Russian approach to Aircraft Design and Aeronautical Education

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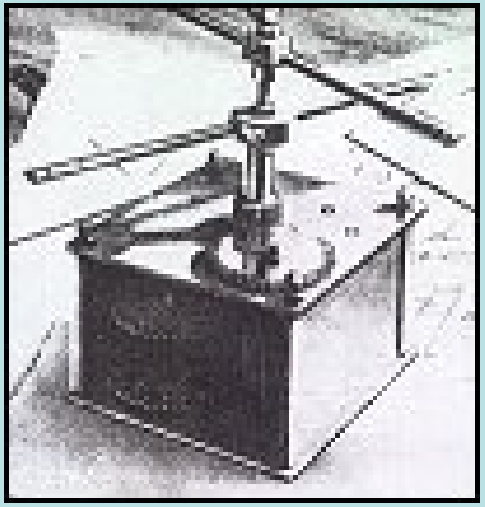
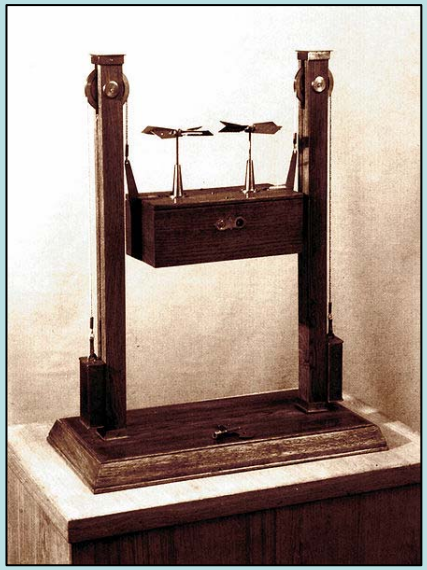
1.1. Fist steps, problems and achievements

The Model of The First Russian Aircraft

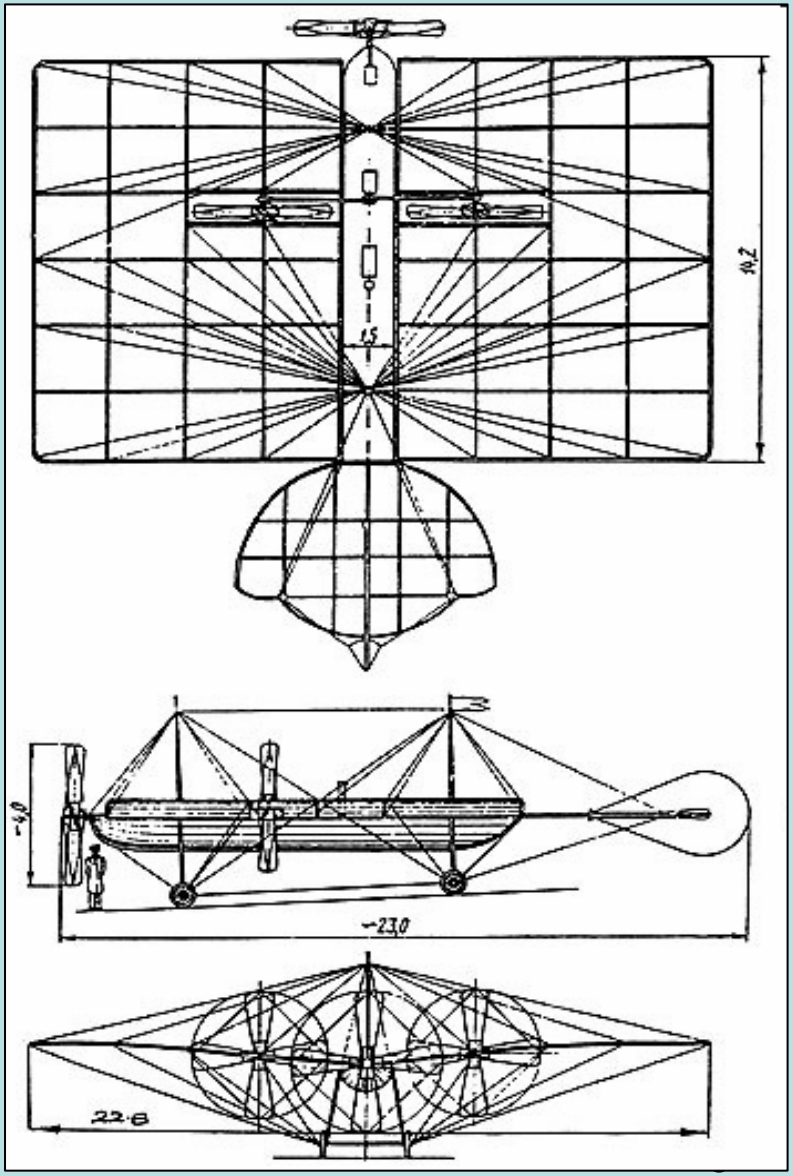
In 1754 the distinguished Russian scientist Mikhail Lomonosov created a model of a helicopter.





Who got into the air first?

In 1881-1885 the Russian engineer A.F. Mozhaisky designed and manufactured the first Russian full-scale airplane with two propellers and two **steam engines**. The airplane passed the ground tests and took off successfully, but crashed on landing.

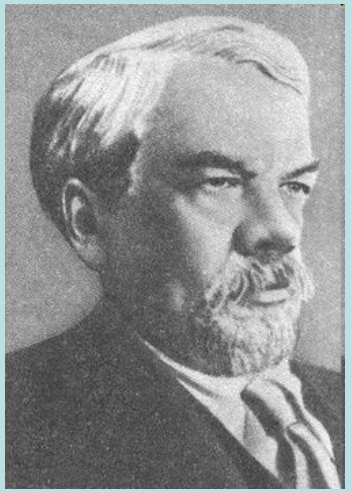


The First Russian Aeronautical Scientific Research

In 1897-1910 the famous Russian aeronautical scientists Nikolai Zhukovsky and Sergei Chaplygin made a research, which was very important for development of the basis of aerodynamics science.

Their fundamental published works are:

- About the optimal angle of attack of an airplane (1897, N. Zhukovsky)
- About jet flow (1902, S. Chaplygin)
- About attached vortex (1905, N. Zhukovsky)



First Steps Russian Aeronautical Education in Moscow University

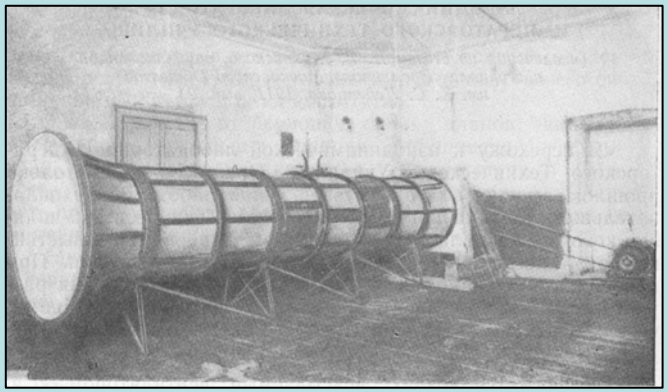
Professor Zhukovsky

1886 – started to lecture a course on Hydrodynamics;

1889 – began the aeronautical research at the Applied Mechanics Laboratory of Moscow University;

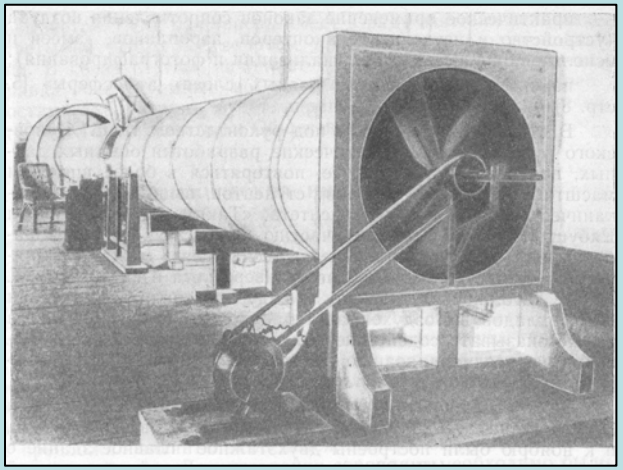
1902 – founded an aerodynamics laboratory, which was equipped with:

