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SECRET

NATIONAL RESEARCH COUNCIL OF CANADA

RADIO AND ELECTRICAL ENGINEERING DIVISION

CATALOG OF FLUTTAR WAVEFORMS

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OTTAWA

APRIL 1955

ABSTRACT

This report is primarily a collection of typical waveforms obtained in an experimental dual bi-static detection system of the fluttar or McGill Fence type. A brief statement of the equipment is given and some general conclusions drawn.

It is shown that sense of crossing can be readily determined. Approximate location of crossing and an estimate of crossing velocity may also be obtained.

CATALOG OF FLUTTAR WAVEFORMS

- E.L.R. Webb -

The waveforms contained in the 11 plates were recorded "live" during the period, Summer, 1953, to Spring, 1954. Many hours of construction and preparation preceded and followed the actual recording time of a little more than 4 hours (250 minutes). The records have been preserved in some 7.5 miles of dual-channel magnetic tape.

The waveforms are, in most cases, the direct-coupled output from the diode second detector of a pair of receivers in a dual fluttar link aircraft detection system. Unless otherwise stated no filtering was used other than that inherent in the magnetic pen oscillograph.

Determination of sense of crossing was one of the main aims of the project. The geography of the experimental setup is shown in Fig. 1. One transmitter was located at the Arnprior (Ontario) airfield. Originally it was a crystal controlled multiplier-amplifier chain adapted from a coherent radar experiment. The nominal output was 50 watts c.w. at 500 mc/s. It was connected by waveguide feeder to an antenna originally designed for a radar experiment on 600 mc/s. The antenna was a horn-fed, parabolic reflector re-shaped to give a cosecant vertical pattern up to 30°. While it was far from being a suitable antenna for an operational system it did serve to illuminate the receivers and give coverage, except over the transmitter. The horizontal beam width at 500 mc/s was about 8°. For the most part the transmitting antenna was aimed directly (098°) at the receivers, except where stated otherwise. Later the transmitter was simplified to a cavity-controlled three-stage oscillator-multiplier combination. Still later an RCA "Spider Web" transmitter was used.

Three receiving antennas were used at various times. All were located at the Field Station of the Radio and Electrical Engineering Division, NRC. Those at "A" and "B" in Fig. 1 were pole-mounted horn-reflector combinations. They were RCA of Canada versions of an early NRC radar design, and had a horizontal beam width of about 12°. For high cover over the receivers it was necessary to tilt back.

The third receiving antenna, at "C", was identical to the transmitting antenna, but was mounted on a turntable atop a short tower.

The receivers were initially of NRC design and construction -- later RCA "Spider Web" equipment was used. Each receiver was located on the ground near its antenna, but the outputs were remoted to a central recording position.

Preservation of the d-c and low-frequency components of the fluttar signals on the magnetic tape was achieved by means of an FM carrier system.

An Ampex 307-2 dual-channel telemetering tape recorder was used. Tape speed was 30 in/sec, and the FM carriers were at about 25 kc/s, with a 35% available shift each way. Voice announcements were added on one channel without mutual interference with the data signal.

On play-back the demodulated waveforms were recorded on a dual-channel Brush magnetic pen oscillograph. The chart speed was normally 5 mm (or 1 division) per second. Where it was desired to show high-frequency details, a speed of 5 divisions per second was used.

The output of the most southerly receiver ("A") was invariably written on the No. 1 Channel of the tape recorder and on the upper half of the pen recorder chart. The other channel was used for either receiver "B" or "C" as indicated.

The live fluttar waveforms available on playback have proven very useful for experimental work. They have all the properties of the originals, in addition to the important ones of repeatability and availability. Problems of weather and aircraft serviceability become memories only.

The first and most obvious method of comparing the dual waveforms has proven to date to be also the simplest. The two receiver outputs are applied to the horizontal and vertical inputs of a cathode-ray tube oscilloscope. When there are no aircraft in the system, the picture on the scope produced by the two uncorrelated noises is a symmetrical ball of noise. The intensity is roughly Gaussian in any radial direction. When an aircraft enters the system the noisy spot performs a generalized form of Lissajous pattern. It has been found possible to tell the nature of the crossing and its sense by watching the scope closely. Its main disadvantage is lack of memory.

During the period, August, 1953, to May, 1954, recordings were made on eleven days, of at least three types of aircraft with a total of 97 controlled or known crossings. With the increasing air traffic density in the vicinity of Uplands airport many unknown (and, for the most part unwanted) crossings were recorded, sometimes forcing postponement of trials. In the accompanying plates some 30 dual waveforms, considered typical of all those recorded, are presented together with appropriate comments.

CONCLUSIONS

Some general conclusions may be drawn:

(i) The sense of crossing is in every case determined correctly by a visual inspection of the pen recordings.

(ii) There is a lower limit on the spacing between the two halves of a dual link system determined primarily by the waveforms themselves, and secondarily by the chart speed at which they are recorded. The waveforms, of course, are functions of frequency, link length, and aircraft course and speed. It is felt that spacings of a few hundred yards would be practical. Work is in progress on electronic means to extract order of occurrence of two nearly identical overlapping waveforms. This is being done with a view towards enabling useful spacings of the order of tens of yards, or less.

(iii) The correlation between the flight data, and the delay between the waveform pairs, is very good considering that no attempt at precision was made in determining the flight data (actual point of crossing, heading, speed, wind, etc.)

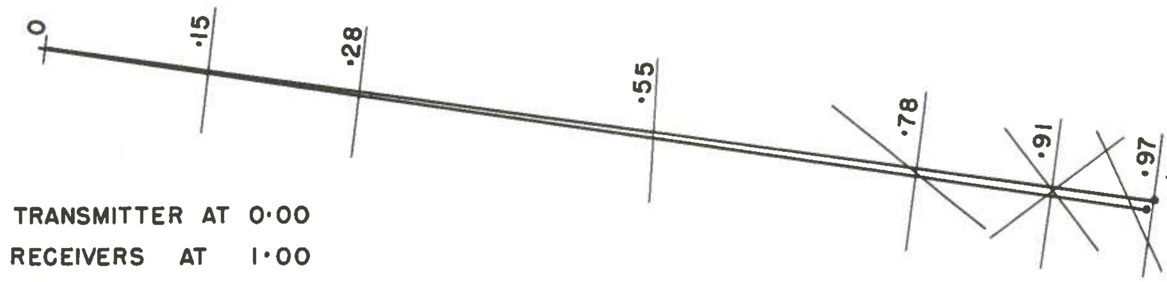
(iv) Sense determination based on amplitude in frequency variations in a single off-set system is not infallible.

(v) The now well known property of bi-static detection systems, namely forward-scatter enhancement, is evident on many of the waveforms. The nulls in the envelope of waveforms have already been discussed in NRC report ERA-273 (SECRET).

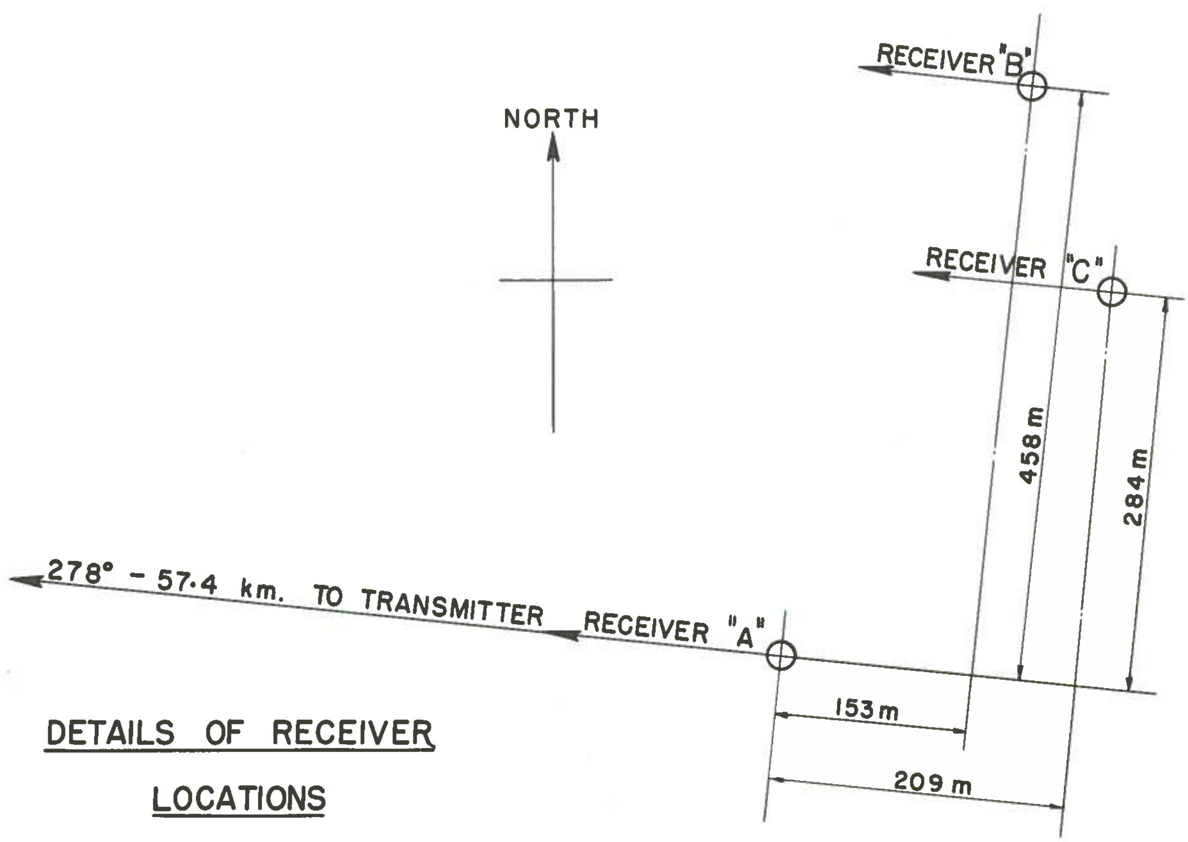
(vi) A great deal of hitherto unused information is available in the waveforms, and in any detection system they ought to be preserved as far as possible.

