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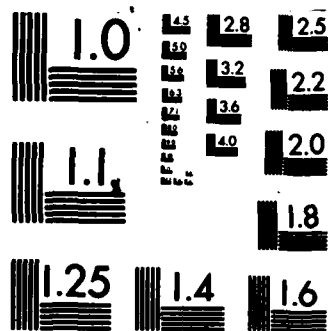
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PROPULSION SYSTEM SIMULATION TECHNIQUE DURING WIND TUNNEL TESTING

Huang Xijun

Altitude integration in design is required of advanced fighter planes using a turbojet engine for power. Especially in matching the propulsion system, a two-dimensional nozzle, reverse thrust/thrust direction change nozzle, back installed type intake channel, and short S-shaped subsonic compression expanding sector are a series of advanced propulsion components applied in the next generation of advanced supersonic fighter planes. Such new applications will increase the mutual interference among the intake channel, fuselage and nozzle; not only are the stream fields of the intake and exhaust channels affected, but also the stream interference between the propulsion system and the aerodynamic airfoil. In addition, during conditions of undesignated cruising and maneuvering flight, as well as STOL/VTOL [short and vertical takeoff and landing], the effect of the interference is more obvious. This requires the study of how to correctly estimate the degree of mutual interference among various components of the aircraft in the design process, including how to correctly simulate the propulsion system during wind tunnel testing.

The present commonly used methods of simulating the propulsion system are:

During wind tunnel testing of scaled-down models of the aircraft, at present generally the flow-through model and jet effect model tests are used to determine the aerodynamic force of the aircraft and the mutual effect with the propulsion system. The flow-through model can be used to correctly simulate the geometric shape and flow characteristics of the intake channel of the propulsion system; a method of blocking the nozzle of the model is used to control intake flow of air. Since the geometric conditions and low total pressure flow characteristics of this type of nozzle cannot correctly simulate the geometric shape and jet characteristics of the propulsion system nozzle, the interference characteristics of the jet flow through the tail nozzle of an aircraft cannot be accurately estimated. In order to solve this problem, some researchers used jet effect models to correctly simulate the nozzle conditions. In this model, an equivalent-weight cone is used to block the air intake channel; the intake air current winds around the intake opening; therefore the geometric and flow conditions of the intake channel cannot be correctly simulated. In nozzle jet flow, the high pressure air from an exclusive high pressure source passes the fulcrum seat and enters the model nozzle before being expelled. By compiling the test results of the aforementioned two models and other related data, the aerodynamic properties of the aircraft system can be estimated. The estimation process of the corresponding thrust/resistance is shown in Fig. 1.

Development of propulsion system simulator

The main disadvantages of applying the flow-through model and jet effect model are that they are unable to simultaneously simulate the geometric and flow conditions of air intake and gas mixture exhaust; therefore, we are unable to correctly estimate the effect of mutual interference among the air intake channel, the fuselage and nozzle. With intensifying integration of aircraft design, it is required to study a new testing technique simultaneously simulating conditions of intake and exhaust. Since 1969, the U. S. Air Force Aeronautical Propulsion Laboratory (AFAPL) has continuously supervised the development of a supersonic propulsion system simulator; participants include the McDonnell Douglas Aircraft Corporation,

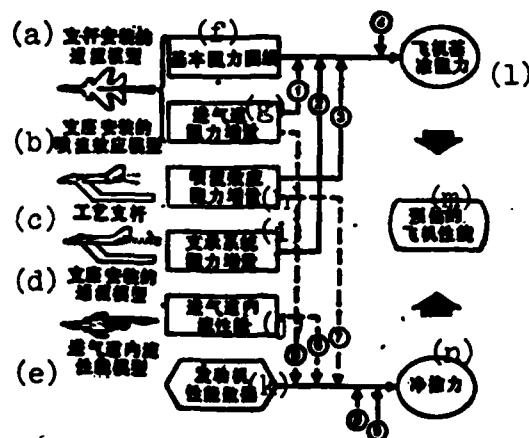


Fig. 1. Estimation process of typical thrust/resistance for a conventional model.

Key: (a) Flow through model with installation of fulcrum bar; (b) Jet effect model with installation of fulcrum seat; (c) Fulcrum bar; (d) Flow-through model with installation of fulcrum seat; (e) Model with internal flow (of air intake channel) characteristics; (f) Basic resistance curves; (g) Increment of resistance in air intake channel; (h) Increment of jet effect resistance; (i) Increment of bearing system resistance; (j) Characteristics of internal flow of air intake channel; (k) Engine performance data; (l) Aircraft datum resistance; (m) Estimated aircraft performance; (n) Net thrust.

the General Electric Corporation, and the Technology Development Company. In the period from 1969 through 1975, they developed three multi-mission aircraft propulsion simulators (MAPS). Certification tests of these simulators in wind tunnels were conducted on some aircraft models with an accumulated operation time of 179 hours. Through these tests, the feasibility of MAPS was proven; however, problems remain in oversized dimensions and not wide enough simulation range of the circulation working conditions.

