REPORT 16

NATIONAL RADIO ASTRONOMY OBSERVATORY
POST OFFICE BOX 2
GREEN BANK, WEST VIRGINIA 24944
TELEPHONE ARBOVALE 456-2011

REPORT NO. 16
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PAGE 1 OF
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PROJECT: LFST

SUBJECT: Statistics of Wind Velocities at Green Bank

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Summary

The price of a large telescope, using homologous deformations and standing in the open, is entirely defined by wind forces: either by wind deformations (observing a specified shortest wavelength λ in winds up to a specified velocity V_{ob}), or by survival winds (withstanding a specified maximum velocity V_{sv}). Velocity measurements at Green Bank have been made during two years, recording the highest velocity of each hour, at the 300-foot and the old 85-foot telescope. The velocity distribution shows that the wind is 1/4 of all time below 4.9 mph, 1/2 of all time below 9.9 mph, and 3/4 of all time below 16.6 mph.

If V_{ob} is defined such that 25% of all time are lost for wavelength λ due to high winds, we obtain for an average location at Green Bank V_{ob} = 17 mph. If this specification is used instead of the usual 25 mph, then the price (if defined by wind deformation) is reduced by a factor of 2.0.

If V_{sv} is defined such that the chance of loosing the telescope within 30 years is 0.1%, then two different estimates yield 88 and 98 mph, and V_{sv} = 100 mph is adopted. For comparison: the 300-foot withstands 90 mph, whereby the chance for a loss is still only 1%; but the 140-foot withstands 160 mph and certainly is much too strong.

Winds are lower during summer. If V_{ob} is defined for six summer months only, then the price (if defined by deformations) is reduced by a factor of 1.6; this would imply either that the shortest wavelength during winter is twice that of the summer, or that the time lost during winter is 45% for the same wavelength where it is 25% during summer.

The 300-foot is somewhat shielded by a nearby mountain ridge, more than the 85-foot. At the 300-foot location, the price is reduced by a factor of 2.0 if defined by wind deformations, and by a factor of 1.3 if defined by survival winds. Still better locations can be found at the Greenbrier valley close by, and a further reduction in price is to be expected there.

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1. Introduction

In general, the price of a telescope is defined by either one of four items: maximum survival loads, wind deformations during observation, gravitational deformations, and the minimum stable structure. If the principal of homologous deformations is used, and if the telescope stands in the open, then the last two items vanish, and the price is defined by survival loads or by wind deformations. If snow and ice are taken care of with a jet engine as done at the 300-foot telescope, then the price is entirely defined by wind forces.

Two specifications then are needed for the design, defined as follows:

Specified maximum wind velocity	defined by the maximum tolerable	
a) during observation, V_{ob}	fraction of time lost due to winds above V_{ob}	(1)
b) for survival, V_{sv}	chance of losing telescopes in storms above V_{sv}	

The definitions of both specifications involve wind measurements as well as personal judgements; first, one must know the prevailing velocity distribution; second, one must agree as to what could be tolerated. The wind velocities depend on the geographical region and on the special location within this region; they are, for example, significantly different at the 300-foot and the old 85-foot (being separated by 7000 feet). The following results and conclusions are derived for these two locations at Green Bank; but they show in general how the problem might be attacked at any other place, and what kinds of effects are to be expected.

2. The Material

Wind velocities were measured, with identical equipment on two 40-foot towers, at the old 85-foot telescope during over two years, and at the 300-foot during one year, as shown in Table 1. The data are not always complete, as seen by the numbers n of hours recorded per month. The measured velocities are recorded per hour, they are defined as

$$v = \text{highest velocity during each hour.} \qquad (2)$$

This definition includes gust factors, already.

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Table 1. Average Monthly Velocities, Measured at 85' and 300'.
n = number of hours measured
( ) = uncertain, because n is too small

Month		85'		300'	
		n hours	$\bar{v}_{85}$ mph	n hours	$\bar{v}_{300}$ mph
1961	Nov.	713	16.4		
	Dec.	619	11.3		
1962	Jan.	594	12.0		
	Feb.	672	11.9		
	Mar.	744	12.3		
	Apr.	629	13.5		
	May	720	7.8		
	June	743	12.6		
	July	726	9.8		
	Aug.	724	9.3		
	Sept.	711	9.4		
	Oct.	726	14.1	110	(17.6)
	Nov.	720	15.6	411	(17.1)
	Dec.	108	(8.8)	446	(18.6)
1963	Jan.	708	17.1	389	(8.6)
	Feb.	672	17.4	671	11.3
	Mar.	744	18.0	744	14.4
	Apr.	720	16.6	722	15.2
	May	744	12.1	744	11.3
	June	706	8.9	677	9.7
	July	744	8.8	603	7.7
	Aug.	737	5.9	606	7.8
	Sept.	687	9.6	255	(6.5)
	Oct.	737	9.7		
	Nov.	716	12.3		
	Dec.	744	14.7		
1964	Jan.	743	18.1		
	Feb.	307	(11.5)		

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Both telescopes are located on the NRAO site, about 7000 feet apart. There is an almost level plane to the south-east, terminated by a mountain ridge 4 miles away. A mountain ridge to the north-west, called "Little Mountain", is near the telescopes and gives some shielding against NW winds, especially to the 300-foot which is much closer to this ridge:

Little Mountain	85-foot	300-foot
height of ridge above telescope	600 ft	660 ft
distance of ridge from telescope	8500 ft	2500 ft
distance of foot from telescope	4500 ft	1000 ft

(3)

3) Seasons

Table 2 and Figure 1a give the average of v over each month of the year. All available measurments are used, reduced to an intermediate location (average of v_{85} and v_{300}).