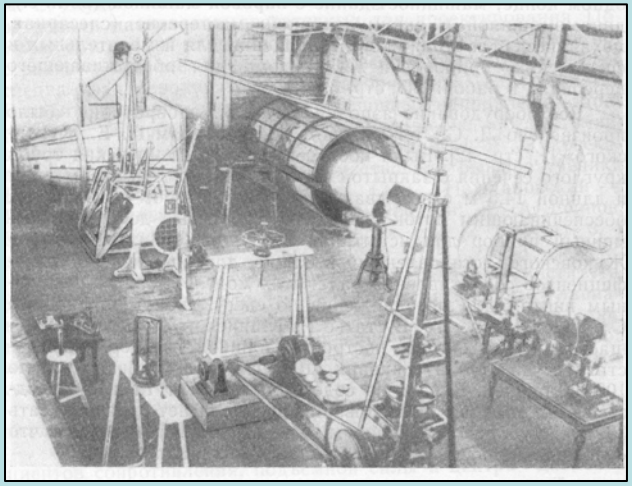
- a wind tunnel,
- a device for testing airplane propellers.



The Beginning of Russian Aviation Science and Education

1904 – Dmitriy Ryabushunskiy created Aerodynamics Research and Development Institute under the supervision of Professor Zhukovsky. This was one of the first Research Institutes in the world, which was situated in the village of Kuchino near Moscow.





First Steps Russian Aeronautical Education in Technical Universities

In Moscow Technical University

Professor Zhukovsky

1908 – created the Aeronautical Society

1909 –started to lecture a course on “Aeronautics”

1910 – created the aerodynamics laboratory

1916 – created the Aeronautical Research and Development Department

1919 – created Moscow Aviation College

Other Russian TechnicalUniversities

1909 – Beginning the training of aeronautical engineers at St. Petersburg Polytechnic University.

1919 – Creation of the Aeronautical Faculty of Donskoy Polytechnic University.

1921 – The start of preparation of aeronautical engineers at Kiev Polytechnic University.

1923 – Creation of the Aviation Faculty of Kharkov Teichnical Institute.

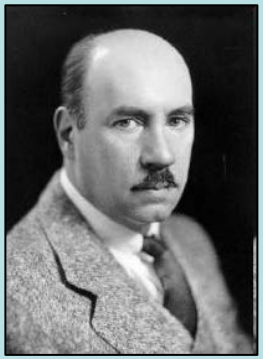
Russian Aviation Industry during World War I

- In 1913 Russia manufactured 270 airplanes.
- Fast growth of Russian aviation industry during World War I:
  - in 1914 1,871 workers
  - in 1917 7,385 workers

  were employed by aviation plants.
- During the period from 1914 to 1917 Russia manufactured 5,565 airplanes on:
  - 17 airplane manufacturing plants;
  - 7 aviation engine manufacturing plants;
  - 3 propeller manufacturing plants;
  - 1 aircraft instrument manufacturing plant.

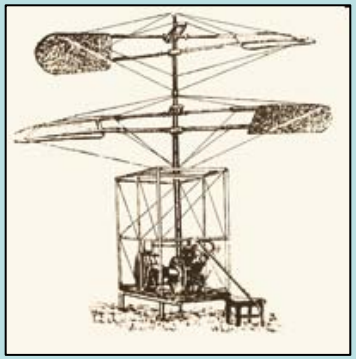
A Lot of Russian Aviation Specialists were Forced to Leave the Country after 1917

Igor Sikorsky – the creator of "Iliya Mutomets" airplane, the creator of the first serially manufactured helicopters in USA and the founder of the "Sikosky" helicopter company.



Igor Sikorsky

"Ilya Muromets", 1913



The first Sikorsky helicopter, 1909

Alexander Prokofiev-Seversky **– designer of P-47 "Thunderbolt";**

Alexander Kartveli **– designer of P-47 "Thunderbolt", F-84 "Thunderjet", F-105 "Thunderchief";**

Mikhail Strukov **- founder of the "Chase" aircraft company, designer of C-123 "Provider" and YC-134;**

Mikhail Watter **–designer of 02U Corsair, 03U, X04U; "Martin B-10", "Martin 170 Mars","Martin 162 Mariner", "Budd RB1 Conestoga"… and thousands of others.**

Main Milestones of Russian Aviation Science and Education, 1918-1920

1918 –1930 foundation of

- The Central Aerohydrodynamics Institute (TsAGI). It was headed by Professor Zhukovsky.
- CIAM – the Central Institute of Aviation Motor-Building
- VIAM – the All-Soviet Union Institute of Aviation Materials
- The Flight Test Department of TsAGI (later became LII – Flight-Research Institute)
- Foundation of aeronautical faculties in universities.

Assimilation of Western experience

Invitation of Foreign Aviation Designers to Russia

A number of future chief designers of Soviet aircraft firms worked under the supervision of famous French designer ***Paul Richard*** in his Design Firm in USSR in the end of 1930th and gained experience: Lavochkin, Kamov, Korolev, Beriev etc.

Roberto Oros di Bartini left Italy and came to USSR in 1923. He became a well-known aircraft designer and scientist. Bartini was imprisoned from 1938 till 1946. He worked in CKB-29 with Tupolev and other designers. Bartini created over 60 projects of various aircraft, many of which were unique.

Roberto Oros di Bartini

Vertical Take-Off Aerodynamic Ground-Effect Craft VVA-14 by Bartini

Licensed of Douglas DC-3 (Li-2) American Cargo-Passenger Airplane

The documentation and drawings of the initial DC-3 were revised with the purpose of converting all dimensions and material thicknesses into metric measurement system. This revision also included a careful reevaluation of all structure elements according to the Soviet strength standards.

The airplane was serially manufactured in USSR since 1938.

Repressions of the Russian Aircraft Designers and Scientists since 1929

First wave of arrests of Russian aircraft designers was in 1929-1931.

