State of the Art and Prospects of Rosaviacosmos Projects on Reusable Space Transportation Systems

Workshop on Long-term Russian – European cooperation in Space, Moscow, Russia

Anfimov Nikolay, Kostromin Sergey, Panichkin Nikolay, Tsvetkov Andrey

March 5, 2002

OBJECTIVES OF RUSSIAN “ORYOL”/“GRIF” PROGRAMS

- Economical efficiency of Space Transportation System due to Reusability
- Sustainable development of Competitiveness in Space Transportation System Technology through Innovations
- Independent Access to Space in Future
- Creation of New Space Markets (elastic demand)
- Shrinking or Liquidation of Drop Zones
- New Functional Parameters (readiness to flight, better condition for manned flights etc.)
- Increasing of Reliability and Safety of Space Flights
- «Test bed» for International Large Scale Cooperation and Division of Labor in High Technology Projects

OBJECTIVES OF RUSSIAN "ORYOL" / "GRIF" PROGRAMS (CONT.)

- ORYOL Program - 1993-2000

Priorities: System study, Preliminary Design Works, Advanced Technology Identification and Research

- GRIF Program - 2001-2003

Priorities: Development of key technologies, Development of Ground Test and Flight Demonstration Programs, System studies and complex validation of Reusable Space Transportation Systems (RSTS) creation and operation prospects

"ORYOL" / "GRIF" PROGRAMS MANAGEMENT SCHEME

LEADING INSTITUTES

Rosaviacosmos

System Integration
Numerical Analysis
Testing

- *TsNIIMASH* – *VTO*
- *TsAGI* – *HTO*

WORKING GROUP
N.Anfimov/N.Panichkin
(TsNIIMASH)
Key Experts

Propulsion Concept
Theoretical & Experimental
Research

- *Keldysh RC* – *RE*
- *CIAM* – *RAM/SCRAM*

INDUSTRY

Space utilisation economic efficiency
AGAT
NIIEPU
….

