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THERMAL AND WIND DEFORMATIONS OF THE SURFACE PLATES

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Introduction

The design of the surface plates seems to be finished (Fig. 1). One plate made at Green Bank workshop fulfilled all specifications, like surface accuracy, deformations after walking on plate, and gravitational deformations; but it is planned to make two more plates and check them, too. Design and results will be given in a future Report.

The present Report deals only with thermal and wind effects, with special emphasis on the measurements of temperature differences during clear days and nights. The main goal is to find the surface accuracy of the plates, as a function of the hour, under extreme thermal conditions.

I. Temperature Measurements

1. The Set-Up

Measurements were taken at Green Bank from Oct. 12 through Nov. 9, 1970, including several days with extremely clear sky. We used Nickel Foil temperature sensors, a strain indicator as a bridge, and a calibrator. We call, in °F,

s = temperature of plate skin, measured from below, (1)

r = temp. of long lower rib, close to its center (Fig. 1), (2)

b = temp. of a blank unpainted aluminum sheet, (3)

a = temp. of air (shadow and blower). (4)

The first 10 days we measured only s and r, later also b and a. All four sensors were calibrated as mounted, and the mean error of temperature differences between any two was found as $\pm$ 0.15 °F. Skin and all ribs of the plate are covered on all sides with the same white protective paint as all our telescopes.*)

*) High Reflectance Flat White No. 6
Triangle Paint Co., Berkeley, California

The plate was mounted 5 ft. above ground, 10 ft. west of a building and 40 ft. north of another wing, for wind protection. The plate was almost level, the northern side lifted by 6° for draining. At noon, the sun was 45° south of the plate normal. The plate surface was extended east and west by shields, giving shadow to all ribs at all times.

During the first days of October, the plate was measured inside a workshop building.

2. Indoors (Adjustment)

During clear nights, when it matters most for short wavelengths, the skin is colder than the rib (sky colder than ground). But the plate shape will have been adjusted inside a factory with $s - r > 0$ (temperature gradient in closed room). Adjusting the plate to the telescope parabola thus would lead to considerable thermal deformations during clear nights.

But since the plates can be adjusted to any shape wanted, they should be adjusted with a "thermal offset" such that the telescope parabola is best fitted during clear nights. In order to adjust all plates with the same offset, the room should always have the same gradient (or none, using fans).

In order to see how much it matters if no precaution is taken, the plate was measured indoors in a normally heated room (without own thermostat) during seven days. The temperature changed from 67 °F in the morning to 78 °F in the evening, with a sharp increase between 13:00 and 14:00, caused by sunshine through windows (into room, but not on plate). This was correlated with a sharp rise in $\Delta T = s - r$:

Hour	$\overline{T}$	$\overline{\Delta T}$	$\Delta T_a = \mathrm{rms}(\Delta T - \overline{\Delta T})$
8:00 - 13:00	68	.97	.66
14:00 - 18:00	77	2.75	.67
together	73	1.76	1.10

(5)

What matters is the last column, the thermal adjustment error ΔT_a, which would be 1.10 °F if no precaution were taken.

We suggest that the manufacturer uses a room for adjusting the plates which has its own thermostat and has shades against sunshine. For this case we assume an rms error of

$$\Delta T_a = 0.5\ °F. \tag{6}$$

3. Influence of White Paint

Fig. 2 shows the comparison of painted and unpainted aluminum surface, by plotting s - a against b - a. First, we see that the painted skin is always colder than the blank sheet. The paint is white in the visible for decreasing the heat absorption from sunshine, and is black in the far infrared for increasing its radiative cooling. And the latter gives an effective radiative connection to the cold sky, which is so strong that $(s - a)_{max} \approx - (s - a)_{min}$, the effect of the cold night sky being about as strong as the effect of clear sunshine.

Second, we have from Fig. 2

$$s - a = 0.19\ (b - a) \text{ for full sunshine} \tag{7}$$

and

$$s - a = 1.40\ (b - a) \text{ for clear nights.} \tag{8}$$

This means that the white paint improves the thermal deformations by a factor 5.3 during sunshine, but makes them worse by 40% during clear nights.

Fig. 3 shows the structural temperature difference, skin - rib, as a function of the external difference skin - air. The first is smaller than the latter,

$$s - r = 0.67\ (s - a), \tag{9}$$

because of radiative (and some conductive) exchange between skin and rib. This is another advantage of the white paint.

4. The 24 Hour Period

Fig. 4 shows the air temperature and its change as a function of the hour, for clear days only (less than 40% cloud cover). The temperature is normalized to zero at 14:00 for each day. For the largest difference day-night we obtained

$$\Delta T_{24} = T_{max} - T_{min} = \begin{cases} 22\ ^\circ\text{F minimum} \\ 27\ ^\circ\text{F average} \\ 40\ ^\circ\text{F maximum} \end{cases} \quad (10)$$

We had three days with extremely clear and dry air. For comparison, the annual average is ΔT_{24} = 28 °F at Tucson, Arizona.

The change of air temperature, dT/dt, is given in Fig. 4b. For comparison, the largest change on 3 random days in July at Tucson was only 4 °F/hour, half as large as on Fig. 4b. Although measured at Green Bank, we may use the data of Fig. 4 as representing extreme thermal conditions in a desert site for the telescope.

Finally, Fig. 6 shows the data to be used for calculating the thermal deformations under extreme thermal conditions (clear, dry, calm). For Fig. 6a, we used the upper and lower envelope of Fig. 5a. The resulting curve then was made symmetrical about 12:50, the local solar noon, omitting the shadow of the building; the width of this peak was broadened since the telescope may always point into the Sun while the plate was fixed; and the amplitude was multiplied by $\sqrt{2}$ since the plate normal was 45° off the Sun at noon.

If the telescope would look always at zenith during nights, the plates should be adjusted with a thermal offset of about -3 °F according to the average s - r of Fig. 5a during nights, and the scatter of s - r + 3° would be only $\pm$ 1 °F. Actually, the telescope moves, and looking at horizon must give s - r = 0 from symmetry. Since s - r in Fig. 5a goes down to -4 °F, we should adjust with an offset of

$$\text{adjust } (s - r) = -2\ ^\circ\text{F} \quad (11)$$

and the scatter then is $\pm$ 2 °F which is entered into Fig. 6a between 23:00 and 8:00.