Beginning from 1976, they developed a down sized MAPS. In 1981, a down sized MAPS conducted 55 hours of operation tests in the R2C4 testing facility at Arnold Engineering Development Center. According to the test results, the aforementioned participating companies are set to produce several of these simulators for wind tunnel testing by the NASA Ames Research Center and the U. S. Air Force.

The MAPS includes a four-stage axial-flow compressor, and a single-stage turbine, supported by two bearing fulcrums; the MAPS configuration is shown in Fig. 2. The figure shows that the single-stage turbine is driven by air; the maximum pressure driving the air is 2000 lb/in^2 and the maximum rotating speed of the turbine is 88,600 rpm. The overall length of the simulator (not including nozzle) is 10.42 in; the maximum diameter is 4.18 in; and the overall weight is 17 lb. The simulator is a thin-wall casting structure. The pressure adjusting and driving the air can change the rotating speed and flow of the compressor; the gas flow from the turbine can be divided into two routes: one gas flow route through a mixer blending with the main stream through the compressor before being expelled from the tail nozzle. The other gas flow passes through the turbine and then is expelled through the overflow pipe channel. Different overflow quantities can simulate different engine working conditions and the corresponding ratio of the nozzle working pressure. Therefore the simulated engine circulation parameters can be changed by controlling the driven pressure to the air and the exhaust overflow quantity from the turbine.

In addition, the variation range of the ratio of the nozzle working pressure is related to the following three important variables: throttle area of the nozzle, exit area of the mixer, and the pressure loss of overflow air pipe channel. The combination of nozzle and mixer cross-sectional area is the most important factor.

Simulation range of MAPS

The capability of the MAPS simulation engine in circulation parameters can be revealed by comparing the working pressure ratio and the working

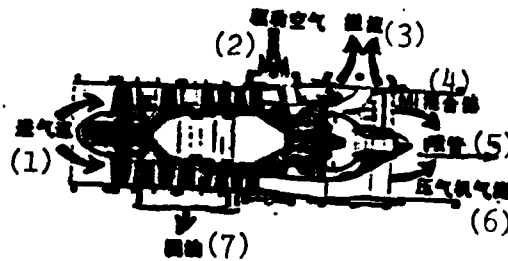


Fig. 2. Structural schematic diagram of propulsion system simulator.

Key: (1) Air intake channel; (2) Driving air; (3) Overflow; (4) Mixer; (5) Nozzle; (6) Compressor air current; (7) Oil return.

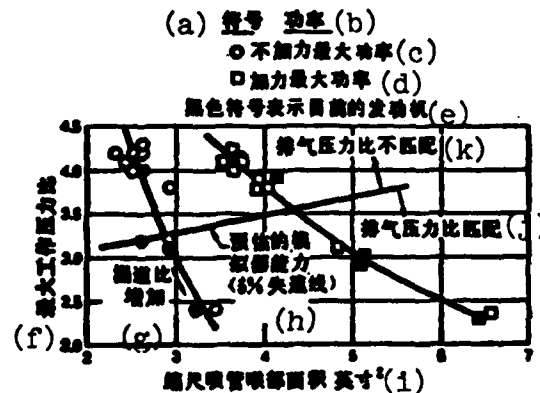


Fig. 3. Simulation capability of MAPS.

Key: (a) Symbols; (b) Power; (c) Maximum power without applying force; (d) Maximum power applying force; (e) Black symbols represent the present engine; (f) Ratio of maximum working pressure; (g) Increase of culvert ratio; (h) Estimated capability of simulator (5 percent stall line); (i) Scaled-down nozzle throttle cross-sectional area expressed in square inches; (j) Matching of exhaust pressure ratio; (k) Not matching exhaust pressure ratio.

flow (corresponding to the flow passing through the cross-sectional area of the nozzle throttle) with the engine parameters under development. Generally the simulation capability of a simulator is restricted by the ratio of maximum working pressure. Figure 3 presents the simulation range of MAPS. In the figure, the ratio of the nozzle working pressure and cross-sectional area of the nozzle throttle can represent the working range of the simulator and the corresponding parameters of the presently available advanced engines. The listed engines in Fig. 3 include turbojet engines and turbofan engines, which have a range of culvert ratio of 0.2 through 2.0. There are two working conditions of the engines: one is the maximum power state without application of forces, and the other is the maximum power state with application of forces.

We can see from Fig. 3 that in the region above the maximum working pressure ratio of a simulator, the engine parameters exceed the simulation capability of MAPS; the said region represents the relatively small turbofan and turbojet engines. In other words, at present the MAPS can only simulate in the near future advanced turbofan engines with medium culvert ratios.