Table 2. Average Monthly Velocities During the Year

Month	$\bar{v}$ mph	Month	$\bar{v}$ mph
Jan.	14.7	July	8.7
Feb.	12.1	Aug.	7.8
Mar.	14.4	Sept.	8.9
Apr.	14.2	Oct.	11.1
May	9.5	Nov.	13.8
June	10.5	Dec.	14.7

Figure 1a could be fitted by a sine curve, but just as well by a one-step function as shown in the graph, dividing the year into summer and winter only. The average velocities and their dispersions are given in Table 3. Per definition, the first quartile has 1/4 of all measurements below it, the median 1/2, and the last quartile 3/4; the difference between last and first quartile is a good measure of the dispersion; the mode is define as the highest point of the distribution (the most probable velocity).

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SUBJECT: Table 3. Average Velocity and Dispersion (both in mph)

	center values			dispersion		
	average	median	mode	first quartile	last quartile	difference
summer (Apr thru Oct)	9.4 ± 0.5	7.4	0	3.2	13.0	9.8
winter (Nov thru May)	14.0 0.4	11.7	8	6.7	19.6	12.9
whole year	11.7 0.8	9.9	5	4.9	16.6	11.7

Figure 2 shows the velocity distribution, where f(v)dv is the probability of having a velocity within the range v....v+dv, and F is the probability of having a velocity $\geq$ v. Summer and winter do not only differ in their average values, but show qualitatively different distributions.

It turns out that the difference between summer and winter is so large that one may consider using a telescope at its shortest wavelength mainly during summer, and using during winter mainly somewhat longer wavelengths. For example, if the last quartile is used as V_{ob} (1/4 of the time lost due to high winds), and if the price of the telescope is defined by wind deformations, then the price is reduced by a factor $(16.6/13.0)^2 = 1.63$:

> If V_{ob} is specified for the six summer months only (instead of the whole year), then the price of the telescope (if defined by wind deformation) is reduced by a factor of 1.6. (4)

And since the shortest wavelength λ, for a given telescope, goes with v^2, and $(19.6/13.0)^2 = 2.27$, we find:

> If a telescope is designed for the shortest wavelength λ_s during summer, then the shortest wavelength during winter is $\lambda_w = 2.3\ \lambda_s$. (5)

This does not mean that λ_s could not be observed during winter, too; it means only that a larger fraction of time would then be lost. From Figure 2a we read:

> If a telescope, observing <u>all</u> year at wavelength λ_s, loses 25% of the time (due to high winds) during summer, then it loses 45% during winter. (6)

Regarding these results, I would recommend to specify a shortest wavelength λ_s for the summer only, which reduces the price (if defined by wind deformation) by a factor of

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1.6. This will double, during winter, either the shortest wavelength or the fraction of time lost in high winds.

4) Location

Where in Table 1 the measurements are fairly complete for both telescopes (Feb through Aug 1963), the velocities are mostly somewhat higher at the 85-foot than at the 300-foot, especially for higher velocities. There are two exceptions, and an inspection of the data showed that the result of June is real, while the result of August probably is caused by the missing data. Omitting August, we have, for the six remaining months:

$$\Delta\overline{v} = \overline{v}_{85} - \overline{v}_{300} = (2.0 \pm 1.0) \text{ mph.} \tag{7}$$

Result (7) is obtained from the average velocities. Since the distributions in Figure 2b are heavily crowded at low velocities, whereas for defining V_{ob} and V_{sv} we are interested in higher velocities only, we must investigate them separately.

With respect to V_{ob}, the following sample was selected:

a) From all hours where both 85-foot and 300-foot are measured, for the periods of Oct 62 through Feb 63, and June through Sep 63, (8a)

b) select all those hours where $15 \leq v_{85} \leq 25$ mph; (8b)

c) call $\Delta v = v_{85} - v_{300}$ for each hour. (8c)

The distribution of the winter-part of sample (8) is shown in Figure 1b; the summer part shows a similar kind of distribution, but with a much larger dispersion. We obtain

selection (8)	n	median of Δv	dispersion of Δv (last-first quartile
Oct - Feb	637	5.5 $\pm$ 0.3	6.8 $\pm$ 0.4
June-Sept	265	4.5 0.6	11.9 1.1
total	902	5.3 0.3	

(9)

The difference in the dispersions means that the velocities at both locations are stronger correlated during winter than they are during summer. For the average of Δv,

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the data yield:

$$\overline{\Delta v} = (v_{85} - v_{300})_{av} = (5.9 \pm 0.4) \text{ mph.} \tag{10}$$

One can show that (10) has a slight positive bias, resulting from the form of the velocity distribution in Figure 2b, and we finally adopt:

$$\overline{\Delta v} = 5.6 \text{ mph, for } 15 < v_{85} < 25 \text{ mph.} \tag{11}$$

The average v_{85} in this interval is 19.3 mph, and the average v_{300} then becomes 19.3 - 5.6 = 13.7 mph. Since $(19.3/13.7)^2 = 1.98$, we have:

> At the location of the 300-foot, as compared to that of the old 85-foot, the price of a telescope (if defined by wind deformation) is reduced by a factor of 2.0. (12)

With respect to V_{sv}, the selection was made according to:

a) and c) same as in (8);

b) select all those hours where $v_{85} \geq 40$ mph and/or $v_{300} \geq 40$ mph. (13)

The resulting average from this sample is (with n = 100):

$$\overline{\Delta v} = (8.8 \pm 2.1 \text{ mph, for any } v \geq 40 \text{ mph.} \tag{14}$$

In addition, a different and maybe more meaningful approach for obtaining Δv was taken, by selecting all <u>days</u> with high winds, and comparing the maximum velocity of each <u>day</u> from the 85-foot with that of the 300-foot:

a) From all days (Oct 62 through Sept 63) where both 85-foot and 300-foot are measured,

b) select all those days where any $v_{85} \geq 40$, and/or any $v_{300} \geq 40$ mph; (15)

c) call v_{85m} the maximum of all v_{85} on that day, and similar for v_{300m}; call $\Delta v_m = v_{85m} - v_{300m}$ for each day.

This was done for three limits, $v \geq 40$, 45, 50 mph, and the result is:

$v \geq$	n	$\overline{\Delta v}_m$
40	29	4.4 ± 1.9
45	15	5.6 2.8
50	3	12.0 5.3

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From (14) and (16) we finally adopt $\Delta v = 7.0$ mph for $v \geq 50$ mph, and since $(50+3.5)^2 / (50-3.5)^2 = 1.33$, we find :

> At the location of the 300 foot, as compared to that of the old 85-foot, the price of a telescope (if defined by survival winds) is reduced by a factor of 1.3. (17)

5) Highest Velocity for Observation, V_{ob}

In order to specify V_{ob}, the observers must agree as to what fraction F of time lost (due to high winds) can be tolerated at the shortest wavelength, and discussions with several observers showed that about 25% might be accepted. F(v) is shown in Figure 2a, and some values are given in Table 4. Since previously we have mostly specified 25 mph, the price (if defined by wind deformation) is reduced by a

$$\text{cost reduction factor, } C = (25/V_{ob})^2. \tag{18}$$

Table 4. Fraction F of Time Lost Due to High Winds above V_{ob}, and Cost Reduction Factor C.

V_{ob}	10	15	17	20	25	30	mph
C	6.25	2.78	2.16	1.56	1.00	0.69	-
summer	39	19	15	9	3	1	F, in %
winter	58	36	30	23	13	6	F, in %
whole year	49	29	24	17	8	3	F, in %

Which value of V_{ob} should we adopt? Taking F = 25% for summer, for example, would result in a reduction factor of C = 3.5; but the price as defined by wind deformation, then, would be so low that, actually, it gets meaningless since the price as defined by survival will be the higher one. Some estimates showed that a good value for a large telescope might be about

$$V_{ob} = 17 \text{ mph} \tag{19}$$

where the price is down by a factor of 2; in summer, we lose 15% of the time, in winter 30%, and 24% in the average over the whole year.

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The velocities used for Table 4 and for (19) are the average for the locations of the 85-foot and the 300-foot. But it seems well possible to choose a location even better than that of the 300-foot, for example, in the Greenbrier Valley right next to the present border of the NRAO site. This would further reduce V_{ob}, and the price will rather be defined by survival winds.

6) Highest Velocity for Survival, V_{sv}

This is the most difficult quantity to choose. Any reasonable site for a large telescope will be selected on the condition that no great storms are recorded there in the past. How, then, can we estimate the probability of a great storm occurring there in the future?

The following approach was taken. We know from our measurements the velocity distribution up to 60 mph; we fit a simple function to this distribution and extrapolate to higher winds. From the definition of the cumulative distribution F(v) one can show that the time interval t between velocities above v is given by

$$t = 1.14/(10^4 F(v)) \text{ years.} \quad (20)$$

As to the fitting function, we decided to take two-parameter functions only, and to try the four easiest ones as given in Table 5. They are shown in Figures 3-6, which are all plotted in such a way that the fitting curve is a straight line. We see that the best fit is reached by No. 2, the exponential-power function, but it seems difficult to give this function a physical meaning. If two orthogonal components of the wind velocity (for example the NS and EW components) are randomly Gaussian distributed and mutually uncorrelated, then the density function f(v) will have the form "v times Gaussian", which happens to be the derivative of a Gaussian, so that the cumulative distribution F(v) is a Gaussian again. This is case No. 4 in Table 5, and is shown in Figure 6. It is the second best fit (failing only for $v \leq 10$ mph). The two remaining cases, power law and exponential law, give bad fits and just are added for comparison.

Table 5. Some Two-Parameter Functions for Fitting F(v)

No.	function	formula	best fit A mph	best fit B -	range in v of fit, mph
1	power law	$F(v) = (v/A)^{-B}$	24.0	10.0	30 - 60
2	expon.-power	$F(v) = e^{-(v/A)^B}$	12.8	1.46	0 - 60
3	exponential	$F(v) = B\ e^{-v/A}$	4.14	99.8	40 - 60
4	Gaussian	$F(v) = B\ e^{-(v/A)^2/2}$	14.6	0.269	15 - 60

Next, we adopt a time after which a telescope becomes obsolete, say, 30 years. Then we adopt a chance of, say, 1% for losing the telescope before it gets obsolete. With these numbers, we have t = 30 x 100 = 3000 years, and from (20) we find F = 3.8×10^{-8}. This value then is entered into the two well-fitting formulae of Table 5; we solve for v and call the result V_{sv}, as shown in Table 6:

Table 6. Survival velocity V_{sv}, as obtained from the demand that the chance of losing the telescope in a storm, within 30 years time, is 1% or 0.1%; for two fitting-curves.

