CHALLENGES OF ADVANCED PROPULSION SYSTEMS DEVELOPMENT FOR FUTURE CIVIL AIR TRANSPORT

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Director General

FSUE “CIAM named after P.I. Baranov”

09.09.2014

STATE SCIENTIFIC CENTER OF THE RUSSIAN FEDERATION

- **BASIC RESEARCHES** (gas dynamics, strength, heat transfer, combustion, acoustics)
- **APPLIED RESEARCHES** (study of different air-breathing engines architecture, designing of units and systems of air-breathing engines, provision of reliability and non-failure operation
- **TESTS** (tests of air-breathing engines, their units and systems in real operational conditions, designing of test cells, test equipment, and measuring tools)
- **METHODOLOGY FOR CREATION OF ENGINES** (authorities documentation for development and certification of air-breathing engines and industrial gas turbine, strength and airworthiness, Authorities Documentation harmonization, …)

CIAM is the single scientific-research organization in the Russia performing complex scientific researches and developments for aero engine industry

ACADEMICIANS AND CHIEF DESIGNERS, WORKED IN CIAM


V.S. Avduevsky


M. V. Keldysh


G. P. Svitshev


L. I. Sedov


V. Ya. Klimov


A. M. Lulka


V. S. Chelomey


K. S. Tumansky


G. I. Petrov

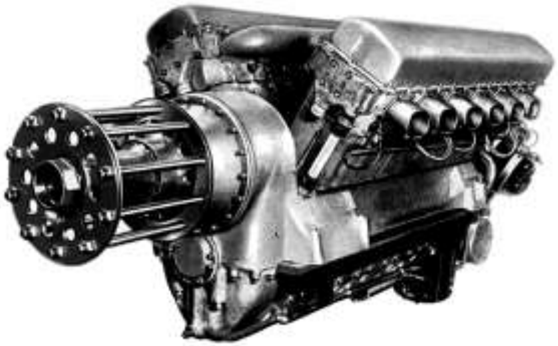

A. A. Mikulin


G. G. Cherny

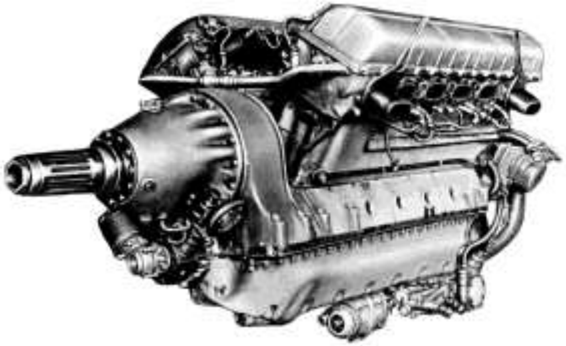

O. N. Favorskyy

AERO ENGINES DEVELOPED IN CIAM

1930th



M-34 piston engine by academician A.A. Mikulin (1931)

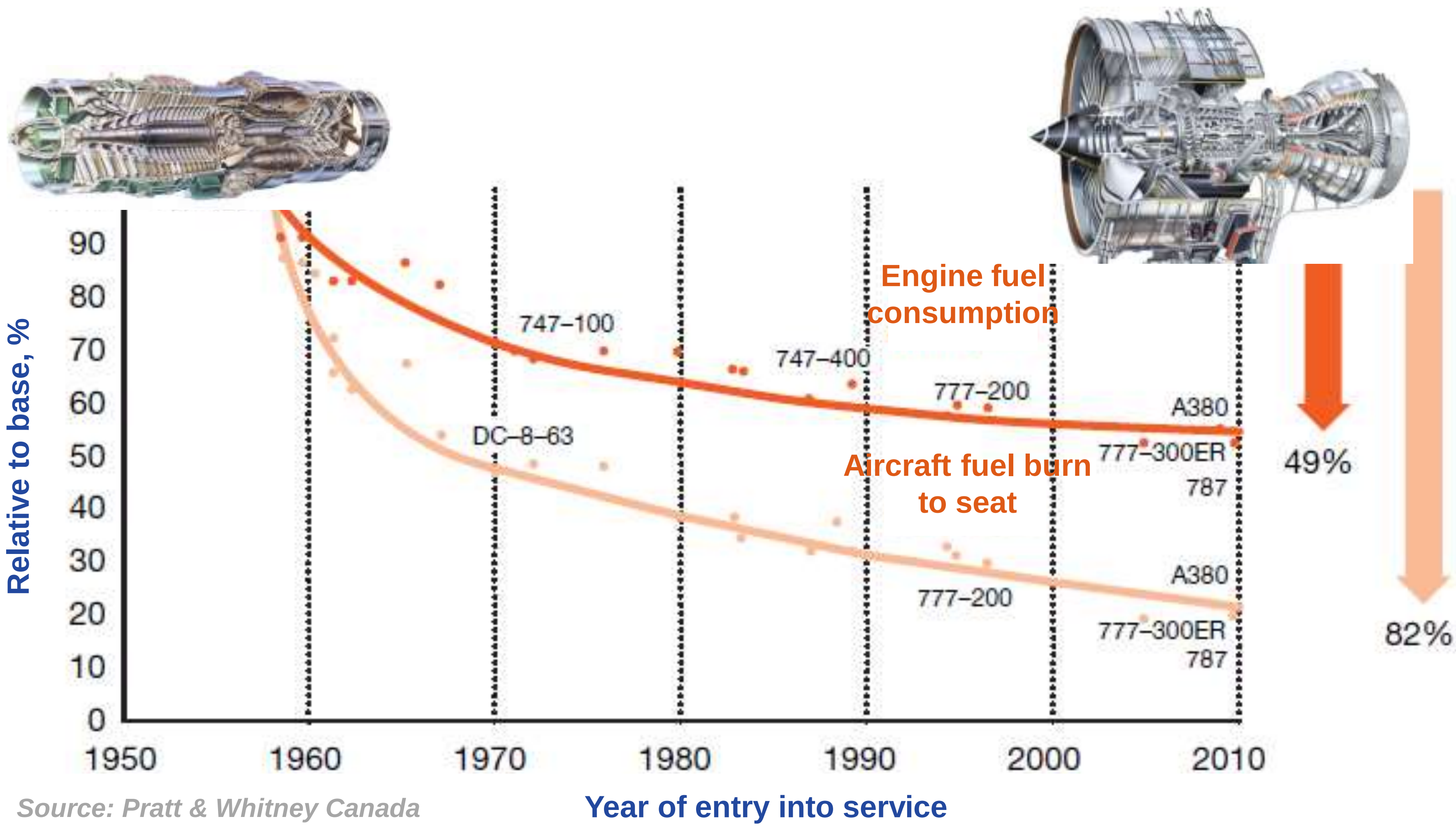


АЧ-30 diesel engine by Chief designer A.D. Charomski (1932)

1970th-1990th

Axisymmetrical SCRAMJET

AERO ENGINES MODERN STATE



Source: Pratt & Whitney Canada

Years: 1950, 1960, 1970, 1980, 1990, 2000

Aero Engines Generation: I, II, III, IV, V

I

TJ / TJ with AB

- Axial or centrifugal compressor, PR=3÷5
- Non-cooled turbine, TET=1000÷1150 K
- Steel, Al-alloy, Mg-alloy

TR-1, RD-10, RD-20, VK-1, Dervent, NIN, J35, J47

II

TJ (with AB), TP, TS

- Axial one or two spool compressor, PR=8÷13
- Non-cooled turbine, TET=1150÷1250 K
- Steel, Al-alloy, Ni-alloy

AM-5, AM-3, RD-9B, R-11F2-300, AL-7F, NK-12, AI-20, J57, J75, J79, Avon, Olympus

III

TF (BPR=0.3÷2)
TF w/AB (BPR<0.7÷1)

- Axial two spool compressor, OPR=14÷20

- Cooled turbine, TET=1300÷1450 K
- Steel, TI-alloy, Ni-alloy

D-20P, D-30, D-30KU, NK-8, NK-144, Conway, Spay, Olympus 593, JT8D, TF30

IV

TF (BPR=4÷6)
TF w/AB (BPR=0.5÷2)

- Axial two spool compressor, OPR=20÷35
- Cooled turbine, TET=1500÷1650 K
- TI-alloy, Ni-alloy, composites