For instance they may be analyzed to verify flight path characteristics or alternatively, and more important, they may be made to yield a measure of the location of crossing and the crossing component of velocity. It is well known that the rate of change of fluttar frequency ought to be constant over a significant portion of the crossing. This arises from the (very good) parabolic approximation for the excess path length of the scattered signal, giving a similar law for relative phase of the two components of the received signal. The first derivative $\left(\frac{d\phi}{dt}\right)$ or phase velocity is better known as frequency, and it is linear with time. The second derivative $\frac{d^2\phi}{dt^2}$ or phase acceleration does not appear to have any widely accepted name. We shall call it "glide" and represent it by the symbol "g". With the information from the two halves of a dual system we can determine the location of crossing "h", as illustrated in Fig. 2, valid for the mid-link case.

The labor of reduction has resulted in only partial analysis of a few crossings. Work on waveform analyses, both manual and electronic, is still under way and will be reported separately. However, a few results are given to show the possibilities. The "instantaneous" frequency was found by inspection from the waveforms on speed-up oscillograph charts, and plotted in the graphs of Figs. 3, 4, 5. The calculations and results are tabulated in Fig. 6.



NOMINAL LOCATION & ORIENTATION OF AIRCRAFT TRACKS.



DETAILS OF RECEIVER LOCATIONS

FIG. 1

L = "location" = $\dfrac{\text{distance } L\text{-}T}{\text{〃} \quad R\text{-}T}$.

D = link length.

V = a/c speed, normal to link.

S = receiver separation 〃 .

τ = time between crossings.

g = "glide" = $\dfrac{d^2\phi}{dt^2} = \dfrac{df}{dt}$

It can be shown that $\phi \doteq \dfrac{V^2 t^2}{2\lambda D L(1-L)}$

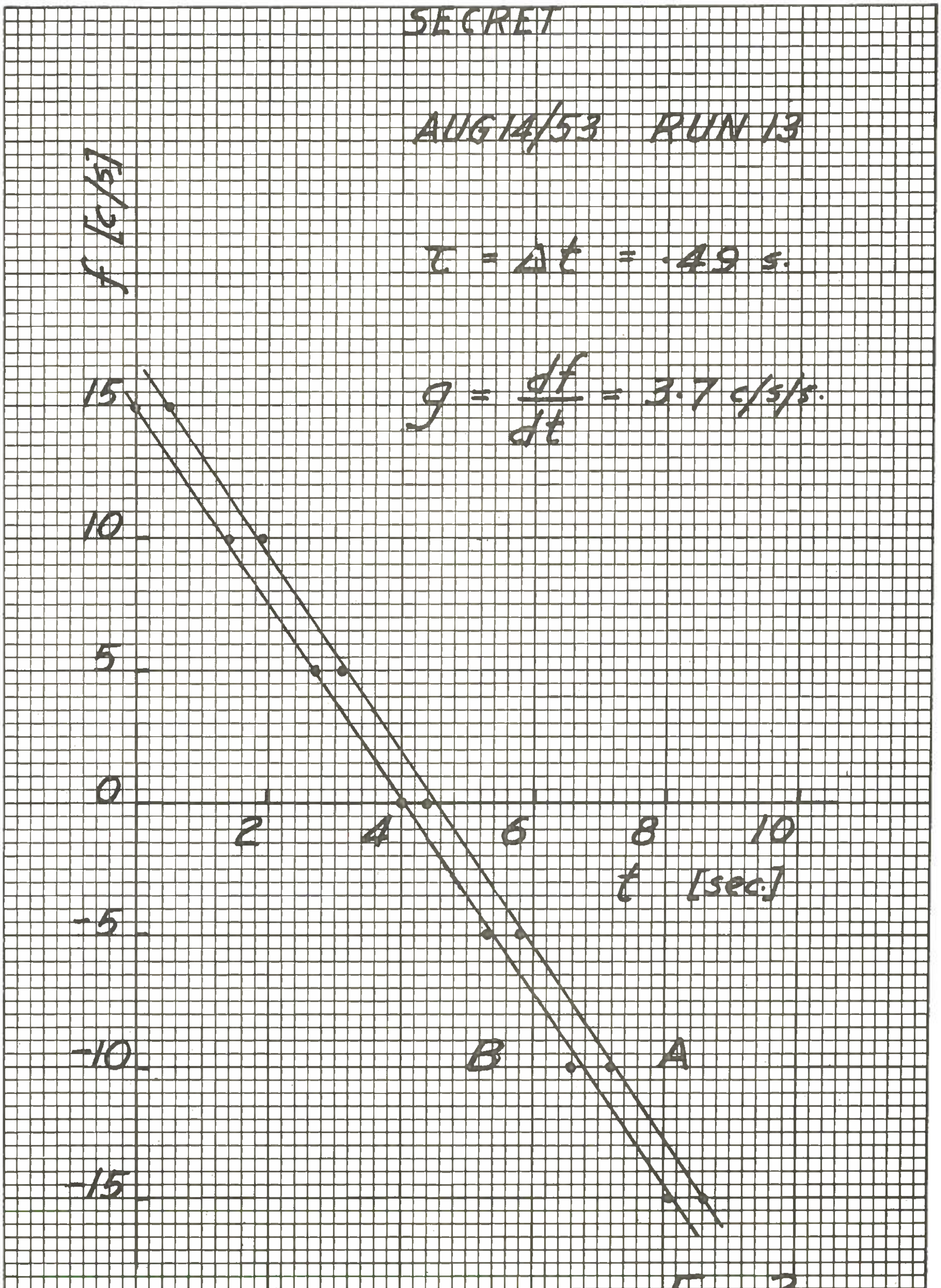
and $g = \dfrac{V^2}{\lambda D L(1-L)}$,

also we have $V = LS/\tau$.

Solving for L: $L = \dfrac{g\tau^2}{g\tau^2 + S^2/\lambda D}$.

and $\dfrac{1}{V} = \dfrac{\tau}{S} + \dfrac{S}{\tau} \cdot \dfrac{1}{g\lambda D}$.

FIG. 2.



SECRET
AUG 14/53 RUN 13
τ = Δt = ·49 s.
g = df/dt = 3·7 c/s/s.
f [c/s]
15
10
5
0
-5
-10
-15
2
4
6
8
10
t [sec.]
B
A

