JAXA TechCLEAN Project

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Abstract

The JAXA's TechCLEAN project (2003 - present) is summarized, with the interim technical achievements. TechCLEAN is collateral program with the NEDO engine project to accelerate R&D work of small passenger aircraft engine as well as to develop innovative environment technologies applicable to the future improvements. In the project NOx reduction, CO2 reduction and noise reduction are targeted. Component level researches and system demonstrator validation are planned with test facility renovation and demonstration base engines.

Introduction

Project initiation

The Japan Aerospace Exploration Agency, JAXA, has been promoting the TechCLEAN project since 2003, which is aiming new engine technologies development for environmentally friendly and affordable passenger aircraft engines of small and medium size. The objective of the project is set by typical engine indicators of exhaust emission NOx, airport noise, and the SFC as the reflection of vast concern about around airport air pollution and noise, as well as airline proficiency. Those are well clearing the current ICAO regulation and viable within ten years but still challenging.

The project consists of two parts, the support activity for the Japanese governmental R&D program, "Environmentally Compatible Engine for Small Aircraft Project (ECO Project)" and advanced technology development work. We are taking concurrent approach for these works as;

1. Design analysis of new modeling with reliable tools
2. Component and sub-component test with refurbish facilities
3. Component and sub component technology research with innovative apparatus
4. Improvement of analysis tools and validation with actual hardware
5. Engine development support and advanced component validation

Objectives

Background

More than 80 years we have utilized aircraft as the mean of travel and transportation. The advantage of vehicle speed has never overtaken by other vehicles, ships, trains and automobiles. Distributed ground system, which is composed of no longer than 4 kilometers well paved runways and navigation facilities enable aircraft operation connecting any pair cities and city networks, which prevents abused reclamation. The number of aircrafts and revenue passenger miles of air transport continuously increase. In these days not only fighting against other transportations, but the cooperating with other transportation like high speed trains and airport shuttle, rental cars provide us the seamless services for users.

On the other hand, quantitative expansion of air transportation has proportionally growing impacts on surrounding communities. Powerful jet engine generates comparable noise with thunderbolts, and hundred times greater amount of exhaust emission substances than ships of the same weight. Since 1970's ICAO has set regulations on aircraft noise and engine emissions around airport operation. All the aircraft and engine manufacturers and research organizations, universities have devoted to the ceaseless technology developments for reducing the emissions.

Historical environmental issue

The first passenger jet aircraft of the world is De Havilland Comet powered by RR Ghost turbojets in 1952, which has almost the same dimensions with Douglas DC-6 and range performance (**Table 1**). There was no concern about environmental issue at this moment though it flies with pure jet sound and black smoke trail.

Table 1 Comparison of airplanes

	Comet IV	DC-6B
Length [m]	33.99	32.18
Span [m]	35	35.81
Cruise speed [km/h]	784	509
Range [km]	4590	4300
Passenger	76	82

Technical ideas for lengthen the range or improve the fuel consumption were found in the patent of 1930's. The emerge of turbofan engine delayed in 20 years since high compression ratio needed multi spools compressor or variable stator vanes, the low bypass ratio engines, RR Conway, P&W JT3-D have as half the fuel consumption rate and resulted in large turbo-plop aircrafts soon disappeared. In 1970's world oil crisis and environmental concern of citizen's movement arose. It denied high speed flight because of sonic boom, airport noise and expensive cost.

Rather it called for larger passenger airplane with higher bypass ratio engines as P&W JT9D, GE CF6, and RR RB211 which have lower fuel consumption with lower exhaust gas speed, which seems preferable for noise abatement, but required much higher compression ratio and elevated combustion temperature. They brought high temperature resistant material developments and effective turbine cooling technologies and low NOx combustion.

Target engine class

The size of aircraft and its engine have evolved to 800 passenger A380 aircraft and 3 meters diameter giant GE90 engines. Short range air routs should be covered by smaller aircrafts. One of the congested air routs in the world is between Tokyo and Osaka, which is 500km apart, where Japanese Shin-kansen super express train carries 1600 passengers every 10 minutes (**Table 2**).

