Overview on Past and Present Projects in Germany to Flight-Test Reentry Technologies

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Outline

- Historical notes
- Problems of reentry
- Flight tests in 1990s
- USERS project
- Flight test projects (EU)
  - IRDT, EXPERT
  - TETRA – SHEFEX
  - ASTRA / PHOENIX
- Concluding remarks
Historical Notes

- 1960: first successful recovery of reentry capsules

- 1961: Vostok (Gagarin, first manned flight)
- 1961-1972: Mercury, Gemini, Apollo
- since 1967: Sojuz

Winged Vehicles:
- since 1981: Space Shuttle

Reentry Projects of J & EU:
- 1994-1996: OREX, EXPRESS, HYFLEX (J)
- 1995-1998: EXPRESS, MIRKA, ARD (EU)
- 2003: USERS (operational s/c)
Why is Reentry Flight so Difficult to Achieve?

• **Problem areas** that must be mastered:
  – Rocket deorbit maneuver, AOCS
  – Thermal protection system (TPS) to withstand extreme heating & mechanical loads
  – Aerothermodynamic prediction (AT CFD)
  – Navigation, guidance, and control (GNC) of maneuvering lifting bodies in atmosphere
  – Blackout phenomena; landing & recovery ops.

→ **Demand for flight testing**
  – to demonstrate maturity of system concept and / or technologies involved
  – Approach: ballistic – lifting – winged s/c
Atmospheric Flight

Descent (exoaatmosph.)

Entry

\[ v = 7.6 \text{ km/s} = 27360 \text{ km/h} \]

Ballistic reentry

2000-4000km

Parachute landing

Lifting flight

Low, long Heating rates (10-20 min.)

GNC Flight control

low deceleration < 2g

\[ \text{Ma} \approx 2.5 \]

\[ h \approx 24 \text{ km} \]

Horizontal landing

TAEM approach

10000-14000km

Atmosphere

\[ h = 120 \text{ km} \]
Mission Scenario of USERS

Source: Ijichi, Wakasugi (IAF-97-U.1.03)
Flight Tests of Past Decade

EXPRESS 1995
(D-J-R)
• Material
• Instrumentation

MIRKA 1997 (D; SPA, Sensors)

ARD 1998 (EU)
System demonstr., operation
Material, GNC, AT
Ballistic Capsules for Flight Testing Reentry Technologies

**EXPRESS:** Cooperation Japan – Germany (1995)
- Partial success, uncontrolled entry
- German experiments:
  - PYREX, RAFLEX
  - CETEX high temp.
  - Resistant C/SiC tile

**MIRKA:** Cooperation Germany – Russia (1997)
- Objectives achieved
  - Qualification of selfsupporting SPA-structure concept
  - Aerothermodyn. (AT) experiments
  - Generate AT flight data base
MIRKA Recovery 1997

Recovery in Kazakhstan

Capsule damage due to severe surface winds!

d = 1m / m = 154kg
Early Objectives of USERS (1995)

Project implementation to take advantage of experiences from EXPRESS, SFU

Promote utilization of space environment by:
- Operational and utilization advantages vs. ISS (JEM, COF), EURECA
- Payload delivery & retrieval independent from US Space Shuttle → operational authority
- Providing excellent microgravity level for long duration experiments
- Lower operating cost, shorter lead and turn around times of experiments, etc.

Strong interest of German space industry for long term cooperation with Japan
- Continuation of successful cooperation in EXPRESS project
- Joint development of a demonstrator & an operational USERS
- Joint research, and mutual use of space system
- Management methods „Cheaper, Faster, Better“ employing conventional technology, commercial parts, standardization of interfaces etc.

USERS proposal of G industry not supported by DARA, that opted for X-38
Achievements of the USERS Project

Main objectives fully met:

- Long duration material processing experiment (SMAP) conducted
- Deorbit, reentry, and recovery operations successfully accomplished
  - vehicle dynamics & loads as expected, TPS performed well (though some damage observed, Inatani 2003, Matsuoka et al. IAC-03-V.3.04)
  - landing in planned area indicates adequate performance of deorbit maneuver control, and capsule aerodynamic behaviour
- Design methods employing conventional methods (e.g. ballistic entry, blunted cone, ablative TPS), commercial parts, and standardization techniques demonstrated with good results
  Cheaper, faster?

Unmanned on-orbit experiment infrastructure comprising SEM and REM qualified to benefit future research programs

→ Very ambitious project, impressive results
**USER Results / Lessons Learned**

**SEM Orbit operations established:**
- Any shortcomings / deficiencies observed?

**Reentry flight results:**
- Anomalies experienced ?:
- Amplitudes of tumbling motion and n-loads within limits
- Capsule Aerodynamics / TPS performance as expected ?

