CESMA – 1st International Symposium on "Hypersonic Flight: from 100.000 to 400.000 ft"

THE EUROPEAN EXPERIENCE: PAST AND PRESENT PROGRAMS on ATMOSPHERIC RE-ENTRY VEHICLES

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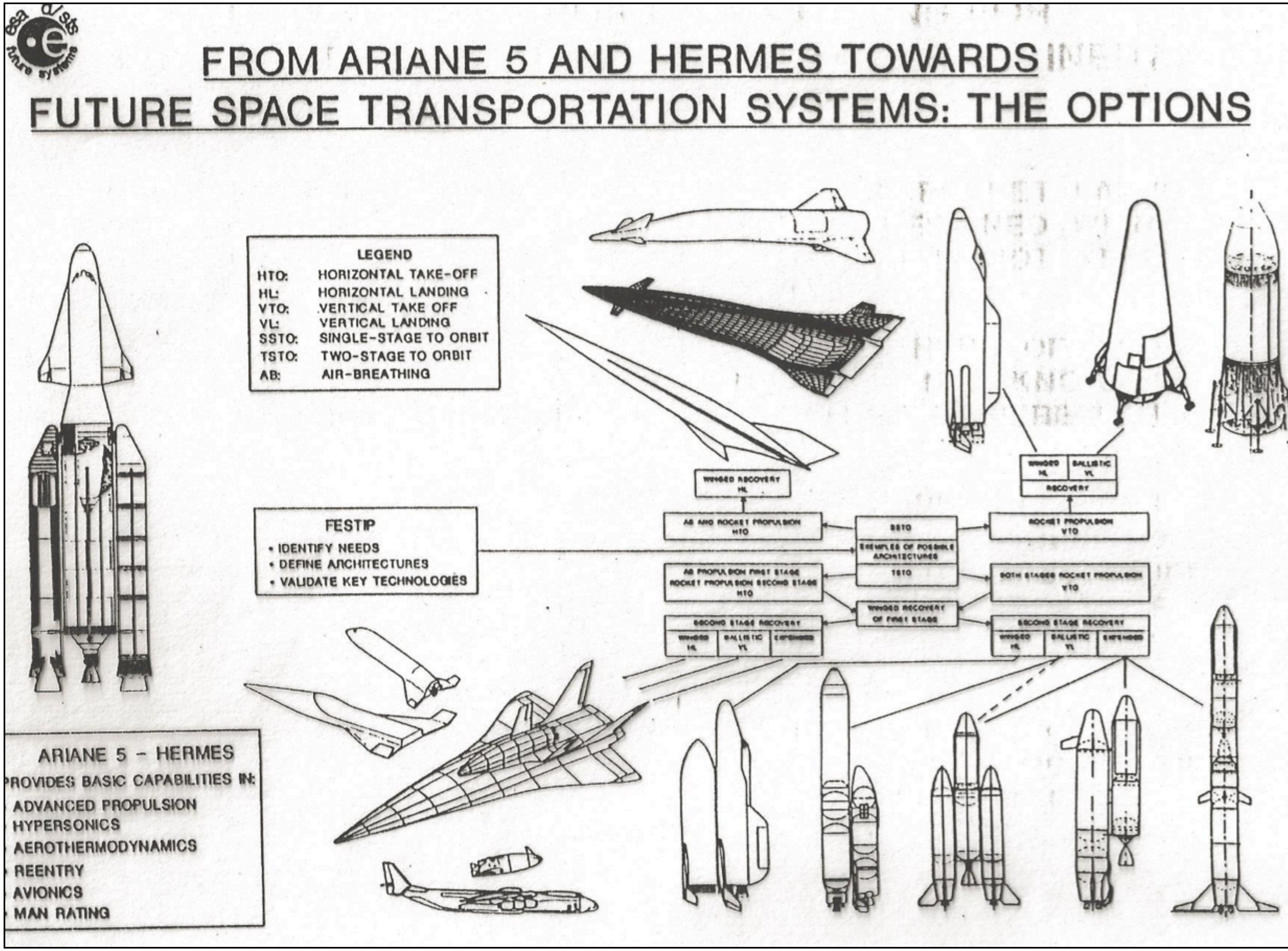
Hypersonic Vehicles: a cyclic interest

Capsules, Scramjets, Spaceplanes, Shuttles -Re-entry vehicles



Definitions

- **Space tourism:** initially used to indicate the space flight of paying individual on orbital platforms (MIR, ISS), it is now more used in its commercial sense of flights to the conventional limit of space (100 km altitude) with **low velocity** (max speed during the descent trajectory **M~3-4**).