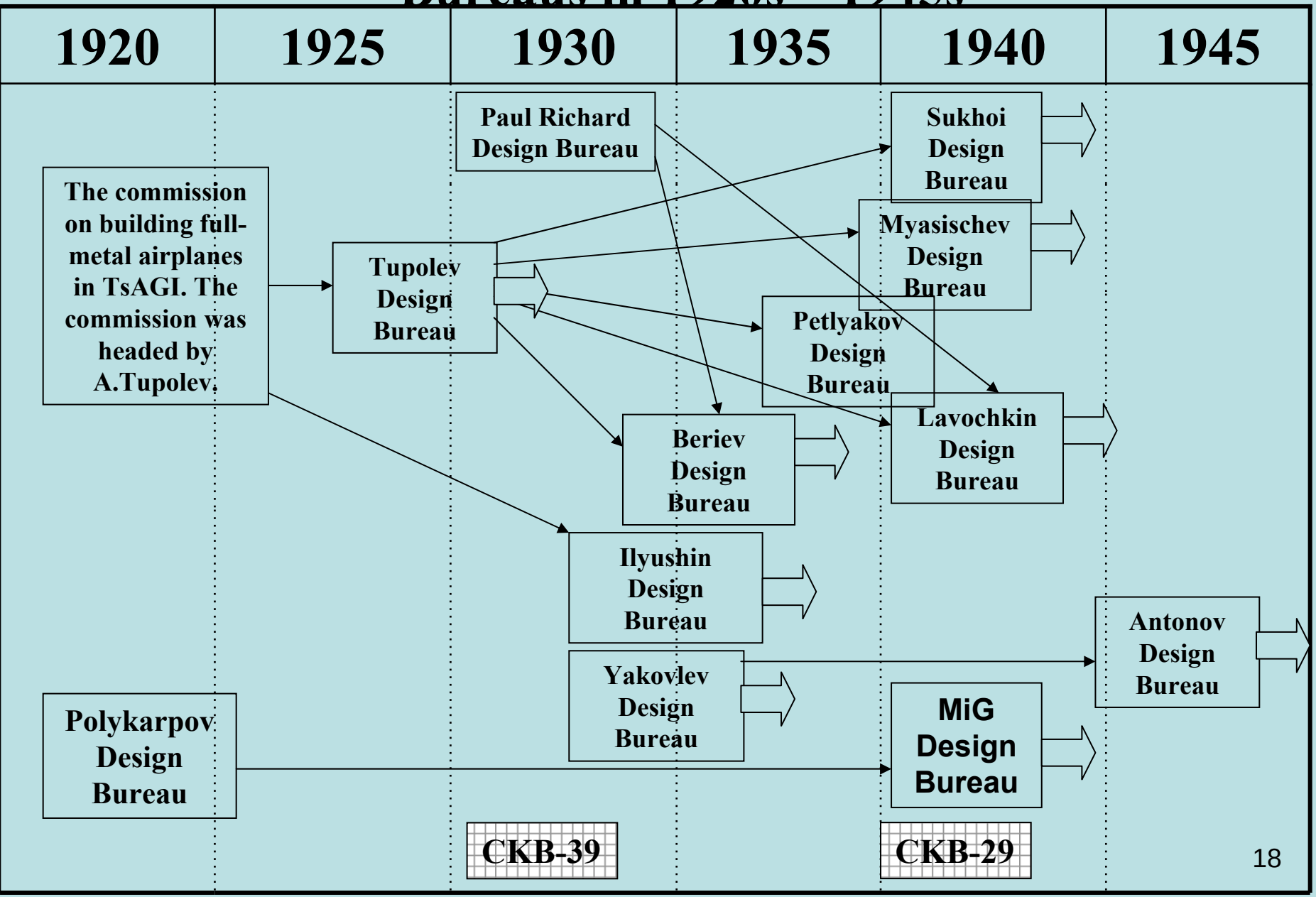
In 1937 new arrests started. Their scale was even wider than previous ones. Many thousands of specialists from all aviation organizations were arrested. Among them:

- **TsaGI directors,**
- **Most of CIAM directors,**
- **Famous airplane, rocket-and-space designers:**
  - **Andrey Tupolev,**
  - **Roberto Bartini, who came to USSR as a political immigrant from Italy,**
  - **Constantine Kalinin, who was shot dead in 1938,**
  - **Vladimir Myasischev,**
  - **Vladimir Petlyakov,**
  - **Sergey Korolev,**
  - **Valentin Glushko.**

1. History of Russian Aviation till 1945

1. 2. Aviation Organizations

The Development of the System of Aircraft Design Bureaus in 1920s – 1945s

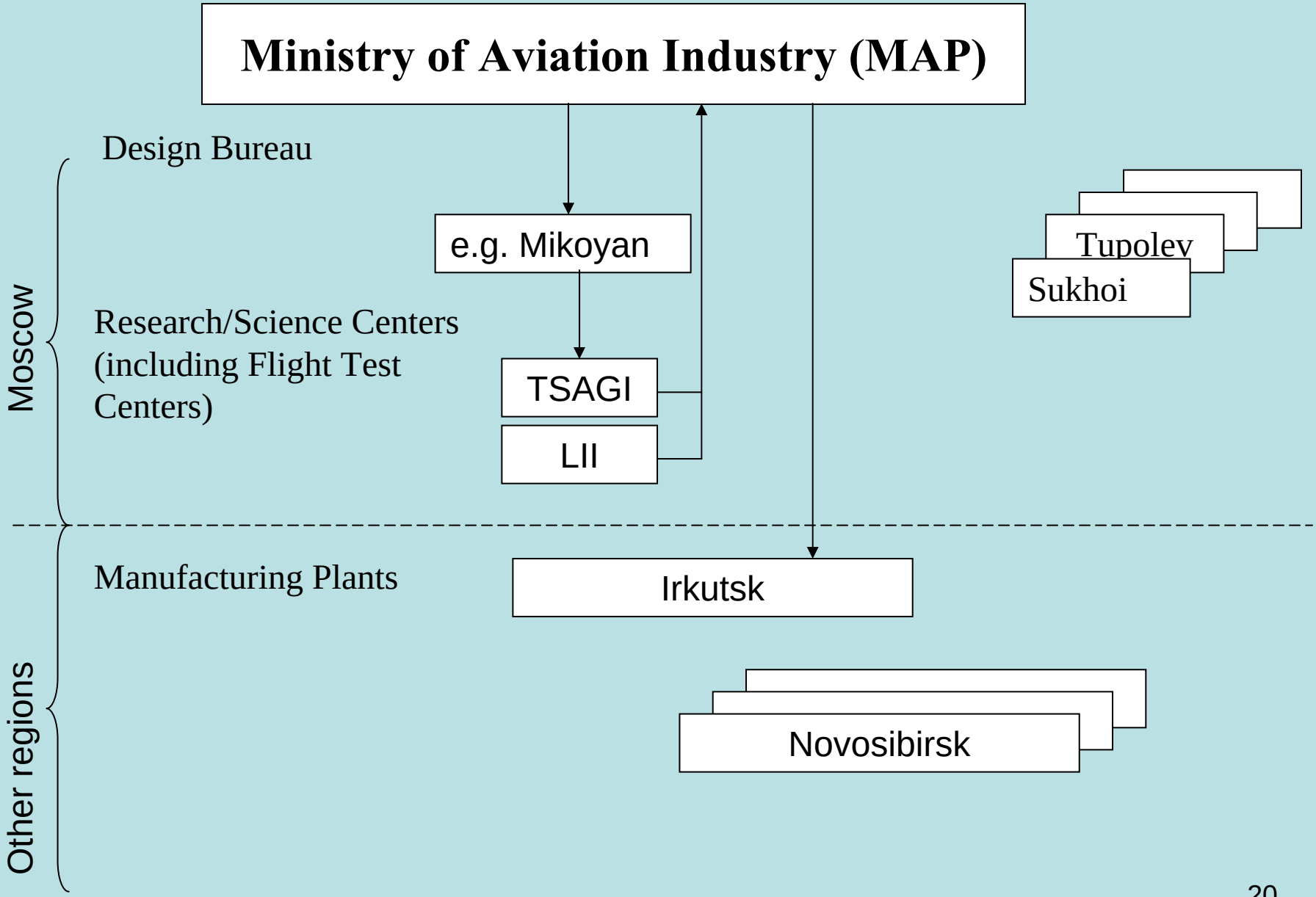


Creation of Ministry of Aviation Industry (MAP) of USSR in 1939 year

The Reasons for the Creation of MAP

- There was a national necessity for the creation and manufacturing of large quantities of airplanes.
- The average technological level of Soviet industry was very low.
- The average level of education, skills and qualification of population of USSR was low:
  - The average education level of USSR citizens in 1937 was around first 3 grades of primary school.
  - The amount of people with higher education was around 0.3%.
- MAP played an important role until the beginning of 1990s.