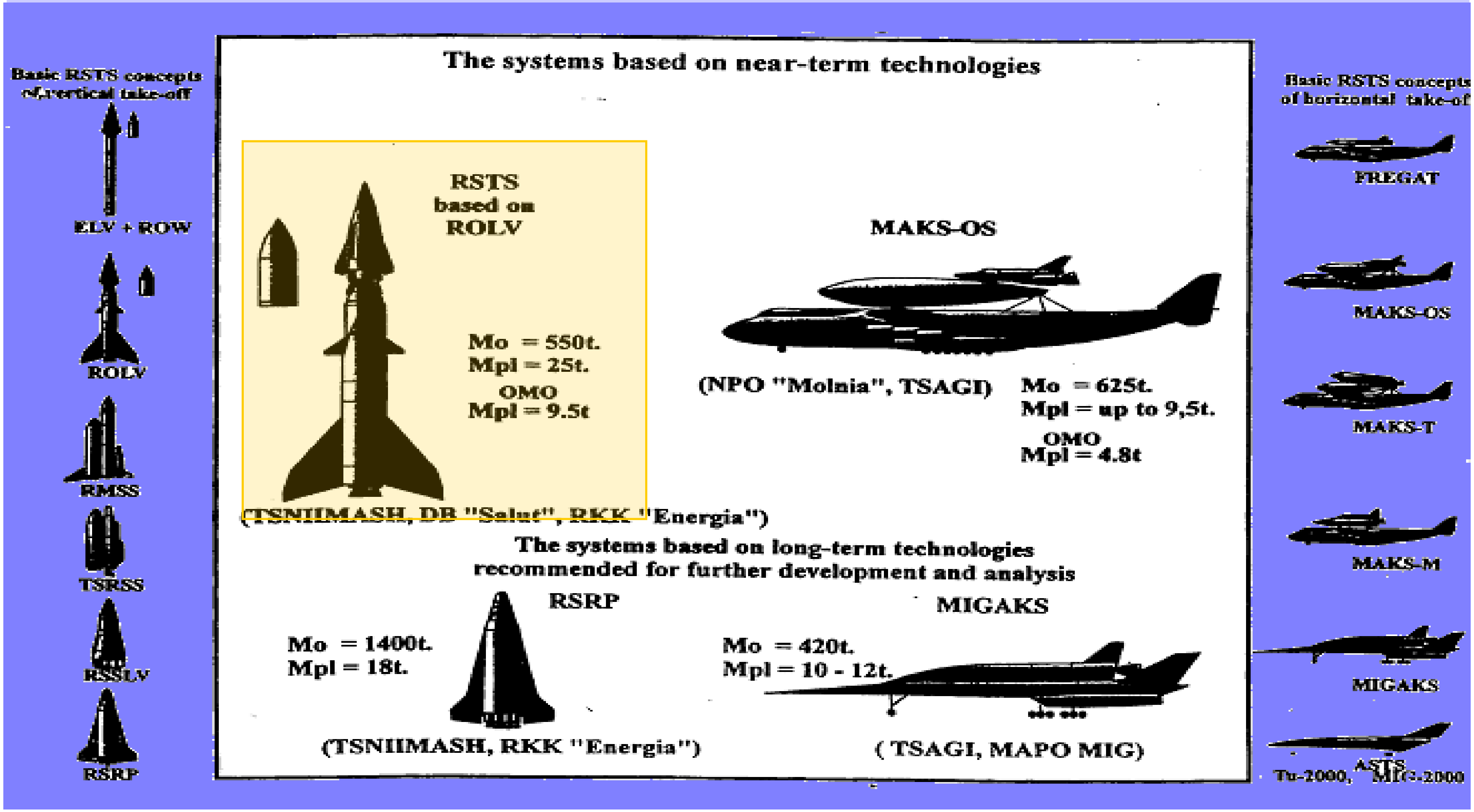
Preliminary design analysis (Feasibility study)
Energiya RSC
Khrunichev GKNTs
NPO Mash
Makeev DB
NPO Molniya
Mikoyan DB
Tupolev DB …
…