  Current for Virgin Galactic Spaceship (under developm) : Max. alt. 71000 ft, M=1.4. Targets: 110 Km, 4000 km/h

- **Sounding Rockets:** rocket propelled systems aimed at a steep parabolic trajectories, offering automatic payloads several minutes of microgravity environment for scientific investigation. Unsuitable for human spaceflight (~15 g). Max altitude: ~700 km, Max. **Mach: 3-4** .

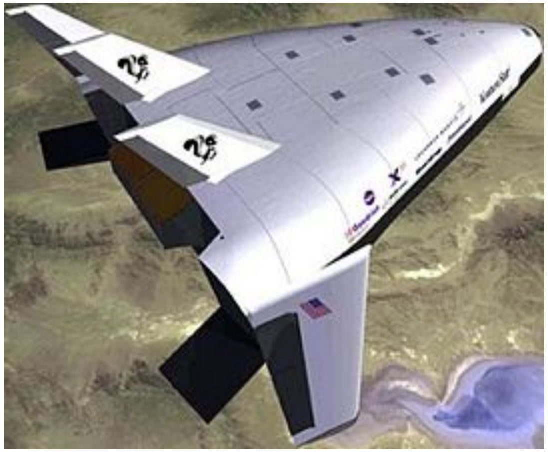
- **Hypersonic vehicles:** vehicles flying through the atmosphere at speeds above M=5.5, and encountering dissociation and ionization of air and high heat loads. Also indicated as the limit above which ramjets do not produce thrust. Usually adopted for vehicles which aim at flying at high speed in presence of atmosphere for extended periods, generating thrust which allows them to accelerate and overcome friction produced by the atmosphere. **Mach: 5- 15**, Altitude: 25 – 35 km.

- **Orbital re-entry vehicles:** space vehicles which have been launched through the atmosphere to space by complementary systems (usually rockets) and aim at returning to Earth (or other planet) crossing the atmosphere and using the atmosphere itself to dissipate the energy corresponding to their orbital velocity. **Mach: 25**. Altitude: from 120 km down to 0 km.

Activities on Hypersonic Space-planes

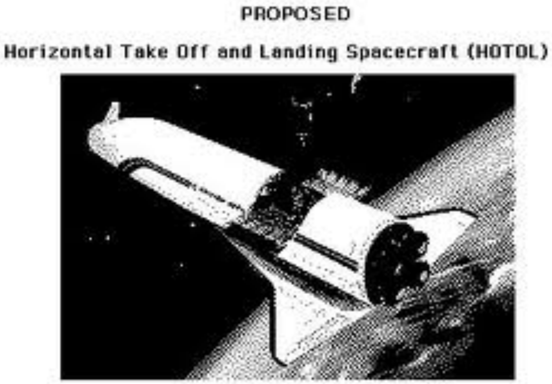
USA Space-planes
(with huge investments)

- X-vehicles high speed
- NASP / Rockwell/X-30
- DC-X (BMDO)
- SSTO X-33/Venture Star
- ASTP
- Scramjet experiments



ESA Launch Systems

- A5 + Hermes
- Hotol
- Saenger II
- FESTIP
- FLTP
- FLPP



Ramjet / Scramjet Propulsion for Spaceplanes

Airbreathing Propulsion

- Ramjet does not produce thrust above M=4.5 – 5
- Scramjet: above M=5, in investigation (few experiments performed: NASA Univ. of Queensland, DARPA).
- NASA X-43A (rocket accelerated) 2001-04: Scramjet testbed M = 9.68, 110 000 ft

Only very short duration operations have been achieved

- USAF X-51, 2010-13, Waverider Scramjet demo, supersonic combustion at M=5, 210 seconds

Combined Cycle Propulsion

- Scramjet requires air to accelerate, flies at 30 -32 km
- Growth of the boundary layer reduces air intake efficiency and propulsion system thrust.
- Combined cycle engine required with successive transition to rocket to achieve orbit.
- Hydrocarbon vs liquid hydrogen as fuel: hydrogen much more efficient, but low density. A huge vehicle results which has to overcome the corresponding atmospheric friction.
- At this time first application of scramjet is seen in high speed strike weapons. Hydrocarbon fuel is preferred.