FIG. 3

SECRET

MAY 18/54 RUN 10

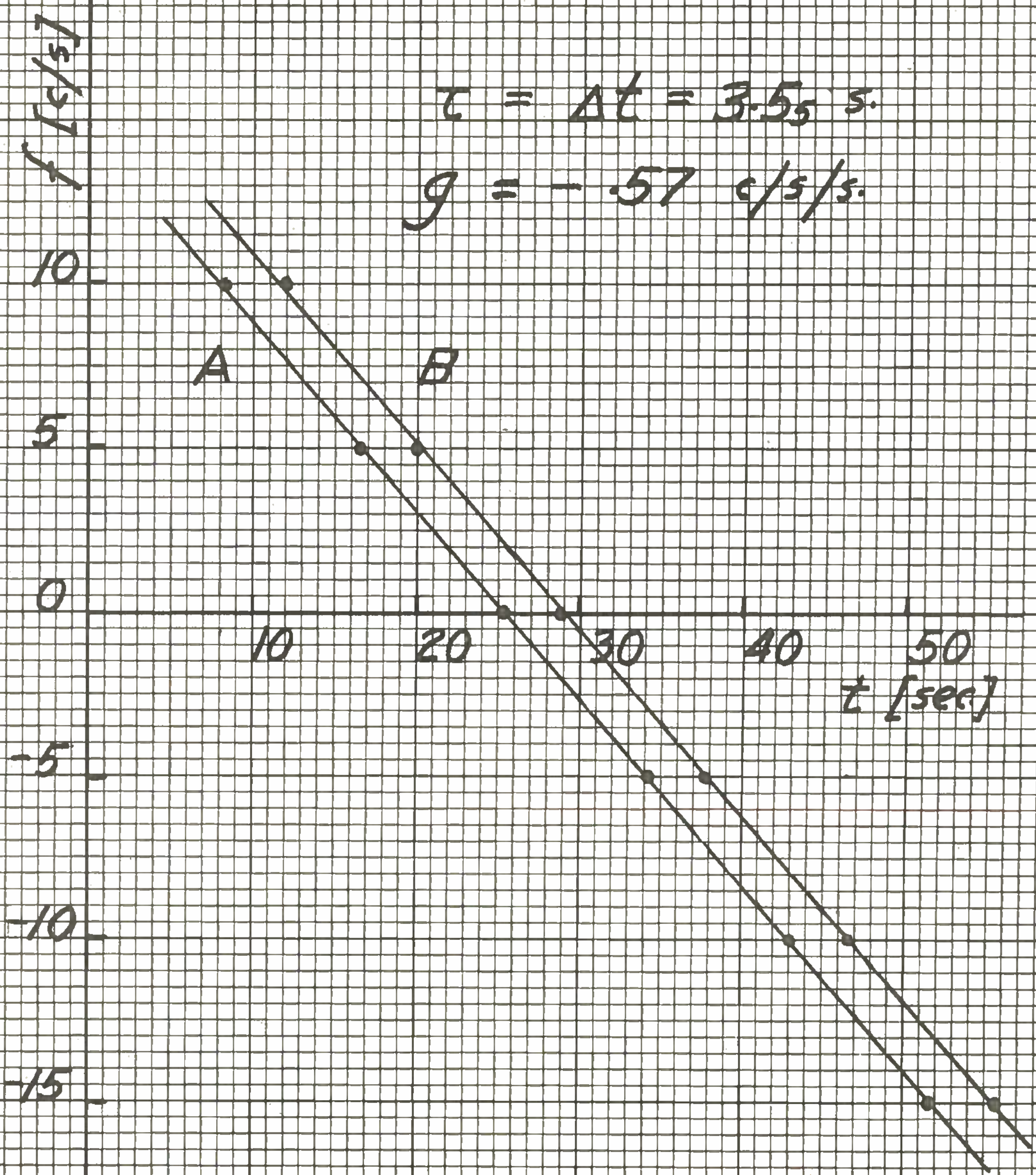


FIG. 4.

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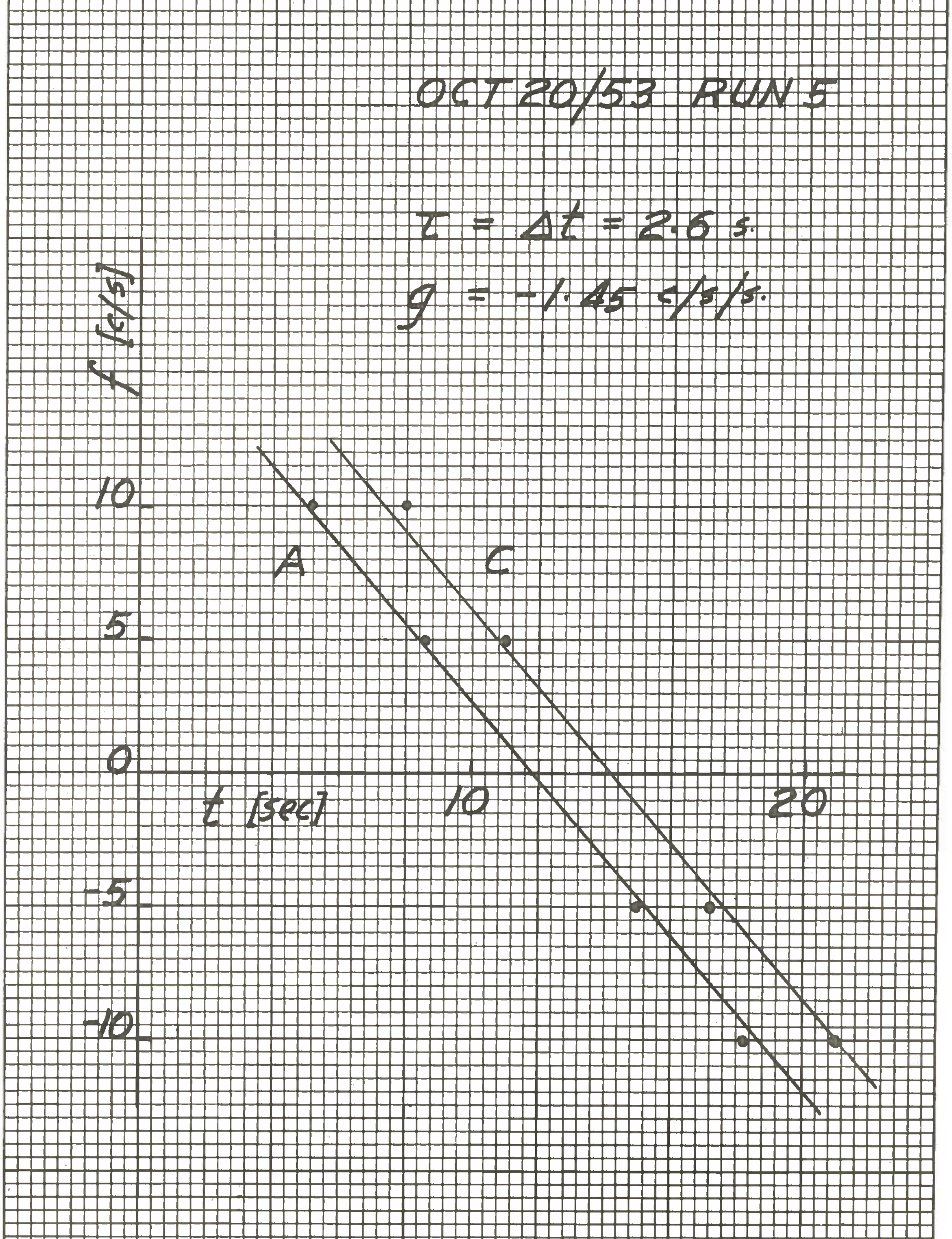

OCT 20/53 RUN 5
$\tau = \Delta t = 2.6$ s.
$g = -1.45$ c/s/s.
f [c/s]
t [sec]
A
C
10
5
0
-5
-10
10
20

FIG 5.

a) Aug 14/53: $\frac{s^2}{\lambda D} = \frac{458^2}{.6 \times 57400} = 6.10$,

& on run 13, $g\tau^2 = 3.7 \times .49^2 = .89$

b) May 18/54: $s^2/\lambda D = 6.10$,

& on run 10, $g\tau^2 = .57 \times 3.5^2 = 7.2$

c) Oct 20/53: $\frac{s^2}{\lambda D} = \frac{284^2}{.6 \times 57400} = 2.34$

& on run 5, $g\tau^2 = 1.44 \times 2.55^2 = 9.36$

$$L = \frac{g\tau^2}{g\tau^2 + s^2/\lambda D} \qquad V = Ls/\tau$$

	Flight data.		Experimental	
	L	V (m/s)	L	V (m/s)
a	.15	129	.13	118
b	.55	66	.54	70
c	.78	98	.80	89

FIG. 6.

SECRET

DATA FOR PLATE 1

Aug. 14/53

TRANSMITTER: Beam width 8°
Aimed 098°

RECEIVERS: Beam width 12°
Aimed 278°

AIRCRAFT: MUSTANG   Altitude 4000 ft.   Speed 129 m/s (250 kts)

