SOVIET VENERAS AND MARS: FIRST ENTRY PROBES TRAJECTORY RECONSTRUCTION AND SCIENCE

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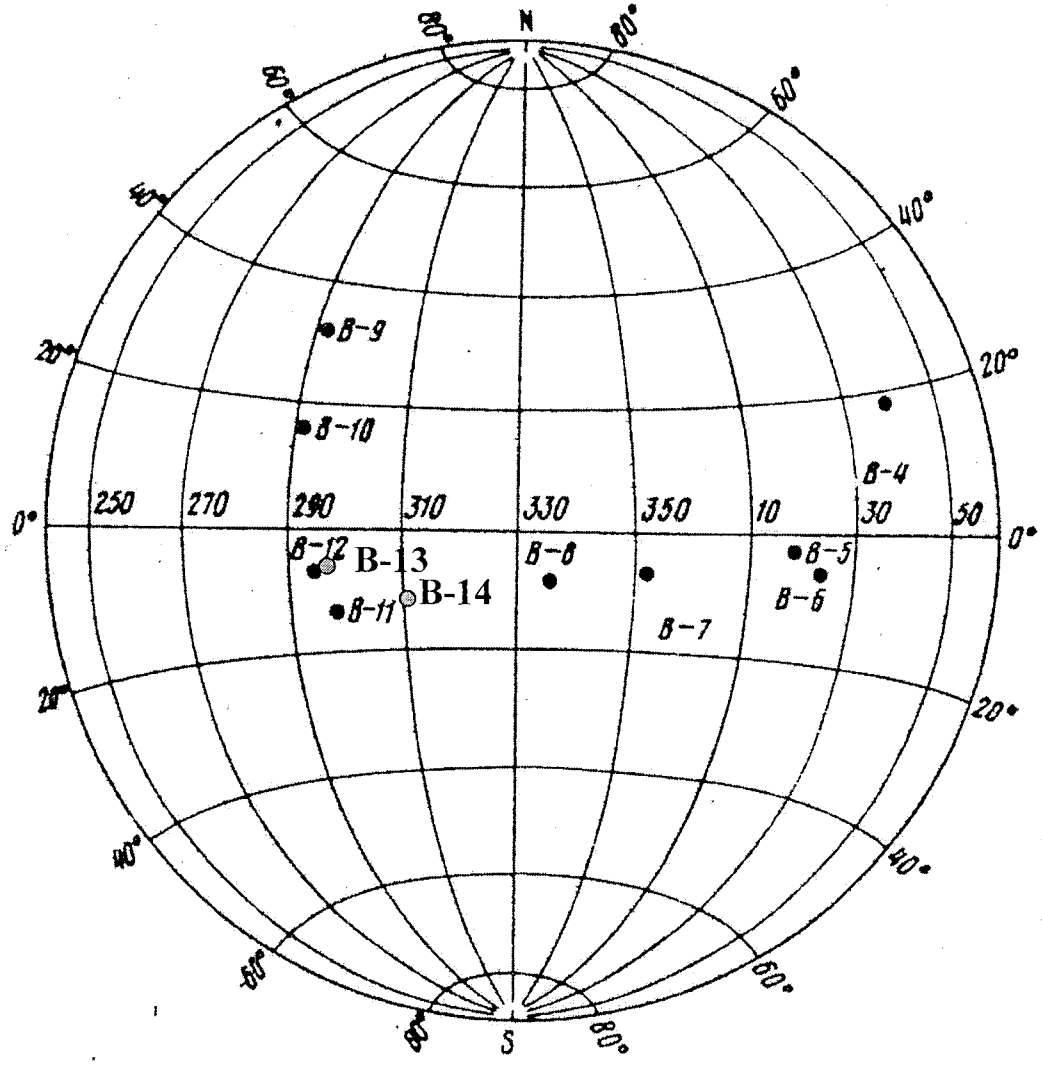
VENERAS' SCIENCE OBJECTIVES

- VENERA 4-8: FIRST RECONNAISSANCE MISSIONS TO RESOLVE MAJOR AMBIGUITIES
  - SURFACE PRESSURE RANGE: 3-1000 atm
  - SURFACE TEMPERATURE 200-800K
  - COMPOSITION UNKNOWN
  - WINDS PRESUMABLY < 5 M/S IN THE BULK OF ATMOSPHERE
  - SOLAR RADIATION UNKNOWN
  - SURFACE COMPOSITION UNKNOWN
- VENERA 9-14, VEGA: DETAILED STUDIES OF ATMOSPHERE AND SURFACE

VENERA 4-8: FIRST PLANETARY ENTRY PROBES

- ENTRY ANGLES 43-65°
- MASS 400-500 kg
- EGG-SHAPED ~ 1 m DIAMETER
- G-LOADS 400-500 g
- BARE-BONE SCIENCE SENSORS
- MECHANICAL (!) TELEMETRY
- L-BAND DIRECT-TO-EARTH 1 bit/s (!)
- VENERA 4-6 WERE CRASHED BY PRESSURE AT 25-20 km
- VENERA 7 AND VENERA 8 LANDED AND SURVIVED ON THE SURFACE 23 AND XX MIN RESPECTIVELY
- SCIENCE OBJECTIVES ACCOMPLISHED WITH DISCOVERIES

VENERAS' LANDING SITES



VEGA–1: 8.1°N 176.7

VEGA–2: 7.2°S 179.4

VENERA 4-8 SPACECRAFT

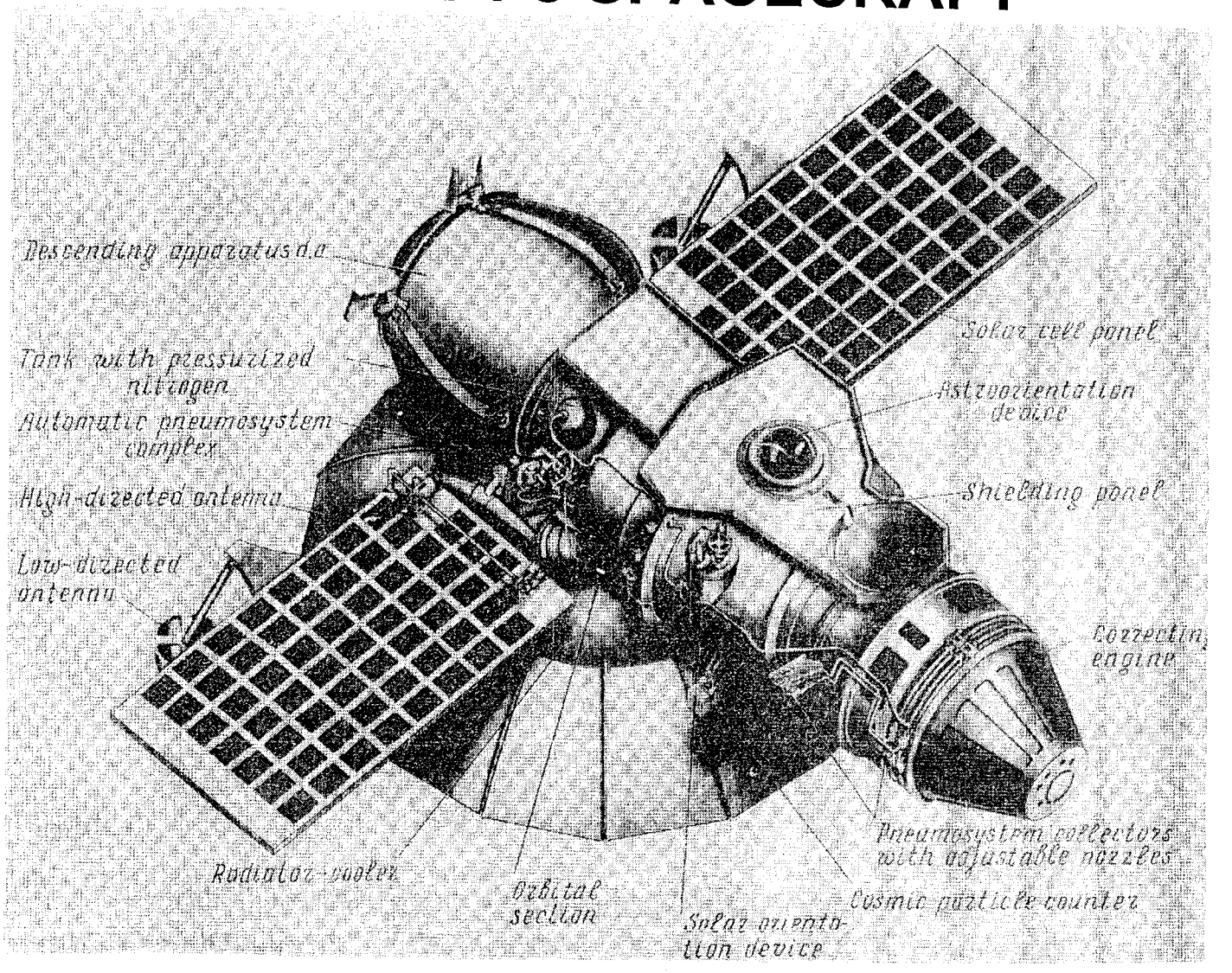
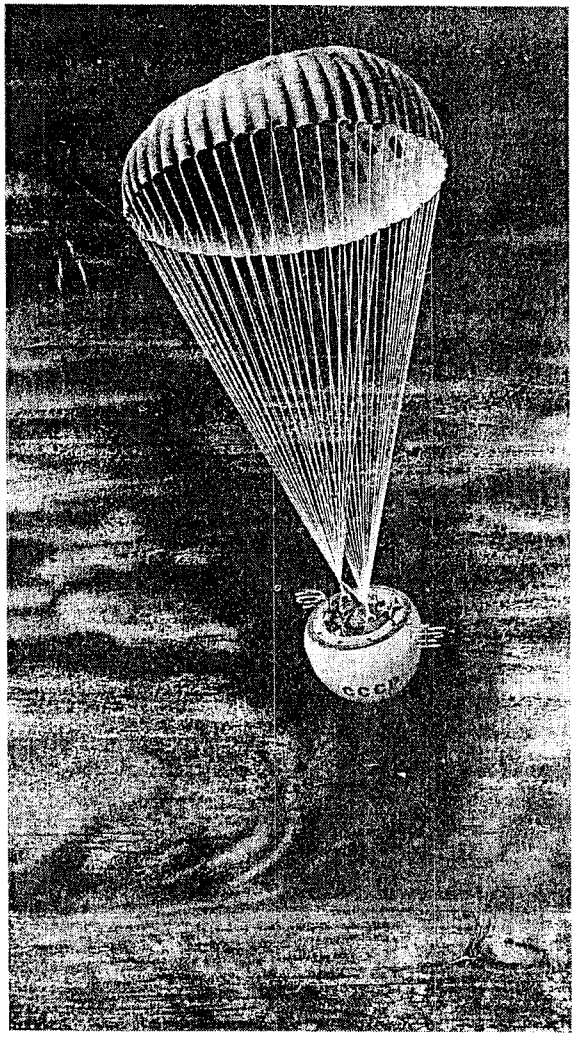


Fig. I. Automatic Interplanetary Space Station Venera 7

VENERA 4 DESCENT



VENERA 7 ENTRY VEHICLE

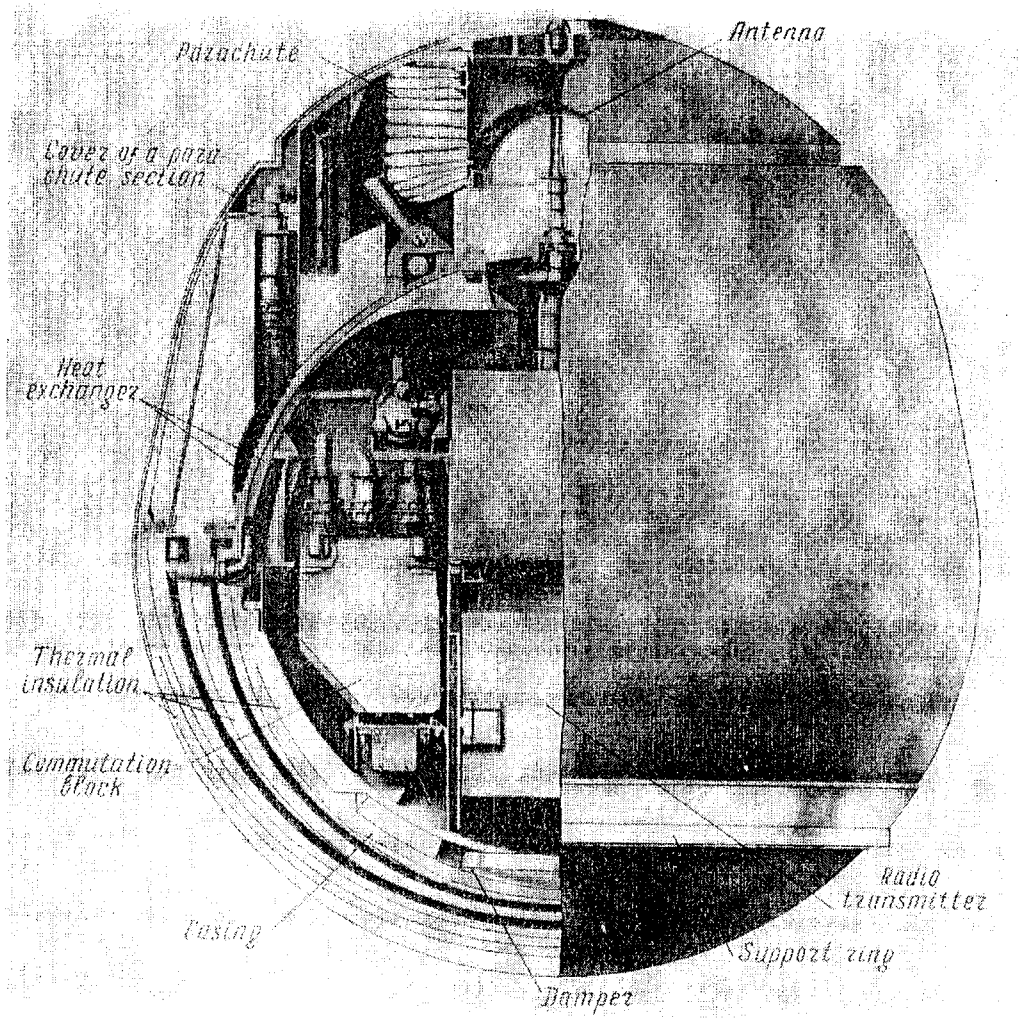
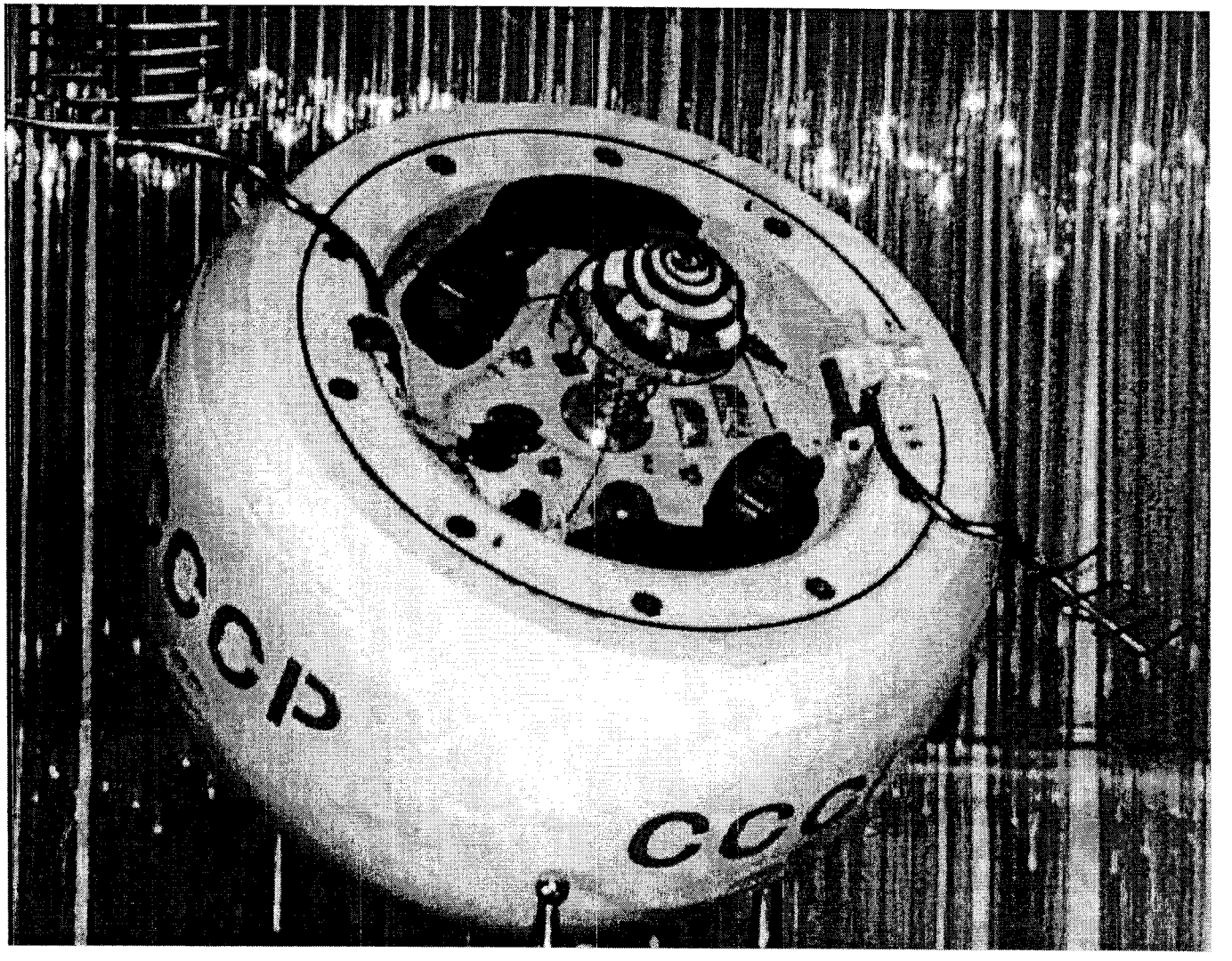


Fig. 2. The descending probe Venera 7

VENERA 4-7 LANDER



VENERA 8 ENTRY VEHICLE

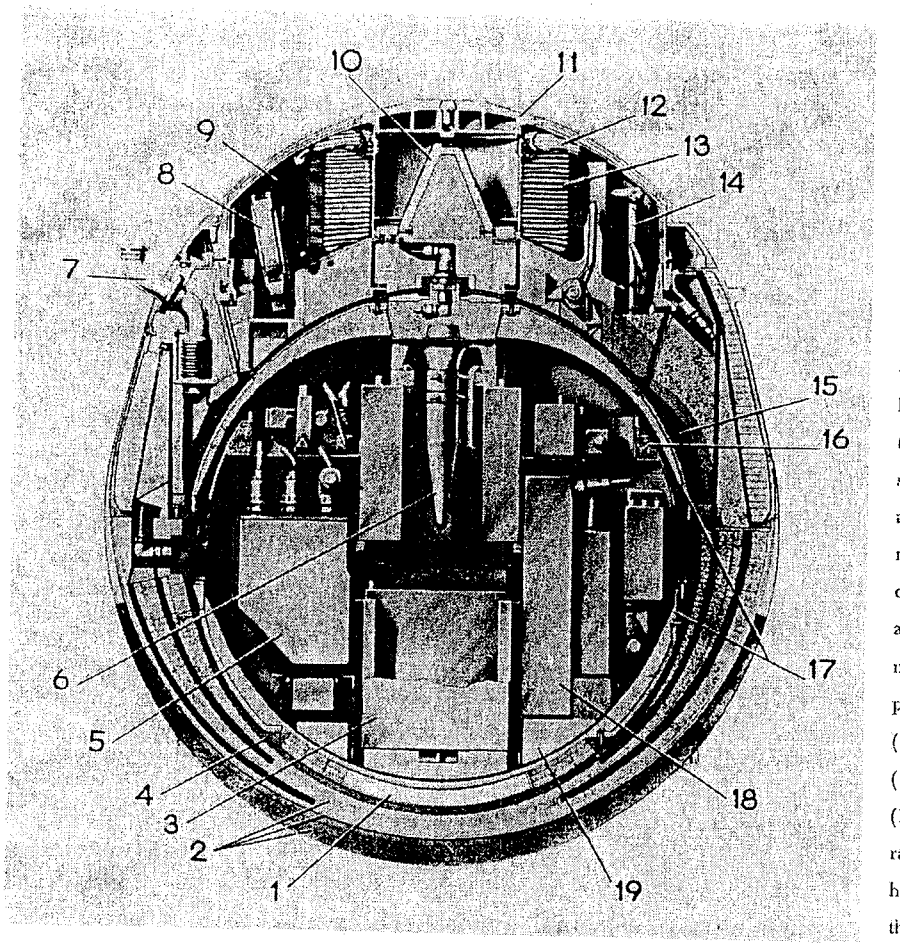
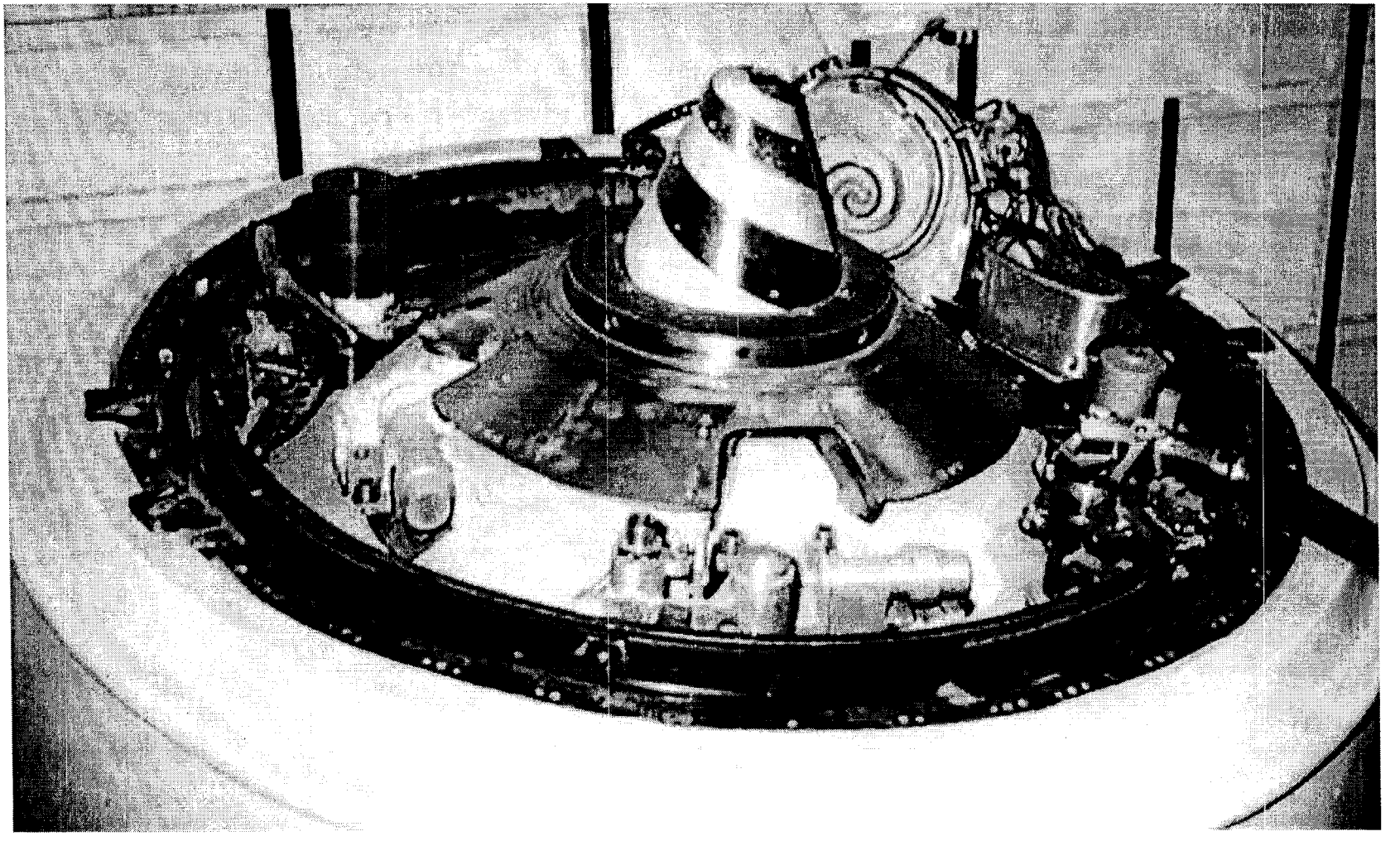
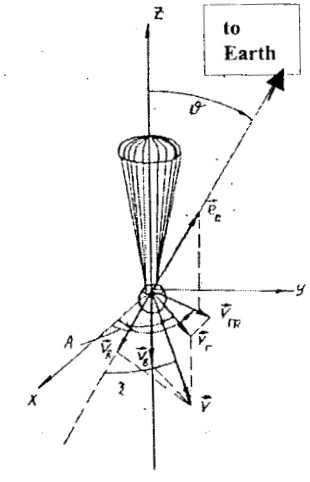