Table 2 Air rout congestion (2005)

	City pair	Seats/day
1	Tokyo – Sapporo	27,445
2	Tokyo – Osaka	26,192
3	Tokyo – Fukuoka	25,094
4	Rio de Janeiro- St. Paulo	24,683
5	Sidney – Melbourne	23,435
6	Taipei – Hong Kong	23,232
7	Seoul – Jeju	19,999
8	Beijing – Shanghai	19,797
9	New York – Chicago	18,769
10	New York – Atlanta	16,131

East Asia is densely populated and 200 cities over million residents, which is promisingly growing market covered by 100 passenger 1000 km range class aircrafts for airlines, those aircrafts could be powered by the turbo-plop or the turbo-fan category.

Here, we are taking turbo-fan engine considering high speed adaptability and near term entry into service.

Technical difficulties with this engine are found out as a logical tree chart **Fig. 1**.

Stringent environmental regulation

Fig. 2 & 3 show the ICAO environmental regulation rule on the new products to promote innovation and accelerate obsolete aircraft retirement accounting for balancing the proper airline management and the social demand fulfillment. The regulation level should be considered not the development target but the margin of lifelong usage.

The goals of Eco-engine project are to reduce the emissions of NOx by more than 50% from the ICAO CAEP 4 standards and noise by 20 dB from the ICAO Chapter 3 regulation and to improve thermal efficiency by 10% over the most recent small aircraft engines[1)]. TechCLEAN set higher level for those measures as on the charts.

Low NOx combustion

Scientific approach

Current liquid spray combustion technology reached the level of nearly 100% combustion efficiency at design point. To lessen the nitrogen oxide content of exhaust gas many ideas have been proposed and tried. There are three practical methods are under developed, lean pre-mixed pre-vaporized, rich burn & quick quench, and rapid mixing flame. All these ideas need fine fuel droplet size spray atomization technique, precise air and fuel distribution control technique at wide range of engine operation.

Theoretical design method has not been acquired on combustor development. Try and error development does not suit for time and cost, but parametric screening procedure is usually taken as mentioned bellow.

Optical measurement

Combustion phenomena comprises complex physical process of two phase flow of liquid fuel droplet and air spray atomized and vaporized, then chemical reaction of many species occurs. A special laser instrument was developed for observing fuel spray under high pressure to evaluate fuel nozzle characteristics.

Fig. 4 is the outlook of the instrument equipment and laser diagnostics of droplet size and distribution[2,3)].

Numerical simulation

The air flow inside the combustion chamber is so complex that swirl and recirculation impinging wall cooling air and dilution exist. Recent development reveals the flow by computational fluid dynamics simulation **Fig. 5**. The particle tracing method enables summation residual time, which has close relation with NOx formation.

Single burner test

Fuel spray and fundamental combustion characteristics with certain swirler combination are examined at actual pressure and temperature condition as a single burner test.

Sector combustor rig test

Current turbofan engine anonymously adopts an annular type combustor which is light weight and small volume. Sector combustor model consists of several portions of three or more fuel nozzles **Fig. 6**.
Test results are graphed in **Fig. 7**, which clears the target value[4,5)].

Annular combustor rig test

Full annular combustor test is necessary work of combustor development since the sector combustor test includes the side wall effect which affects in quantitative evaluation in emission. Igniter location, exit gas temperature profile are also examined in this configuration.

For this purpose 30 years old annular combustor test facility was renovated to resume operation in JAXA **Fig. 8** [6].

CO2 reduction

Oil crisis

As comparable market dependency of 1972 oil crisis, the fuel price has steeply come up as **Fig. 9**. And it reached 100 dollars in the beginning of this year **Fig. 10** [7]. Air transportation market wants it calm down. Engine development projects are expensive investment which are sensitive to airline management balance and reflect market prospect.

Technical aspects of CO2 reduction is comprises with system and component efficiencies improvement and engine weight reduction. From the view of the engine cycle efficiency, higher bypass ratio is advantageous for better fuel consumption, but mechanical difficulty and cost up exists for especially small size engine.

Advanced composite material application, higher work loading turbo machinery, geared fan, booster less fan, and etc, those are of course innovative and suitable for certain application. We should continue to seek those technologies but in short term difficult to adopt because of lack of basic data.

Turbine cooling improvement

High temperature combustion and turbine technology is essential for the engine technology, because theoretically maximum thermal efficiency depends on the temperature ratio of the engine cycle by thermodynamics.

