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FOCAL LENGTH ADJUSTMENT OF THE 140-FT

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Summary

As a first step of future improvement of the 140-ft, the focal adjustment is investigated. Good agreement is found between observational data of K. Kellermann, and a computer analysis of W. Y. Wong. The gravitational deformations cause the focal length F to change with zenith angle θ as

$$F(\theta) \;=\; F_0 - 17.6 \text{ mm } (1 - \cos\theta)$$

which could be automatically corrected for right now. The remaining residuals are rms(ΔF) = 1.3 mm at night, and 3.7 mm during days, in agreement with expected temperature differences in the structure for which the computer analysis yields

$$\Delta F \;=\; 1.15 \text{ mm } / \text{ }^\circ\text{F}.$$

It is suggested to install some thermistors in the sturcture, for correcting the thermal effects as well, after an observational calibration.

It is expected that these corrections will be sufficient (≤ 2% gain loss) for wavelengths down to λ = 1.5 cm, for all zenith angles and all thermal conditions.

I. Structural Analysis

The backup structure of the 140-ft has been computer-analyzed by Woon-Yin Wong, regarding both gravitational (deal load) and thermal deformations. These deformations then define a best-fit paraboloid, which in general has six degrees of freedom: translation (3 degrees), rotation (2 degrees), and change of focal length (1 degree). Since the deformations of the surface panels are much smaller, we just have estimated them using formulas which apply to thin plain trusses.

1. Gravitational Deformations

If a sturcture is rotated through 360° about any axis, then the distance between any two joints must follow a simple sine wave (von Hoerner and Wong, 1975). From the symmetry of the telescope structure it then follows that the focal length F can only depend on the zenith angle θ (= 90° - elevation), and that $F(\theta)$ must have the form:

$$F(\theta) \;=\; F_0 - B\,(1 - \cos\theta), \tag{1}$$

where B is the difference in focal length between zenith and horizon. Since the observer actually adjusts the feed box with regard to the apex of the feed legs (doughnut), we must also know the z-deformation of this apex, as well as the z-translation of the vertex of the best-fit paraboloid. In summary, the computer analysis yielded:

$$\left.\begin{array}{lcr} \text{(a) change of focal length} & = & 14.96\ \text{mm} \\ \text{(b) deform. of feed leg apex} & = & 4.80\ \text{mm} \\ \text{(c) transl. of parab. vertex} & = & 2.03\ \text{mm} \end{array}\right\} \begin{array}{l} a + b - c \\ = 17.7\ \text{mm} \end{array} \tag{2}$$

The surface panels deform under dead loads at their center by

$$\Delta z_m = \frac{1}{8}\frac{\rho}{E}\frac{\ell^4}{h^2} = 0.12 \text{ mm}, \tag{3}$$

where ρ = density, E = modulus of elasticity, ℓ = length = 272 inch, and h = depth = 38 inch. The average sag then is

$$\overline{\Delta z} = (2/3)\ \Delta z_m = 0.08 \text{ mm}. \tag{4}$$

For the total gravitational change, as seen by the observer, we must subtract (4) from (2), and obtain the constant B of equation (1) as

$$B = 17.6 \text{ mm}. \tag{5}$$

2. Thermal Deformations

For the computer analysis, a simple thermal gradient in z-direction (telescope axis) was used, such that the apex of the feed legs was 10°F warmer than the downmost point of the backup structure, which is 108.2 ft below the apex. This setup yielded a change of focal length of $\Delta F = + 3.02$ mm. A realistic interpretation would be to ask for the temperature difference where it actually matters: between the more central part of the surface, and 1/2 the height of backup cone and wheel; this is a distance of 26.5 ft, or a temperature difference of $\Delta T = 10$ °F (26.5/108.2) = 2.45 °F. The result of the analysis then reads:

$$\Delta F = 1.23 \text{ mm/°F} \quad \text{(up, if surface is warmer)}. \tag{6}$$

For the panels, one has at their center

$$\Delta z_m = \frac{1}{4} C_{th} \, \Delta T \, \frac{\ell^2}{h} = 0.124 \text{ mm/°F}, \tag{7}$$

and again 2/3 of that for the average:

$$\Delta z = 0.08 \text{ mm/°F} \quad \text{(down, if surface is warmer)}. \tag{8}$$