Organizational Set-Up



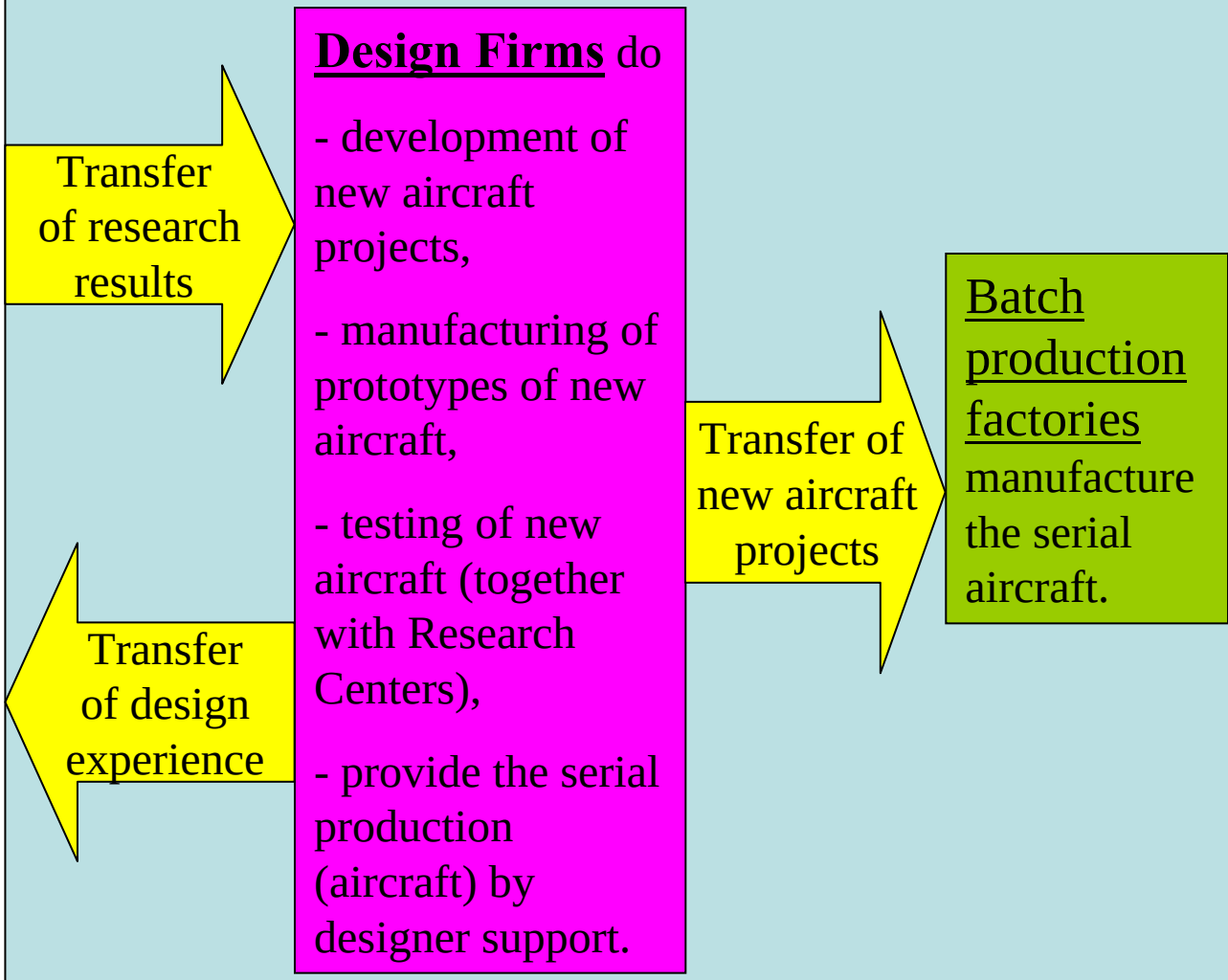
Cooperation of MAP Structures

Research Centers do

- fundamental (basic) research (for all Design Firms),
- applied research (for development of specific aircraft by Design Firm)
- testing of new aircraft (together with Design Firms)
- formulation of conclusion about accomplishment of every main stage of aircraft project

with taking into account of collaboration with all Design Firms and experience of all Design Firms.

Analysis and integration of design experience of all Design Firms.



2. The Jet Era. From 1945.

2.1. Products developed

Usage of German Aviation Technologies After World War II

Before 1945 there was almost no developments concerning jet airplanes in USSR. After WW II German jet engines were manufactured in USSR under the following designations and were installed on the following Soviet airplanes:

- **RD-10 (RD-10A, RD-10F) – Jumo-004 – *Yak-15, Yak-17, Yak-19, Su-9*;**
- **RD-20 – BMW-003 – *MiG-9*;**
- **RD-21 – BMW-003C – *MiG-9*.**

Usage of British Turbojet Engines

In 1947 the Soviet Government bought the most advanced British turbojet engines. They were:

- Rolls Royce “Nene-I”,
- Rolls Royce “Nene-II”,
- “Derwent V”.

These engines were copied very fast and their manufacturing technology was studied, adopted and applied. They were used on a number of airplanes under a different designation:

- RD-45 (“Nene-I”) and RD-45F (“Nene-II”) – MiG-15, Il-28, Tu-14, La-176;
- RD-500 (“Derwent V”) – La-15, Yak-23, Yak-25 and FKR-1 cruise missile.

The Development of Tu-4 Long-Range Bomber – A Copy of the American B-29 Superfortress

No development of new long-range bombers was carried out in USSR during World War II. Therefore Stalin gave a personal order to Tupolev to create Tu-4 long-range bomber, which should have been an exact copy of one of the best long-range bombers of the time - B-29 Superfortress.

Tu-4 was created as an exact copy of B-29 (except for the engines).

B-29

Tu-4

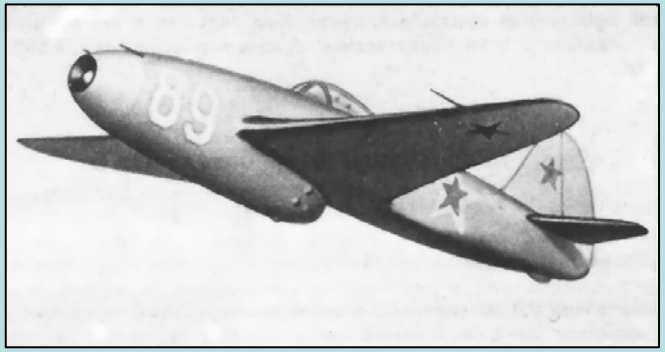
The First Soviet Jet Fighters

24th of April 1946

The first Soviet jet fighter **MiG-9** made its first flight **at 11^{12}**. It could be equipped with either two RD-20 (BMW-003) turbojet engines. 602 airplanes were built during 1946-1948.

MiG-9

The second Soviet jet fighter **Yak-15** made its first flight on the same day **at 13^{00}**. It was equipped with two RD-10 (Jumo-004) turbojet engines. 280 airplanes were built during 1946-1947.



Yak-15

Competition was alive

Jet Fighters of the 1st and 2nd Generations

MiG-15

MiG-15 was the most produced jet fighter ever. More than 15,000 airplanes were built total.

First flight in 1947. Operated till 2005.

MiG-15 took part in the war of Korea.

MiG-15

MiG-21

One of the most widely-known and widely-used jet fighters in the World.
The airplane made its first flight in 1956.
More than 10,000 airplanes were built.
MiG-21 took part in Vietnam war.

MiG-21

Korean War: MiG-15 versus F-86 “Sabre”

MiG-15

F-86 Sabre

	MiG-15	F-86E “Sabre”
Maximum take-off weight, kg	6105	8030
Maximum engine thrust, kg	2700	2355
Thrust-to-weight ratio	0,442	0,293
Maximum speed near ground, kph	1076	967
Maximum speed (at the height of, m) kph	1044(5000)	1070(10670)
Operational service ceiling, m	15500	14630
Maximum range of flight, km	1330	1700
Maximum operational overload	+8	+7
Weapons	3 cannons: 1×30 mm; 2×23 mm	6 machine guns 12,7 mm 6

Vietnam War: MiG-21 versus F-4E Phantom II

MiG-21bis

F-4E Phantom II

	MiG-21bis	F-4E Phantom II
Maximum take-off weight, kg	9080	17964
Maximum engine thrust, kg	6960	2×8120
Thrust-to-weight ratio	0,767	0,904
Maximum speed near ground, kph	1300	1200
Maximum speed, kph	2175	2410
Operational service ceiling, m	17800	21600
Maximum range of flight, km	1210	4180
Maximum operational overload	+8,5	+6
Weapons	1 cannon 23 mm, 4 Guided Missiles	1 cannon 20 mm, 6 Guided Missiles

MiG-23 and MiG-27 Fighters of the 3rd Generation with Variable Wing Sweep

MiG-23 Multi-Purpose Fighter

First flight in 1967. Serially manufactured from 1976 till 1985 (over 5,000 airplanes).

