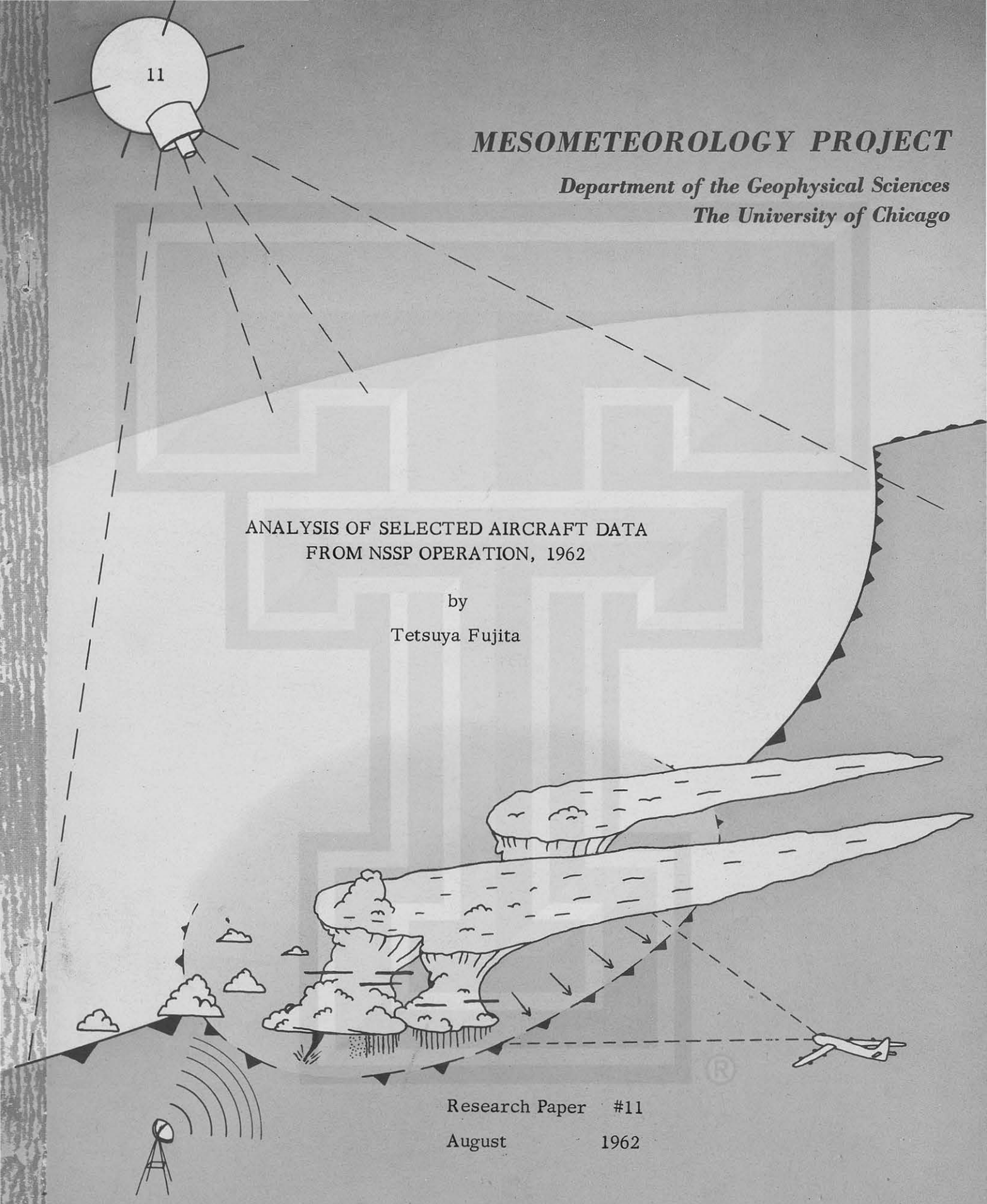

MESOMETEOROLOGY PROJECT

Department of the Geophysical Sciences
The University of Chicago

ANALYSIS OF SELECTED AIRCRAFT DATA FROM NSSP OPERATION, 1962

by

Tetsuya Fujita

Research Paper #11

August 1962

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Serial photogrammetric research of clouds has been sponsored by the National Science Foundation under grant NSF G 18984.

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1. GENERAL STATEMENTS.

In view of the fact that aerial photographs taken from the Weather Bureau's DC-6B by Fujita during the 1961 NSSP operation helped in the understanding of severe local storms and in subsequent investigations, an attempt was made this year to shoot as many aerial photographs as possible. Both Fujita and Ushijima participated in this operation. The period of our participation, only about 10 days during the month of May, was relatively short. However, three cases involving squall lines, isolated thunderstorms, and cumulus streets turned out to be excellent for future research.

Other cases which are not included in this report are:

May 17, 1962 - Fujita and Ushijima flew with a DC-6(40C) obtaining 34 photographs using a 21-mm lens and, 39 using a 25-mm lens. Appearing in these photographs are the distant and close-up views of three groups of thunderstorm cells extending in a horse-shoe shape from west of Dalhart, Texas, to Clovis, New Mexico, and a distinct edge of Sc areas extending north to south half-way between Sharock and Oklahoma City can be detected.

May 18, 1962 - Ushijima attempted to make about 15-position fixes while flying with DC-6(40C). The total number of photographs taken with 25-mm lens is 103.

May 21, 1962 - Fujita photographed 16 frames from B26 using 21-mm lens, while Ushijima, making 5-visual fixes, took 80 photographs with 25-mm lens.

Photographs and other data for these cases are on file in Fujita's office at the University of Chicago and are available upon request.

2. SQUALL LINES OF MAY 22, 1962.

Fujita and Newton flew with DC-6(39C). Unfortunately, the Doppler navigation system developed some difficulties and shortly after departing from Bartlesville VOR it failed to function. The flight path presented in Fig. 1 was determined with the use of approximately 60-visual fixes obtained by Fujita during the flight. The circles in the figures are those fixes with their time given in hours (CST), minutes, and seconds.

The plane departed from the Oklahoma City VOR and climbed to 9,000 ft. on course to Tulsa, Oklahoma. Thereafter the altitude was kept at about 9,000 ft. until a climb to 18,000 ft. was made while circling over Barlesville, Oklahoma. Investigation of a squall line extending south-southwest from Kansas City was performed from the 18,000 ft. level.

A total of 185 pictures (21-mm lens) taken by Fujita is listed in Table I. The table includes the frame numbers, the time of exposures, and the direction of the principal lines. The direction represents the azimuth of picture centers as viewed from the camera. When the direction is accurate within a possible error of up to five degrees, the suffix "due" is used. The direction such as N 10 W indicates that the principal line is oriented 10 degrees toward the west when measured from the true north. Magnetic north was not used as a reference to the principal lines. The hours 03h, 09h, ..., were used to indicate the relative azimuth of principal lines with respect to the aircraft, the heading being 12h. This type of azimuth determination is usually necessary when the flight is made over an undercast area where no ground references are available. Typical photographs are shown in Fig. 2.

Given in Table II are the visual fixes, the accuracy of which falls within one statute mile. Statute miles, true north and magnetic north are abbreviated as SM, N and N', respectively. These fixes were made by estimating the distance of the aircraft subpoint with the aid of section lines on the ground which are usually laid out at about one-statute-mile intervals.

Results of preliminary rectification of these photographs are presented in Figs 3-7. In all figures large areas of convective clouds with their bases below

10,000 ft. are stippled. Hatched areas represent other clouds including anvils whose bases are above 10,000 ft. It should be pointed out that these cloud charts were constructed through a crude photogrammetry, and are subject to revision when more exact photogrammetric analyses are completed in the future.

On board the B-26 piloted by Cook, Ushijima took 22 pictures as indicated in Table III. While taking pictures, the 11 visual fixes listed in Table IV were obtained. No charts were prepared at this stage since the B-26 navigation and meteorological data are now being processed at NSSP.

Two types of convective systems in lines were documented during these flights. One was a line (band) of altocumulus castellanus with its base along the western edge at about 16,000 ft. and its western edge sloping up to 30,000-ft. MSL, where it indicated a cirrostratus appearance. The total width of the band was between 40 and 60 miles. There were disorganized mammatus and scattered showers along the western edge of the band. No more than 1/10 of cumulus clouds were in existence beneath this high level convective cloud to the south of the 36^{o} parallel. To the north, however, there was a vast area of stratocumuli extending beneath the band of altocumulus castellanus forming two distinct layers of convection separated by clear air.

The second type was a cumulus to cumulonimbus convection in a long line oriented almost parallel to the above mentioned high-level convection system. The zone between these two convection lines, separated by approximately 50 miles, was relatively clear with 1 to 3 tenths of cumuli either scattered or in streets. Due to the rapid development of cells, only one active portion of the squall line was circled only once.

As a result of the DC-6 borne Doppler failure, it is rather difficult to determine the wind field around the squall line. It seems feasible, however, to obtain the wind fields averaged over the distance between two reliable visual fixes.

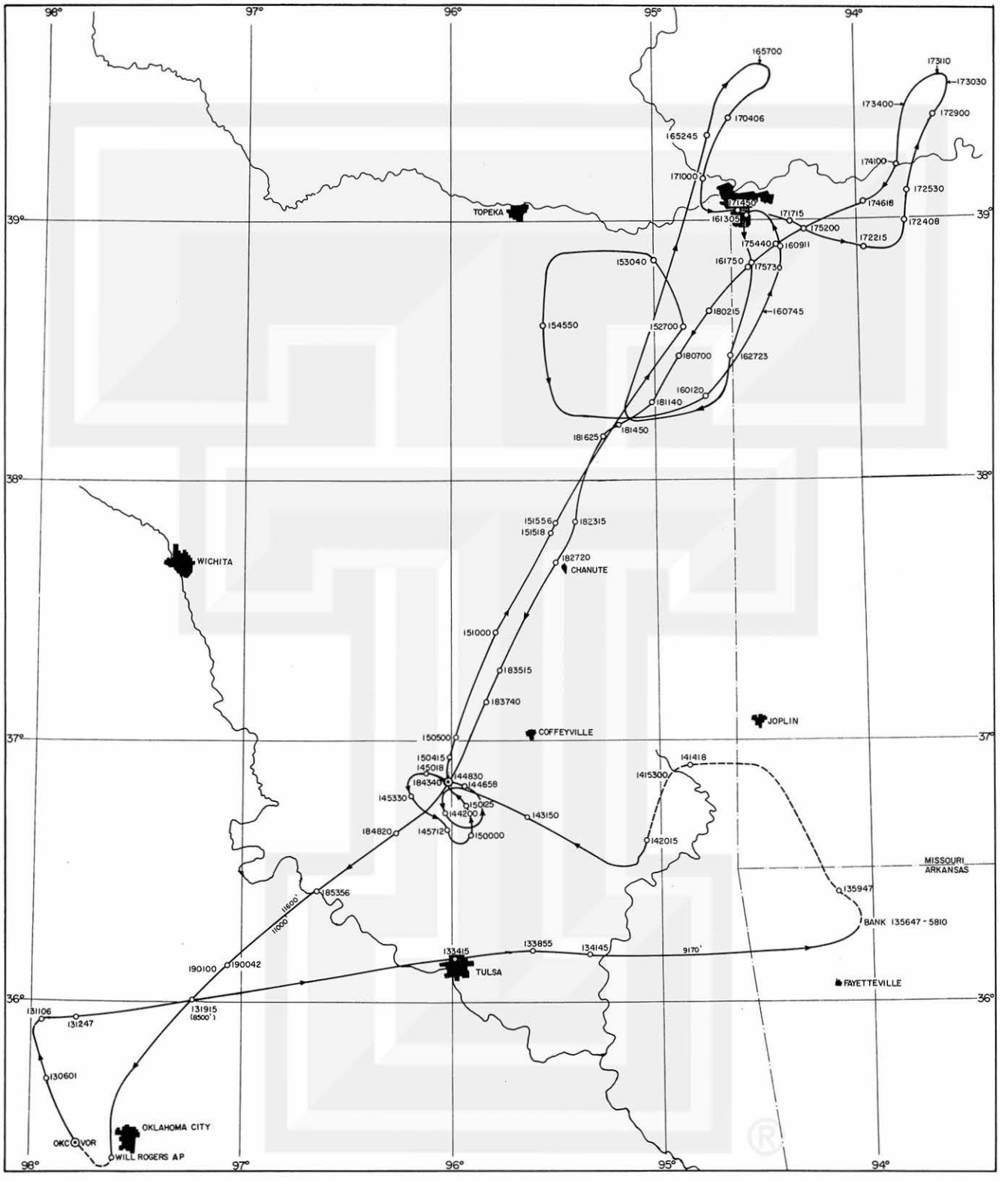

Fig. 1. Flight path of DC-6(39C), May 22, 1962, fixed visually by Fujita.