Fig. 2.27. The descent module from the Venera-8 automatic station, in cross section. The structural elements and onboard equipment are as follows: (1) the damper, (2) thermoinsulation (outer), (3) the radiotransmitter, (4) the payload case, (5) the commutation block, (6) the fan, (7) the tube of the thermocontrol system, (8) the ejected antenna of the radiotransmitter, (9) the parachute compartment, (10) the main antenna of the radiotransmitter, (11) the lid of the parachute compartment, (12) the drag parachute, (13) the main parachute, (14) the antenna of the radar altimeter, (15) the heat exchanger, (16) the thermoaccumulator, (17) thermoinsulation (inner), (18) the time-program de-

VENERA 8 LANDER



INTRODUCED ONE-WAY DOPPLER TO STUDY WINDS, DYNAMIC OF DESCENT AND RECONSTRUCTION OF TRAJECTORY



$$\boxed{V_D} = -c\frac{f_D}{f_0} - V_{1r} - \frac{1}{c}\left(\frac{V^2}{2} - V_{1r}^2\right)$$

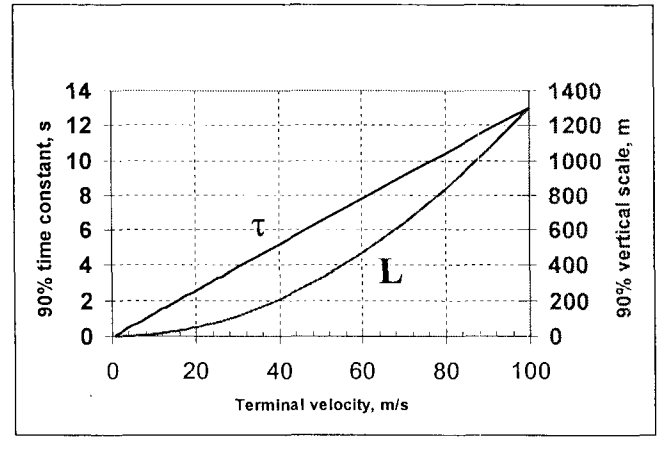
- Measures component of the vehicle in direction of receiver
- Requires knowledge of transmitted frequency f_o; stability of USO – main error factor
- V_D = velocity in atmosphere when orbital motion and propagation effects subtracted = descent velocity + wind drift
  - =Velocity of descent when receiver is near zenith
  - =Wind velocity when velocity of descent subtracted
- Vehicle aerodynamics effects

EFFECTS OF PARACHUTE / PROBE DYNAMICS

- Gliding – additional horizontal velocity of unknown direction
  - Measure parachute aerodynamic coefficients to estimate gliding
  - Use non-gliding parachutes
- Own oscillations mask effect of turbulence
  - Measure own frequencies
- Probe/parachute inertia may cut high frequency turbulence
  - Transfer function

    $H=a\,e^{-at}$, $a=2g/(1+\lambda/M)$, λ – added mass of air, M – mass of probe
  - Time constant and vertical scale

    $\tau_{0.9}=2.3/a$, $L=V_t\,\tau_{0.9}$



DIFFERENT METHODS FOR ALTITUDE RECONSTRUCTION

- Radar altimeter on Venera 4-8
- Pressure and temperature measurements + gas law + hydrostatic equation to calculate h(t) (all Veneras)
- Integrate one-way Doppler when Earth is close to zenith (Venera 7)
- Different equations to check matching of temperature and pressure measurements using terminal velocity equation
- Confusion when Venera 4 altitude drop calculated from P&T measurements coincided with ambiguity+zero reading of radar altimeter – erroneous conclusion of landing

$$z = \int_{t_0}^{t_1} V\,dt = \left(\frac{2M}{C_x S}\right)^{1/2} \int_{t_0}^{t_1} [\rho g_0^2 (1 - \rho/\rho_L)]^{1/2}\,dt$$

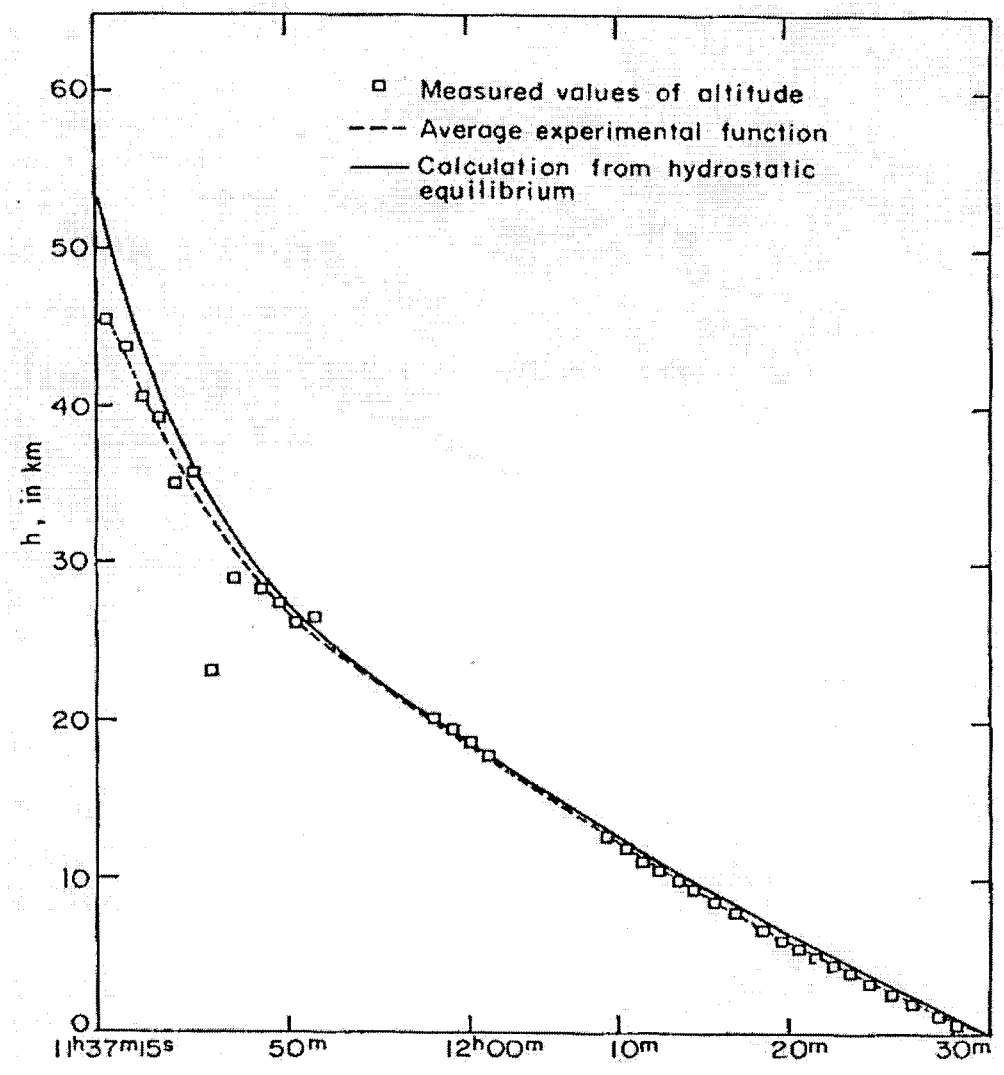
$$P_n^{1/2}(t_0) - P_n^{1/2}(t) = \int_{t_0}^{t} \left(\frac{mg^3\mu}{2C_x S R_0}\right)^{1/2} \frac{d\tau}{T_n^{1/2}(\tau)}$$

$$p(t) - p_0 = A \int_0^t \sqrt{\rho(t)}\,dt.$$

$$\rho_1 T_1 - \rho T = 2C \int_{t_1}^{t} \sqrt{\rho(t)}\,dt,$$

$$w = \frac{R_o T}{2\mu g}\left[0.5\frac{d\ln P}{dt} - \left(\frac{mg^3\mu}{2C_D S R_0}\right)^{1/2} PT\right]^{-1/2}$$

VENERA 8 ALTITUDE RECONSTRUCTION



VENERA 4-12 VERTICAL PROFILES

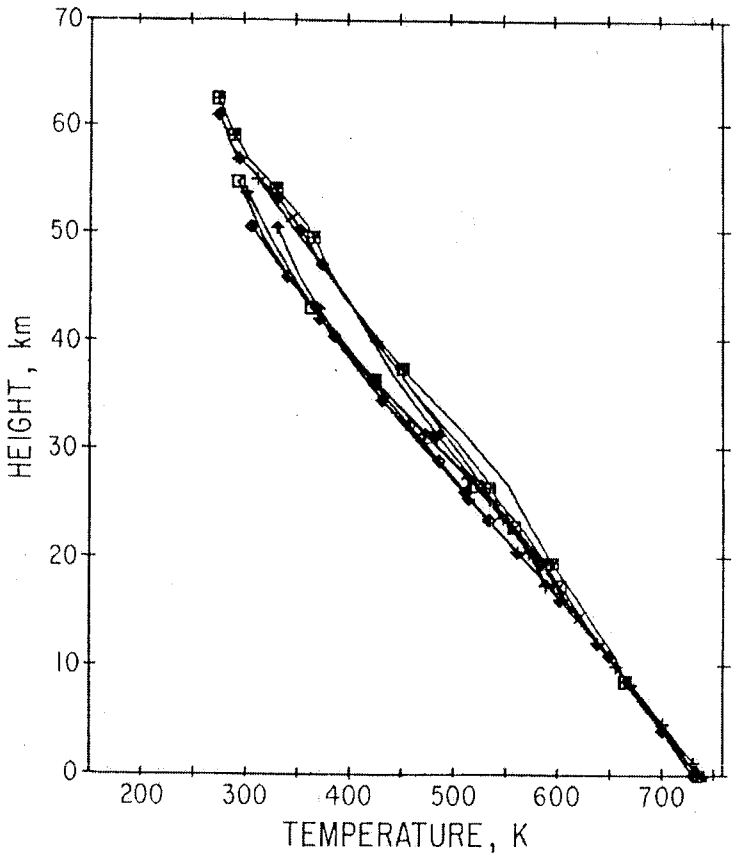


Fig. 4. Altitude profiles of the temperature of the lower atmosphere, according to data of direc measurements from Venera probes. Marks correspond to measurements in the same manne as for Fig. 3.

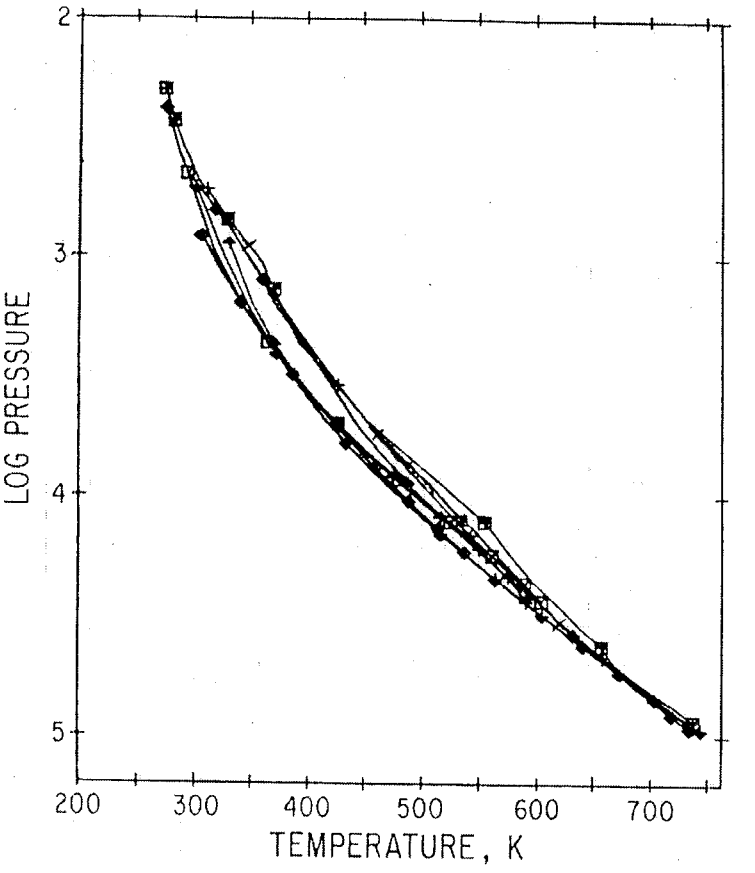


Fig. 3. Results of direct temperature and pressure measurements of Venera probes (V 4–V 12) in coordinates of log P–T. ⊕, V4; ⊡, V5; ↑, V6; ↓, V8; ⊞, V9; ⊕, V10; ×, V12; ⊡, V9 (processing did not take into account one of the five temperature sensors).

VENERA 4 DOPPLER RESIDUALS

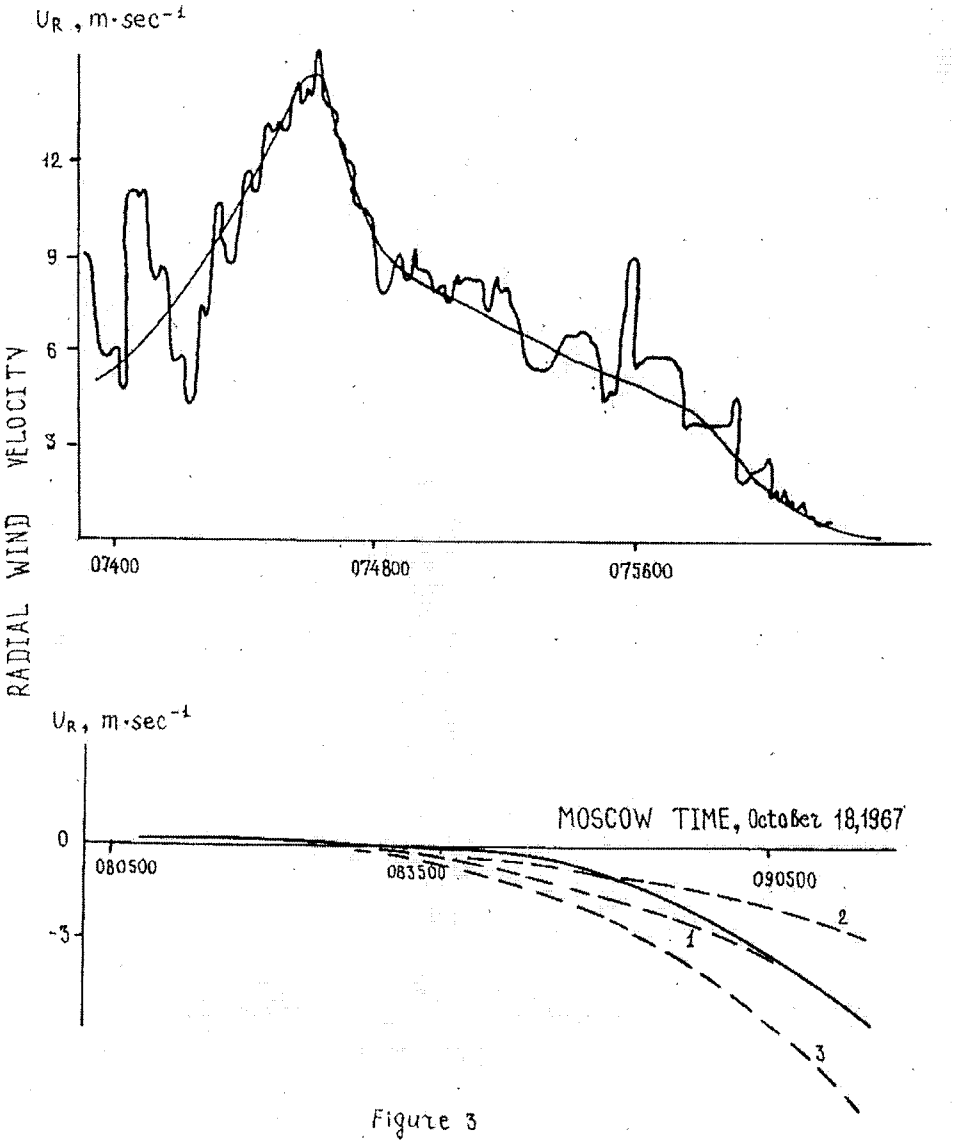


Figure 3

VENERA 6 DOPPLER RESIDUALS

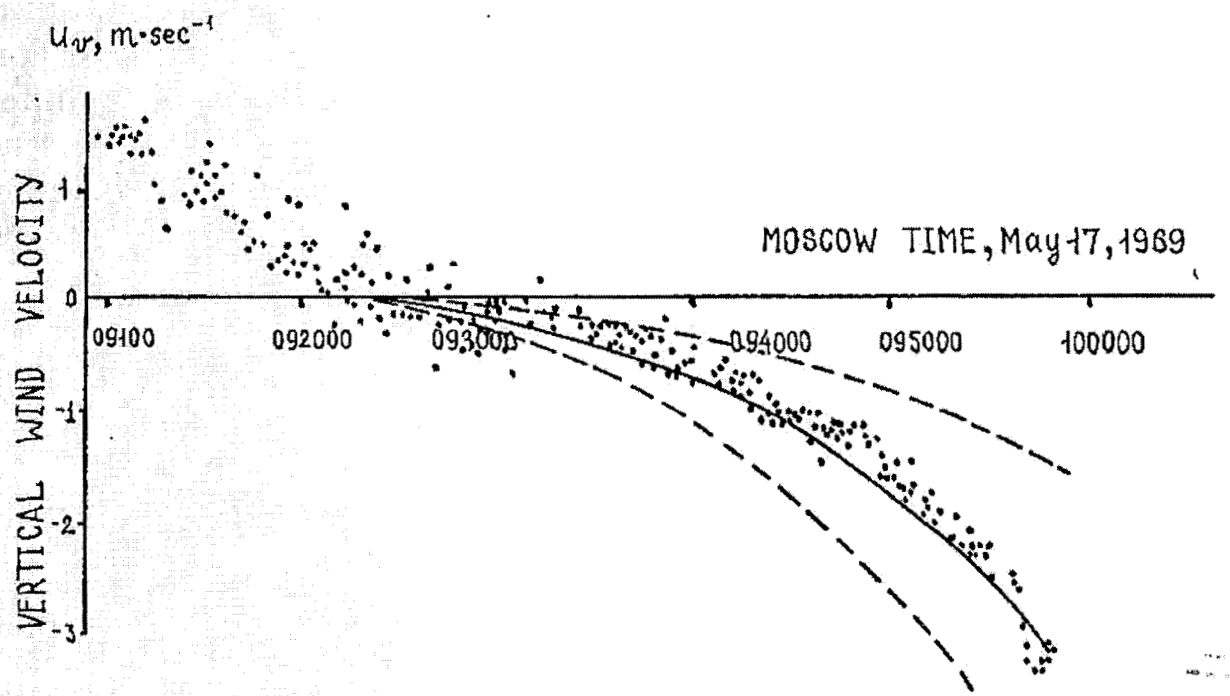
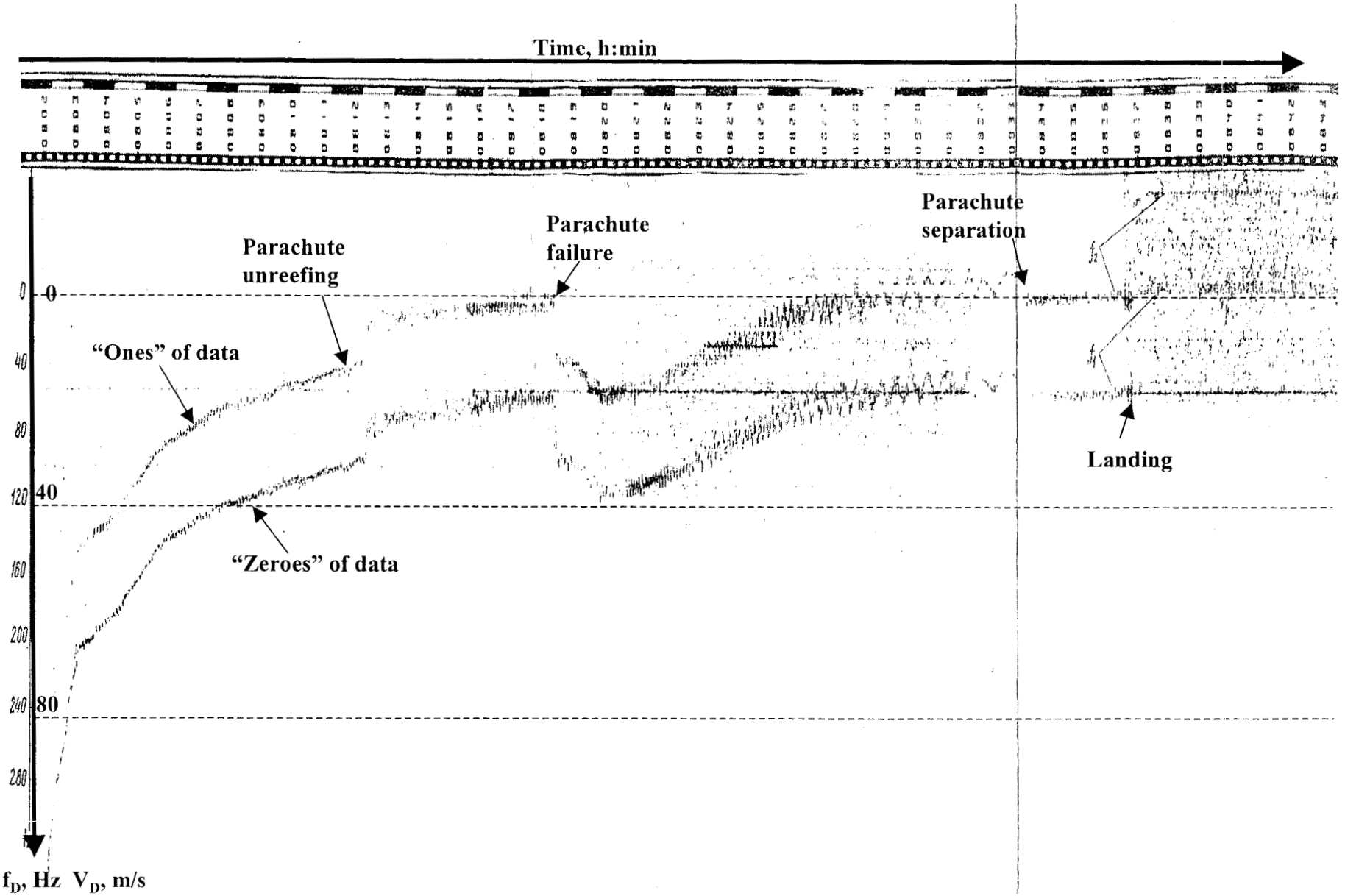


FIG. 5. Fluctuations of the vertical component of the wind velocity during descent of Venera 6. 1 is the most probable; 2, 3, the extreme temperature drift of the oscillator frequency.