MiG-23

MiG-27 Fighter-Bomber

MiG-27 was created on the basis of MiG-23.

First flight in 1974. Serially manufactured from 1973 till 1977 (around 560 airplanes).

MiG-27

2 times more models of Soviet serial aircraft had variable wing sweep (6) as compared to USA (3).

Sukhoi T-4 Reconnaissance-and-Strike Missile-Carrying Bomber ("Item-100") and Tu-160 Strategic Bomber

T-4 Reconnaissance-and-Strike Missile-Carrying Bomber

T-4 was intended for the destruction of aircraft-carrier ships and strategic reconnaissance.

The development started in 1961.

First flight in 1972, last flight in 1974.

Titanium alloys are the main structural material of the airplane.

T-4

Tu-160 Strategic Bomber

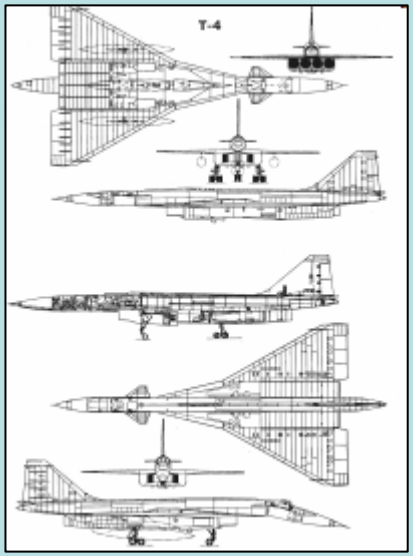
First flight in 1981. Series manufacturing started in 1984 and officially lasts until now.

The aircraft operation started in 1987 and lasts until today.

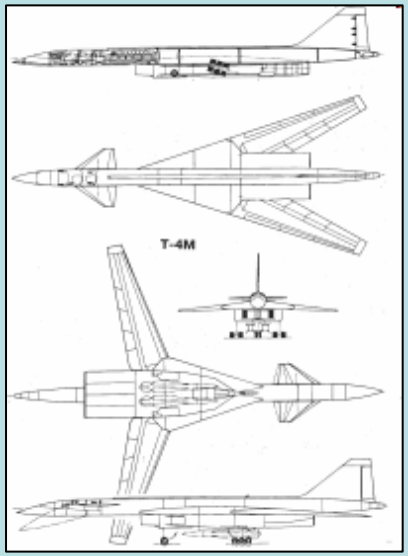
Tu-160

Alternative conceptual layouts of T-4

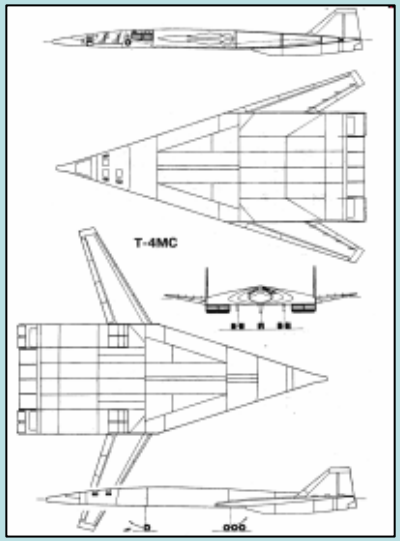
T-4



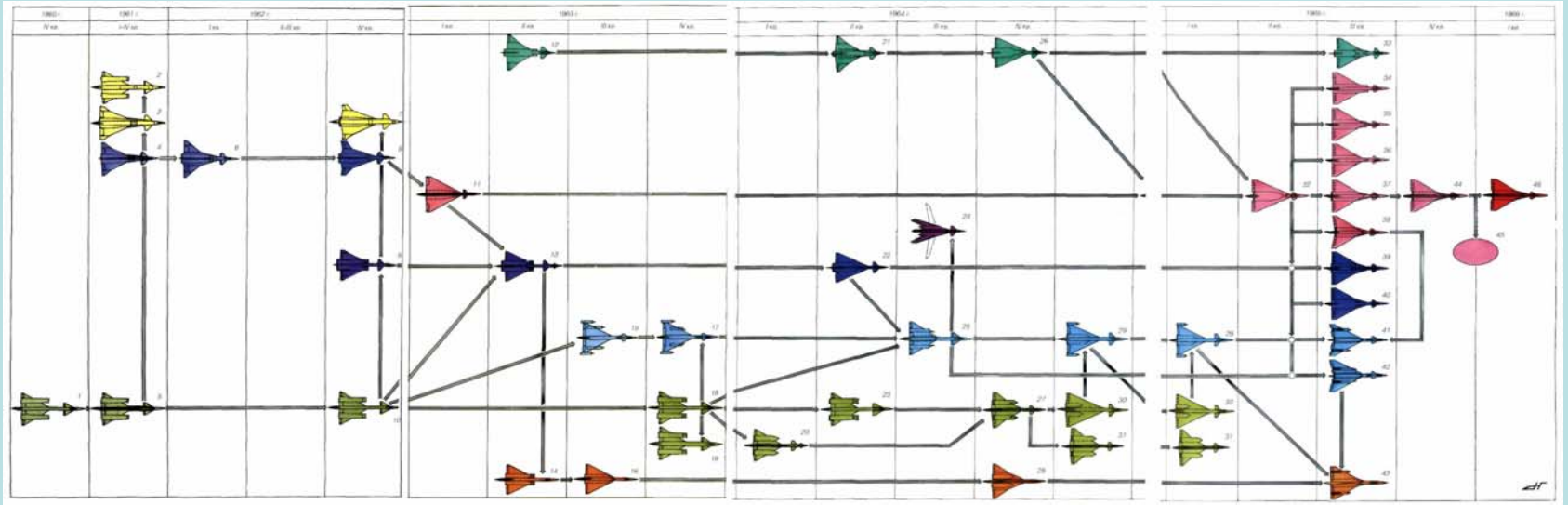
T-4M



T-4MS



More than 40 different alternative conceptual layouts were offered and studied during the development of T-4.



Tu-144 Supersonic Passenger Airplane

The development started in 1962.

Tu-144 made its first flight in 1968 (3 months before Concord).

16 airplanes were produced.

Operation was from 1975 till 1978.

Cruise flight speed - 2300 km/h, Maximum flight speed - 2500 km/h.

Range of flight - 2900 km.

Operational service ceiling – 20,000 m.

140 passengers.

Transportation of Buran on top of a fuselage (the Russian Shuttle Program – Buran - Energya)

3M

Created on basis of strategic bomber.

3M

An-22

First flight in 1988. Only one airplane was made.

Max weight of cargo - 250 tons.

An-225

MiG-29 –Fighters of the 4th Generation: MiG-29 and Su-27

MiG-29

First flight in 1977. Serially manufactured from 1982.

The following variants of MiG-29 are currently produced in Russia:

- **Frontline fighter;**
- **Multi-purpose fighter;**
- **Carrier-based fighter;**
- **Training-combat airplane;**
- **Multi-purpose twin-seater;**
- **Airplane with thrust-vector control.**

Su-27

First flight in 1977. Serially manufactured from 1984.

The following variants of the airplane exist:

- **Su-27UB training-combat airplane,**
- **Su-33 carrier-based fighter,**
- **Su-30 and Su-35 multi-purpose fighters,**
- **Su-34 frontline bomber,**
- **Shenyang J-11 (is built in China under a license from Sukhoi) – a copy of Su-27SK.**

Carrier-Based VTOL airplanes

Yak-38 attack airplane

First flight in 1971.

Operation - from 1976 till 1991.

231 airplanes were manufactured.

