OBSERVATIONS OF THE RUSSIAN MOON PROBE *LUNA* 9

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ON January 31, 1966, Tass announced the launching of the Moon probe *Luna* 9. Signals from the probe were acquired at Jodrell Bank on February 1 and on February 2 the observations were transferred to the Mark I 250-ft. diameter radio telescope. From previous information available from the flights of *Lunas* 5, 7 and 8 it was anticipated that the probe would arrive at the Moon during the evening of February 3, an expectation supported by a second Tass announcement that *Luna* 9 would reach the Moon at 22h 00m U.T. on February 3. In the event, the landing of *Luna* 9 on the Moon occurred at 18h 45m. The purpose of this article is to give a short account of the observations made at Jodrell Bank of the landing phase and reception of the television photographs from this first successful landing of scientific apparatus on the lunar surface.

Experimental Arrangement

The receiving system consisted essentially of the Mark I 250-ft. radio telescope working on a frequency of 183·535 Mc/s. The gain of the telescope on this frequency is 40 dB and its beamwidth 2 deg. to half power. The full gain was not realized in this experiment because the telescope was simultaneously engaged on other research programmes and the pre-amplifier had to be placed at some distance from the primary feed involving a cable loss of about 2·5 dB. The pre-amplifier was a *DET*29 grounded grid triode with a 2-dB noise factor. After further amplification the output of the pre-amplifier was converted to an intermediate frequency of 10·555 Mc/s using an oscillator locked by means of a Gertsch *FM*-6 frequency meter to a 1-Mc/s frequency standard with a short-term stability of $\pm 2 \times 10^{-10}$. The 10·555 Mc/s signal was then fed into a Racal *RA*17 receiver. The local oscillator of this receiver had a frequency stability of 2 c/s over 1 min with a maximum excursion of about 20 c/s.

The signal from the 100 kc/s intermediate frequency of the Racal with an 8-kc/s bandwidth was fed to a phase-locked oscillator and by synchronous detection the phase modulation was extracted. The detected phase-modulated signal was recorded together with appropriate time and frequency standards on an Ampex *FR*100*A* tape recorder. The frequency of the phase-locked oscillator, which was proportional to the signal frequency, was measured using a digital counter and printed out automatically every 2 sec. The printed figure was the integral frequency count of the previous 1-sec interval.

The Landing Phase

The variation in received frequency from 17h 50m to 18h 45m U.T. is shown in Fig. 1. From 17h 50m to 18h 44m U.T. the intermediate frequency decreased from 100,932 to 100,638 c/s, representing an increase in the line of slight component of the velocity of 494 m/sec,

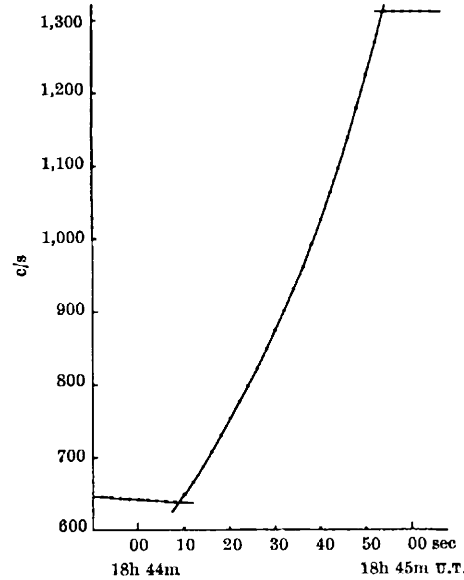
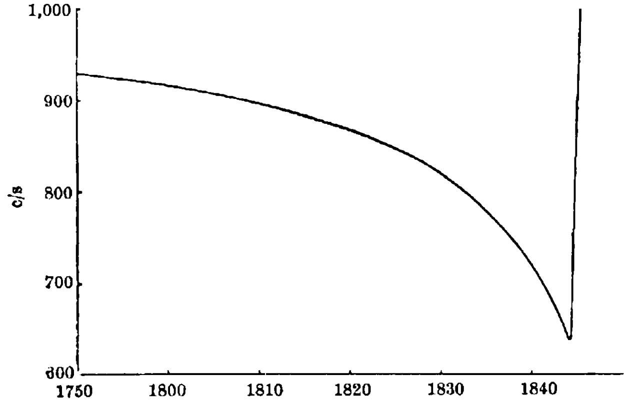