New materials
VIAM
NPO Kompozit
…

Hardware
Avionics
Experimental Base
NPO Technomash
NPO AP
MARS
LII Gromov
…

Propulsion concept analysis
DBKhA
Energomash NPO
Soyuz TMDC
Saturn NPO
…

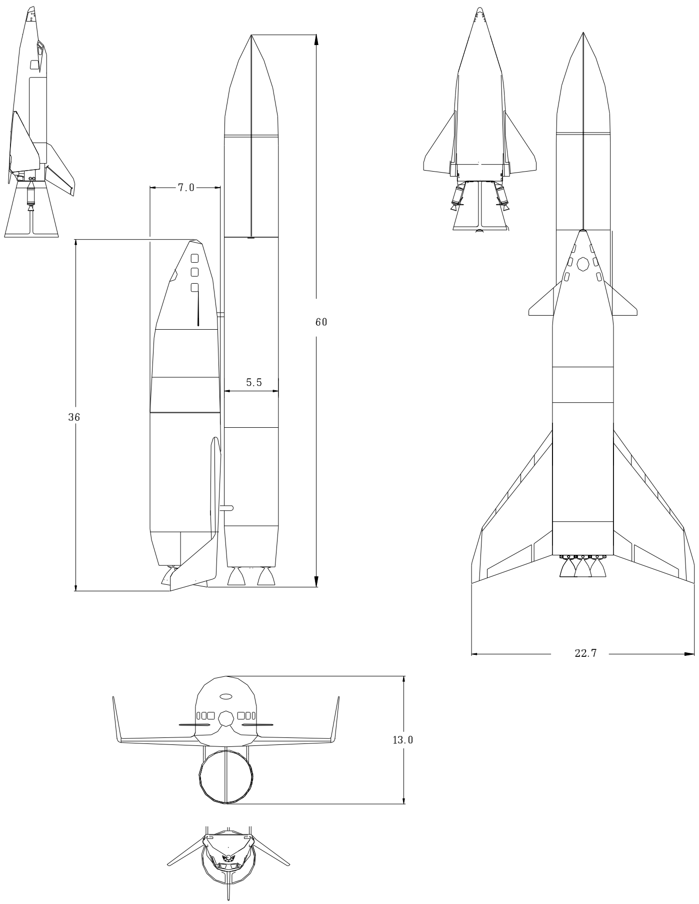
REUSABLE SPACE TRANSPORTATION SYSTEMS (RSTS) - «ORYOL» PROGRAM



EVALUATED PERFORMANCES OF BASIC "ORYOL" RSTS CONCEPTS

RSTS conceptions	Conceptions based on near-term technologies		Conceptions based on long-term technologies	
	ROLV	MAKS-OS	RSRP	MIGAKS
Number of stages	2	2	1	2
Take-off mode	Vertical	Horizontal	Vertical	Horizontal
Landing mode	Horizontal	Horizontal	Horizontal	Horizontal
Reusability	Partial	Partial	Full	Full
Take-off mass	550 t	625 t	1400 t	420 t
Landing mass 1st.	52 t	290 t	141 t.	180 t.
Landing mass 2st.	11,5 t (ROV)	21,5 t (OP)		40 t
Engine types 1st.	LRE	TJ	LRE	TJ+Scramjet
Engine types 2st.	LRE	LRE		LRE
Propellant mass 1st.	187 t (LH2+LOX)	84 t (Kerosene)	1202 t (Ker+LH2+LOX)	75 t (Ker+LH2)
Propellant mass 2st.	254 t (LH2+LOX)	242 t (Ker+LH2+LOX)		124 t (LH2+LOX)
Payload up mass (H-200 km. j-51°)	25 t	8 ÷10 t	18 t	10÷12 t
Payload down mass	2.5 t	6.3 t	10 t	12 t