Yak-38

Yak-141 supersonic fighter

Development started in 1975.

First flight in 1987.

The airplane made several flights, which ended in 1992.

Maximum flight speed is 1800 kph.

Yak-141

Russian Ekranoplans

Sea Experimental Ekranoplan-Ship KM (Caspian Monster "Kaspiyskyi Monstr" or Prototype Ship "Korabl-Maket")

Designed and created in 1964-1965.

Only one KM was built. Operated in 1966-1989.

Maximum take-off weight - 544 tons. Cruise flight speed - 430 kph. Practical range of operation - up to 1500 km.

It had 10 VD-7 turbojet engines.

The heaviest aircraft in the world until An-225.

KM

Orlenok (Eaglet) Sea Ekranoplan

Intended for transportation of assault forces over a distance of up to 1500 km.

First flight in 1972.

5 ekranoplanes were produced.

Maximum flight speed - 500 kph.

Cruise flight speed - 425 kph.

Maximum take-off weight - 120 tons.

Two turbojet takeoff engines and one turbofan cruise engine.

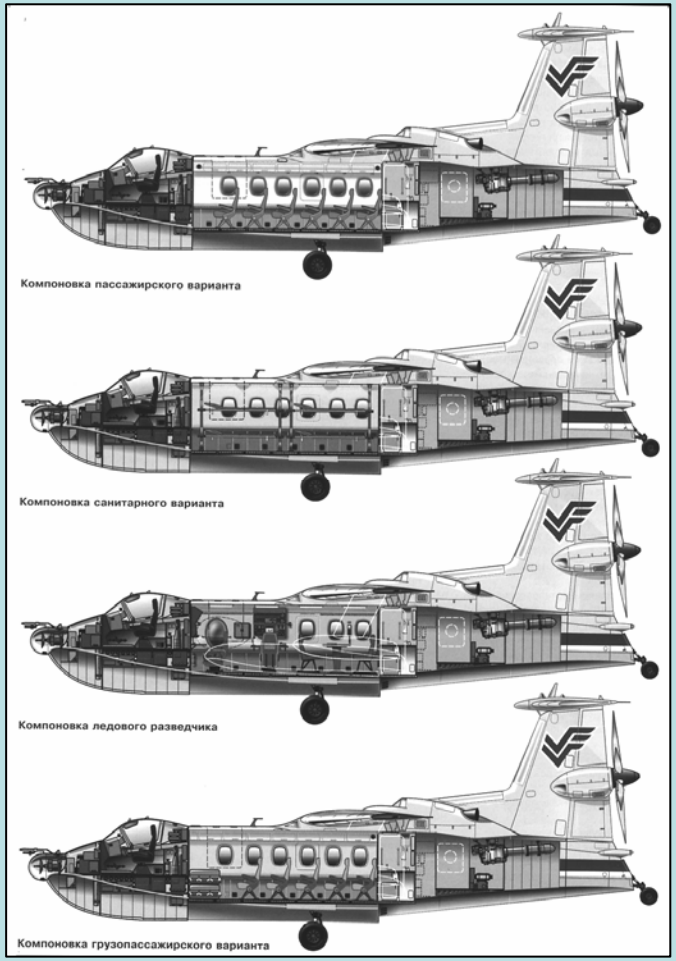
Orlenok

2. The Jet Era. From 1945.

2.2. Distinctive Features of Russian Airplanes Design

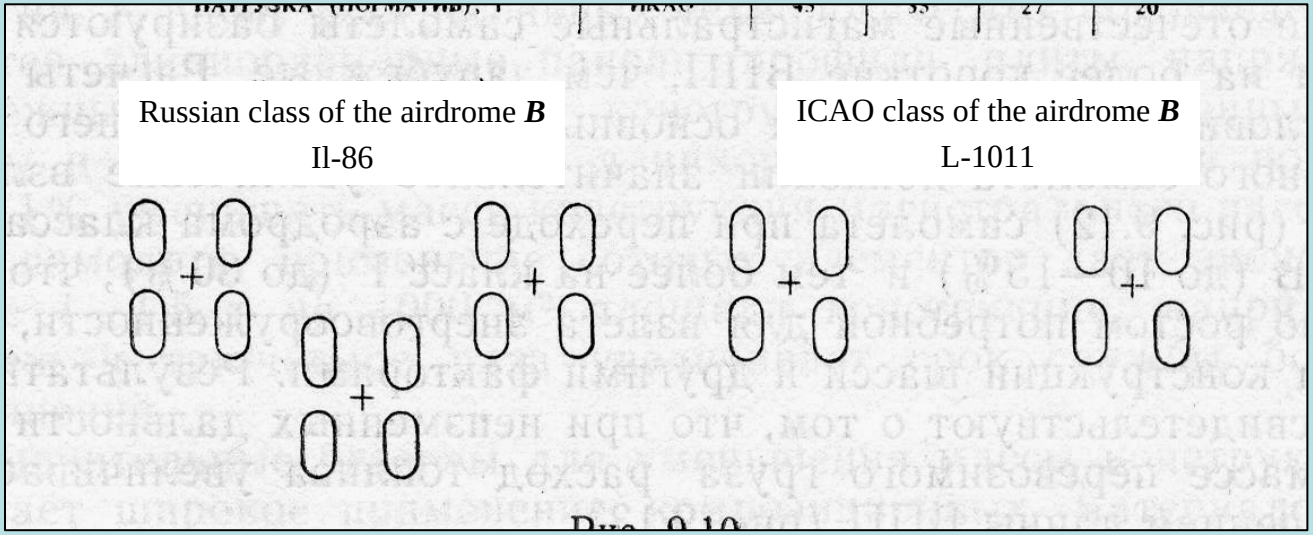
Structural Design Solutions, which Provide for Possibility of Maintenance within a Wide Temperature Range
“Yamal” Amphibious Airplane

The placement of engines in the tail of the fuselage at the root of the vertical fin provided an excellent environment for maintenance of the main powerplant systems: all maintenance can be done within the fuselage when the temperatures are very low.



Airfield Conditions and Landing Gear Requirements

The maximum allowable load on one wheel of an airplane in Russia is 30…40% lower than the ICAO requirements for the same class of the airdrome.



Wheels of main landing gear lags of Il-86 and L-1011 with similar take-off weights

Distinctive Features of aircraft design in Russia

Usage of composite materials in Russian aircraft structures

The carbon fiber utilization in Russian aircraft structures is quite low compared to Western ones.

Ka-18

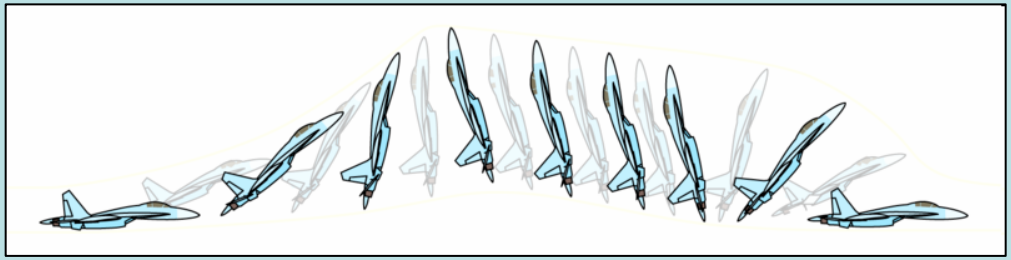
But:

Composite materials in the structures of Soviet helicopters dates back to the end of 1950s. In 1958 Ka-15 and Ka-18 had main rotor blades made out of glass fiber. Modern Russian helicopters have a considerable amount of composite materials. For example, around 30% of Ka-50 structure and around 60% of Ka-60 structure are made of composite materials.

Su-47

Composite materials are also widely used in the structures of the newest Russian combat airplanes. For example, the wing of Su-47 is 100% composite materials.

High Maneuverability of Russian Fighters



The scheme of carrying out the "Cobra" maneuver by Su-27

During the creation of Su-27 heavy fighter the Sukhoi Design Bureau managed to create a highly-maneuverable airplane, which is capable of fulfilling the mission of air supremacy.