Fig. 2. The variation of received signal frequency from *Luna* 9 between 18h 44m U.T. and 18h 45m U.T. on 1966 Febr. 3. The ordinate is the intermediate frequency minus 100 kc/s. Abscissa is time in U.T. on February 3, 1966



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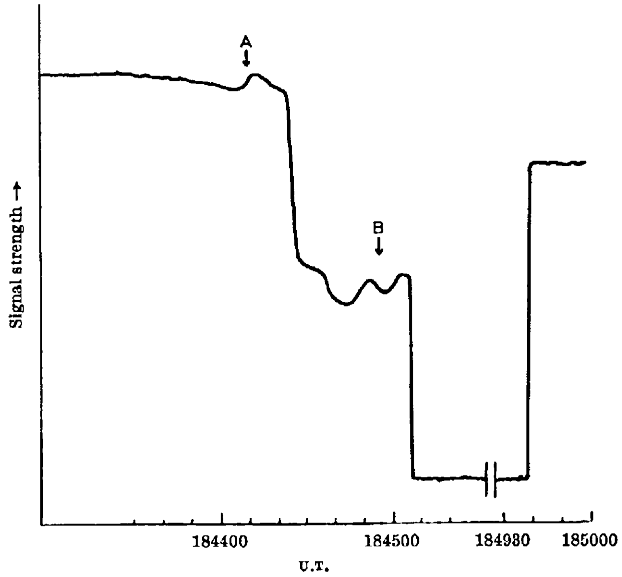

Fig. 3. Tracing of the received signal strength from *Luna* 9 during the landing phase. The ordinate is the signal amplitude in arbitrary units (the level at *A* is about 12 dB signal : noise ratio). The abscissa is the time in U.T. on February 3, 1966