Installation of MAPS models in a wind tunnel

Besides simulation of performance parameters, another important problem is how to match installing the MAPS with a suitable scaled-down model fuselage. First, the scaled-down model of the fuselage should be maintained consistent with the scaled-down MAPS. The scaled-down ratio of MAPS can be calculated from the following formula:

$$\text{Scaled-down ratio} = (\text{maximum converted flow of simulator compressor} / \text{maximum converted flow of the engine compressor})^{(1/2)}$$

The maximum converted flow developed at present is 1.65 lb/sec; however, generally the flow is 150 to 250 lb/sec for engines of the advanced fighter plane. Therefore the corresponding scaled-down ratio is 8 to 11 percent. If the scaled-down ratio of the fuselage model is too small, the

simulation of the fuselage will be destroyed. If the scaled-down ratio is too large, the air flow of the propulsion system does not match the fuselage.

During wind tunnel installation of MAPS, there are still problems in measurement scheme, installation of the fulcrum seat and arrangement of air intake channel. For example, during a wind blowing test of the fuselage model, thrust, resistance and aerodynamic moment should be measured. Therefore, MAPS should be separated from the components of the exterior fuselage, air intake channel and others; an elastic sealed member connection should be used between measurement and non-measurement components. For internal channels and the tail nozzle of the simulator measured without application of force and moment, the surface pressure can be measured with integration to determine the force acting state of the fuselage tail. When considering the connection layout of the air-driving channel and air overflow channel, compensation should be estimated in advance for displacement due to thermal expansion of the channel in order to eliminate the thermal stress of MAPS. When designing the fulcrum seat, sometimes consideration is given to compensate the relationship of pressure loss through the channel and dimensions of the fulcrum seat.

Thrust/resistance estimation process when using MAPS

One of advantages in using MAPS is its simultaneous simulation of geometric conditions of the air intake system, and the situations of flow fields of intake air and the expelled gas mixture. Therefore, the estimation process of aircraft thrust/resistance is different from the process shown in Figs. 4 and 5. In Fig. 4, from the aircraft model with the simulator installed on the fulcrum seat, the aerodynamic properties of the aircraft can be obtained with consideration of the effect of the air intake channel and tail nozzle from field; only the interference on the fulcrum seat needs to be considered in revising the test data. Thus, the non-flow-through model installed with a probe arm type fulcrum bar is used for testing. Then a fulcrum seat is installed before wind blowing. After comparison, the interference revision with fulcrum seat installation can be obtained. Under this situation, the net thrust of the propulsion system can be

obtained by compiling the data on internal flow properties in the air intake channel and the engine performance data. The thrust/resistance properties of the aircraft can be calculated by compiling the aforementioned data.

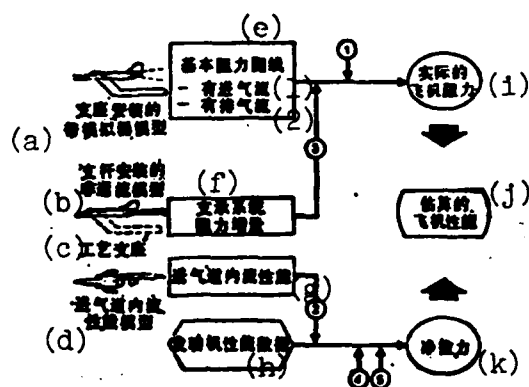


Fig. 4. Thrust/resistance estimation process of achieving the fundamental aerodynamic performance by using a model with a simulator.

Key: (a) Model with simulator with installation of fulcrum seat; (b) Non-flow-through model with installation of fulcrum bar; (c) Fulcrum seat; (d) Air intake channel model with internal flow characteristics; (e) Fundamental resistance lines: (1) with air inlet stream, (2) with gas exhaust stream; (f) Resistance increment with bearing system; (g) Internal flow (in air intake channel) characteristics; (h) Engine performance data; (i) Actual aircraft resistance; (j) Projected aircraft performance; (k) Net thrust.

In this estimation method, a smaller number of wind blowing models is required, and the fundamental aerodynamic properties can be directly obtained. Therefore, the testing accuracy is relatively high. However, the main shortcoming is the effect of engine throttling (the effect due to varying resistance in the air intake channel and the varying jet resistance at the tail nozzle). Thus, it is difficult to separate various factors causing variation of aircraft performance, and to determine if the effect is due to problems of fundamental aerodynamic characteristics, of integration of the propulsion system, or of the fundamental performance of the engine.