Fig. 6b was obtained in a similar way, using the envelopes of Fig. 4b. It shows two large maxima, one at 18:30 and the other at 11:30; both times will depend on the times of sunset and sunrise.

5. Temperature Equalization from Wind

At the long side of the plate and level with it, 3 large fans were mounted which could be turned high, low, and off. Averaged over the plate surface, the air velocity was $v = 5.3$ mph for low, and $v = 8.6$ mph for high. Measurements were taken both in full sunshine and during clear nights.

We call $\Delta T = s - r$ the internal structural temperature difference, with ΔT_o for $v = 0$, and we assume a constant radiative heat exchange with the surrounding, plus a convective exchange which is linear with v. This leads to

$$\Delta T = \frac{\Delta T_o}{1 + (v/v_o)} \qquad (12)$$

with one parameter, v_o, to be found by the measurements. The result of 13 measurements is

	$\Delta T/\Delta T_o$	v mph	v_o mph
low	.408 ± .019	5.3	3.65 ± .29
high	.312 ± 0.18	8.6	3.90 ± .34

(13)

The agreement of both values v_o shows that (12) is a satisfactory assumption. The average,

$$v_o = 3.8 \text{ mph} \qquad (14)$$

is the speed at which convection equals radiation.

II. Thermal Deformations

1. Measurements

The plate was adjusted to its parabolic shape indoors. Then it was mounted outdoors as described, and was measured on an extremely clear day. The shape was measured at 11:00 (full shadow of building) and at 14:00 (full sunshine) at the 37 points of Fig. 8. The difference skin-rib was -6.95°F (some frost on skin) at 11:00, and +2.10°F at 14:00, which is $\Delta T = 9.05$ °F in between. The difference of the two shapes, Δz, is shown in Fig. 8. From these data we obtain

$$\Delta z_{center} = 2.58 \times 10^{-3} \text{ inch/°F} \quad (15)$$

$$\overline{\Delta z} = 1.76 \quad " \quad " \quad (16)$$

$$rms(\Delta z) = 1.87 \quad " \quad " \quad (17)$$

$$rms(\Delta z - \overline{\Delta z}) = .67 \quad " \quad " \quad (18)$$

2. Application

If all plates on the telescope would have the same ΔT, which were true if the surface were flat instead of curved, we should use (18) applied to ΔT of Fig. 6a. Actually, the worst case is when half of the surface is shadowed by its rim; the sun then shines into the other half with an average angle of 40° between surface and sun. In this case we use (~~12~~17) divided by $\sqrt{2}$, and apply it to $\Delta T \sin 40°$. With $\sin 40° \times 1.87/\sqrt{2} = 0.85 \approx 0.9$, we have for the whole telescope the rms thermal plate deviation

$$\Delta z = 0.9 \times 10^{-3} \text{ inch/°F} \quad (19)$$

if applied to ΔT of Fig. 6a. This finally gives

$$\Delta z = \begin{cases} 8.3 \times 10^{-3} \text{ inch} = 0.21 \text{ mm, noon sun,} \\ 1.8 \times 10^{-3} \text{ inch} = 0.05 \text{ mm, at night.} \end{cases} \quad (20)$$

III. Wind Deformations

1. Measurements

The plate was supported at its four corners, and many bolts of 24 lb. total were equally distributed over the surface; with 14.75 ft^2 plate area, this is $p_o = 1.63$ lb/ft^2. The resulting deformation was measured at 36 points, yielding $rms(\Delta z) = 3.56 \times 10^{-3}$ inch and $rms(\Delta z - \overline{\Delta z}) = 1.73 \times 10^{-3}$ inch.

Again, we should use the latter value if the telescope were flat and the wind steady. For the actual case of a curved surface and gusty wind, an estimate gave 2.50×10^{-3} inch, for $p_o = 1.63$ lb/ft^2. For the wind pressure p we use (with a shape factor of $C_s = 1.4$ for flat plates)

$$p = .00256\ C_s\ v^2 = .00358\ v^2 \quad \left|\ \begin{array}{l} p \text{ in lb/ft}^2 \\ v \text{ in mph} \end{array}\right. \tag{21}$$

and obtain

$$\Delta z = .0055 \times 10^{-3} \text{ inch } v^2, \tag{22}$$

or

$$\Delta z = 1.78 \times 10^{-3} \text{ inch} = .045 \text{ mm, for } v = 18 \text{ mph.} \tag{23}$$

2. <u>Combined Wind and Thermal Deformations</u>

Finally, we have for thermal deformations from (20), (12) and (14), in the presence of wind

$$\Delta z = \begin{cases} \dfrac{8.3 \times 10^{-3} \text{ inch}}{1 + v/3.8 \text{ mph}} & \text{in full sunshine,} \\[2ex] \dfrac{1.8 \times 10^{-3} \text{ inch}}{1 + v/3.8 \text{ mph}} & \text{at night,} \end{cases} \tag{24}$$

while the wind deformation is given in (22). For the total deformation, we add (22) and (24) quadratically, and the result is shown in Fig. 9.

We see that we have either large thermal deformations or large wind deformations, but not both simultaneously. The combined deformation equals the thermal deformation (at $v = 0$) for $v = 18$ mph at night, and for $v = 39$ mph in full sunshine. The combined deformation is smallest for $v = 8$ mph at night, and for $v = 14$ mph in full sunshine.