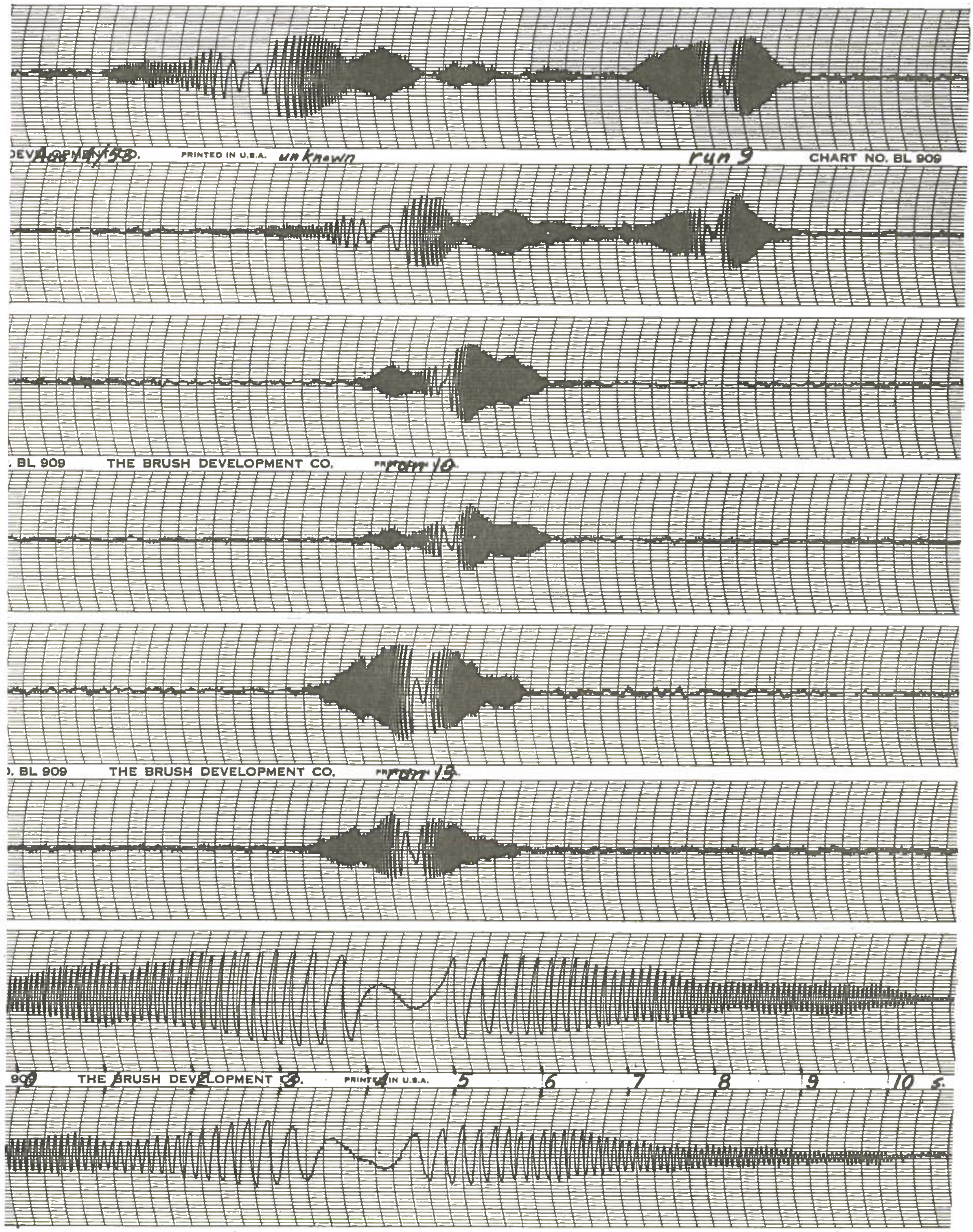
Pair	Run	Location	Heading	Δt (Calculated)	Δt (Measured)
1	9	.15	188	.53	.5
2	10	.15	008	.53	.5
3	13	.15	188	.53	.49
4	13 (expanded)				

An extra aircraft (near receivers) appears on Pair 1 just before Run 9.

Chart speed on Pair 4 was expanded five times to 5 div/sec.

From the geometry of the fluttar link and the aircraft, the rate of change of frequency was estimated to be 3.8 c/s/s. The rate obtained from the expanded waveform of Run 13 was 3.7 c/s/s.

PLATE 1 SECRET



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DATA FOR PLATE 2

Sept. 2/53.

TRANSMITTER: Beam width 8°
Aimed 098°

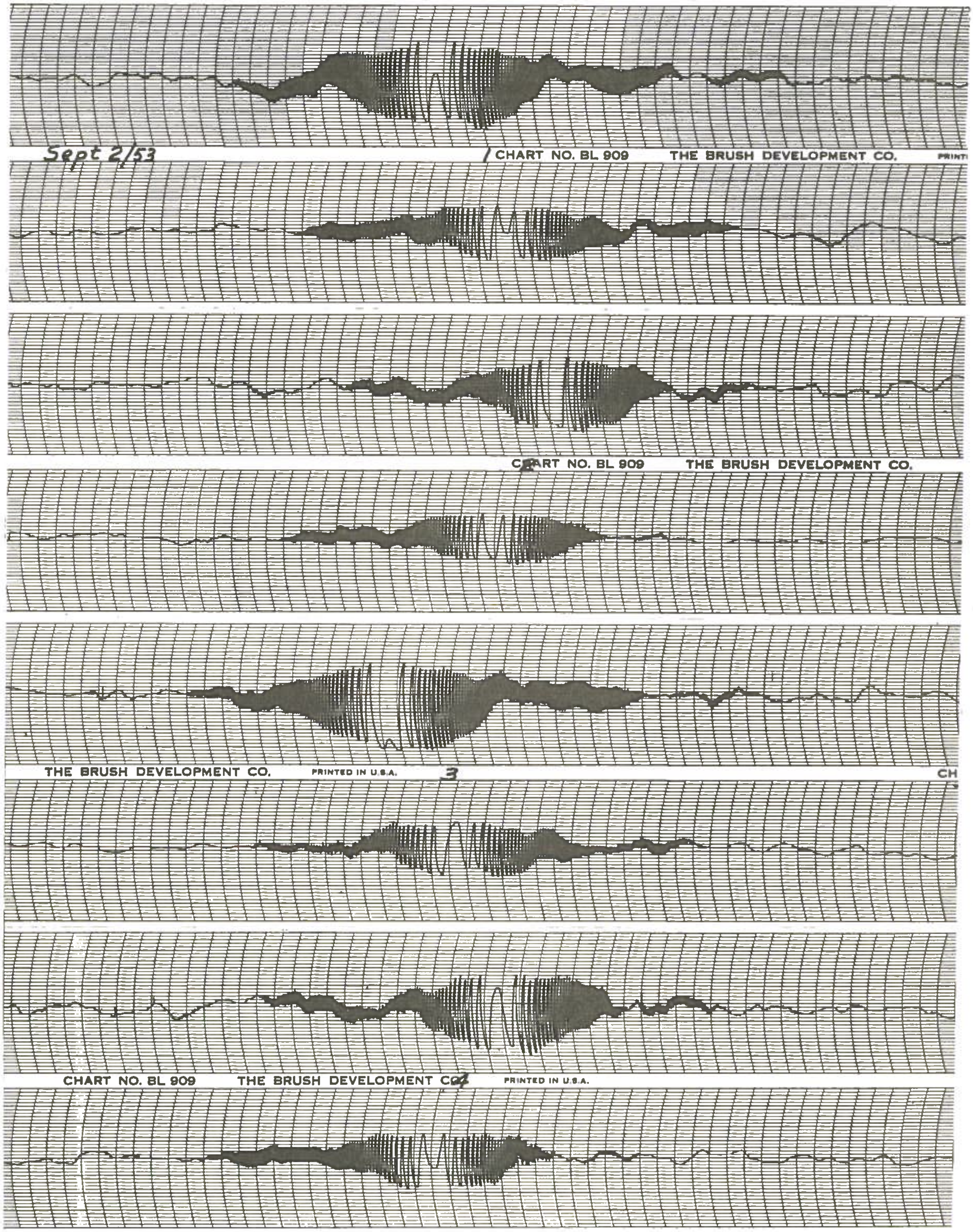
RECEIVERS: Beam width 12°
Aimed 278°

AIRCRAFT: MUSTANG   Altitude 4000 ft.   Speed 100 m/s (195 kts)

Pair	Run	Location	Heading	Δt (Calculated)	Δt (Measured)
1	1	.78	008	3.6	4.0
2	2	.78	188	3.6	3.5
3	3	.78	008	3.6	4.0
4	4	.78	188	3.6	3.5

Four crossings in alternate directions in quick succession near the 3/4 point from transmitter to receivers, illustrating the kind of symmetry to be expected and the large forward-scatter enhancement signals typical of fluttar systems.

PLATE 2 SECRET



DATA FOR PLATE 3

Sept. 3/53.