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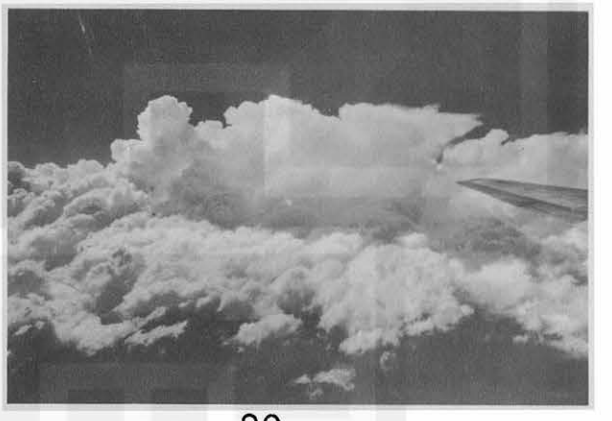

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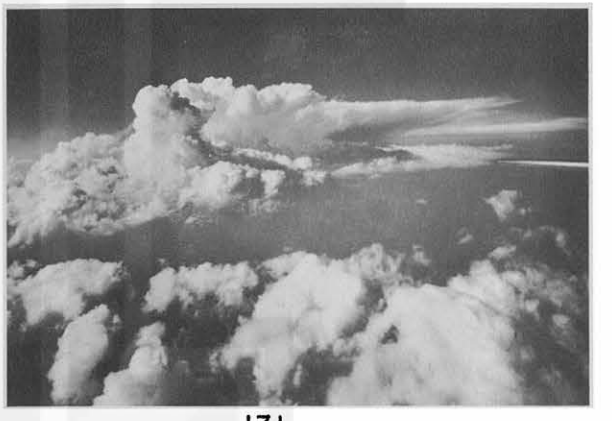

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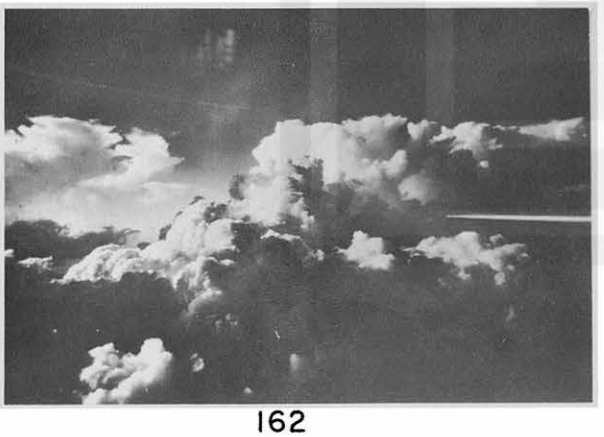

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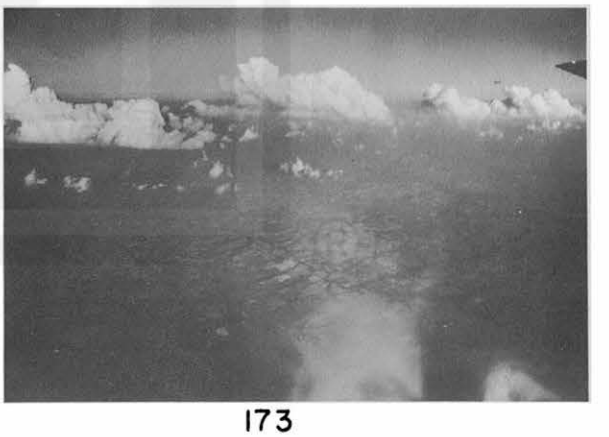

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Fig. 2. Typical cloud photographs taken by Fujita with a 35-mm camera (21-mm lens) during the 39C flight on May 22, 1962.

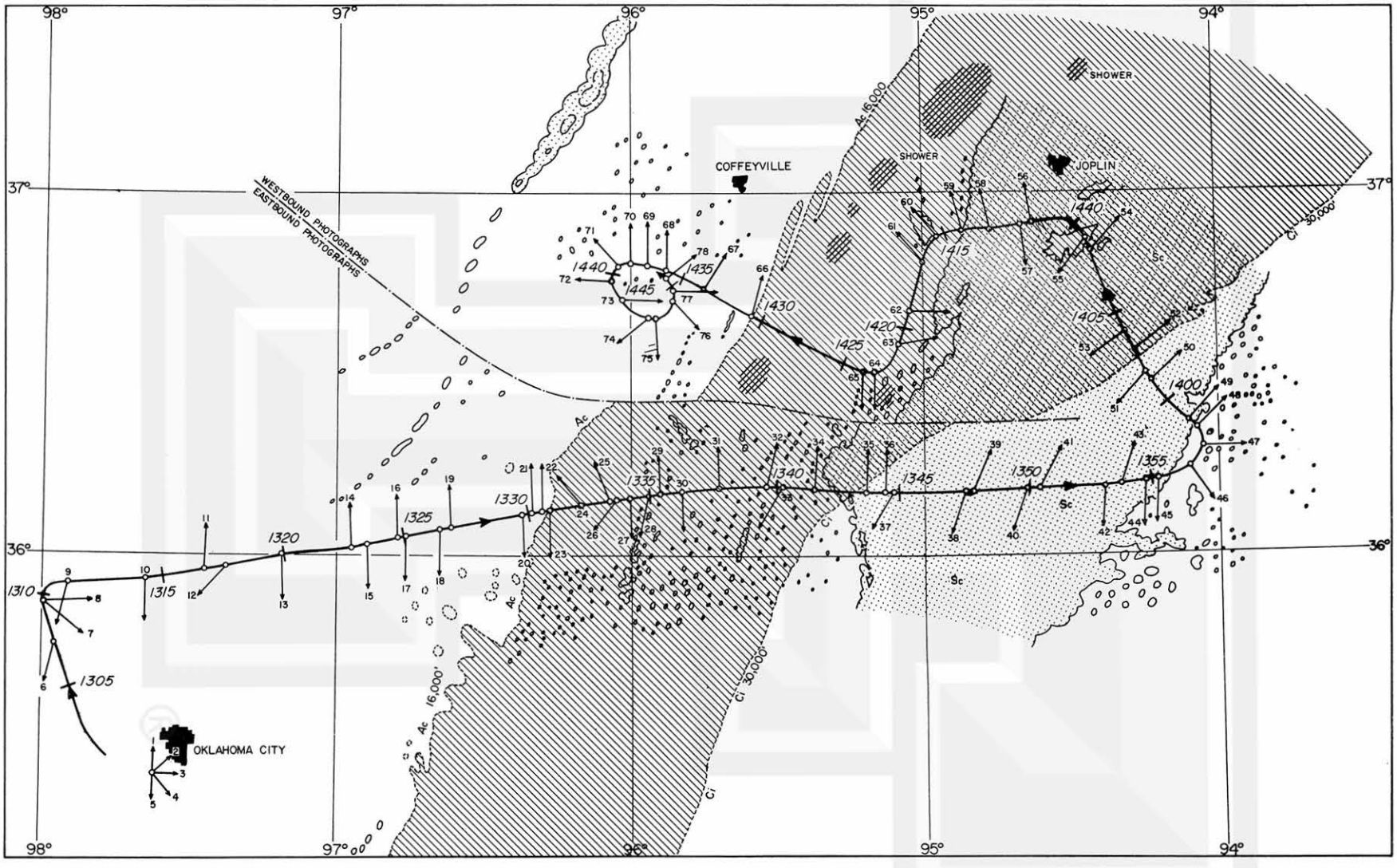

Fig. 3. Altocumulus castellanus and altostratus in a wide band. 1305-1455 CST, May 22, 1962.

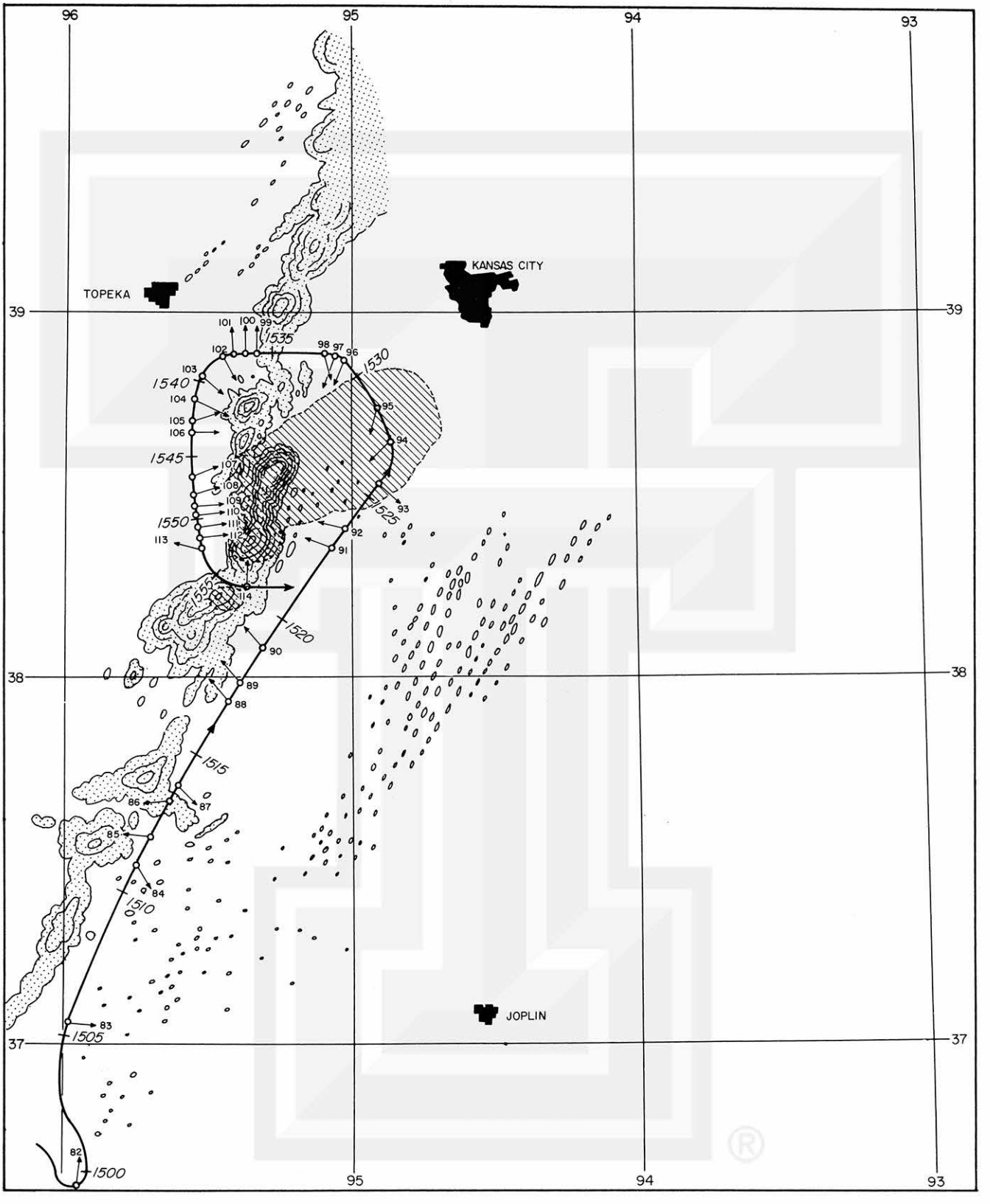

Fig. 4. Flight along a squall line in pre-mature stage southwest of Kansas City. 1500-1600 CST, May 22, 1962.