GENERAL ARRANGEMENT AND PERFORMANCES OF THE ROLV-BASED RRSS



Lift-off mass, t... 548

PL mass (Hα =155km, Hπ =-6km, i=51deg.), t........25

FBB usable propellant mass, t.............................187

FBB separated mass, t... 51,7

CS usable propellant mass, t...............................254

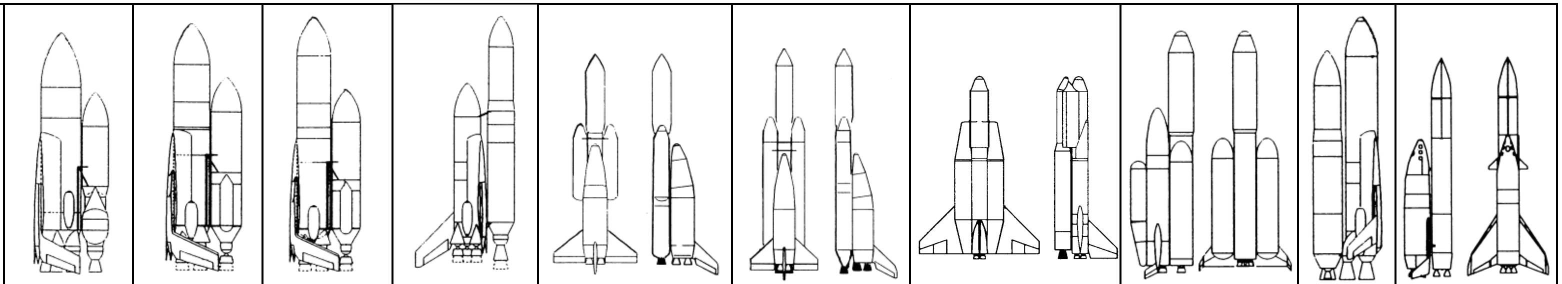
CS separated mass, t.. 29,8

Lift-off thrust, t...822

FBB thrust, t...576

CS thrust, t..246

ROLV OPTIONS PERFORMANCES BY THE RESULTS OF DESIGN BUREAUS WORKS



Designer	Option 1 RKK "Energia"	Option 2 RKK "Energia"	Option3 RKK "Energia"	Option 4 RKK "Energia"	Option 5 DB "Salut"	Option 6 DB "Salut"	Option 7 DB "Salut"	Option 8 DB "Salut"	Option 9 NPO Mash	Option 10 TsNIIMASH
Project date	1996	1995	1995	1995	1997	1997	1995	1995	1995	1995
ROLV lift-off mass, t	674	670	670	750	624	750	763	533	570	548
Payload mass H=200km; i=51°, t	26	25,4	25,9	27,1	25	24,1	26,1-28	22,7-21,9	25	25

KEY TECHNOLOGIES OF REUSABLE SPACE TRANSPORTATION SYSTEM

Materials and Structures (M&S):

- new structural light-weight Al-Li alloys
- composite three-layer (sandwich) structures with coal-plastic load-bearing layers
- composite wall – liner structure for fuel tanks and high pressure vessels
- combined intermetallics for structure and heat-protection
- metal and composite sandwich coal-plastic structures

Reusable Rocket Engines (RRE):

- optimization of power parameters, selection of the RRE scheme and propellant components
- RRE design parameters improvement
- improving or development of new industrial technological processes, equipment
- composition and technology for highly effective heat-protection coating
- seals for on-ground operation
- heat resisting materials and coatings for gas and oxidizing channels of the engine
- maintenance of propellant components rectification
- structurally perfect armature and its materials
- hydrostatic bearing for oxygen pumps of RRE turbo-pump aggregate
- metal-silicon coatings for heat-intensive units of RRE
- new alloys and composite materials for blades of turbines safe life extension
- unified emergency protection system of early diagnostic channel
- technology for turbine ceramic disks with metal shaft soldering;
- technical diagnostic system including measurement system and sensor instrumentation.

Aerogasdynamics :

- some refinements of several calculation methods and ground test facilities

KEY TECHNOLOGIES OF REUSABLE SPACE TRANSPORTATION SYSTEM (continued)

Heat Exchange Processes (HEP) and Thermal Protection System (TPS):

-thermal insulation structure based on application of low conductivity honeycomb structures
-combined heat- protection / cryogenic insulation structure for cryogenic fuel tanks
-technology and ground test facility for research of thermo-mechanical stability of LV coatings
-TPS materials thermal stability development
-experimental research of heat exchange with use of fast Infra-Red scanning camera
-calculation of complex shape vehicle TPS convection heat exchange at their 3D streamline
-physical-chemical models and software for calculation of high-temperature flows of non-equilibrium multicomponent radiate gas

Guidance and Navigation Systems (GNS):

-mathematical RSTS models as objects of flight control
-utilization of navigational systems based on perspective inertial sensing elements
-multichannel small-sized instrumentation of satellite navigation with small weight and power-consumption
-data integration on the most responsible modes of flight

Project management (PM):

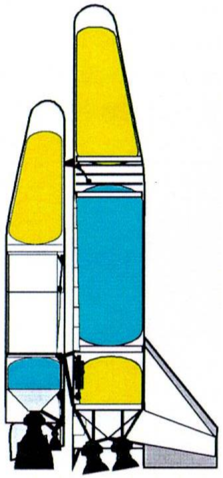
-Total risk management technology
-RSTS life cycle cost parametric model
-system engineering of reliability, life time, safety of RSTS and its elements
-RSTS PM technology on the whole

