Aeronautics Challenges & New Opportunities for International Cooperation

Sergey L. Chernyshev
Executive Director
TsAGI
TsAGI: Central Aerohydrodynamic Institute

“ЦАГИ” — The Russian Abbreviation

- Russia’s Leading Aerospace R&D Center
- Over 96 Years of Technology Excellence
- World Largest Testing Facility in Single Location
- Mother Organization for Many Russian R&D Institutes and Design Bureaus
- Training facility for top Russian Technical Universities
- Russia’s ICAS Member since 1970
Aeronautics Early Days: Zhukovsky—Kutta Postulate

$L = \rho \cdot V \cdot \Gamma$

Prof. Nikolay Zhukovsky
1847–1921

Prof. Martin Kutta
1867–1944

1904—1910 publications
Ludwig Prandtl at TsAGI, 1929

“I will always remember with thanks the days I spent in TsAGI. Young Russia can be proud of that Institute wherein serious scientific work in many areas is carried out...

Moscow, September 24, 1929
L. Prandtl”

L. Prandtl’s note in TsAGI Distinguished Guests Book
Theodor von Karman at TsAGI, 1927

“I am glad to visit TsAGI 10 years after I visited it for the first time. I congratulate the leaders and collaborators of that big institution with the progress and successful work carried through that period of time. Russian scientists can excellently combine the mathematical theory with the experimental investigations and put them into practice. This, practically speaking, is one of the reasons for my interest in TsAGI Works and I am glad to have the possibility now to intercommunicate personally with collaborators of this excellent collective.

Theodore von Karman.
June 23, 1937”

Von Karman’s note in TsAGI Distinguished Guests Book
1965 — Russian Top Level Aviation Delegation at ONERA
Back to Our History, 1967 — TsAGI-ONERA

Tu-144 at descent
First flight in Dec 1968

Flatter test of scaled model of the Tu-144 at supersonic wind tunnel T-109
High Speed Flight Research based on the Tu-144 Test Bed

NASA—TsAGI—Tupolev Flight Test Program

- Overall & distributed aerodynamic characteristics
- Thermodynamics and surface temperature measurement
- Take-off and landing ground effect
- Stability and controllability
- Sound radiation and noise management
- In-flight structure aeroelasticity
- Sonic boom
NASA — TsAGI Cooperation in Aeronautics

Dr. Wesley Harris (left)
NASA Associate Administrator
TsAGI, 1999

Mr. Richard Christiansen
NASA Associate Administrator
TsAGI, 1993
Political & Technical Exchanges — the 90s
Russia — US Student Exchange
ONERA — TsAGI Scientific Seminar

2001 — Zhukovsky, Russia
2002 — Chatillon, France
2003 — Zhukovsky, Russia
2004 — Madan, France
2005 — Moscow, Russia
2006 — Paris, France
2008 — Moscow, Russia
2009 — Toulouse, France
2010 — Gelengik, Russia
2012 — Meudon, France
2012 — St. Petersburg, Russia
2013 — Palaiseau, France
2014 — Peterhof, Russia
TsAGI — ONERA Scientific Seminar
Scientific cooperation of TsAGI & ONERA

Denis Maugars Award for young researchers, established in September 2014
TsAGI–DLR Young Scientists Workshop
Moscow-2009, Berlin-2010
TsAGI – CAE Scientific Conference on Aerodynamics, Flight Dynamics, Strength & Structures, Aeroacoustics

Since 2001 held every year alternately in Russia and China

Participants:

Russia: TsAGI, SibNIA, VIAM, MAI, LII etc.

China: SADRI, ASRI, FAI, CFTE, Northwestern Polytechnical University etc.
International Forum for Aviation Research (IFAR)

- The world’s only aviation research establishment network established in 2008
- Aims to connect research organizations worldwide, to enable the information exchange and communication on aviation research activities

- The IFAR focus: non-competitive aviation research related to global technology challenges:
  - Emission
  - Noise
  - Safety & Security
  - Efficient Operations
EU—Russia Cooperation in Aeronautics Research

Technology Seminars - 2006, Brussels

- Russia’s participation in the Framework Programmes
- Main areas of the EC–Russia cooperation in aeronautics
- Prospective joint projects
EU–Russia Cooperation in Aeronautics Research

Technology Seminar - 2007, Moscow

- The main topics of the EC-Russia cooperative research projects of FP7
- Organized by the Russian Agency for Industry with involvement of TsAGI, GosNIIAS, VIAM, CIAM and Sukhoi Civil Aircraft Co.
EU–Russia Cooperation in Aeronautics Research

Technology Seminar - 2010, Moscow

- Improvement of the EU–Russia cooperation in aeronautics research
- Support of the Russian participants involvement in FP7
- Support of the EU–Russia Coordinated Calls, the 3rd Call of FP7
FP Projects with TsAGI Participation
Air Transport System: Aircraft, Airport, ATM

