Summary of the engine system research using small jet engines in JAXA

Hisao Futamura, Keiichi Okai, Masaharu Koh, Takuya Mizuno, Ryoji Yanagi
Institute of Space Technology and Aeronautics, JAXA
7-44-1 Jindaiji Higashi-machi, Chofu, Tokyo 182-8522, JAPAN
futamura.hisao@jaxa.jp

Keywords: Engine system, Engine Test

Abstract

A possible and practical engine system research method is proposed. Varieties of objectives of the engine component and system technology developments are fulfilled by the small scale rig and engine demonstration. Some research applications of small jet engines in National Aerospace Laboratory of Japan (NAL) are presented together with historical overview.

Introduction

More than sixty years' engineering efforts around the world in jet engine research and development have already clarified the fundamental characteristics and have developed many design methodologies. The jet engine evolved in size so that the pioneer engines which thrust was about thousand pounds to today's huge one of hundred times greater thrust for giant passenger aircraft or less than hundred pound thrust to the smallest end for unmanned model airplanes (Fig. 1). Those were the outcome of demand for expanded mission requirements of the flight vehicle and for the propulsion systems. The choices of the propulsion systems depend on the designers' will so that some are from existed off the shelf engines, others are engine modification, or new development. Performance, number of deployment, lead time for the entry into service, cost, etc. make their decision. The experience and the number of engine types tell the difficulty of new engine development.[1, 2] Analogy of fluid dynamics, structure, and physics don't allow simple scale model development in jet engines. JAXA is planning new engine technology research programs by cost effective methods using small model engines.

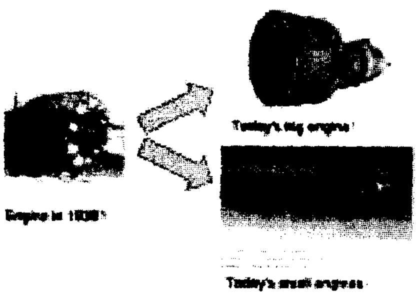

Fig. 1 Evolution of jet engine

Research history of NAL engine

In 48 years NAL had devoted to the aircraft engine research activities. Many accompanied scale model component researches were conducted.

JR series lift engines

NAL started its aircraft engine research on the vertical takeoff and landing (VTOL) technology. During 1950's and 60's simple and light weight jet engines were developed (Fig.2). Several component test facilities were built for the project. A flying test bed was manufactured and succeeded in lifting off and hovering by control system with two lift jet engines and air jet reaction control.

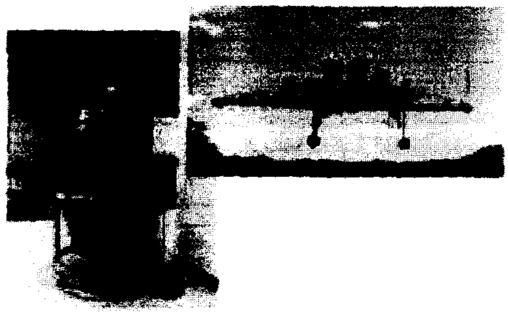

Fig. 2 JR100 lift engine and FTB

FJR series high bypass turbofan engines

NAL and AIST (agency of former Ministry of Industry, Trade and Investment) jointly developed high bypass ratio turbofan engine which enables twice the cruise range by low fuel consumption and low noise. FJR710 engine (Fig. 3) is the first Japanese turbofan engine. Prior to the engine development large combustor facility and sea level engine test facility were built.

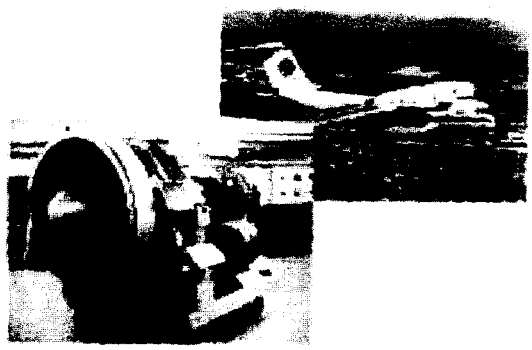

Fig. 3 FJR710 engine and ASUKA

Later FJR710 engines are installed on a STOL research vehicle "ASUKA" to demonstrate Upper

Surface Blowing technology. This technique depends on jet flow momentum, so a wind tunnel test was conducted with air turbine engine simulators. For the airworthiness program FJR was tested in ATF of NGTE in England, and Icing, water ingestion, bird strike, side wind, and noise test were conducted in agreement with ICAO type certification procedure.