Cukve	V_{sv} 1%	V_{sv} 0.1%
exponential-power	89.6 mph	97.8 mph
Gaussian	82.2	88.0

From Table 6 we may conclude that, at an average location at Green Bank,

$$v_{sv} = 100 \text{ mph} \tag{21}$$

is really all we need, which even may go down to, say, 85 mph for a better shielded location at the Greenbrier.

This result holds as long as Green Bank is not hit by a hurricane, but it seems difficult to estimate a chance for this happening. A possible way would be to take all recorded hurricanes above 100 mph, and note of each one the closest distance it came to Green Bank.. The distribution of these distances then could again be extrapolated, down to, say, 50 miles distance; and the chance of this happening within 30 years can be found. But, since hurricane velocities are so much higher than (21), this procedure should never be used for specifying V_{sv}; instead of, it would only tell how good or bad a region like Green Bank is for building a large telescope there, and different regions could be compared this way.

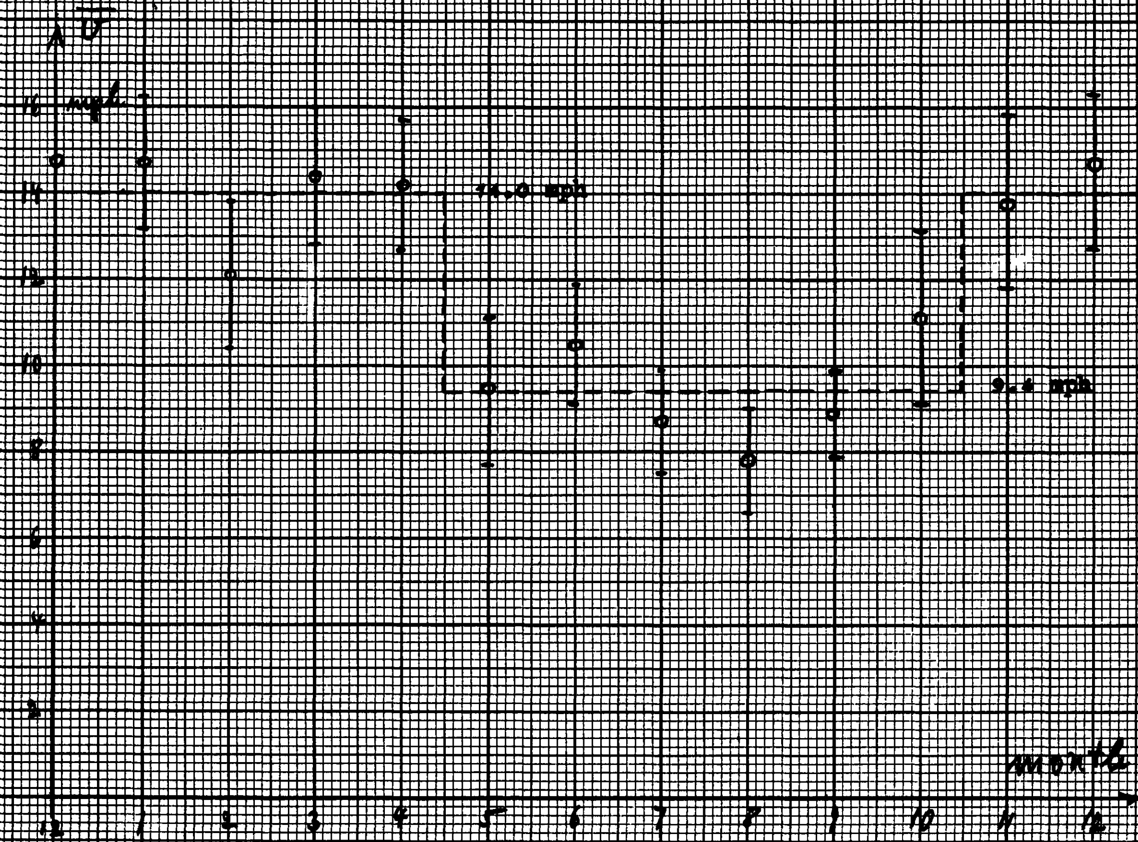

__Fig. 1a.__ Average velocity of each month, with mean errors.

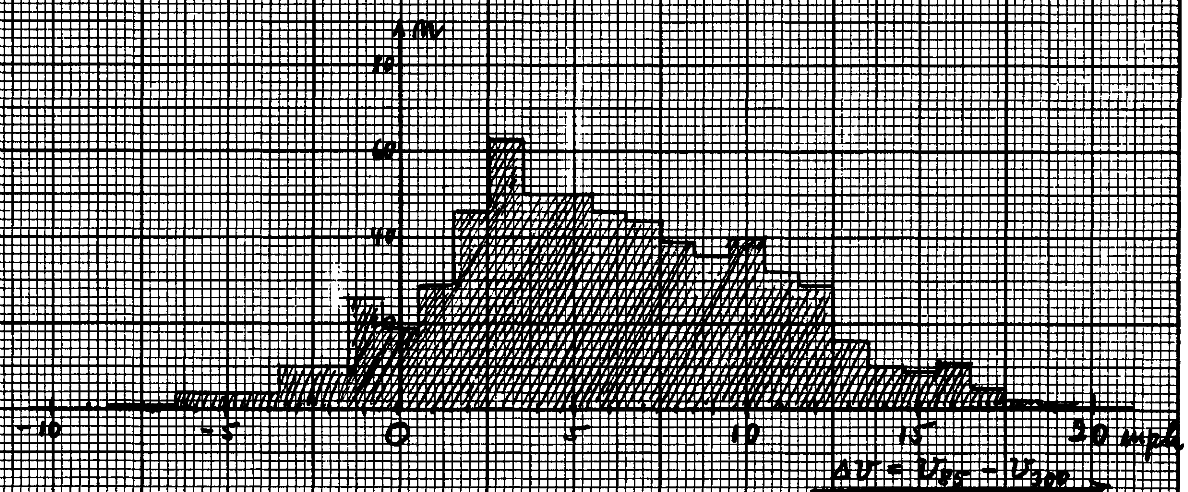

__Fig. 1b.__ Velocity-difference distribution, between 85-foot and 300-foot, during Oct. 1962 through Feb. 1963; for $15 \leq v_{85} \leq 25$ mph only.

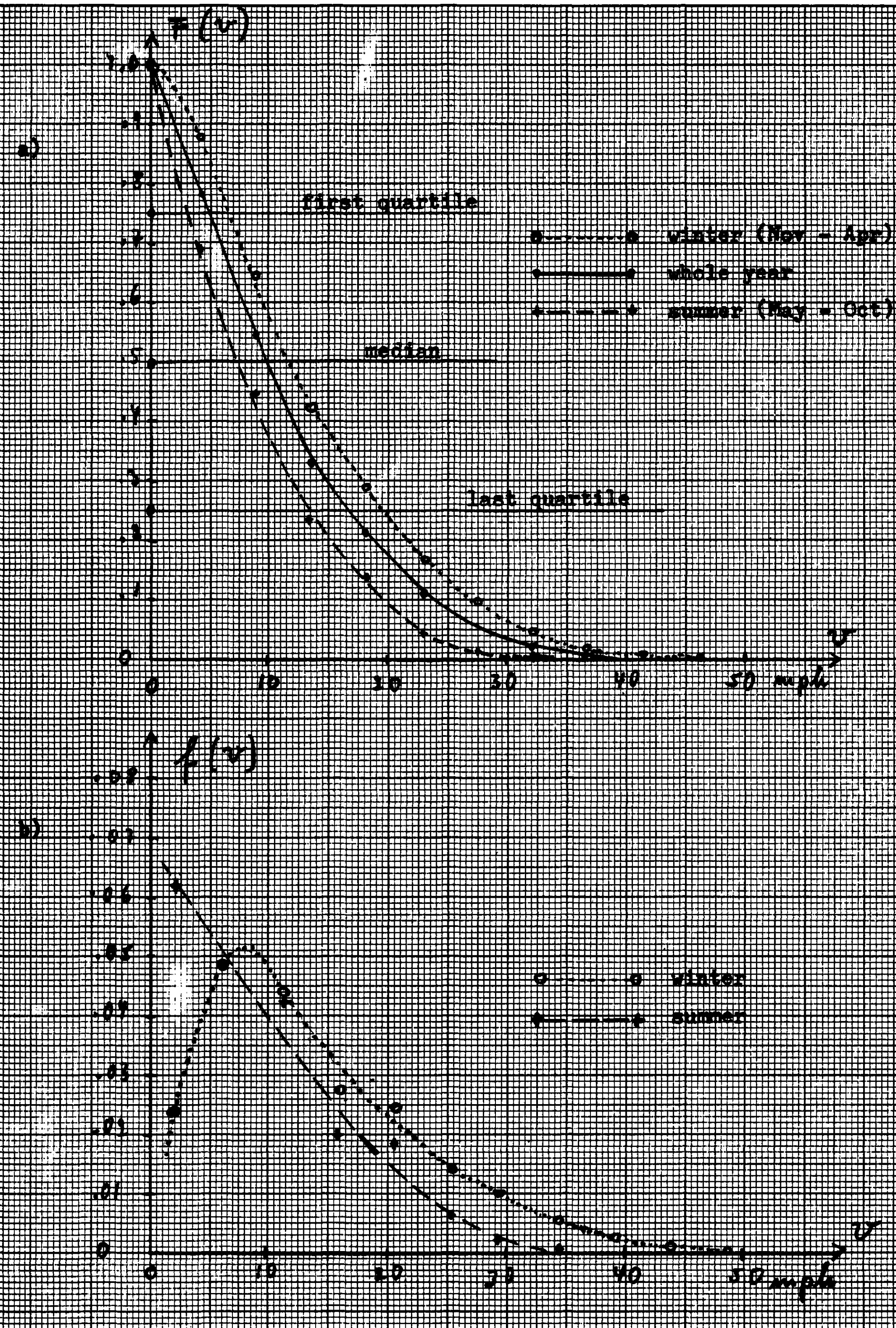

Fig. 2. Distribution of velocities.