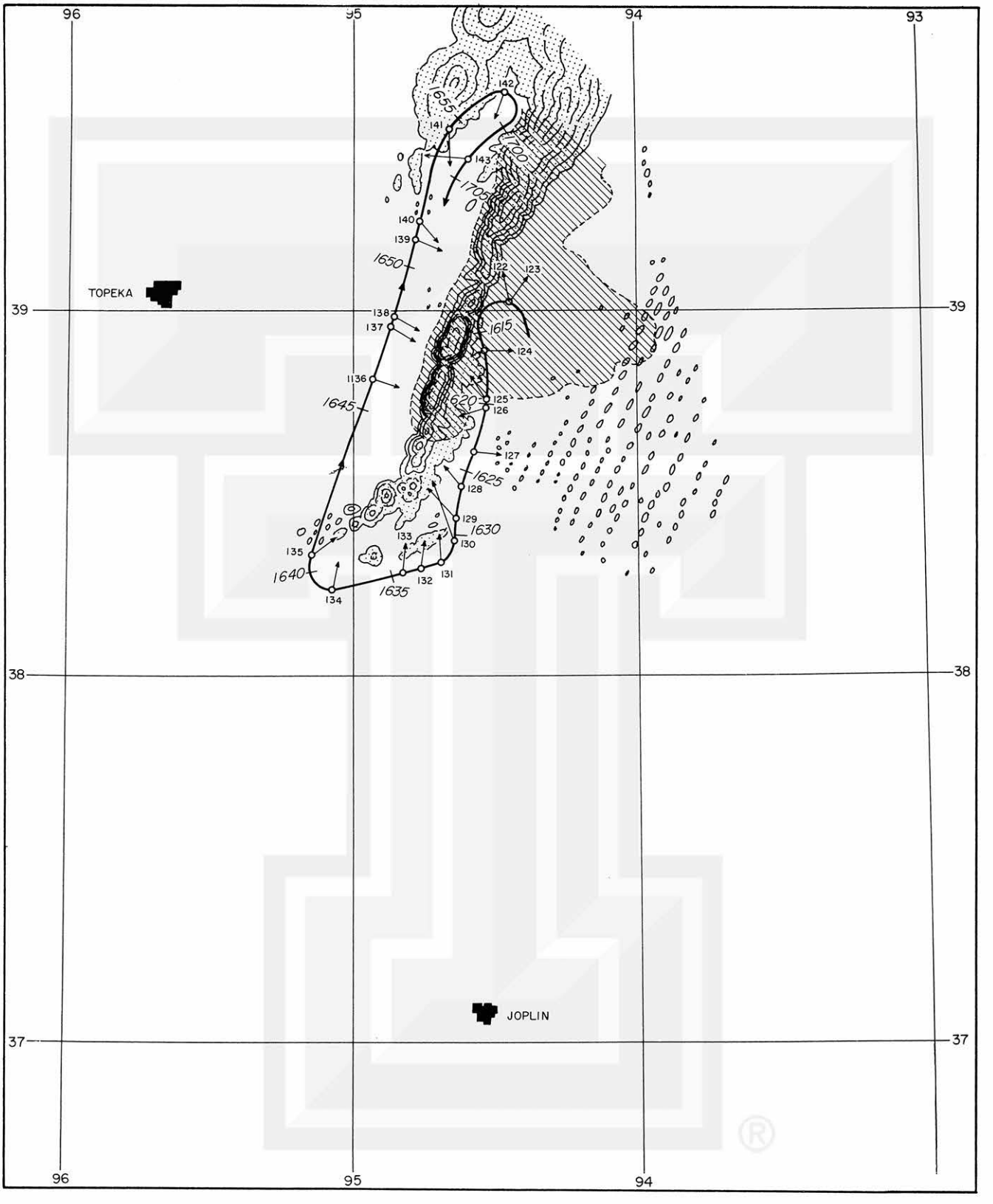

Fig. 5. Mature squall line near Kansas City. No penetration was made in view of the expected turbulence with possible hail. 1610-1705 CST, May 22, 1962.

Fig. 6. Intense activity northeast of Kansas City. A hook shaped echo was observed by an airborne radar. 1705-1735 CST, May 22, 1962.

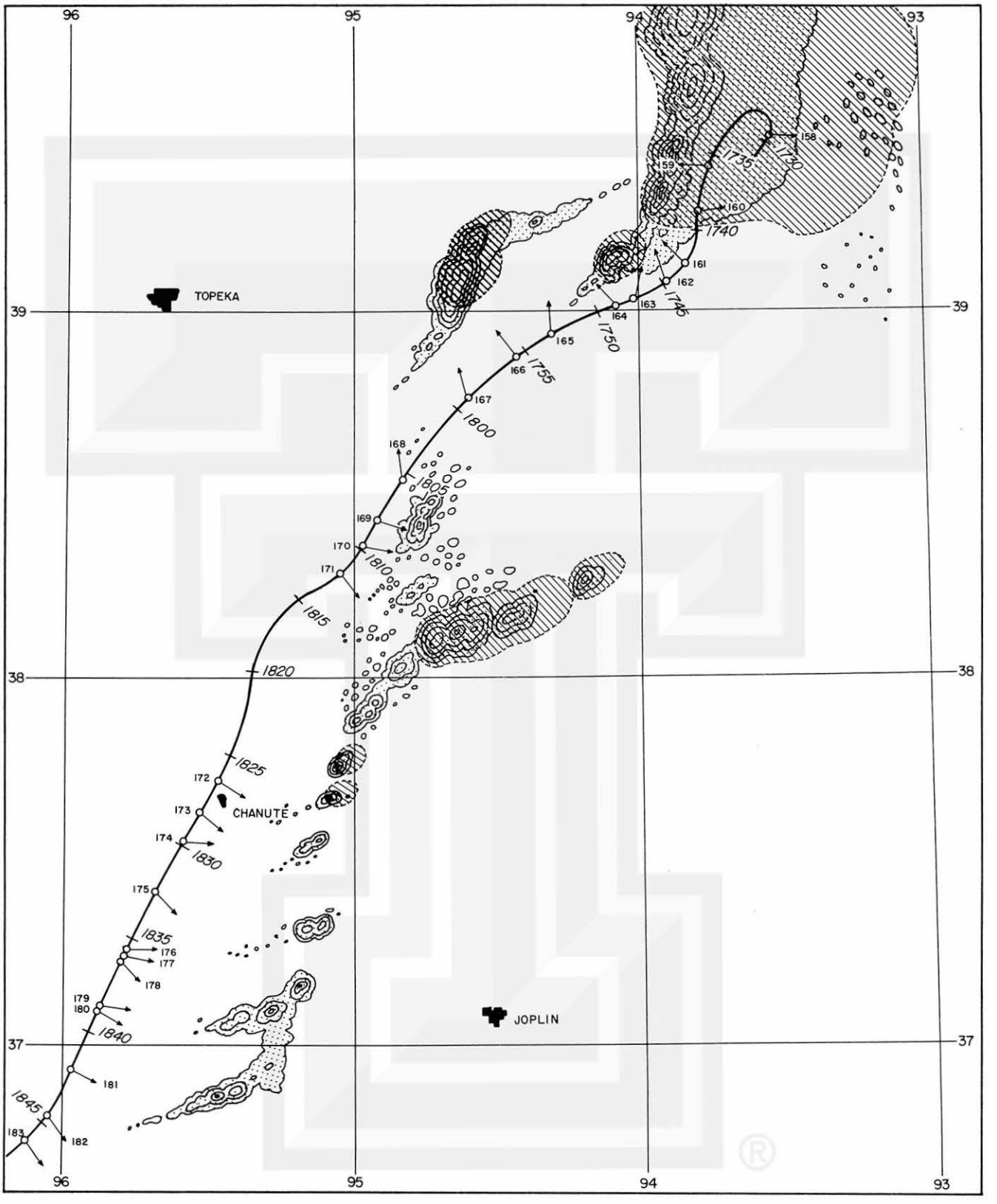

Fig. 7. Southwestern end of a squall line extending from near Kansas City to Tulsa. 1730-1845 CST, May 22, 1962.

Frame No.	Time	Principal Line	Frame No.	Time	Principal Line	Frame No.	Time	Principal Line
1	122600	N	65	142355	due S	130	163014	NNW
2	122602	NE	66	143030	NNE	131	163205	N
3	122604	E	67	143325	NE	132	163320	N
4	122608	SE	68	143624	due N	133	163425	N
5	122610	S	69	143727	N	134	163810	N 10 E
6	130730	SSW	70	143905	due N	135	164025	NE
7	130948	SE	71	143956	NW	136	164605	ESE
8	130952	E	72	144032	due W	137	164751	ESE
9	131142	SSW	73	144135	E	138	164815	ESE
10	131404	due S	74	144325	SW	139	165059	ESE
11	131652	N	75	144344	S	140	165135	SE
12	131740	SW	76	144425	SE	141	165440	S
13	132000	due S	77	144500	E	142	165700	SSW
14	132248	N 10 W	78	144545	NE	143	170325	WSW
15	132315	due S	79	144605	N	144	170510	WNW
16	132430	due N	80	145044	NNE	145	170625	ENE
17	132500	due S	81	145628	due E	146	170717	SE
18	132616	due S	82	145903	NNE	147	170802	E 10 S
19	132650	due N	83	150528	due E	148	170850	due E
20	132945	due S	84	151115	SE	149	171120	due E
21	133008	due N	85	151209	due W	150	171315	NNE
22	133038	due N	86	151312	due W	151	171320	NE
23	133059	due S	87	151350	SE	152	171525	N 10 E
24	133209	NW	88	151650	NW	153	171715	N 5 E
25	133310	due NNW	89	151720	NW	154	171935	NNE
26	133345	SW	90	151825	NW	155	172050	NNE
27	1333xx	S	91	152245	WNW	156	172308	NNW
28	133458	due SSW	92	152330	WNW	157	172751	WSW
29	133527	due N	93	152603	SE	158	173015	due E
30	133618	due S	94	152745	SW	159	173540	W
31	133741	due N	95	152850	SSW	160	173850	E
32	133935	due N	96	153111	SSW	161	174255	NW
33	134022	SW	97	153130	SSW	162	174500	NNW
34	134118	due N	98	153155	SSE	163	174730	N
35	134318	09h	99	153606	N	164	174859	NW
36	134410	due N	100	153650	due N	165	175320	due N
37	134430	due SW	101	153735	N	166	175540	NW
38	134720	03h	102	153807	SE	167	175915	NNW
39	134740	09h	103	153947	SE	168	180520	N 5 W
40	135000	03h	104	154114	SE	169	180810	ESE
41	135028	09h	105	154225	ENE	170	180955	E 10 S
42	135318	03h	106	154315	due E	171	181206	SE
43	135347	09h	107	154641	ENE	172	182635	SE
44	135448	03h	108	154804	ENE	173	182822	SE
45	135625	S	109	154835	due E	174	182957	due E
46	135710	SE	110	154950	due E	175	183234	due SE
47	135735	due E	111	155040	due E	176	183600	NE
48	135803	due NE	112	155125	due E	177	183603	E
49	135833	due NE	113	155235	WNW	178	183606	SE
50	140124	03h	114	155605	NNW	179	183842	due E
51	140156	09h	115	155725	NNE	180	183845	due SE
52	140305	03h	116	155810	SW	181	184203	ESE
53	140410	09h	117	155945	due N	182	184443	SE
54	140823	03h	118	155950	NE	183	184615	due SE
55	140900	09h	119	160212	NW	184	185015	due SE
56	141215	03h	120	160343	due W	185	185445	SSE
57	141240	09h	121	160430	due SE			
58	141334	03h	122	160820	ESE			
59	141418	NNW	123	161120	NNE			
60	141530	NW	124	161622	due E			
61	141635	NW	125	161950	NW			
62	141851	S	126	162015	WSW			
63	142117	E	127	162330	ESE			
64	142312	due S	128	162606	NW			
			129	162813	NW			

