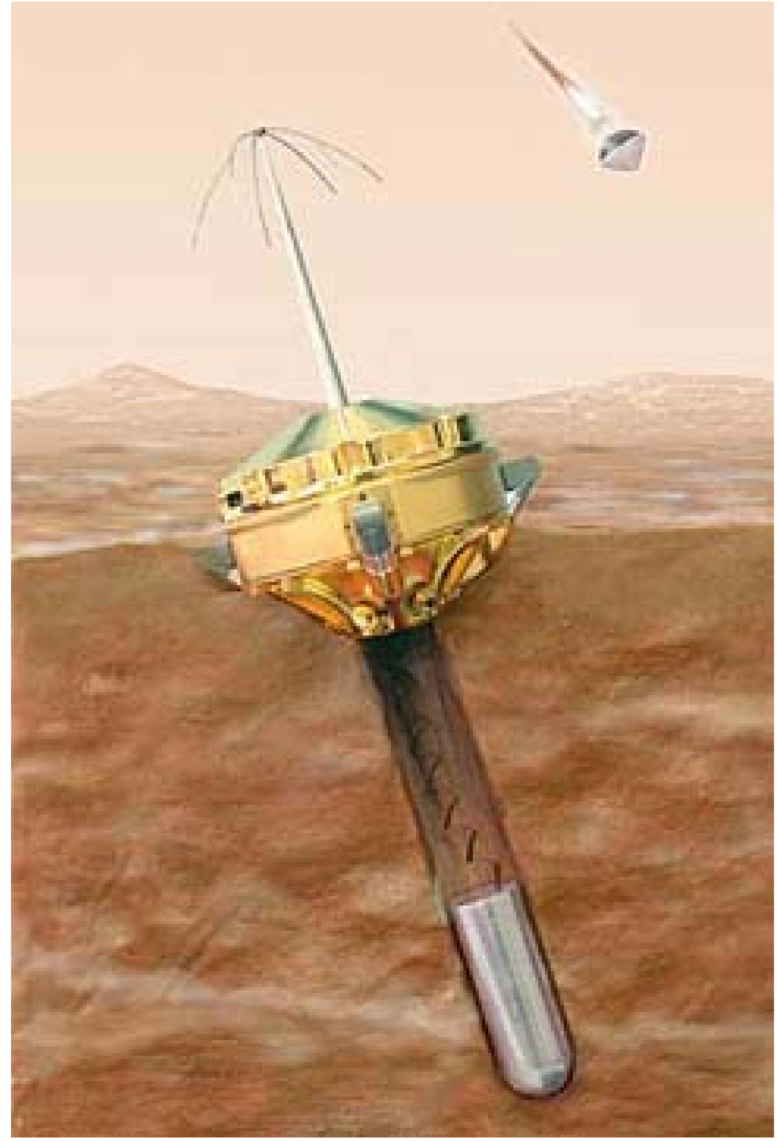
New Millennium DS-2 Mars Microprobes
(and penetrators in general)



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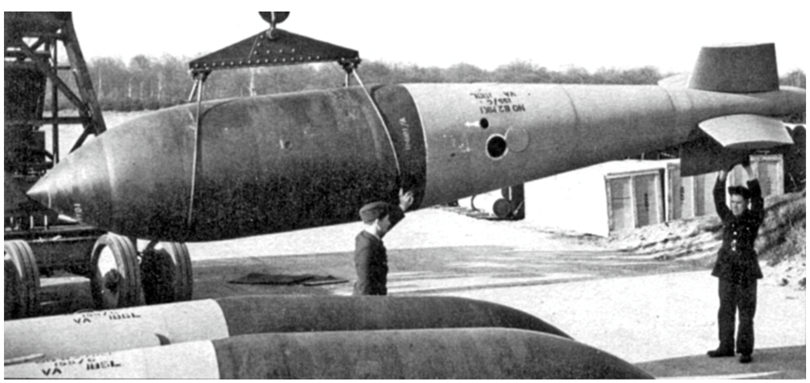
Tall Boy / Grand Slam

Slender, very heavy weapons devised in WW2 by British engineer Barnes Wallis (of 'Bouncing Bomb' fame) to attack hardened targets (e.g. U-boat pens, tunnels, earthen dams ; later also used on Tirpitz battleship and V2 launch complex at Le Coupole)

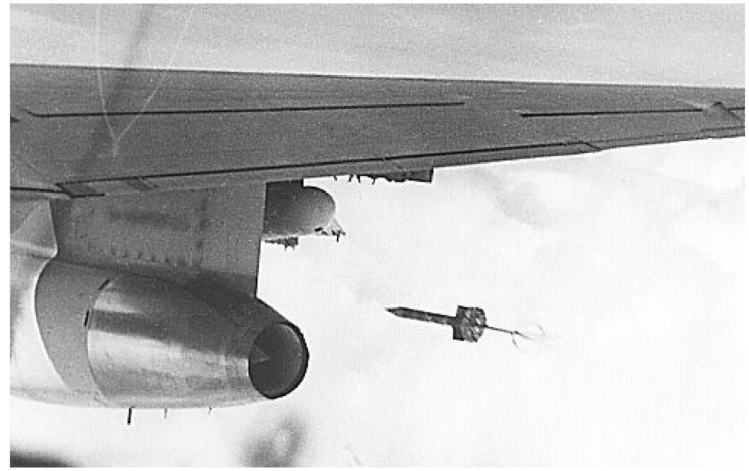
Design intent was to penetrate to depth to enable strong seismic coupling, hence description as 'earthquake bombs'

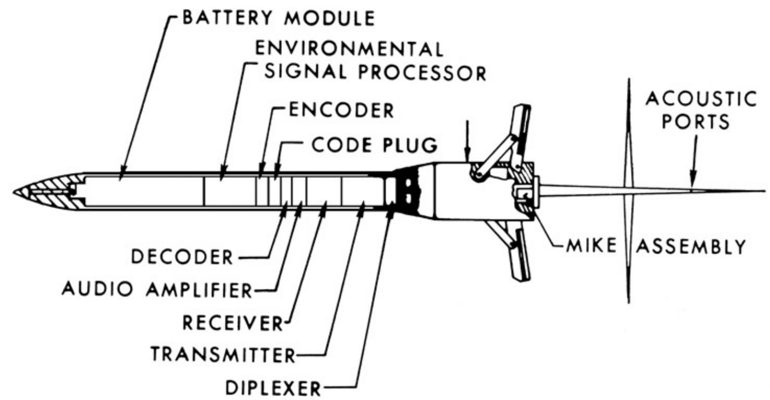
Slender shape and spin-stabilization permit supersonic impact. Could penetrate ~40m of earth or several meters of concrete. Particular efforts to assure reliable fuzing.