In airline operation maintenance cost of aircraft engine is of great concern. It is controversial in that turbine cooling air reduction is necessary for lower SFC and NOx reduction. The turbine cooling mechanism is so complex that convective and impinging and film cooling are applied to the small turbine blade. JAXA developed advanced numerical conjugate simulation which calculate flow field inside and outside of turbine blade and calculate heat transfer of blade at the same time **Fig.11**. They are also experimentally validated with infrared thermo viewer camera measurement **Fig. 12** [8,9,10].

New cooling channel design turbine was invented for small size engine which is so small that traditional cooling mechanism can not be applied **Fig. 13** [11].

High temperature material

Among the engine parts HPT blade is shortest life due to thermal deterioration. Directionally Solidified process and Single Crystal process are common in casting the HPT blades. The microscopic investigation of the test piece tested under sinusoidal thermal stress and oxidation simulated low cycle fatigue reveals the rafting mechanism of super-alloy crystal **Fig. 14 & 15** [12].

Engine Noise reduction

Fan noise and jet noise

High bypass ratio turbofan engine is much less noisy than the old engines. There are mainly two kind of noises generated in the turbofan engine. One is the fan noise which is caused by the rotating fan blades and the other is the jet noise which is caused by the sear layer interaction of high speed exhaust jet and surrounding air. The aircraft noise near airport is evaluated the sum of noise (EPNdB) at takeoff, side line and approach. At takeoff jet noise and buzz saw fan noise are dominant and at approach fan blade tone noise is significant.

CFD simulation of fan noise

Noise is pressure oscillations of flow field. Unsteady inviscid high order Eulerian scheme computation of fan and OGV is shown on **Fig. 16**. The sound wave generated by the blade and vane interaction transmits forward through the fan blade is observed. Outside of the engine the sound wave propagation with acoustic equation theory is calculate[13]. Jet noise is also analyzed by LES. [14].

Noise measurement and dynamic source allocation

Engine noise measurement technology is also developed using small turbojet engine out field test **Fig.17**, which shows the jet noise is dominant at high speed and fan noise at low speed **Fig.18**. The ICAO noise regulation is applied for the airplanes which takeoff and landing at the airport. Noise source allocation technique should be capable of analyzing moving object. Innovative measure and analysis system was developed using simulated scale model aircraft flight **Fig. 19** [15].

System demonstration

Engine control

Environmental and economic requirement may result in operational limitation of certain modules of the high bypass turbofan engine as Fig. 1. FADEC, full authority digital engine control system is mostly used for proper engine operation and systematic interface with FCC in current airplane system. Rapid evolution of Intelligent Technology enables data acquisition and engine control in real time. Today’s computer has much stronger potential to calculate complex engine parameters and to compare with the database and to judge the adaptability to the prescribed logic, so called intelligent control. The innovative technology should be validated in test engine operation before it is thought to be of the art. We are developing control system with small turbojet engines in ATF of our own **Fig.20** [16].

ESPR demonstrator

More practical and direct resolution of control system development is to apply the control system to the actual engine system. ESPR engine demonstrator was developed in 2000 as the HYPR 90-T VCE based two-spool turbofan engine. JAXA got the transfer of this engine from NEDO in 2006 **Fig. 21**. It features high loading fan, high temperature combustion. Counter rotating spools, low noise exhaust mixer which are common with the Eco-engine design. The ESPR engine test is started in this January.

Conclusion

Current issues, the global climatic warming issue, surging crude oil price by swelled up financial fund, optical chemical smog revival in the East Asia, those are not directly obligated to aero engine origin, but local environmental impact of noise and air pollution might obstruct healthy evolution of air transportation.