D-36, D-18, PS-90A, D-436, RD-33, AL-31F, D-30F6, CF6, RB211, CFM56, F100, F101, F110, F404/F414, RB199, M53

V

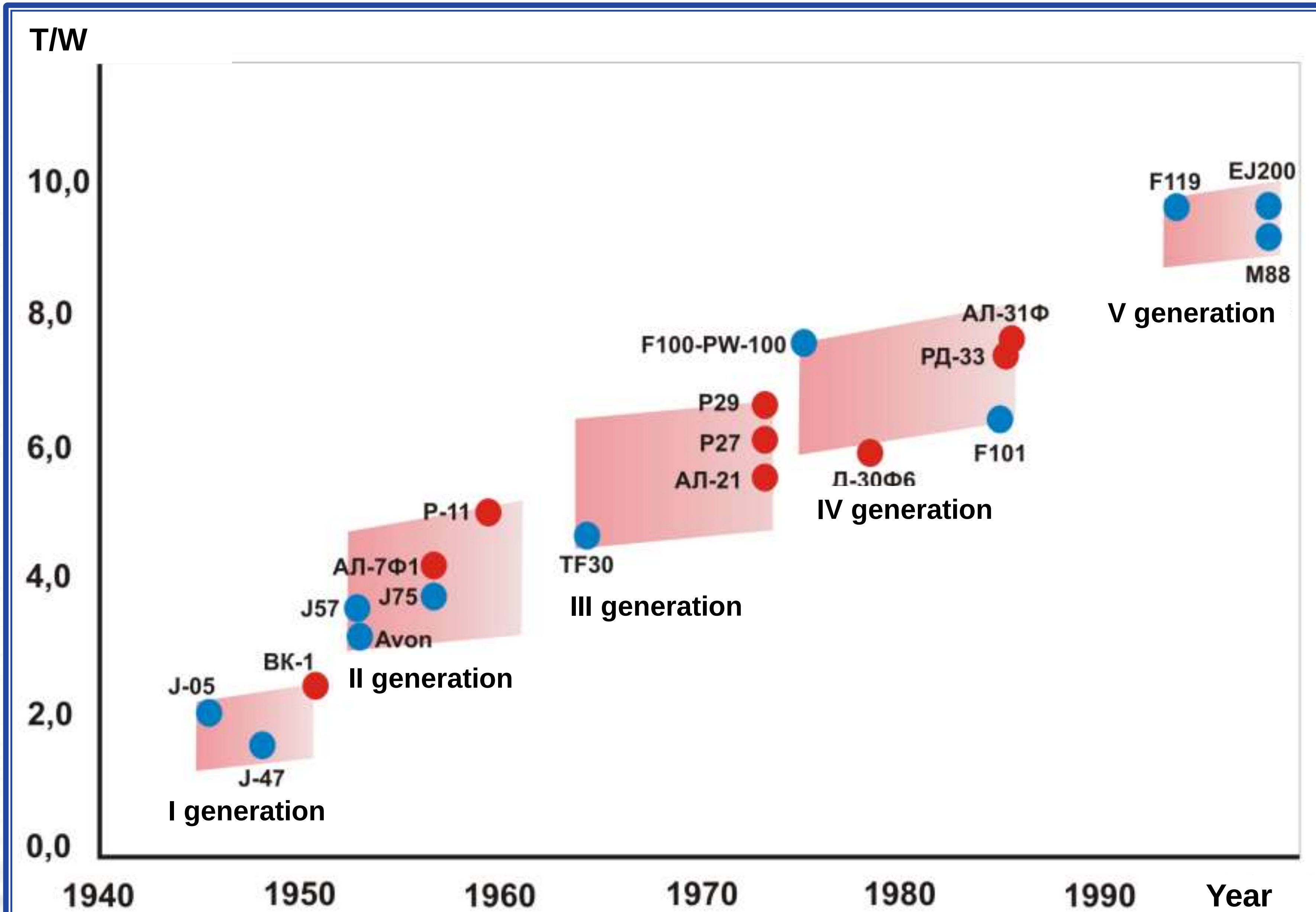
TF (BPR=6÷9)
TF w/AB (BPR<1)

- Axial two spool compressor, OPR=25÷50
- Cooled turbine, TET=1850÷1950 K
- Turbomachinery with low stage count
- Geared drive fan
- TI-alloy, Ni-alloy, TiAl, composites

GE90, Trent, PW4000, F119, EJ200, M88

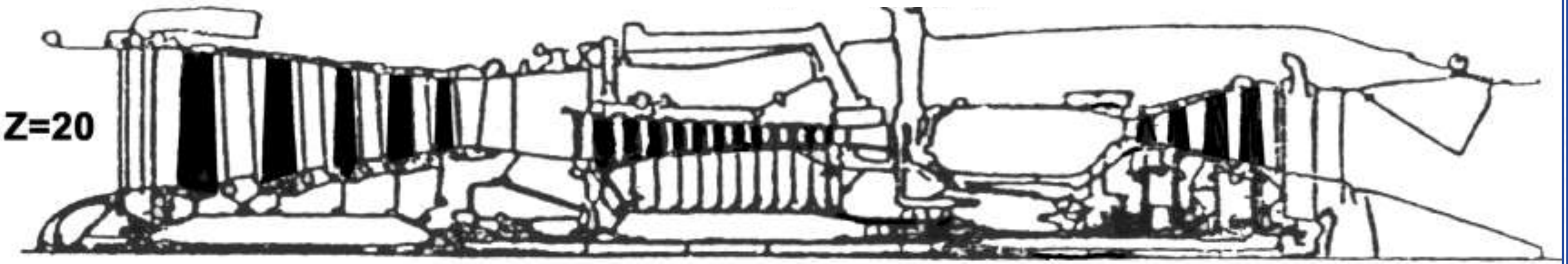
IMPROVEMENT OF THRUST-TO-WEIGHT RATIO FOR AERO ENGINES OF SUPERSONIC AIRCRAFT

RS



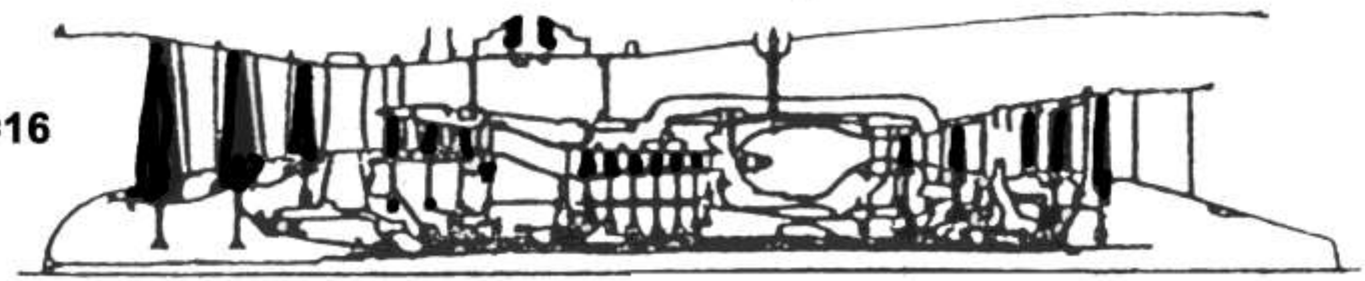
III generation (1960's)

Z=20



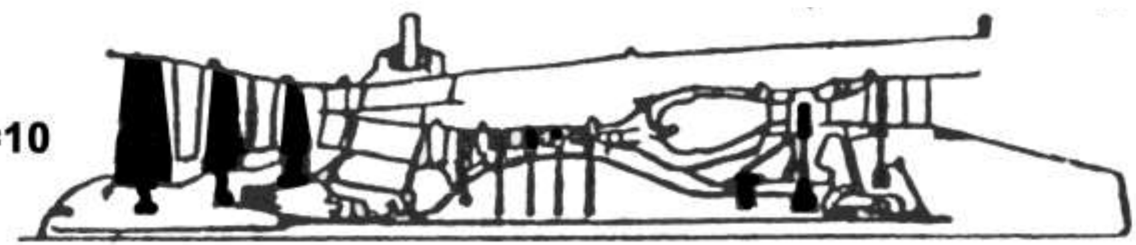
IV generation (1970's…1980's)