'Igloo White'

This ~$1.5B project during the Vietnam war air-dropped seismic, acoustic, magnetic and chemical instrumentation around HoChi Minh trail in an attempt to cue strikes to interdict supply operations. (Operations center was the largest building in S. Asia)

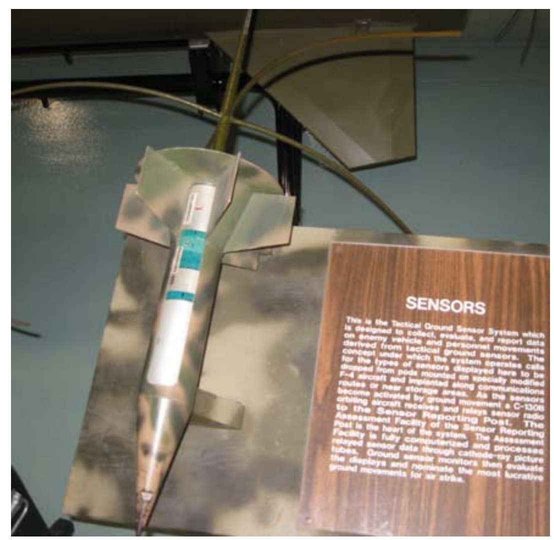




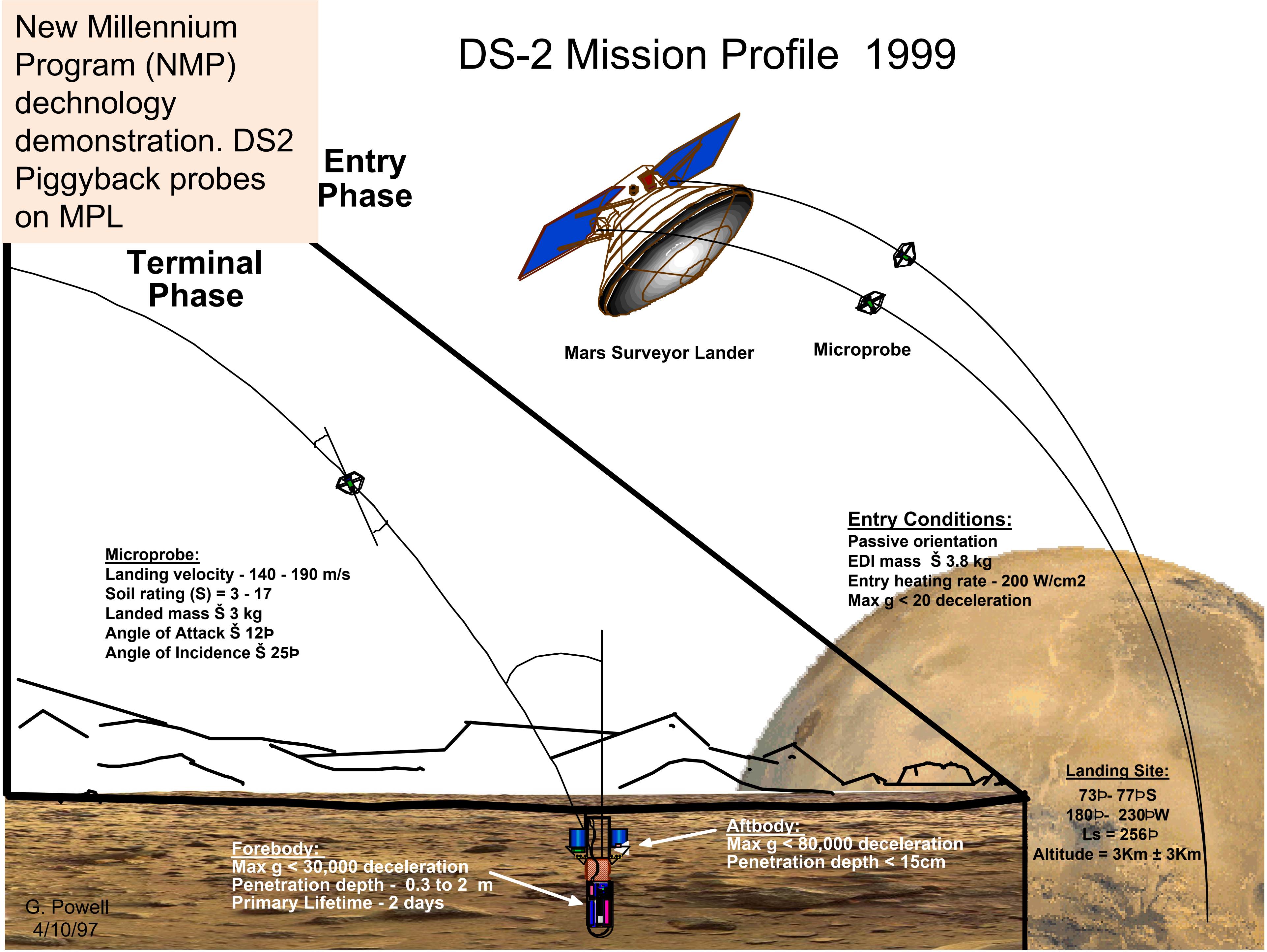
Tens of thousands of sensor units (e.g. ADSID - Air-Delivered Seismic Intrusion Detector. 20kg, 1.3m long; battery life several weeks) were dropped, sending back data via radio relay aircraft. Dropped in strings of ~6 (expectation ~3 might work ; actual stats ~80% operated).

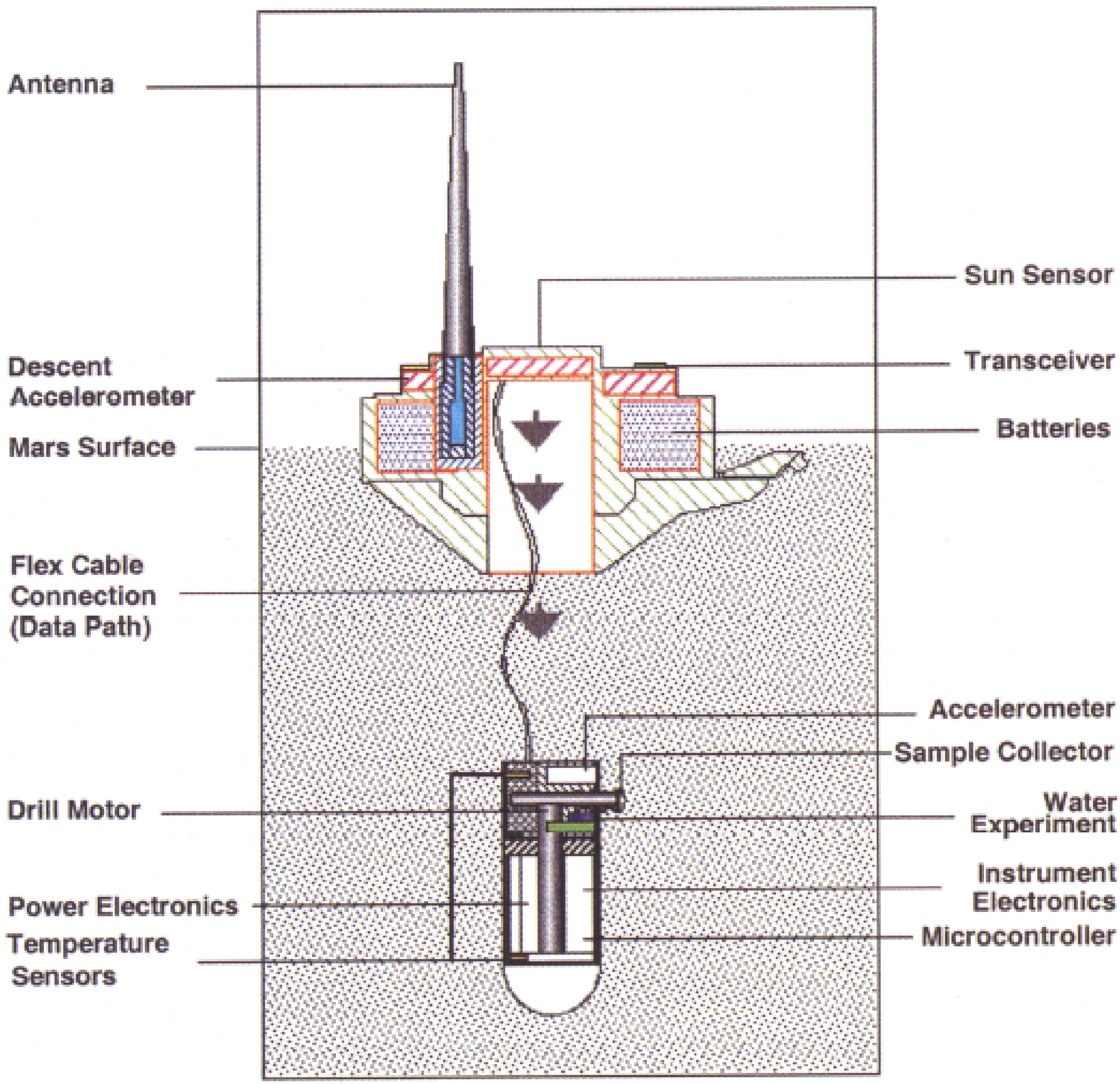
Geophones could tolerate 2000g impact pulse (few ms long) from air-drop deployment, yet were sensitive enough to detect human footsteps ~30m away.