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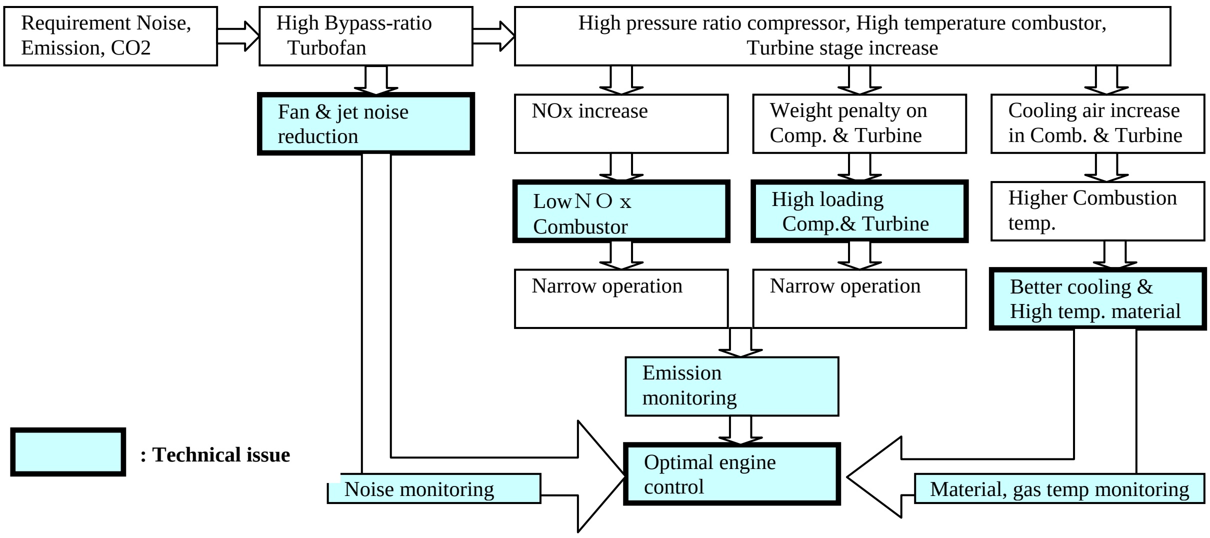