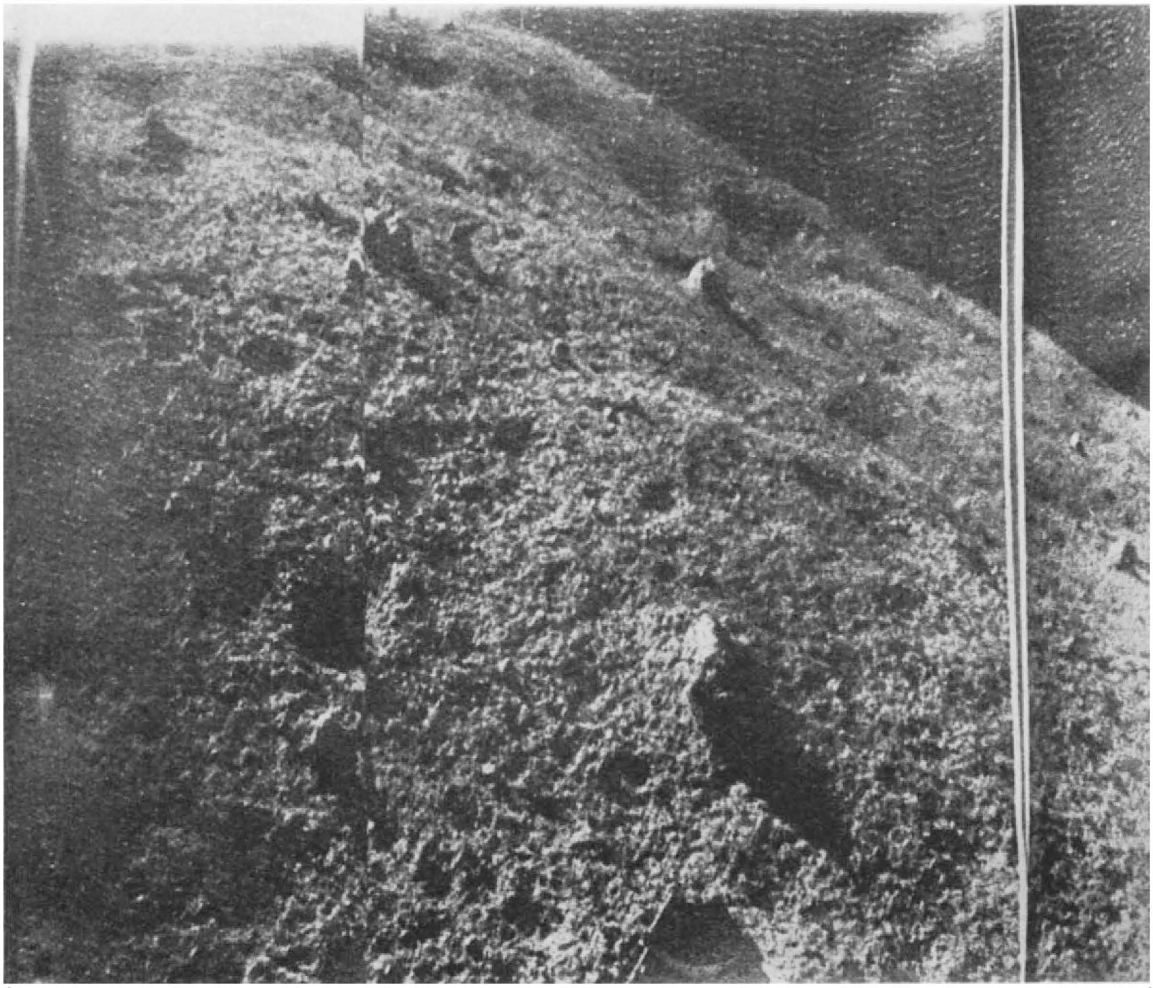

Fig. 4. Photograph of the lunar surface as received from *Luna* 9 on 1966 Febr. 4 between 15h 30m and 16h 55m U.T. A part of the protective fairing of the probe is visible in the foreground. According to information received from the U.S.S.R. the horizontal scale is compressed by 2·5 times