Z=16

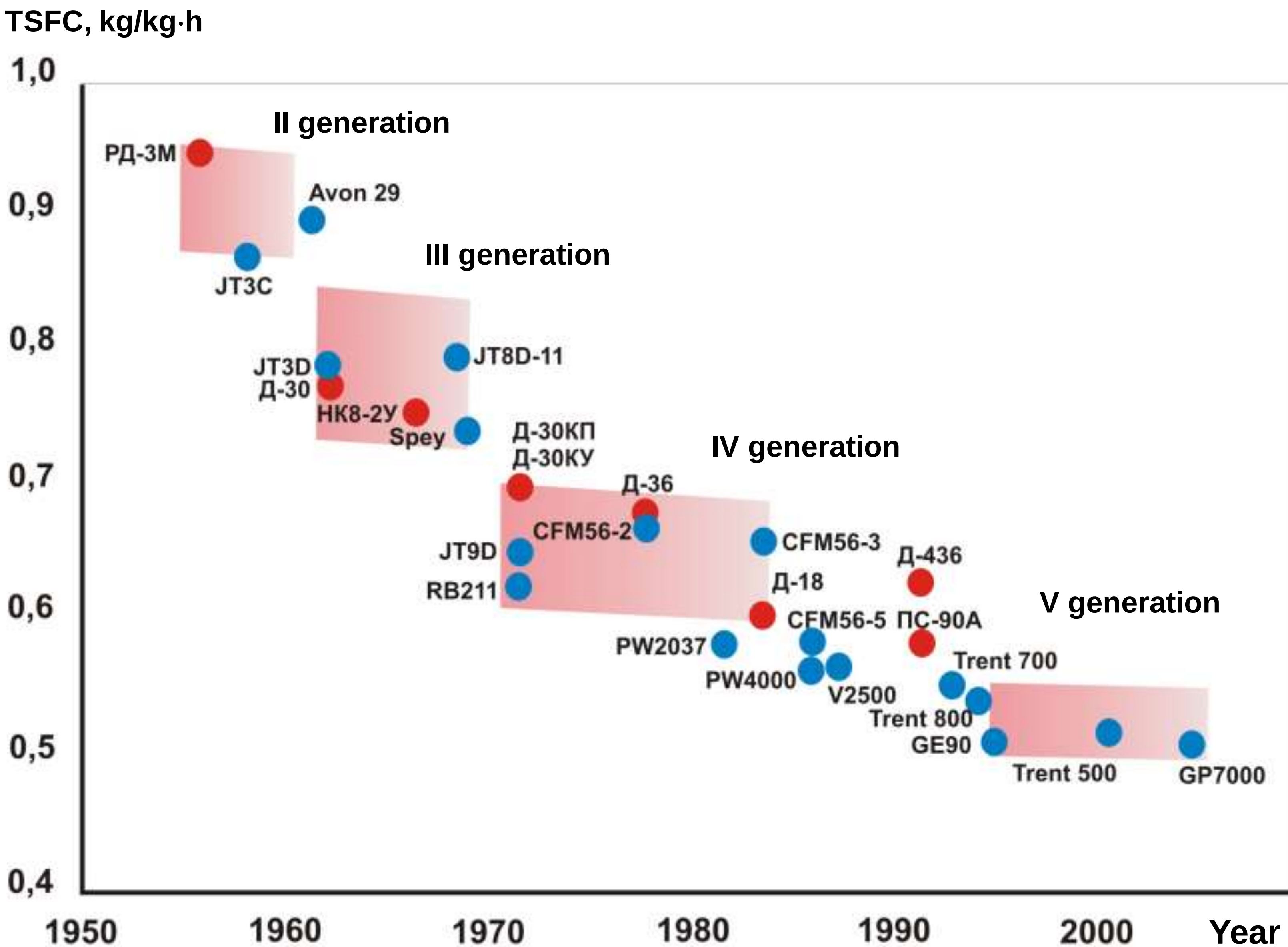


V generation (1990's…2000's)

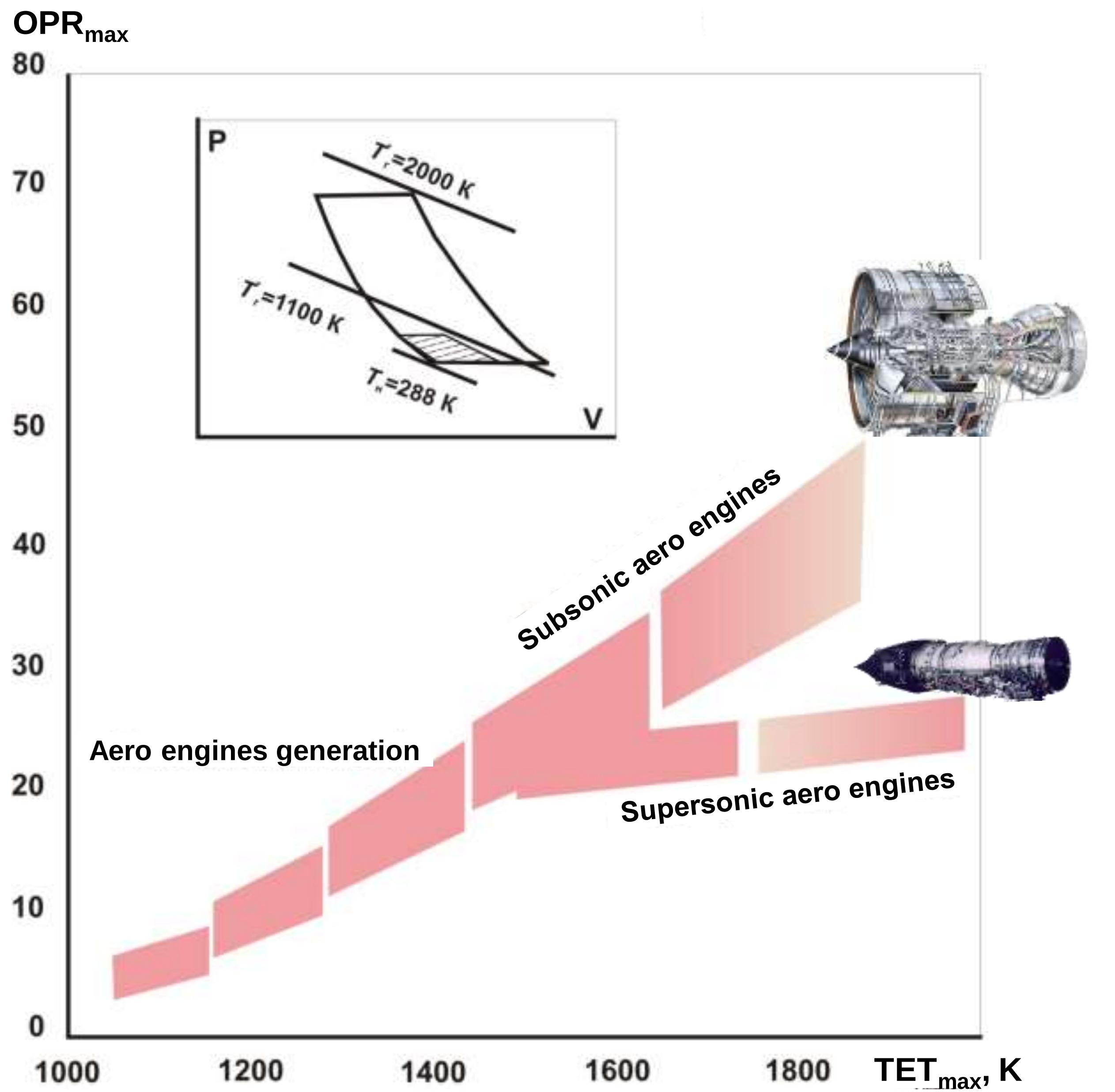
Z=10



IMPROVEMENT OF CRUISE SPECIFIC FUEL CONSUMPTION FOR CIVIL AERO ENGINES

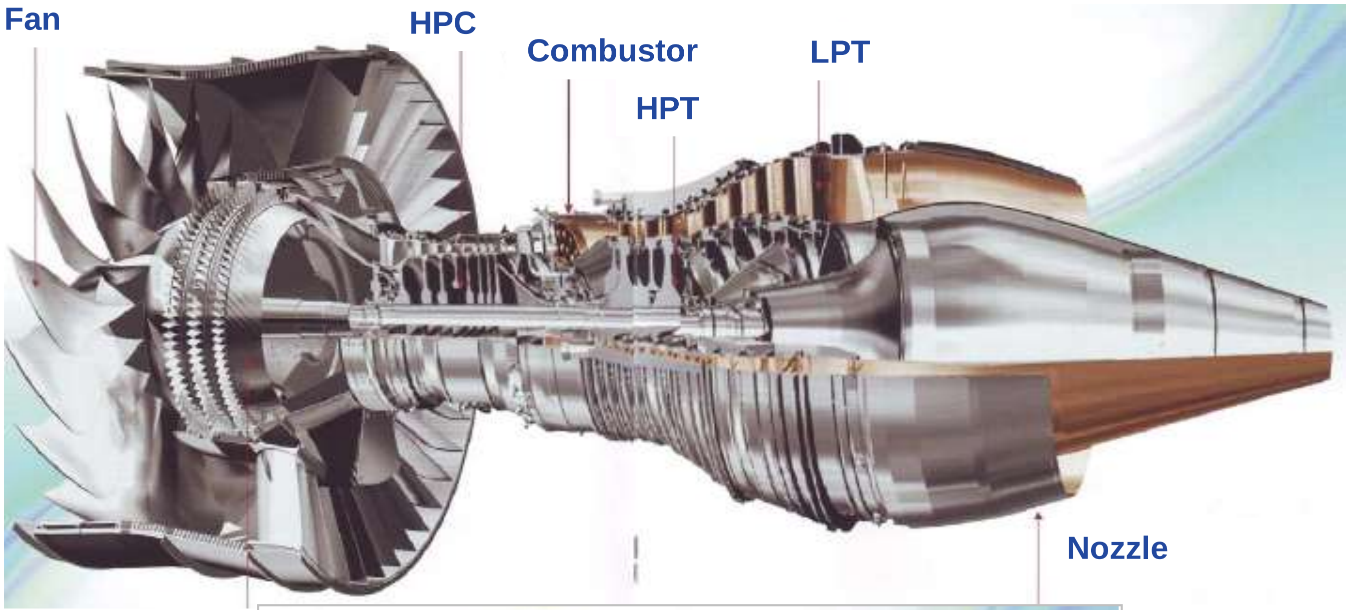


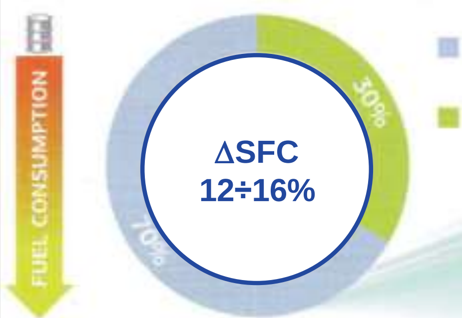
AREAS OF MAXIMUM VALUE OF CYCLE PARAMETERS