Fig. 1 Logical tree chart of TecCLEAN project issues

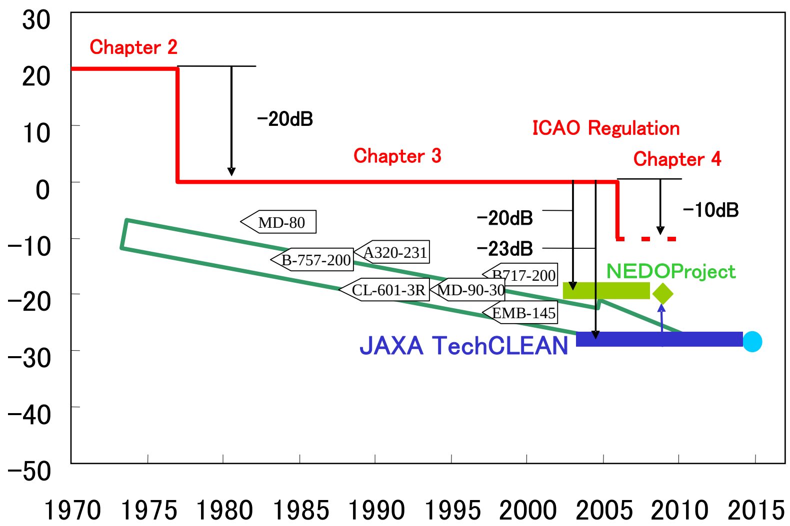


Fig.2 ICAO Noise Regulation & target

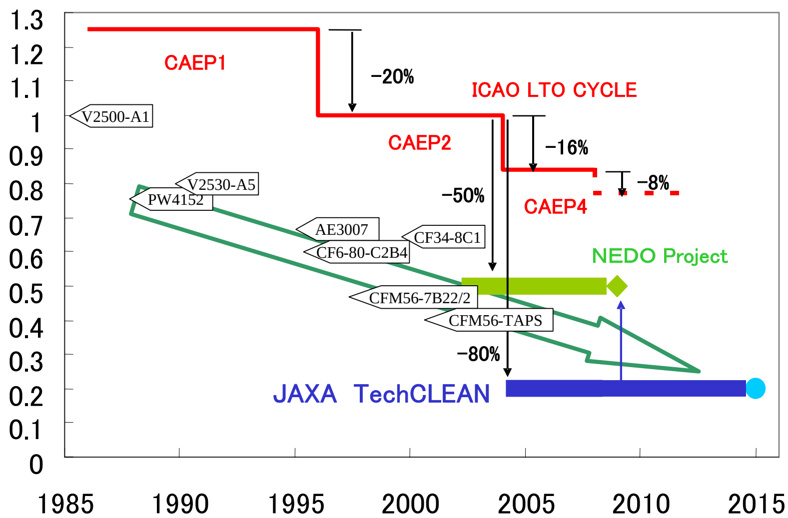


Fig.3 ICAO NOx Regulation & target

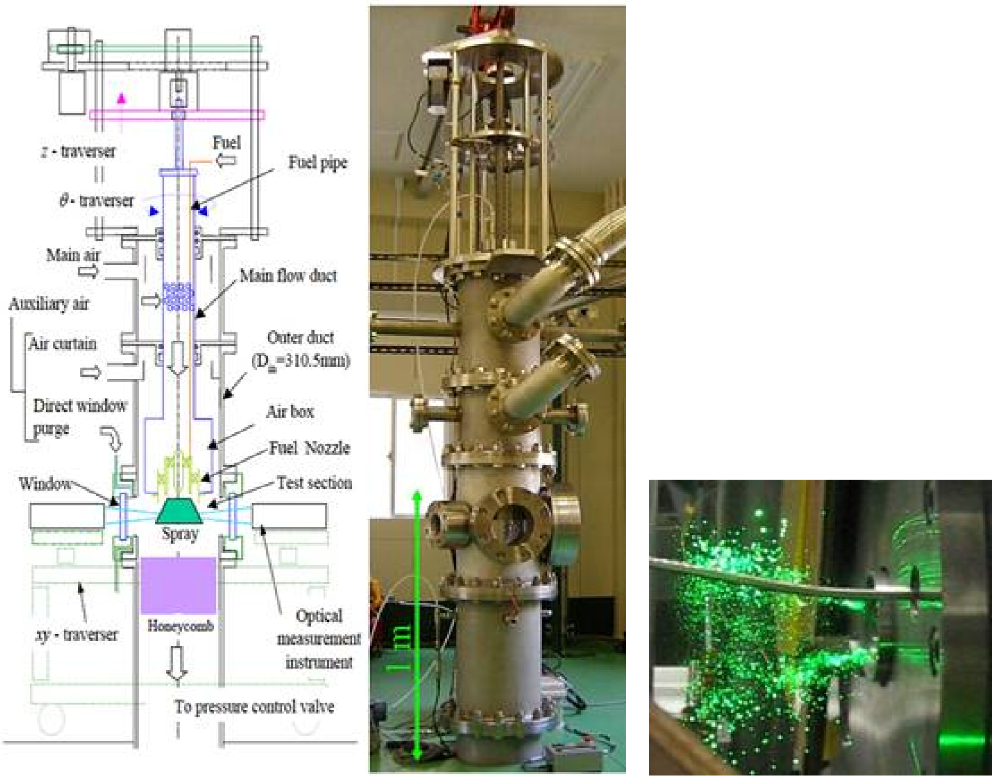