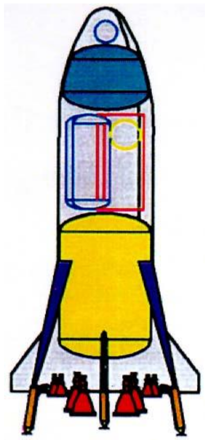
INTERNATIONAL COOPERATION

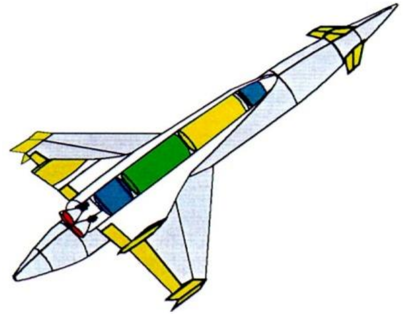
SPECIFICITY OF RSTS PROGRAMS

- Market driving
- Economical viability and Technological feasibility as a trade-off within the specified time limit
- High Concentration of Key Innovative Technologies
- Extremely High Cost of Programs
- Governmental funding is a mandatory requirement for R&D phase
- International Collaboration is conceived as a preferable option to provide Program affordability

RLV PROGRAM LIFE CYCLE COST ESTIMATION (Data from FESTIP)



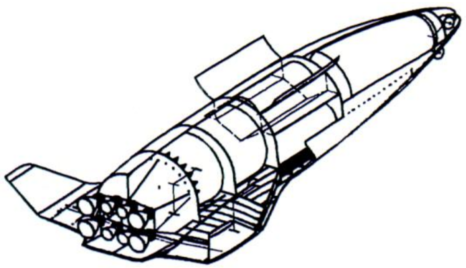


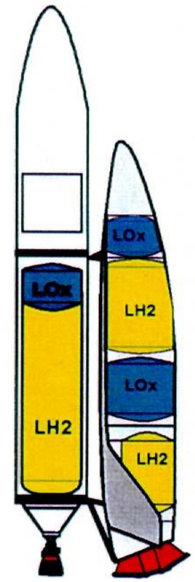


Life cycle phase	Average cost Bil., USD
•Development	18,0
•Manufacturing	22,0
•Operation	10,0
•Disposal	0,185
Total	50,185

*** Assumptions:**

Operational life time (Y) - 30
Launch rate per LV (per Y) - 12
Operational fleet size - 3
Total missions - 1080
Total missions per LV - 120
Total fleet size - 9





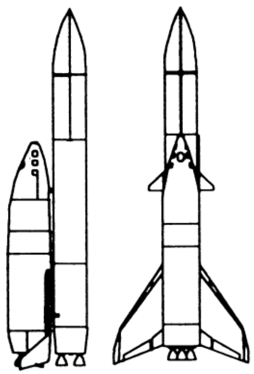
RUSSIAN EXPERIENCE OF COMMERCIAL AND JOINT WORKS ON FOREIGN RSTS PROGRAMS (1992-2001)

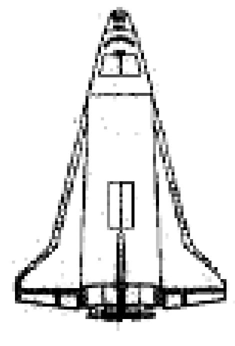
- **Hermes, MSTP (CTV), FESTIP - Europe**
- **Sanger, ASTRA - Germany**
- **Interim-HOTOL - Great Britain**
- **Prepha, ANGEL - France**
- **HOPE - Japan**
- **X-Planes, incl. Delta Clipper; K-1 etc. - USA**

JOINT TEAM ON ORYOL- FESTIP PROGRAMS COLLABORATIVE WORKS (1996-1998)