Passenger traffic in Russia, billion rpkm

- 1990
- 2000
- 2010
- 2020
- 2030

200
400
600
# National Plan for Aeronautics Research & Target Goals

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2020</th>
<th>2030</th>
<th>2050</th>
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</thead>
<tbody>
<tr>
<td><strong>Safety</strong></td>
<td></td>
<td></td>
<td>Fivefold accident reduction</td>
<td></td>
</tr>
<tr>
<td><strong>CO₂</strong></td>
<td>−33%</td>
<td>−40...−50%</td>
<td>−70% and more</td>
<td>−75%</td>
</tr>
<tr>
<td><strong>NOₓ</strong></td>
<td>−65%</td>
<td>−78...−80%</td>
<td>−78% and more</td>
<td>−90%</td>
</tr>
<tr>
<td><strong>Noise (relative to Chapter 4 ICAO)</strong></td>
<td>−32 dB</td>
<td>−30...−42 dB</td>
<td>Commeasurable to average city noise level</td>
<td>−65%</td>
</tr>
</tbody>
</table>
Russia: Infrastructure and Climate Challenges

- Areas where air transportation is the only way of mobility
- Area where limited ground transportation is available
Russian National Aeronautics R & T Plan 2025

Total funding — $6 B till 2025, Including $ 200 M for international cooperation

- New configurations
- Better airframe-engine integration, Higher L/D, Lower weight
- UHBR Engines and Integration
- Open rotor
- Alternative fuels
- Pro-composite structures with new structural designs
- Active aeroelasticity
- “Smart” structures
- NG IMA
- Smart cockpit
- NG Systems
- More electric aircraft
### Aircraft 2020: Integrated Technology Demonstrators Higher TRL

<table>
<thead>
<tr>
<th>New configurations</th>
<th>NG Aerodynamics</th>
<th>Engines &amp; integration</th>
<th>Advanced materials &amp; structures</th>
<th>Avionics &amp; systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide body A/C</td>
<td>Advanced wing with higher aspect ratio</td>
<td>Turbofan:</td>
<td>Pro-composite structure</td>
<td>Advanced avionics, IMA-2</td>
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<tr>
<td></td>
<td>Laminar flow</td>
<td>– UHBR</td>
<td>Active aeroelasticity</td>
<td>Smart control system</td>
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<tr>
<td></td>
<td>Ultra high aspect ratio braced wing</td>
<td>– Mixed thermodynamic cycle</td>
<td>Hybrid metal/composite structure</td>
<td>More electrical aircraft</td>
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<tr>
<td></td>
<td>Blended wing body</td>
<td>– High thrust to weight ratio</td>
<td>Ultra high aspect ratio braced wing</td>
<td>Heat &amp; energy balance</td>
</tr>
<tr>
<td></td>
<td>Active flow control</td>
<td>– Distributed Power Plant</td>
<td>Morphing structures</td>
<td></td>
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<tr>
<td></td>
<td>Natural/hybrid laminarization</td>
<td>Turboprop:</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>High lift system for STOL</td>
<td>– Open rotor</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Low noise &amp; low sonic boom configuration</td>
<td>– Low noise propellers</td>
<td></td>
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<tr>
<td>Green regional aircraft</td>
<td></td>
<td>Engine/airframe integration:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low boom supersonic business jet</td>
<td></td>
<td>– Over the BWB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STOL transport aircraft</td>
<td></td>
<td>– In the fuselage tail</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Over the wing</td>
<td></td>
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<td></td>
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<td>Distributed air intakes</td>
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<td></td>
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<td>Low noise nozzles</td>
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</table>
Innovations for BWB Aircraft

- Active load control system
- Engines upper mount for noise screening
- UHBR Engine
- Low-emission combustion chamber
- Fuel cells APU
- Laminar nacelles
- Pro-composite airframe structure (including 3D stitching, isogrid)
- More electrical aircraft concept
- Riblets on central airframe surface
- Intelligent control system
- Flow control system
- Natural/hybrid LFC
- Morphing structures,
Wing Active Flow Control System

Using jet blowing system provides:

<p>| | |</p>
<table>
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<tr>
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<tbody>
<tr>
<td>Speed and range increase</td>
<td>8–10%</td>
</tr>
<tr>
<td>Fuel burn reduction</td>
<td>–(5–7)%</td>
</tr>
<tr>
<td>Take-off and landing speeds reduction</td>
<td>–(10–15)%</td>
</tr>
<tr>
<td>Runway length reduction</td>
<td>–(30–35)%</td>
</tr>
</tbody>
</table>

Laminar airfoil

\[ M_1 > 1 \]

\[ K = 1.2 \]

\[ M = 0.78 \]

\[ \Delta K = 1.2 \]
Numerical and Experimental Research of Power Plant Integration
Advanced Aircraft Structures

- Light and reliable discrete designs for Integral airframe structure
- New generation hybrid structures for critical units
- Integrated active load control and comfort improvement system
- Individual loading and health monitoring in real operation condition
- Adaptive morphing structures using “smart materials”
Composite Geodesic (Isogrid) Integrated Structures

Benefits of the new structures
• Up to 10-12% weight reduction.
• Long lasting reliable FOD protection
• Up to 40% less junction weight compared to “black metal”.