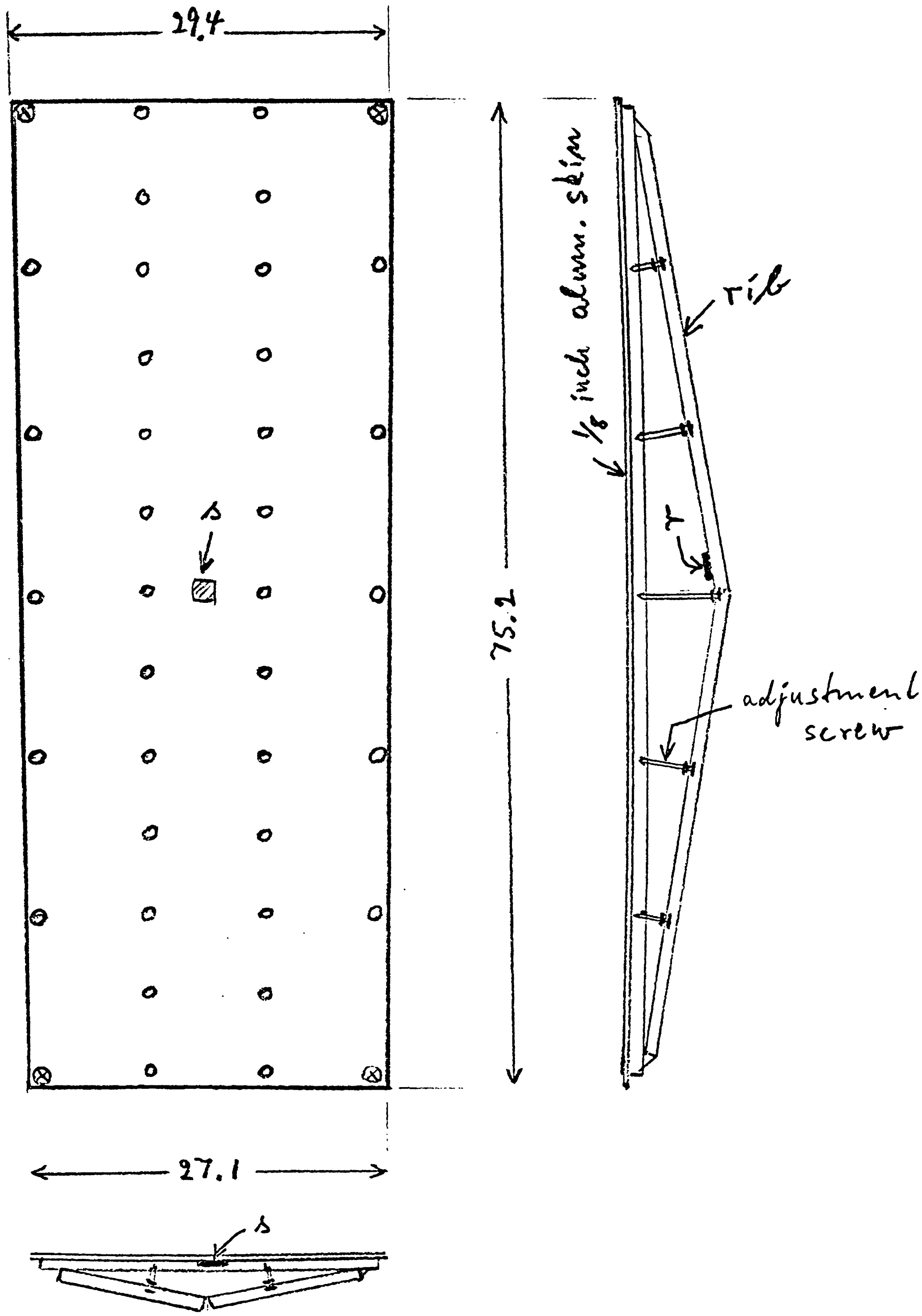
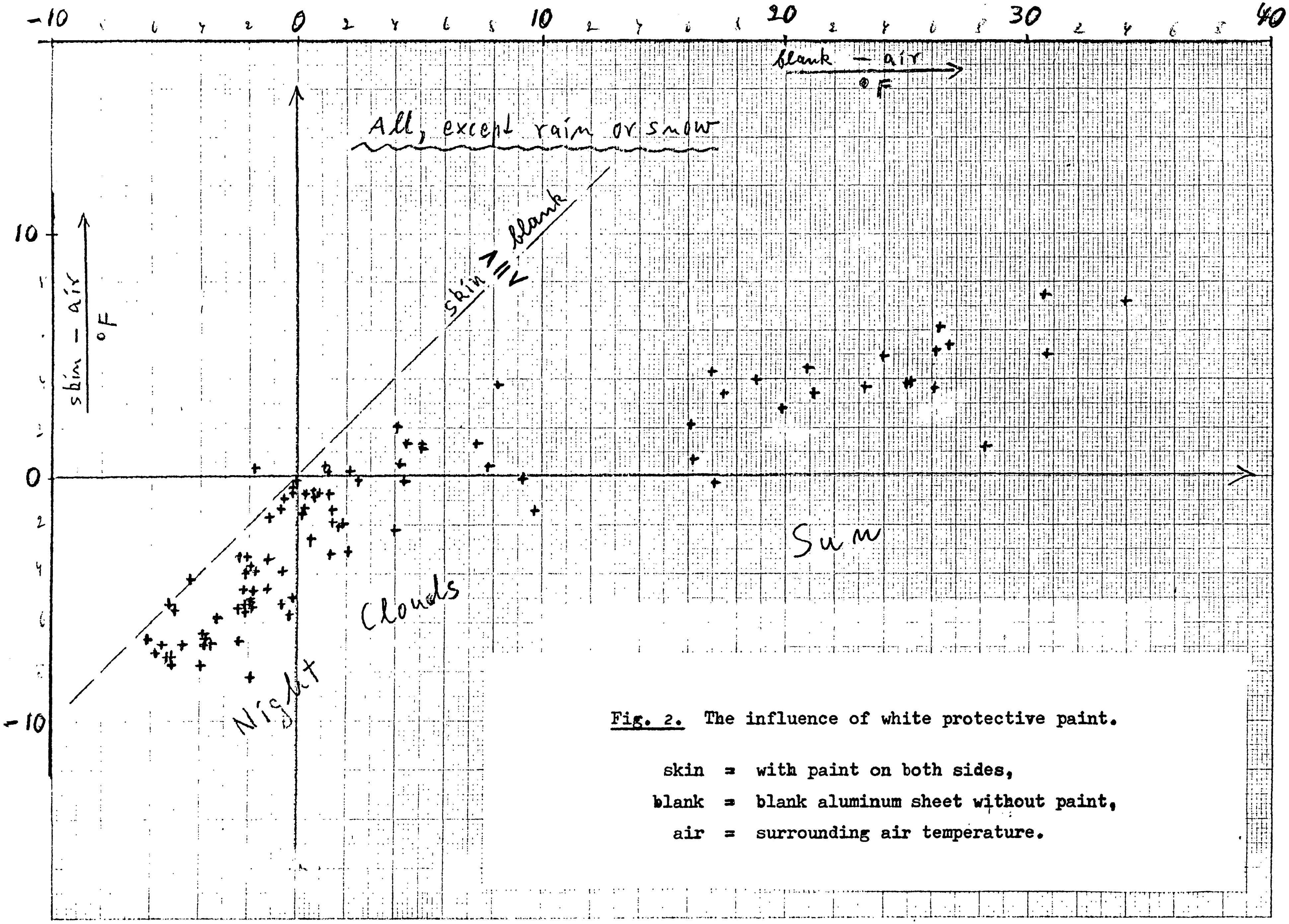