TRANSMITTER: Beam width 8°
Aimed 098°

RECEIVERS: Beam width 12°
Aimed 278°

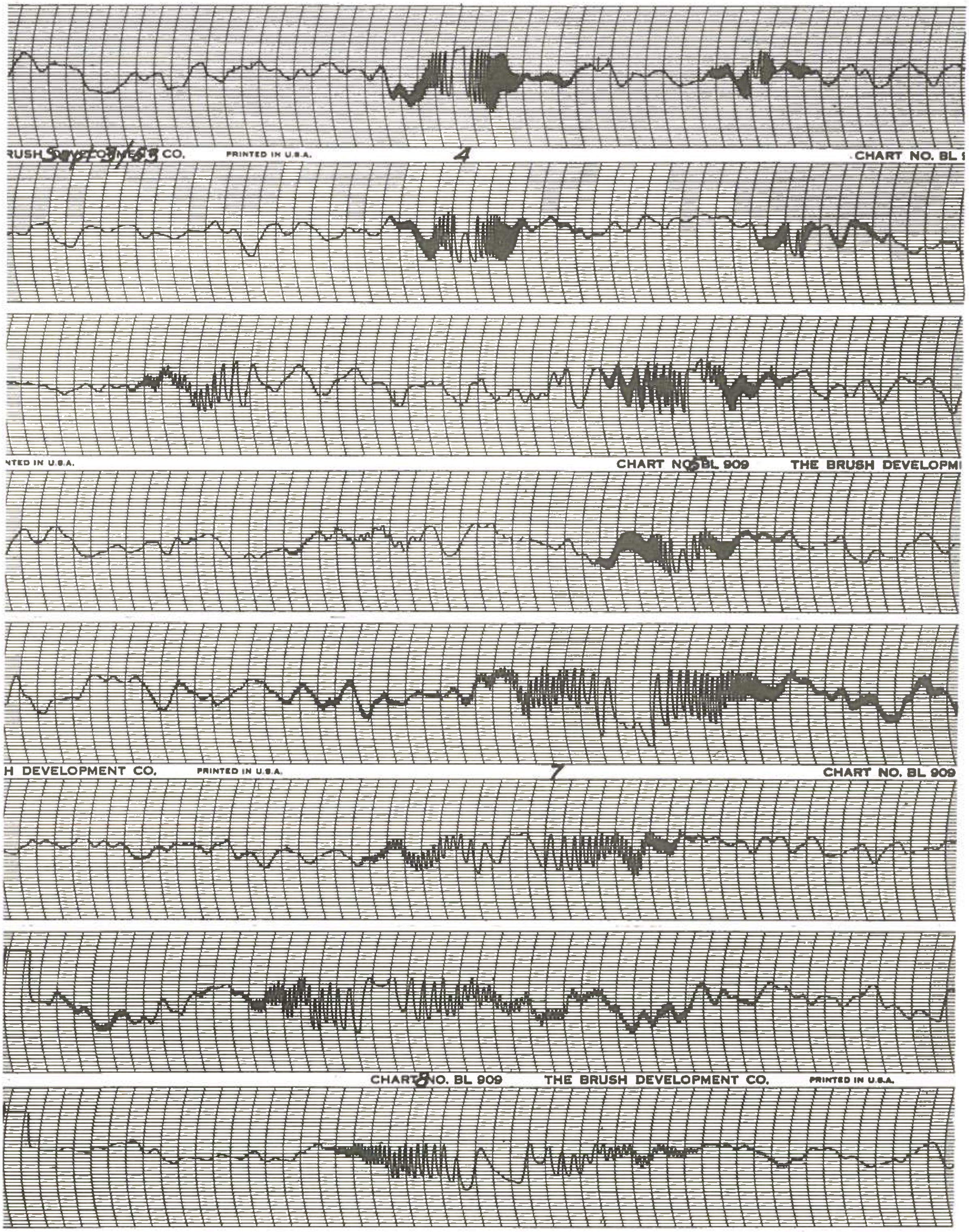
AIRCRAFT: MUSTANG   Altitude 4000 ft.   Speed 108 m/s

Pair	Run	Location	Heading	Δt (Calculated)	Δt (Measured)
1	4	.15	008	.6	.5
2	5	.15	188	.6	.5
3	7	.78	128	6.6	6.5
4	8	.78	308	6.6	7.0

Run 4 was followed closely by a random aircraft of unknown characteristics. About all that can be said of it is that it was fast, more than half-way to the receivers, and heading north.

Runs 7 and 8 show the effect of small (30°) angles of crossing in stretching out the waveforms.

PLATE 3 SECRET



DATA FOR PLATE 4

Sept. 8/53.

SECRET

TRANSMITTER: Beam width 8° Aimed 098°

RECEIVERS: Beam width 12° Aimed 278°

AIRCRAFT: MUSTANG Altitude 2000 ft. Speed 116 m/s

Run 8

First half of Pair 1 (1 div/sec)
Pair 2 (5 div/sec)

Location .97 Heading North

Δt (calc)	3.9 sec
Δt (meas)	4.6 sec

Run 10

Second half of Pair 1 (1 div/sec)
Pair 3 (5 div/sec)

Location .97 Heading North

Δt (calc)	3.9 sec
Δt (meas)	4.6 sec

N.B. The expanded waveforms (Pairs 2 and 3) were also filtered to remove the d-c and low frequency components, and Pair 3 in particular shows the effectiveness of filtering in removing the interference caused by a slow random aircraft.

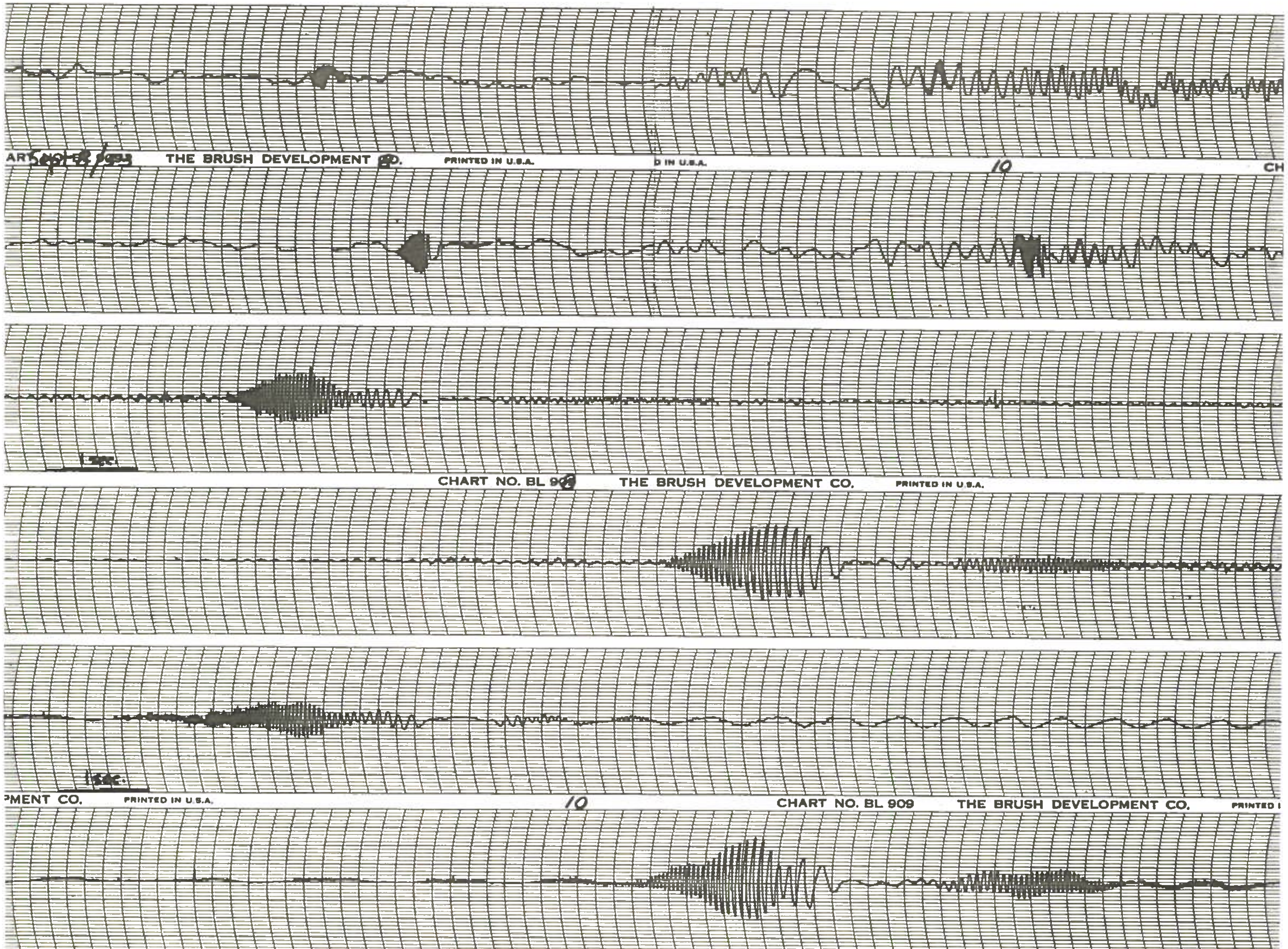


PLATE 4

SECRET

SECRET

DATA FOR PLATE 5

Sept. 8/53.

TRANSMITTER: Beam width 8°
Aimed 098°

RECEIVERS: Beam width 12°
Aimed 278°

AIRCRAFT: MUSTANG Altitude - Run 7 - 3000 ft. Run 13 - 2000 ft. Speed - 116 m/s

Run 7

First half of Pair 1 (1 div/sec)
Pair 2 (5 div/sec)

Location .97 Heading South

Δt (calc)	3.9 sec
Δt (meas)	4.0 sec

Run 13

Second half of Pair 1 (1 div/sec)
Pair 3 (5 div/sec)

Location 1.0 Heading South

Δt (calc)	4.3 sec
Δt (meas)	3.6 sec

N.B. The expanded waveforms (Pairs 2 and 3) were also filtered to remove the d-c and low-frequency components.

