet, "we had to make a very heavy nozzle box, as the trunnions were located on it, and design a rather fancy temperature and distortion-accommodating front mounting system." There were also a number of differences in the accessory drives, and other major details. In the end, however, this "four point mounted" Mark I Orenda did go into the third CF-100 to replace the Avon. But to save weight and clean up the whole installation, the Orenda was subsequently changed to a "three point mounting." To show how he did meet his interchangeability criteria in the early Orenda, Winn Boyd points out: "It is worth noting that there were probably more airframe modifications required to change from the original Orenda (four point mounting) to the three point arrangement, than to change from the Avon to the original Orenda."

To Boyd's credit, he also suggested and pioneered another major powerplant change. Says he: "In the spring of 1949 we had the best jet engine in the world, the Orenda, and North American had the fastest fighter in the world, the F-86 Sabre. It therefore seemed axiomatic that we should put the two together." He made the proposal to Fred Smye, general manager of Avro Canada. In due course, North American adapted a Sabre to the Orenda configuration, and later Canadair completely re-engineered and productionized the lashed up version, to turn out the Orenda-powered Sabre 5's and 6's.

Looking back over these typical patterns of progress it is readily apparent that most of the problems were concerned with the geometry of the engine, the mountings, space requirements, services, accessories, and other such "positive" mechanical details. But the first hint that the pathway of the past may not be the footpath of the future came when a higher powered Orenda was fitted into the Sabre. Here aerodynamics entered the arena. In this case it was the inlet duct. The duct must obviously be large enough to allow sufficient air to pass down it to the engine so the latter can develop its full power. In other words, the duct must be matched to the mass flow of the power plant.

**Room to Breathe:** With fuselage-mounted engine installations, if the duct size has to be changed the airframe will suffer extensive modification. The Australians got caught in this net when they decided to put an Avon in their homebuilt F-86's. To get enough air to the Avon they had to

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to the effect that one has a firm belief in George Edwards, his Chief Designer Basil Stephenson and their enthusiastic team to achieve their ambitious target. This is to build the airplane, to test it for a *minimum* fatigue-free life of 30,000 hours, to fly the first aircraft at the end of 1958, and to deliver BEA's twenty the following year. Equally, from personal contact, one feels confident that the Rolls-Royce team, led by J. D. Pearson, A. A. Lombard and A. C. Lovesey will provide the Tynes just as they did the Darts.

## JET POWER

*(Continued from page 16)*

redesign the fuselage to allow a larger intake and duct. This, of course, caused extensive tooling changes and increased cost. After intensive tests at Canadair, and Orenda's laboratory at Nobel, the Canadair Sabre finally squeaked by without changing the duct, intake, or fuselage structure affected by the duct. But it was a hairline decision.

"Reasonable changes in mass flow were often assimilated without too much difficulty," says R. N. Lindley, chief design engineer for Avro Aircraft, and speaking of such subsonic aircraft installations as the Sabre: "This was usually because the initial duct design, based on ignorance, was really too large and therefore the design was conservative. Thus the intake and duct could handle the inevitable increase in mass flow without any redesign."

As Bob Lindley goes on to point out, "We face more and more problems with modern, fast aircraft, because we discover new and better ways to analyse the various engineering situations that arise." Such new and better analyses mean that, in the future, we will no longer design such items as ducts so they are too large for their intended use. From the first line on paper the duct will be designed to just match the powerplant that is installed at the end of it. This, of course, gives us a better, lighter, more efficient structure. But it automatically inhibits the design from major changes in the future, unless we are prepared for extensive costs. This is particularly true with supersonic aircraft, whose powerplants are buried in the airframe to keep the drag low.

**Matchmaking:** But the careful matching of airframe and engine involves more than just the intake duct. Abe Silverstein, the well known U.S. scientist from the laboratories of the National Advisory Committee for Aeronautics explains it this way: "In supersonic flight, *the propulsion system* largely determines the kind of airplane performance that can be achieved. This situation persists even if different probable values of aerodynamic efficiency are used in the calculations." *The propulsion system,* of course, is the complete jet powerplant installation, with its intake, ducting, bypasses, exhaust installation, ejector, and exit nozzle.

As Silverstein and the other experts agree, hereafter there must be extensive studies in the preliminary design stage, if we are to arrive at the optimum configuration of airframe and propulsion system. Only by pinning one proper propulsion system with one properly designed airframe can the best supersonic aircraft be achieved. And the penalties for missing the optimum target are great. As one manufacturer pointed out, there can be a 20 to 50 per cent loss in net thrust, and 20 to 30 per cent reduction in range, at Mach 2.0, when we fail to provide proper optimization.