Main structural elements
1. Lattice structure instead of traditional skin panels.
2. Elastic internal skin for pressurization.
3. Elastic external skin forming aerodynamic surface.
4. Stiff frames with strong and reliable junctions.

EU FP-7 Projects: Alasca & PolarBear
Test Facility for Composite Fuselage Barrel

Lattice fuselage barrel (inside view)

Validation of the structural modeling at the TsAGI test facility
High Aspect Ratio Composite Wing-box Prototype Testing

- Central airframe simulator
- Pylon simulator
- Finite element model of the wing-box (169373 nodes, 192644 elements)
- Stress and deformation on the lower panel
FEM modeling of the Composite Wing-box Stress & Deformation

Modeling foreign objects damage on the upper wing surface

Mathematical modeling visualization
Flight Safety

- angle of attack
- limiting of normal load factor
- limiting of sideslip angle
- airspeed and Mach number limiting
- pitch angle limiting
- bank angle limiting
- pitch and bank angle limiting
- landing
- take-off
Upset Recovery in FP7 SUPRA 2010—2012

- Loss of control in upset conditions.
- To improve pilot training for upset recovery.
- Pilot training based on flight simulator.

SUPRA achievements:
- New A/C dynamic mathematical models in extended flight envelope.
- Motion cueing concept to extend the capabilities of hexapod flight simulators.
ALICIA: 4-D Trajectory Management & Optimization

- 4-D navigation with minimum fuel consumption
- Mostly vertical maneuvering \( (n_z \leq 1.2) \)
- Continuous descent profile of the type “CAS-M-CAS”

Integration of trajectory algorithms

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This poster is produced under the EC contract ACP8-GA-2009-233682
SimSAC: Stability & Flight Control Analysis

TsAGI tasks in the project:

- Software to assess the stability and controllability of A/C
- Wind tunnel tests for aerodynamic stability analysis
- Software for flight control system synthesis
Wake Vortex Safety / ICAO WTSG

Wake length - 40 km
Duration - 3 minutes
Separation Distance Due to Wake Vortex Safety

Flight experiment CFD calculations

Safety matrix (ICAO)
Modeling Emission over Russian Territory

- Stratosphere: NOx → Ozone layer destruction
- Troposphere: CO₂, NOx, H₂O → Climate change
- Ground layer: Noise Emission → Impact near ground surface

CO₂ emission, Mt

modeling ↔ forecast

years
Fuel Burn Target Goals for Narrow Body Aircraft

MC21-200/-300 family: composite wing (black metal) having a higher aspect ratio, new engine.

B737MAX и A320NEO families: more efficient wing tips, new engine.

Innovations introduced in re-engined versions of narrow body families are not sufficient to meet the fuel burn target goals for N+1 generation.
“Alternative” Fuel: Gas-to-Liquid (GTL)

GTL fuel is «greener» compared to conventional kerosene:

• 5–10% less CO$_2$ emission
• less NO$_x$ & CO emission
• Much less soot

Thermal wakes from torches
Existing GTL Fuel Demonstrators & Future Projects

Mil-8GTL

Ilyushin-114

Tupolev-206

Tupolev-336
HISAC — Low Boom Supersonic Business Jet
Low Sonic Boom Supersonic Business Jet

Contribution of TsAGI:

- sonic boom criteria
- sonic boom and aerodynamic modeling
- design of low-boom a/c configuration;
- MDO analyses

Pressure Signatures and Sonic Boom Loudness

<table>
<thead>
<tr>
<th>Altitude, м</th>
<th>Volume L, dBA</th>
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<tbody>
<tr>
<td>12000</td>
<td>Neutral (L &lt; 72 dBA)</td>
</tr>
<tr>
<td>14000</td>
<td>Good (L &lt; 65 dBA)</td>
</tr>
<tr>
<td>16000</td>
<td>Neutral (L &lt; 72 dBA)</td>
</tr>
</tbody>
</table>

$P$, Pa

$G = 51$ ton

$G = 58.5$ ton

$G = 56.5$ ton

$t$, s
Main objective:
Free flight demonstration of radically new conceptual design of hypersonic vehicle based on integration of a highly efficient hydrogen propulsion unit with a high-lifting concept.
TsAGI: Minding the Future of Flight

I invite you to fly together into the future