NEAR-TERMS CRITICAL TECHNOLOGIES

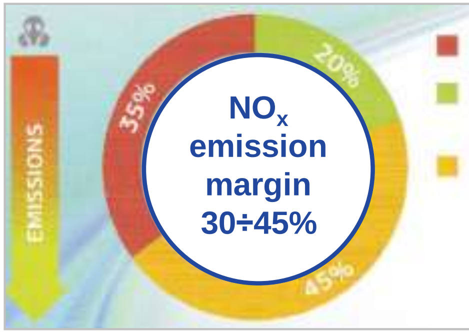
PD-14 TURBOFAN TECHNOLOGIES





Increase of propulsion efficiency:
– high bypass ratio

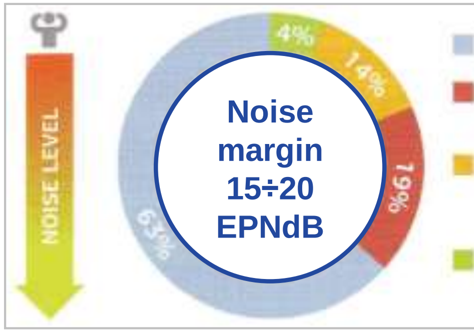
Increase of thermal efficiency:
– 20 to 30% pressure ratio increase
– 2 to 4%of components efficiency Increase



SFC decrease

Use of ceramic composite material in combustor

New type combustor:
– LDI
– multi-module fuel feed



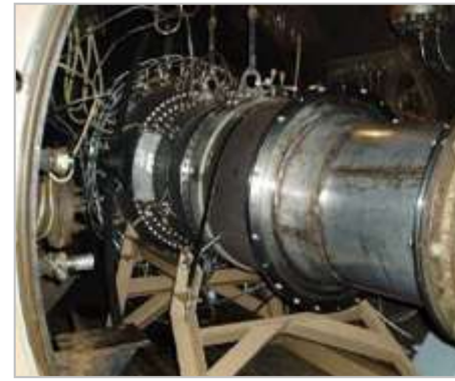
Multilayer acoustic structure

Increase of bypass ratio and transition to another frequency range

Reduction of fan and LPT noise by using new 3D design technique

Use of chevron nozzle

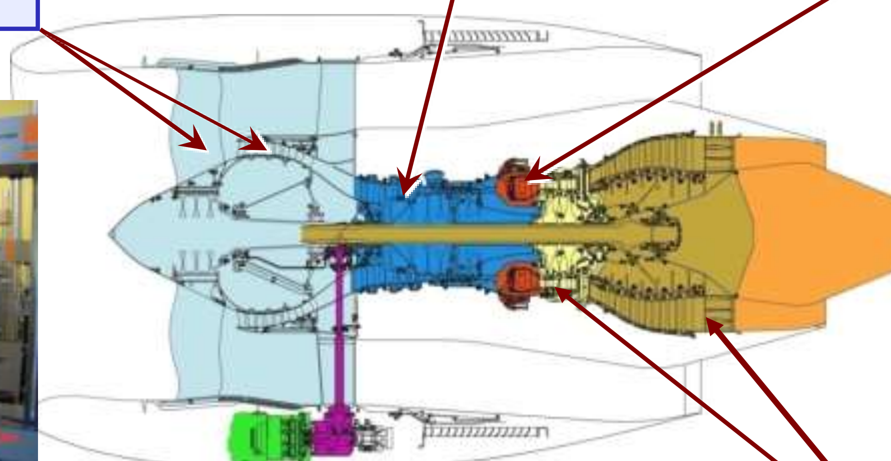
MAIN CIAM ACTIVITY FOR PD-14 ENGINE DEVELOPMENT



LPC
- Aerodynamic design

HPC
- Aerodynamic design
- Gasdynamic engineering

COMBUSTOR
- Definition of design configuration
- Combustor tests at C5-2 test cell



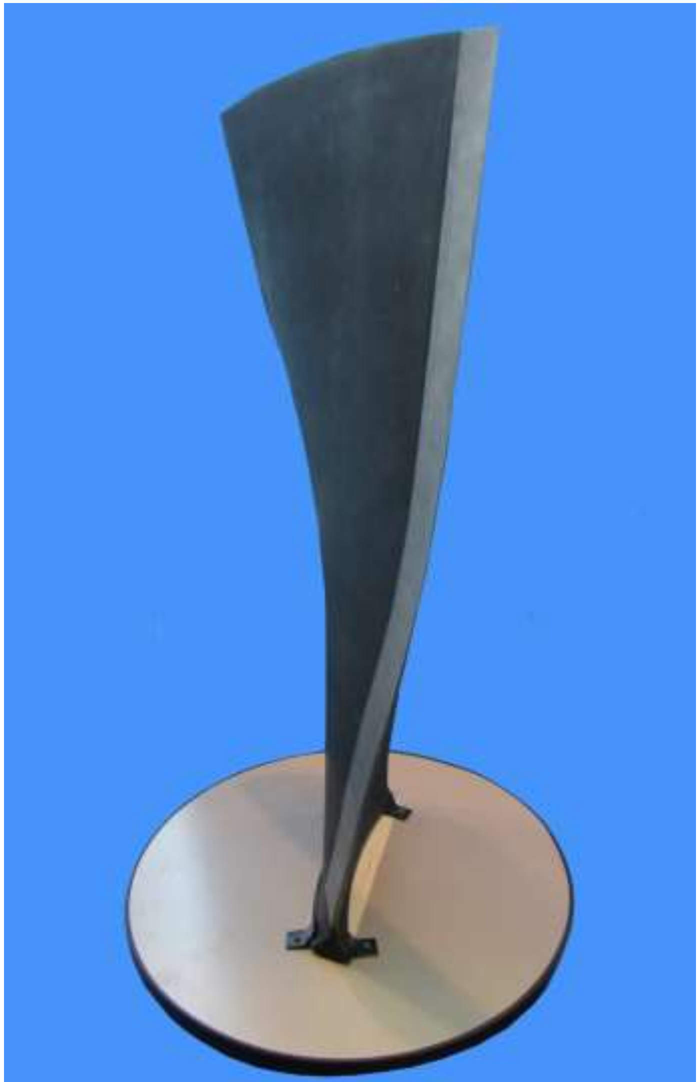
STRENGTH
- Special qualification of materials

AIR SYSTEM
- Recommendations for improvements

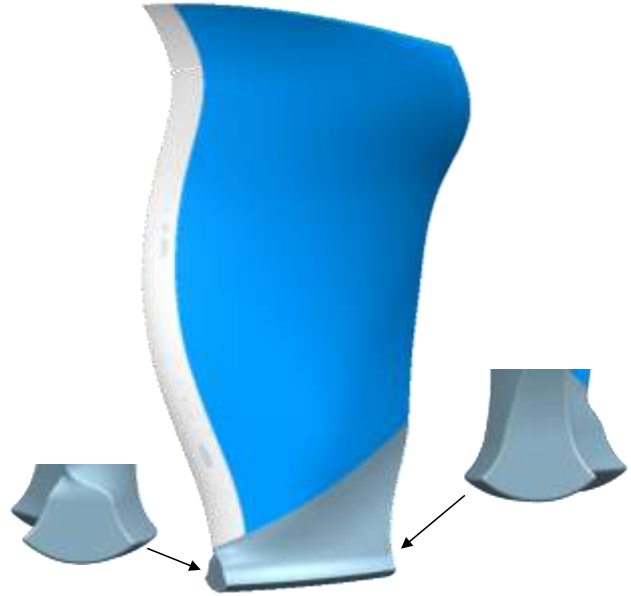
CONTROL
- Mathematical model for FADEC

HPT and LPT
- HPT and LPT tests at TS-2 test cell
- Recommendations

POLIMER MATRIX COMPOSITE WIDE CHORD FAN BLADE



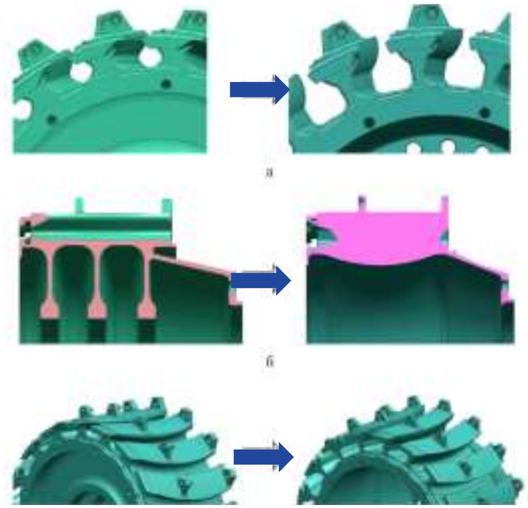
PMC Fan Blade



Fan Blade:

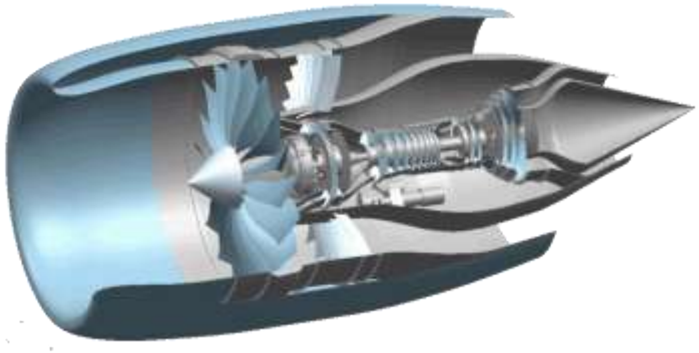
- Blade strength design performed taking into account additional metallic plate on the leading edge
- Root of new type was developed
- Prototype mass is ~65% of hollow titanium blade mass