Fig. 4 Optical measurement of high pressure fuel spray

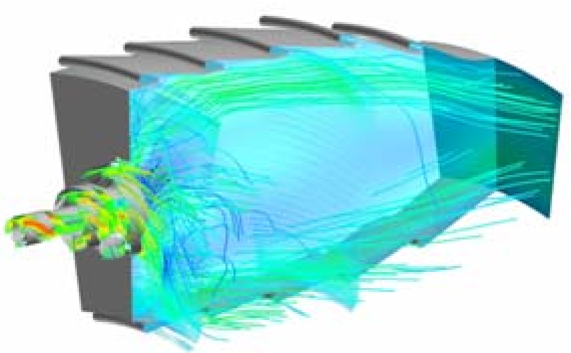


Fig. 5 CFD analysis in the combustion chamber

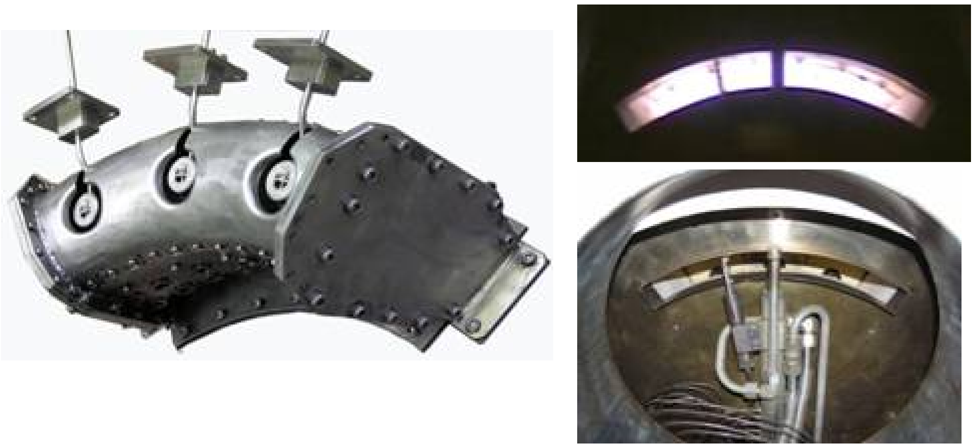


Fig. 6 Sector combustor and traverse measurement

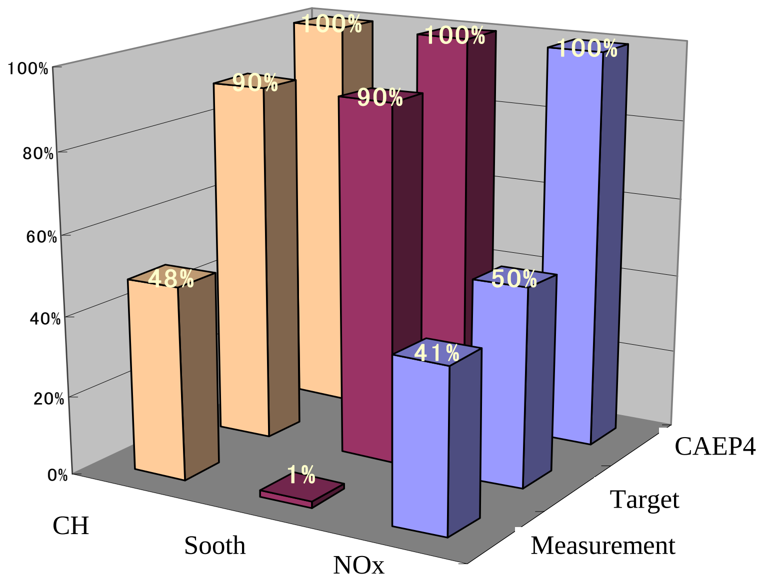


Fig. 7 Test result of sector combustor