Activities on Manned Hypersonic Vehicles

USA Human Spaceflight

- Mercury, Gemini , Apollo capsules

- Space Shuttle

- X-38 rescue crew vehicle for ISS. Unpropelled lifting body

ESA Attempts for Human Spaceflight

- Hermes spaceplane on Ariane 5

- X-38/CRV: cooperation with NASA on lifting body vehicle for the ISS

- Clipper: concept study for a lifting body crew vehicle with Russia

- CSTS: Capsule study in cooperation with Russia
- ATV derived cargo and crew capsule

Main Problems for Space Hypersonic Vehicles

Reduced Payload mass fraction for reusable systems

- For Rocket propelled SSTO: **1%**
- For theoretical combined cycle air-breathing – rocket: 1.5 – 2%

For payloads of interest to human spaceflight (15 – 20 t) this corresponds to huge vehicles (1500 -2000 t) at take off

Current NASA directions:

Air-breathing systems: abandoned for space flight.

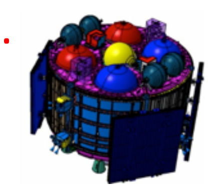
SLS/MPCV: **Multi-Purpose Crew Vehicle** (scaled up Apollo capsule) being developed by NASA for space exploration missions (Asteroid, Moon, Mars).

Commercial Crew Vehicles: being developed by private industry under Agreements with NASA and own funds.

At this time Europe does not have the ambition of developing its autonomous crew transportation system (too limited flights).

Two collaborations have been started:

MPCV ESM: cooperation with NASA for development and manufacturing of the **US exploration capsule service module.**



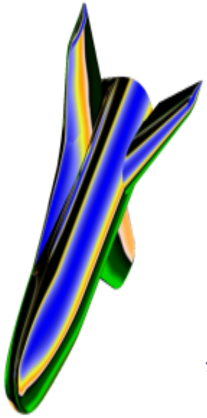
Dream Chaser: cooperation with Sierra Nevada for supply of critical systems to the **spaceplane** under development **for crew access to LEO (ISS).**

European Activities

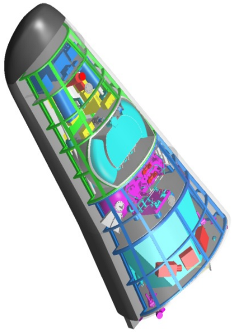
Unmanned Orbital Re-entry Demonstrators

**Trade-off between
Capsules/Lifting/Winged Bodies
Against Objectives and Assumptions**

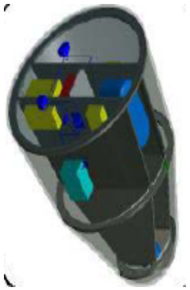
Winged Bodies

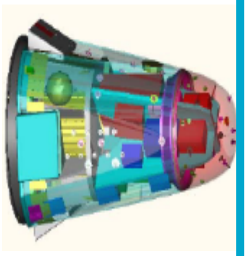


Lifting Bodies



Capsule Bodies



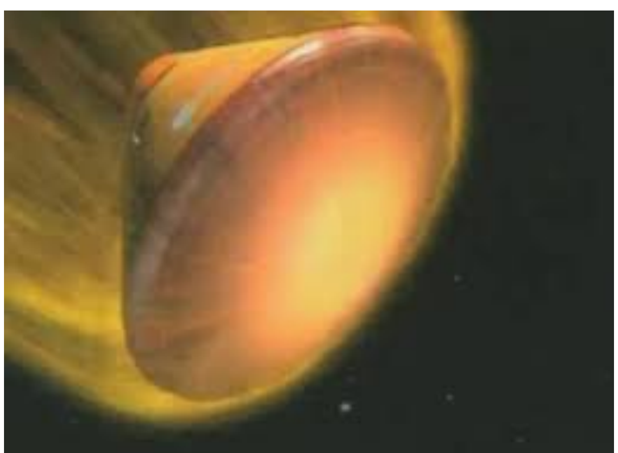


European Activities

Unmanned Orbital Re-entry Demonstrators

- German capsules (Mirka, EXPRESS)
- German TPS test beds: SHEFEX 1 &2
- French warheads ACRV, CTV: capsule studies
- German automatic landing experiment: Phoenix
- Expert, re-entry test-bed
- CIRA: USV drop test, manoeuvrability in atmosphere, no new phenomena
- Science probes planetary exploration Huyghens, Exomars