Industrial Gas-turbines

Reflecting 1970 world Energy Crisis invoked innovative energy consumption reduction technology. Among MITI promoted "The Moon Light Project" was a LNG fuel high thermodynamic efficiency gas turbine technology development. Increasing natural gas import as petroleum substitute the target was set as 50 bar cycle pressure with 1500 deg. C combustion. A high temperature combustion test facility was built in NAL (Fig. 4). The tendency of high cycle pressure ratio and high temperature combustion are the same for tomorrow's aircraft engines.

Fig.4 High pressure combustion test facility

Supersonic/Hypersonic engines

MITI and Industries as long as NAL forecast 21st century high speed transportation system with methane fueled Mach 5 hypersonic vehicle. During 1989 to 1998 the combined engine system (Variable cycle turbo fan + ram jet) were developed (Fig. 5).

Fig.5 HYPR Turbo engine in IHI test cell[5)]

CFD design was adopted all the aerodynamic components. HYPR engine was tested in Japan, United States, and United Kingdom. Supersonic air intake tests were conducted using many supersonic wind-tunnels of NAL and ONERA in France.

Subscale ramjet engines were tested at hypersonic ramjet engine test facility of NAL. (Fig. 6)

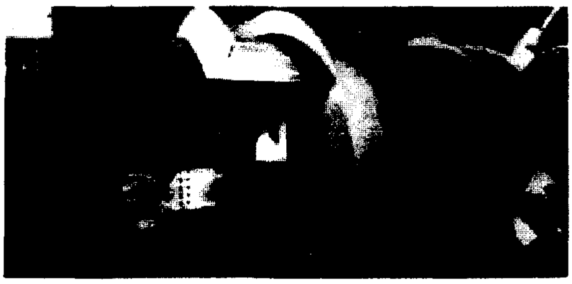

Fig.6 HYPR Ramjet in NAL Kakuda RJTF[6)]

Current engine system research in JAXA

In October 1 last year JAXA was established merging three space agencies, NASDA, ISAS and NAL. Institute of Space Technology and Aeronautics which is a part of JAXA takes over the aeronautical research activity of NAL.

Supersonic Transport Technology

Glowing market and global economy are changing our daily life with fast information technologies, on the contrary the speed of logistics is still limited by the speed of freight. For the steady continuing growth, the high speed flight is beneficial to all the countries, especially Japan. At the earlier stage of technology development it is quite natural that the research should start from the small scale model test. Since 1997 NAL and now JAXA has been seeking the way to the realization of SST technologies. Scaled aircrafts flight research project is undergoing. At the second phase of this project jet engine powered aircraft, NEXST2 would be developed. The vehicle related researches have been progressed with the facilities bellow.

Mini-ATF:

This facility is a modification of large combustor rig test facility. An air supply system feeds 5bar air to the low pressure chamber, which is the test section evacuated by an air ejector utilizing large compressor of the combustor rig to test exhaust nozzles, supersonic intakes originally[7)]. An air dryer, electric air heater, exhaust water cooler was lately added to enable miniature jet engine operation to study propulsion system (Fig. 7). With this facility fundamental characteristics of engine and ATF were

Fig. 7 JAXA Mini-ATF and AMT small engine

obtained[8]. A vacuum chamber for simulating low cabin pressure condition was also recently equipped.

Supersonic Engine Test Facility:
As a part of supersonic aircraft technology research, an altitude engine test facility capable of Mach 2 supersonic flight condition was built in 2001 (Fig. 8). It is designed to fit YJ69-T406 engine which is selected as the engine of flight demonstration aircraft NEXST-2. This engine had been used for the BQM107-E&F, retired Mach 1.5 supersonic target drone in United States. More than twenty years operation proved its performance and durability. But there are unknown factors in the flight research project that the new aircraft has Mach 2 design speed and twin engines configuration with flight computer controlled. Also, the project requires so precise engine thrust force measurement that is compatible to the lift force measurement in wind tunnels.

Fig. 8 Supersonic Engine Test Facility (ATF)

The engine in flight experiences overwhelming weather condition. In case of heavy rain there is the possibility of misfire. On the other hand it could be a thrust augmentation method to ingest water in compressor. A water ingestion test was conducted in-house to prove the operation limit and performance change due to the water flow sprayed in front of the engine (Fig. 9).