Systems of vectored thrust

Su-30MKM with vectored thrust

MiG-35 with vectored thrust

Su-30 and MiG-35 fighters were improved and can be considered as 4+ generation airplanes. Engines with vectored thrust were installed on both airplanes, which ensure super-maneuverability for both of them.

Russian Aircraft Have Highly Reliable Rescue Systems with Ejection Parachute Seats

K-36DM Russian Standardized Ejection Parachute Seat

Ejection from Su-24

Ejection from MiG-29

Ejection from Su-27

3. From 1990

3.1. Products Developed (from 1990)

Missed Cooperation Opportunities

An-70 cargo airplane

First flight in 1994. Serial production not yet started.

Payload up to 47 tons.

The airplane has four turbo-prop engines with fan-propellers (coaxial multi-blade propellers). Different number of propeller blades for the first and second prop!

This airplane satisfies most A400 requirements.

Be-200 multi-purpose seaplane

First flight in 1998.

The following variants of Be-200 exist:

- Fire-fighting airplane (it can take up to 12 tons of water onboard during one draw);
- Search-and-rescue airplane;
- Ambulance
- Cargo airplane;.
- Passenger airplane.

An-70 and Be-200 have been candidates for cooperative programs with EADS.

Russian X-Planes

Multi-Functional Fighter Program (Mnogofunkcionalnyi Istrebitel - MFI) Project 1.42 (1.44) of the MiG Design Bureau

MFI - a “response” to F-22.

Development start - 1980s.

First ground runs - 1994. First flight - 2000.

Had engines vectoring.

“Stealth” technology was applied.

Su-47 Berkut (War Eagle)

Su-47 - a “response” to X-31 and X-29 experimental airplanes.

Development start - 1980s. First flight - 1999.

A number of advanced conceptual design solutions were tested:

- Forward-swept wing;
- Engines with thrust vectoring;
- Composite materials;
- “Stealth” technologies.

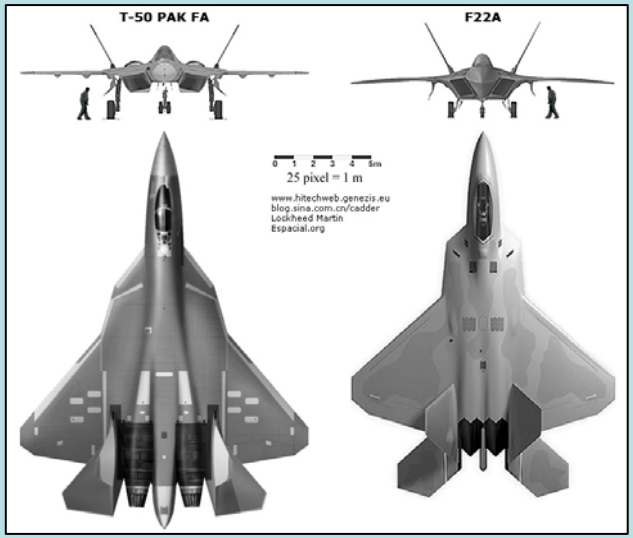
Financing of both projects ceased in 1990s. Airplanes were built mainly with the money of the Design Bureaus.

Advanced Aviation System of Front-line Aviation Program (Perspektivnyi Aviacionnyi Kompleks Frontovoj Aviacii - PAK FA)

The airplane is designed to the requirements for the 5th generation airplanes:

- low maintenance;
- dry thrust cruise speed supersonic;
- high-g maneuverability;
- radar with active electronically scanned array (AESA);
- low signatures (application of “stealth” technology)
- multi-role (Air-To-Air, Air-To-Ground).

T-50 and Su-27



T-50 and F-22

3. From 1990

3.2. Development Approach and Distinctive Features

Objectives of Soviet and Russian Aviation

1980	2000
•Provide a balance of forces; •Provide transportation capacity with 100% Russian systems.	•Develop a profitable (military and commercial) aviation industry which is competitive in the global market.

Western-Manufactured Engines and Onboard Subsystems can be Installed on Russian Aircraft during the Last 20 Years

Yak-130

MiG AT

Both aircraft can be equipped

- with Western or Russian turbojet engines;
- with either Western or Russian avionics.

Co-Development of New Russian Aircraft with Foreign Companies

T-50 Project of Sukhoi Design Bureau (PAK FA)

An export variant of T-50 is developed together with India. It is designated as FGFA – Fifth Generation Fighter Aircraft. The appropriate agreement with Hindustan Aeronautics Limited (HAL) Indian Company was signed in the end of 2008. HAL will develop the onboard computer, the navigation system, the crew cabin data displays and protection systems.

Co-Development of New Russian Aircraft with Foreign Companies

Ilyushin/HAL

Tactical Cargo Airplane (TTS, MTS, Il-214)

- 20 tons of payload;
- range is 2500 km;
- the cruise speed 870 kph;
- airplane can be operated from natural ground airfields as well as in mountainous area;
- all weather conditions.

Program started in 2000s.

Work share of companies is 50/50%.

Start of serial production is planned for 2015.

3. From 1990

3.3 Aviation Organizations after 1993.

Restructuring of Aviation Industry.

The decentralization and division of aviation industry commenced after the start of economic reforms in Russia in the beginning of 1990s:

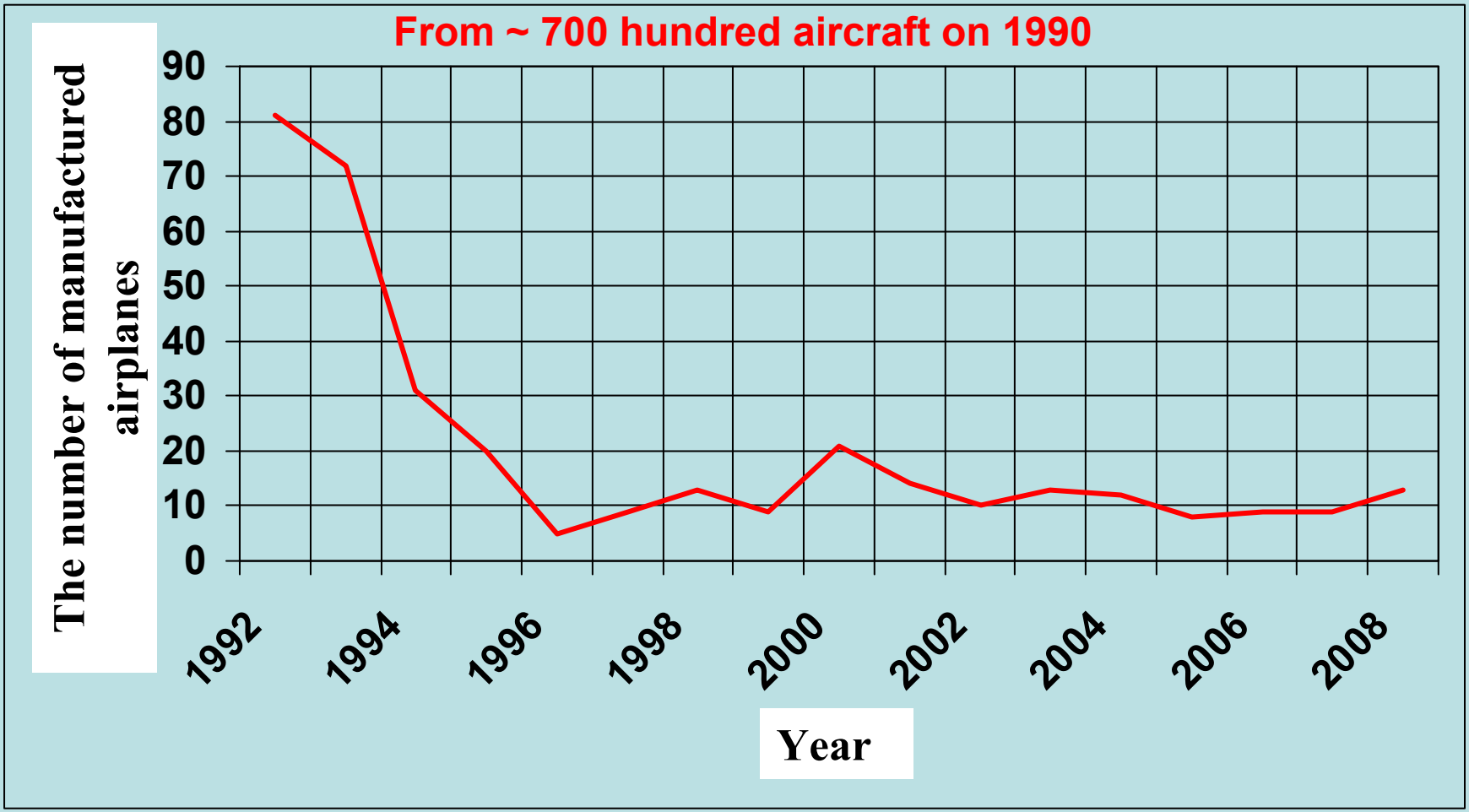
- A large number of serial production plants, Design Bureaus and some of the Science Centers were separated and privatized;
- The technological and financial ties between the serial production plants, Design Bureaus and Science Centers were broken.