These problems of matching jet power with a supersonic airplane start right with the intake. The air must be taken aboard the airplane efficiently, at all angles of attack, and at all speeds from take off, through climb, to high subsonic and supersonic velocities. These variable conditions create a multitude of desirable entry arrangements that can hardly be handled by such simple intakes as those on the T-33 jet trainer or the CF-100 fighter. At low speeds the intake needs to be large; at high speeds, small. In addition, at supersonic speeds the intake ramp and lips must create the proper shock wave pattern so there is the best possible pressure recovery. Fixed and variable intake ramps, bleeds and by-passes, have been experimented with to meet these wide-spread requirements. And the penalty, if they are not met, is extra drag and lower thrust — to an alarming degree.

**Streamlined Airflow:** Aft of the intake, the duct itself must be designed to accommodate streamlined airflow, or flight tests may be catastrophic, with a complete break up of the aircraft even at a very modest Mach number. This streamlined airflow is important too, at the actual entry to the engine. For the powerplant usually performs best when the entering air, though sub-sonic, is smooth and free from disturbing eddys.

Aft of the engine, through the exhaust system, a similar matching of powerplant and airframe also applies. As well as an ejector and final nozzle mated to the requirements of the engine, the airflow over the airframe, where the exhaust ejects overboard, must be considered. Gone are the days when an engine designer could claim a set thrust for an aircraft installation from an independent test bed run. Now the interaction of exhaust and free airflow may add up to extra drag counts. In one U.S. Navy fighter the net thrust was lowered 10 to 15 percent during cruise, by improper design to allow an efficient pattern where exhaust and free airflow came together. Thus from intake to afterbody, there must be a definite tailoring of a specific airframe to a specific propulsion system, if great penalties in thrust and drag are to be avoided.

Bob Lindley of Avro, however, feels that this mating of a supersonic airplane with its powerplant is in a period of transition. He is particularly aware of this situation since the CF-105, the RCAF's supersonic fighter, now in the design stage at Avro, will be fitted initially with a Pratt & Whitney J-75 jet engine from the U.S. The early airplanes, therefore, must be matched to this engine. Later aircraft, however, will be matched to the Orenda Engines Ltd., "Iroquois" powerplant—an engine that has been specifically designed to fit the CF-105 airframe, as well as the airplane's combat mission. "I am convinced," says Lindley, "that as we find our way around in this supersonic business, a whole breed of specialized supersonic engines will become available. Furthermore, if the state of the art remains in the Mach 2.5 regime or lower, these engines will tend towards the same optimum pressure ratio and general similarity."

**Closer than Before:** Lindley may be right. But in any case, we're due for a long period of optimizing of aircraft and engine. And even if we do get to a variety of similar supersonic engines, there will still be a closer tie-in between engine and airframe, than there ever has been in the subsonic era. The emphasis placed on this tie-in should not be underestimated. R. J. Woods of Bell Aircraft goes so far as to say, "For supersonic flight speeds the powerplant system becomes the major aircraft design-controlling component, with the airframe configuration rated as secondary."

This continued emphasis on a specific propulsion system for a specific aircraft has other by-products. For example, it has been a common tendency for the airplane manufacturer to design his airframe, shop around for a suitable engine, and fit the best one that happens to be on the market at the time. But the coming of the supersonic age will bring new rules and concepts. Since engines take longer to develop than airframes, to obtain the maximum and cheapest co-ordination between engine and airframe, the airplane should first be designed on paper, then have a powerplant design mated to it. The contract would then be let for the power plant. One to three years later, with the engine running on the test bed, the order would be placed for airframe. In this way airframe and engine would be mated technically, and come together in the right time scale.

With our present knowledge we were right to get started on supersonic airplanes, with subsonic concepts — or we would never progress. But in the future we should never again start building a supersonic airplane and its powerplant at the same time — as we did with the CF-105 and the Orenda "Iroquois." Never again must we ignore the advice of Air Commodore F. R. Banks, the eminent British engine expert, presently with Bristols in the U.K., about the interdependency of jet engines and aircraft. But such new rules and concepts for the supersonic age will not come easily. Over a year ago, Dr. T. P. Wright of the Cornell Aeronautical Laboratory in Buffalo sounded a warning: "The concept of trying to give engine development a head start over the airframe to which it is assigned, is one of the basic problems we have in this country."

With our own jet power and progress, we in Canada may well heed these words.