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6.1 Overview of External Nacelle Drag and Interference Drag

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Introduction

The purpose of this paper is to provide a written outline record of an oral presentation given at the General Aviation Drag Reduction Workshop.

Historical Review of Multi-Jet Engine Installations

Airplane performance is achieved thru a combination of aerodynamics and propulsion. In terms of the propulsion system, airplane configurations--be they powered by propellers or jets--are developed around the characteristics of a specific engine. For this reason, the integration of the powerplant and the airframe is truly the cornerstone of the aircraft design. The introduction and continued development of the turbine engine has only served to emphasize the importance of achieving a successful engine/airframe interface.

The beginning of the jet age took place on August 27, 1939, when the German Heinkel HE-178 research airplane made its first flight. This airplane was powered by a single gas turbine engine having a thrust of about 1,100 pounds.

The next jet airplane--and the first twin engine jet--was another Heinkel design, the He-280. Powered by two 1,320 pound thrust engines, this airplane made its initial flight in April 1941.

The next jet to fly was the Messerschmitt Me262, which was powered by two 1,850 pound thrust axial flow turbine engines, with the first flight occurring in July 1942. The Me262 certainly ranks as one of the most advanced aircraft designs to be developed during the Second World War and it also has the distinction of being the first jet aircraft to reach operational status.

By the end of the war, the German aviation industry had developed several jet aircraft designs. Examples of actual production flight hardware include the single-engine He-162 fighter and the twin-engine AR234 bomber.

The first allied jet to fly was the British Gloster E28/29. This airplane, powered by a single 860 pound thrust gas turbine engine, designed by Frank Whittle, made its initial flight in May 1941.

The United States entry into the jet era took place on October 1, 1942, when the twin-engine Bell XP-59A "Airacomet" took to the air.

The second American jet to fly was the single-engined Lockheed XP-80, with this flight taking place in June 1944. Neither the P-59 or the P-80 were to see combat in World War II, however, in November 1950, in the skies over Korea, an F-80 became the winner of the first all-jet aerial combat by downing a Russian built MIG-15.

The post-war years ushered in a whole new era in aircraft design. Examples of some of the multi-engine airplanes flown in this period include the twin-engine B-43, the three-engined B-51, the four-engined B-45 and B-46, the six-engined B-47 and B-48, and the eight-engined B-52.

In July 1949, the four-engined deHavilland Comet 1 made its first flight and the dawn of commercial jet transportation had begun. America's first jet transport was the Boeing 707 which made its maiden flight in July 1954, with the first 707 transatlantic service beginning in October 1958. The introduction of jet service on this transatlantic route reduced the flight time from twelve hours to seven hours.

In May 1955, the French entered the commercial transport field with the Sud-Aviation Caravelle. The Caravelle, with its two jet engines mounted on the aft fuselage, represented a design innovation that is still in vogue some twenty years later. The commercial aft-engine jet transports that have been developed thru the years include the following:

Sud-Aviation Caravelle
BAC-11
Douglas DC-9
Fokker F-28
TU-134
Yak-40(3-engine)
Yak-42 (3-engine)
Boeing 727
Hawker Siddeley Trident (3-engine)
TU-154 (3-engine)
Ilyushin Il-62 (4-engine)
BAC VC-10 (4-engine)

It is perhaps of historical interest to note that the original patent for the Caravelle design was filed in November 1951, and was entitled "Improvements in Aeroplanes Propelled by Several Jet Engines."

Development of Business Jet Aircraft

With the successful introduction and acceptance of commercial jet transports it was only a question of time until the performance potential of turbine power was applied to the general aviation airplane.

The origin of the business jet can be traced to the four-place, French built Morane-Saulnier MS760, which first flew in mid-1954. However, a 1955 attempt by Beech Aircraft to market this airplane in North America can best be described as unsuccessful.

The next airplane to enter the small jet transport arena was the Lockheed Jetstar, with the original twin-engined prototype flying in September 1957. The Jetstar was originally designed for the military market in response to the UCX program for a small jet transport with the eventual outcome of this effort being the four-engined C-140.

The next airplane to come along was the North American Sabreliner flying in September 1958, as an entry into the military UTX competition for a trainer category airplane.