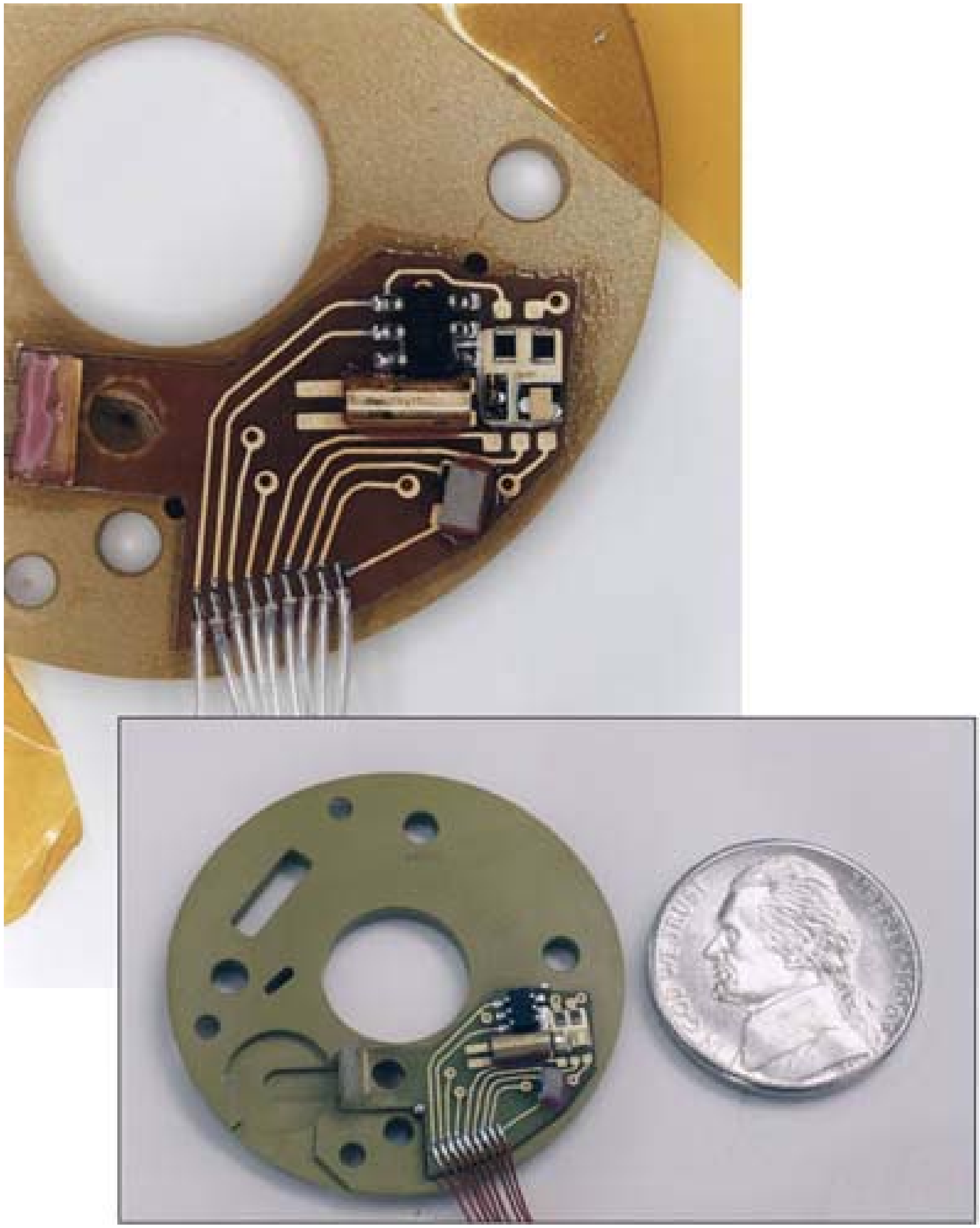
Project introduced early on-board data compression (e.g. 32 sequential footsteps defined a 'pedestrian' encounter')



USAF Armaments Museum, FL. Photo: R. Lorenz


New Millennium Program (NMP) dechnology demonstration. DS2 Piggyback probes on MPL
DS-2 Mission Profile 1999
Entry Phase
Terminal Phase
Mars Surveyor Lander
Microprobe
Entry Conditions:
Passive orientation
EDI mass Š 3.8 kg
Entry heating rate - 200 W/cm2
Max g < 20 deceleration
Microprobe:
Landing velocity - 140 - 190 m/s
Soil rating (S) = 3 - 17
Landed mass Š 3 kg
Angle of Attack Š 12Þ
Angle of Incidence Š 25Þ
Landing Site:
73Þ- 77ÞS
180Þ- 230ÞW
Ls = 256Þ
Altitude = 3Km ± 3Km
Aftbody:
Max g < 80,000 deceleration
Penetration depth < 15cm
Forebody:
Max g < 30,000 deceleration
Penetration depth - 0.3 to 2 m
Primary Lifetime - 2 days
G. Powell
4/10/97

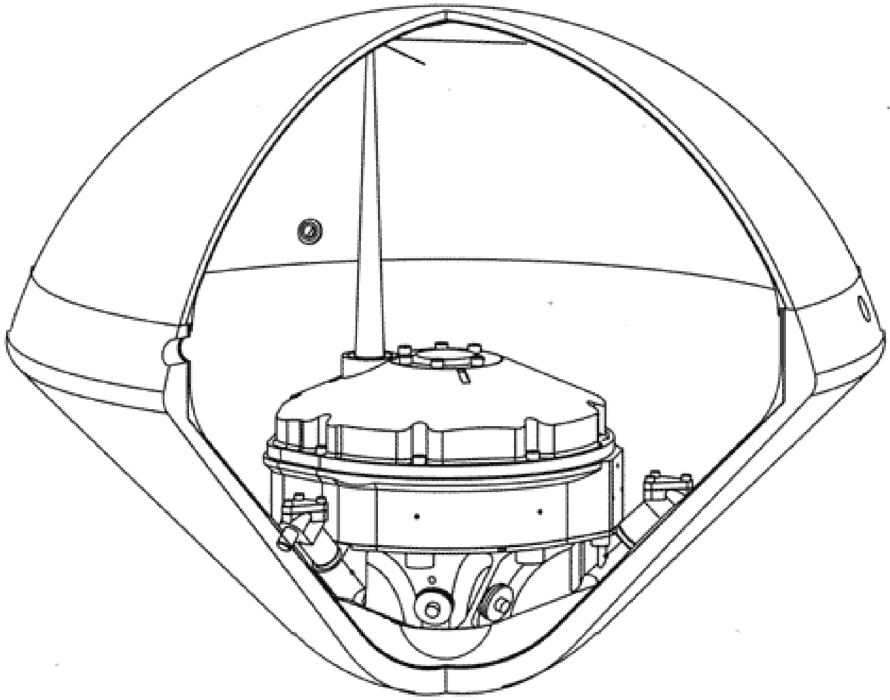

Antenna
Sun Sensor
Descent Accelerometer
Transceiver
Batteries
Mars Surface
Flex Cable Connection (Data Path)
Accelerometer
Sample Collector
Water Experiment
Drill Motor
Instrument Electronics
Power Electronics
Microcontroller
Temperature Sensors