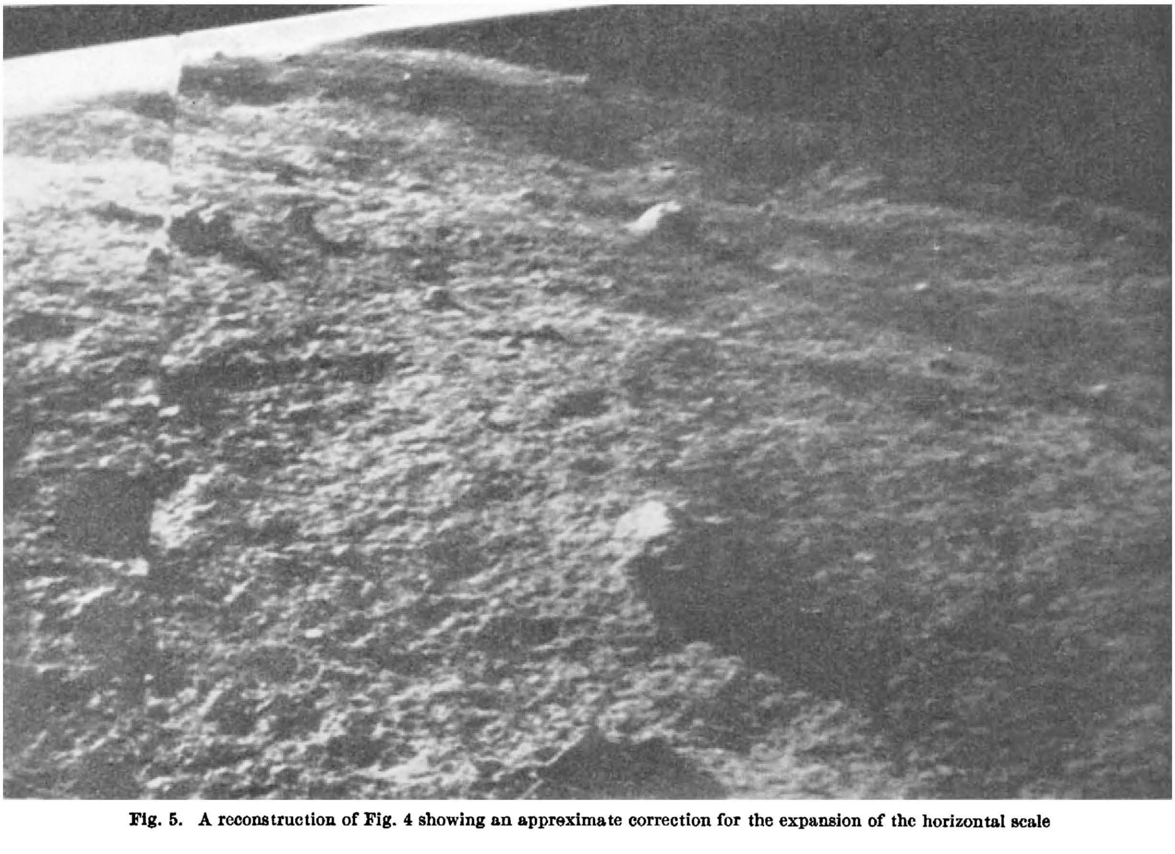

Fig. 5. A reconstruction of Fig. 4 showing an approximate correction for the expansion of the horizontal scale

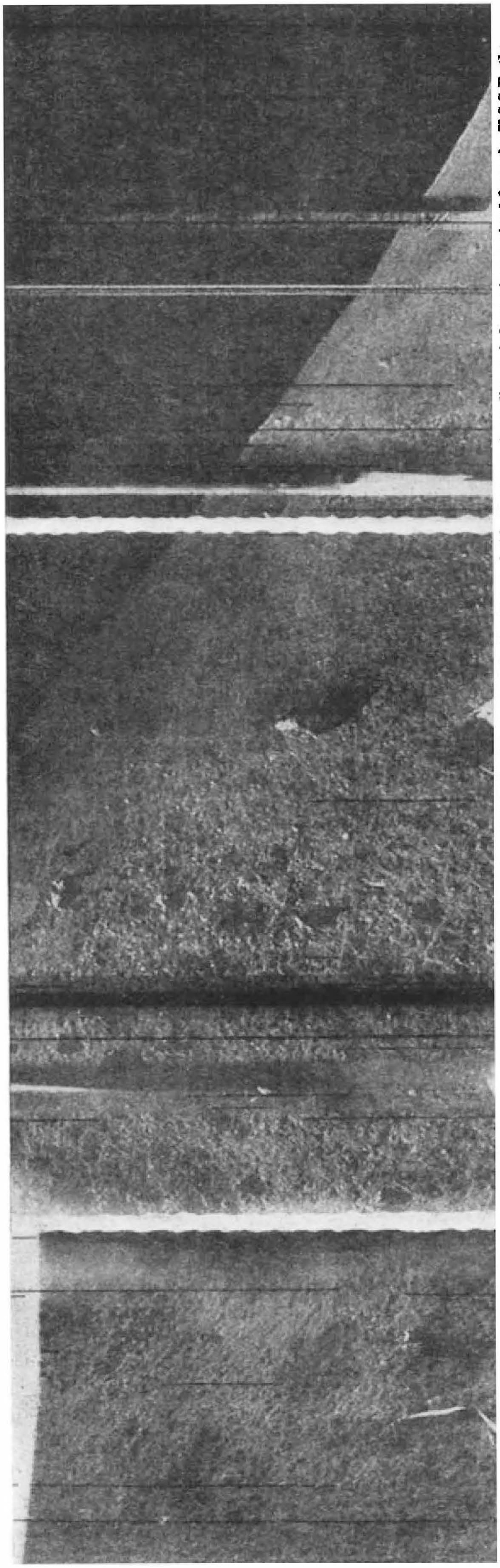

Fig. 6. A reconstruction of a panoramic sequence of the lunar surface as received from *Luna* 9 on 1966 Febr. 5 between 16h 40m U.T. and 17h 40m U.T. According to information received from the U.S.S.R. the horizontal scale is compressed by 2·5 times