Fig. 1. Surface plate, sizes in inch.

⊗ 4 corner points, for external adjustment (on telescope);

o 36 internal adjustment points (in factory);

s, r temperature sensors for skin and rib.



<u>Fig. 2.</u> The influence of white protective paint.

skin = with paint on both sides,
blank = blank aluminum sheet without paint,
air = surrounding air temperature.

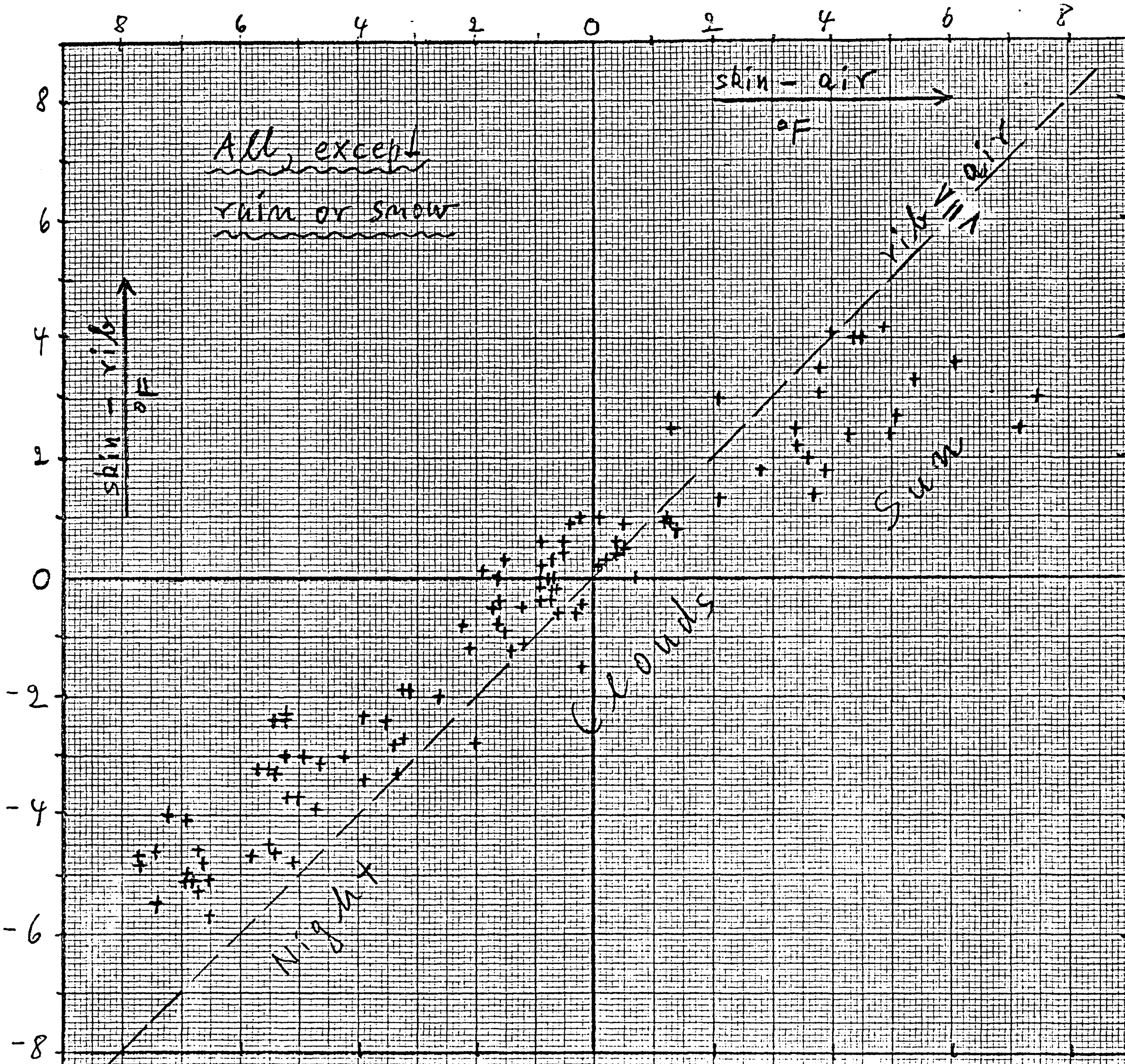


Fig. 3. Temperature differences between skin, rib and air.