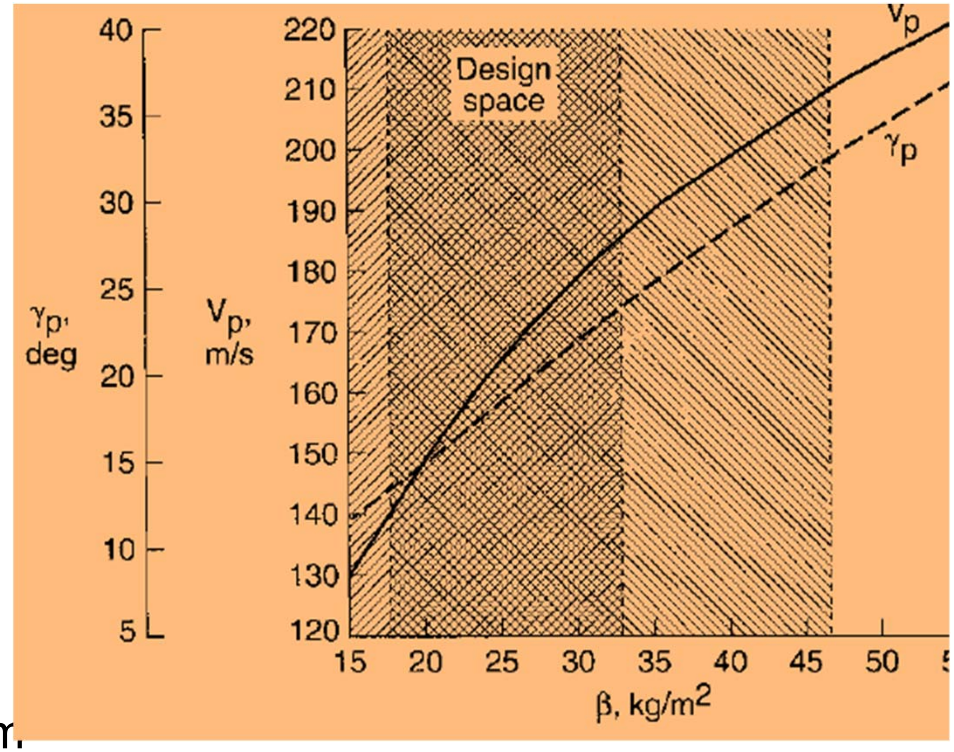


Soil Water detection Experiment

0.9W electric motor runs drill for 5 mins (1cm travel). First three turns opens door. Door sealed afterwards by single pyro.

160 ml heated cup (crude thermal analyzer) with evolved H2O detection by 1.37μm Tunable Diode Laser. (modulated at 5kHz)
2.6cm pathlength defined by single mirror.



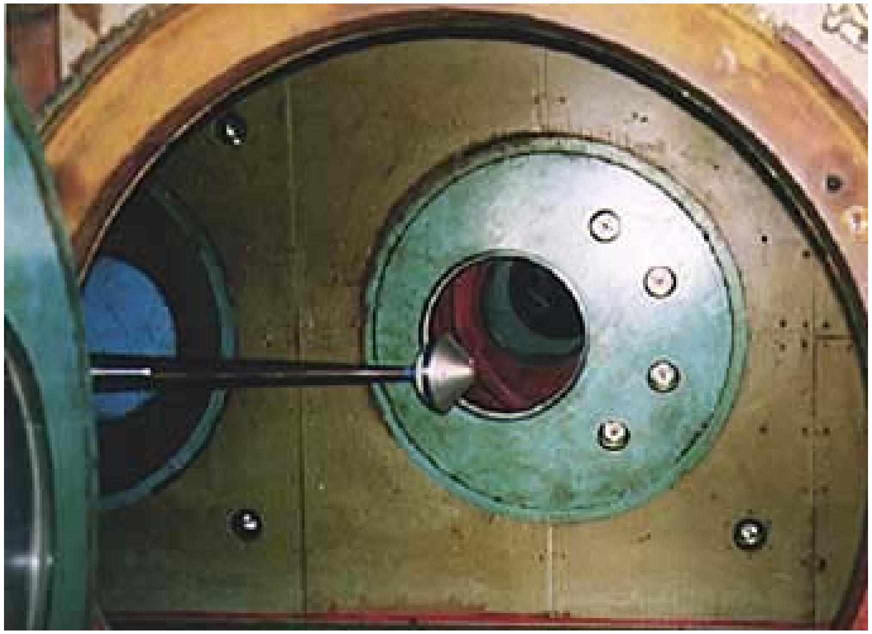


Frangible entry shell 35cm diameter, 28cm high (1.2kg PICA/SIRCA aeroshell)
40mm wide forebody - 0.67kg
1.7kg Aftbody contains batteries, telecom.

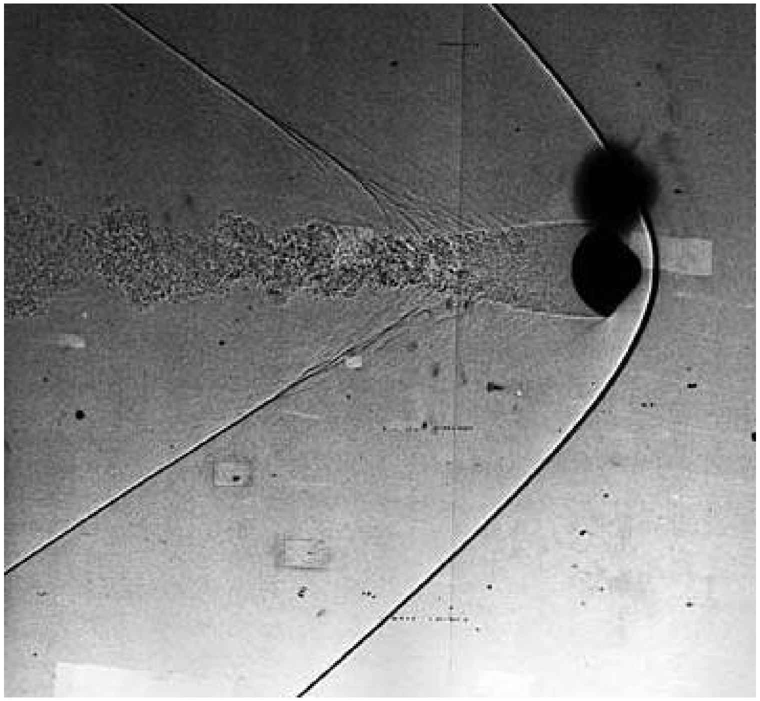
Passive entry stability drives squat configuration - including 'ballast' - tungsten nose on forebody to bring cg forward)

No EDL actuations. Vehicle punches through heatshield at impact.

Entry analysis (Braun et al., JSR, 1999) shows vehicle still decelerating/making gravity turn at impact.