MAIN RESULTS OF COLLABORATIVE WORKS OVER ORYOL (RKA) AND FESTIP (ESA) PROGRAMMES in 1996-98

Selected RSTS Concepts





FESTIP	ORYOL		FESTIP	ORYOL
FSSC-16sr	ROLV		FSSC-15	RSRP
VTHL	VTHL	MODE of Take-off and Landing	HT(sled) HL	VTHL
516	674	Lift-off mass, t	582	1400
20.5	26.5	Payload mass, t	14.8	18
LRE / LH+LOX	LRE/ LH+LOX	Propulsion System	LRE / LH+LOX	LRE/ LH+LOX+KER

MAIN RESULTS OF COLLABORATIVE WORKS OVER ORYOL (RKA) AND FESTIP (ESA) PROGRAMMES in 1996-98 (continued)

Key Technologies

During discussions of a future "Technology Development and Verification Planning" (TDVP) by both sides two major areas are identified of most critical importance:

Reusable Liquid Rocket Propulsion;

Development of low mass advanced heat resistant materials and structures.

Combined propulsion technologies are of common interest as long-term perspective.

The need for flight testing and demonstration of those technologies which cannot be sufficiently and reliably demonstrated on ground was further emphasized.

FESTIP: In Flight Experimentation will be a substantial part of the continuation within a future ESA program ("FLTP").

ORYOL: To provide the development of an advanced HFL ("Hypersonic Flying Laboratory") it is assumed to use available aircraft and rockets for launching hypersonic test-beds.

A continuation of collaborative work is strongly recommended.

STATE-OF-THE ART AND PROSPECTS OF RUSSIAN - EUROPEAN COLLABORATION ON RSTS PROGRAMS

- Great experience of European/Russian Collaboration between Agencies and Industries was achieved for the Period 1992-2001.

- During 2001- 2002 it was signed a set of Protocols, Agreements and Contracts both for Joint and Commercial Works

From Russian side: - Rosaviacosmos, TSNIIMASH, Keldysh Center, Khrunichev Center, TSAGI, CIAM, LII Gromov, Energomash and others

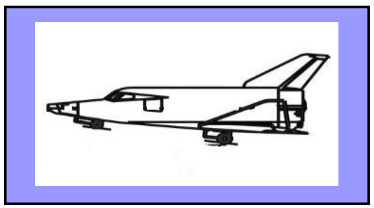
From European side: ESA, CNES, DLR, EADS, ASTRIUM, SNECMA and others

- The convergence of Russian and European Approach on Basic Concepts (RFS and SSTO-VTO) and Key Technologies was achieved. Thus the necessary prerequisites for further near and mid term joint system study, ground and flight experimentation were created

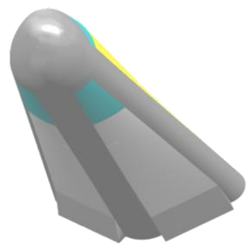
- Long term objectives on Russian-European Collaboration, including joint manufacturing and commercial operation have to be discussed and investigated

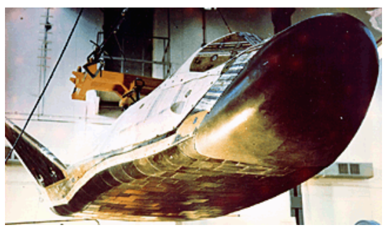
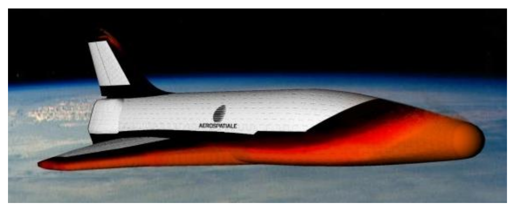
POTENTIAL AREAS OF RUSSIAN-EUROPEAN NEAR TERM COLLABORATION

- **System Study**
  - RFS, including LFBB for both Partially and Fully Reusable LV
  - New Generation of Reusable Orbital Vehicle (ROV)
- **Ground Experimentation (TBD)**
  - Key technologies on ATD, TPS, Materials &Structures, GNS, RRE
- **Flight Experimentation (TBD)**