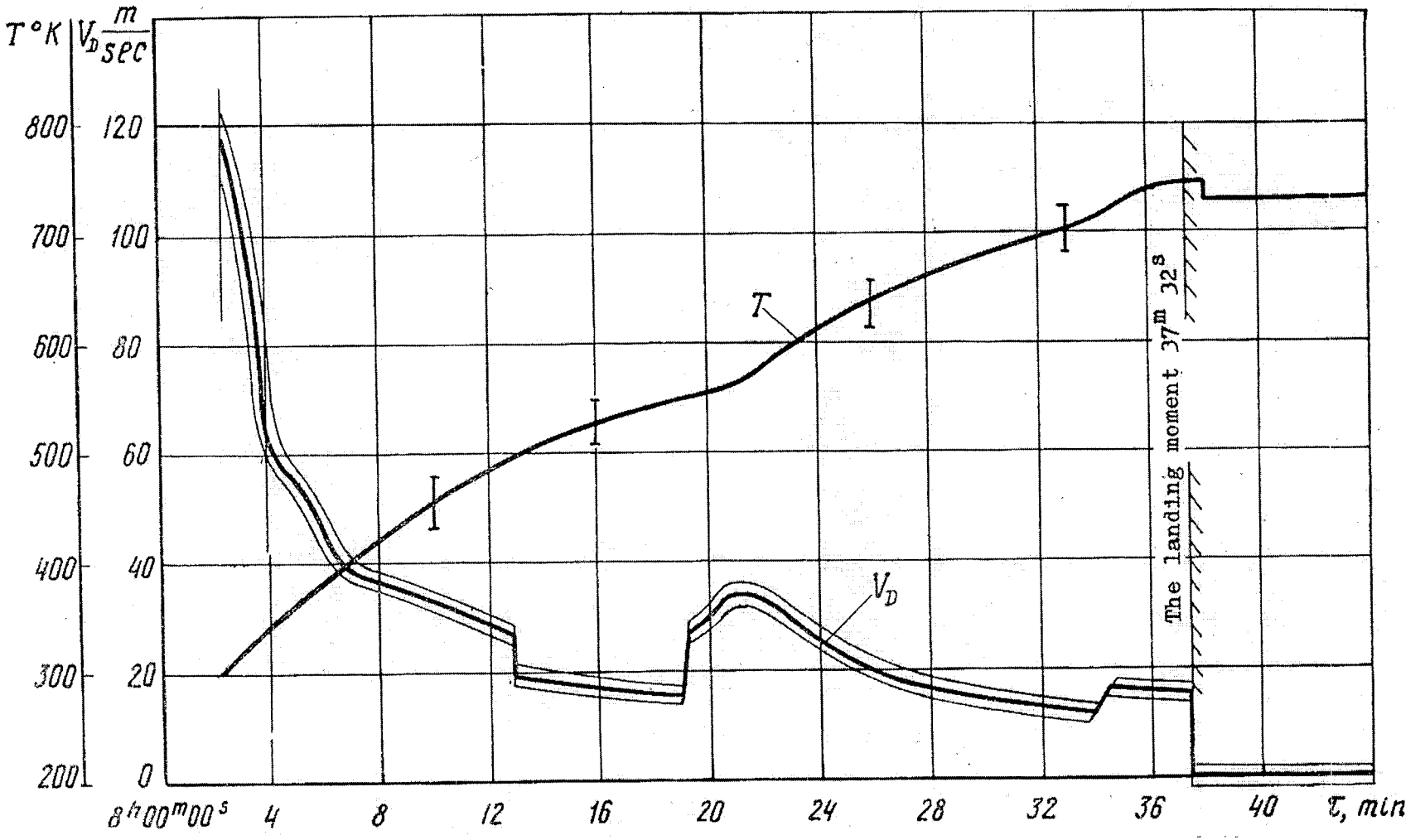
TRAJECTORY RECONSTRUCTION RECOVERED FIRST ATMOSPHERIC PROFILE DOWN TO VENUS SURFACE AT VENERA 7 DRAMATIC DESCENT

- ONLY AMBIENT TEMPERATURE DATA TRANSMITTED
- DOPPLER DATA REVEALED DESCENT DYNAMICS
- PARACHUTE MALFUNCTION @ XX KM
- FREE FALL FROM ~3 km
- WEAK SIGNAL FROM SURFACE DETECTED AT OPEN-LOOP RECORDING
- VELOCITY @LANDING ~17 m/s
- ALTITUDE RESTORED FROM DOPPLER DATA
- PRESSURE PROFILE CALCULATED
- FIRST IN SITU DATA: PRESSURE 92+/-15 atm, TEMPERATURE 747+/-20K
- AFTER VENERA 7 ONE-WAY DOPPLER BECAME A MUST ON ALL SOVIET ENTRY PROBES

VENERA 7 ORIGINAL SPECTRUM RECORDING



VENERA 7 TEMPERATURE AND DOPPLER DATA



VENERA 8 NOMINAL AND MEASURED DOPPLER VELOCITIES

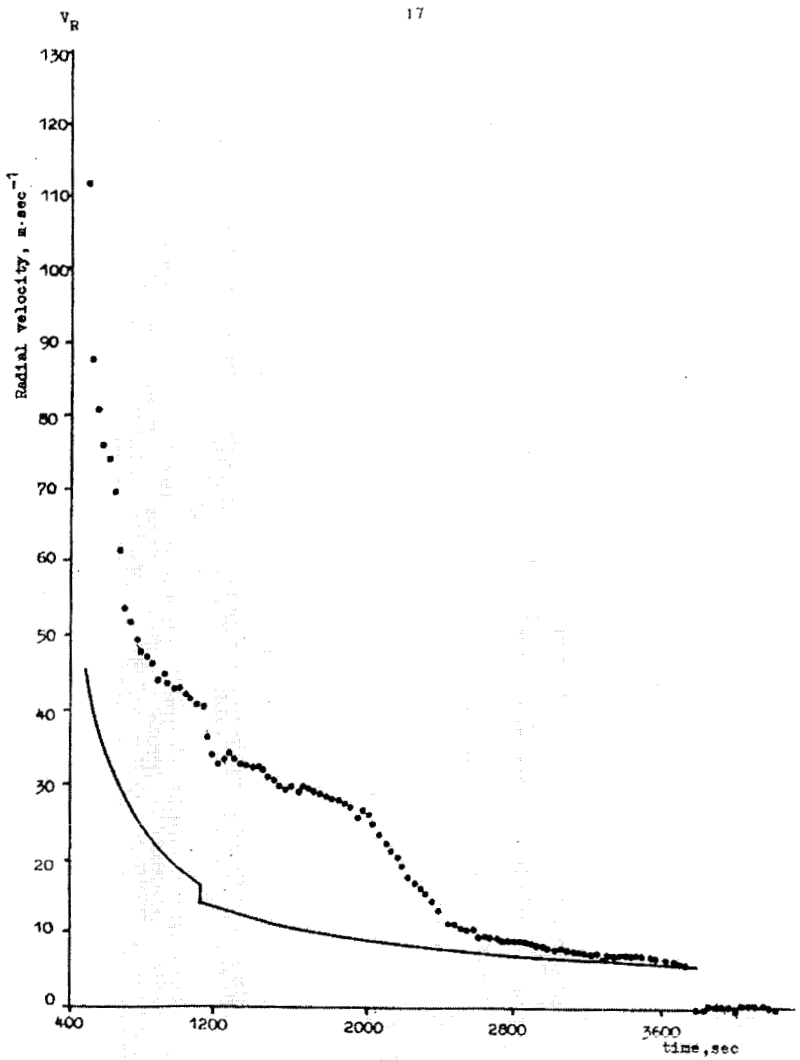


Fig.2.

VENERA 8 WIND PROFILE

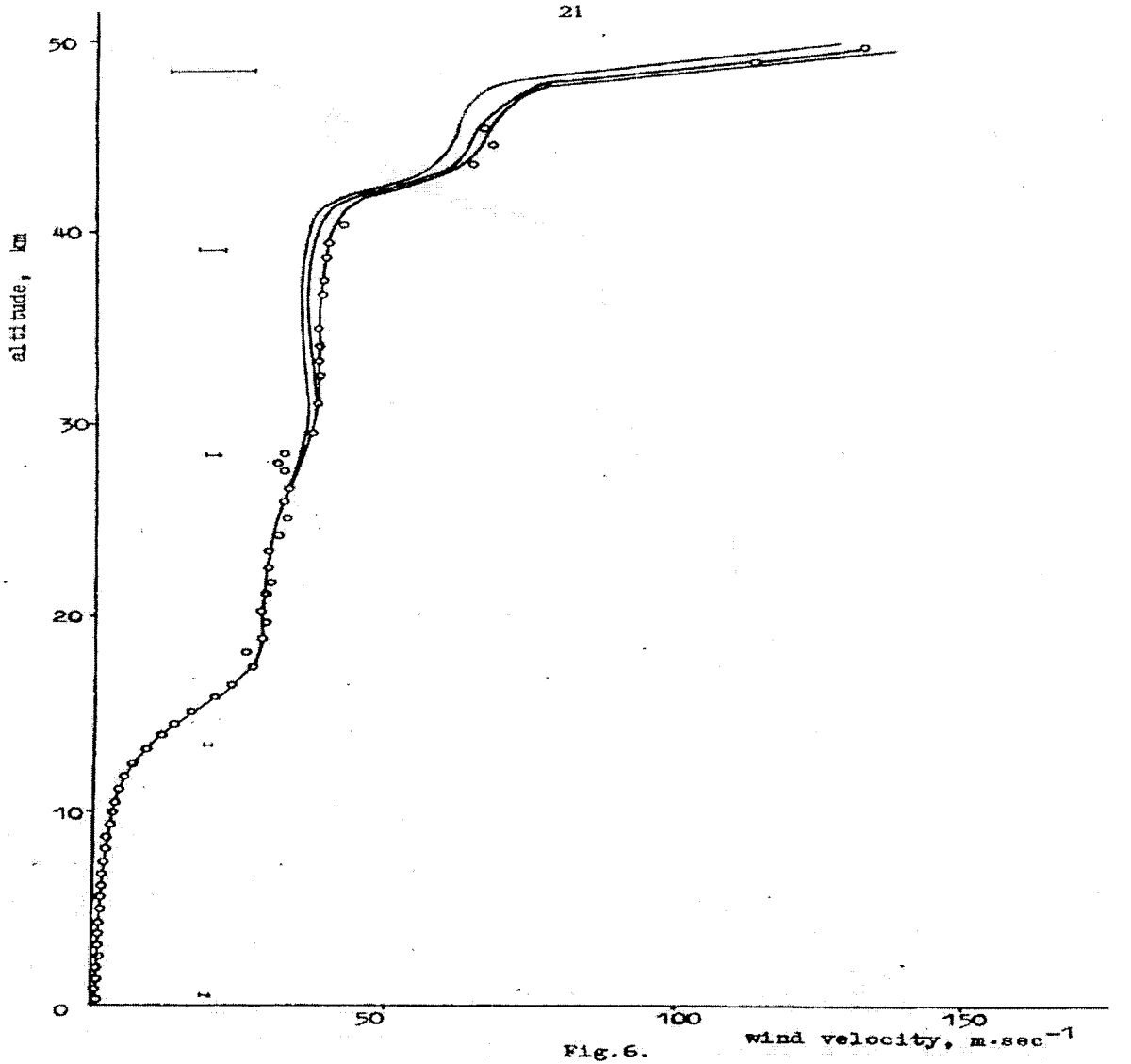


Fig.6.

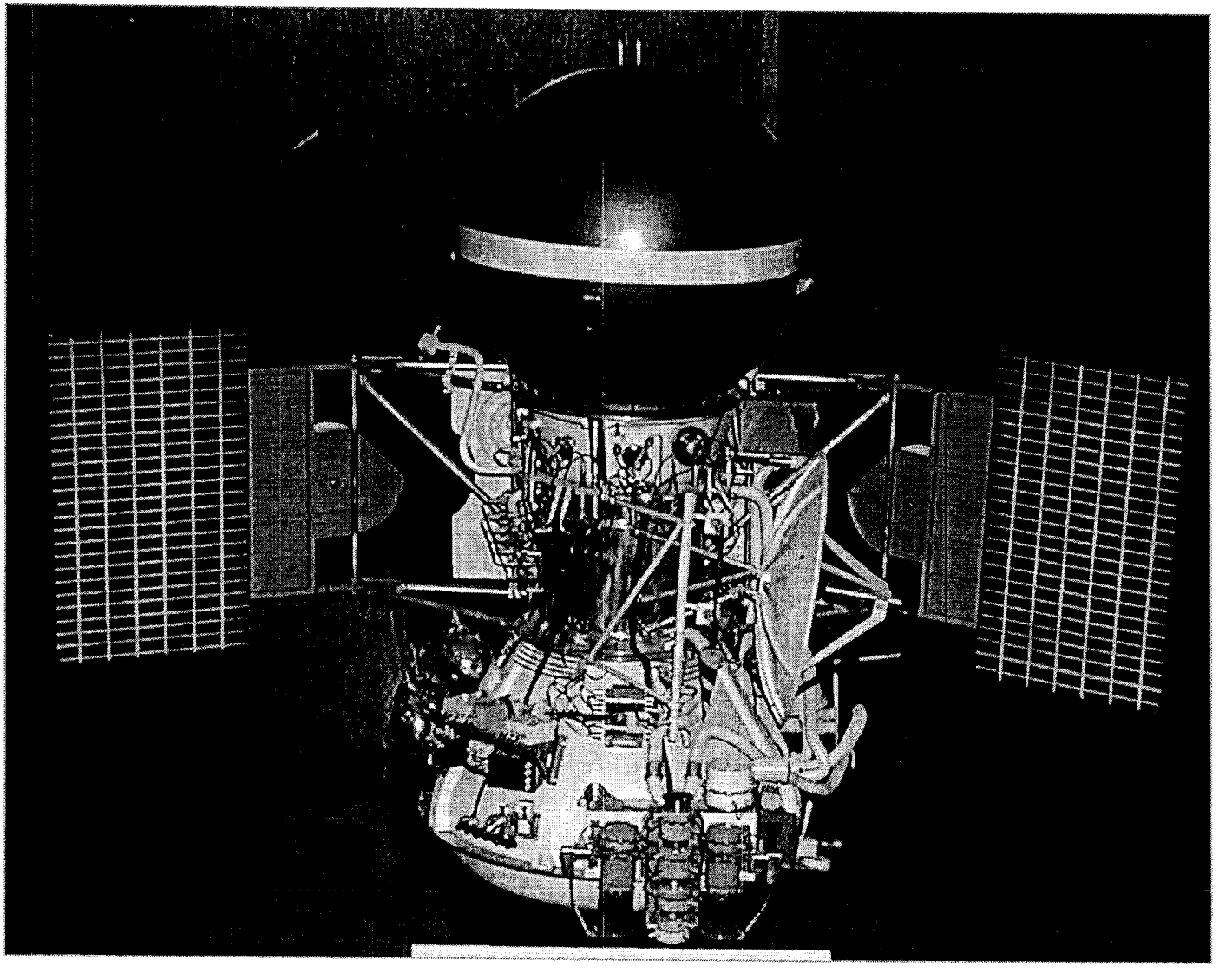
VENERA 4-8 MAJOR DISCOVERIES

- SURFACE PRESSURE ~93 ATM
- SURFACE TEMPERATURE ~735 K
- COMPOSITION – 97% CARBON DIOXIDE
- SUPERROTATION OF BULK OF THE ATMOSPHERE WITH SPEED > 20 m/s ABOVE 17 km
- LOW SURFACE WINDS
- SUNLIGHT PENETRATION DOWN TO THE SURFACE

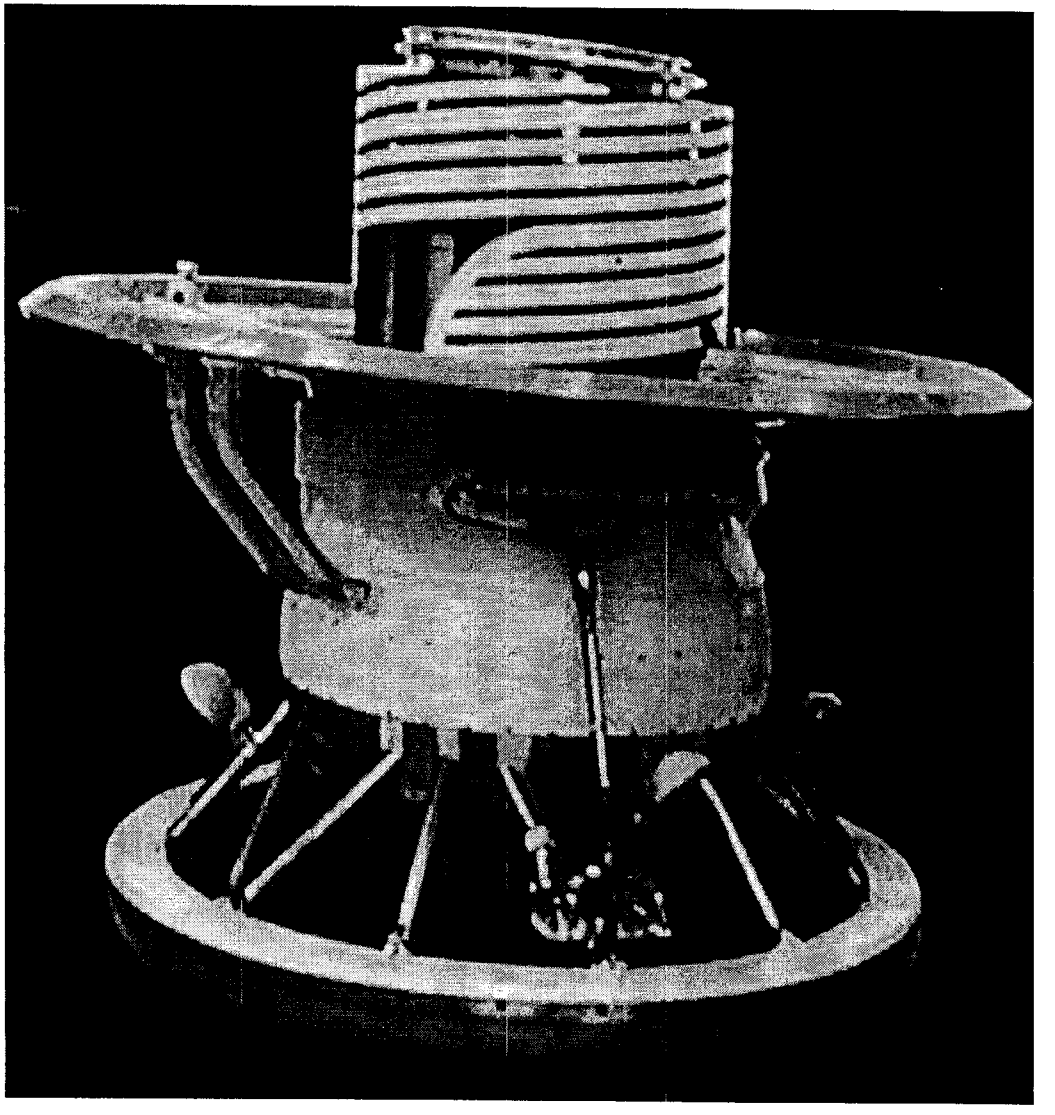
VENERA 9-14 AND VEGA: SECOND GENERATION OF VENUS LANDERS

- MUCH MORE CAPABLE THAN THEIR PREDECESSORS
- ENTRY ANGLES 18-21°
- MASS ~1800 kg
- SPHERICAL SHAPE, 2.4 m DIAMETER, 0.8 m PRESSURE VESSEL
- G-LOADS 150-180 g
- NUMEROUS ATMOSPHERE / SURFACE SCIENCE INSTRUMENTS
- ENGINEERING SENSORS TO STUDY PROBE DYNAMICS
- PARACHUTE / SOLID DISK DECELERATORS OPTIMIZED FOR SCIENCE OBJECTIVES
- VHF RELAY VIA ORBITER/FLY-BY DATA LINK ~ 3 kbit/s
- ALL LANDED SUCCESSFULLY AND SURVIVED ON THE SURFACE UP TO ALMOST THREE HRS
- VELOCITY AT LANDING ~ 7-8 m/s