Aeroballistic testing at Eglin AFB, Fl and Wind Tunnel tests at TsNIIMash, Russia



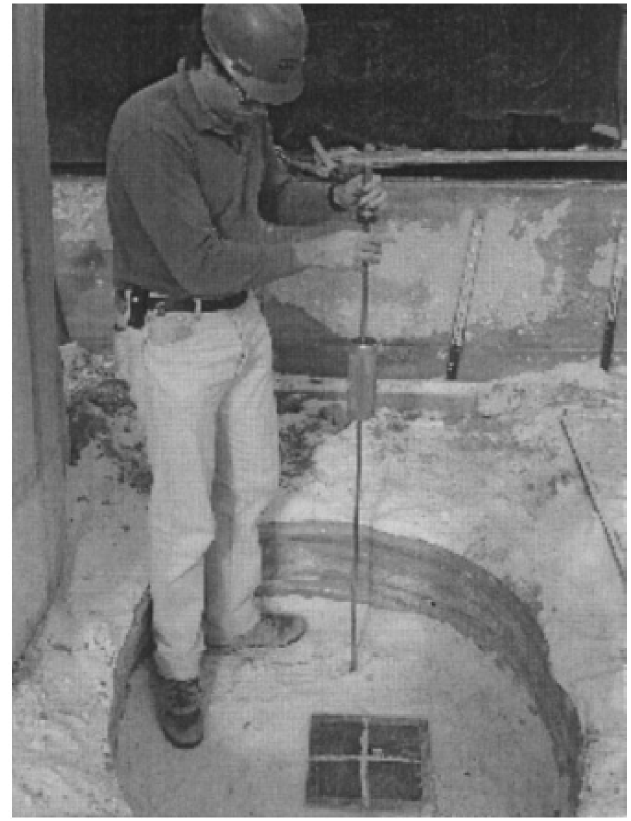
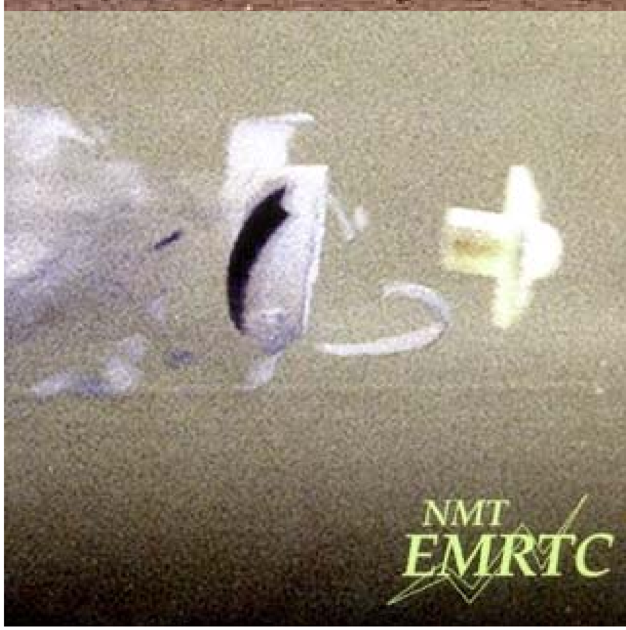
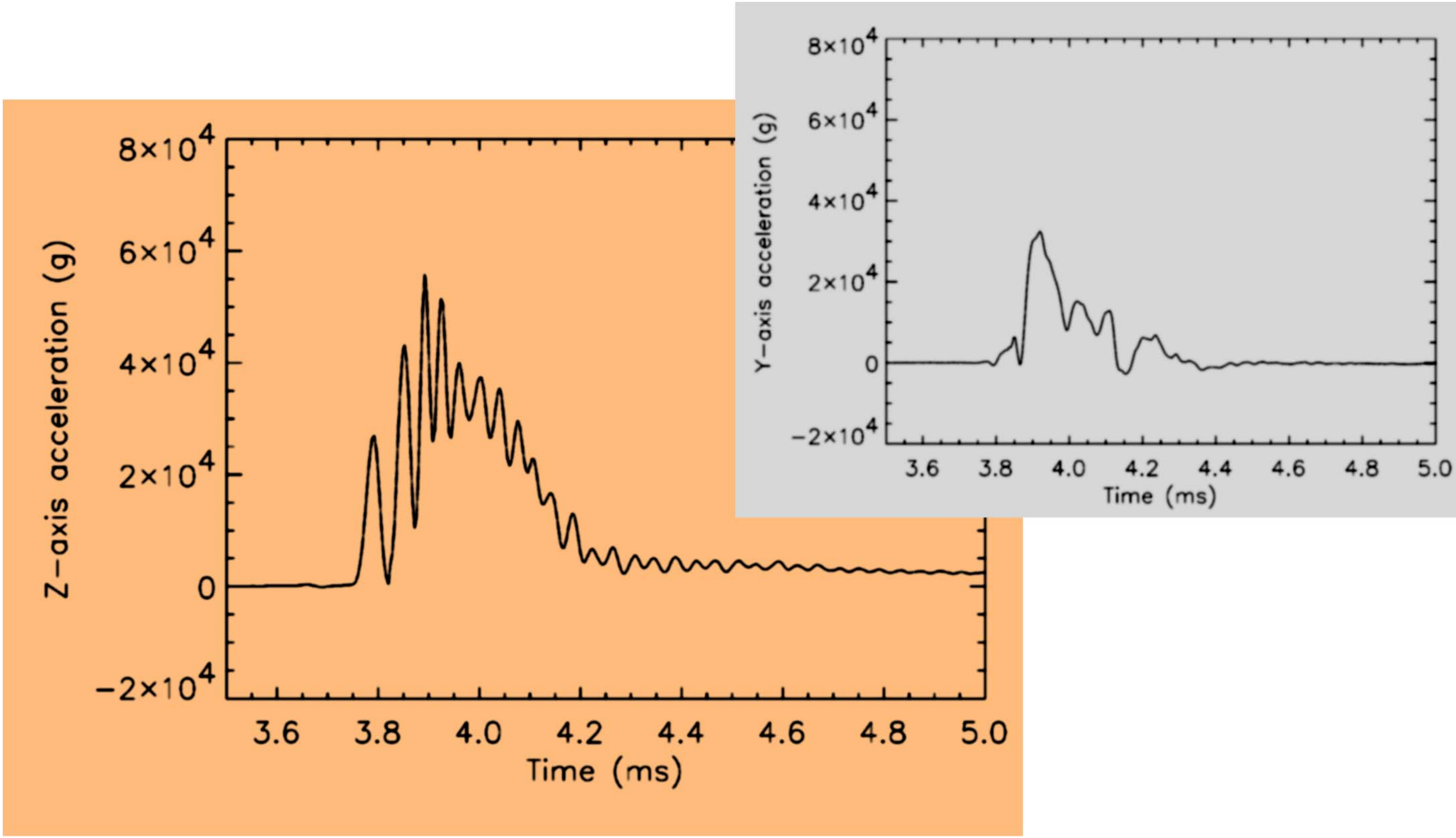


Fig. 15. Testing the hardness of the target at EMRTC. To the left is the X-ray film panel. Square with cross is a panel simulating the entry shell of the penetrator (Photo: J. Moersch).

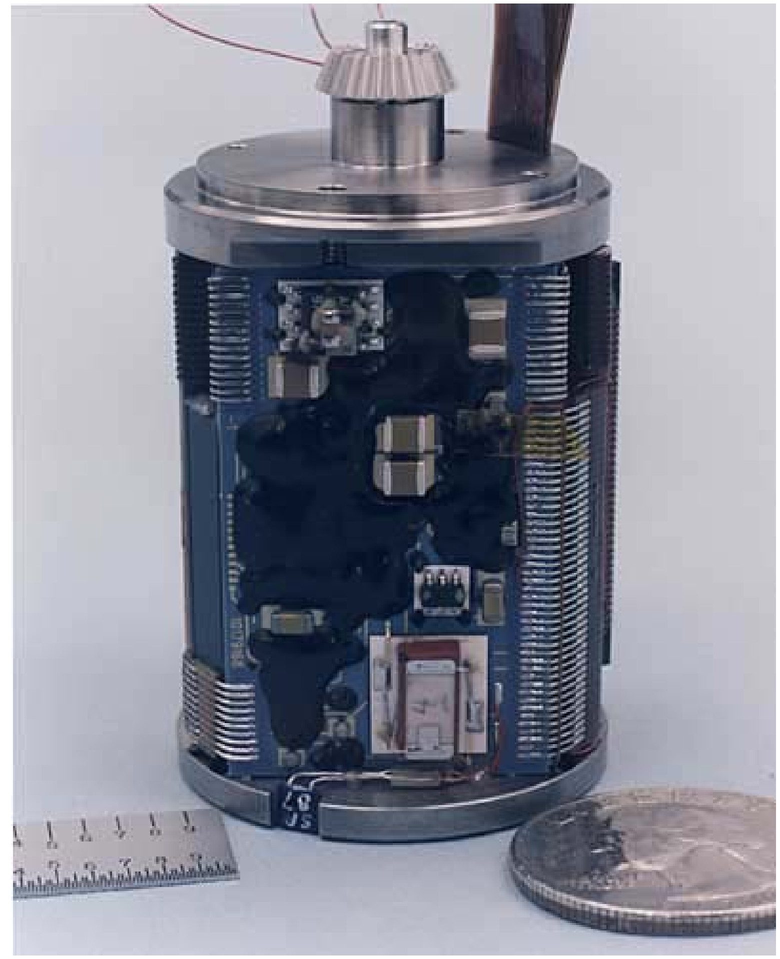


Impact testing at EMRTC in New Mexico 200m/s. ~60 development shots (incl. 2 into cryogenic ice targets)
~6 instrumented science shots. Some post-mission tests. Note testing environment is anathema to spacecraft engineering practice - dirt !