F(v) = cumulative distribution (fraction above v)

f(v) = density distribution (probability of v)

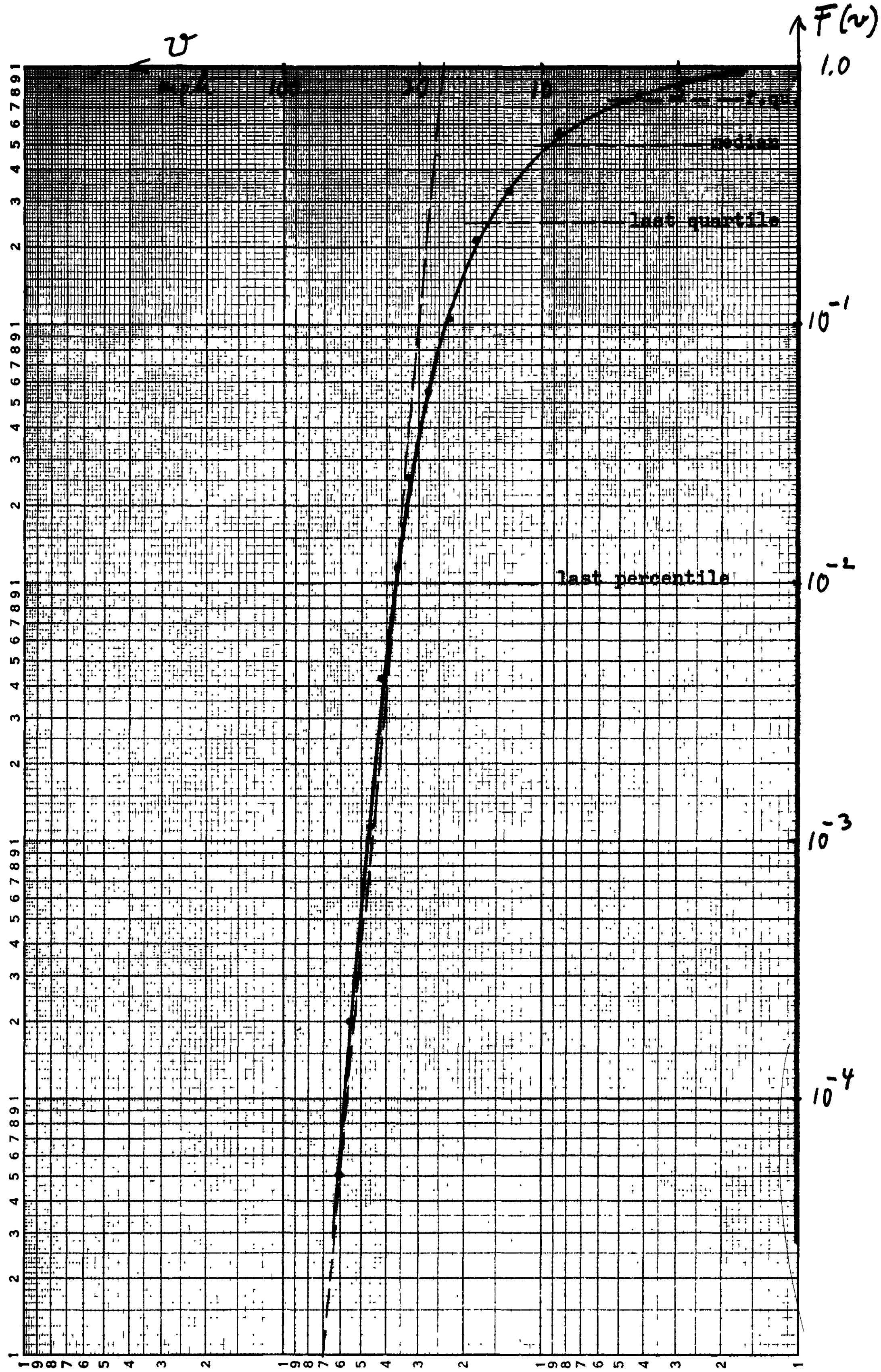

Fig. 3. Test for power law, $F = (v/a)^{-b}$.