For the total thermal change, as seen by the observer, we must subtract (8) from (6) and obtain

$$\Delta F(\Delta T) = 1.15 \text{ mm/°F}. \tag{9}$$

Measurements of temperature differences have been done previously at the 140-ft (Findlay and von Hoerner, 1972), resulting in extreme values at the 95% level:

$$\Delta T = \begin{cases} 2.2 \text{ °F} & \text{at night,} \\ 12.5 \text{ °F} & \text{full sunshine.} \end{cases} \tag{10}$$

Combining (9) and (10), we finally obtain

$$\Delta F \le \left. \begin{matrix} 2.53 \text{ mm} & \text{at night} \\ 14.4 \text{ mm} & \text{full sunshine} \end{matrix} \right\} \text{ for 95\% of all days.} \tag{11}$$

II. Observational Data

Pointing and focusing of the 140-ft was investigated by Ken Kellermann on the following dates:

Period	λ	Temperature Data ?	Number of Readings	
			Night	Day
October 4-5, 1974	6 cm	yes	15	5
January 10-15, 1975	3 cm	no	21	11
March 21-24, 1975	3 cm	yes	34	30
Total			70	46

Temperature data regard only the ambient air temperature, not the structural temperature differences wanted; but the latter may be assumed correlated with the former during clear days (and will be small during nights).

The zero point of the focus adjustment is of course arbitrary, and it was different for each of the three observational periods. We have corrected all periods to the same zero (at night).

The night observations (from 19:00 to 7:00 EST) are shown in Figure 1, together with a straight line of slope B = 17.6 as predicted from the structural computer analysis, equations (1) and (5). We see very good agreement; the data points would give a slope of B = (18.5 ± 1.7) mm. Calling ΔF the deviation of the data points from the straight line of Figure 1, we find the scatter as

$$\mathrm{rms}(\Delta F) \;=\; 1.3 \text{ mm during nights.} \tag{12}$$

The scatter will partly be due to the errors of measurement, and partly to temperature differences in the structure. Neglecting the errors, the full scatter would be explained according to (9) by temperature differences of

$$\mathrm{rms}(\Delta T) = 1.13\ {}^{\circ}\mathrm{F}. \tag{13}$$

For the future, automatic elevation-dependent focus corrections could be used, with equations (1) and (5), leaving residuals of 1.3 mm rms at night, if thermal effects are not corrected for.

The day observations (7:00 - 19:00 EST) are shown in Figure 2. The straight line there has been taken from the night observations, Figure 1. The scatter is now much larger,

$$\mathrm{rms}(\Delta F) = 3.7\ \mathrm{mm} \quad \text{during days,} \tag{14}$$

to be explained by temperature differences of

$$\mathrm{rms}(\Delta T) = 3.2\ {}^{\circ}\mathrm{F}. \tag{15}$$

Furthermore, this scatter goes almost all upward, to larger focal lengths, as is to be expected if the surface is heated by solar radiation while the backup structure is more in the shadow.

Finally, Figure 3 shows the deviations ΔF, of the observed focal length from the straight gravitational lines, as a function of air temperature, for night and day. The results again agree with expectations: (a) no temperature correlation at night; (b) strong correlation during clear sunny days; and

(c) the limiting range of the scatter agrees well with the structural temperature differences of equation (10) as measured in previous experiments.

For the future it is planned to install several thermistors in the structure, automatically reading the thermal structural z-gradient, to be used for automatic focus corrections. This should work well at least for the large deviations during clear days.

III. The Accuracy Demanded

The gain loss L from axial defocusing (Baars, 1966) is for parabolic illumination, approximately,

$$L = \frac{G_0 - G}{G_0} = \frac{1}{18} \left(\frac{\pi \ \Delta F}{\lambda} \right)^2 = 0.548 \ (\Delta F/\lambda)^2. \qquad (16)$$

If we tolerate losses of

$$L \leq 2\%, \qquad (17)$$

we obtain the shortest wavelength λ as given below, if the axial defocusing is not corrected for:

Case	ΔF	λ
Gravity (zenith - horizon)	17.6 mm	9.2 cm
Thermal, Sun (12.5 °F)	14.4 mm	7.5 cm
Thermal, Night (2.2 °F)	2.5 mm	1.3 cm

For observations at shorter wavelength, the automatic focal correction should be used. The gravitational correction could be used right now, equations (1) and (5). For the thermal corrections, we first must have some thermistors installed, and their correlation with ΔF must be calibrated observationally.