Table I. List of 35-mm photographs by Fujita on board DC-6(39C), May 22, 1962. Focal length: - 21 mm

Time	Visual Fixes	Time	Visual Fixes
130601	2-1/4 SM E of Y intersection, 3 SM SSE of Okarche	161305	About 4 SM SE of downtown Kansas City
131106	4 SM N of Kingfisher	161750	1 SM E of Richards-Gebaur AP
131247	Cross Cimarron River flow S, 10 SM N 50 E of Kingfisher	162723	2 SM W of Drexel
131915	3 SM N of Coyle	165245	On highway 4 SM N of MID Continental Intl. AP
133415	2 SM NW of downtown Tulsa	170406	Cross river 8 SM N'30 W' of Kansas City VOR
133527	3 SM W'10 S' of Tulsa VOR	171000	South bank of river 7 SM W'10 N' of Fairfax AP
133855	Cross river flow W, 9 SM E'10 S' of Tulsa VOR	171450	3 SM S, 1 SM W of downtown Kansas City
134145	Directly over Chouteau	171715	5-1/2 SM S'35 W' of Blue Springs VOR
135947	5 SM NE of Bentonville	172215	10 SM S of Odessa
141418	2 SM NE of Miami	172408	Heading N on 4 lane highway
141530	5 SM W of Miami	172530	3-1/2 SM NNW of Higginsville
141851	Due W of Afton	172900	About 6 SM WNW of Carrollton
142015	On highway 5 SM ESE of Vinita	174100	Cross river 4 SM E, 2-1/2 N of Lexington
143150	1 SM N of Nowata	175200	6-1/2 SM S'10 E' of Blue Springs VOR
144200	Cross river flow E, 3 SM S of Bartlesville AP	175440	8 SM E, 4 SM N of Richards-Gebaur AP
144658	2-1/2 SM N of Dewey	175730	2-1/2 SM SE of Richards-Gebaur AP
144830	Over Bartlesville VOR	180215	4 SM NW of Louisburg
145018	Cross railroad 6 SM W'20 N' of Bartlesville VOR	180700	Cross river 6 SM S of Paola
145330	11 SM W'25 S' of Bartlesville VOR	181140	12-1/2 SM E, 2 SM N of Garnett
145712	7 SM S of Bartlesville AP	181450	5 SM SE of Garnett
150000	Cross river flow ESE, 1-1/2 E of N-S highway	181625	7 SM S, 1/2 SM W of Garnett
150125	3 SM S, 1/2 SM E of Dewey	182315	4 SM S of Iola
150415	Cross railroad 6 SM N'10 W' of Bartlesville VOR	182720	2 SM W of Chanute AP
150500	2-1/2 SM W of Caney	183515	5-1/2 SM NW of Independence
151000	Due W of Neodesha	183740	3 SM W, 1 SM S of Independence AP
151518	Due W of Humboldt	184340	Over Bartlesville VOR
151556	3-1/2 SM NW of Humboldt	184820	1 SM S, 4 SM E of Pawhuska
152700	2-1/2 SM NE of Paola	185356	Cross river flow E, 3-1/2 SM S, 1 SM E of Hudson Ranch AP
153040	5 SM W, 2 SM N of Olathe AP		
154550	3 SM NW of Quenemo	190042	Cross highway 2 SM NNW of Stillwater
160120	1 SM SE of La Cygne	190100	2 SM NW of Stillwater
160911	Over town 9 SM E, 4 SM N of Richards-Gebaur AP		

Table II. List of visual fixes by Fujita on board DC-6(39C), May 22, 1962. Time is given by hour (CST), minute and second.

Frame No.	Time	Principal Line	Frame No.	Time	Principal Line	Frame No.	Time	Principal Line
1	145613	E	8	160258	SE	16	162536	N
2	145830	SW	9	161328	S	17	163420	N
3	150027	SW	10	162114	WNW	18	163911	E
4	150401	N	11	162150	WNW	19	164020	E
5	153142	NW	12	162212	WNW	20	165852	SE
6	154437	E	13	162233	WNW	21	165910	SSE
7	155510	E	14	162457	ENE	22	170313	S
			15	162521	ENE			

Table III. List of 35-mm photographs by Ushijima on board B-26, May 22, 1962. Focal length: - 25.5 mm

Time	Visual Fixes	Time	Visual Fixes
142426	Directly over Cushing	164400	20 SM E of Ottawa
145000	Over Gibson Res.	164802	1 SM S of Osawatomie
153330	Over Chanute VOR	165400	Over Ottawa VOR
155405	Over Ottawa VOR	171500	Over Fall River Lake
160305	3 SM E of Paola	174410	Over Ponca City
161806	2 SM W of Garnett		

Table IV. List of visual fixes by Ushijima on board B-26, May 22, 1962.

3. ISOLATED THUNDERSTORMS OF MAY 24, 1962.

While flying with the DC-6(39C), Fujita and Ushijima split responsibilities in data collection. While Ushijima was keeping records of navigation data, Fujita photographed 72 pictures as tabulated in Table V. One of the objectives of this particular flight was to compute vector differences of Doppler and visual fixes which were learned to be rather large. 74 visual fixes were made by Fujita during the six-hour flight making it possible to obtain frequently the actual drift in Doppler positions. Table VI indicates these fixes. Ushijima, who stayed with the navigation instrument throughout the entire flight, made exact records of Doppler fixes so that they could be compared with the visual fixes upon termination of the flight.

The quick result thus obtained by comparing Doppler and visual fixes appears in Fig. 8. The actual flight path obtained by a series of visual fixes (open circle) is shown in heavy lines. Indicated by painted circles are the Doppler fixes corresponding to each visual fix. Now the vector difference was obtained by subtracting the position vectors of visual fixes from those of Doppler fixes, thus

$$\Delta D = G - D,$$

where vectors G, D and ΔD represent, respectively, the visually fixed position, Doppler position and the vector difference of these positions. Attempt was made to calculate both x and y components of this vector difference ΔD.

The result of calculations as tabulated in Table VII turned out to be of extreme interest. When the plane departed from the Oklahoma City VOR at 1217 CST, there was no error in the Doppler position. As the time went on both x and y components of ΔD varied non-linearly throughout the period of flight, reaching the maximum error of $\Delta x = +30.0$ and $\Delta y = -9.4$ shortly before landing at the Will Rogers Airport.

Presented in Fig. 8 are the changes in time of Δx, Δy, and the magnetic heading of DC-6(39C). As a result of possible errors in visual fixes and interpolated Doppler fixes, some scatter of data points is unavoidable. Nevertheless, the smoothed curves

indicate non-linear variations which are closely related to the aircraft heading. There were no jumps in Δx and Δy during any steep banks. However, their time derivatives changed appreciably after each turn.

It is important to realize that the vector sum of the true air speed, T, and the wind velocity, V, are equal to the ground speed of the aircraft. Thus we have

$$T + V = \frac{\partial G}{\partial t} .$$

Putting the vector error of Doppler into the above, we obtain

$$\frac{\partial D}{\partial t} - T = V - \frac{\partial \Delta D}{\partial t} .$$

The left side of this equation represents the wind velocity measured by Doppler. Denoting this wind velocity by V_D , the Doppler wind, we obtain both x and y components of navigation errors, thus

$$V = V_D + i \frac{\partial \Delta x}{\partial t} + j \frac{\partial \Delta y}{\partial t} .$$

These components obtained from Fig. 9 are shown in Table VIII in which also appear the absolute values of wind errors and their directions. They should be added in vector form to the Doppler winds in order to obtain the true winds.

Another phenomenon observed while flying with 39C was an isolated area of cumulonimbus convection initiated near Wellington, Texas. The shadows of the edge of anvil tops were mapped three times between 1440 and 1740 while flight was made around the activities. The areas of shadow mapped between 1400 - 1530 (Fig. 10) indicate the development stage of the main anvil cloud drifting out from three major cells. A small cumulonimbus to the north of the major ones was about to form an anvil top.

When the second trip around the area of activities was made, the major and the new cells merged into a large but isolated system including three large echoes detected by airborne radar (Fig. 11). Typical mamatos and some virga were hanging from the anvil base extending east from the areas of major activity.

The last flight made around the system (Fig. 12) revealed that the anvil covered

such a large area that the whole system looked like a squall line extending through considerable distances. The area, even at this stage, was surrounded by relatively clear areas suggesting that the system under investigation was rather similar to the square-looking cloud appearing on the TIROS I photograph of May 19, 1960.

In view of the fact that the system moved over the area of NSSP network during the evening hours, an organized research of this case will be made by means of mesosynoptic, aerial photogrammetric and radar analyses.

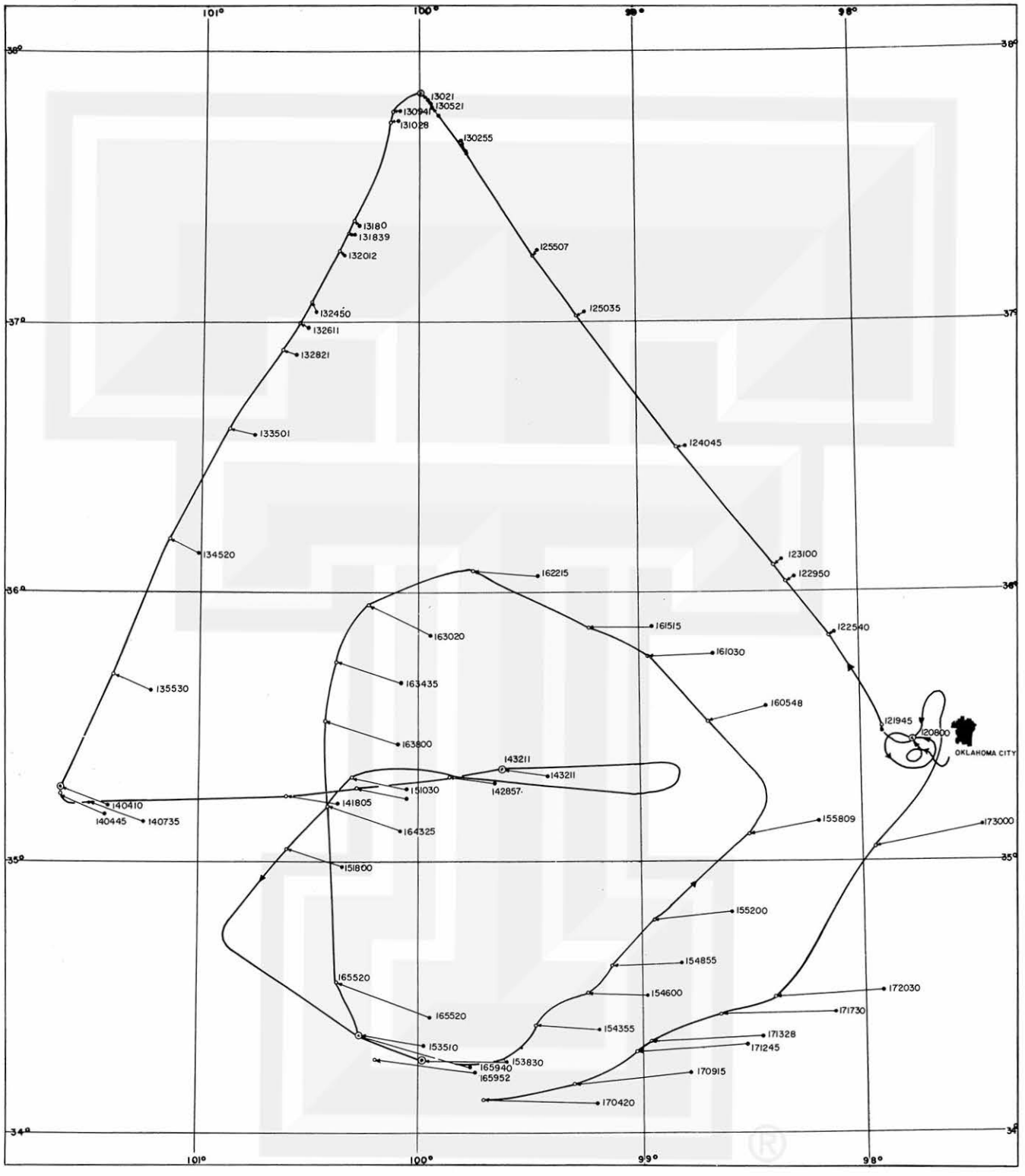

Fig. 8. Flight path of DC-6(39C), May 24, 1962, fixed visually by Fujita, and the vector error (Doppler-Ground Fixes).