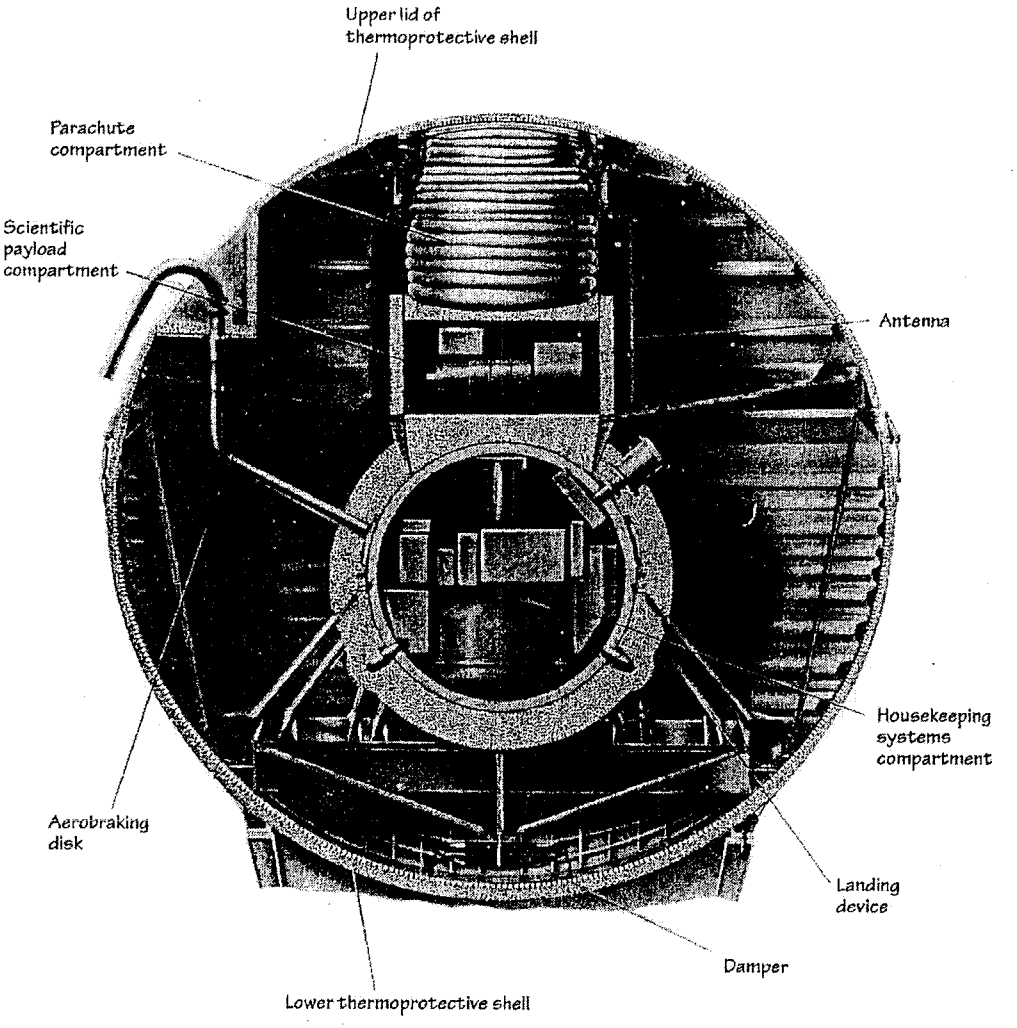
VENERA 9 SPACECRAFT



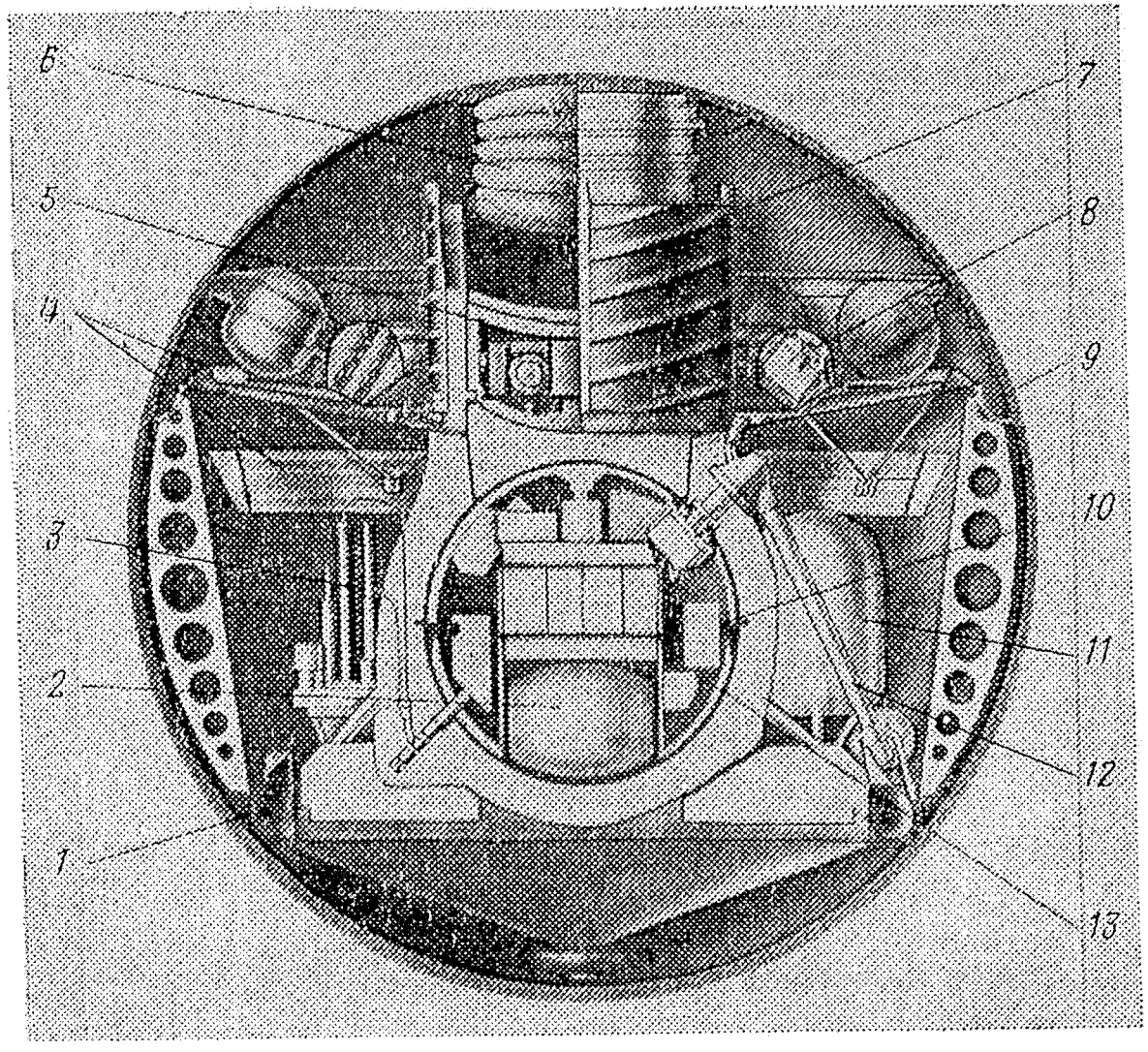
VENERA 9 DESCENT MODULE



VENERA 9 ENTRY VEHICLE



VEGA ENTRY VEHICLE



1 - Landing device

2 – Primary battery

3 – Drill and soil transfer device

4 – Aerodynamic break disk and stabilizer

5 - Atmospheric science instrument compartment

6 – Parachute

7 – VHF antenna

8 – balloon

9 – heat shield

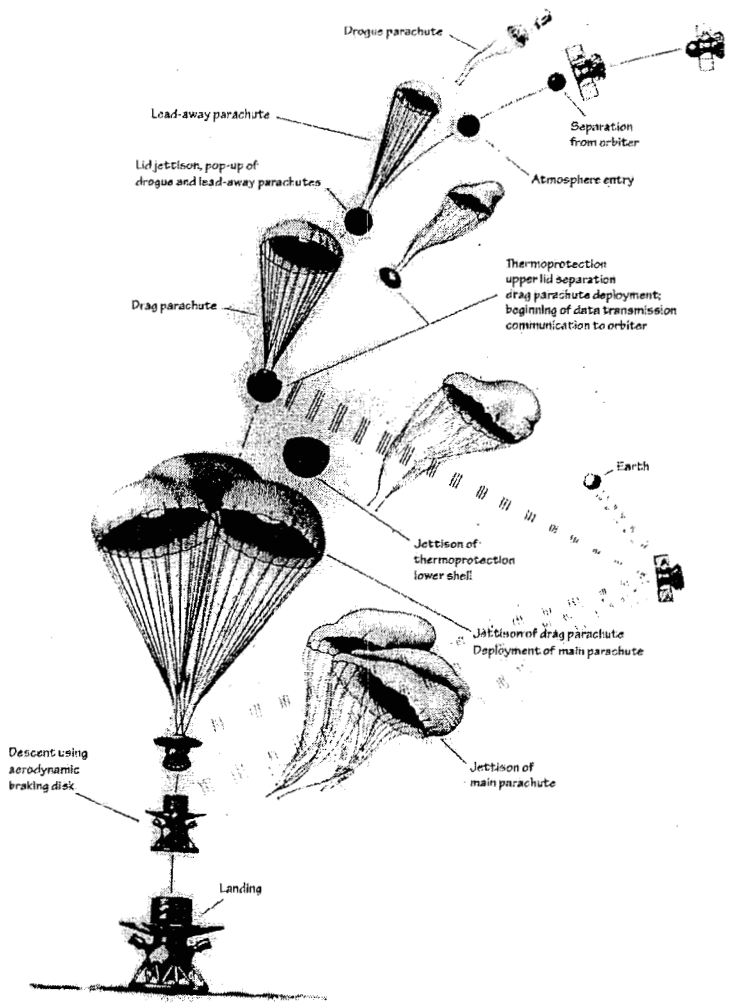
10 – lander

11 – gas chromatograph

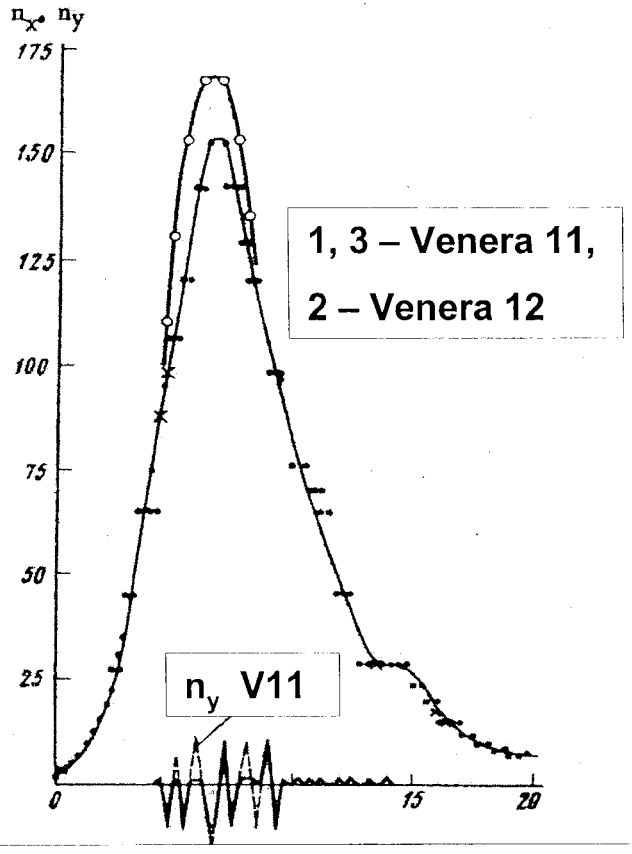
12 – spectrophotometer

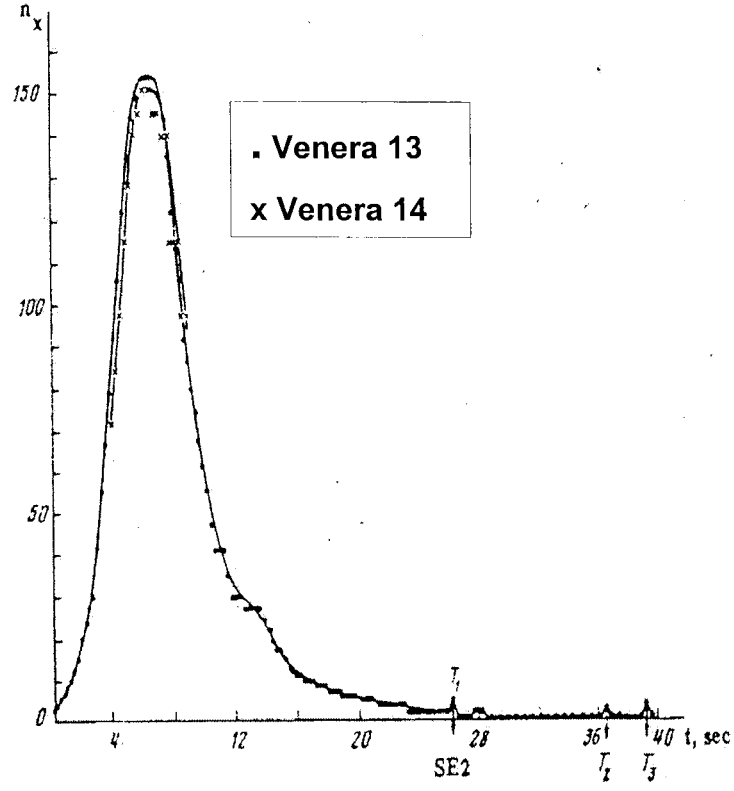
13 – pressure vessel

VENERA 9-10 ENTRY SEQUENCE

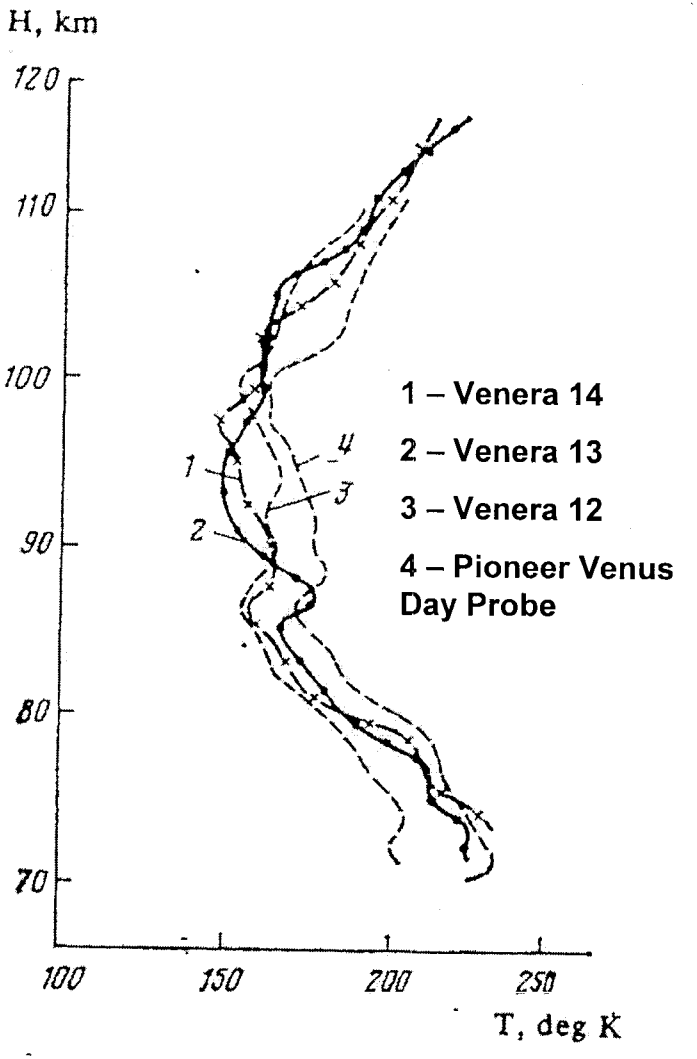


VENERA 11-14: ATMOSPHERIC DECELERATION

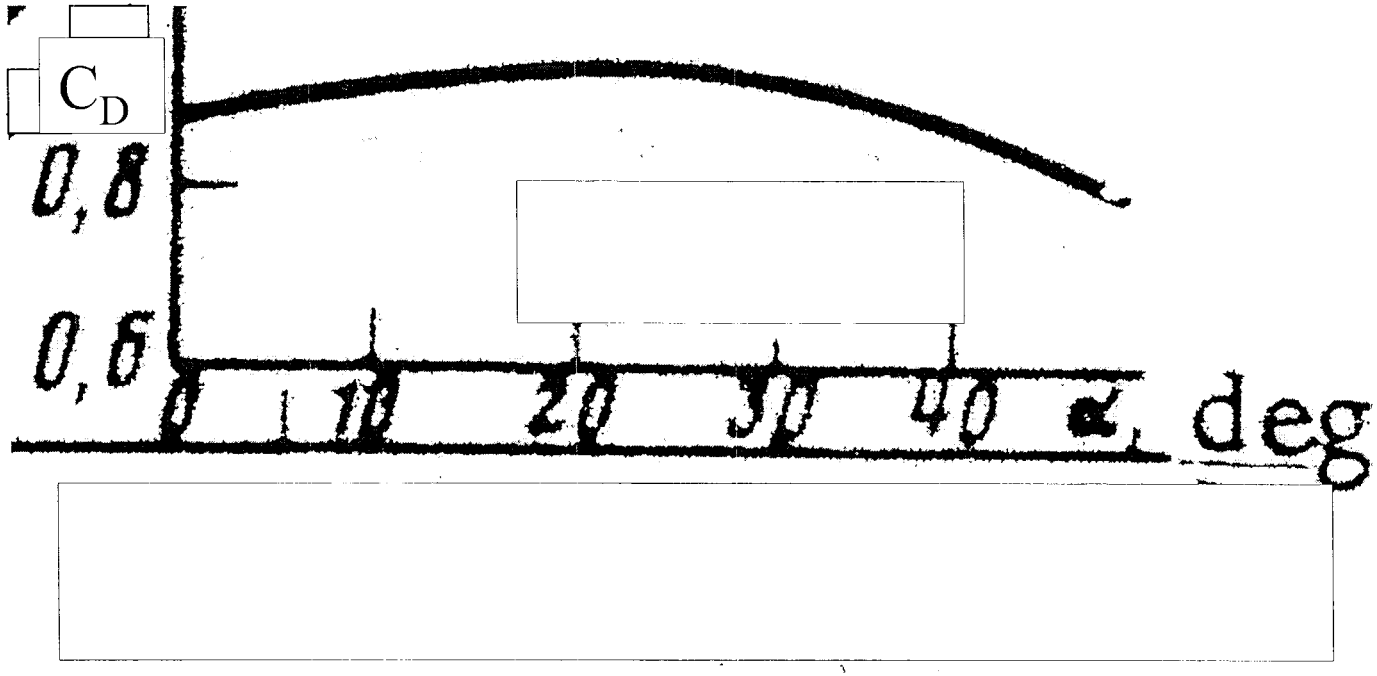




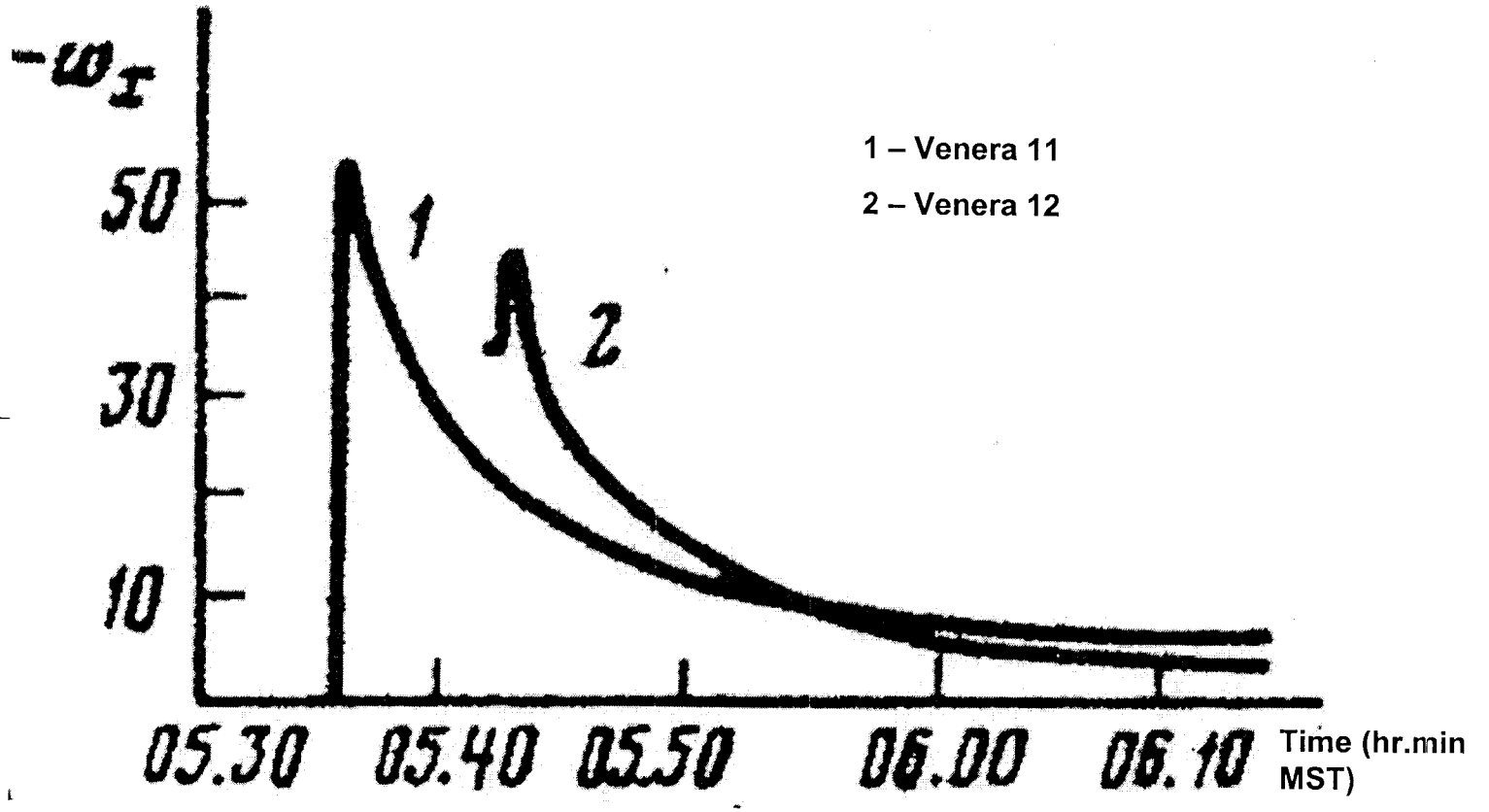
VENERA 12-14 RECONSTRUCTED TEMPERATURE PROFILES