Ti blade PMC blade



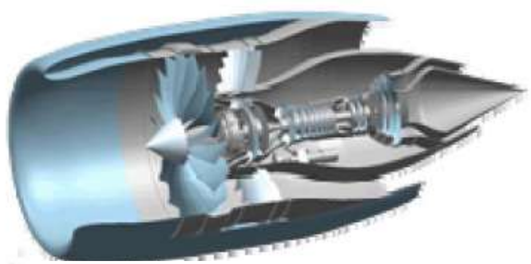
Fan disk:

- Calculation level of stresses is ~20% lower than reference
- No disk hubs
- Increased seating depth and seating width

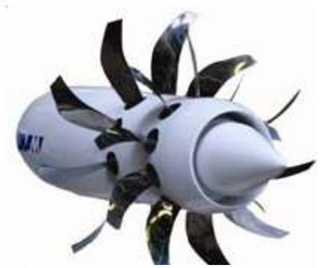


DEVELOPMENT OF LONG-TERMS ADVANCED TECHNOLOGIES

	2015	2020 (Base – 2010 aero engine)	2030
Noise, EPN dB (cum below Stage 4)	15	>20	40
Cruise TSFC reduction, %	10÷15	15÷20	20÷30
LTO NO_x emission (below CAEP/6) , %	30÷45	40÷60	60÷80

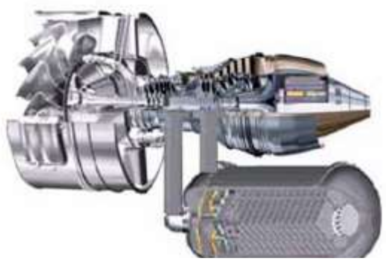


TF / GTF / PDE



Open rotor

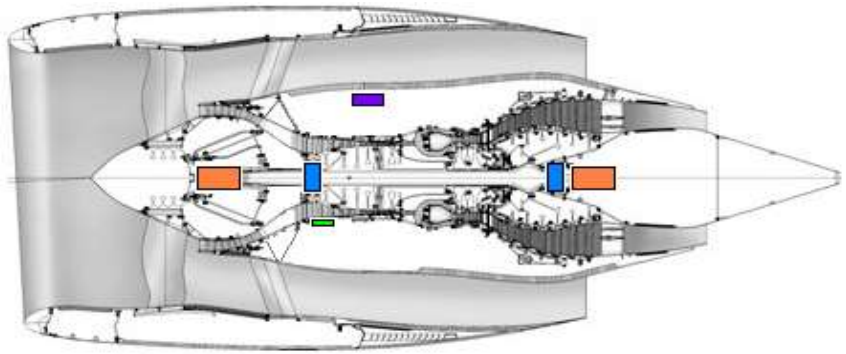
Distributed PS



Hybrid PS

- ❑ Cycle parameters increasing
- ❑ Engine’s units improvement
- ❑ Flow and combustion control
- ❑ Composites
- ❑ Electrical engine
- ❑ Gearbox, pitch change mechanism of fan/propfan

Engine for electrical aircraft – basic power unit



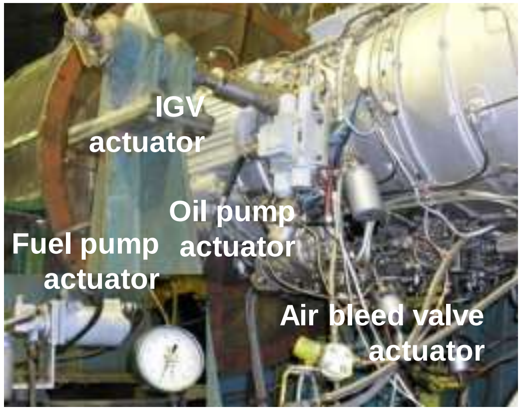
Features

- ➢ No gearbox
- ➢ Electric actuators for fuel pumps and engine units mechanization
- ➢ Integrated internal starter-generator
- ➢ Electric actuator for oil system or magnetic bearings
- ➢ No air bleed for aircraft

Effectiveness

- ❑ Reduction of fuel consumption by 3÷5%
- ❑ 2X increase in reliability
- ❑ 2X reduction in operational costs
- ❑ Reduction in engine mass by 10÷15%

CIAM Activities

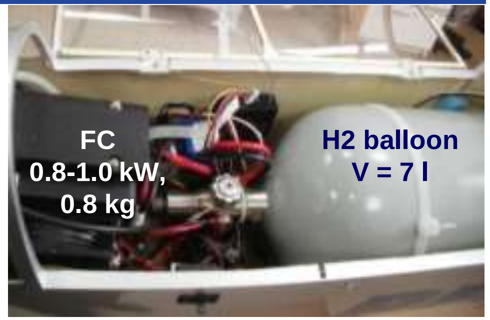


- ➢ Development of concept of electrical GTE
- ➢ In partnership with other enterprises the *DEMONSTRATION SYSTEMS* are designed:
  - electrically driven control system
  - electrically driven fuel feed system
  - electrically driven oil system
  - integrated internal starter-generator
  - magnetic bearing for rotor support
  - electrical actuator with specific weight ~0.5 kg/kW
- ➢ Test cell and engine-demonstrator for testing of electrical driven systems were created

The testing of demonstration systems were carried out

UNMANNED AERIAL VEHICLE WITH FUEL CELL PROPULSION SYSTEM

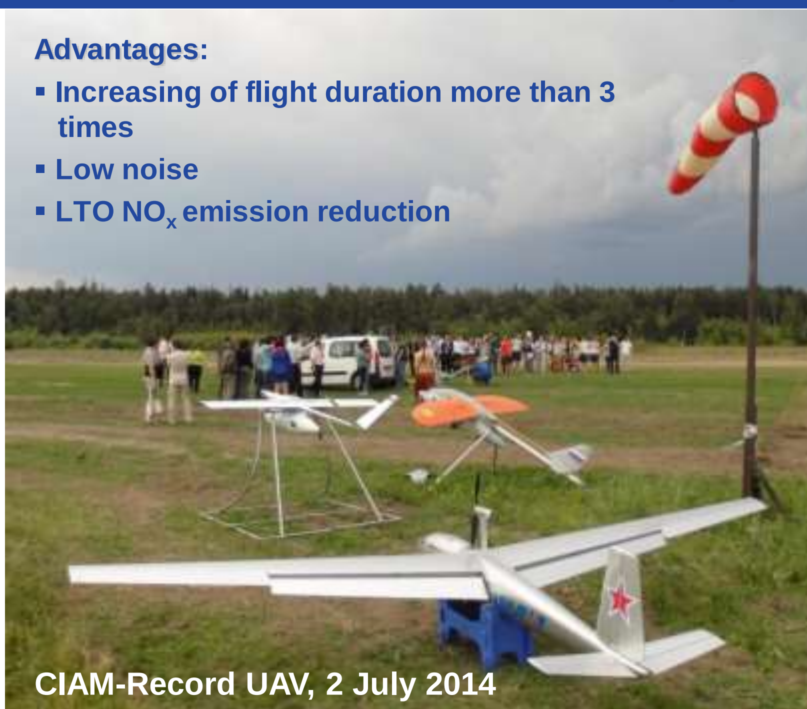
Components of fuel cell propulsion system



First flight in Russia of UAV with fuel cell propulsion system


CIAM-80 UAV, 4 November 2010

CIAM-Record UAV with propulsion system based on Russian fuel cell



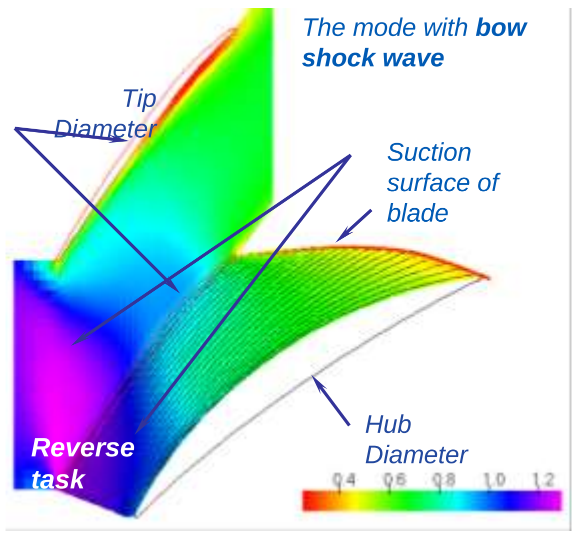
Advantages:

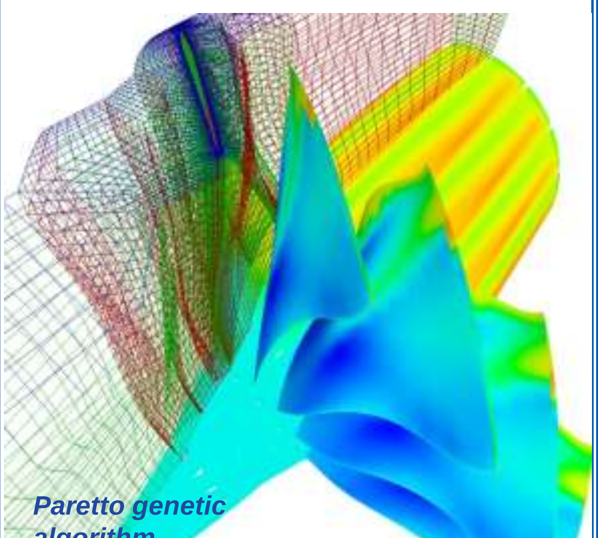
- Increasing of flight duration more than 3 times
- Low noise
- LTO NO_x emission reduction

CIAM-Record UAV, 2 July 2014

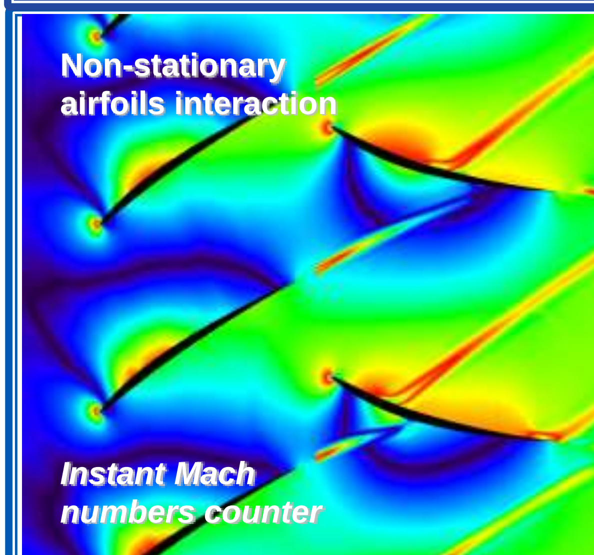
NUMERICAL SIMULATION OF THE AERO ENGINES COMPONENTS

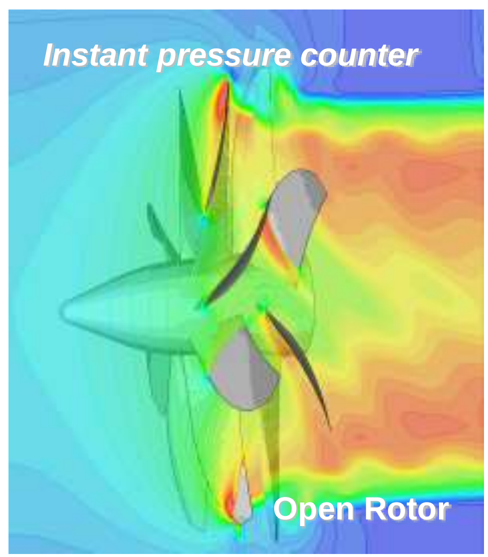
Optimal profiling of fan / compressor airfoils



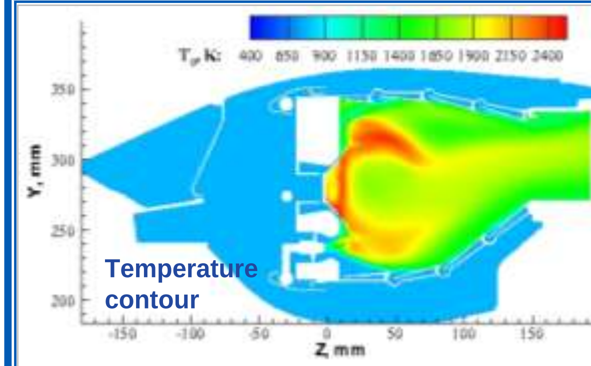


Noise in turbomachinery

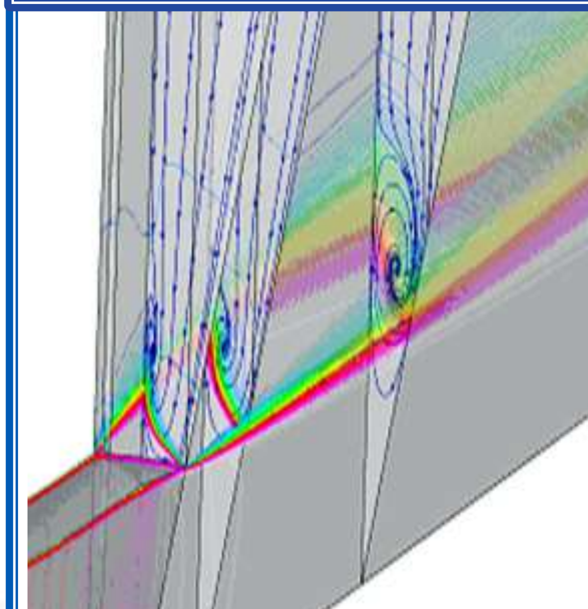




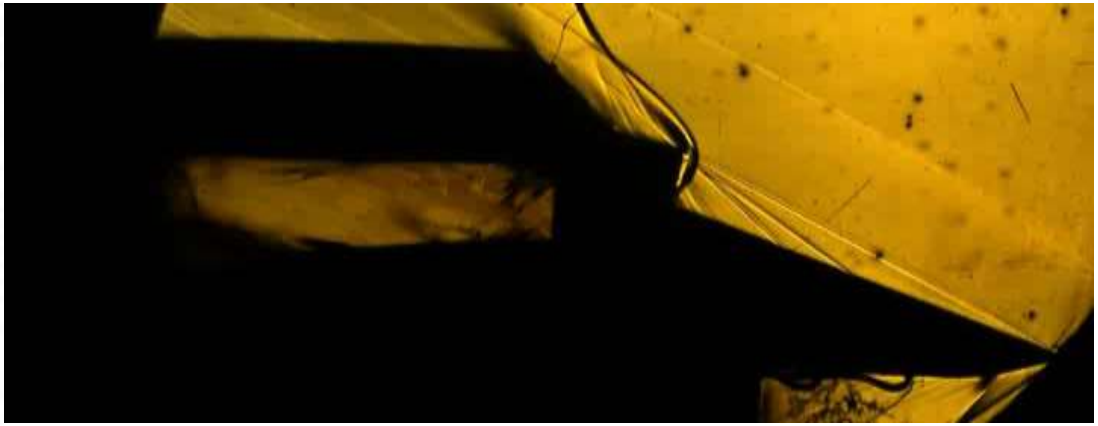
Combustor



Chevron nozzle



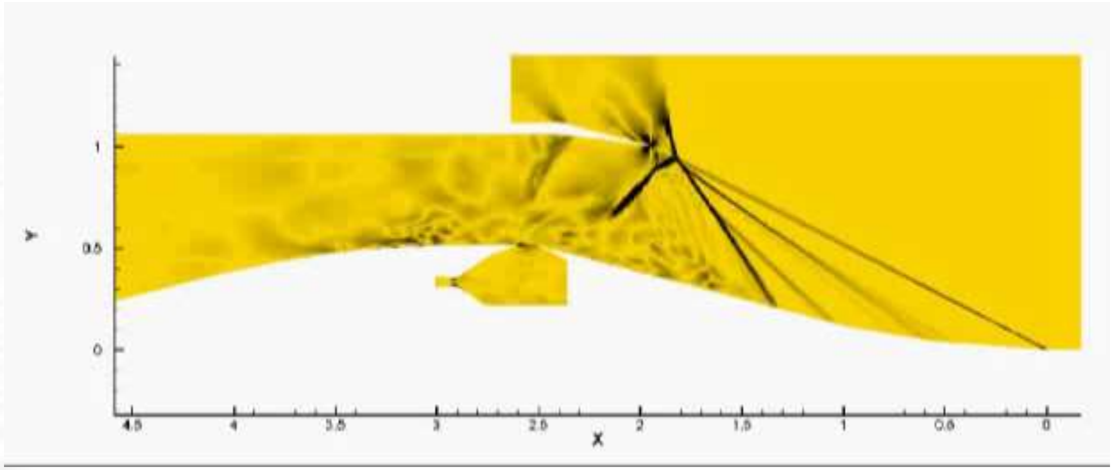
2D inlet model testing



2D Inlet model

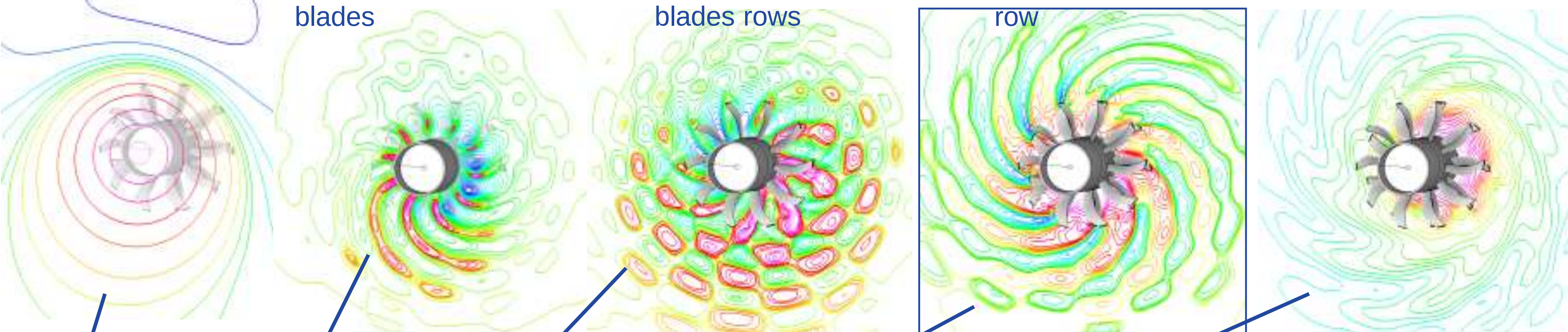
2D inlet model testing (M=2,5)