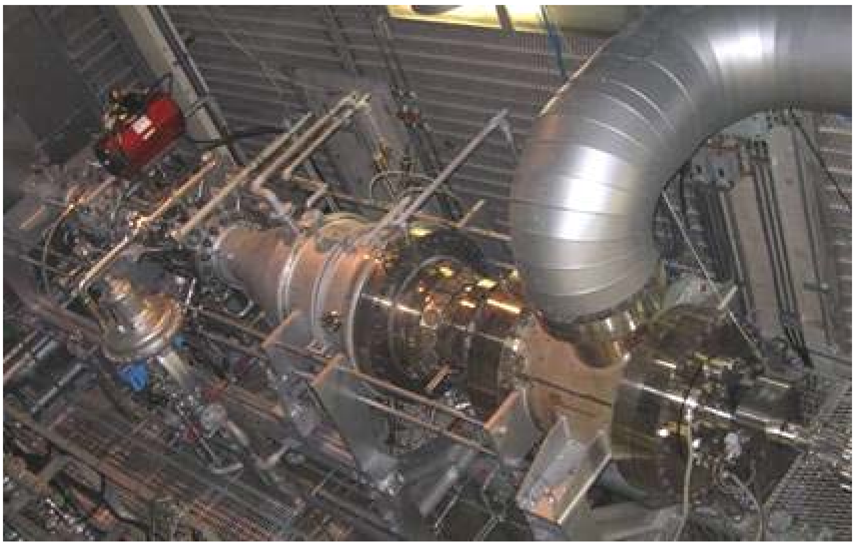


Fig. 8 Annular combustor & test facility

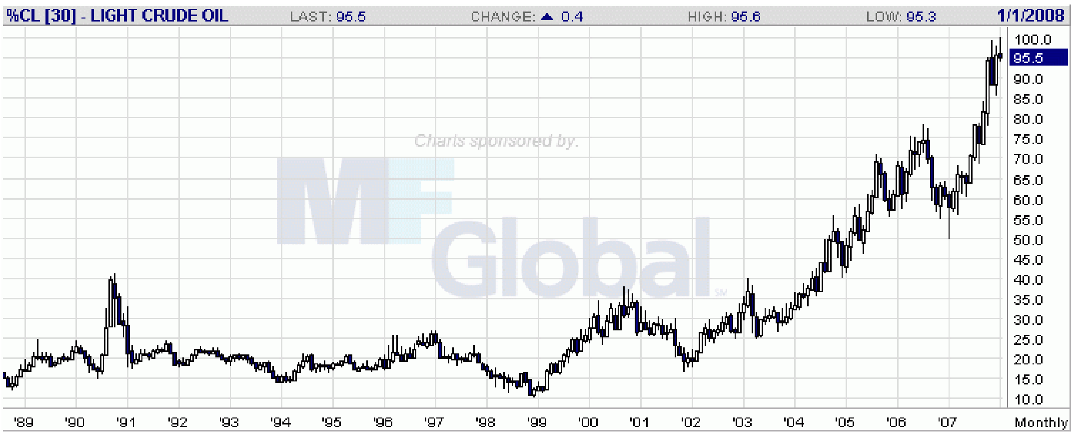


Fig.9 Crude oil market price trend (20 years)

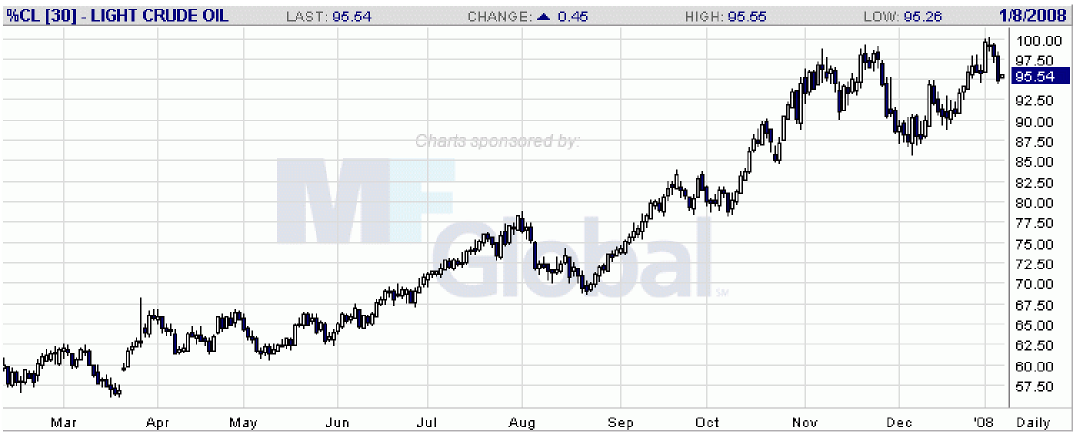


Fig.10 Crude oil market price trend (10 months)