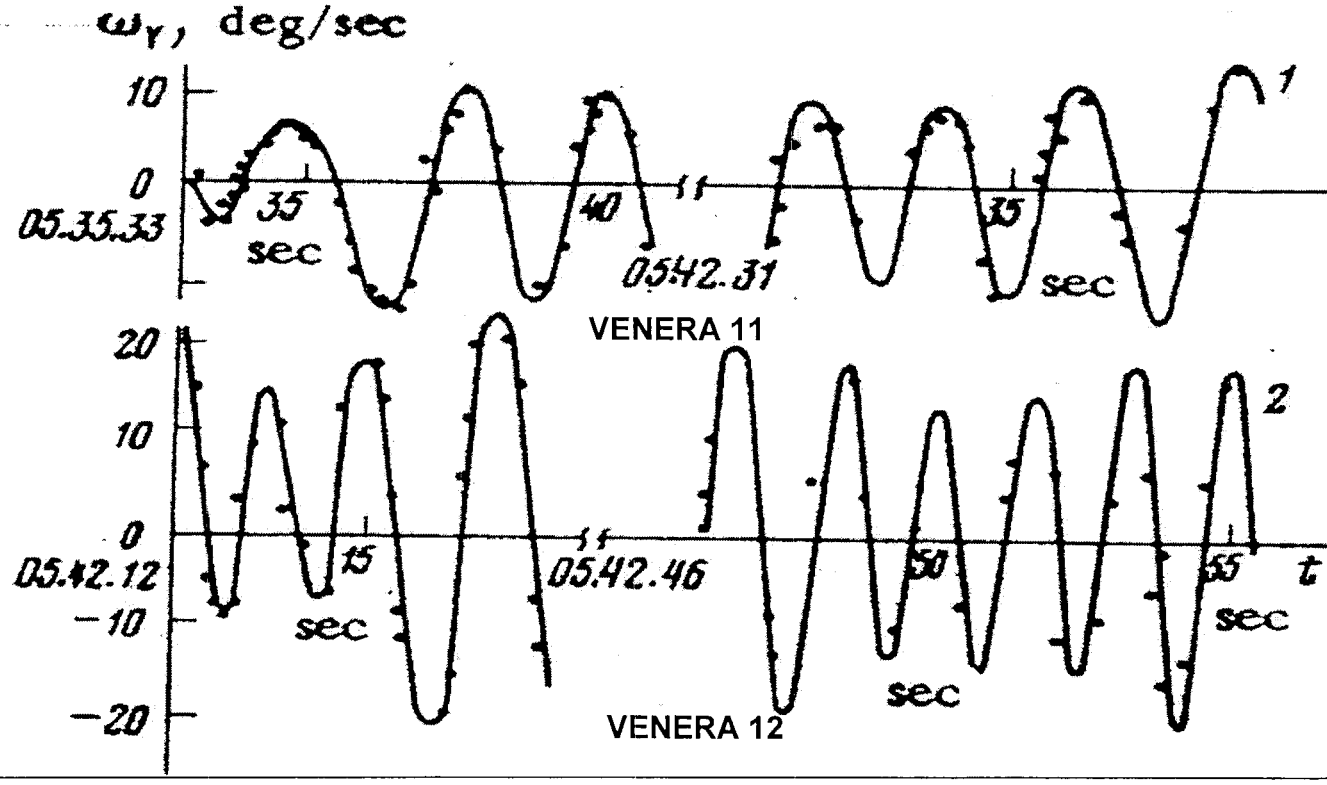
DRAG COEFFICIENT OF VENERAS 9-14 AERODYNAMIC BRAKE DISK



VENERA 11-12: ANGULAR RATES



VENERA 11-12: MEASURED ANGULAR RATES ON PARACHUTE



ORBITAL RELAY GEOMETRY

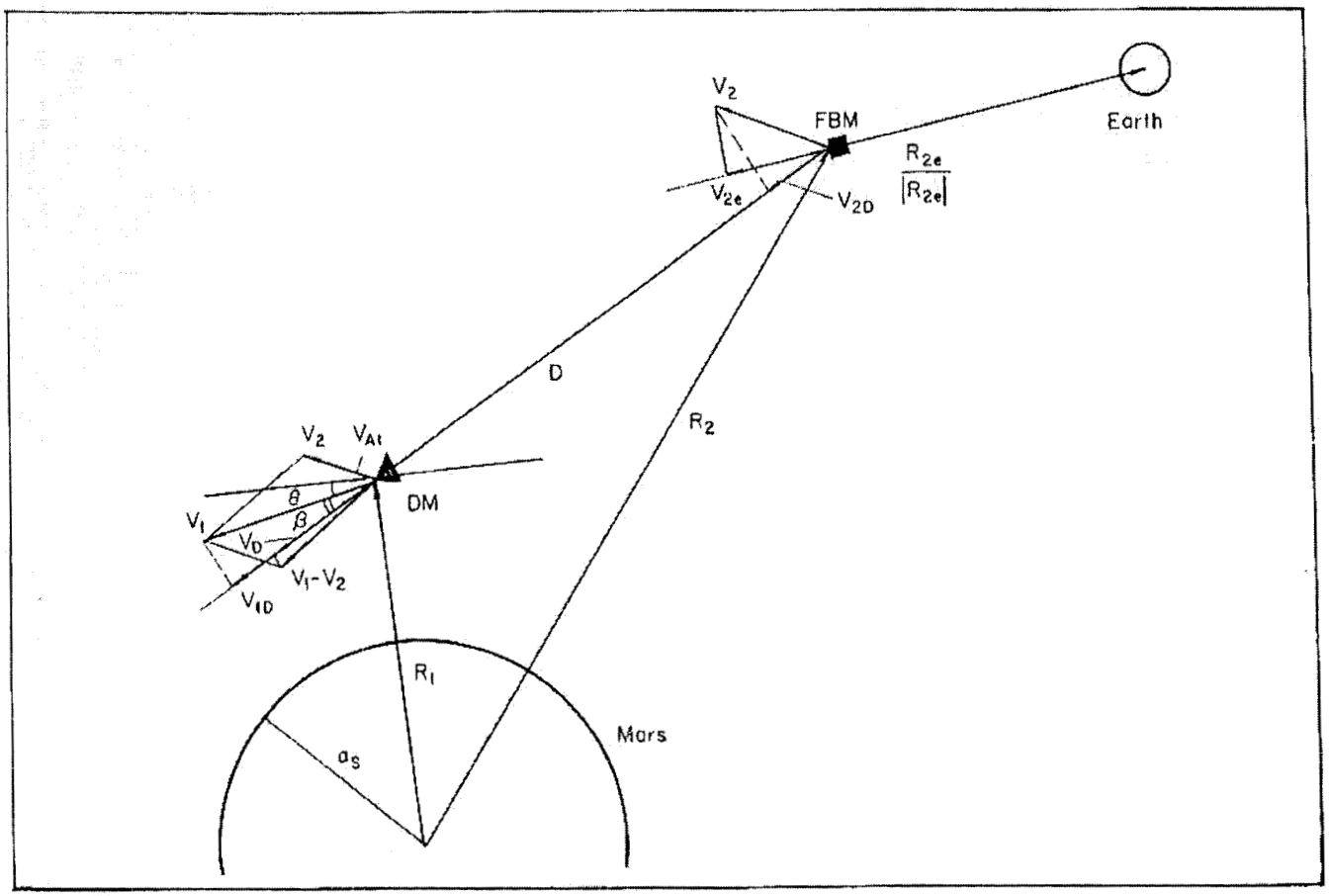


FIG. 2. Geometry of the Doppler measurements.

VENERA AND MARS RELAY LINK

ENTRY VEHICLE

1 – USO

2 – exciter

3 – power amplifier

FLY-BY

4 – LNA

5 – mixer

6 – filter

7, 9 – frequency multipliers

8 – USO

10 – amplifier

11 – modulator

12 – power amplifier

$$H_{\text{с-р-з}} = \frac{H_{\text{с-р}} H_{\text{р-з}}}{H_{\text{с-р}} + H_{\text{р-з}} + F_{\text{р}}}, \qquad (1)$$

ндексы с, р, З означают принадлежность к аппаратуре СА, ретранс-
а или наземной, а индексы с—р, р—З, с—р—З — принадлежность к

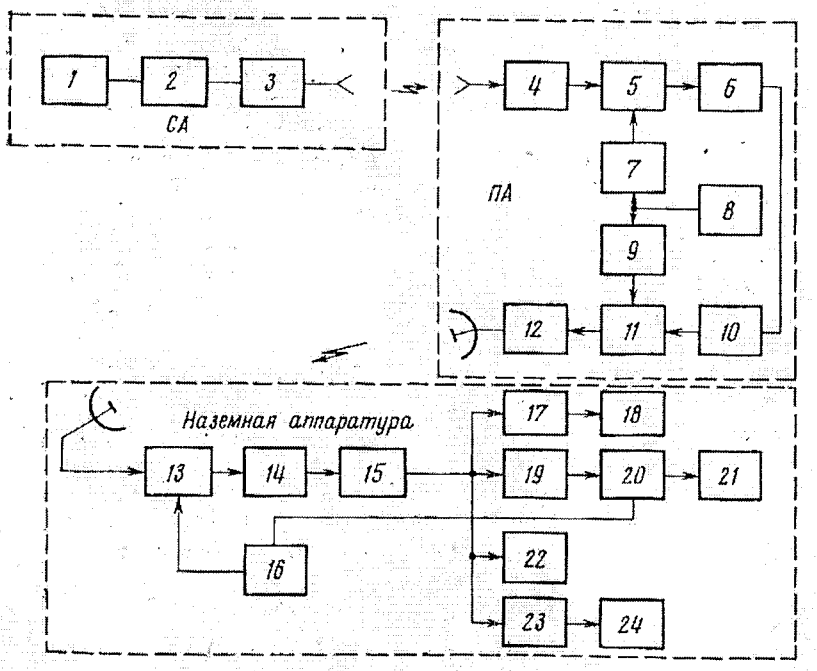


Рис. 1. Блок-схема измерения параметров радиосигнала со спускаемого аппарата

1, 8 — задающие генераторы, *2, 7, 9* — умножители, *3, 12* — усилители мощности, *4* — входной усилитель, *5* — смеситель, *6, 15* — фильтры, *10* — усилитель, *11* — модулятор, *13* — приемник, *14* — демодулятор, *16* — стандарт частоты, *17* — анализатор спектра, *18* — устройство визуальной регистрации, *19* — система ФАПЧ, *20* — отсчетное устройство, *21* — цифровой регистратор, *22* — аналоговый магнитофон, *23* — преобразователь аналог — код, *24* — цифровой магнитофон

GROUND STATION

13 – receiver

14 – demodulator

15 – filter

16 – frequency standard

17- spectrum analyzer

18 – plotter

19 – PLL

20 – frequency meter

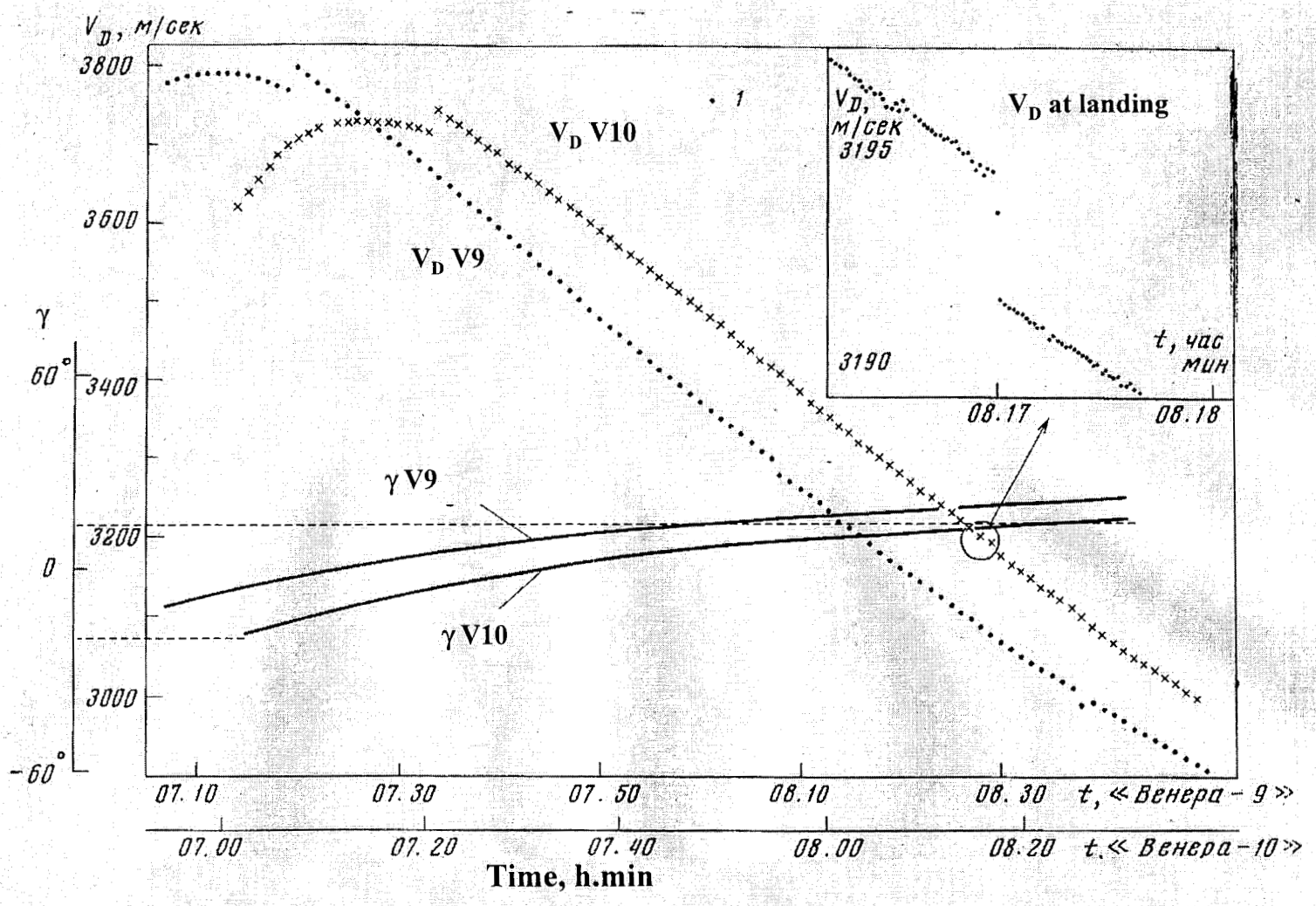
21 – memory

22 – analog tape recorder

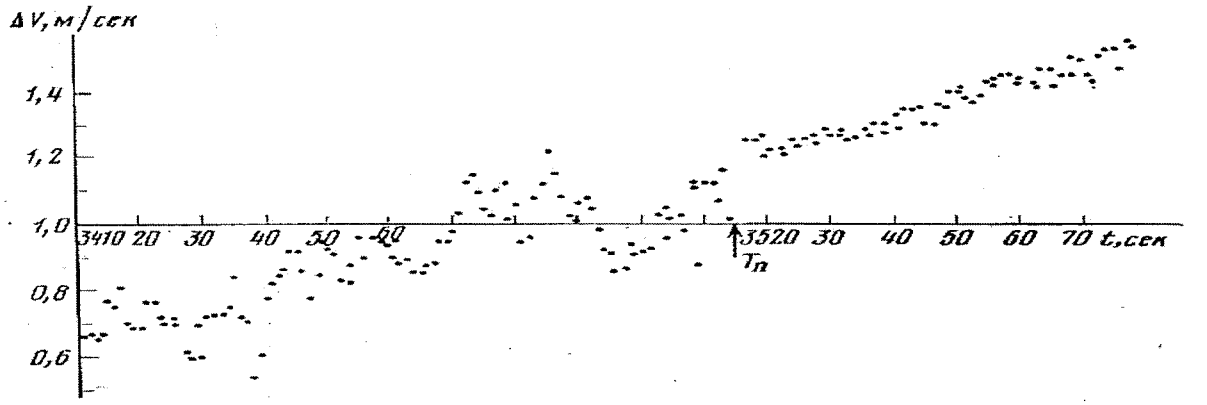
23 – ADC

24 – digital tape recorder

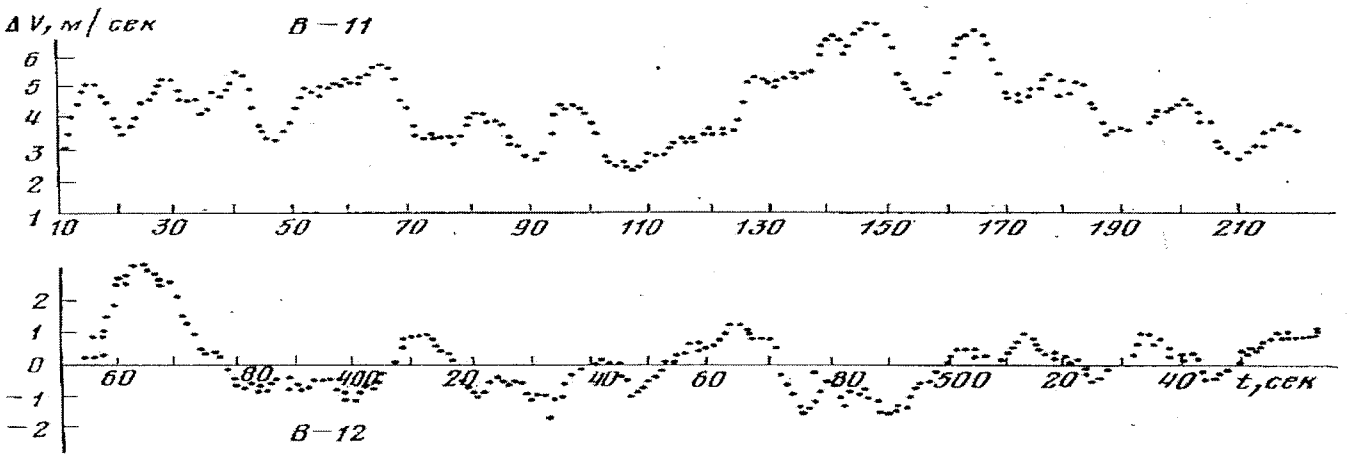
VENERA 9-10: DOPPLER MEASUREMENTS AND ZENITH ANGLES OF ORBITERS



VENERA 11-12 DOPPLER DATA

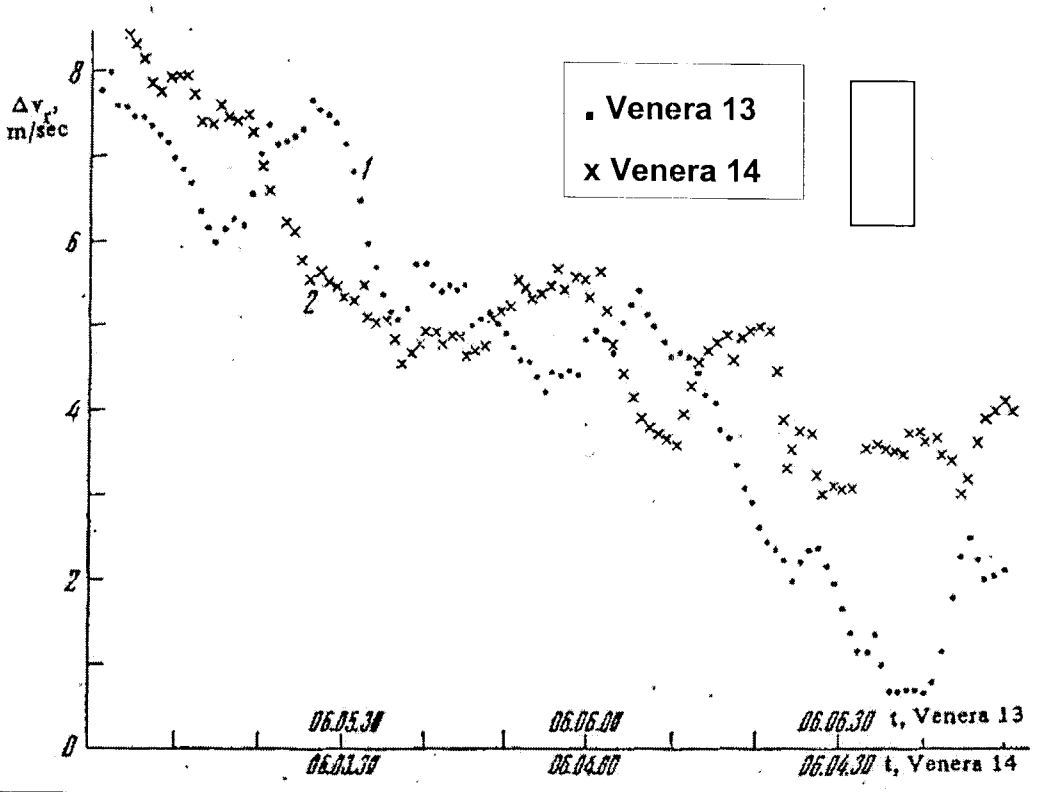


Venera 11 Doppler residual at landing

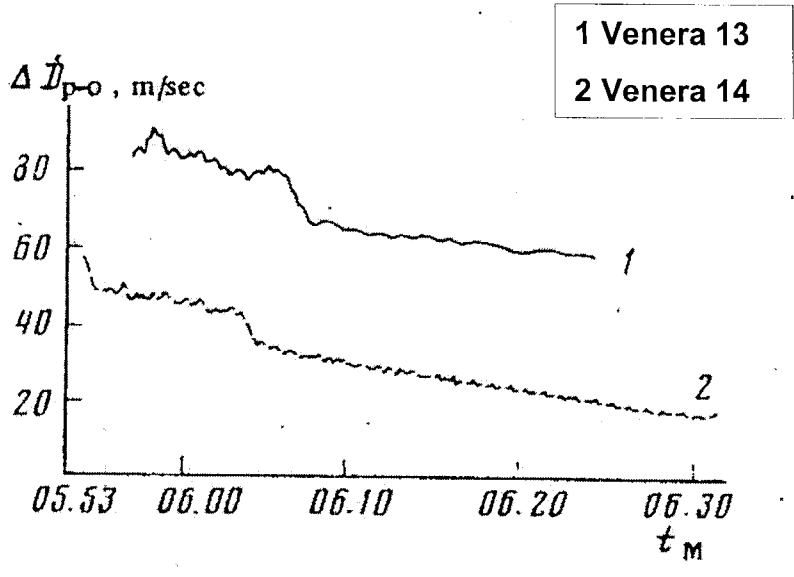


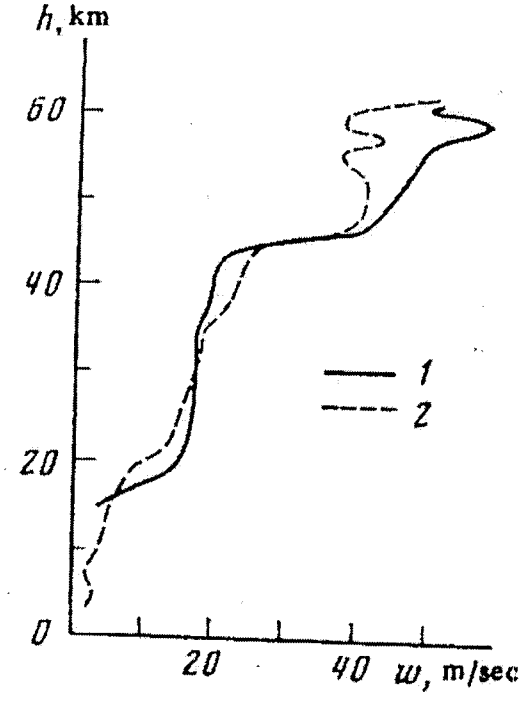
Velocity variations in cloud layer: Venera 11 (upper) and Venera 12 (lower)