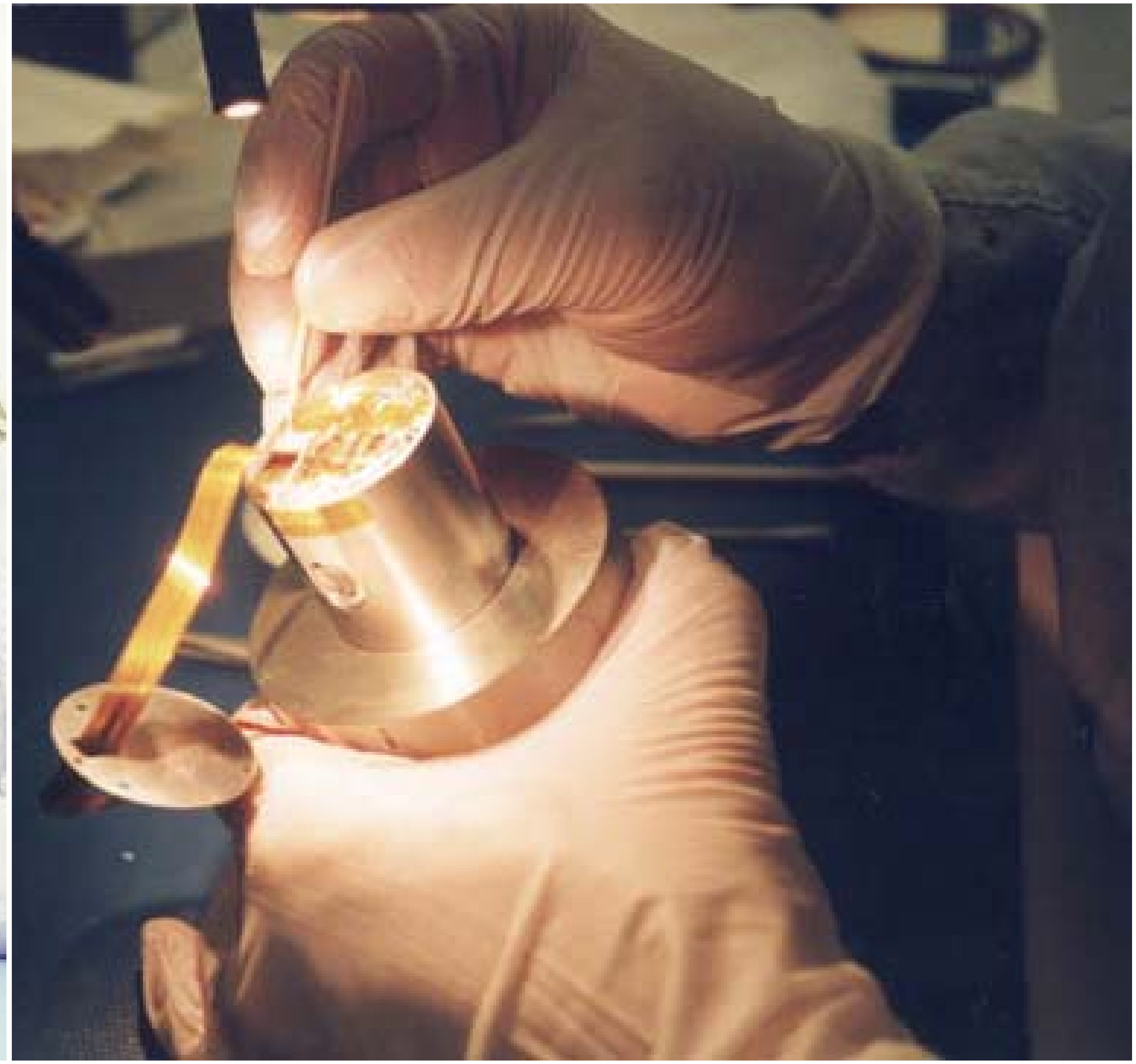
Impact at 180 m/s into sand on clay at EMRTC. Peak faired forebody axial (Z) deeleration = 40,000g. Note strong structural ringing signature. Also note that transverse acceleration (Y) is almost as large.