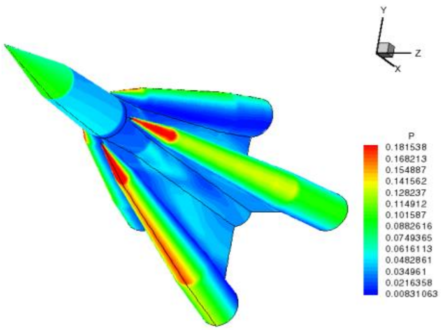


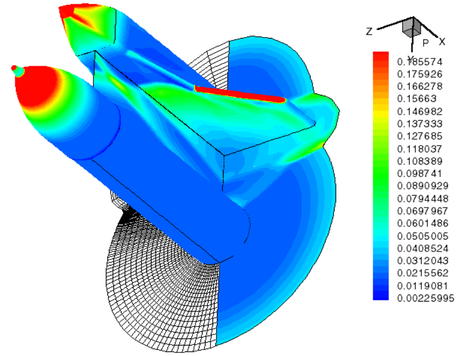


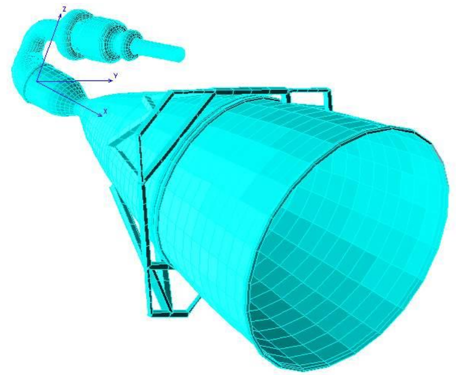


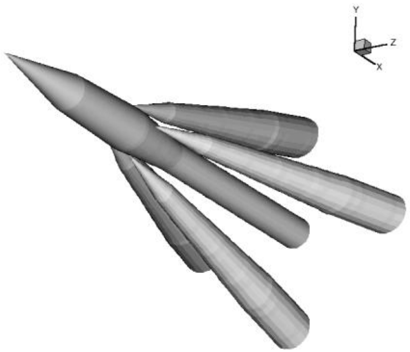




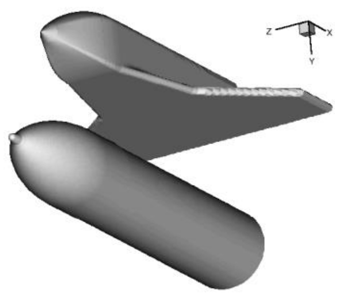
RUSSIAN INTERNAL TOOLS FOR COMPUTATION OF SPACE SYSTEMS AND ITS AGREGATES

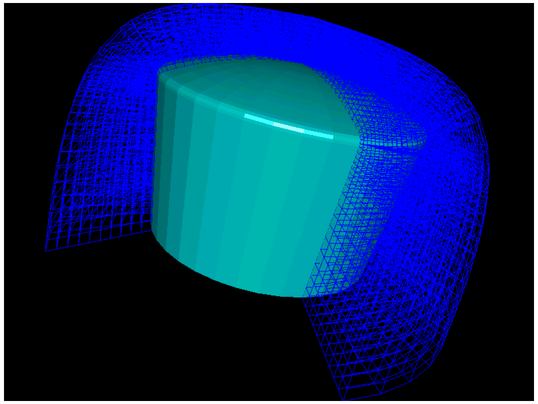