The third small transport took to the air in February 1959, when the four-engined McDonnell Model 220 flew, with this airplane also competing for the UCX contract.

In the final analysis, the Jetstar won the UCX race, the Sabreliner took the UTX contract and McDonnell dropped the Model 220 program.

The next period of activity in this field took place in 1962, when the first deHavilland DH 125 flew. The following year, 1963, produced a bumper crop of airplanes with the first flights of the Jet Commander, the French designed Mystere 20, and the Lear Jet taking place. The swept-forward wing German Hansa Jet and the Italian PD808 made their first flights in 1964. A new era in big business jets began when the Grumman Gulfstream II made its initial flight in 1966. The latest business jets to join the field include the Cessna Citation, the Falcon 10, and the Corvette.

All of these business jets (with the exception of the MS760 and the McDonnell 220) are of the aft fuselage mounted engine configuration.

While the large commercial transports and the smaller business jets are similar in configuration, there is a difference between the two designs. Specifically the aft-engined transport aircraft tend to have the nacelles located well aft of the wing trailing edge, for example the DC-9 and 727. In the case of the smaller airplanes, the nacelles are located quite close to the wing and in several designs the nacelles overlap the wing. Because of the proximity of the nacelles to the wing, the business jet offers some challenging design problems in terms of achieving a minimum drag configuration.

Also, the trend in business aircraft design has been towards the incorporation of high bypass fan engines. These engines, with their larger physical size, make it very difficult to arrive at a wing mounted engine arrangement that is compatible with a high performance business jet design. Thus, the aft-engined airplane appears to be a viable configuration in the years ahead.

A good example of the size impact of a turbofan engine is shown by the Learjet testbed airplane which incorporated the General Electric CJ610 turbojet engine on one side and the AiResearch TFE 731 turbofan engine on the other side.

Current Business Jet Engine Installations

Slides number 44 through 50 provide installation photos of various turbojet/ turbofan aft fuselage mounted engine arrangements on current business jet designs.

Comments on some of the aerodynamic aspects of the installations were offered.

Aft-Engine Nacelle Drag Considerations

Viewgraph 1* presents sketches of a long fan duct and a short fan duct nacelle considered for the FTE 731 installation on the Learjet Model 35/36.

Viewgraph 2 presents a typical nacelle configuration trade-off that can be made for various design studies.

Viewgraph 3 presents wing pressure distribution as affected by nacelle position (data from Reference 9).

Viewgraph 4 presents typical nacelle drag characteristics for a turbojet engine installation and Viewgraph 5 shows the drag characteristics for a turbofan nacelle.

Viewgraphs 6 and 7 show some nacelle geometry configurations.

Viewgraphs 8 thru 12 present some nacelle drag results obtained with various nacelle locations.

Third-Engine Location

For a three-engined airplane there are two rather obvious locations for two of the engines, either on the aft fuselage or wing mounted. As for the third engine, there are also at least two options with examples being the S-duct (727, L-1011) or the straight-through duct (DC-10).

There appears to be little published information on comparisons between these two types of installations. Boeing has reported (Reference 18) that their studies have shown that the weight/performance trade between the S-duct and straight-duct is about even. Design studies conducted by Lockheed have shown that the S-duct offers better

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*Viewgraphs not included in written version for proprietary reasons.

overall performance than a straight-duct. On the other hand, McDonnell-Douglas studies have identified the performance improvements of the straight-duct over the S-duct.

The final choice for the type of third engine installation is not completely clear, however, in terms of numerical numbers the S-duct is the winner. If the weight and drag are in fact an even trade between the two concepts, then other installation factors will dictate the final selection. In fact, as part of the Advanced Transport Technology (ATT) studies, United Airlines (Reference 20) preferred the S-duct from an engine maintenance viewpoint due to the lower engine position.

In the small transport category of aircraft, both the proposed Cessna 700 and the Falcon 50 have elected to utilize the S-duct arrangement.

In terms of an historical viewpoint the Martin XB-51, which flew in October 1951, had its third engine located in the rear fuselage with inlet air being provided via an S-duct configuration.

From the civil aviation standpoint, Sud-Aviation applied in December 1951, for a patent covering "Improvements in Aircraft Equipped with a Propelling Motor at the Rear" with this patent covering various S-duct configurations.