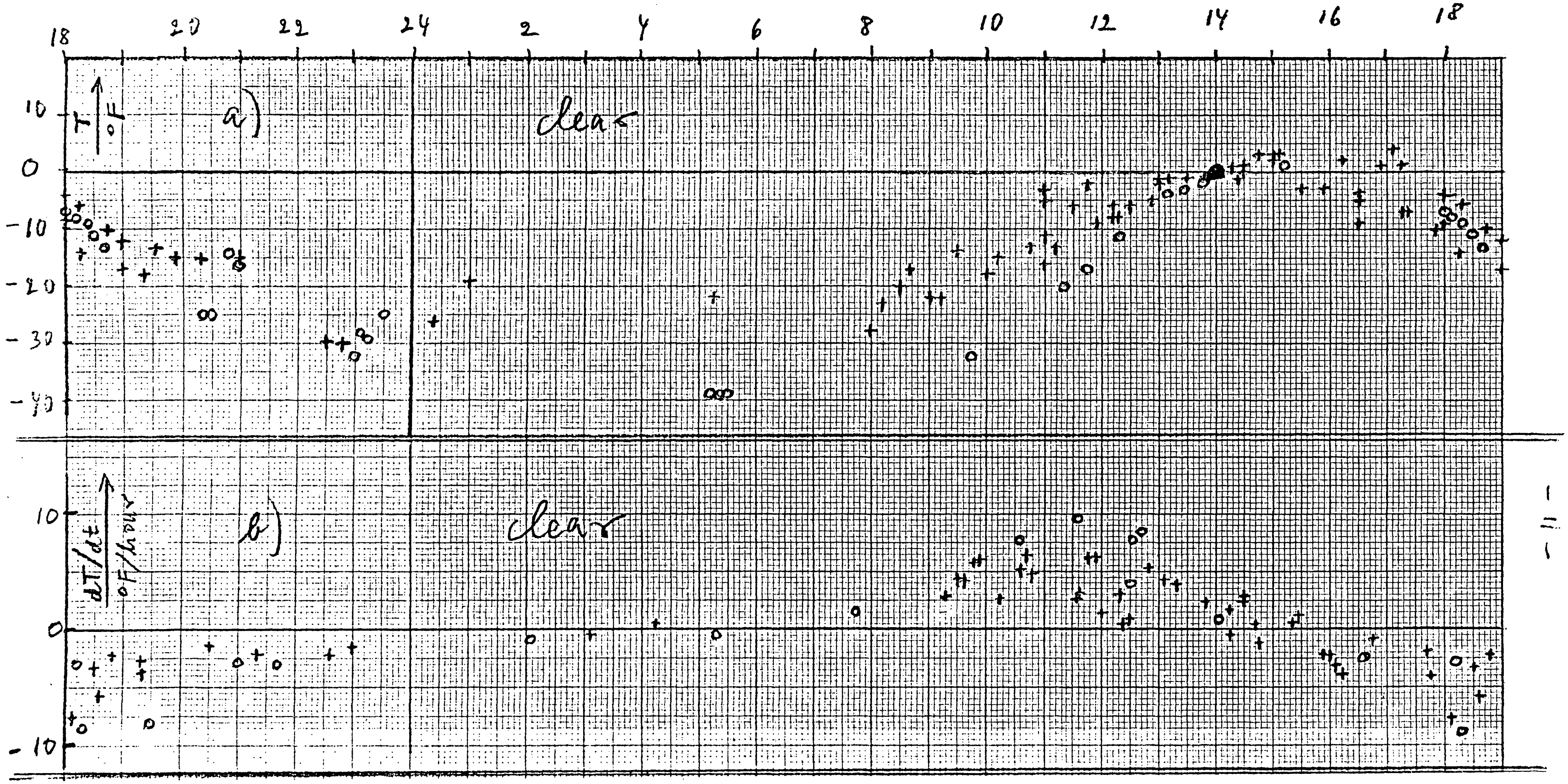
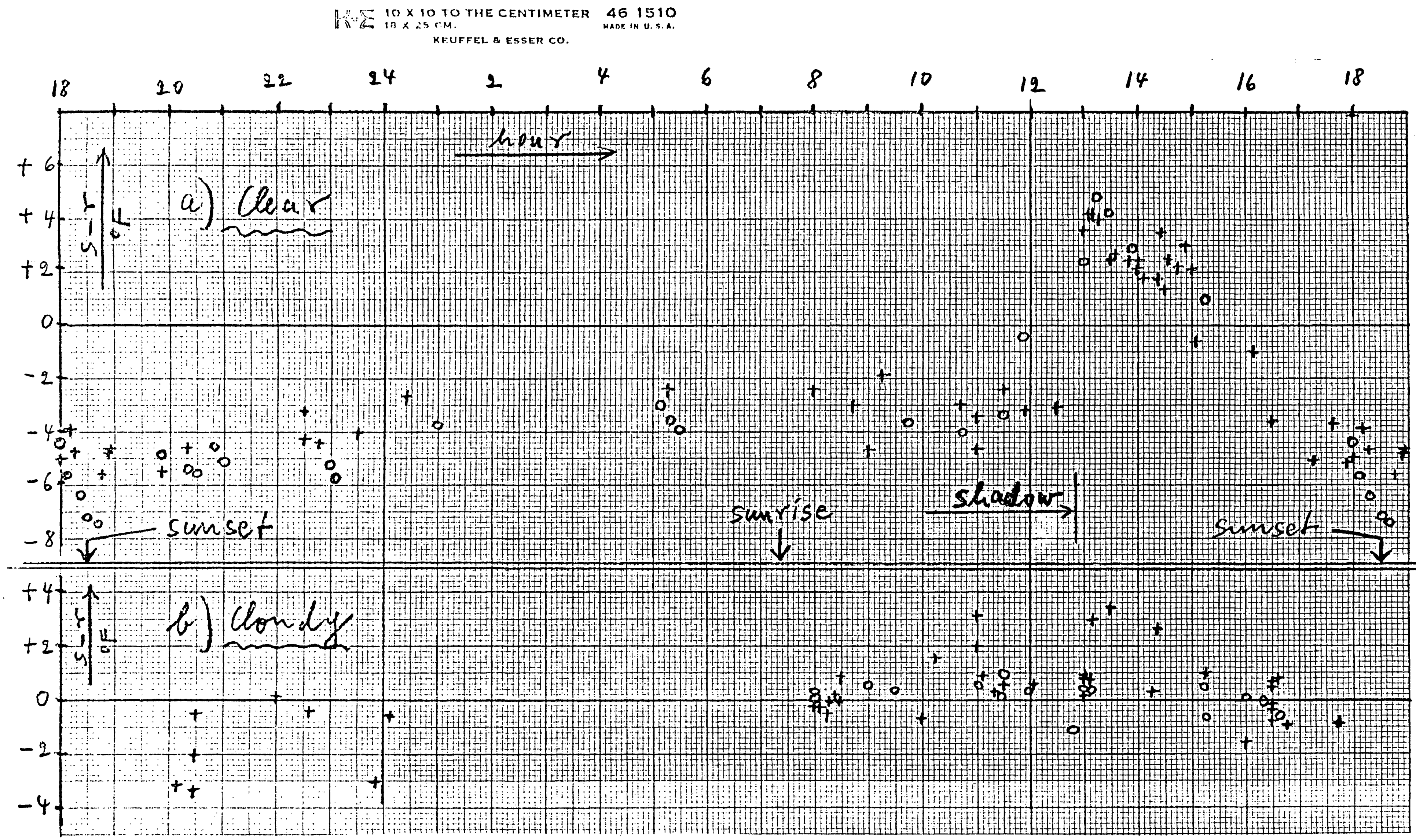