ARD Athmospheric Reentry Demostrator

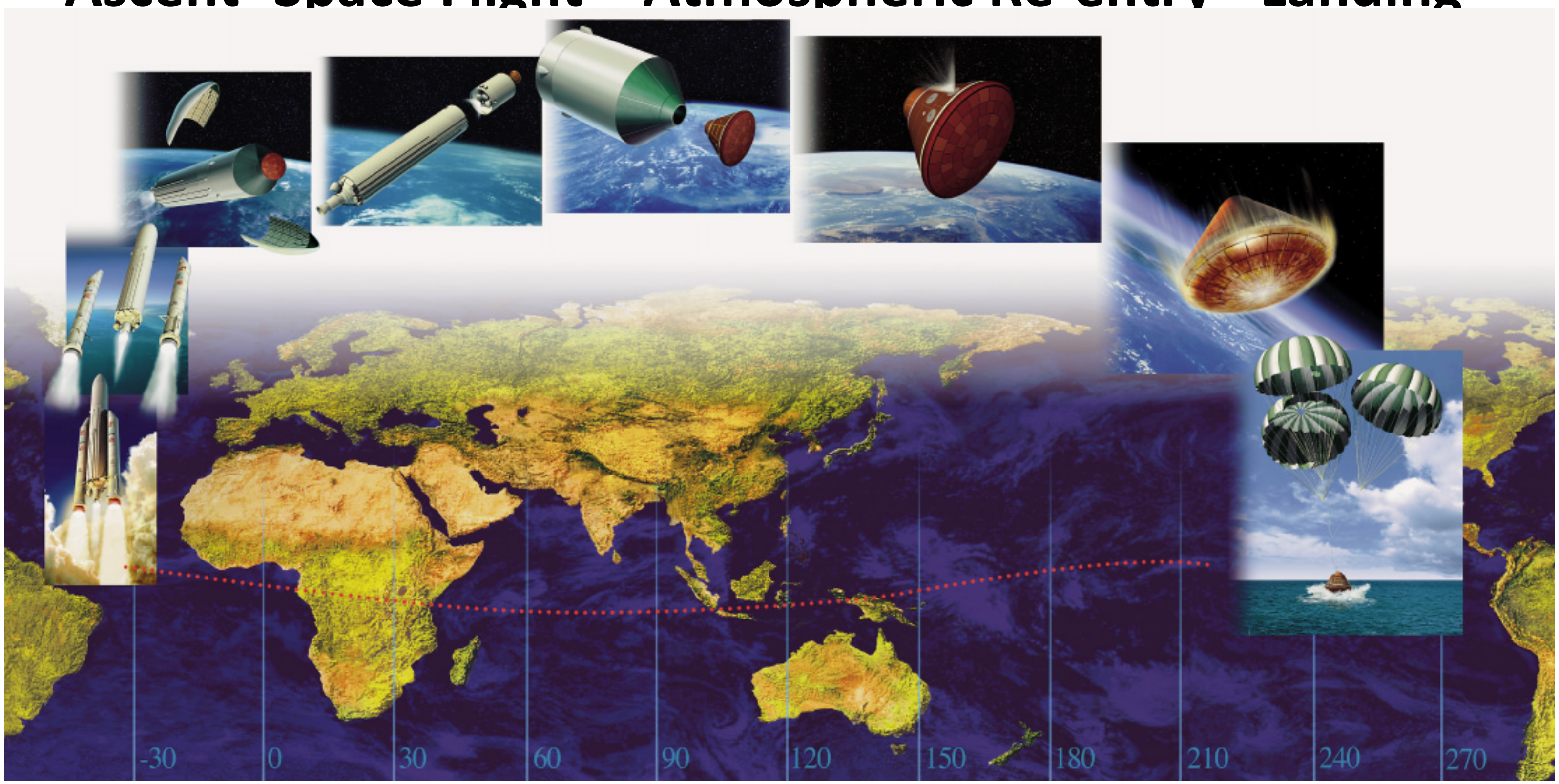


IXV - Intermediate Experimental Vehicle

1st ESA Historical Milestone

ARD - Atmospheric Re-entry Demonstrator, 21/10/1998

GOAL: European capability for a complete spaceflight cycle:
Ascent- Space Flight – Atmospheric Re-entry - Landing