and the rate of change of frequency increased from 2 c/s/min to 24 c/s/min. Extrapolating this curve to 18h 44m 30s, the time at which impact would have taken place had the retro-rockets not been fired, the rate of change of frequency at impact would be 25·8 c/s/min, corresponding to an acceleration of 0·705 m/sec^2. Comparing this with the Moon's surface gravity of 1·62 m/sec^2, it appears that the landing occurred approximately 64° from the centre of the Moon's visible disk. This compares well with the value of 61° computed from the published landing area and allowing for libration.

The variation of frequency from 18h 44m to 18h 45m is shown in more detail in Fig. 2. Each measured point lies on one of three smooth curves. Up to 18h 44m 08s, the points lie on the curve corresponding to free fall; from 18h 44m 10s to 18h 44m 52s a rapid deceleration occurs, increasing from 32·4 to 76·0 m/sec^2 over the interval. After 18h 44m 54s, the frequency remained constant within 2 c/s, corresponding to the transmitter being at rest on the Moon's surface. The total frequency change from 18h 44m 08s to 18h 44m 54s is 675 c/s, corresponding to a line of sight velocity of 1,108 m/sec, or total velocity of 2,540 m/sec, or 1·07 times the escape velocity from the lunar surface. Integration of the deceleration curve indicates that the retro-rockets were fired at a height of 68·5 km. Insufficient detail of the moment of landing is available, but it is clear from the shape of the curve that the impact velocity was very low.

The variation of strength of the received signal over the landing phase is shown in Fig. 3. The deceleration commenced at the point marked *A*, and produced no significant change in strength. Approximately 15 sec later the strength decreased over about 1 sec to about a third of the original power. At the point marked *B*, the deceleration ceased, once again without much change in signal strength. Twelve seconds later, at 18h 45m 07s, the signals ceased. During all this time the carrier was modulated with telemetry information.

The Reception of the Photographs

Approximately 4 min after landing at 18h 49m 38s the signal reappeared at precisely the same frequency, with an amplitude somewhat less than the original and with telemetry of a type different from the previous transmissions. At 18h 58m 45s the type of telemetry again changed and the detected phase modulated signal consisted of a variable tone in the range 1·4–2·6 kc/s. This was quickly recognized to be a facsimile transmission with an approximate one-second line scan. This variable tone was fed through a Muirhead Type *D* 665 FM/AM convertor into a Muirhead picture receiver Type *D*-700-*A*. Fig. 4 is an example of one of the photographs received on February 4 during the facsimile transmissions which began at 15h 30m and ceased at 16h 55m U.T. The Russians stated that the horizontal scale of the pictures issued from Jodrell Bank was compressed in the horizontal direction by 2·5 times. An approximate correction of Fig. 4 to allow for this extension is shown in Fig. 5. Fig. 6 is the panoramic view received on February 5 between 16h 40m and 17h 40m U.T. The signal strength during the reception of the facsimile transmissions decreased from 12 dB in an 8 kc/s bandwidth on February 4 to 3 dB on February 6.

The variation in the length of the shadows between February 4 and 5 is clearly visible by comparison of Figs. 4 and 6, and an idea of the scale can be obtained from the appearance of the protective fairing in the foreground of both pictures. For example, the conspicuous stone near the fairing is about 6 in. across and, on the assumption that the camera was 2–3 ft. above the surface, the horizon is 0·5–1 mile distant. Other parts of the probe are visible in Fig. 6.

We thank the editor of the *Daily Express* for his co-operation in lending us the Muirhead convertor and picture receiver.