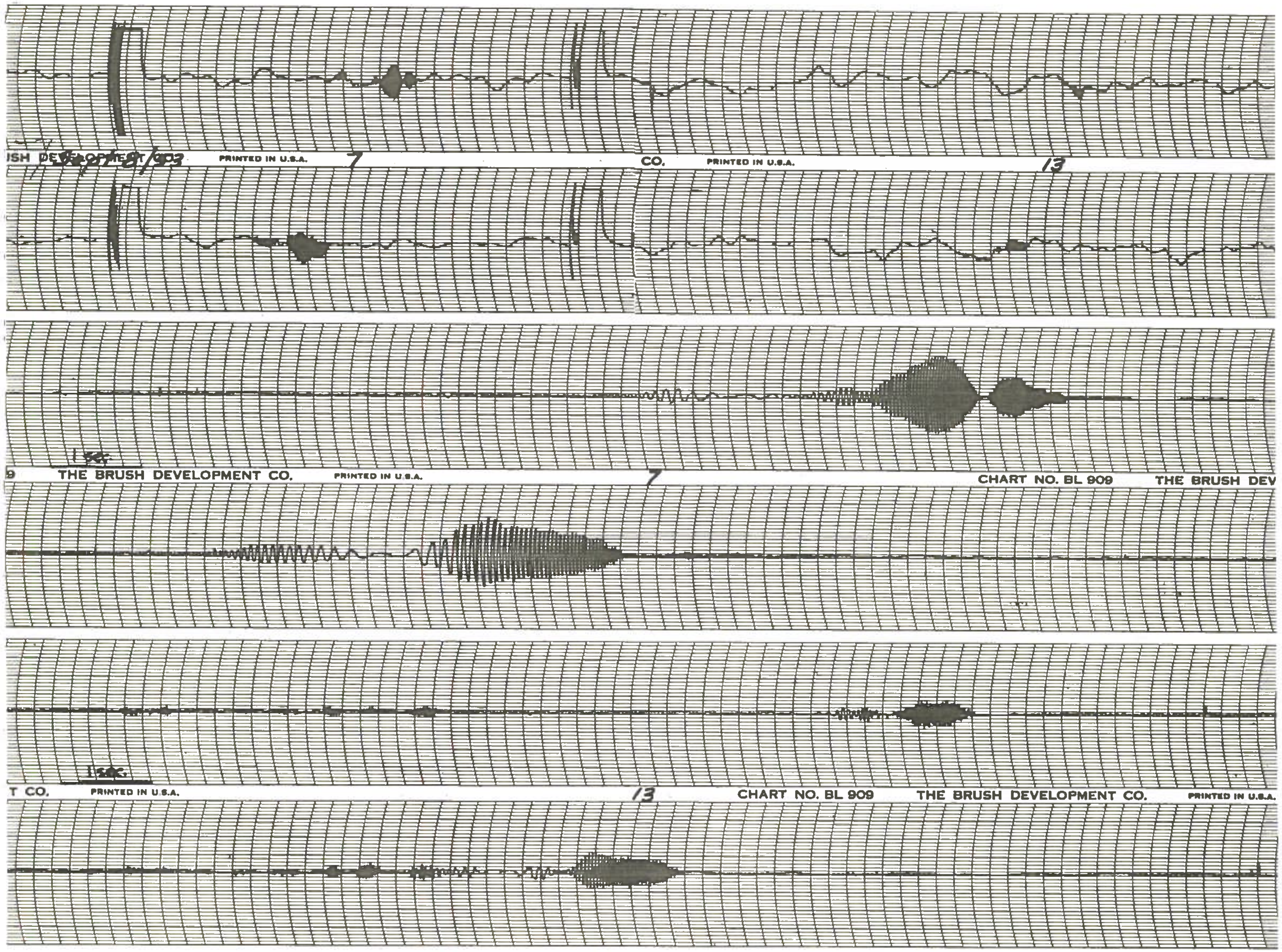


PLATE 5

SECRET

DATA FOR PLATE 6

Oct. 16/53.

TRANSMITTER: Beam width 8°
Aimed 098°

RECEIVER A: Beam width 12°
Aimed 278°

RECEIVER C: Beam width 8°
Aimed - See table

AIRCRAFT: MUSTANG   Altitude - 4000 ft.   Speed - 103 m/s

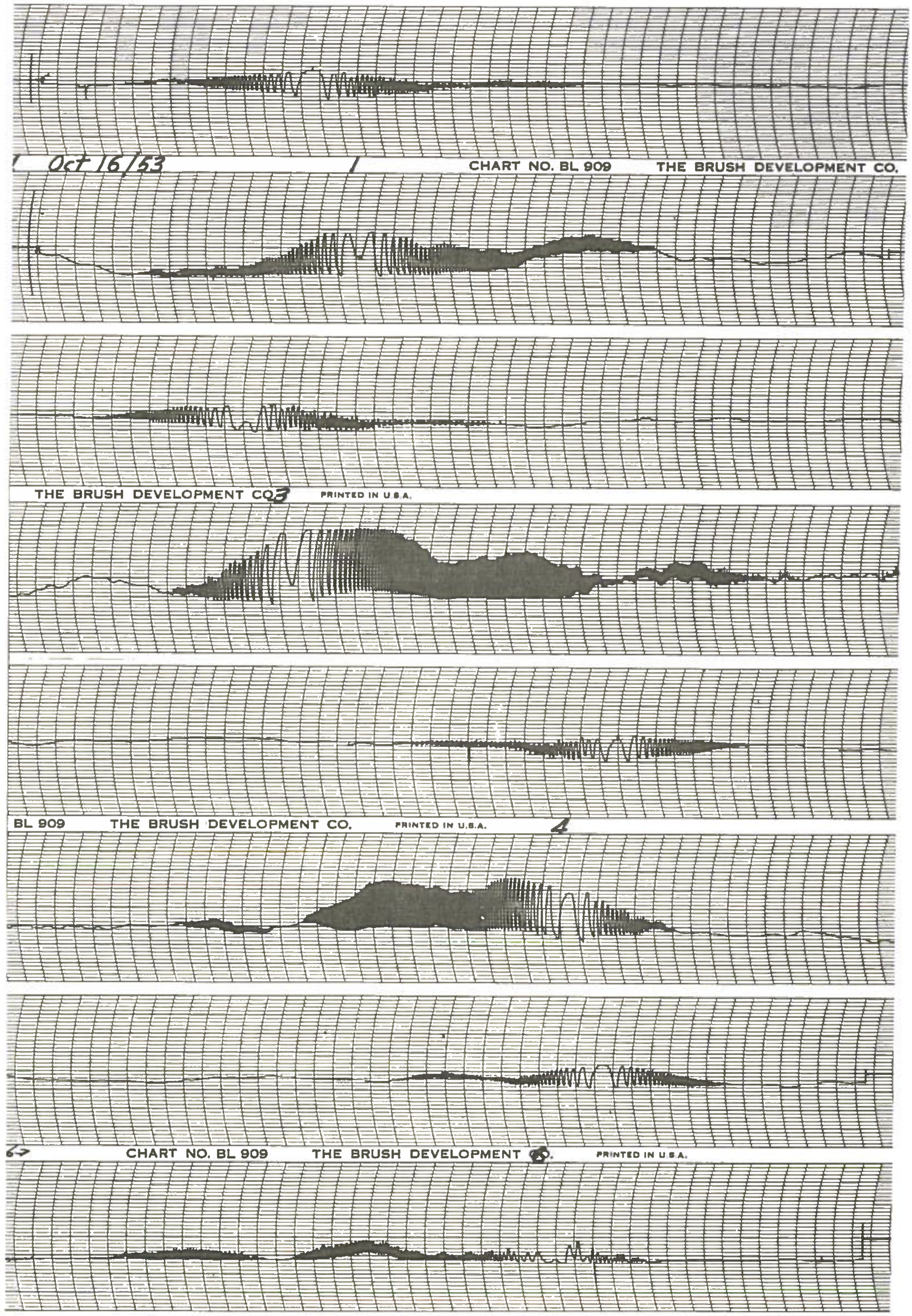
All crossings at Location .78
and nominally at 90°

Δt (calculated) = 2.1 sec

Pair	Run	Heading	Receiver "C" Ant. Aimed	Δt (Measured)
1	1	North	278	2.5
2	3	North	283	2.5
3	4	South	283	2.5
4	6	South	288	2.5

This series of crossings illustrates the general effect of aiming off to enhance the signal received from those portions of the crossings away from the axis (line joining transmitter and receiver).

PLATE 6 SECRET



DATA FOR PLATE 7

Oct. 20/53

TRANSMITTER: Beam width 8°
Aimed 093°

RECEIVER A: Beam width 12°
Aimed 278°

RECEIVER C: Beam width 8°
Aimed 283°

AIRCRAFT: MUSTANG   Altitude - 3000 ft.   Speed - 98 m/s

Pair	Run	Location	Heading	Δt (Calculated)	Δt (Measured)
1	1	.28	008	.8	1.1
2	5	.78	008	2.3	2.55

Note striking simularity (except for Δt) of these waveforms taken at locations nearly symmetrical about the mid-point. The asymmetry in time is due to the aim-off of the antennas.

N.B. The above waveforms were filtered on playback to remove d-c. At 5 div/sec, frequencies of at least 55 c/s are discernable well above noise.