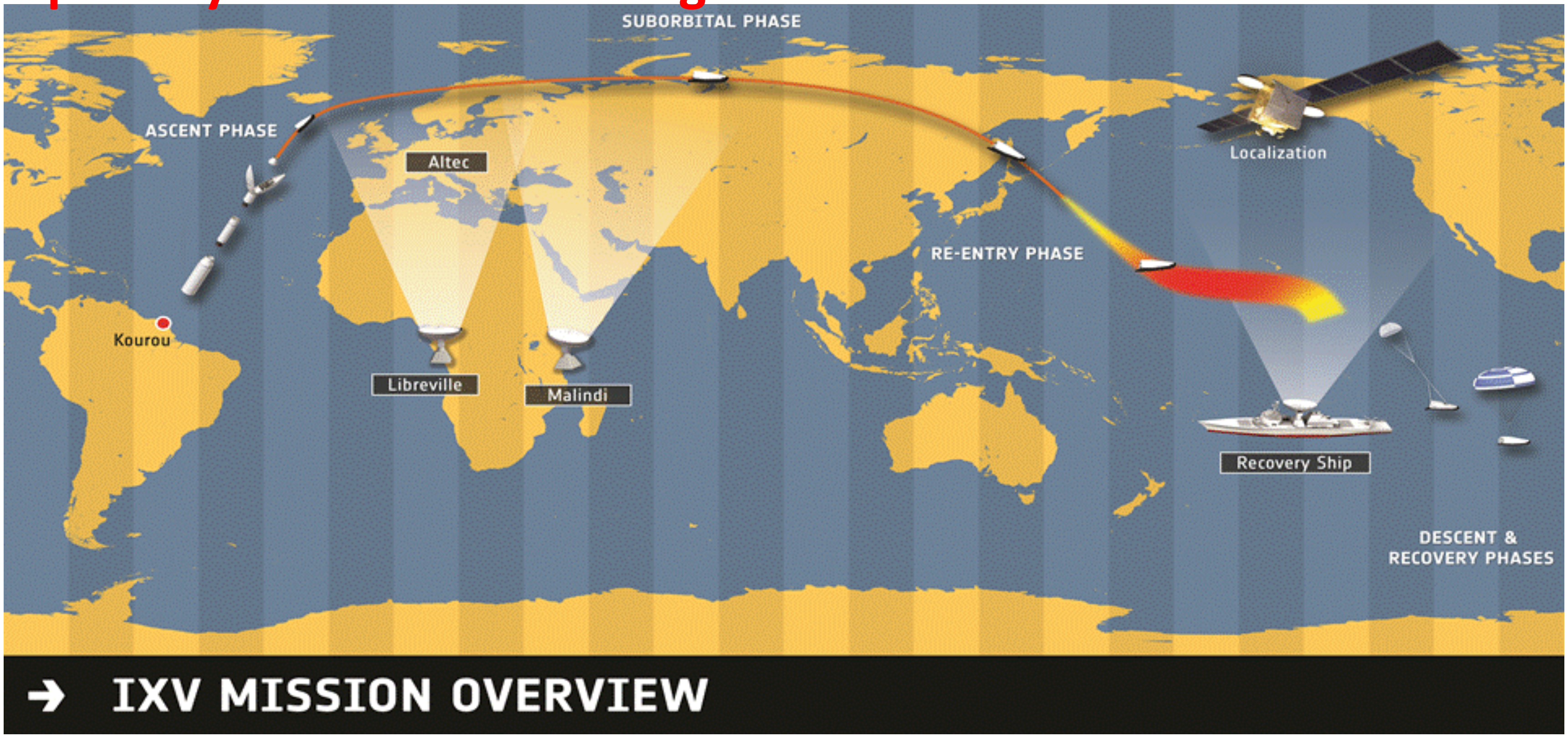


Suborbital reentry test from 800 km altitude. Max heat shield temperature = 2000°C

2nd ESA Historical Milestone

IXV - Intermediate Experimental Vehicle, 07/11/2014

GOAL: European capability for a complete spaceflight cycle: Ascent- Space Flight– Non Ballistic Atmospheric Re-entry – GNC capability – Precision Landing



Suborbital re-entry test of Lifting Body from 430 km altitude with GNC capability.
Max Mach= 25   Max heat shield temperature = 1650°C 300 sensors

The IXV Experimentation Plan

Jointly defined by ESA, European Research Organizations (CIRA, DLR, ONERA, Universities) and Industries.