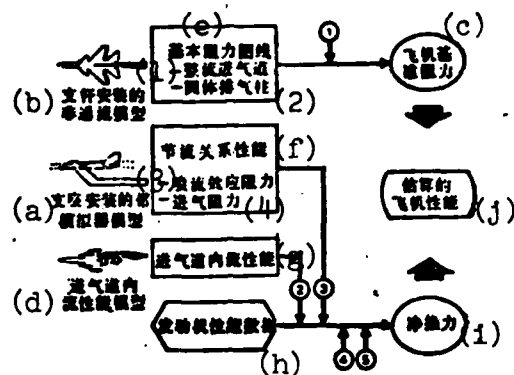


Fig. 5. Thrust/resistance estimation process with engine throttling relationship effect of model with simulator.

Key: (a) Model with simulator with installation of fulcrum seat; (b) Non-flow-through model with installation of fulcrum bar; (c) Fulcrum seat; (d) Non-flow-through model with internal flow characteristics; (e) Fundamental resistance lines: (1) streamlined air intake channel, and (2) gas exhaust solid column; (f) Throttling relationship characteristics: (3) jet effect resistance, and (4) resistance to air intake; (g) Internal flow (in air intake channel) characteristics; (h) Engine performance data; (i) Net thrust; (j) Projected aircraft performance.

Another thrust/resistance estimation process can remedy the shortcoming of the estimation method described in the last paragraph. In this estimation process, the fundamental aerodynamic properties are obtained with a simple model of non-flow-through wind blowing; in addition, an aircraft model with a simulator installed on a fulcrum seat is used for wind blowing tests. Thus, the interference on the nozzle flow field and air intake channel, as well as the effect due to throttling relationship can be obtained. Combining the data of the throttling relationship characteristics, internal flow characteristics in the air intake channel, and the engine data, the net thrust characteristics of the propulsion system can be determined. Then,

adding the test data of the fundamental aerodynamic force on the fuselage, the aircraft performance can be estimated.

From the aforementioned, the application of the MAPS simulated propulsion system in wind tunnel testing can speed up the aircraft development process, shorten the development period, and enhance the level of the estimated aircraft performance. From reports on application experience of MAPS by the McDonnell Douglas Corporation, the use of MAPS for wind blowing tests can reduce expenses by 4 percent, and shorten the time for model wind tunnel tests by 13 percent as compared to the conventional combined tests of the flow-through model and jet effect model. As revealed from the development situation, at present the flow calibration and air intake channel connection of MAPS should be further improved.

CERTIFICATION PASSED FOR TOP TANGENT TECHNIQUE FOR FAN

Zhang Bonian

The Jiaotong University in Shanghai is the first in China proposing a scheme of an engine fan stage with its top tangent to an external culvert in order to remodel a Chinese made aircraft turbofan engine into a marine model. The remodeling scheme was approved by the China Shipbuilding Industrial Corporation and the Ministry of the Aviation Industry. Based on the approved development plan, six stages of experiments were conducted; significant progress has been obtained in the top tangent technique for the fan. In January 1983, the technique was certified.

All the more than 70 delegates from 28 units attending the technical certification meeting unanimously announced that the fan top tangent technique proposed by the Shanghai Jiaotong University is successful. In addition, the technique achieves an advanced domestic level in the following aspects: creatively applying the statistical method, the streamline curvature method, and parallel compressor theory in solving the compressor stage performance calculation problem with the top tangent fan stage, as well as determination of fan top tangent dimensions, compressor oscillation model and oscillation boundary. The engine idling test and simultaneous fan stage top tangent remodeling compressor component test are adopted so that the remodeled combustion gas producer is the combination of test components and the power source driving the test components. On the variation of aerothermodynamic properties of the entire engine with the fan top tangent

technique, the researchers proposed a series of theories and techniques for overall adjustment in solving the key problems of reliable start, idling stability, safety in speed increase, estimation of the closing process of the oscillation-preventing valve, and optimization of design parameters. The scheme has its creativity in the composite solution method of multi-variable gas turbine, partial equivalent flow-through theory, and performance calculation of the variable-geometric shape gas turbine; this scheme has its instructive significance in estimation, adjustment and testing.

The aforementioned achievements of the Shanghai Jiaotong University in the fan top tangent technique open a new route of multi-usage remodeling of aircraft turbofan engines; in addition, the scheme provides a useful reference for technical remodeling of a similar type of engines in China.

AIRBORNE TRANSMITTER LABORATORY

The Northrop Corporation in the United States was awarded a U.S.\$2,700,000 contract by the U.S. Army for a night vision and photoelectric laboratory, which is development and installation of a comprehensive transmitter laboratory for UH-1H helicopters. The laboratory is also called the airborne transmitter certification and testing system, including a stability stand with installation of a foresight infrared device, a laser and photoelectric transmitter, a digital scanning conversion device, controllers, displays, auxiliary electronic devices, a computer and recording equipment. The airborne laboratory will be used to test and certify various transmitters and signal processing equipment under flight conditions.

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