Nov. 6/53

TRANSMITTER: Beam width 8°
Aimed 098°

RECEIVER A: Beam width 12°
Aimed 272°

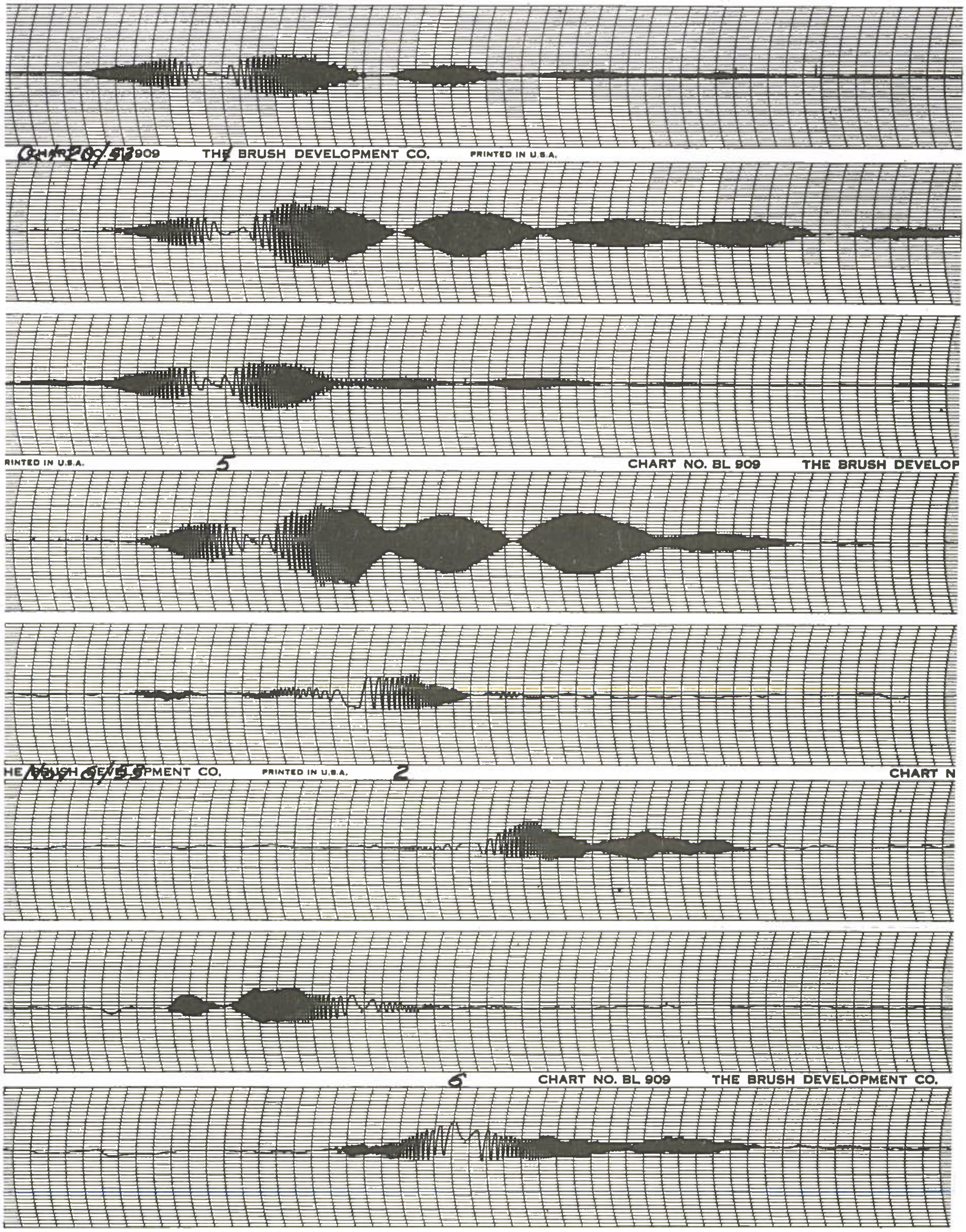
RECEIVER B: Beam width 12°
Aimed 284°

AIRCRAFT: MUSTANG   Altitude - 4000 ft.   Speed - 103 m/s

Pair	Run	Location	Heading	Δt (Calculated)	Δt (Measured)
3	2	.91	053	5.7	6.7
4	6	.91	323	5.7	6.1

Note the dissymmetry in amplitude with different angles of crossing. This, in conjunction with the characteristic "slit" nulls at places where the fluttar frequency is not zero, legislate against accurate sense determination in a single link (off-set) system.

PLATE 7 SECRET



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DATA FOR PLATE 8

May 17/53.

TRANSMITTER: Beam width 8°
Aimed 098°

RECEIVERS: Beam width 12°
Aimed 278°

The three pairs of waveforms make up a continuous record of two or three unknown aircraft followed by Run 1 which was two Dakotas - 100 ft. apart (wing tips) at 2000 ft. and speed 93 m/s.

The first unknown was quite slow, the last unknown quite fast.

Pair	Run	Location	Heading	Δt (Calculated)	Δt (Measured)
1 & 2		Unknowns			
3	1	.55	188	2.7	3.7

Note

Run 1 was typical of several flown in close succession. The measured times on all runs were more consistent with a speed of 67 m/s or 3.7 seconds and may be the result of writing 180 knots for 130 knots.

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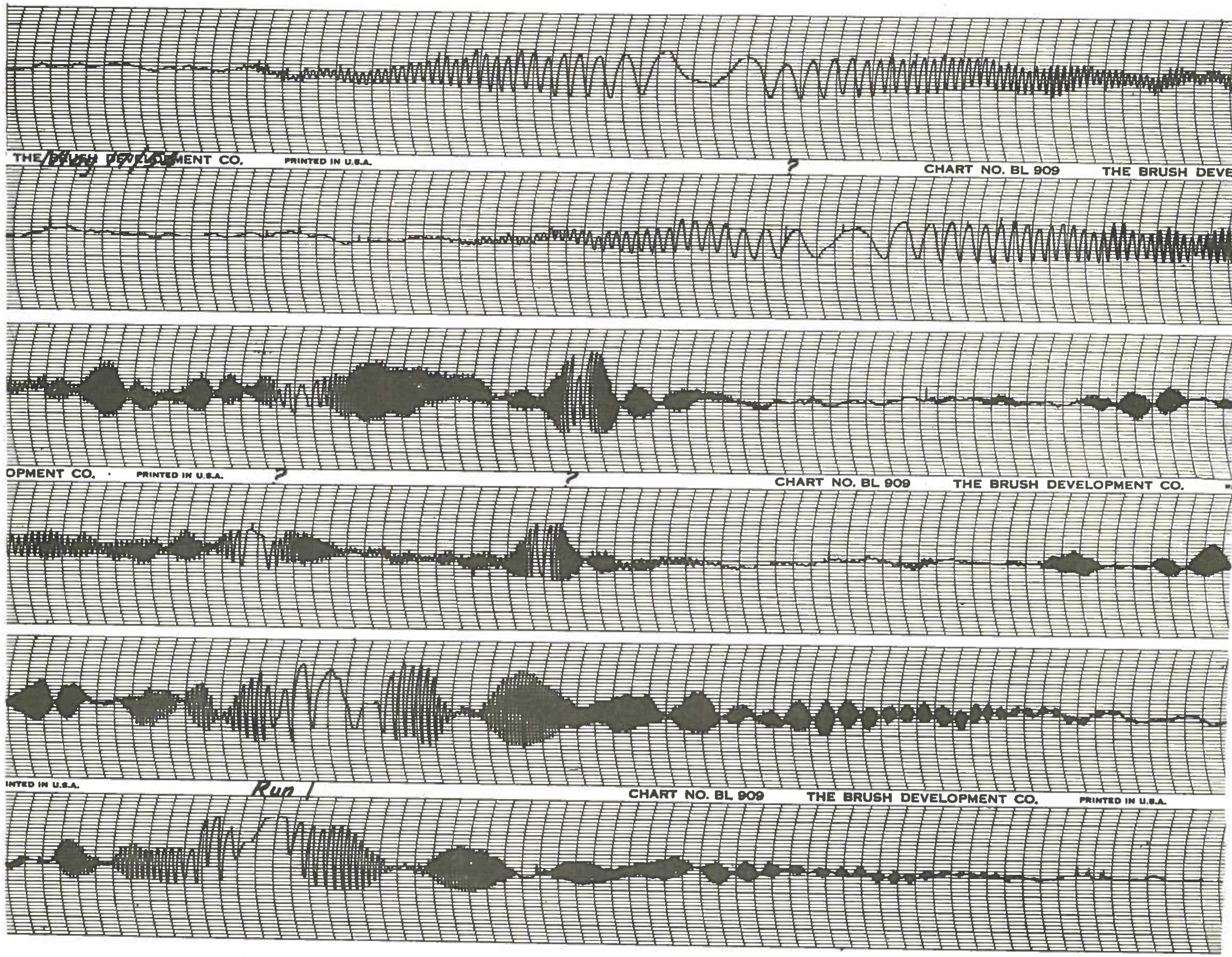


PLATE 8

DATA FOR PLATE 9

May 18/54.