DISCIPLINES

AERODYNAMICS AEROTHERMODYNAMICS

THERMAL PROTECTION SYSTEM

FLIGHT MECHANICS GNC

EXPERIMENTS

Continuum Flow
High Altitude Aerodynamics
Flush Air Data System
Base Flowfield
General Heating
Wall catalysis
Flap ATD+SWBLI
Jet Flowfield Interaction
Laminar to Turbulent transition
IR CameraTemp Mapping
Cavity heating
Slip Flow/Skin Friction

C/SiC Nose Cap
C/SiC Shingles
TPS Junction
Body Flap
Hinge Line Seal
Ablative TPS

Vehicle Model Identification

SENSORS

Type S Thermocouple	**105**
Type K Thermocouple	**89**
Absolute Pressure Sensor	**37**
Differential Pressure Sensor	**2**
Displacement Sensors	**12**
Strain Gauges	**48**
Infra Red Camera	**1**
Inertial Motion Unit	**1**

EDAR

Experiment Data Acquisition & Recording System

One Data Acquisition Unit Master
Four Data Acquisition Units (DAUs)
One Ethernet Switch
Two Solid State Recorders
One Exp Telemetry Transmitter
Two Exp Telemetry Antennas
Four Redundant Recorders on DAUs
IR camera Data Handling Unit

ESA most interesting activity for Italy:

VEGA + the IXV evolution

Access + Apps at LEO + Navigation and Re-entry : When?

Activities on Manned Hypersonic Vehicles

USA Human Spaceflight

- Mercury, Gemini , Apollo
- Space Shuttle
- X-38
- DC-XA
- SLI/OSP
- SLS/MPCV

ESA Attempts for Human Spaceflight

- Hermes
- ACRV, CTV
- X-38/CRV
- Clipper
- CSTS
- ARV
- MPCV ESM

USA activities

Human Spaceflight

- Dynasoar
- Mercury, Gemini
- Apollo
- Space Shuttle
- X-38
- DC-XA
- SLI/OSP
- SLS/MPCV

Launch Systems

- X-vehicles high speed
- NASP / Rockwell/X-30
- DC-X (BMDO)
- SSTO X-33/Venture Star
- ASTP

- Glenn technology work

Past European Activities

Human Spaceflight

- Hermes
- ACRV, CTV
- X-38/CRV
- EXPERT
- Clipper
- CSTS
- ARV
- MPCV ESM

Launchers

- WLC
- Hotol
- Saenger II
- FESTIP
- FLTP
- FLPP / IXV

Unmanned Vehicles

- Sounding rockets
- German capsules (Mirka, EXPRESS)
- German TPS test beds: SHEFEX 1 &2
- French warheads
- German automatic landing experiment: Phoenix
- CIRA: USV drop test, manouverability in atmosphere, no new phenomena
- Science probes planetary exploration Huyghens, Exomars

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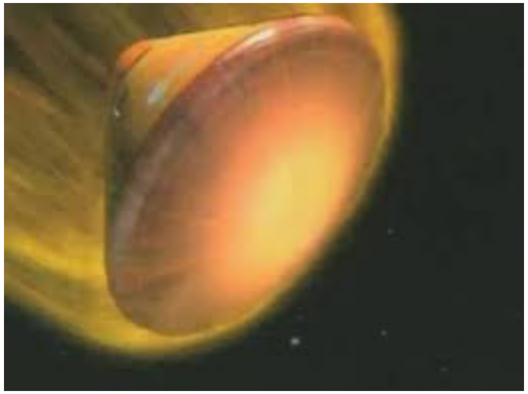
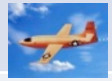


Name	Agency, Manufact.	Picture	Vehicle	First flight	Purpose
X-1	USAF, NACA Bell Aircraft		High-speed plane	1946	High-speed, high-altitude flight. M=1
X-2	USAF Bell Aircraft		High-speed plane	1952	High-speed, high-altitude flight. M>3
X-3	USAF, NACA Douglas Aircraft		High-speed plane	1952	Long duration high-speed: not achieved
X-15	USAF, NACA North American		Hypersonic plane	1959	Hypersonic rocket propelled flight. M>6
X-17	USAF, USN Lockheed		Three-stage solid fuel sounding rocket	1956	Atmospheric re-entry M=14.5
X-20					
X-23					
X-24					
X-30					
X-33					
X-34					
X-37					
X-38					
X-40					
X-41	USAF	?	Manoeuvring re-entry vehicle (classified)	1998 - ?	Steerable warhead
X-43	NASA - Microcraft		Scramjet testbed (seconds)	2001 - 2004	X-43A (rocket accelerated): M = 9.68, 110 000 ft
X-51	USAF - Boeing		Waverider, Scramjet demo	2010 - 2013	Hypersonic flight M=5, 210 seconds