Fig. 4. a) Air temperature T, normalized to zero at 14:00, and b) its change dT/dt; both as a function of the hour.

+ 60 - 95 % } cloud-free sky.
o ≥ 95 %



<u>Fig. 5.</u> Structural temperature difference, skin - rib, as a function of the hour. The plate is shadowed by a building until 12:50.

a) clear { + 60 - 95% / o ≥ 95% } cloud-free sky; b) cloudy { + 0 - 20% cloud-free, / o rain, fog, snow.

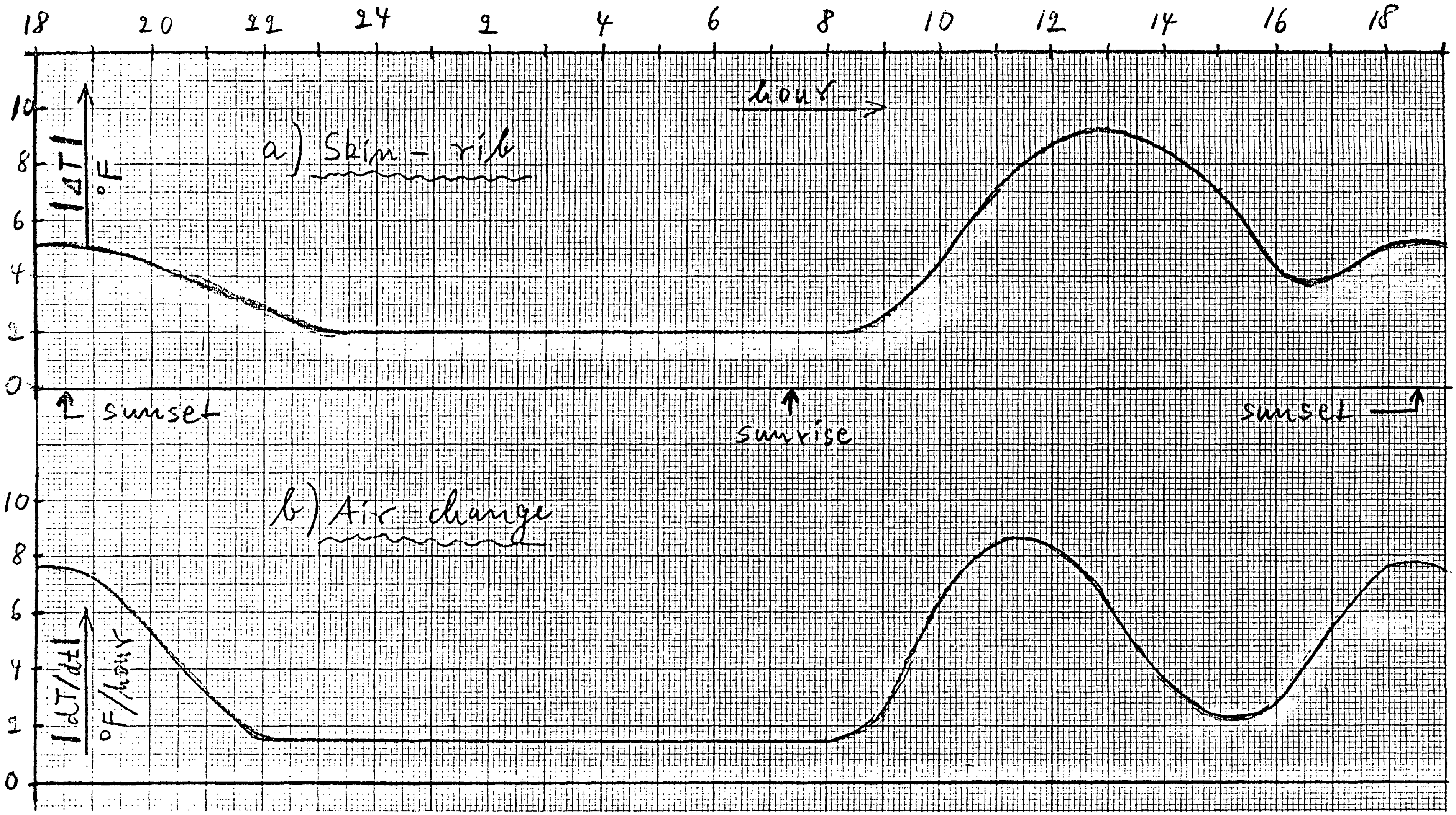


Fig. 6. Absolute values of a) ΔT = skin - rib + 2 °F,
b) dT/dt = time derivative of air temperature,

as a function of the hour. From envelopes of Fig. 5a and Fig. 4b, resp.

Maximum values for clear, calm days, to be used for performance calculations.