VENERAS 13-14 DOPPLER DATA NEAR BOUNDARY OF LOWER CLOUD

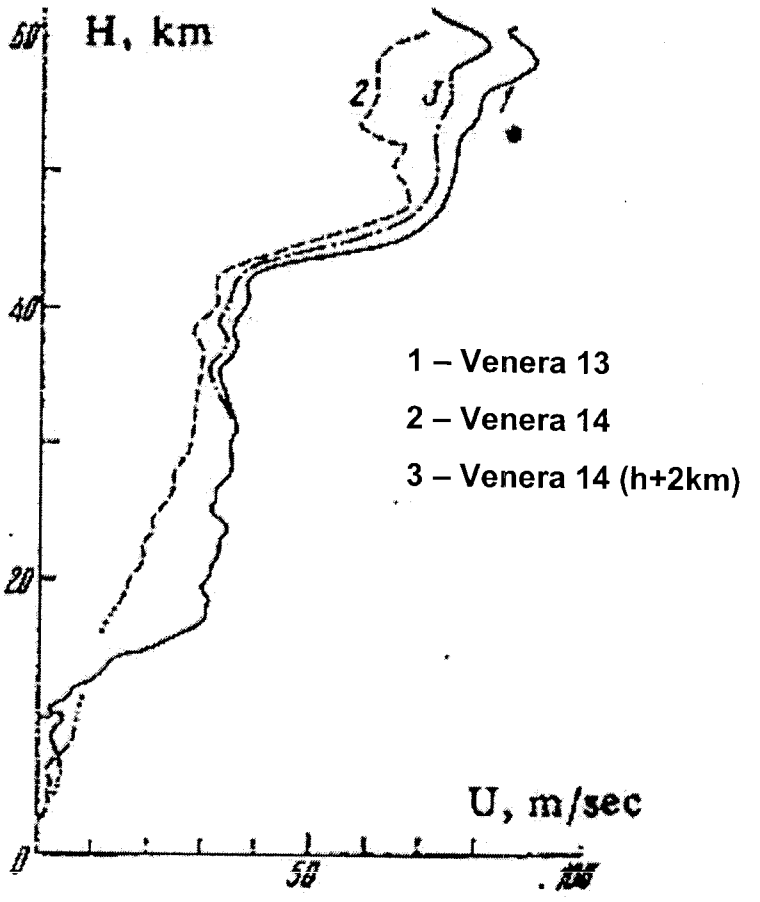


VENERA 13-14 DOPPLER RESIDUALS (INCLUDE WIND EFFECT ONLY) AND DERIVED LINE-OF-SITE COMPONENT OF WINDSPEED

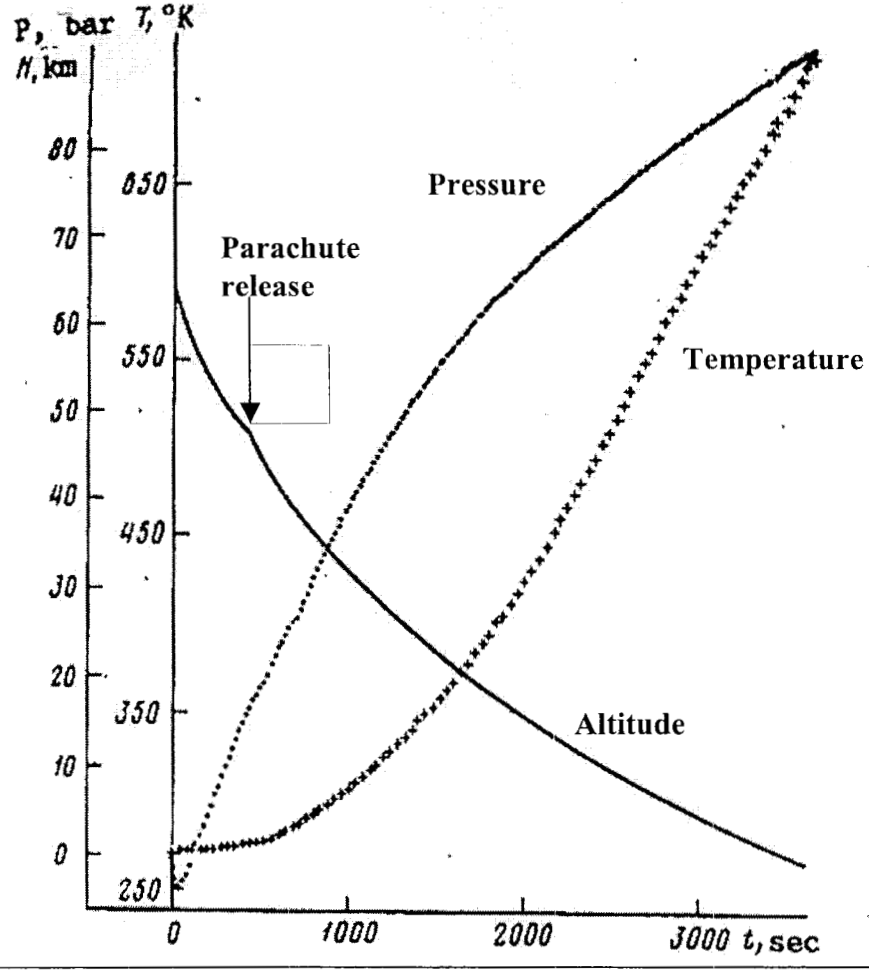




VENERA 13-14 ZONAL WINDSPEED



VEGA 2 LANDER MEASUREMENTS AND ALTITUDE RECONSTRUCTION

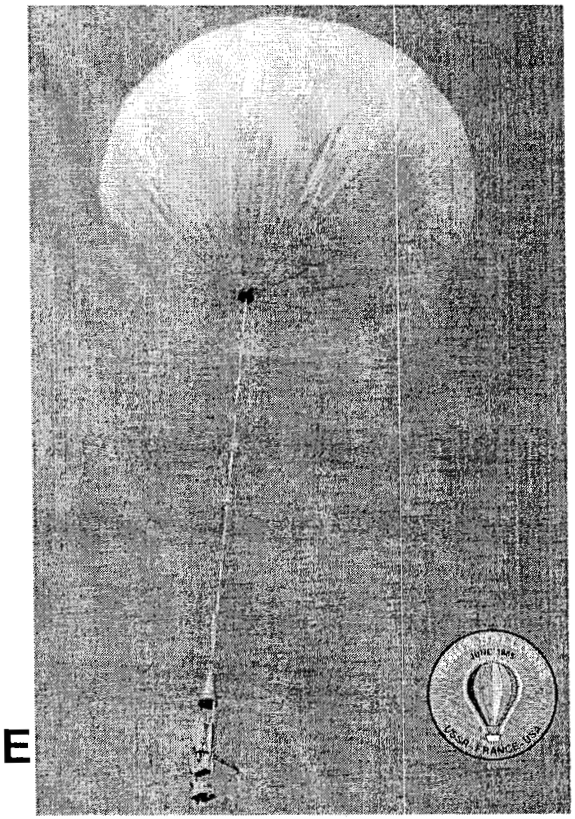


VENERA 9-14 AND VEGA LANDERS: MAJOR ACCOMPLISHMENTS

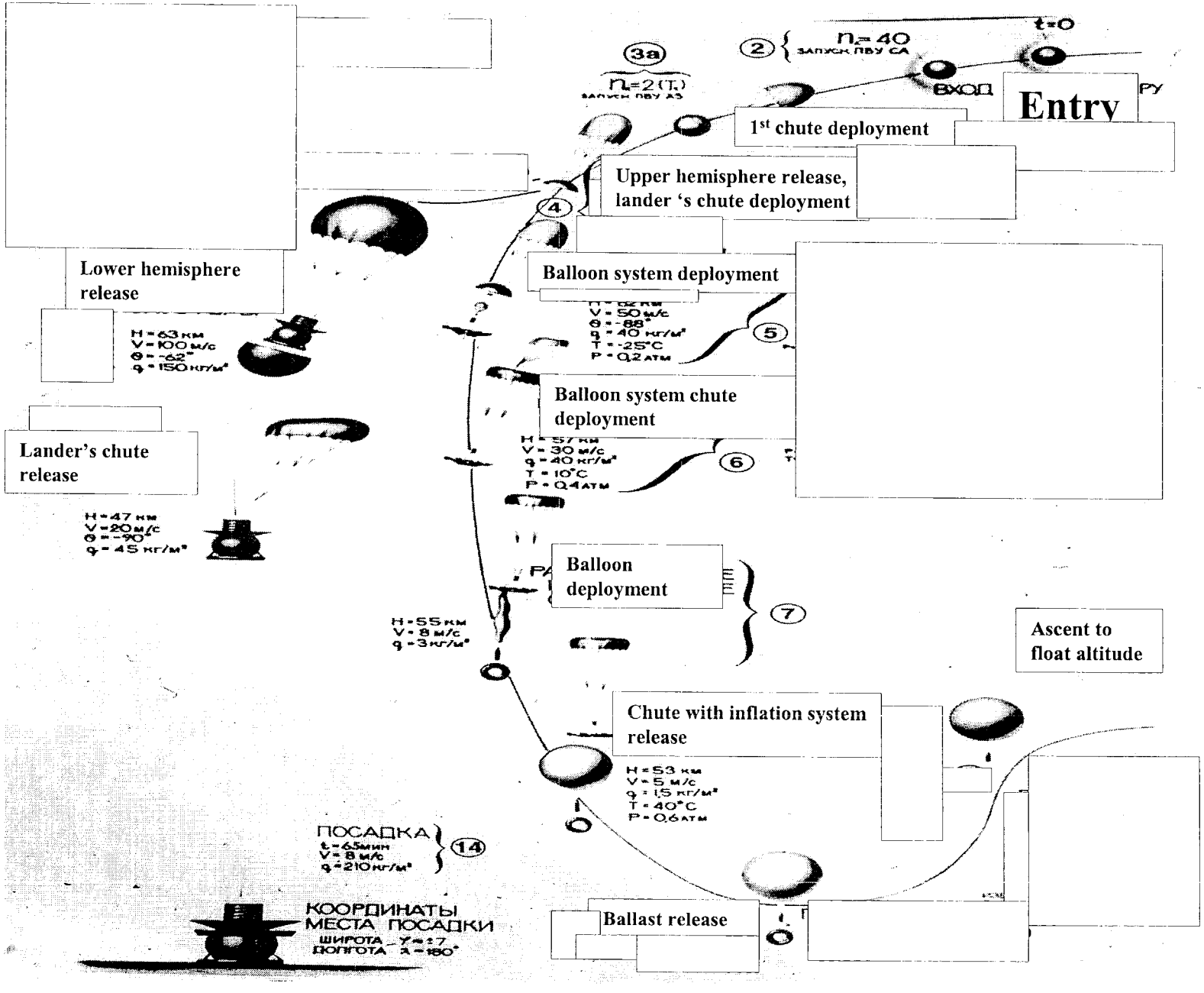
- DETAILED CLOUD STRUCTURE
- SPECTRAL IRRADIATION PROFILES TO THE SURFACE
- DETAILED COMPOSITION OF ATMOSPHERE
- CONFIRMED STABLE CIRCULATION PATTERN
- DETECTION OF LIGHTNING
- MEASURED SURFACE WINDS
- FIRST B&W AND COLOR IMAGES
- ROCK ANALYSIS
- FIRST DRILLING AND SAMPLE ANALYSIS
- ACCURATE THERMAL STRUCTURE DOWN TO SURFACE

VEGA BALLOONS – FIRST PLANETARY AERIAL VEHICLES

- PIGGY-BACK ON VEGA LANDERS
- 3.5 m – DIAMETER SPHERICAL SUPERPRESSURE BALLOONS
- FLOATING MASS 21 kg
- DIRECT-TO-EARTH 18-cm COMMUNICATION LINK 4 / 1 bit/s
- PRESSURE, TEMPERATURE, VERTICAL WINDSPEED, BACKSCATTER, ONE-WAY DOPPLER MEASUREMENTS
- FLOAT ALTITUDE 53-55 km IN EARTH-LIKE ENVIRONMENT
- ACTIVE FLIGHT TIME ~46 hrs EACH TO BATTERY DEPLETION
- TRAVERSED ~ 11000 km IN EQUATORIAL ZONE
- DVLBI MEASUREMENT OF POSITION WITH WORLD-WIDE 17 RADIO TELESCOPES



VEGA BALLOON / LANDER EDL



VEGA BALLOON GONDOLA

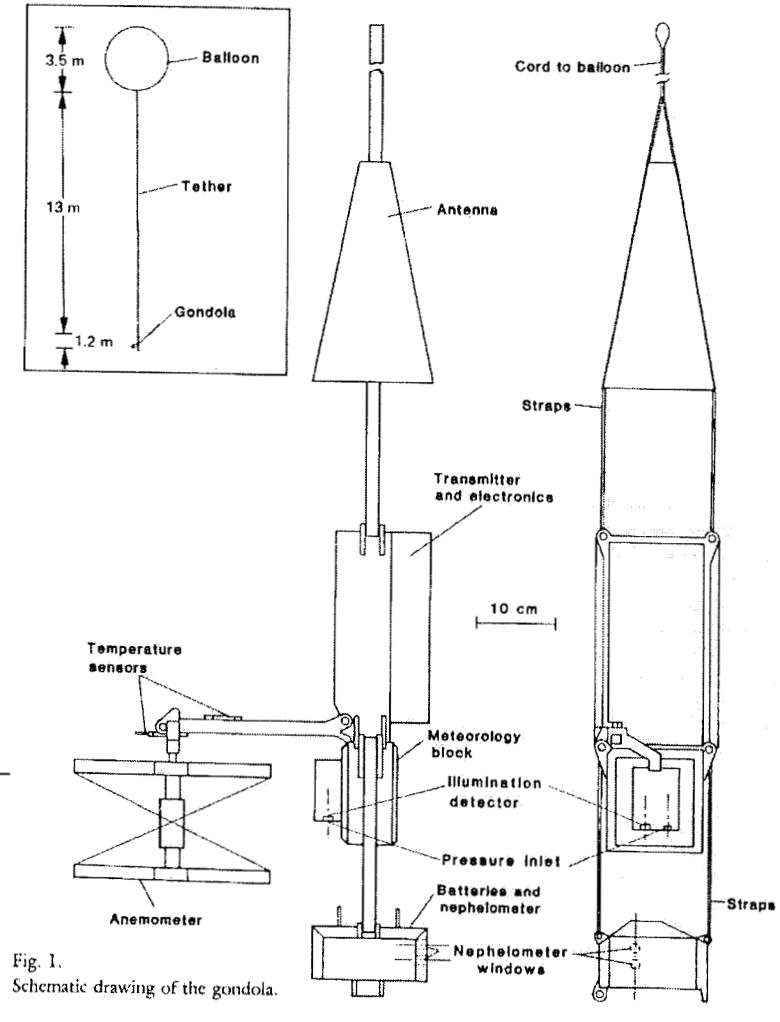


Fig. 1.
Schematic drawing of the gondola.

Total mass 7.5 kg

ONE-WAY DOPPLER: ALMOST CONSTANT WINDSPEED AT FLOAT ALTITUDE

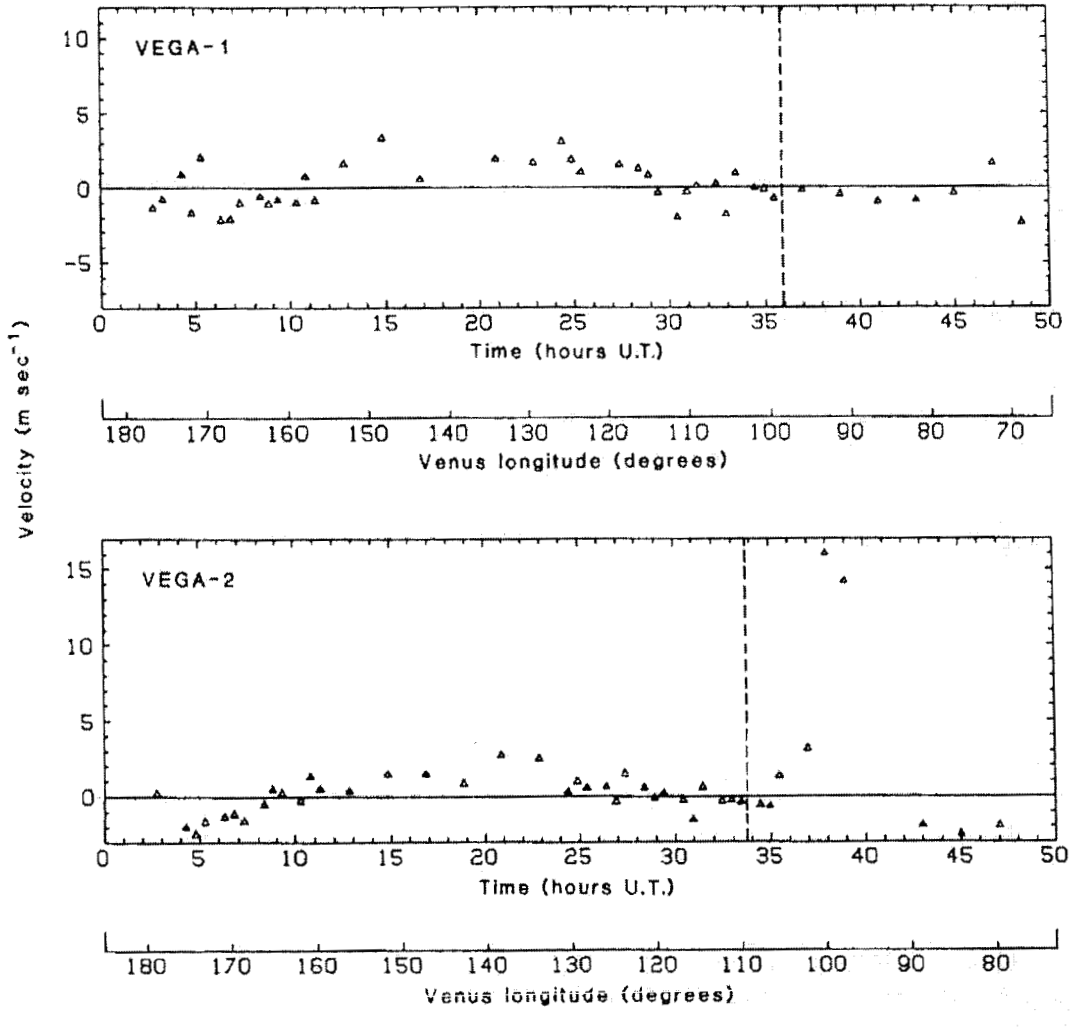


Fig. 1. Doppler residuals with respect to the model of constant zonal wind for each balloon. Dotted vertical lines indicate estimated times of crossing into the sunlit hemisphere.

STRUCTURE OF ATMOSPHERE FROM BALLOON DATA

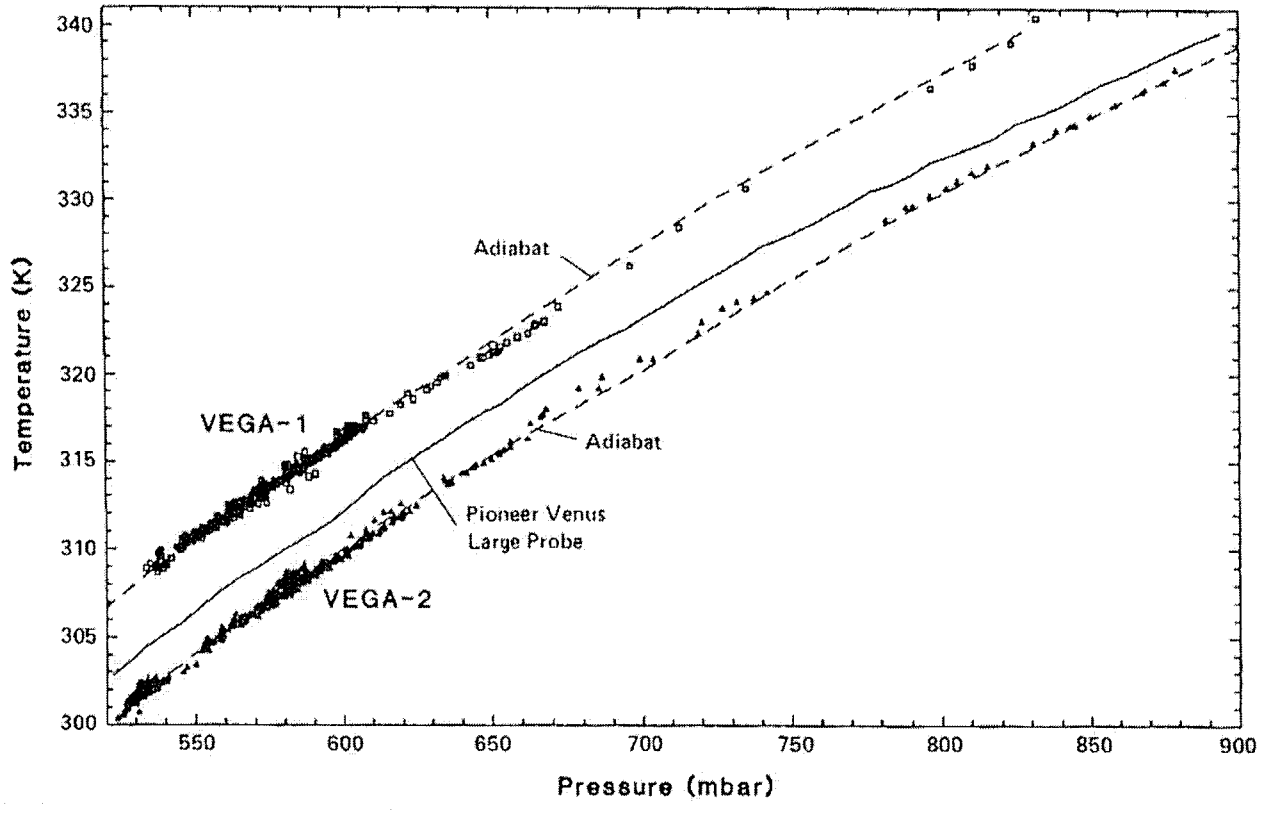


Fig. 1. Measurements of temperature as a function of pressure from the two VEGA balloons compared with data from the Pioneer Venus Large Probe. The data from each balloon define a single curve of variation with small scatter. However, data from the two balloons are offset by 6.5 K at a given pressure and lie on either side of the Large Probe data. The balloons and the probe were within 7° of the equator at injection.

VENERAS' SCIENCE OBJECTIVES

- VENERA 4-8: FIRST RECONNAISSANCE MISSIONS TO RESOLVE MAJOR AMBIGUITIES
  - SURFACE PRESSURE RANGE: 3-1000 atm
  - SURFACE TEMPERATURE 200-800K
  - COMPOSITION UNKNOWN
  - WINDS PRESUMABLY < 5 M/S IN THE BULK OF ATMOSPHERE
  - SOLAR RADIATION UNKNOWN
  - SURFACE COMPOSITION UNKNOWN
- VENERA 9-14, VEGA: DETAILED STUDIES OF ATMOSPHERE AND SURFACE

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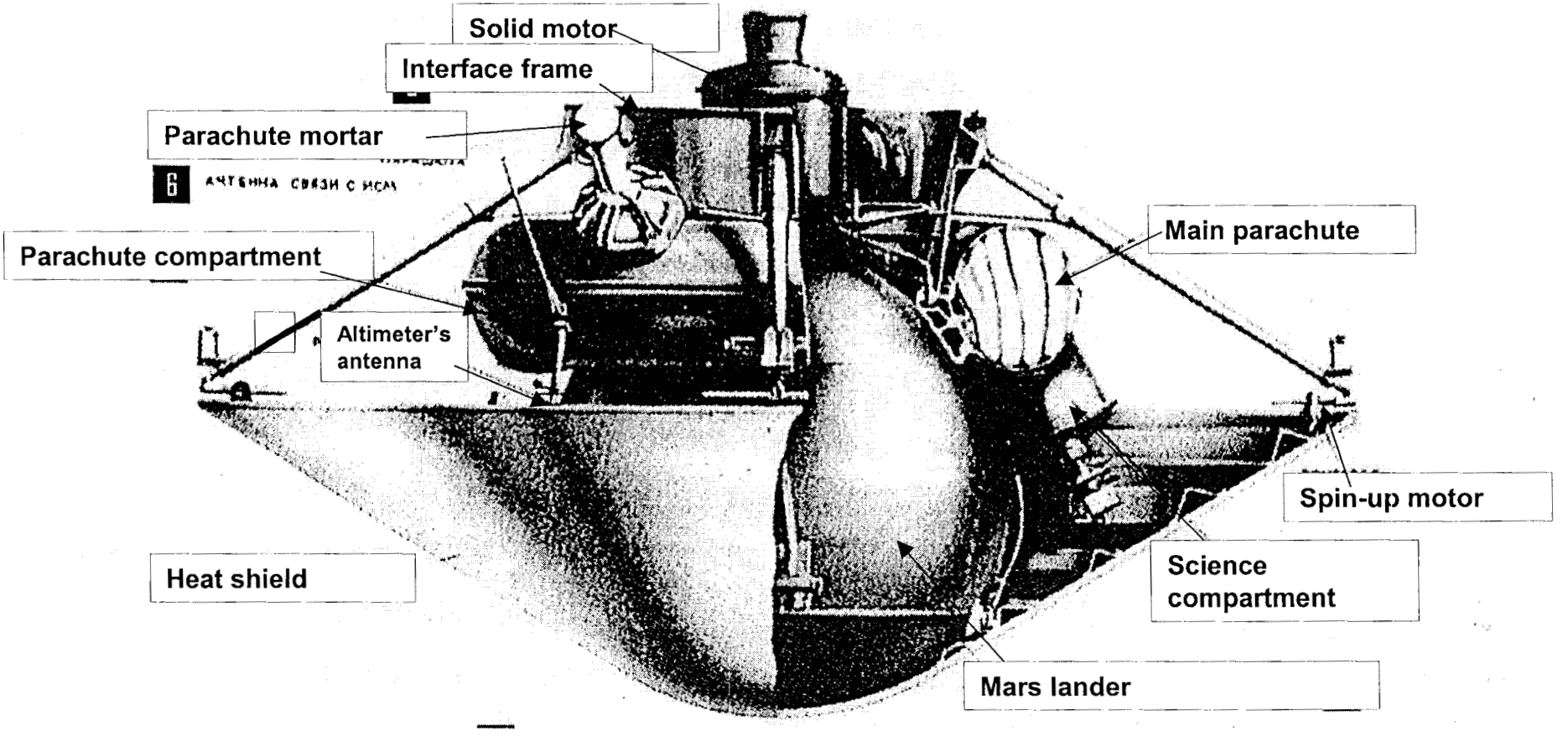
MARS 3-6 EV CROSS SECTION