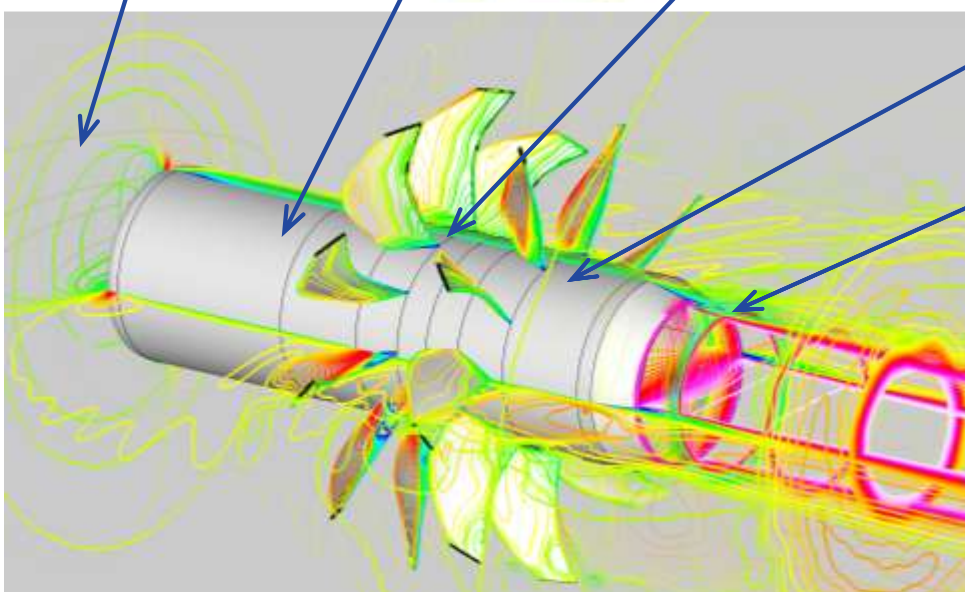
Flow calculation in 2D inlet model (RANS/LES)



Calculation of non-stationary flow in 2D inlet model RANS/LES

M=0.76. angle of attack 3°, instant distribution of static pressure
Grid – 56B cell, 3D non-stationary calculation (URANS)

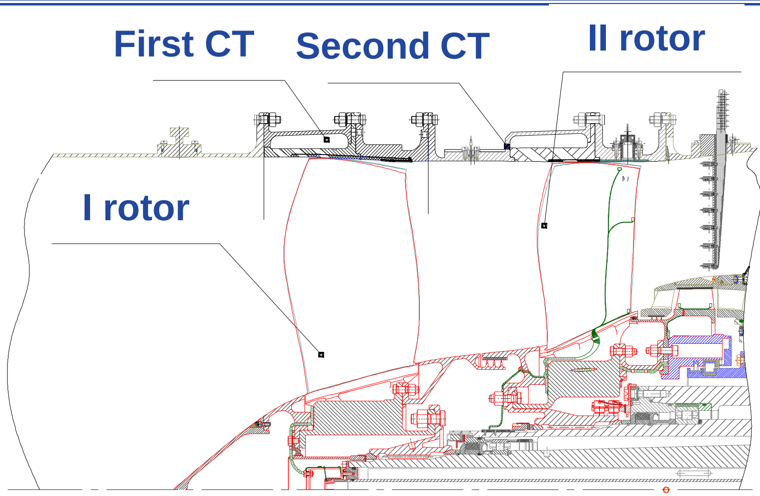


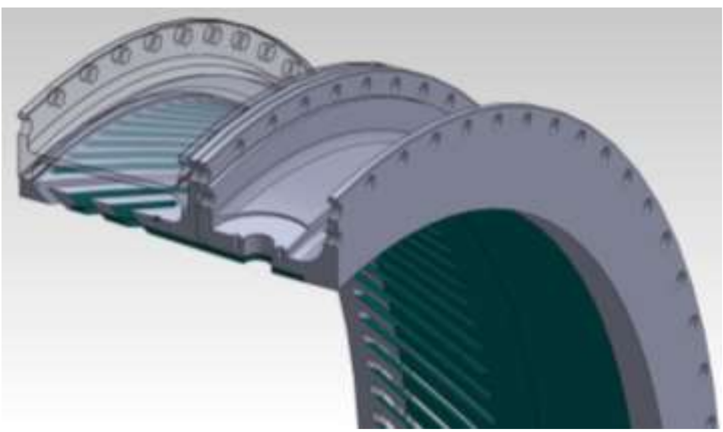


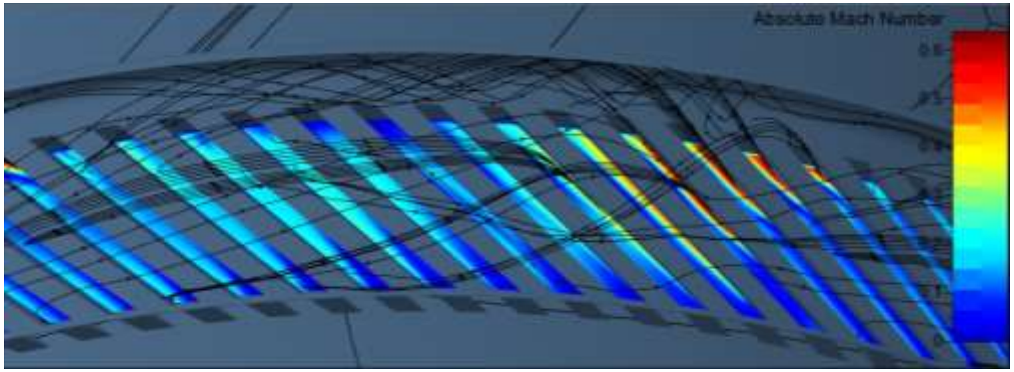
Instant distribution of Mach numbers

Results of 3D optimization:

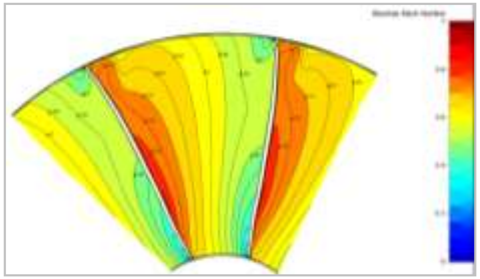
- **high efficiency (>85% on cruise)**
- **thrust increasing by 3%**
- **noise reduction**
- **Integrated aerodynamic characteristics of propfan poorly depend on an angle of attack (M=0.76, AOA=0-4 grad)**
- **Changes of angle of attack leads to fast growth the pulsations of forces and the moments on blades (at the change of angle of attack by 3 grad both the pulsations of thrust and the moments on the row blades have reached 100 % of average value)**
- **The pulsations of forces and the moments on the front row blades twice has more than on the rear row blades**



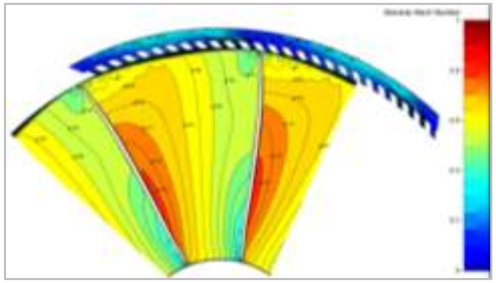




Flow features in case treatment cavities



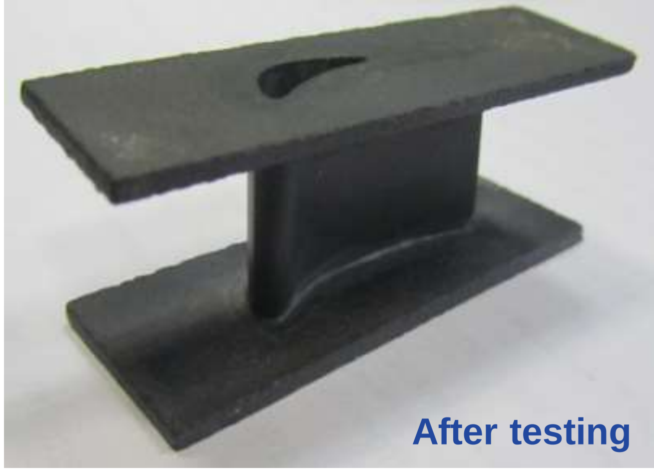
No case treatment



First and second case treatment

- Methodology of new generation case treatment based on 3D non-stationary mathematical model was developed
- New generation case treatment for birotative fans were developed which at the same efficiency provide an increase of stall margin by 4-6% and noise reduction (tone noise – by 4-6 dB; broadband noise – by 2-4 dB)