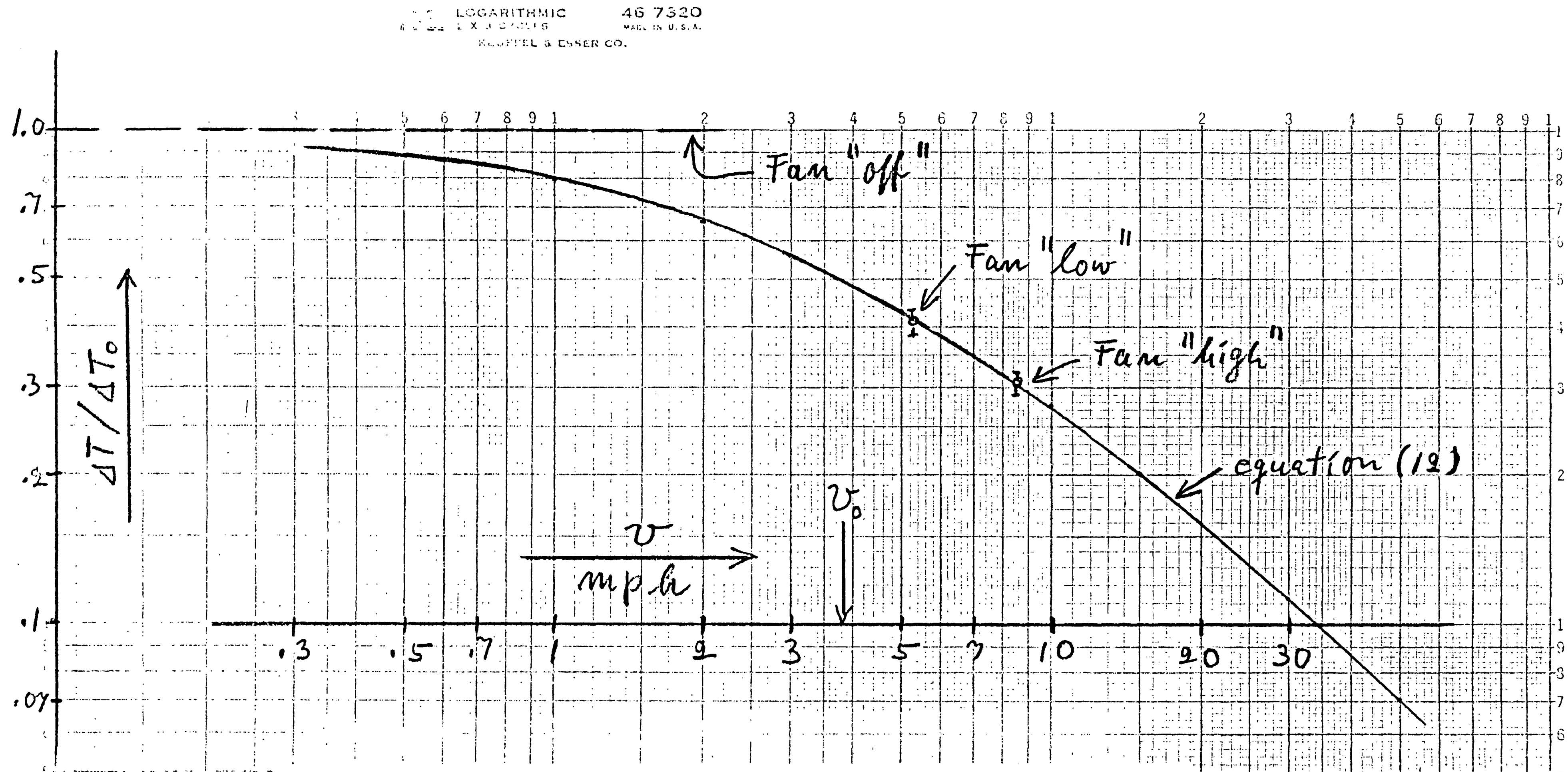


Fig. 7. Temperature equalization from wind.

ΔT = temperature difference skin - rib,

$\Delta T_o = \Delta T$ for $v = 0$,

v = wind velocity.