MARS 3-6 LANDER CROSS SECTION

1 - radar altimeters

2 – shock absorber

3 – telemetry unit

4, 6, 7 – comm system

5 – antennas

8 – science instruments

9 – telephotometers

10 – petals' lock

11 – deployment boom

12 – science sensors

13 – thermal insulation

14 – MLI

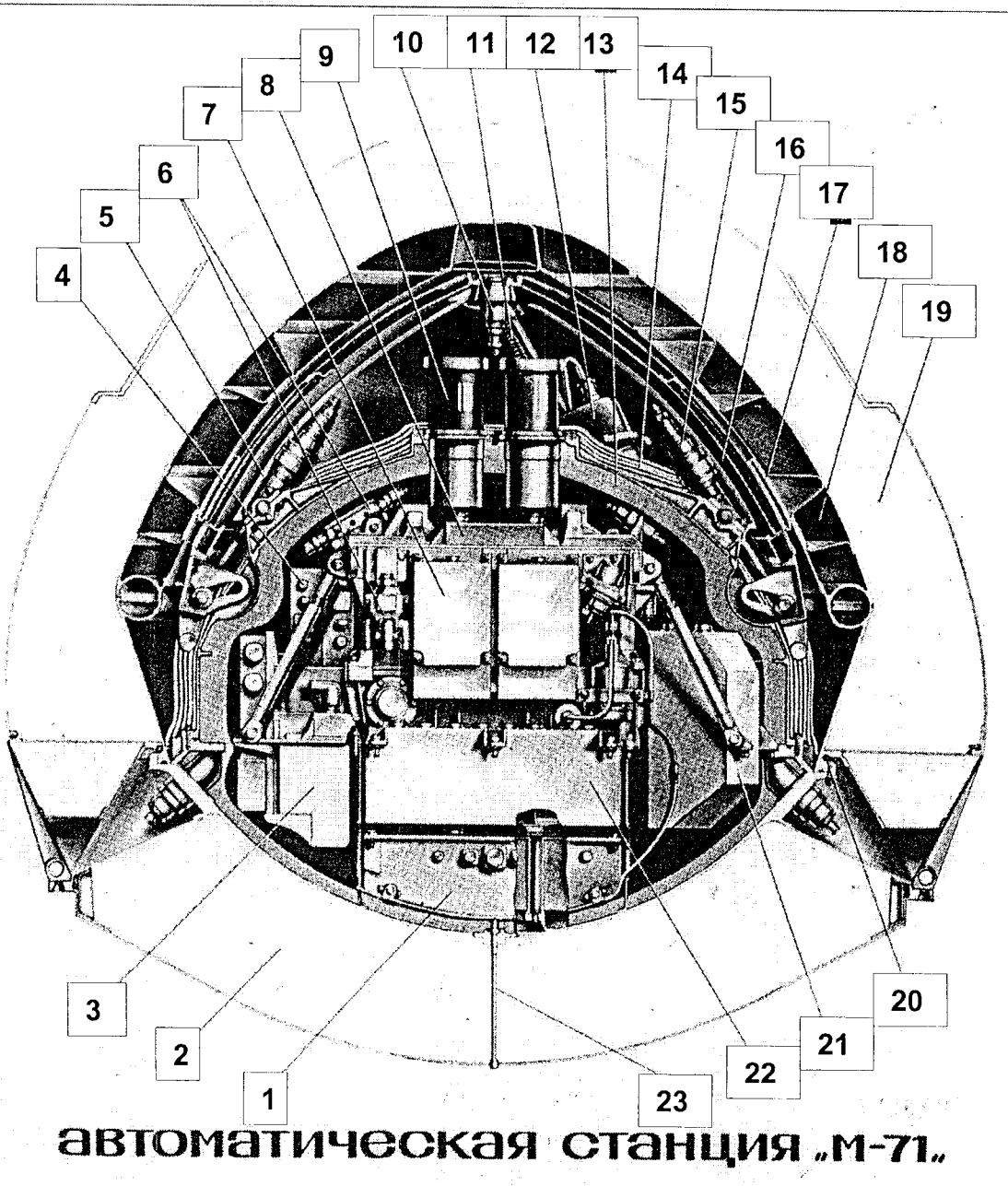
15 – pyro cylinders

16 – petals

17 – displacing bag

18 – aftshell

19 – shock absorber



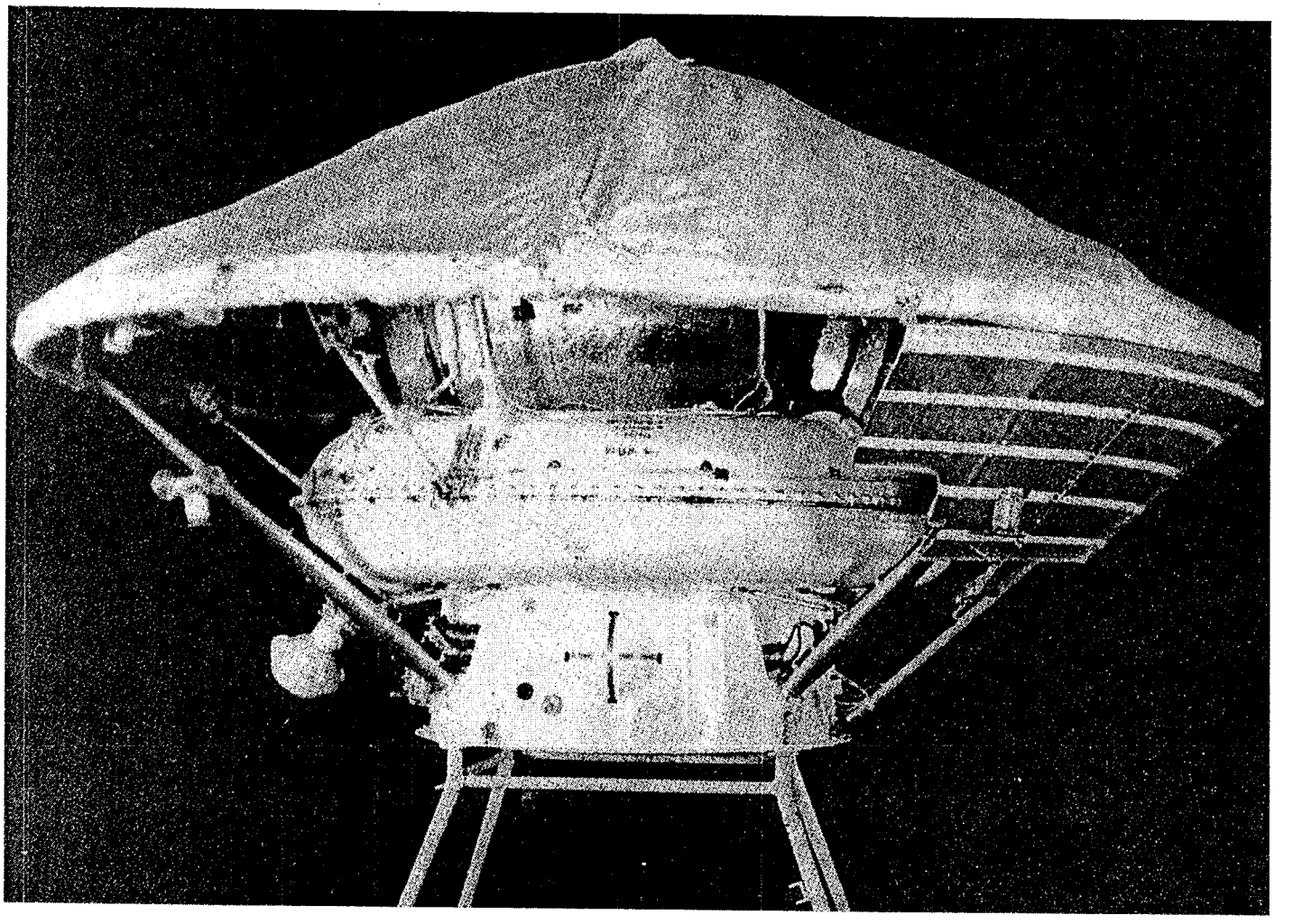
20 – aftshell release pyro

21 – control system

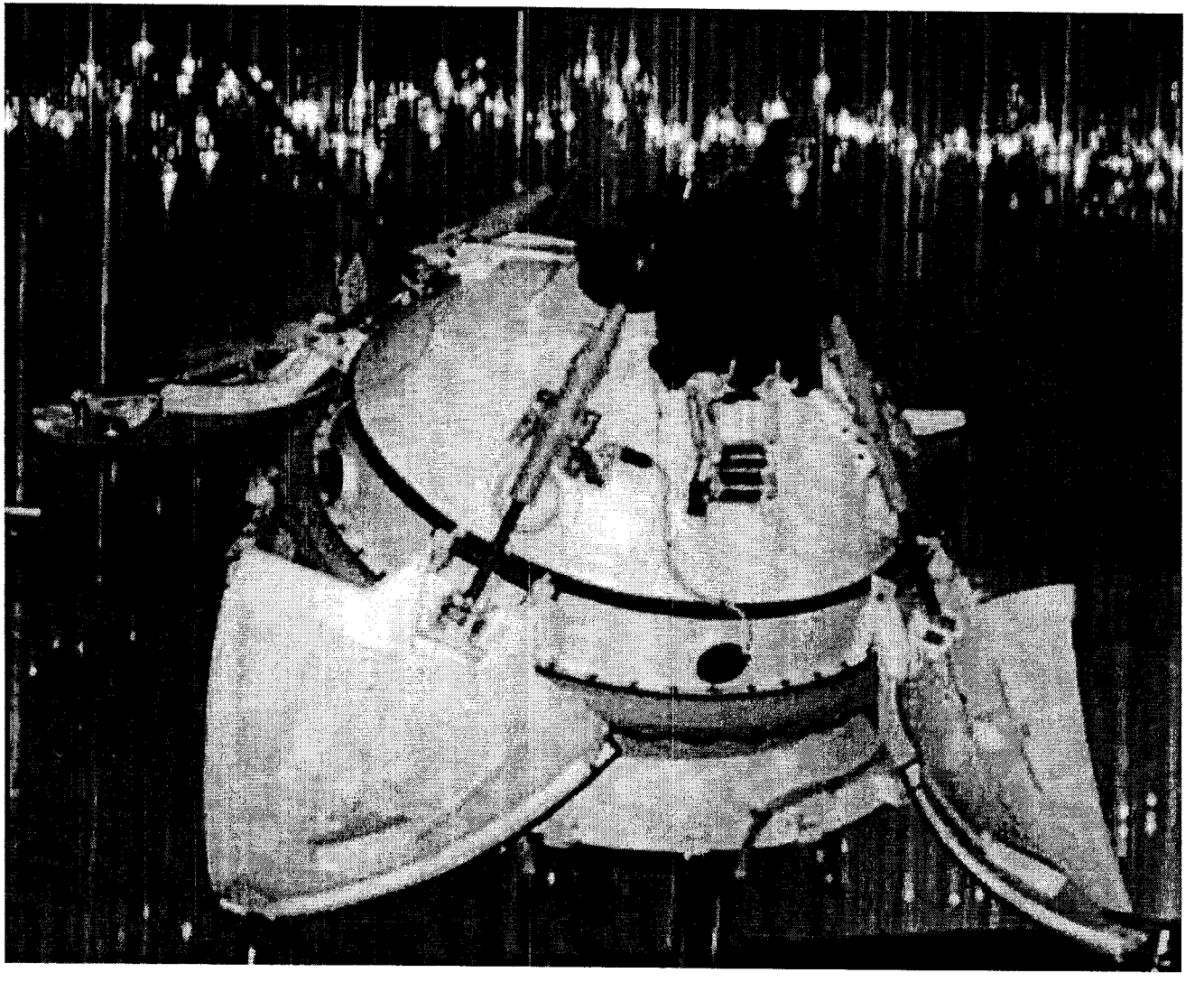
22 – primary batteries

23 – pressure inlet

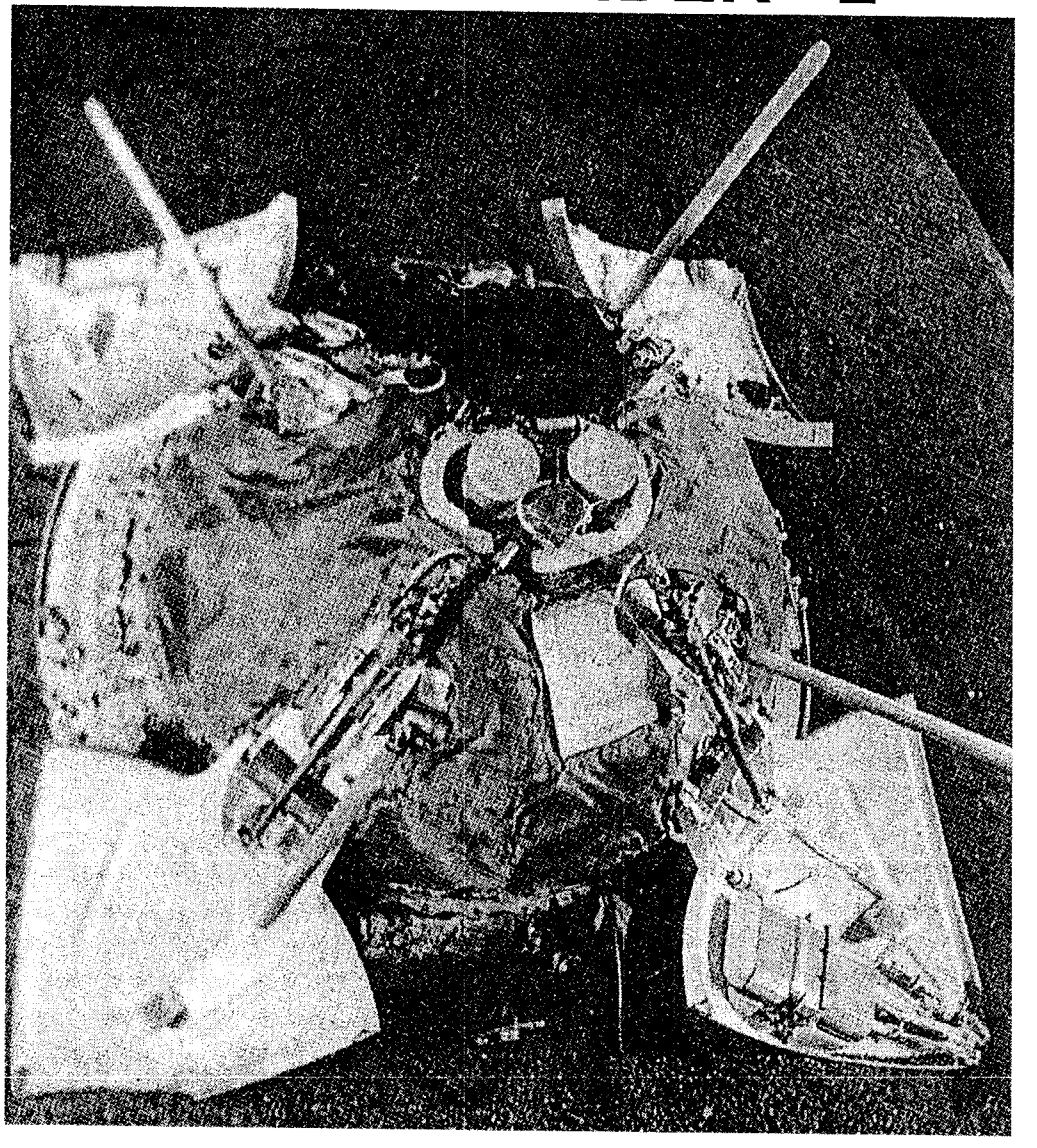
MARS 3-6 ENTRY VEHICLE



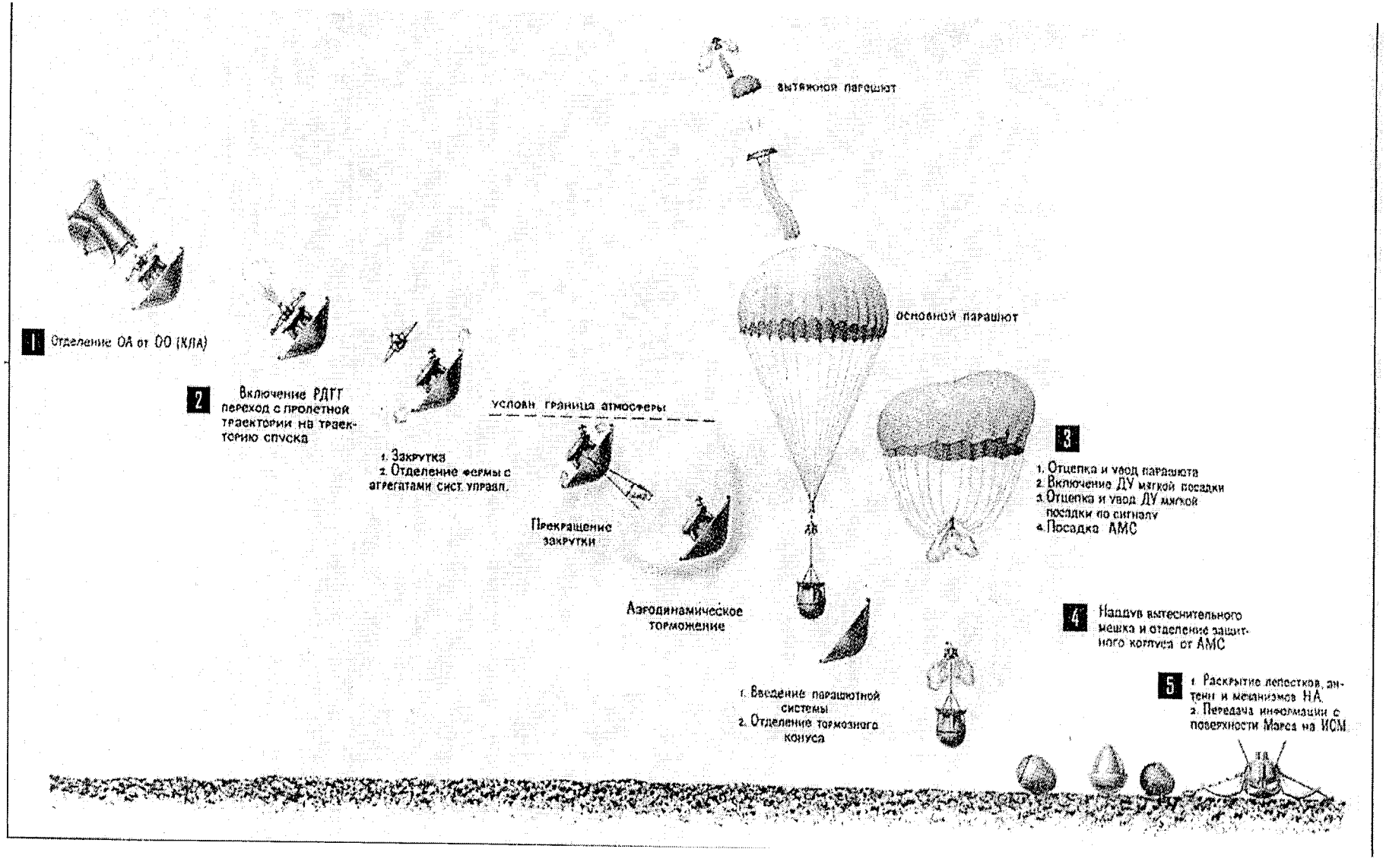
MARS 6 LANDER - 1



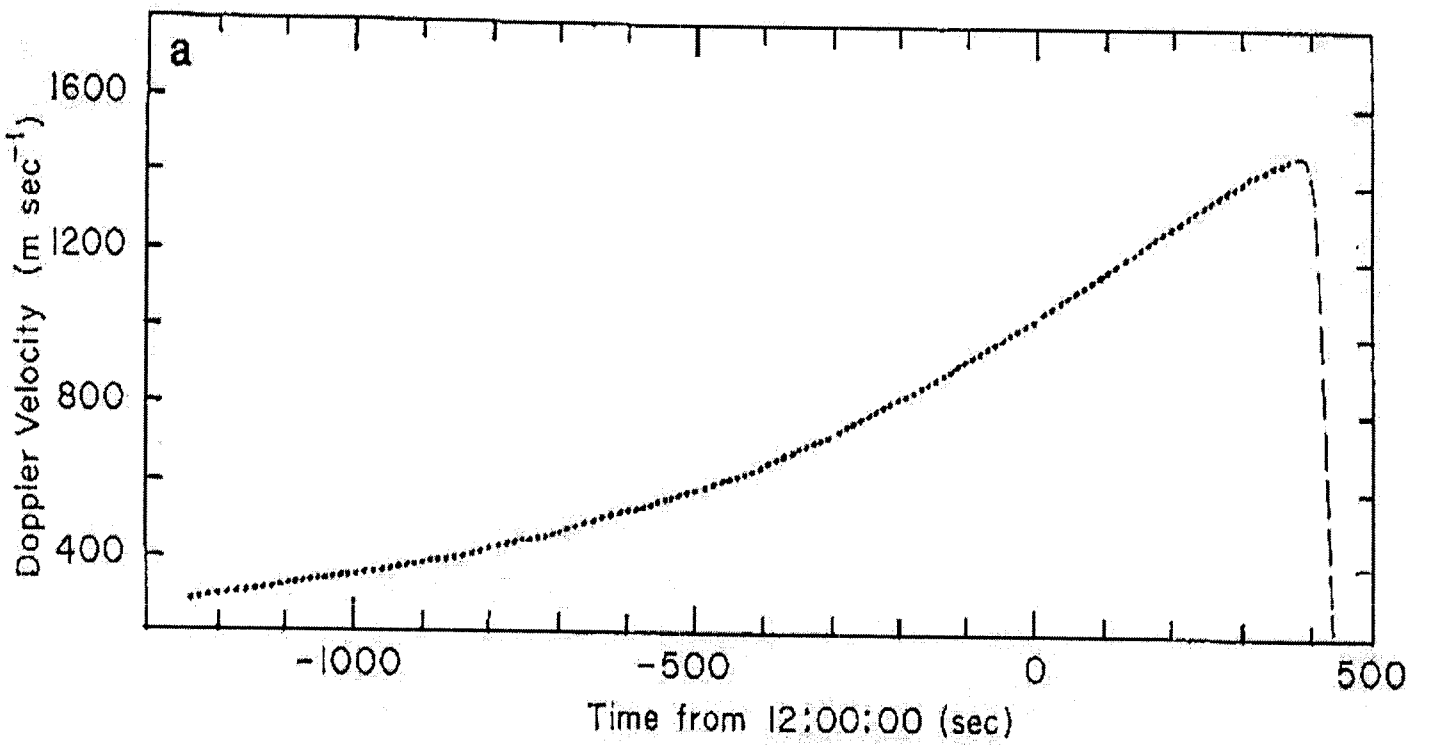
MARS 6 LANDER - 2



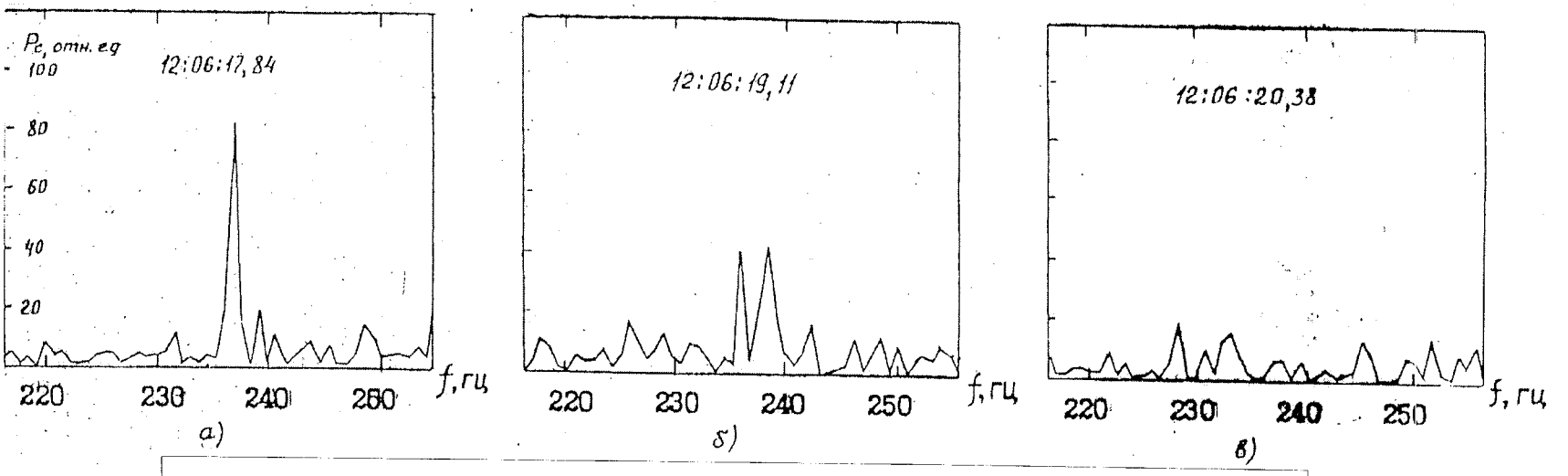
MARS 3-6 EDL SEQUENCE



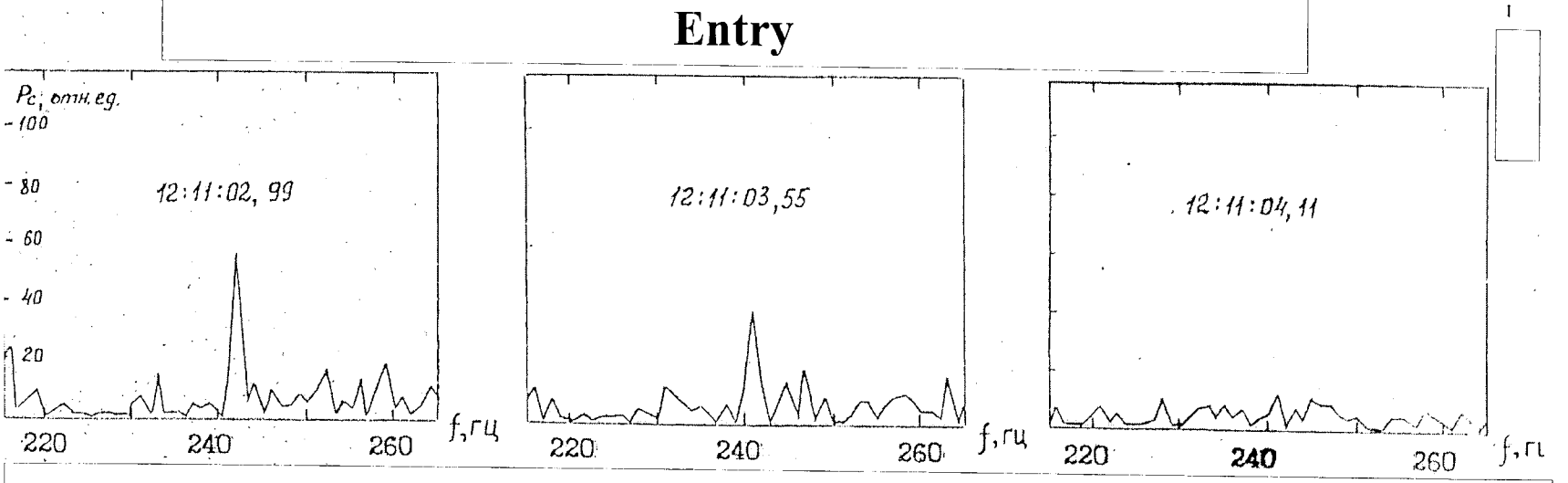
MARS 6: DOPPLER FREQUENCY PRIOR TO ENTRY



MARS 6 SIGNAL SPECTRUMS

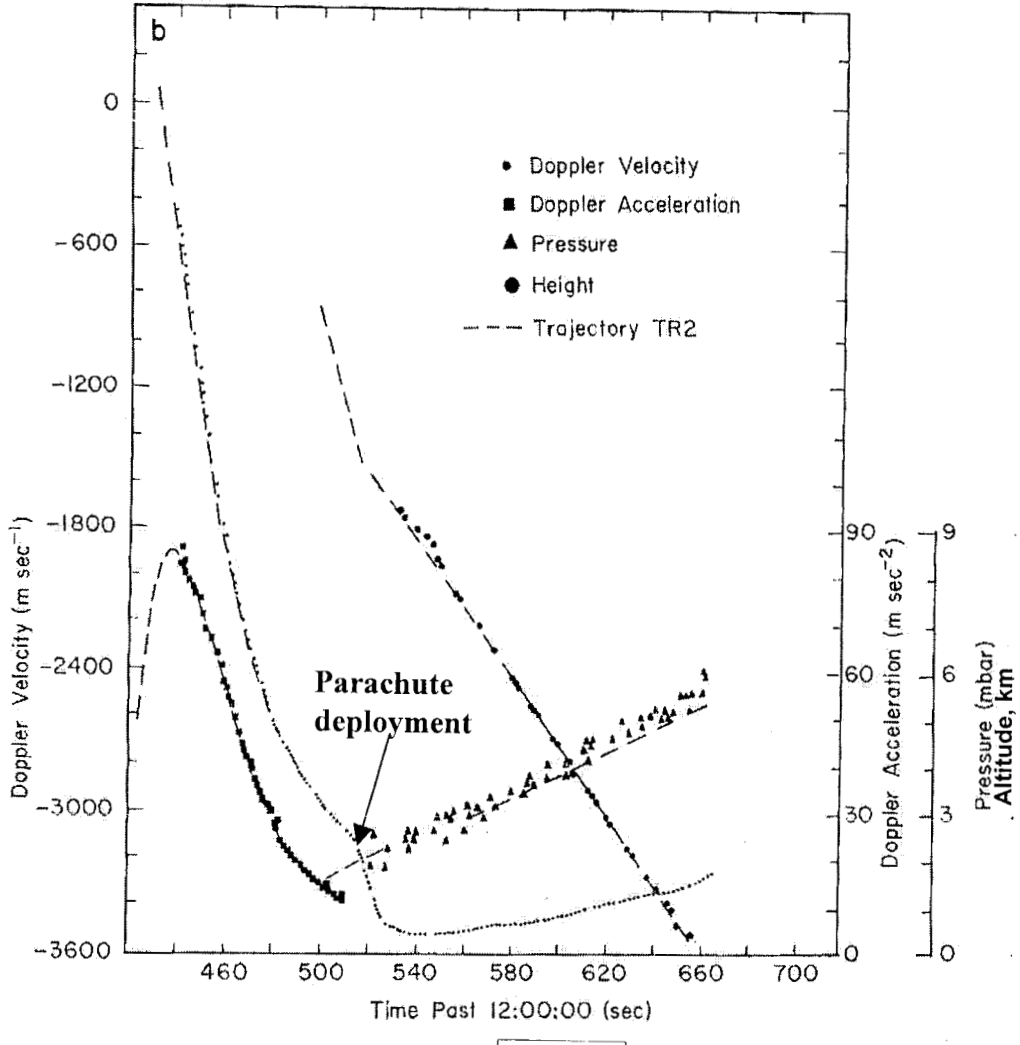


Entry



Landing

MARS 6: MEASUREMENTS IN THE ATMOSPHERE



MARS 6: ATMOSPHERIC DECELERATION MEASUREMENTS

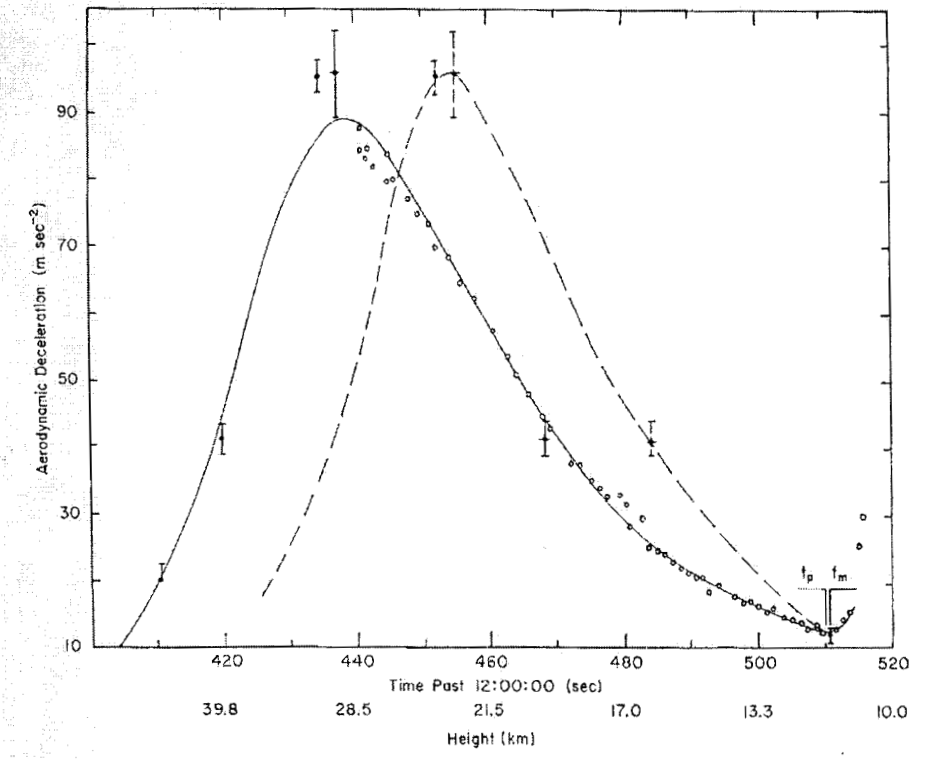


FIG. 4. Aerodynamic deceleration of the descent module, obtained by the Doppler measurements (circles) and predicted by trajectory TR2 (solid line). The data corresponding to the measured time intervals between the fixed levels of deceleration and the measured maximum deceleration with their uncertainties are shown by squares and crosses: squares are tied to the moment of reaching a deceleration of 19.6 m sec^{-2} (the first fixed level) in trajectory TR2. Crosses and the dashed line are plotted in accordance with the results of the separate analysis of the deceleration measurements (Fig. 3 from Avduevsky *et al.*, 1975a); t_m and t_p are the measured and predicted (for trajectory TR2) moments of deceleration 0.14 $\dot{V}_{max}$.

MARS 6: ATMOSPHERIC DECELERATION AT ENTRY FROM DOPPLER DATA

0 V. V. KERZHANOVICH

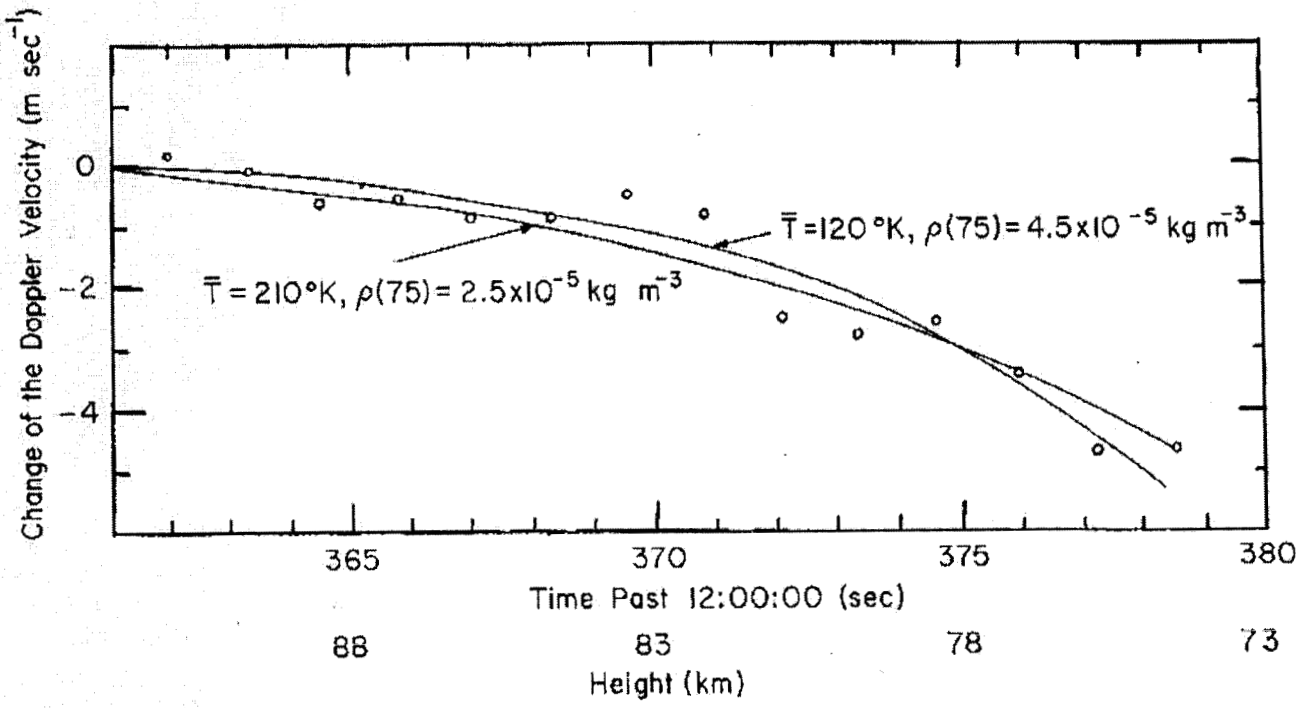


FIG. 6. Change of the Doppler velocity, at 75 to 93 km, caused by deceleration in the atmosphere. Circles correspond to the two-point average residuals between values predicted for free motion and the measured Doppler velocities. A small change of the signal frequency due to the plasma concentration growth is introduced as a correction in the data.