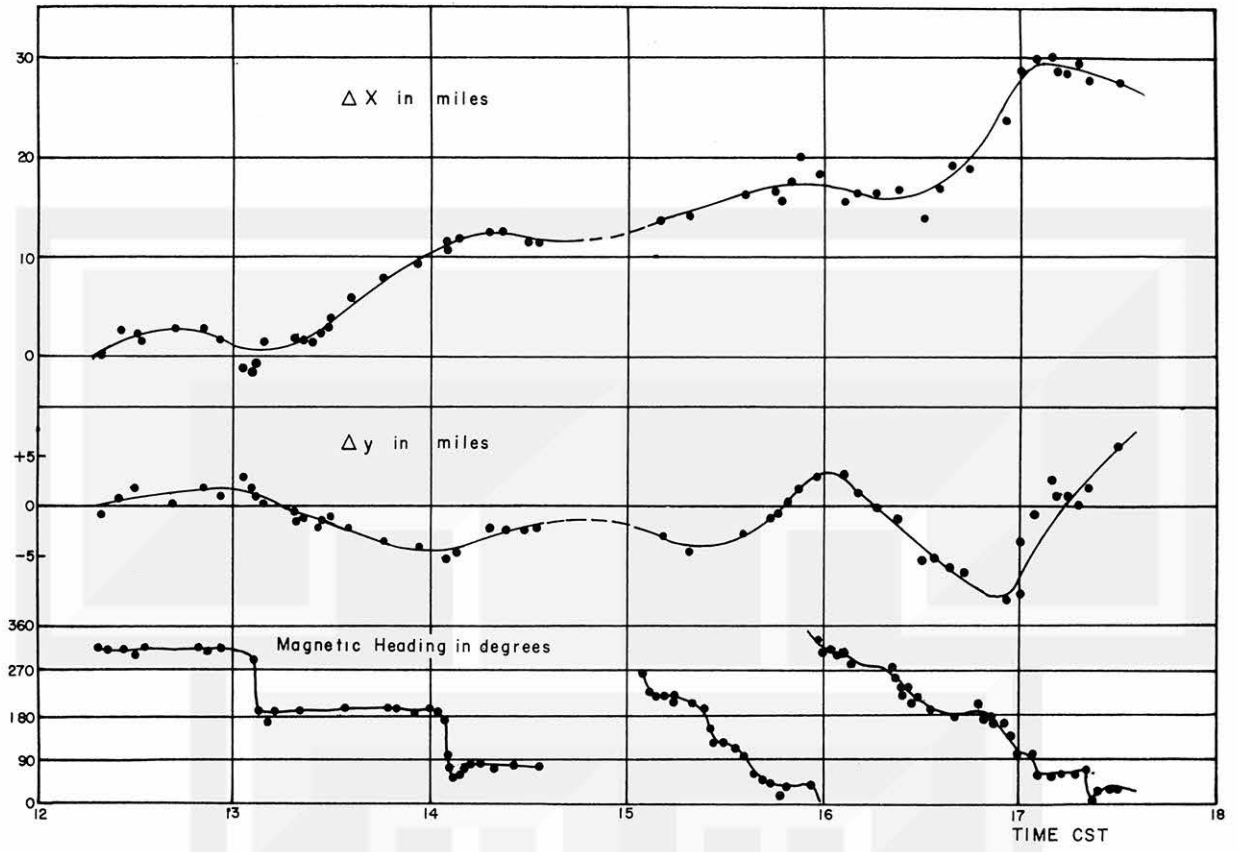

Fig. 9. Both x (east) and y (north) components of vector error of Doppler fixes. Sharp banks of the aircraft do not add much error to these components, instead, the rate of change in these components varies appreciably after significant turns.

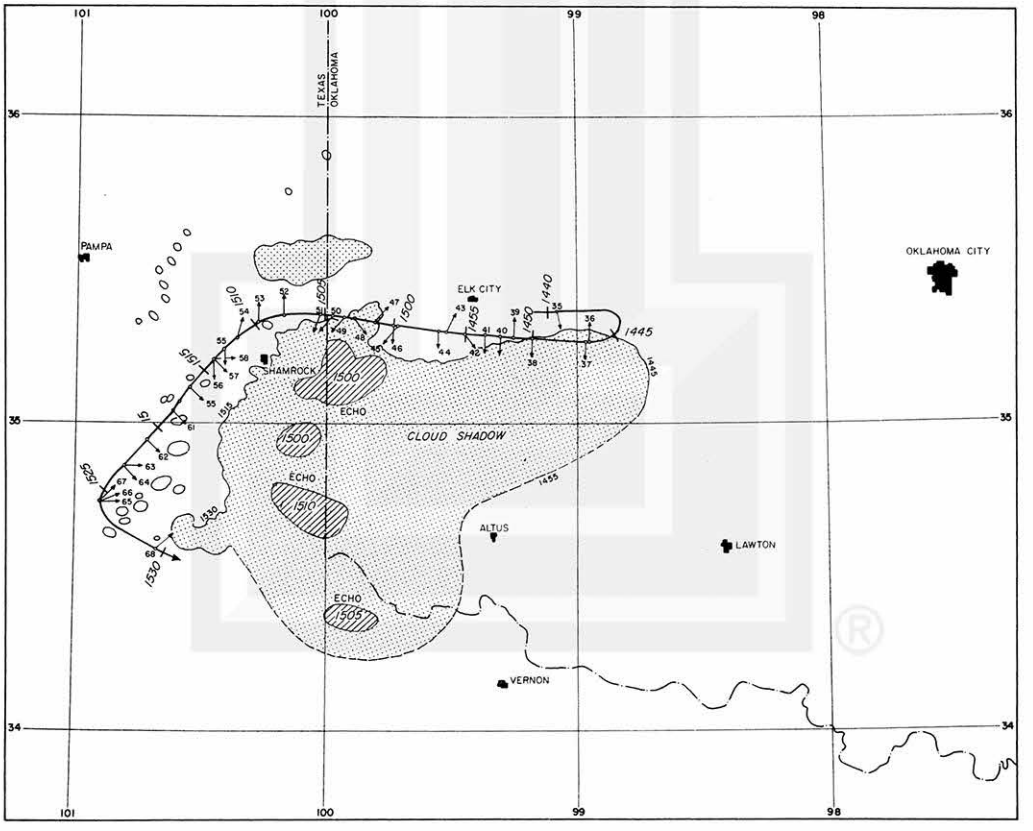

Fig. 10. Cloud shadows determined by Fujita while flying around an isolated large convective system of May 24, 1962. Hatched areas represent echoes from Conover's sketches of airborne radar scopes. Time in CST.

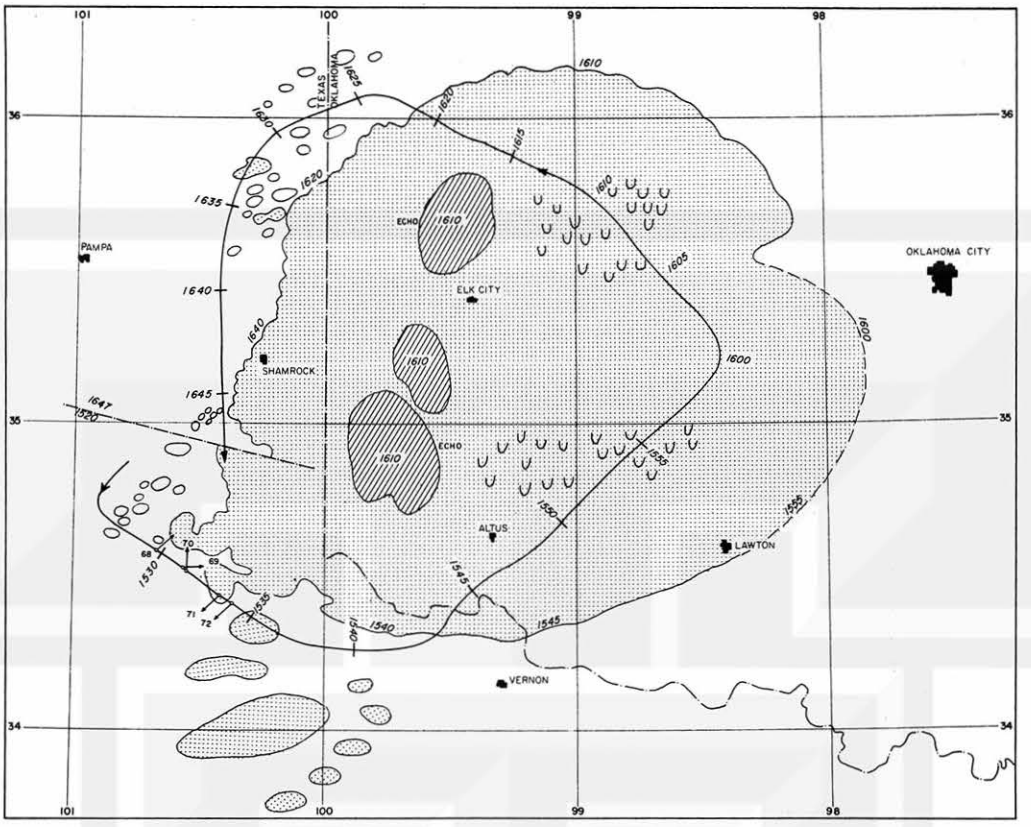

Fig. 11. The development of shadows observed during the second run around the nephsystem. A small anvil to the north of the main system now merged while growing rapidly. May 24, 1962.