The accuracy to be achieved by these corrections must be found observationally. I would expect that it will be good enough, for all cases, down to about $\lambda = 1.5$ cm.

References

Baars, J., 1966, NRAO Electronics Division Internal Report No. 57.

Findlay, J. W., and von Hoerner, S., 1972, "A 65-m Telescope for Millimeter Wavelength".

Hoerner, S. von, and Wong, W. Y., 1975, IEEE Trans. Antennas and Propagation.

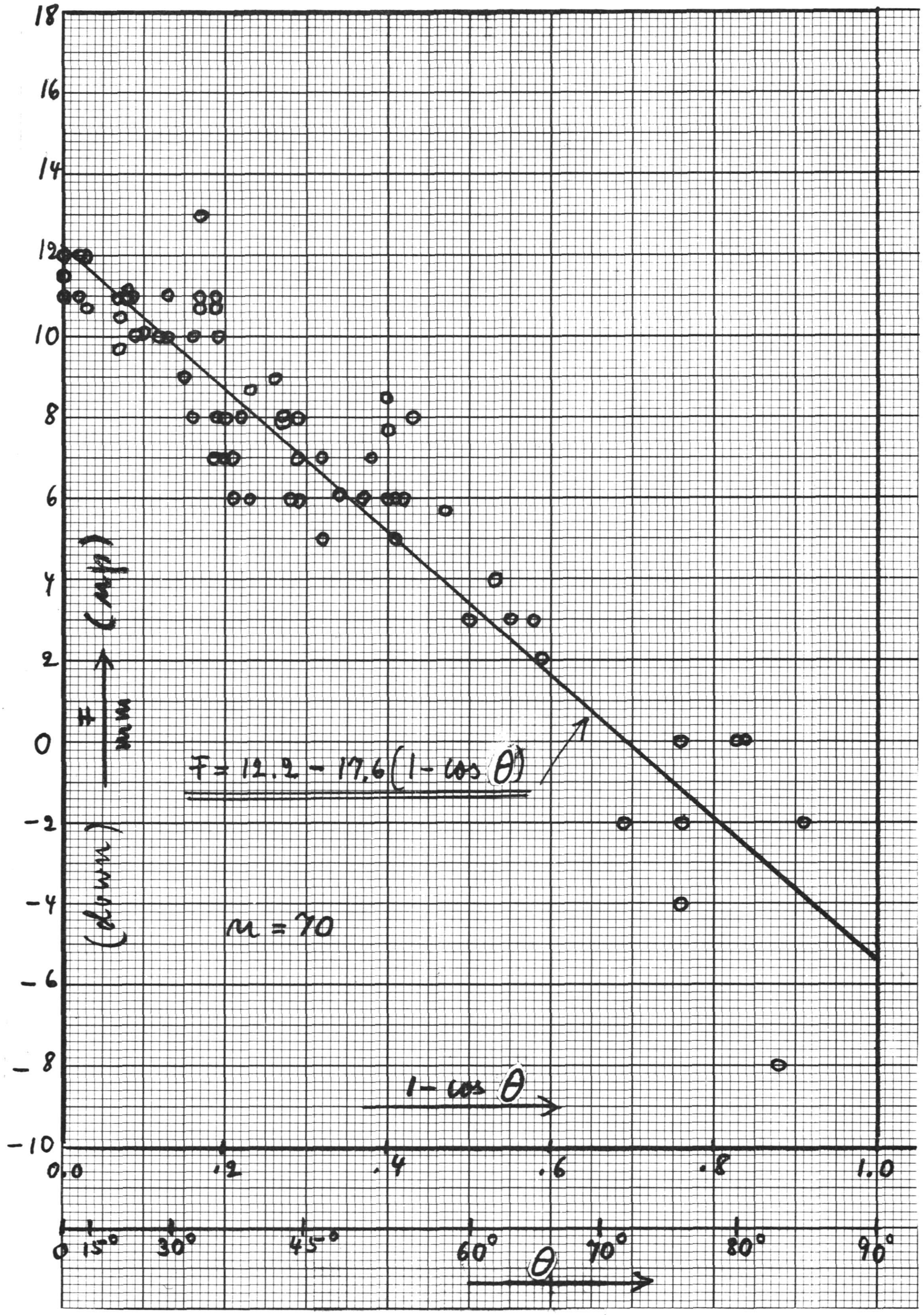

Fig. 1. Focal adjustment F (arbitrary zero) at night, as a function of zenith angle θ.

o observations (K. Kellermann),

—— gravitational computer analysis (W.Y. Wong).