The Crisis of Russian Aviation Industry during 1990s and 2000s

There was a disastrous reduction of aircraft manufacturing in the 1990s caused by:

- a strong decline of transportation volumes of Russian civil aviation;
- cease of state support for purchases of civil aircraft by Russian airline companies in 1994;
- the massive reduction of purchases of aircraft by government institutions (by Ministry of Defense).

The Volume of Production of Civil Aircraft by Russian Aviation Industry during 1992-2008



History of Russian Aviation Industry

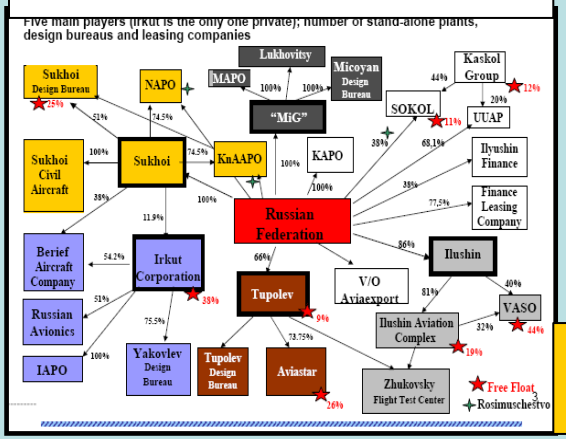
1939-1992

Ministry of Aviation Industry (MAP) – Integrated Aviation Corporation

Disintegration

1992-2005

Hundreds of Independent Research Centers, Design Firms and Serial Production Plants



Reintegration

2005-2010

Five Industrial Corporations

- United Aircraft
- Russian Helicopters
- United Engines
- United Avionics
- Aircraft Equipment
- Tactical Missile Armament

Set of Research Centers

4. Russian aeronautical education

History of Development of Russian System of Aeronautical Education

Aeronautical Faculties, Specialties and Specializations (**1909-1930**) at Regional Engineering Universities (Novocherkassk, Kiev, SPb, etc)

Aeronautical Specialization for Mechanical Engineers **(1911)**, which later turned into Specialty of Aeronautical Engineers at the Mechanical Faculty of Moscow Engineering University

1920s

Aeromechanical Faculty of Moscow Engineering University

1930s

Moscow Aviation Institute (1930)

Kharkov Aviation Institute (1930)

Kazan Aviation Institute (1932)

Rybinsk Aviation Institute (1932)

1940s

Ufa Aviation Institute (1942)

Samara Aviation Institute (1942)

SPb Institute of Aviation instrument engineering (1941)

Moscow Aviation Manufacturing Institute (1940)

After 1940s

Aviation and Aerospace Faculties and Institutes in Komsomolsk-on-Amur, Irkutsk, Novosibirsk, Perm, Voronezh, Tbilisi, Tashkent, and Ulyanovsk

Geographical Distribution of Russian Aviation Industry and Aeronautical Universities

- Aviation serial production factories are distributed among many Russian regions.
- Aviation research centers and design firms (design bureaus) are concentrated in Moscow and Moscow Region.
- There is a higher concentrations of universities, which train aviation specialists (especially for research centers and design firms), in Moscow.

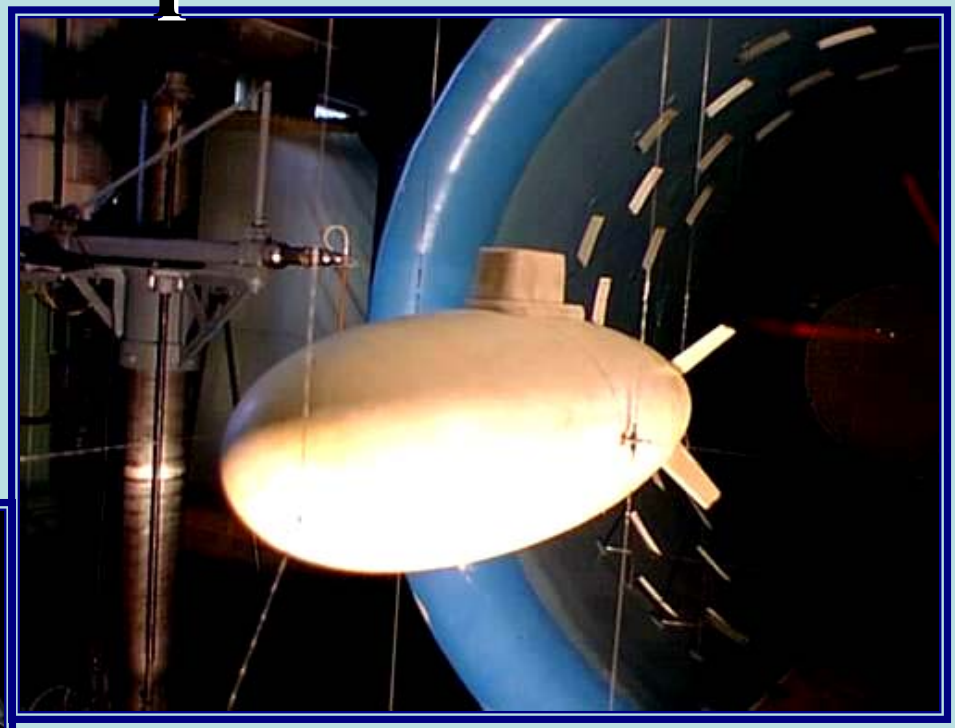
Geographical Distribution of Russian Aeronautical Universities

Education and Training of Aeronautical Engineers in Moscow Aviation Institute

- Engineer Degree is obtained during 5-6 years;
- The training includes 2 hours of actual airplane piloting;
- 6 months of basic training (familiarization with manufacturing, tools and processes);
- 6 months of training in an aeronautical design office.

Essential Basis of Education Process of Aeronautical Specialists

Wind tunnels, simulators, test rigs, and so on (Moscow Aviation Institute)



Essential Basis of Education Process of Specialists in the field of Aircraft Design

Laboratory-hangars with specially de-skinned aircraft, aircraft units and subsystems on display (Moscow Aviation Institute).

Conclusions

1. Russian aircraft industry and aeronautical education have a long and successful tradition.
2. Many Russian developed aircraft are unique and represent practical solutions of technical problems.
3. Methods and approach for aircraft development are very similar to those in Europe and USA.
4. The time lag/gap for similar aircraft developed in Russia and US shows an increasing trend in favour of the US.
5. The Russian aviation industry is being restructured to become competitive on the global market.
6. Use the opportunity to access the Russian knowledge base and capabilities.

Thank You!