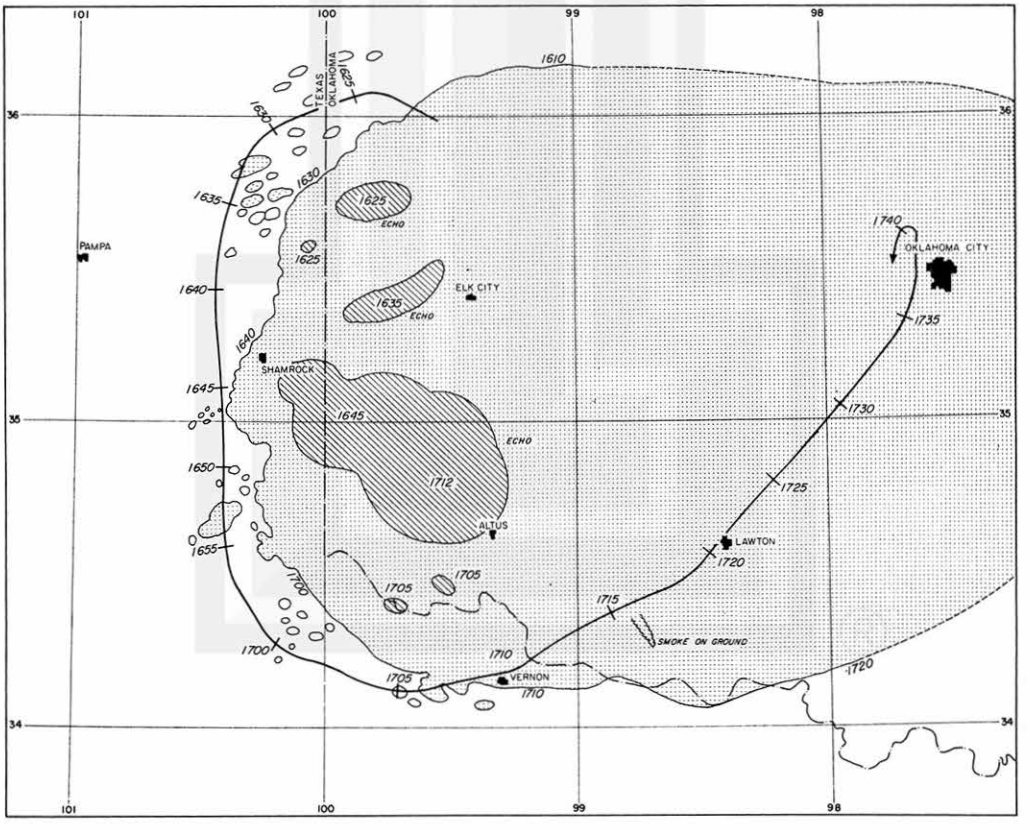

Fig. 12. The shadows as observed during the last flight around the areas of intense activities. Tornadoes and high winds were in progress near Altus. May 24, 1962.

Frame No.	Time	Principal Line	Frame No.	Time	Principal Line	Frame No.	Time	Principal Line
1	120850	due S	25	142647	due N	49	150339	SW
2	121006	due E	26	143440	due N	50	150425	SW
3	122344	due E	27	143520	NE	51	150514	SSW
4	122723	ENE	28	143530	NNE	52	150807	due N
5	123420	NE	29	143541	N	53	150955	due N
6	124630	SSW	30	143551	NNW	54	151200	E 10 N
7	125215	ENE	31	143728	due N	55	151253	due S
8	125410	WSW	32	143811	SSE	56	151400	S
9	131028	due E	33	143851	S	57	151402	SE
10	131629	ESE	34	143944	due S	58	151404	E
11	132237	E	35	144036	due SSE	59	151645	SE
12	133636	ESE	36	144655	due N	60	151725	due E
13	134928	SE	37	144658	due S	61	151850	ESE
14	135615	E	38	145006	due S	62	152125	SE
15	140030	SE	39	145158	due N	63	152300	E
16	140155	SE	40	145235	due S	64	152302	SE
17	140845	due S	41	145336	due S	65	152543	E
18	140941	due N	42	145459	SE	66	152545	ENE
19	141747	SSW	43	145622	NNE	67	152547	NE
20	141850	due N	44	145648	due S	68	152930	NE
21	141915	SSW	45	145956	SW	69	153115	E
22	142155	due N	46	145958	S	70	153145	due N
23	142437	SSW	47	150141	NE	71	153305	SW
24	142615	SSW	48	150251	SE	72	153345	SW

Table V. List of photographs taken by Fujita on board DC-6(39C), May 24, 1962.

Time	Visual Fixes	Time	Visual Fixes
120705	4 SM E'45 S' of Oklahoma City VOR	142857	Due N of Erick
120800	Over Oklahoma City VOR	143211	Over Sayre VOR
121242	1/2 SM S of railroad bridge NE of Tuttle	143851	1 SM N of Clinton Sherman AP, 4435 HD SW
121426	3 SM W of Will Rogers AP	144513	1 SM S, 7 SM E of Cordell
121657	Over Oklahoma City VOR	145826	2 SM N of Sayre
121823	5 SM W'20 S' of Oklahoma City VOR	151030	Cross North Fork Red R. 8 SM NNW of Shamrock
121943	1 SM E of intersection US 66 and 81, 2 SM SE of El Reno	151800	Cross river 12 SM due S of McLean; 2440 starts left bk
122540	Over highway bend 15 SM E of Watonga	152734	Cross Tex 256
122950	Over railroad N of Hitchcock	153510	Over Childress VOR
123100	Cross railroad W of Okeene	153830	Over Lazare
124045	3 SM NE of bridge, 4 SM S of Waynoka	154355	Cross Red River 10 SM ESE of Eldorado
125035	Over highway corner 16 SM S, 2 SM E of Coldwater	154600	Over Altus VOR
125507	Due W of Coldwater	154855	Over Headrick
130207	SW of Ford	155200	5-1/2 SM SE of Roosevelt
130255	2-3 SM W of Ford	155809	4-1/2 SM E of Carnegie; 5900 starts left bk
130517	2-1/4 SM W of Wright	160548	Over Weatherford: 0945 starts left bk
130621	Cross river E'30 S' of Dodge City VOR	161030	6-1/2 SM S of Putnam; left bk ends
130647	Start left bank past VOR	161515	7 SM E of Leedey
130731	Heading W: 0810, HD SW; 0913, HD S	162115	3 SM S of Arnett; 2135 starts left bk
130941	Over Ford County AP	163020	About 4 SM SE of Glazier
131028	Due W of Dodge City	163435	On highway 4 SM S of intersection US 83 and 60
131802	Due W of Fowler	163800	1 SM W of Mobeetie
131839	Cross highway N of Meade	164325	On US 66, 10 SM W of Shamrock
132012	3 SM W of Meade	165520	3-1/2 SM E, 2 SM N of Estelline; left bk starts
132450	2 SM W, 1 SM N of 2735 ft. tower	165940	Over Childress VOR
132611	Cross Cimarron River	165952	8 SM S'45 E' of Childress VOR
132821	On US 64, 5 SM W of Forgan	170420	Cross Tex 283, 2 SM N of Pease R. Bridge
133501	2 SM W of intersection US 83 and Okla. 3	170915	Cross Pease R. 2-1/2 SM NNW of Vernon
134425	Cross Tex 15	171245	Cross US 183
134520	1 SM E of Spearman	171328	1 SM S of Frederick AP
135530	1 SM W of Borger AP	171730	1 SM N of Chattanooga
140410	Over Amarillo VOR	172030	Over Lawton VOR
140445	Over St. Francis	173000	1/2 SM NW of Chickasha
140735	5 SM W, 1 SM N of Conway	173405	6 SM E of Tuttle
141850	2 SM N of McLean	173535	2 SM W of Will Rogers AP
142314	3 SM WNW of bridge, 4 SM N of Shamrock	173725	2 SM SSW of Tulakes AP
142345	Due N of Shamrock	175308	On ground Will Rogers AP

Table VI. List of visual fixes by Fujita on board DC-6(39C), May 24, 1962.

Time (CST)	Δ x (miles)	Δ y (miles)	Time (CST)	Δ x (miles)	Δ y (miles)	Time (CST)	Δ x (miles)	Δ y (miles)
121945	-0.1	1.0	135530	-9.9	3.9	162215	-16.5	1.1
122540	-2.8	-0.8	140410	-11.7	4.6	163020	-13.8	5.5
122950	-2.3	-1.8	140445	-10.9	5.0	163435	-16.9	5.1
123100	-1.9	-1.5	140735	-11.7	4.6	163800	-19.4	6.0
124045	-2.4	-0.2	141805	-12.6	2.0	164325	-19.0	6.6
125055	-2.4	-1.8	142314	-12.7	2.2	165520	-23.9	9.4
124407	-1.8	-1.2	142857	-11.5	2.2	165940	-28.9	8.9
130255	1.1	-3.0	143211	-11.5	2.0	165952	-25.5	2.8
130517	1.1	-2.1	151030	-13.9	2.9	170420	-30.0	0.8
130621	0.5	-1.3	151800	-14.4	4.2	170915	-30.0	-2.8
130941	-1.6	-0.4	153510	-16.5	2.8	171245	-28.9	-1.2
131028	-1.6	-0.3	153830	-21.6	0.2	171328	-28.9	-1.2
131802	-1.8	0.8	154355	-16.4	1.1	171730	-29.5	-0.2
131839	-1.5	1.1	154600	-15.8	0.7	172030	-27.9	-1.8
130212	-1.5	1.1	154855	-17.5	-0.7	173000	-27.7	-6.0
132450	-1.5	2.5	155200	-19.6	-2.0			
132611	-2.5	1.2	155809	-18.3	-3.0			
132821	-3.1	1.0	160548	-15.5	-3.5			
133501	-5.8	2.0	161030	-16.5	-1.3			
134520	-8.1	3.3	161515	-16.2	0.0			

Table VII. Both x and y components of vector difference of Doppler and visual fixes.

Time	$\frac{\partial \Delta x}{\partial t}$ mph	$\frac{\partial \Delta y}{\partial t}$ mph	Error of Doppler Wind direction	speed (kts)	Time	$\frac{\partial \Delta x}{\partial t}$ mph	$\frac{\partial \Delta y}{\partial t}$ mph	Error of Doppler Wind direction	speed (kts)
					15h 00m	---	---	---	--
					10	+8	-8	315	10
12h 20m	+9	+4	245	8	20	+7	-3	295	7
30	+8	+3	250	7	30	+6	+8	215	9
40	+3	+2	235	3	40	+5	+14	200	13
50	-9	+1	95	8	50	+1	+19	185	16
13h 00m	-4	0	90	4	16h 00m	-3	0	90	2
10	+3	-8	340	7	10	-6	-16	20	15
20	+10	-7	305	11	20	0	-17	360	15
30	+16	-6	290	15	30	+9	-17	305	17
40	+15	-6	290	14	40	+18	-16	310	21
50	+13	-6	295	12	50	+27	-10	290	25
14h 00m	+11	-5	295	10	17h 00m	+21	+29	215	30
10	+6	+7	220	8	10	-3	+25	175	22
20	0	+6	180	5	20	-6	+21	165	18
30	-5	+6	140	7	30	-6	+19	160	17
40	---	--	---	--					
50	---	--	---	--					

Table VIII. Error in wind velocity computed from visual fixes.

4. CUMULUS STREETS OF MAY 25, 1962.

This case was flown along the line connecting Wichita, Kansas and Little Rock, Arkansas. Fujita, on board 39C, took 172 pictures and Ushijima took 65 pictures from 40C (Fig. 13). The lists of these photgraphs appear in Tables IX and X. Rather frequent visual fixes, as indicated in Table XI, were accomplised by Fujita. Preliminary investigation revealed that the position error of Doppler fixes increased while flying east, but decreased during the westbound flight.

These flights were made for the purpose of investigating a meteorological cross-section along the line connecting Wichita and Little Rock. Results of the preliminary photogrammetric analysis of cloud patterns on both sides of the flight paths are presented. The first flight leg appearing in Fig. 14 indicates that there was no growing cumulus over the entire area. Photographed between Wichita and Little Rock are extensive areas of cumulus streets which had no indication of vertical growth. Fujita's Photograph Nos. 40 and 103 were taken from approximately the same location toward northeast. When Frame No. 40 was exposed, the plane was near the eastern edge of the cumulus streets (Fig. 15). By the time Photograph No. 103 was taken, from almost the same spot 1 hr. 45 min. later, the central region of the cumulus streets moved in beneath the aircraft (Fig. 16).