Slides number 62-67 provide illustrations of various third-engine installations. Viewgraphs 13 thru 15 provide additional information of S-duct configurations.

R & D Study Recommendations

a) There appears to be a need and requirement to investigate the interference drag of nacelle configurations mounted on the aft fuselage with specific emphasis on configurations having the nacelle in close proximity to the wing.

b) For high bypass ratio turbofan engines the drag interference problem of the short cowl nacelle on the aft fuselage should be examined.

c) There appears to be a need for published research information on the aerodynamics of S-ducts and other third-engine installation aerodynamics.

Reference Material

The following reference material presents some sources containing information relating to the overall subject of aft-engine installations and basic nacelle design considerations.

T-Tail/Aft-Engine Configurations

1. Taylor, Robert T., and Ray, Edward J., "Deep-Stall Aerodynamic Characteristics of T-Tail Aircraft." Conference on Aircraft Operating Problems, May 10-12, 1965, NASA SP-83, pages 113-121.

2. Ray, Edward J., and Taylor, Robert T., "Effect of Configuration Variables on the Subsonic Longitudinal Stability Characteristics of a High-Tail Transport Configuration." NASA TM-X-1165, October 1965.

3. Taylor, Robert T., and Ray, Edward J., "Factors Affecting the Stability of T-Tail Tranports." Journal of Aircraft, July-August 1966, pages 359-364.

4. Taylor, Robert T., and Ray, Edward J., "A Systematic Study of the Factors Contributing to Post-Stall Longitudinal Stability of T-Tail Transport Configurations." NASA TM-X-56882, November 1965.

5. Thomas, H.H.B.M., "A Study of the Longitudinal Behavior of an Aircraft at Near-Stall and Post-Stall Conditions." AGARD Conference Proceedings No. 17, September 20-23, 1966, pages 729-769.

6. Kettle, D. J., and Kerby, D. A., "Low-Speed Wing Tunnel Tests on the Effects of Tailplane and Nacelle Position on the Superstall Characteristics of Transport Aircraft." R.A.E. R&M 3571, August 1967.

7. Shevell, Richard S., and Schanfele, Roger D., "Aerodynamic Design Features of the DC-9." AIAA Paper 65-738, November 1965.

8. Waaland, I. T., and Curtis, E. J., "Gulfstream II Aerodynamic Design." SAE Paper 670242, April 1967.

9. Lobert, G., and Thomas J., "Engine Airframe Ingegration Problems Peculiar to Aircraft Configurations with Nacelles Mounted Above the Wing." Paper presented at 31st meeting of the AGARD Flight Mechanics Panel, Gottingen, Germany, September 13-15, 1967.

10. Putman, Lawrence E., and Trescot, Charles D., Jr., "Effects of Aft-Fuselage-Mounted Nacelles on the Subsonic Longitudinal Aerodyanmic Characteristics of a Twin-Turbojet Airplane." NASA TND-3781, December 1966.

11. Aoyagi, Kiyoshi, and Tolhurst, William H., Jr., "Large-Scale Wing-Tunnel Tests of a Subsonic Transport with Aft Engine Nacelles and High Tail." NASA TND-3797, January 1967.

12. Neal, Ronald D., "Correlation of Small-Scale and Full-Scale Wing Tunnel Data with Flight Test Data on the Lear Jet Model 23." SAE Paper 700237.

13. Williams, P. R. G., and Steward, D. J., "The Complex Aerodynamic Interference Pattern Due to Rear Fuselage Mounted Power Plants." AGARD Conference Proceedings No. 71, Aerodynamic Interference, September 1970.

14. Callaghan, J. T., Donelson, J. E., and Morelli, J. P., "The Effects on Cruise Drag of Installing Re-Fan- Engine Nacelles on the McDonnell Douglas DC-9." NASA CR-121219, May 1973.

15. Blaha, Bernard J., "Integration of Aft-Fuselage-Mounted Flow-Through Engine Nacelles on an Advanced Trasnport Configuration at Mach Numbers from 0.6 to 1.0." NASA TM-X-3178, March 1975.

16. Swan, Walter C., and Sigalla, Armand, "The Problem of Installing a Modern High Bypass Engine on a Twin Jet Transport Aircraft." AGARD Conference Proceedings No. 124 on Aerodynamic Drag, April 1973.