RUSSIAN GROUND TEST FACILITY FOR RSTS RESEARCH

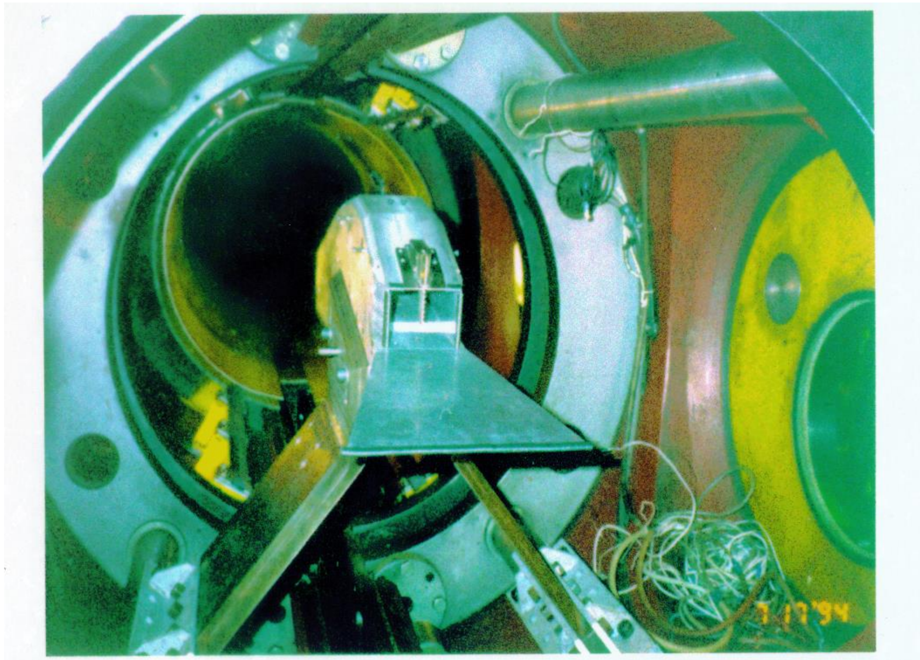
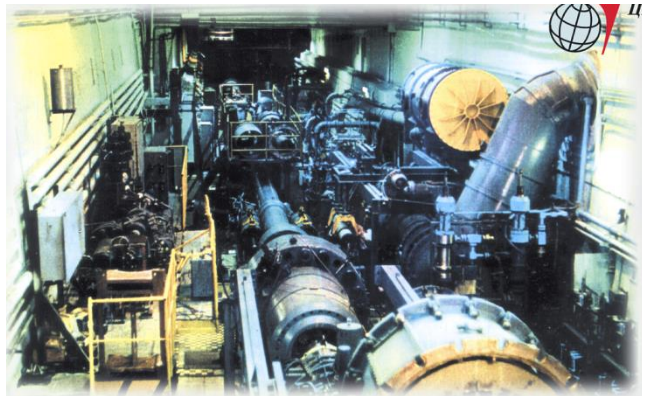
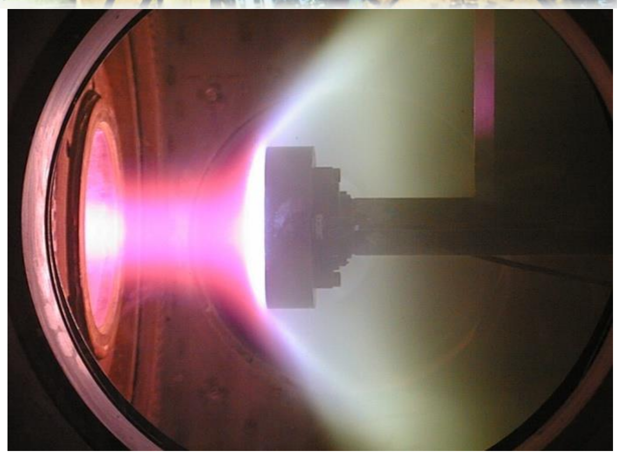
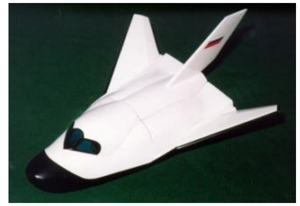


Fig. Front view of NASA GASL model mounted in PGU-11 test section.







EURUS 2015 ?