TRANSMITTER: Beam width 8° Aimed 098°

RECEIVERS: Beam width 12° Aimed 278°

AIRCRAFT: DAKOTAS (5) Altitude 2500 ft. Speed 60 m/s

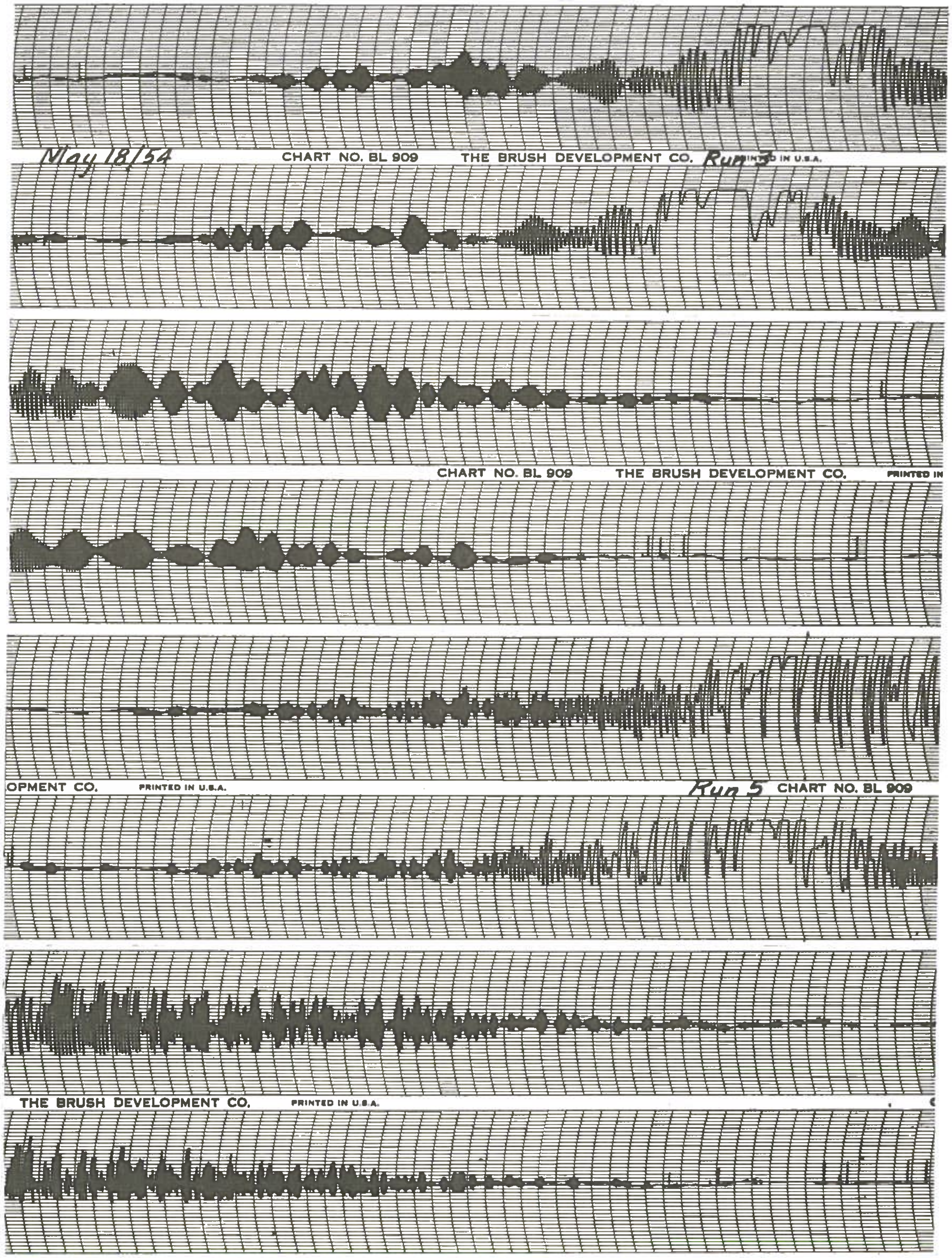
Pair	Run	Location	Heading	Δt (Calculated)	Δt (Measured)
1 & 2	3	.55	188°	4.2	3.9
3 & 4	5	.55	188°	4.2	4.5 $\pm$ .5

Run 3 was five aircraft in a close wing-tip to wing-tip formation.

Run 5 was the same aircraft in a "V" formation.

The scattering in the latter case is much greater, as would be expected.

PLATE 9 SECRET



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DATA FOR PLATE 10

May 18/54.

TRANSMITTER: Beam width 8°
Aimed 098°

RECEIVERS: Beam width 12°
Aimed 278°

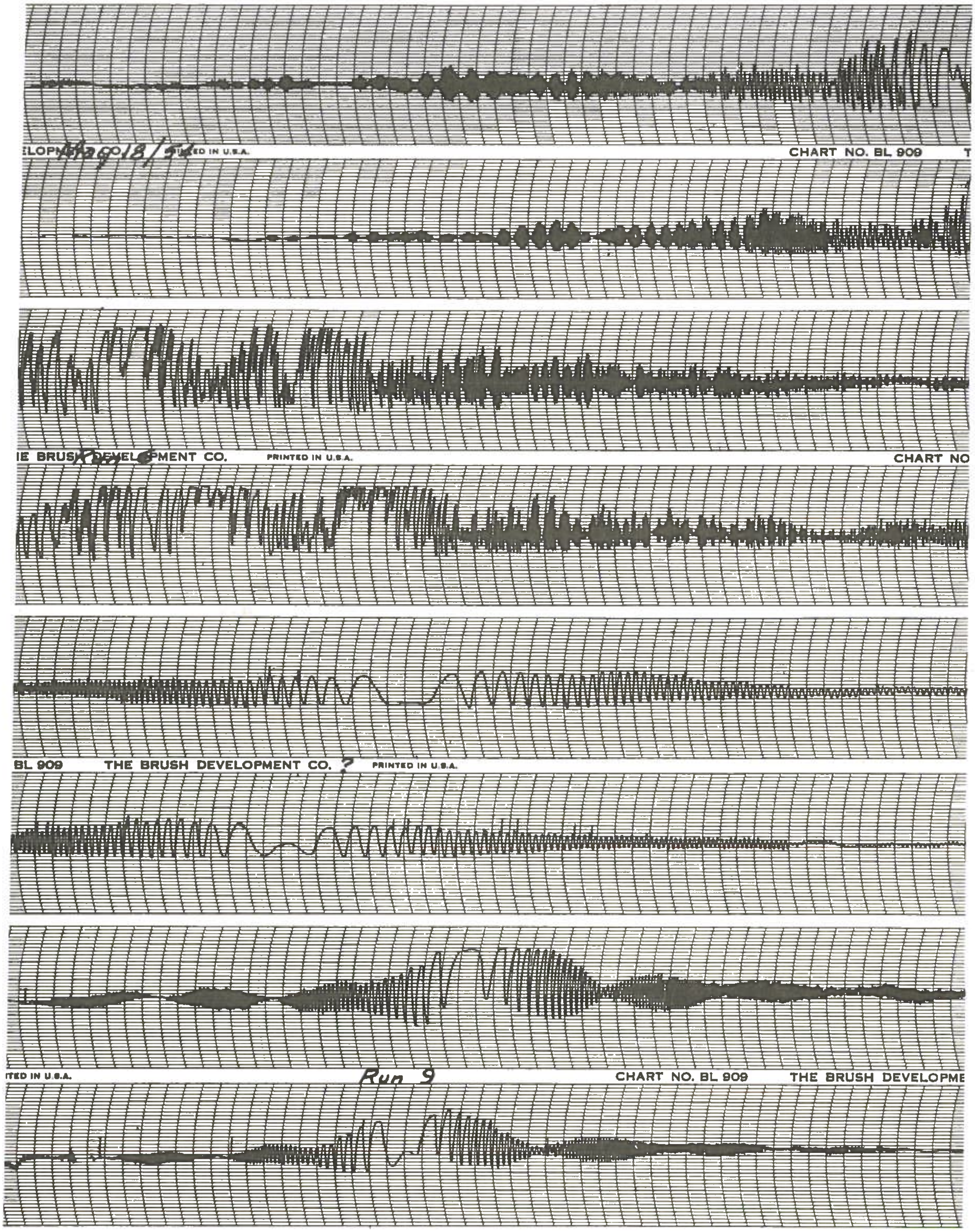
AIRCRAFT: DAKOTAS Altitude - 3000 ft. Speed - 60 m/s

Pair	Run	Location	Heading	Δt (Calculated)	Δt (Measured)
1,2, & 3	6	.55	008	4.2	4.7
4	9	.55	188	4.2	3.6

Run 6 consisted of a loose formation of five aircraft attempting to form a "V", followed closely (in time) by a random aircraft later identified as a Dakota proceeding in a southerly direction.

Run 9 was a single Dakota and shows the pronounced nulls discussed in Report ERA-273.

PLATE 10 SECRET



DATA FOR PLATE 11

May 19/54.

TRANSMITTER: Beam width 8°
Aimed 098°

RECEIVERS: Beam width 12°
Aimed 278°

AIRCRAFT: CF-100 MK III

Speed - 206 m/s

Pair	Run	Location	Heading	Δ t (Calculated)	Δ t (Measured)
1	1	.55	008	1.2	1.2
2	2	.55	188	1.2	1.3
3	6	1.00	188	1.2	---

Altitude Runs 1 & 2 - 2500 ft.

" Run 6 30000 ft.

Run 6 is typical of several crossings when the aircraft was followed visually by means of its contrail but no waveform materialized although the alarms operated. The sharp pulses are associated with the alarm relay.

PLATE II SECRET