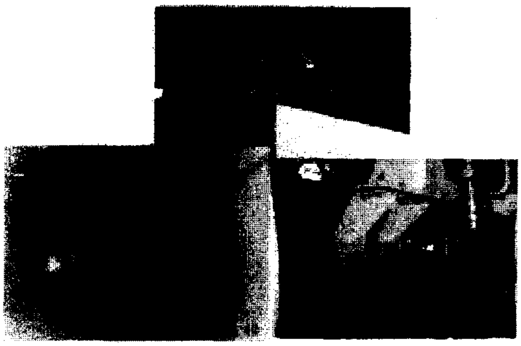

Fig. 9 Water ingestion test of YJ69

At the transonic flight speed aircraft is unstable because of non-linear nature of intake characteristics and drag divergent Mach number.
Simple constant speed type fuel controller does not match without knowing flow characteristics. A Semi-Freejet Test is good for understanding the fluid dynamic phenomena in this point to visualize the duct shock wave pattern by optical method (Fig. 10).

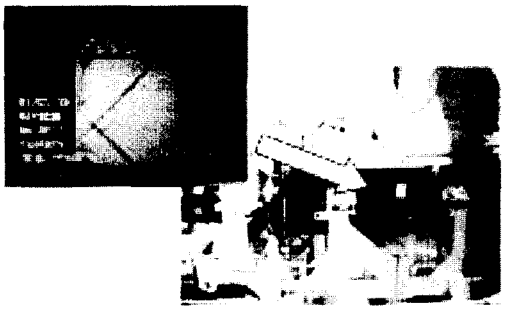

Fig.10 Semi-Freejet Test and shock waves

The jet engine is generally tested with a bell-mouth to get the basic or un-installed performance in the engine development. The bell-mouth introduces smooth air flow into the engine, but the actual incoming air flow through the air intake, especially supersonic intake has distorted inlet condition. It is very important how the inlet air is distorted and whether the engine functions normally by the inlet distortion test (Fig.11).

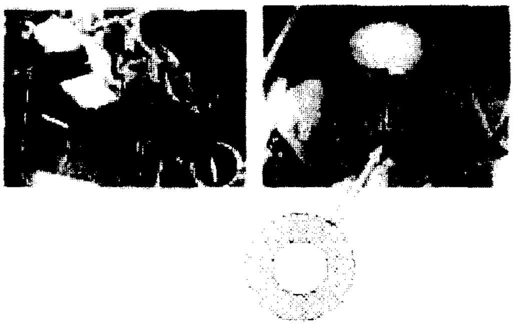

Fig. 11 Supersonic inlet and distortion test

There are still many other tests waiting to be confirmed before flight.

Aircraft Environmental Technology

Rapid growth of air transportation is bringing congestion on airports and ground traffic world wide. The importance of air travel makes people understood that surrounding community environment should be well preserved. The environmental issues are urgent concern and JAXA is expanding "Clean engine program" as descendent of on-going research program which also includes finishing METI funded ESPR program.

Noise Abatement Technology
Stringent engine noise regulation (Fig. 12) needs new technological solutions. Jet exhaust speed reduction by higher bypass ratio design alone would not meet further noise reduction. The remedy should be well integrated one because the engine noise is the mixture of fan noise, jet noise and others. The engine must be

designed so that generates less noise and absorbs it and dissipates it.

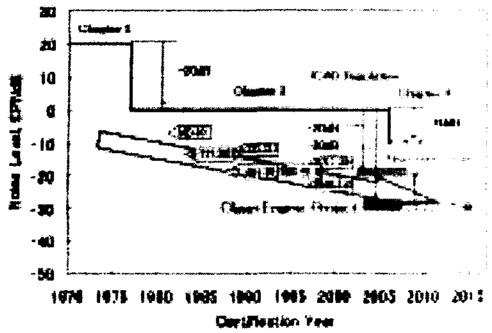

Fig. 12 Engine Noise: regulation and certification

First of all, precise noise measurement and analyzing skill should be learnt. Fan noise consists of blade wake interaction and buzz, and they are dipole and monopole sound sources. Jet noise is quadrant-pole source roughly 8 times proportional to the exhaust gas velocity. Those are equally affected by Doppler shift when the source is moving. Then the perceived noise data must be break down to the static noise and the influence of source velocity by flight vehicle noise measurement. JAXA has developed real-time noise source measurement technique using scale model jet aircraft (Fig.13).

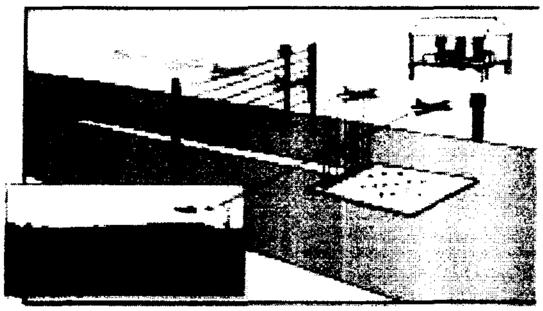

Fig.13 Flight dynamic sound measurement test

Though magnitude of sound pressure is millionth smaller than the atmospheric pressure and mathematically governing equation is different, far field sound propagation could be estimated using computational fluid dynamics. The sound wave reflects on the ground, large buildings, cloud and diffracts with vertical air density distribution, and is carried along with winds.