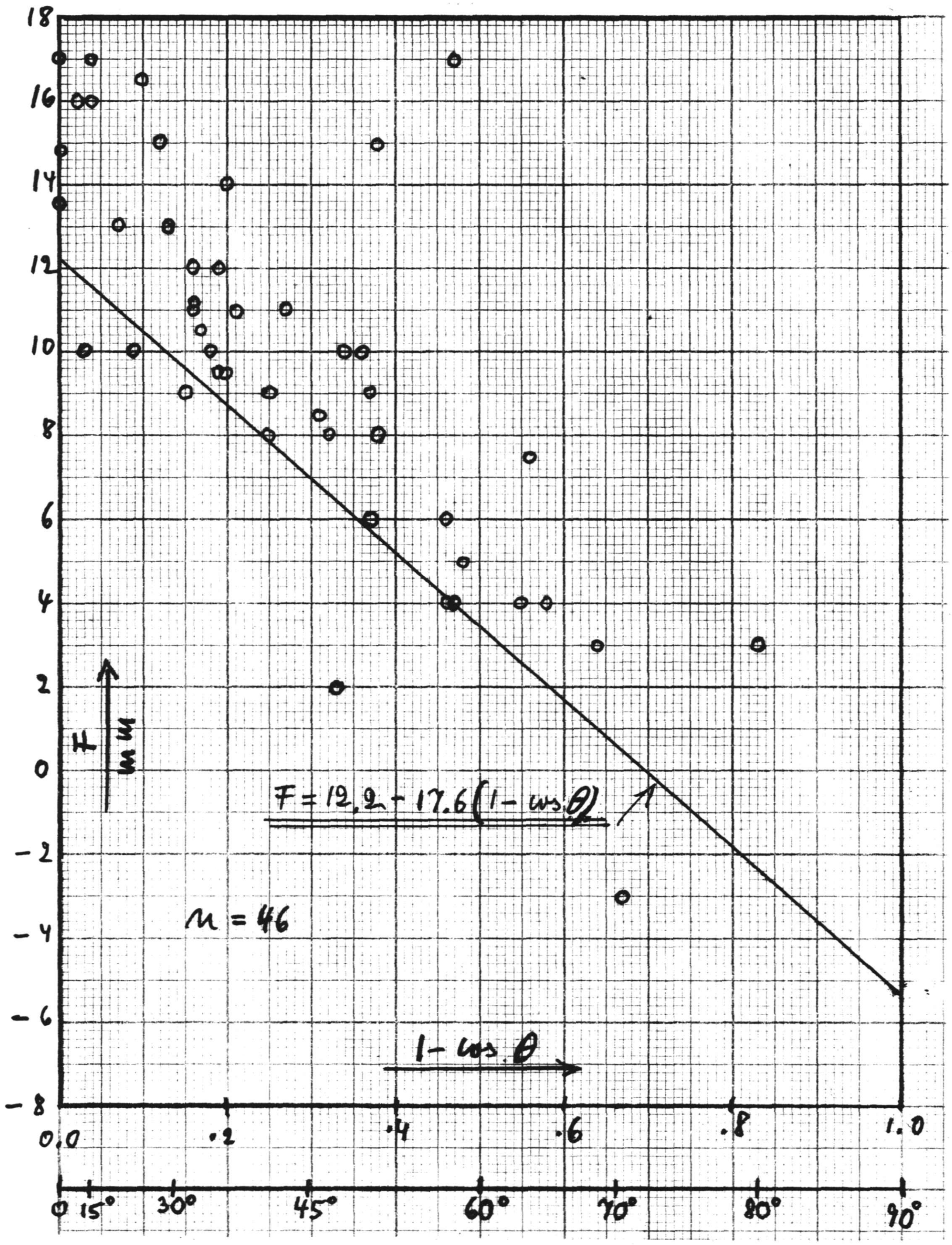

Fig. 2. Focal adjustment during daytime.