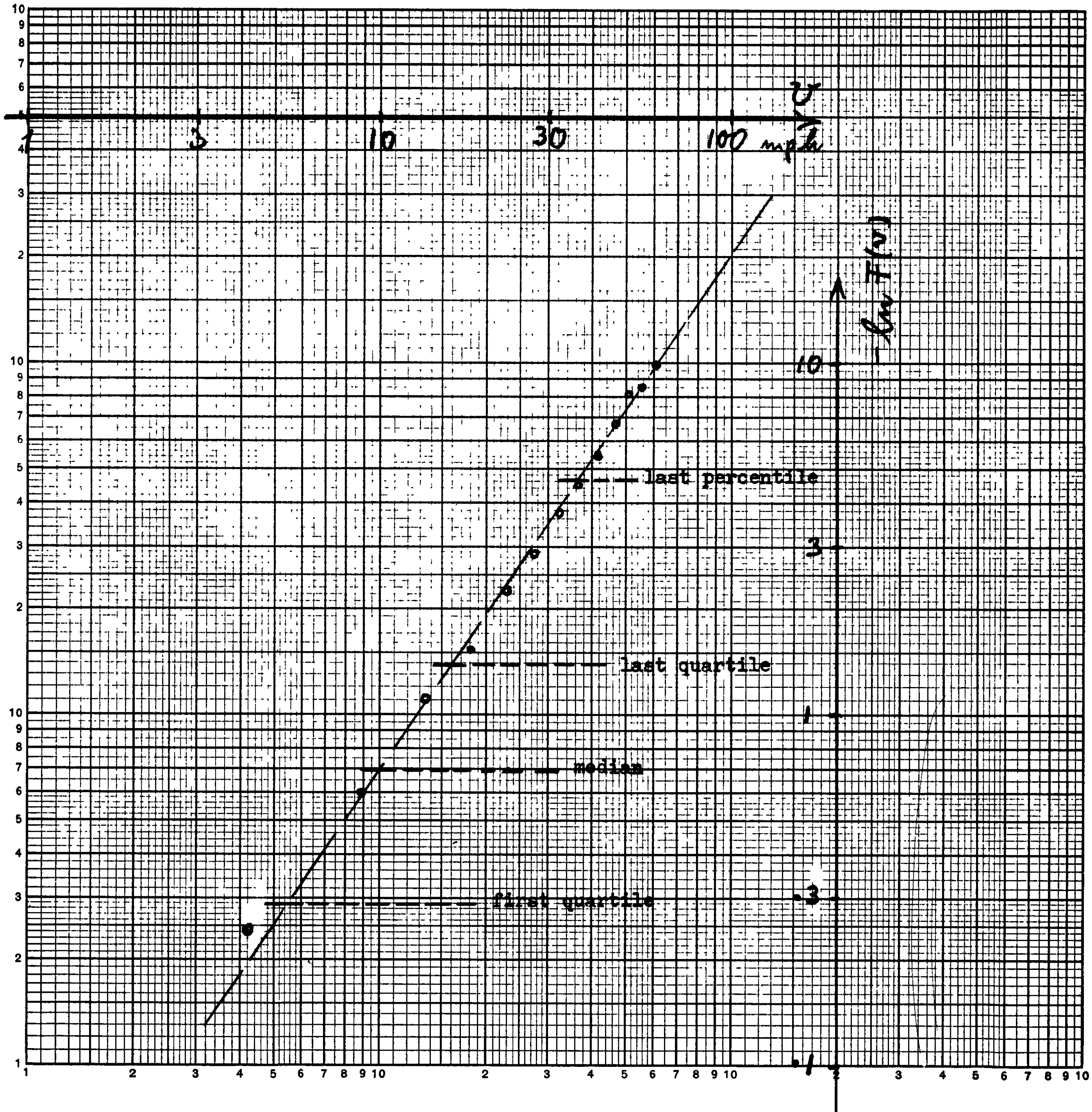

Fig. 4. Test for exponential power law, $F = e^{-(v/a)^b}$.