Technology Developments

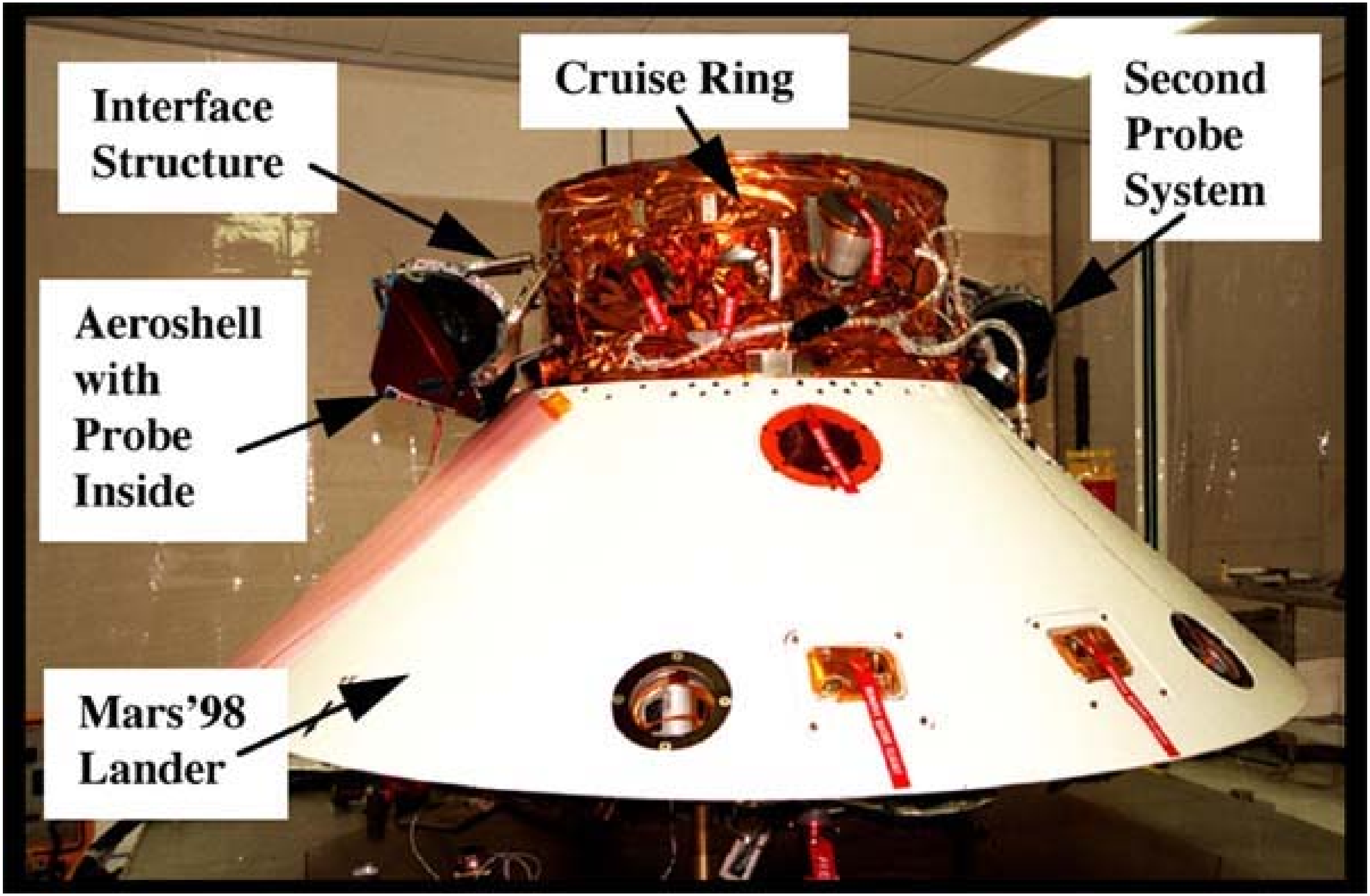


Impact- and cold-tolerant Lithium Thionyl Chloride batteries (lithium tetrachlorogallate salt instead of the more conventional lithium aluminum chloride salt to improve low-temperature performance) by Yardney. 4 cells each 40g, 600 mAh. Batteries and systems tolerant to -50 (perhaps -80C)

Custom Power Management Unit electronics and Advanced Microcontroller (80C51 @ 10 MHz with 32 channel ADC, 6 mW operating, 0.5mW sleep)

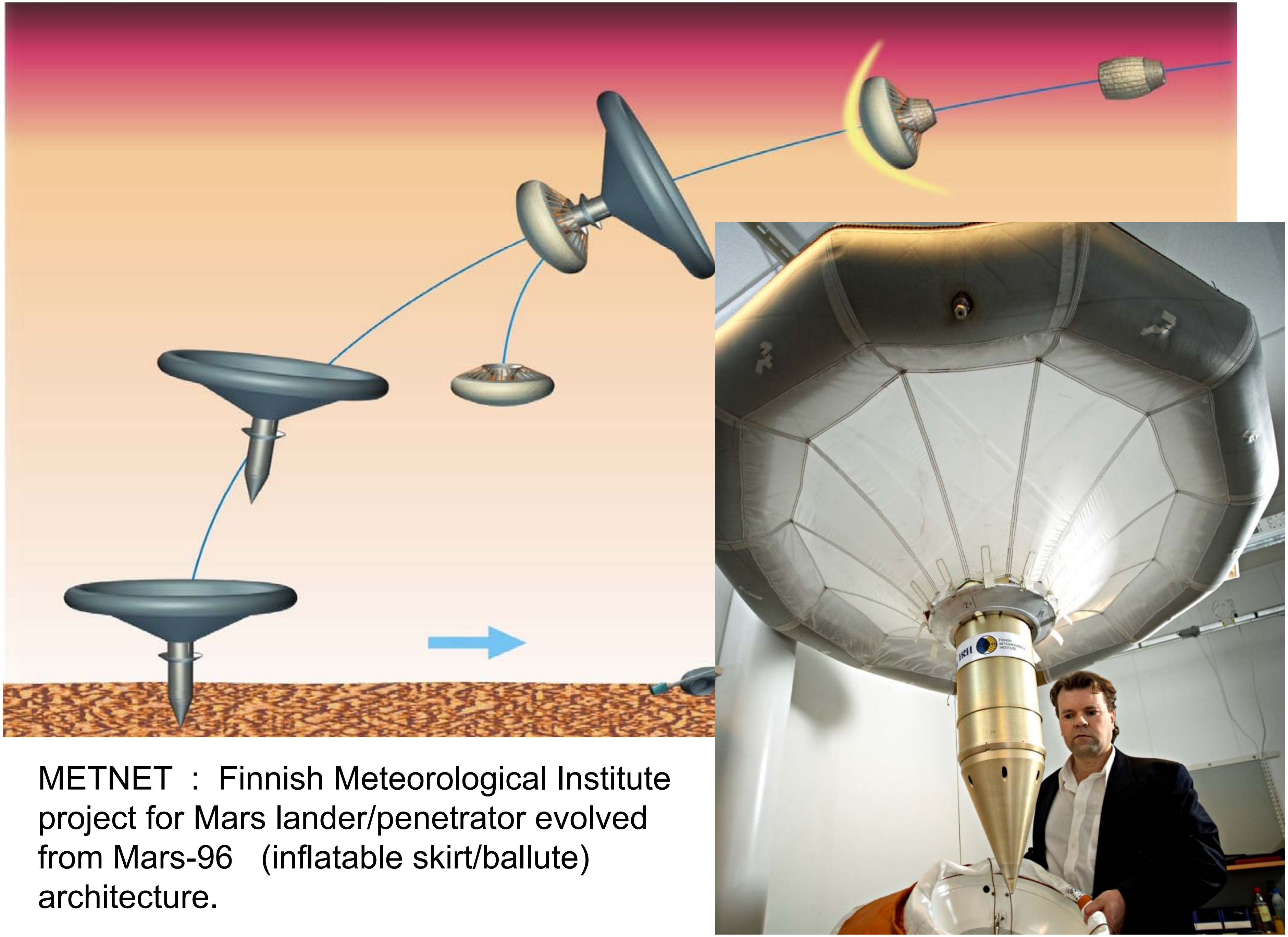
 

Penetrators have very tight volume constraints - have to build all systems into a whole (not provide a set of 'boxes'.)
A particular challenge with very small tightly-integrated systems - insufficient volume for fasteners and access - press-fit or adhesive attachment makes it impossible to non-destructively disassemble after assembly….