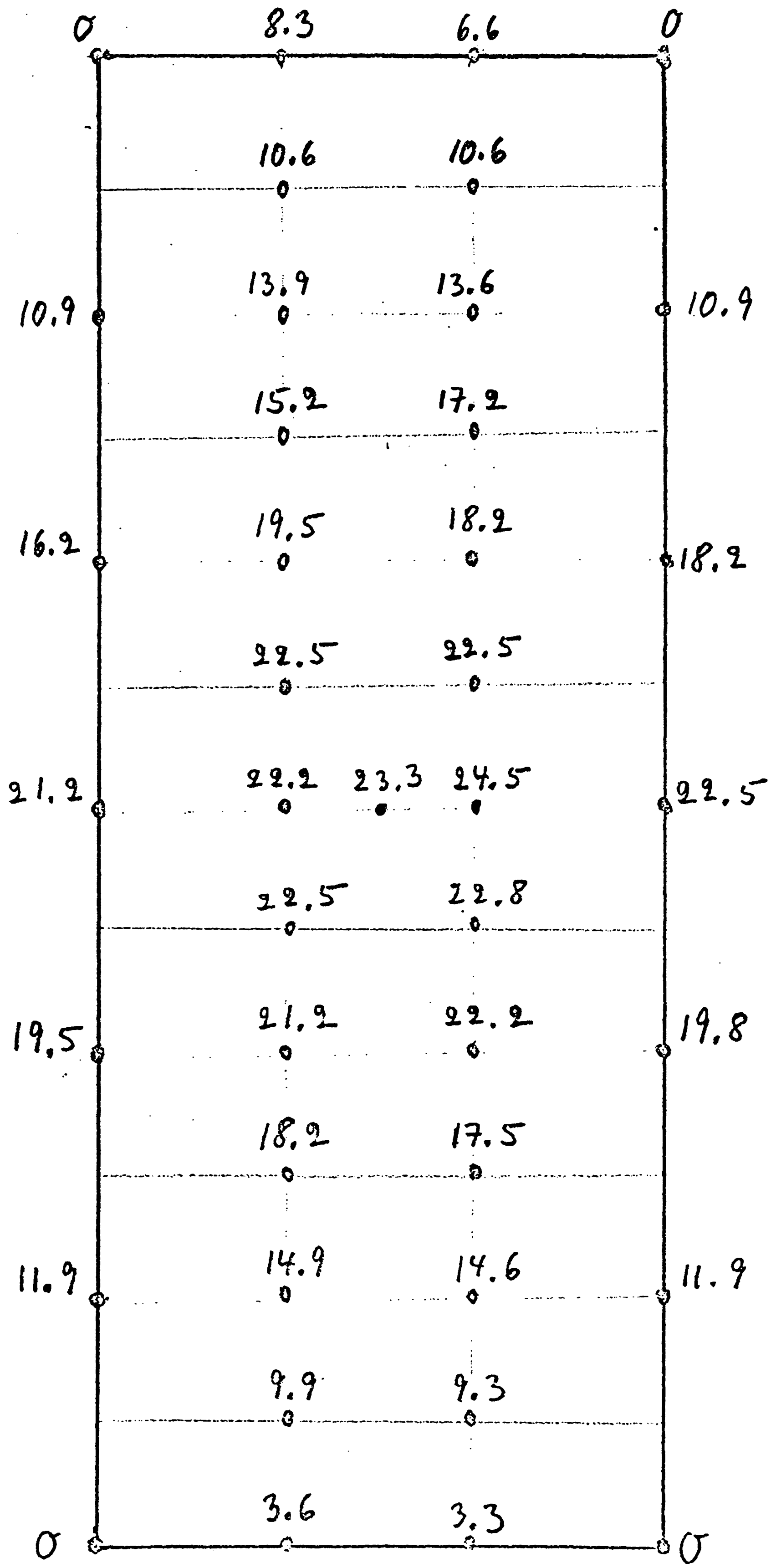


Fig. 8. Thermal deformation Δz of 37 points of the plate, in 10^{-3} inch, resulting from ΔT = 9.05 °F difference between skin and rib.

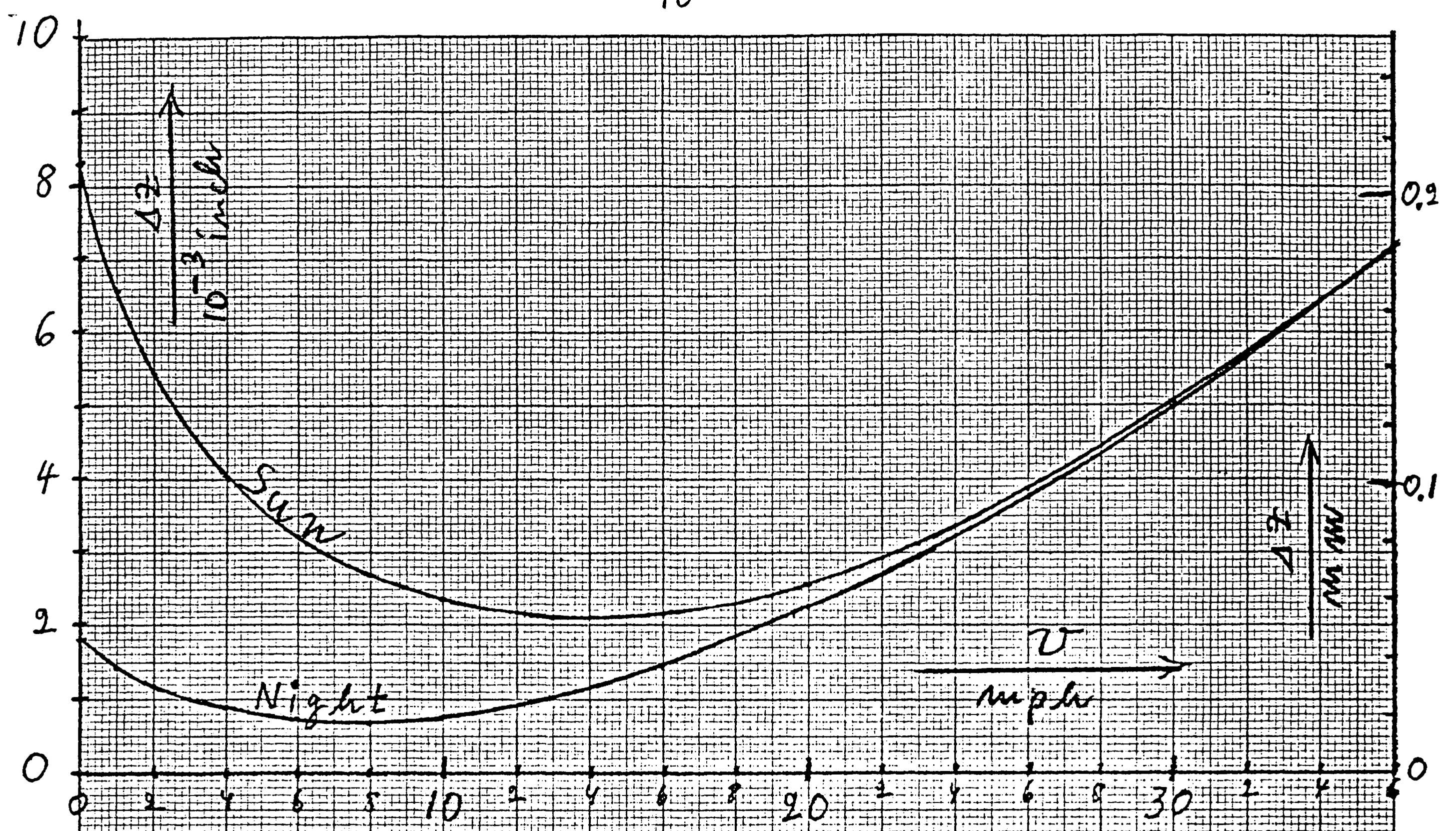


Fig. 9. Combined deformation of surface plates, from thermal effects and wind.

Extreme thermal conditions, rms over whole telescope surface.