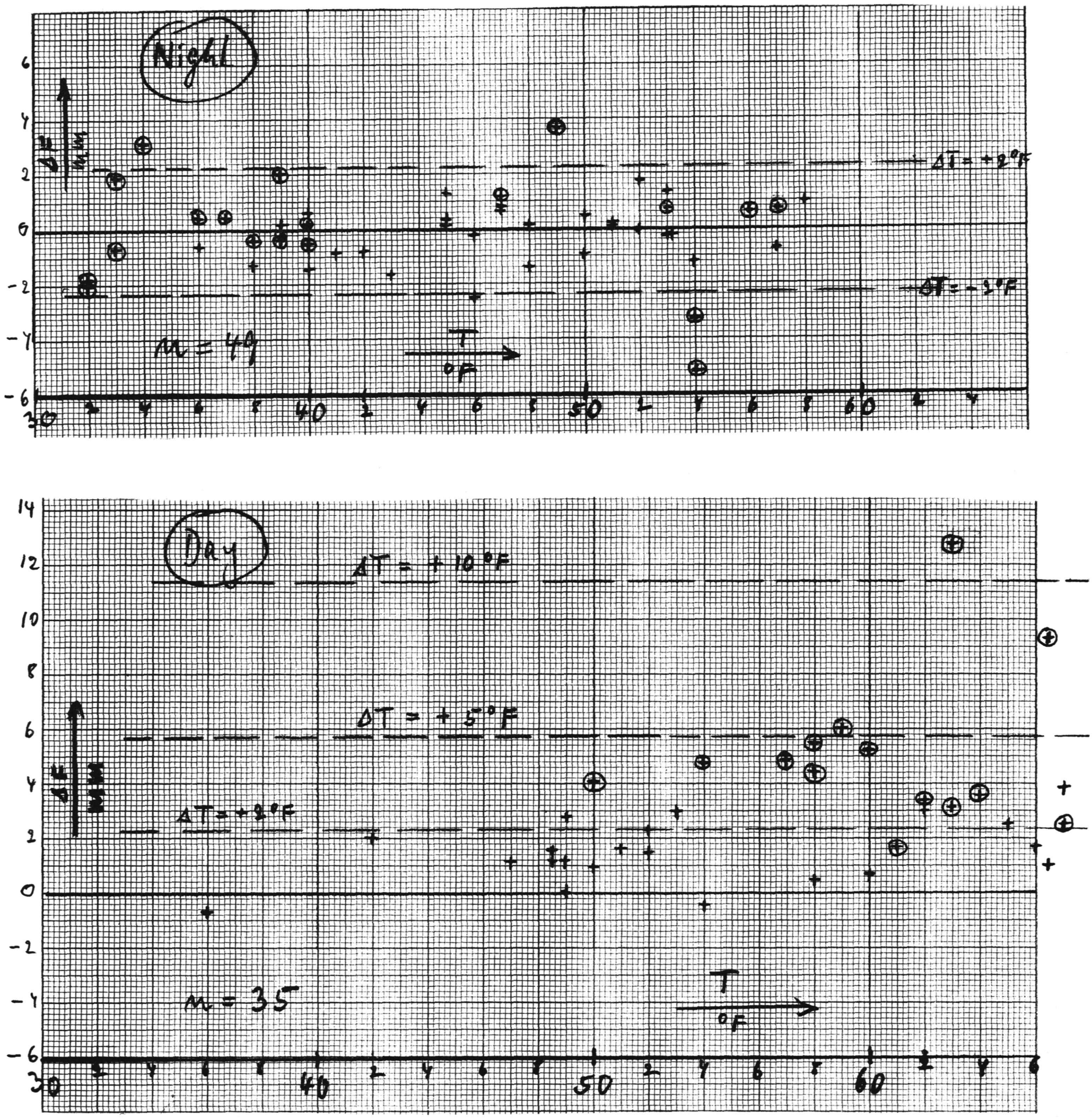

Fig. 3. Deviations ΔF, of observations from straight gravitational lines in figures 1 and 2, as a function of ambient air temperature T.

Encircled points: clear sky.