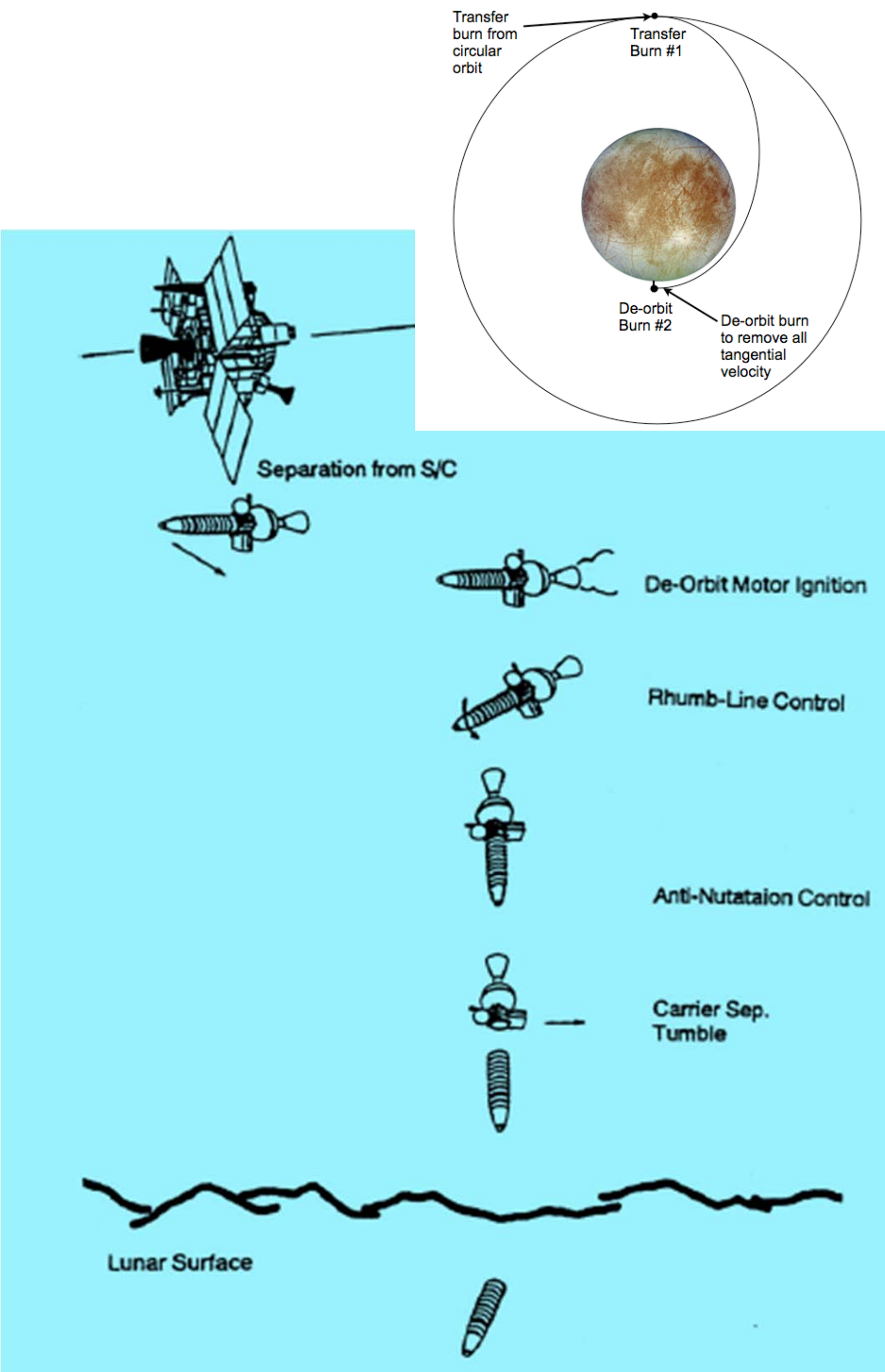

Interface
Structure
Cruise Ring
Second
Probe
System
Aeroshell
with
Probe
Inside
Mars'98
Lander

Bioassay swab for Planetary Protection

DS-2 Development was ~$28M, including ~$1M science team.
Note team overall quite small, and quite young.
Launch 3.21pm 3rd January 1999 on Delta II with MPL.
Never heard from again..



METNET : Finnish Meteorological Institute project for Mars lander/penetrator evolved from Mars-96 (inflatable skirt/ballute) architecture.



Penetrators for Moon or Europa
(qv JAXA Lunar-A, proposed Akon Europa mission, etc.)

>1.5 km/s de-orbit Delta-V, then free-fall. Must use cold-gas or similar to precess attitude to vertical (and actively suppress nutation) during free-fall descent time (~1 minute).

Flight path angle uncertainty at impact depends on motor ΔV dispersion and/or IMU capability. (if impact speed = 100 m/s, then 10^{o} FPA uncertainty demands horizontal speed < 6 m/s.

Unlike at Mars, a 'simple' penetrator (with thermal, communication, challenges..) here demands formidable propulsion and an agile, precise GNC system. And is still at the mercy of the terrain…. Viable IMHO only for large networks where N of M failures allowed..

DS-2 showed that small entry/impact systems can be implemented and carry modest in-situ science payloads.

Accommodation as piggy-back payload restricted testing/development time. Reason for loss not known.

Mars remains an appealing target for similar architecture (aerodynamic deceleration, pointing) but Catch-22 exists : due to terrain risk, penetrators are only really viable at traditionally-acceptable levels of mission risk (1%) for large network missions (>10 stations), but can NASA tolerate perceived risk of large network without first flying a smaller (thus riskier) precursor……?

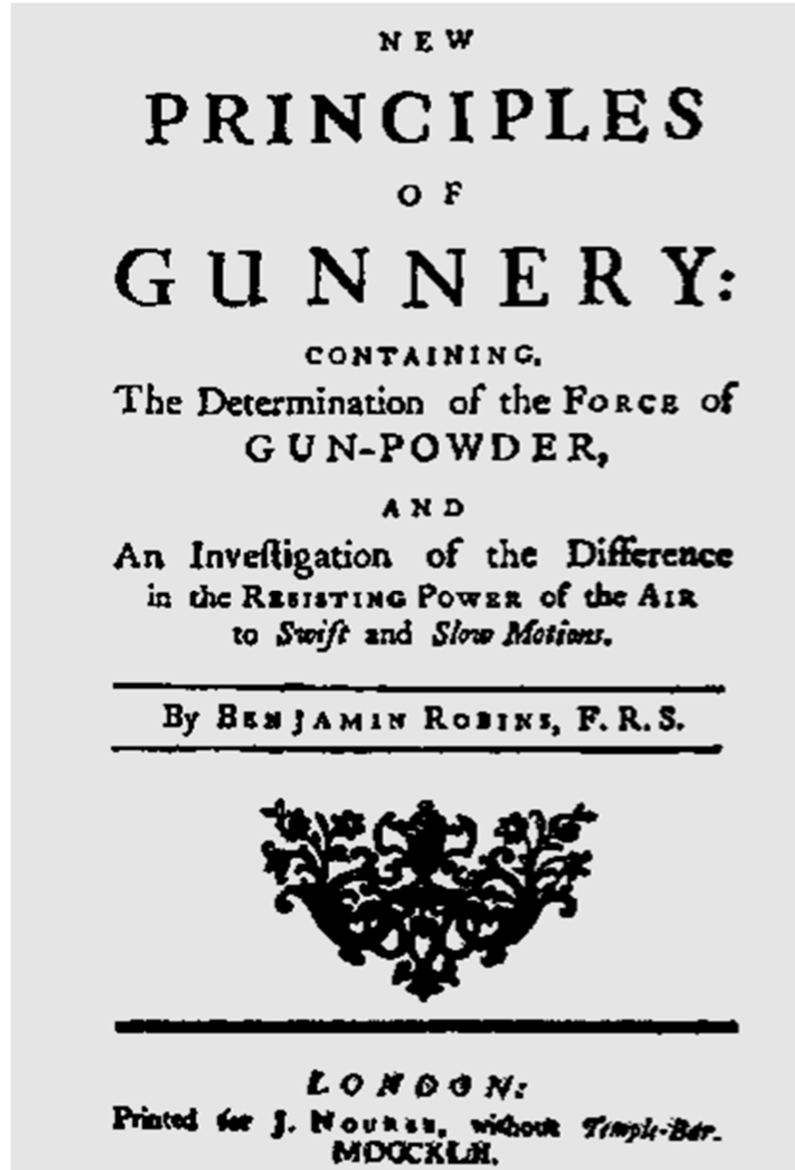
Europa, Moon etc. are even harder.

First quantitative assessment of projectile penetration into the ground was by Benjamin Robins, Engineer-General to the East India Company, notably in his 1742 treatise 'New Principles of Gunnery', which applies Newton's (1698) analytic methods to artillery.

He devised the ballistic pendulum to measure launch velocity and a whirling-arm apparatus to measure aerodynamic drag.

His scientific measurement approach (special precision cannonballs, carefully-measured powder charge) allowed him to understand the effect of streamlining, to detect the effect of spin on projectiles (the Robins-Magnus effect, often rather unfairly referred to only by the latter) as well as the transonic rise in drag coefficient (the 'sound barrier').

He determines that the penetration of shot into solid materials varies as the square of velocity.



NEW

PRINCIPLES

OF

GUNNERY:

CONTAINING,

The Determination of the Force of GUN-POWDER,

AND

An Inveſtigation of the Difference in the Resisting Power of the Air to *Swift* and *Slow Motions*.

By Benjamin Robins, F.R.S.

LONDON:

Printed for J. Nourse, without *Temple-Bar*.

MDCCXLII.