17. Williams, P. R. G., and Steward, D. J., "An Aircraft Designer's Review of Some Airframe and Engine Ingegration Concepts." Paper presented at 1st International Symposium on Air Breathing Engines, June 19-23, 1972.

18. Goodmanson, Lloyd T., and Schulta, William H., "Installation and Integration of Transonic Transport Propulsion Systems." SAE Paper 710762.

19. Hawkes, J. E., "Development Status of the L-1011 TriStar." SAE Paper 710755.

20. "Assessment of the Application of Advanced Technologies to Subsonic CTOL Transport Aircraft." NASA CR-112242, April 1973.

Nacelle Design

21. Saylor, James M. and Smith, Robert E., "Internal and External Aerodynamics of the C-141 Nacelle." AIAA Paper 65-604.

22. Allison, H. B., and Leslie, H. R., "Installation Considerations for High Bypass Ratio Turbofan Engines." AIAA Paper 67-390.

23. Viall, W. S., "Aerodynamic Considerations for Enginer Inlet Design for Subsonic High-Bypass Fan Engines." SAE Paper 660733.

24. Frazier, G. T., "Aerodynamic Considerations for Engine Exhaust Design for Subsonic High-Bypass Fan Engines." SAE Paper 660734.

25. Viall, W. S., "The Enginer Inlet on the 747." ASME Paper 69-GT-41.

26. Saylor, J. M., and Hancock, J. P., "C-5 Engine Inlet Development." ASME Paper 69-GT-52.

27. Hancock, J. P., and Hinson, B. L., "Inlet Development for the L-500." AIAA Paper 69-448.

28. Rohling, Walter J., "The Influence of Nacelle Afterbody Shape on Airplane Drag."

29. Leynaert, Jr., "Engine Installation Aerodynamics," paper given at AGARD Lecture, Series No. 67, Prediction Methods for Aircraft Aerodynamic Characteristics. AGARD-LS-67, May 1974.

Wing Mounted Nacelles

30. Patterson, James C., Jr., "A Wind-Tunnel Investigation of Jet-Wake Effect of a High-Bypass Engine on Wing-Nacelle Interference Drag of a Subsonic Transport." NASA TN D 4693, August 1968.

31. Patterson, James C., Jr., and Flechner, Stuart G., "Jet-Wake Effect of a High-Bypass Engine on Wing-Nacelle Interference Drag of a Subsonic Transport Airplane." NASA TND-6067, November 1970.

32. Raney, D. J., Kurn, A. G., and Bagley, J. A., "Wind Tunnel Investigation of Jet Interference for Underwing Installation of High Bypass Ratio Engines." ARC C.P. No. 1044, March 1968.

33. Kurn, A. G., "A Further Wind Tunnel Investigation of Underwing Jet Interference." ARC C. P. No. 1156, April 1969.

Powered Nacelle Testing

34. Fasano, A., Erlandsen P., and Barrett, D., "The Powered Nacelle as an Experimental Tool." AIAA Paper 70-636, June 1970.

35. Welge, H. R., and Ongaroto, J. R., "Powered Engine Simulator Porcedures and Experience for the DC-10 Wing Engine at High Subsonic Speeds." AIAA Paper 70-590, May 1970.

36. Grunnet, James L., "Designing Jet Aircraft Wing-Tunnel Test Programs with Propulsion System Simulation." J. Aircraft, Vol. 8, No. 6, June 1971.

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1. He-178 Single-Engine Jet Airplane
2. He-280 Twin-Engine Jet Airplane
3. Me161 Twin-Engine Jet Airplane
4. He-162 Single-Engine Jet Airplane
5. AR 234 Twin-Engine Jet Bomber
6. Gloster E28/39
7. Bell XP-59
8. Lockheed XP-80
9. Douglas B-43
10. North American B-45
11. Convair B-46
12. Boeing B-47
13. Martin B-48
14. Martin B-51
15. Boeing B-52
16. Boeing 707
17. Caravelle
18. DC-9
19. Fokker F-28
20. BAC-111
21. Yak 40

22. 727
23. 11-62
24. VC-10
25. MS760
26. Jetstar
27. Sabreliner
28. McDonnell 220
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