Before the aircraft made a turn near Wichita, Kansas to fly back to Little Rock, a number of towering cumuli were observed (Fig. 17). No distinct line of convection was recognized. However, one of the clouds about 40 miles northeast of Wichita showed an anvil top with virga hanging down near the convective tower. It will be of interest to investigate the reason of vertical growth in this area, since the other areas on both sides of the repeated flight paths were characterized by streets of flat cumulus to stratocumulus clouds.

This flight will provide an excellent case for cross-section study along a fixed line connecting Wichita and Little Rock.

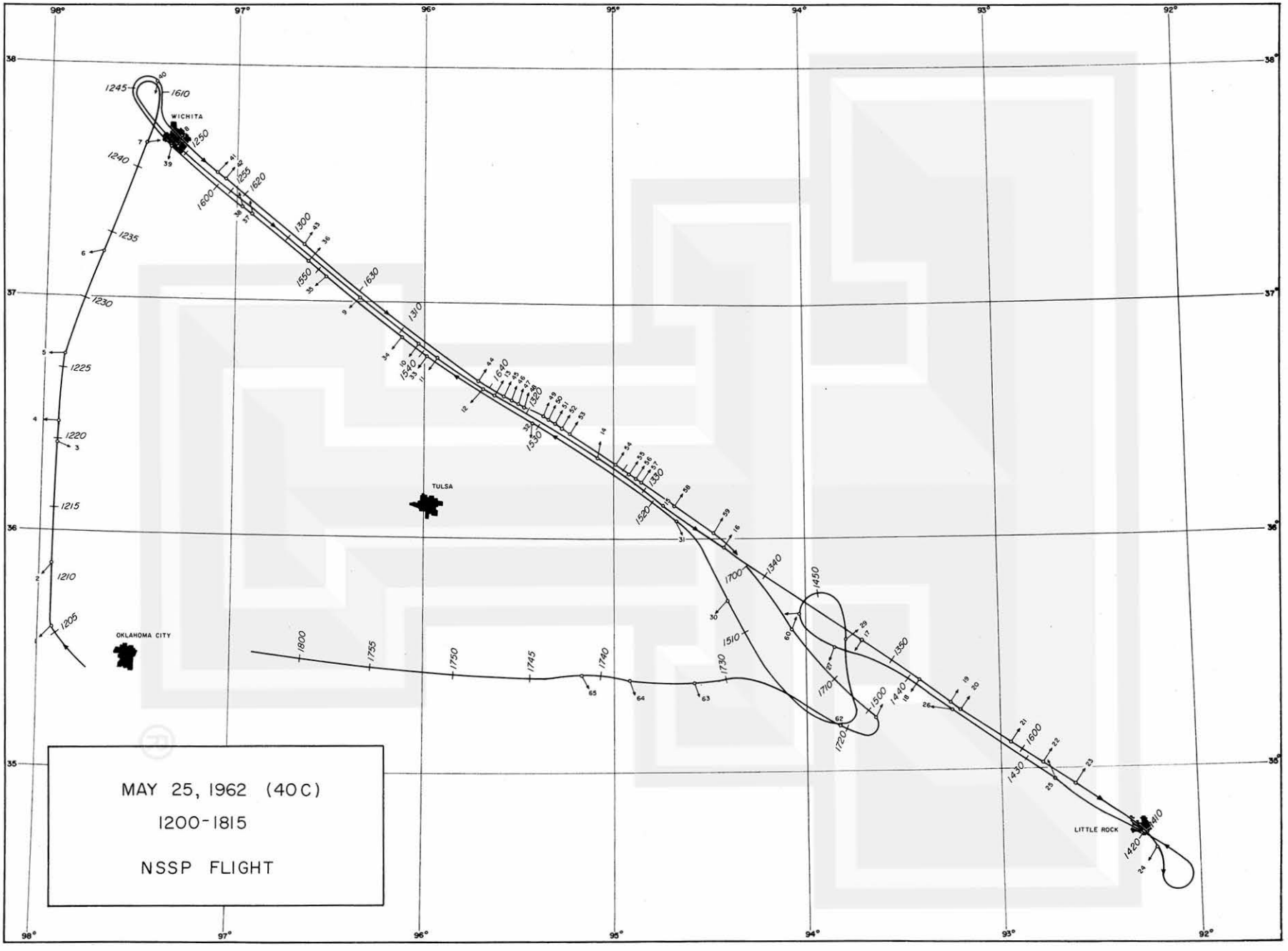

Fig. 13. Flight path of the DC-6(40C), determined by Ushijima, and his pictures taken during the flight. May 25, 1962.

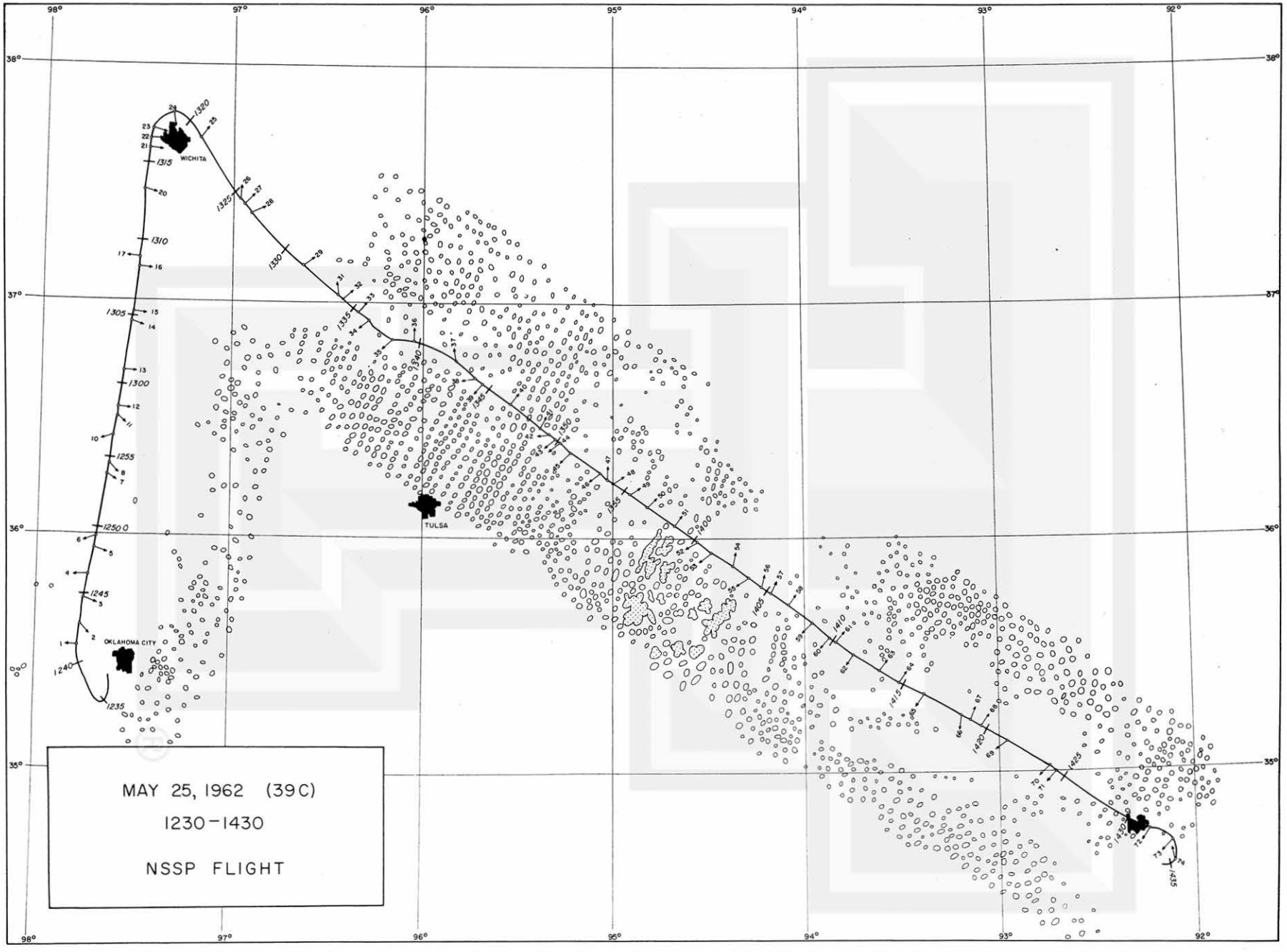

Fig. 14. Cloud distribution during the first cross-section flight between Wichita and Little Rock. Clouds were fixed approximately by Fujita from his pictures taken from DC-6(39C) flying at 18,000 ft. May 25, 1962.

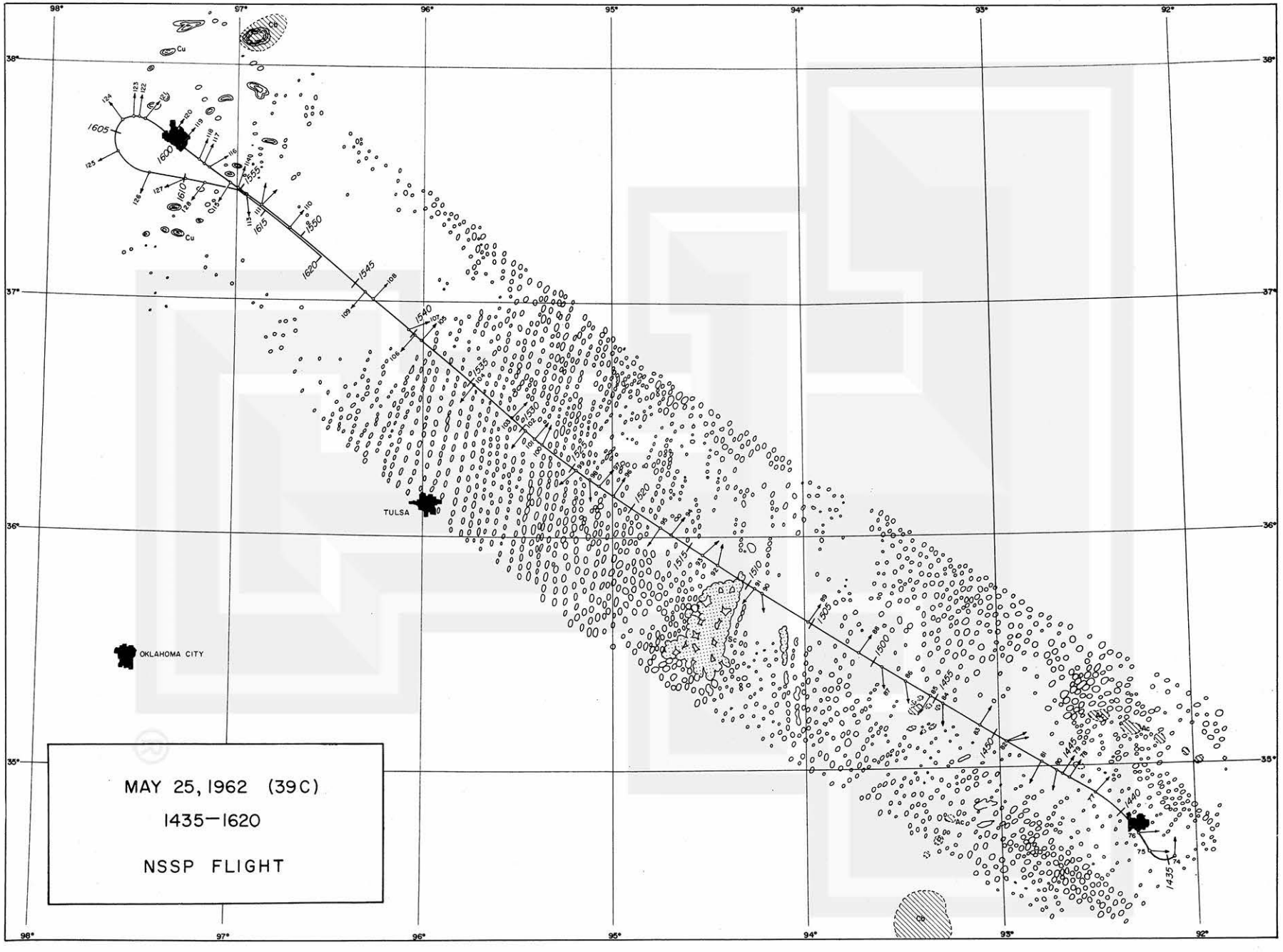

Fig. 15. Cumulus streets and some altocumuli photographed during the second cross-section flight from Little Rock to Wichita. It was practically clear to the west. May 25, 1962.