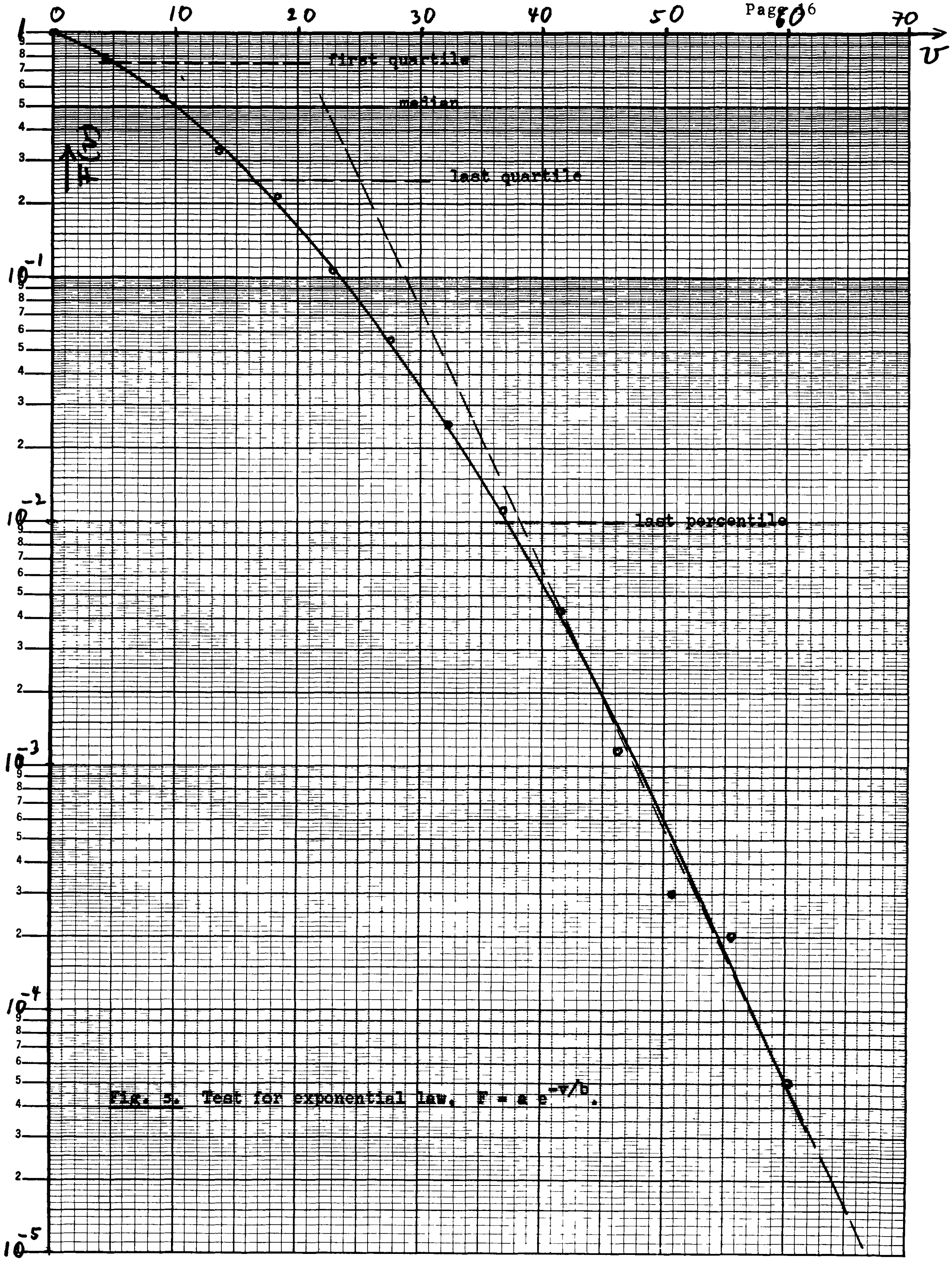

Fig. 5. Test for exponential law, $F = a\,e^{-v/b}$.

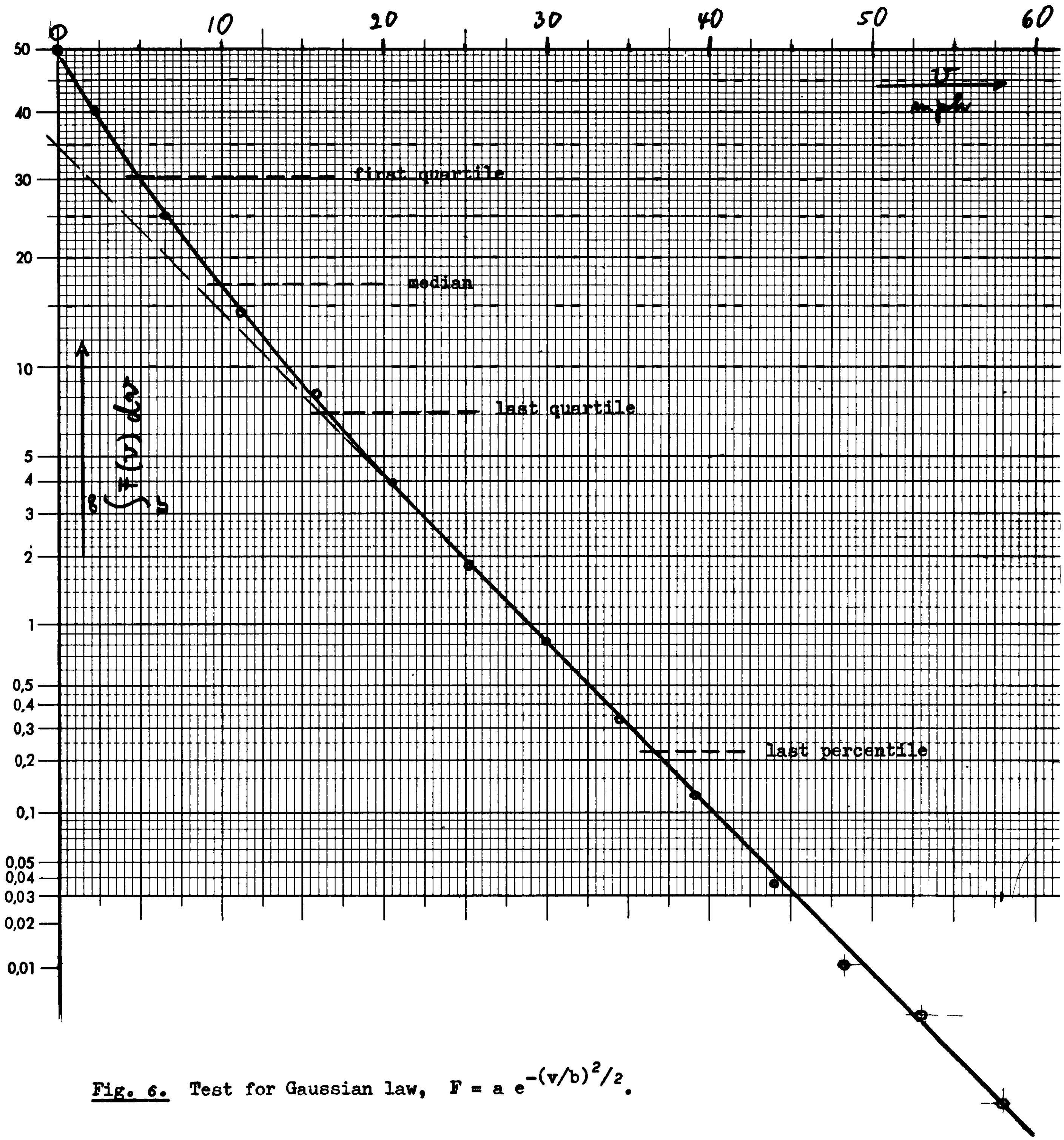

Fig. 6. Test for Gaussian law, $F = a\, e^{-(v/b)^2/2}$.