Testing of HPT CMC vanes at the high temperature



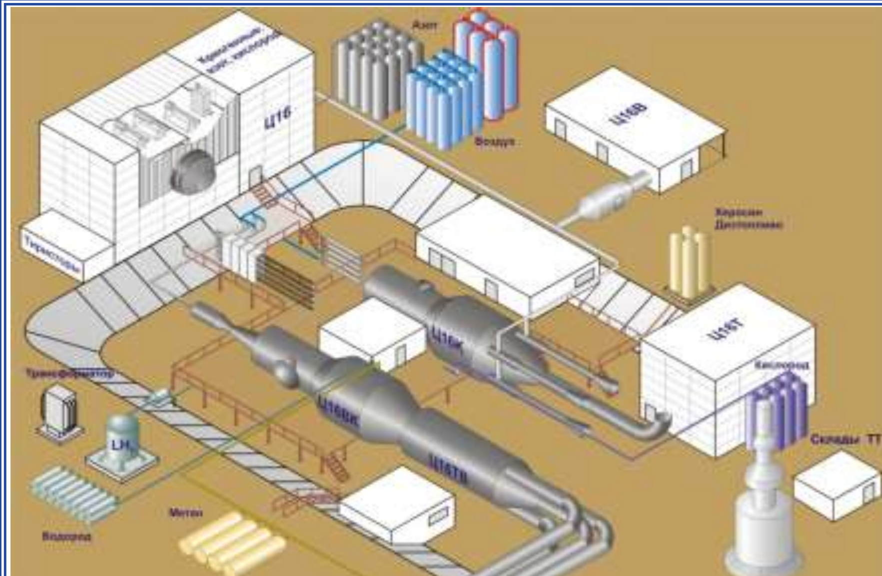
Vane failures of vane after testing are missed

CMC combustor liner testing

 	2015	2020 (Base -- 2010 piston engine)	2030
Increase of Thrust-to-Weight ratio, %	5÷10	10÷15	20÷25
PSFC reduction, %	0	10÷15	15÷20
Service life, moto-hours	>2000	>3000	>4000

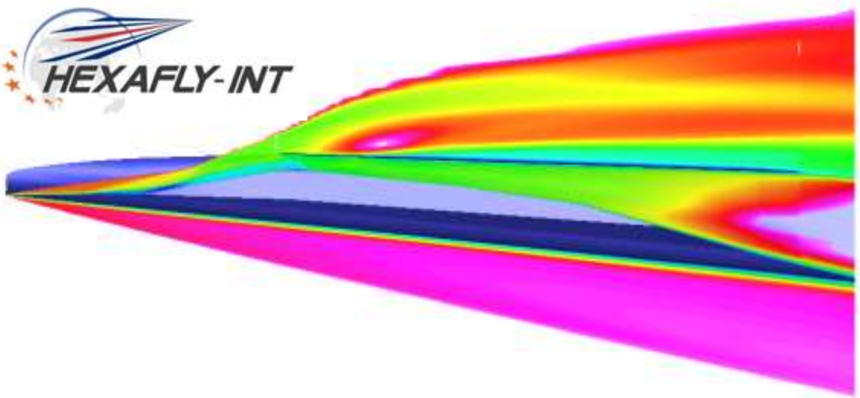
- ❑ Composite pistons
- ❑ Composite cases
- ❑ Direct fuel injection
- ❑ Microprocessor control system
- ❑ Variable charger
- ❑ Multifuel

	2015 г.	2020 г.	2030 г.
Flight range increasing, %	30	50	100
Propulsion system for civil high speed FV (M_f)	-	4÷7	>6÷8



Largest in Europe a test cell for large scale models of high speed flying vehicle testing was built in CIAM (M=6÷8, D_N=1.8 m)

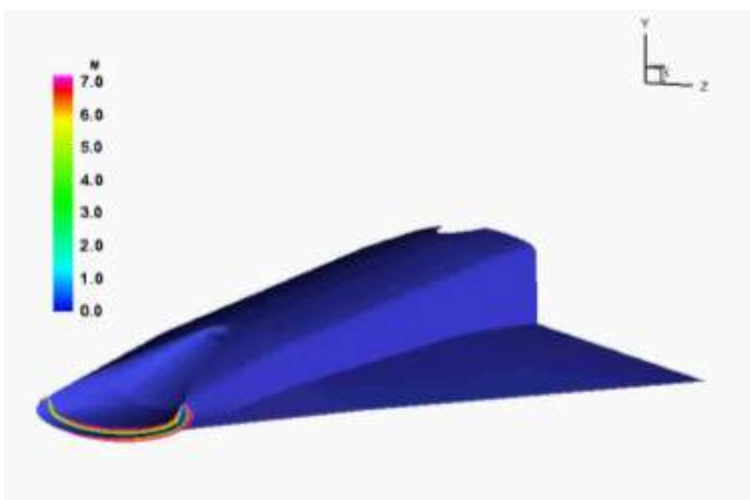
NUMERICAL SIMULATION OF HYPERSONIC FLYING LABORATORY WITH UPPER LOCATION OF HYDROGEN SCRAMJET



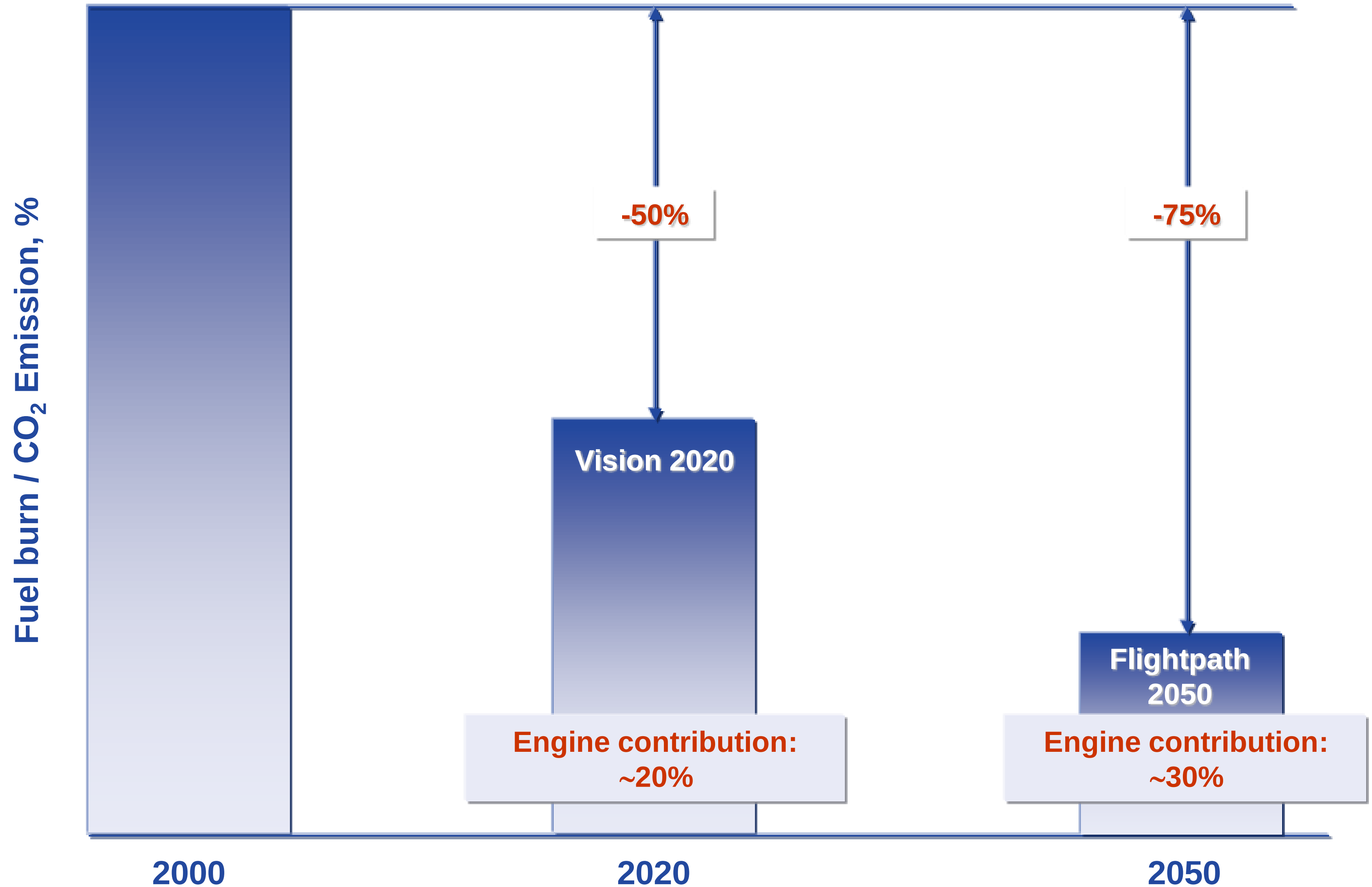
A demonstrator of hypersonic flying laboratory with upper location of hydrogen scramjet is developed in FP7 HEXAFLY-INT project

PROJECT MAIN GOAL:
To demonstrate a positive forces balance at the hypersonic flight speed

Numerical simulation of HFL demonstrator flow (CIAM CFD code)



ENGINE CONTRIBUTION IN IMPROVEMENT OF FUEL BURN AND AND CO_2 EMISSION



Source: ACARE

THANK YOU FOR ATTENTION !

QUESTIONS ?