MARS 6: RESIDUALS FOR INITIAL AND FINAL TRAJECTORIES

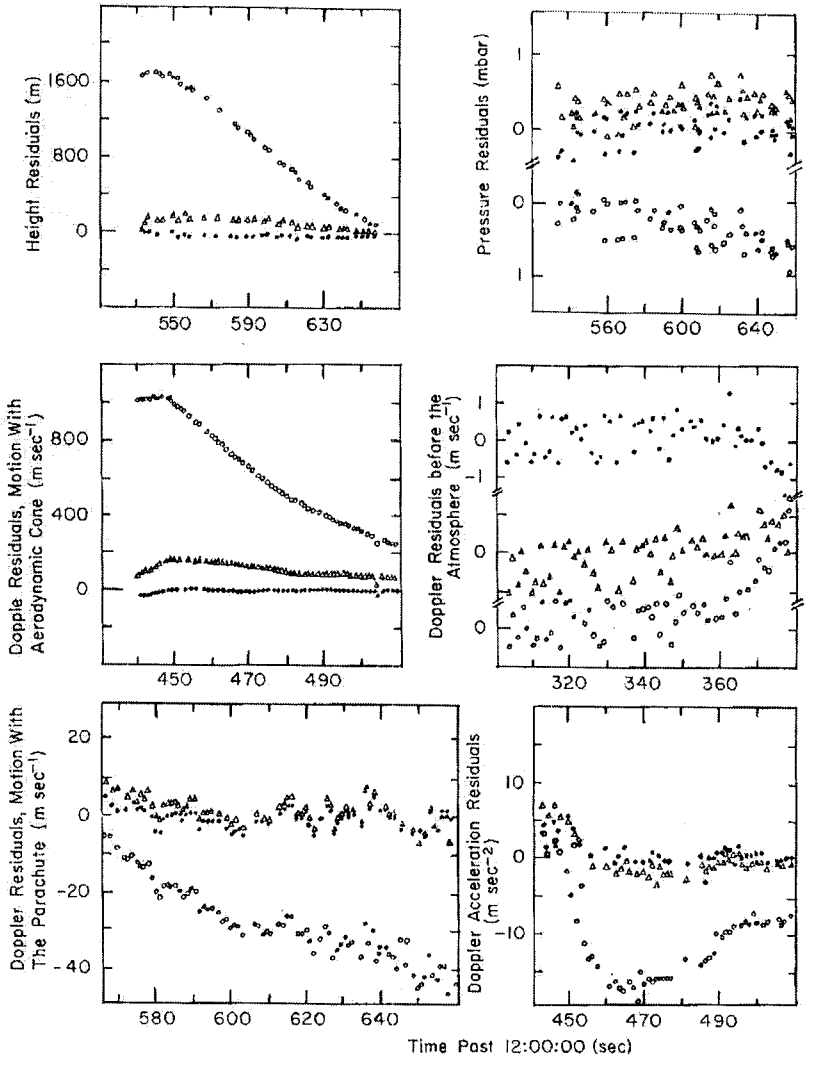
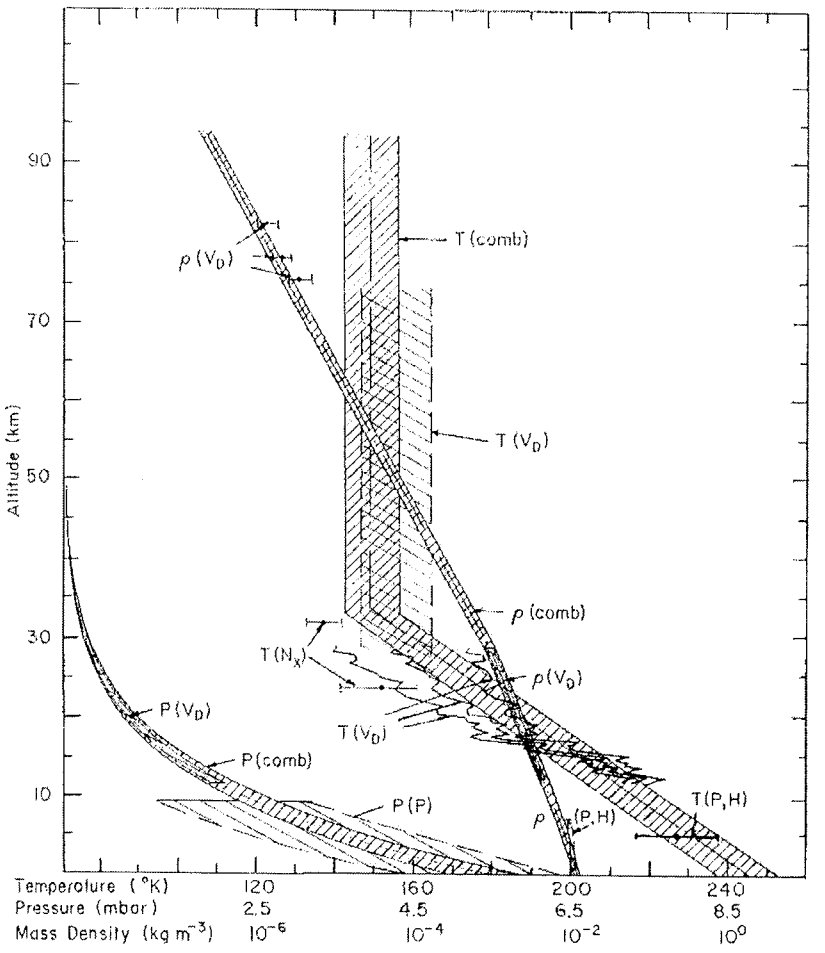


FIG. 7. The residuals of the measured pressures, heights, Doppler velocities, and Doppler accelerations for the trajectories: initial TR0 (open circles), preliminary TR1 (triangles), and TR2 (closed circles).

ATMOSPHERE OF MARS AND WIND PROFILE FROM MARS 6 DATA ANALYSIS

ANALYSIS OF MARS 6 DESCENT MODULE MEASUREMENTS



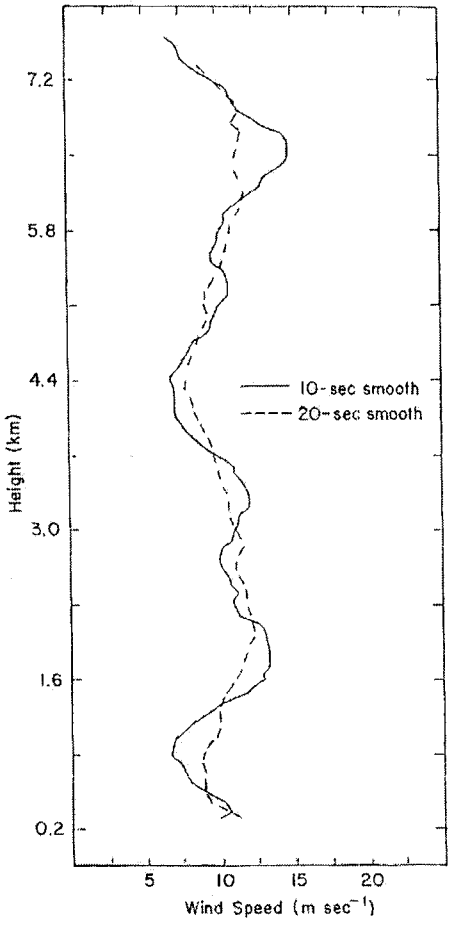


FIG. 9. The vertical profiles of zonal wind speed obtained by 10- and 20-sec running averages.

SOVIET VENERA AND MARS ENTRY PROBES

			COLLECTED DATA	*Descent time/ functioning on surface*	*Mass/Diameter/Entry angle / peak deceleration*	*EV shape/ decelerator*	*Data rate, bit/s*
Venera 4	October 1967	Crashed at 25 km	P,T, density, altitude, composition, atmosphere dynamics @ 60-25 km	94 min / -	405 kg/0.8 m/- 60°?/500g?	Egg shaped / parachute	1
Venera 5, 6	May 1969	Crashed at 20 km	P,T, density, altitude, composition, turbulence @ 60-20 km	51-53min /-	Same	Same	1
Venera 7	December 1970	Landed	Temperature, velocity @ 60-0 km First landing	35 min / 23 min	500 kg?	Same	1
Venera 8	July 1972	Landed	P,T, density, altitude, illumination, winds and turbulence @ 60-0 km	55 min/50 min	500kg//-43° /378g	Same	1
Venera 9, 10	October 1975	Landed	P,T, winds and turbulence + others @ 60-0 km, First panoramas, rock analysis	/53 min /65 min	1800kg/ 2.4m/-18.5° /165g	Sphere / parachute / break disk	3072
Venera 11, 12	December 1978	Landed	P,T, winds and turbulence + others @ 60-0 km, rock analysis	/>35 (>95 min total) />110 min	~ Same	Same	3072
Venera 13, 14	March 1982	Landed	P,T, winds and turbulence + others @ 60-0 km, color panoramas, drilling and rock analysis	/127 min /57 min	~ Same	Same	3072
Vega	June 1985	Landed	P,T, winds and turbulence + others @ 60-0 km, drilling and rock analysis	62/20 min 60/	~ Same	Same	3072
Vega Balloons	June 1985	Floated at 54 km	P,T, W, One-way DTE Doppler, DVLBI	46 hrs	21 kg at float	Same	4 / 1
Mars 3	December 1971	Landed	Part of images	240 s /40 s	385 kg (lander)	120° cone / chute/retrorockets	72000
Mars 6	March 1974	Crashed at landing	P,T, deceleration, altitude, one-way DTE Doppler	240 s / 0	As Mars 3/ ///9g	Same	72000