There are many ideas to absorb the noise with perforated attenuation wall. The acoustic treatment on the jet engine is getting thicker and wider. The weight and space of acoustic treatment tends to the obstacles for engine system designers.

An attractive concept has been proposed: an active noise control technique is an excellent method. High speed sound measurement and frequency analysis and reverse sound generation cancels the noise. After speaker test, miniature engine test and YJ69 engine test was conducted.

Fig. 14 Active noise control test of YJ69

To study the validity of these technologies on transonic fan noise, the compressor test facility, Engine field noise measurement tests are planned (Fig.15).

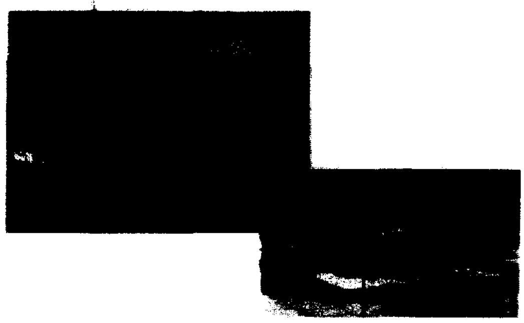

Fig.15 Engine noise tests (YJ69 left, FJR right)

Emission Suppression Technology

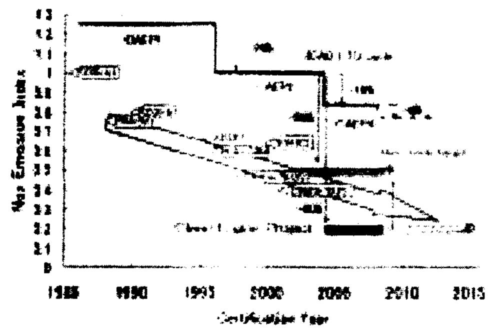

Fig.16 NOx Emission: regulation and certification

The fossil fuel consumption of aircraft engine is rather small portion, but the exhaust emission can not be removed by the secondary means, such as absorbent or catalytic reaction. ICAO is proposing farther regulation on aircraft engine NOx emission (Fig. 16).

On contrast to the noise research combustion process begins with microscopic approach; the fuel characterization, atomizing, air-fuel mixing, and etc. Those physical phenomena are characterized with dimensions, so similarity does not hold good. Then scale combustor test is useless.

The development process proceeds as: burner test single sector combustion test, multi sector combustion test, full-annular combustion test. The difficulty of tests is air flow source demand and instrumentation in combustor. Optical measurements and CFD flow pattern estimation are powerful research tools.

Reusable Space Launching Technology

High Speed Flight Demonstration

Since 1988 NAL and NASDA (Both are now JAXA) began study re-entry technology. In 2002 Jet engine powered test vehicle HSFD-1 succeeded automatic unmanned flight with GPS and altimeter.

Spaceplane technology

A future space propulsion system for reusable launch system using airbreathing engine has been proposed.

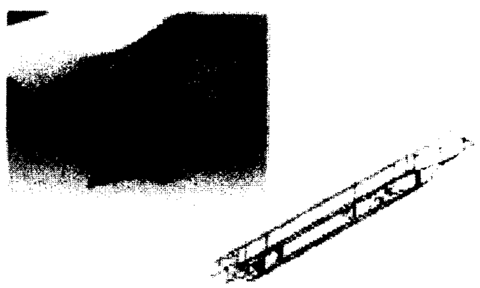

Fig.17 TBCC concept and model ramjet engine

An air pre-cooled turbojet combined with ramjet is promising one[9] (Fig.17). At the technology development phase scale model test is the necessity because of the test facility limitation. This ramjet is designed to be fitted 500mm square facility nozzle size. According to the progress of space activities larger test facility should be built along with flight testing.

Conclusion

JAXA (NAL) engine research activities mentioned above are calling for 21st century aeronautical innovations. Over 60 years worldwide engine development trials seem to be covering all the application in civil and military aircraft. They spun off many technologies to other field as the engineering front runner. Now, the technologies originated in other fields, such as: advanced materials, intelligent digital controls, laser optics, etc. are whispering unexpected ideas in new engine development. Engine component and system research with small scale engines is tracing pioneers' thinking and tells us the road map to the success. The products' life is extending to be longer than the one engineer's career. Safe, comfortable and reasonable transportation system is built and maintained by the agreement of theories and practices.

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