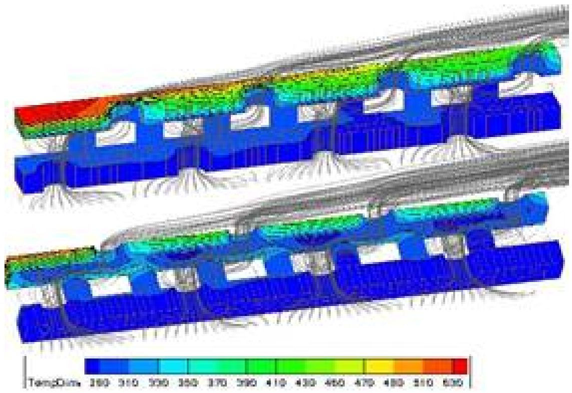


Fig. 11 Conjugate CFD analysis on turbine wall

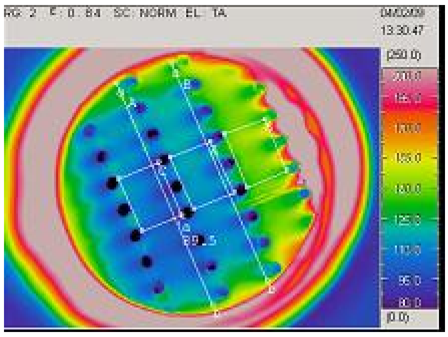


Fig. 12 Temperature distribution measurement by infrared thermo viewer

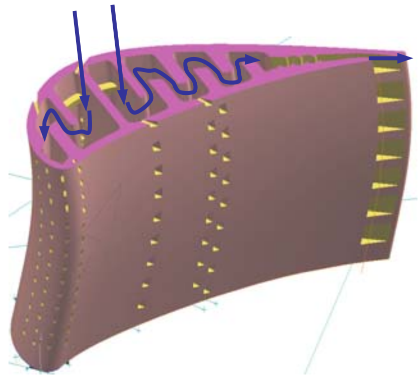


Fig. 13 Invented turbine blade cooling method

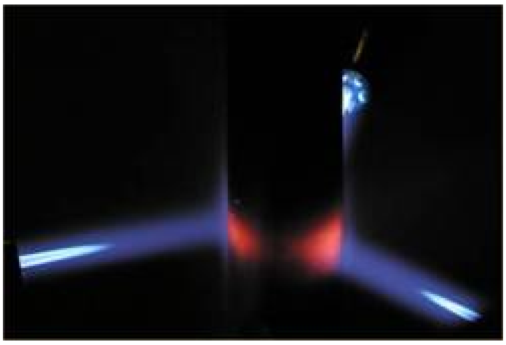
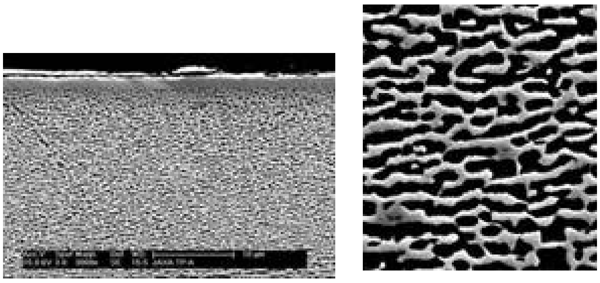
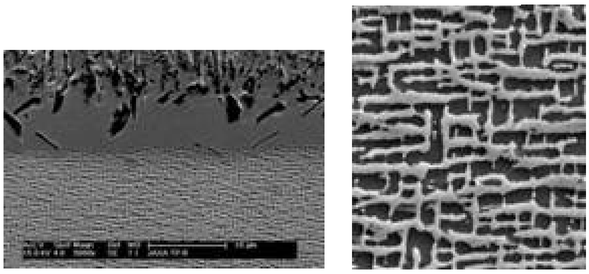


Fig. 14 Thermal fatigue Burner rig test



1st generation SC material



4th generation SC material

Fig. 15 SC alloy structure after thermal fatigue test

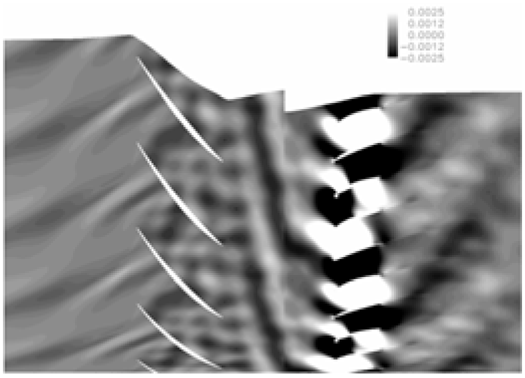


Fig. 16 Sound wave field of blade and OGV

Fig. 17 turbojet engine noise test at Noshiro test center

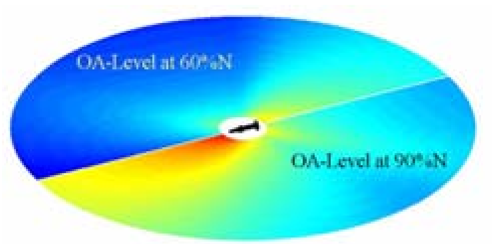


Fig. 18 Overall noise level of turbojet engine

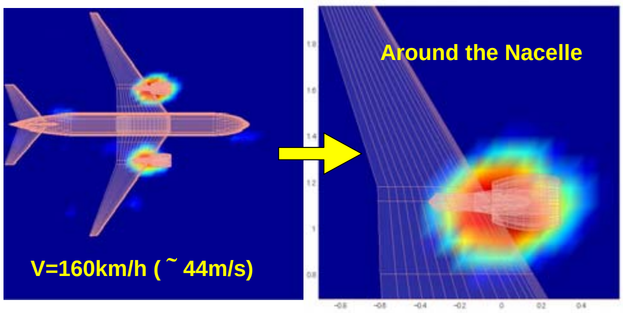


Fig. 19 Dynamic noise source allocation

Fig. 20 JAXA ATF test of small turbojet engine

Fig. 21 ESPR engine installed into renovated engine cell