**Lessons learned:**
- Mission operation, entry flight and recovery successful
- Qualification of selfsupporting ablative design concept, strengthening structure required ?
- AT prediction accuracy vs flight data ?
- Improvements of deorbit to reduce recovery area / cost ?
- Extensions for controlled semi-ballistic flight planned?
Concept Demonstrator Capsules IRDT, ARD

**ARD:** Atmospheric Reentry Demonstrator (1998)
- Low L/D for aerodynamic maneuvering
- Objectives achieved, guided entry
  - 4 CMC samples embedded in shield
  - 2 FEI test samples on cone
- Aerothermodynamic Measurements
- GNC hard- & software flight tested
  → Discrepancies predictions and data

**IRDTh:** Inflatable Reentry, Descent Techn. (2000-2004)
- Objectives:
  - Qualify IRDT concept (origin: Mars 96 s/c; adapted to Earth entry)
  - Two flight tests in 2000 & 2002
    - not successful; next flight 11.04
  → Tests using infrastructure of R
IRDT Concept (cooperation EU-G-R)

- Ballistic cone shaped s/c, m $\approx 100kg$
- Two inflatable structures
- Payload retrieval from ISS proposed
- Reflight mission IRDT-2R in Nov. 2004?
PARES Using IRDT – Missionprofile (courtesy EADS)
In-Flight Research on Real Gas Effects (EXPERT)

EXPERT
European Experimental Reentry Testbed

Objectives: validate aerothermodyn. CFD predictions to improve deficiencies wrt flight data by accurate measurements of critical phenomena

- Flow transition and separation
- Catalicity and oxidation
- Real gas effects on shock wave boundary layer interaction

Vehicle and Mission:
- Vehicles of different $m = 250–400$ kg
- Launched by Russian Volna rocket
- Three flight tests planned beginning in 2006

EXPERT Capsule (ESA)
Blunt cone / flap configuration
TETRA – Reentry Technologies for Future STS

Demonstrator X-38 (NASA) → CRV

German and ESA support:
- Delivery of essential hardware / software
- Engineering expertise in design, AT
- GNC algorithms
- Major EU interest → flight testing

Germany developed & qualified:
- Nose assembly \( T_{sp} \leq 1750 \, ^\circ\text{C} \)
  C/SiC Nose Cap, CMC tiles, sensors
- Body flaps and Health Monitoring system
- Flexible External Insulation (FEI)
  → Experience will benefit future projects

Project X-38 cancelled by NASA
Aerothermodynamic CFD Predictions (AT)

Much progress, but problems exist:
- Discrepancies between flight measurements and aerothermodyn. prediction results
- Real gas effects, flow transition, flow separation, inadequate models of finite rate chemistry (catalicity, oxidation)
→ Flight testing for CFD validation

Oxidation effects on C/SiC-TPS:
- Active oxidation results in significant increase in temperature and surface erosion
- Ref.-missions of X-38, EXPERT enter passive-active transition regime
- Adverse effects on reusability to be avoided
Sensorsystem PYREX-KAT38

Temperature distribution on Nose:
- Heating rates max. at stagnation area temperatures up to 1750 °C
- PYREX measurement locations shown

Six channel sensor system:
- Qualified for flight X-38 V201
Motivation for Facetted Design Concept SHEFEX

\[ \Rightarrow \text{reduced manufacturing cost by flat panels (~70 %), and improved inspection, maintenance and repair expected} \]
Objectives of SHEFEX Flight Experiment

**SHEFEX goal:**
- Suborbital flights for **concept testing**
- Launch by two stage rocket system (DLR Moraba; VS 30, Orion)

**Experimental vehicle:**
- Length ~1 m, diameter ~ 0.5 m
- Convex and concave shapes
- Different TPS panels used; CMC, metallic, FEI
Mission Profile
- Second stage attached to provide control
- Jettisoned before parachute deployment
- Experiments in h ≈ 100 – 40 km, 20 – 30 s

Altitude-velocity profile
(HEG High Enthalpy Tunnel)
ASTRA – PHOENIX Flight Experiment

**ASTRA (D):**
Advanced Systems & Technologies for RLV Applications
- Develop RLV technologies
- Design representative test vehicle PHOENIX (rear c.g.)
- Demonstrate GNC, automatic landing capability

**Flight tests:**
- Three flight tests successfully performed in May 2004 at Vidsel / Sweden

**Growth potential:**
- Structural design allows extension of flight envelope to Ma ~ 2-2.5

**Future steps:**
- Propelled PHOENIX-2 (VTO, HTO) within FLPP of ESA

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Courtesy EADS
Concluding Remarks

- Overview given on EU reentry flight test programs (incomplete) with emphasis on German contributions
- Long term goals of German main efforts are winged RLV
- Broad EU flight test projects seem fragmented; many projects with different goals by various countries / organizations
- By comparison, the Japanese approach appears straightforward, steps:
  - EXPRESS / SFU → operational USERS
  - HYFLEX, ALFLEX, HSFD → reusable HOPE-X
ERNO EXPRESS Configuration

EXPRESS: Wandtemperatur bei maximaler Wärmebelastung für aerodynamischen Rückkehrflug
(Eintritts-Bahnwinkel $\gamma_e = -1.81^\circ$)