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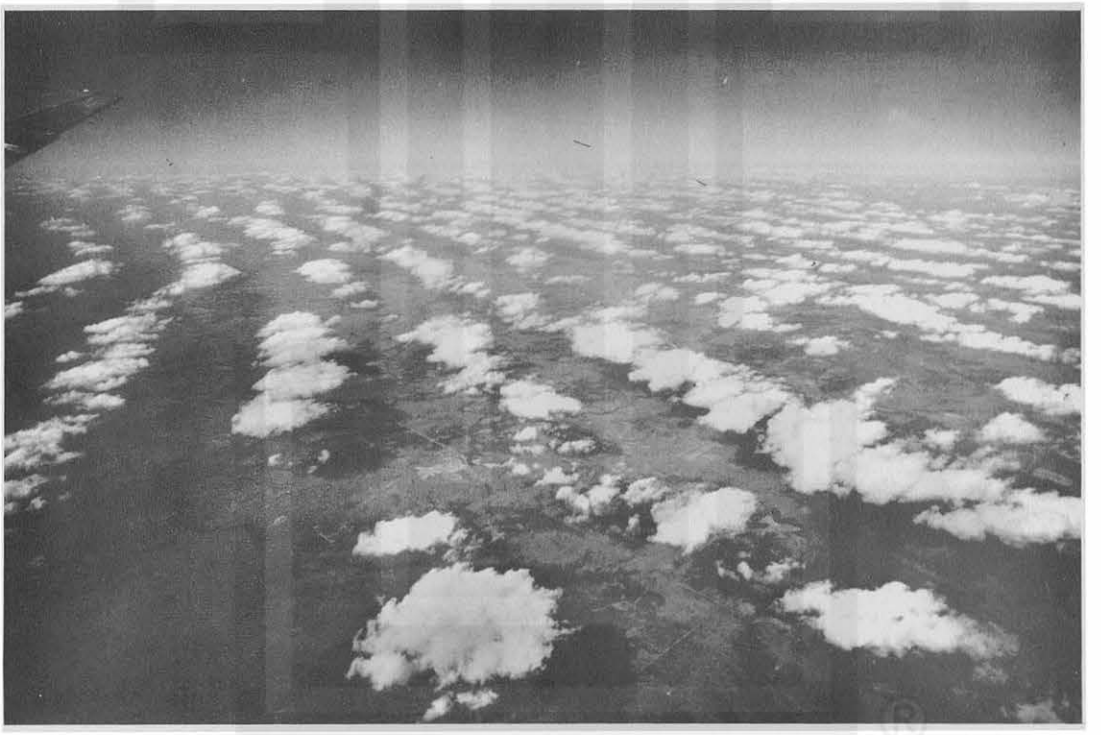

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Fig. 16. Two pictures taken from the same spot during the first and second cross-section flight about 1 hour and 45 minutes apart. The difference in cloud patterns is a result of the actual change and the advection of clouds. May 25, 1962.

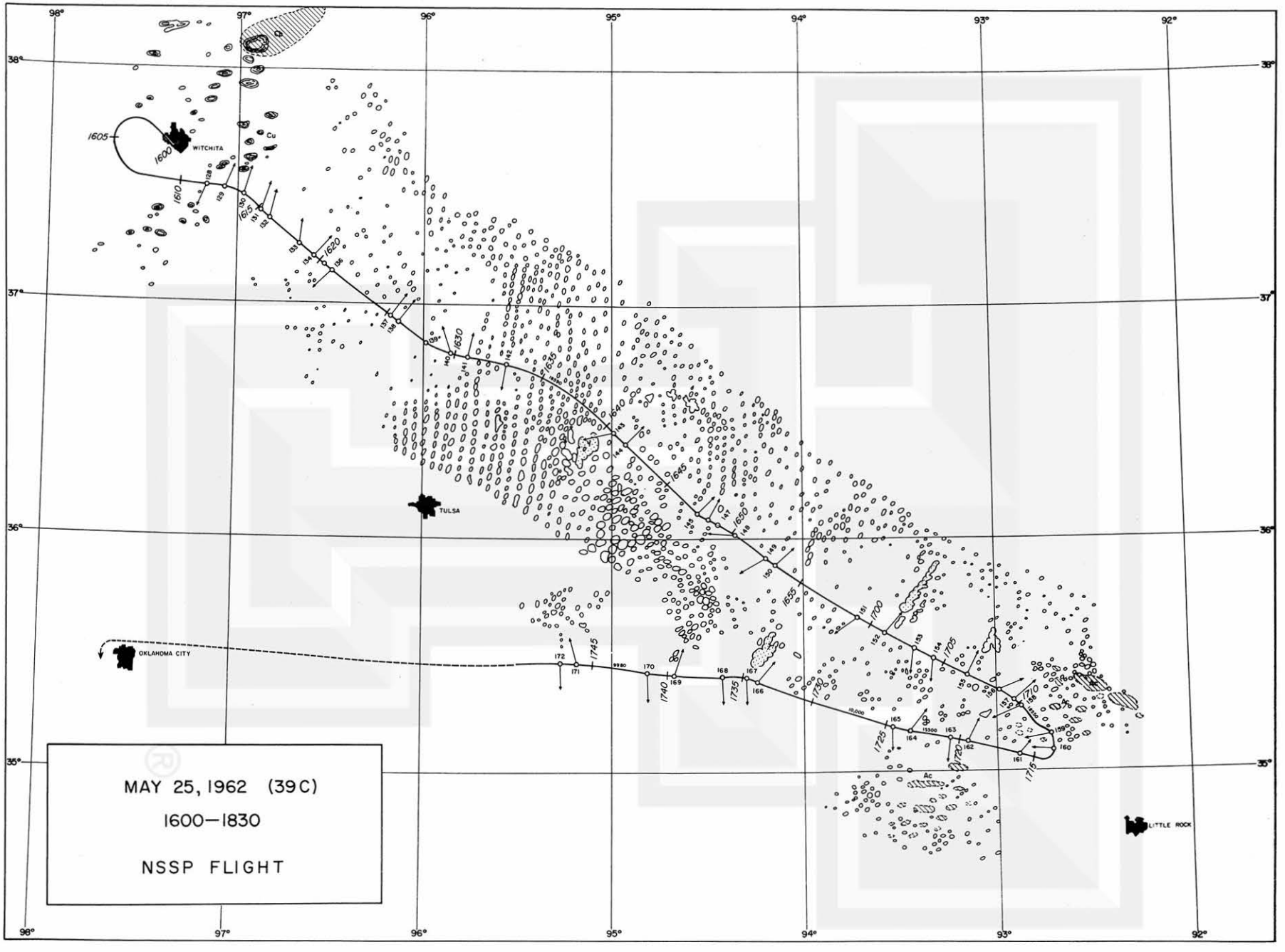

Fig. 17. The third or the last cross-section flight at 18,000 ft. from Wichita to near Little Rock. Activities of small cumuli, both scattered and arranged in streets, now diminished. It is partially because of the time of the day and the cirrus overcast which moved in from activities west of Oklahoma City. May 25, 1962.

Frame No.	Time	Principal Line	Frame No.	Time	Principal Line	Frame No.	Time	Principal Line
			60	140951	SW	120	160058	NE
1	124147	due W	61	141032	NE	121	160250	NE
2	124302	SE	62	141200	SW	122	160255	N
3	124446	ESE	63	141305	NE	123	160325	due N
4	124650	due W	64	141450	NE	124	160403	NW
5	125320	ESE	65	141631	SW	125	160630	WSW
6	124900	WSW	66	141820	SSW	126	160815	SSW
7	125358	SE	67	141853	NNE	127	161005	WSW
8	125425	SE	68	141945	NE	128	161130	SSW
9	------	---	69	142135	SW	129	161230	NNE
10	125630	WSW	70	142410	SW	130	161346	NNE
11	125830	SE	71	142430	SW	131	161454	NNE
12	125835	E	72	143130	SW	132	161531	NNE
13	130115	due E	73	143315	SW	133	161805	N
14	130413	ESE	74	143440	N	134	161930	NE
15	130504	due E	75	143650	due E	135	162015	due N
16	130750	ESE	76	143818	due E	136	162100	SW
17	130829	WNW	77	144225	NE	137	162516	NE
18	------	----	78	144418	due NE	138	162710	NE
19	------	----	79	144458	due NE	139	162745	NNW
20	131326	ESE	80	144505	SSW	140	162950	NNW
21	131610	ESE	81	144705	due SW	141	163055	NNE
22	131646	E	82	144912	ENE	142	163320	SW
23	131705	ESE	83	145134	NE	143	164050	WSW
24	131832	due S	84	145420	S	144	164116	NE
25	132152	NE	85	145525	SW	145	164736	NE
26	132545	due N	86	145730	due S	146	164755	NE
27	132550	NE	87	145915	due S	147	164847	due SW
28	132650	ENE	88	150130	NE	148	165005	due W
29	133155	NE	89	150523	NE	149	165230	SW
30	------	----	90	150900	due S	150	165310	due NE
31	133340	due N	91	150930	SW	151	165857	due SW
32	133404	NE	92	151305	NNE	152	170100	NE
33	133530	NE	93	151400	NE	153	170245	due S
34	133625	SW	94	151623	NE	154	170455	due S
35	133814	SW	95	151730	09h	155	170630	09h
36	133935	due N	96	152147	due NE	156	170805	ENE
37	134225	NNE	97	152244	due NE	157	170930	NE
38	134341	due W	98	152335	due S,	158	171015	SW
39	134404	SW	99	152440	due SW	159	171235	WSW
40	134630	NE	100	152758	NNE	160	171355	W
41	134815	NE	101	152858	NE	161	171600	NE
42	134902	due W	102	152948	SW	162	171955	due NNE
43	134930	SW	103	153142	due NE	163	172052	due S
44	135030	due SW	104	153452	due SW	164	172345	due NE
45	135125	due SW	105	153915	NE	165	172435	due S
46	135310	SW	106	153954	SW	166	173400	due NE
47	135355	due N	107	154025	ENE	167	173445	due S
48	135355	NE	108	154340	NE	168	173650	due S
49	135545	NE	109	154414	due SW	169	173945	NNE
50	135636	NE	110	155110	NE	170	174120	due S
51	135830	NE	111	155303	NE	171	174752	NNW
52	140000	SW	112	155330	NNE	172	174823	due S
53	140115	SW	113	155423	due S			
54	140231	NNE	114	155505	NNE			
55	140325	SW	115	155550	due SSW			
56	140430	NNE	116	155727	ENE			
57	140545	NNE	117	155744	NNE			
58	140710	NE	118	155758	NNE			
59	140753	SW	119	155930	NE			

Table IX. List of photographs taken by Fujita on board DC-6(39C), May 25, 1962.

	Frame No.	Time	Principal Line	Frame No.	Time	Principal Line	Frame No.	Time	Principal Line
				25	142833	NW	50	164502	NNE
	1	120602	SW	26	143706	WNW	51	164516	NNE
	2	121125	SSW	27	144415	S	52	164538	NNE
	3	121955	ESE	28	144703	W	53	164739	NNE
*	4	122143	WNW	29	145423	E	54	164905	NNE
	5	122625	W	30	151257	SW	55	165130	NNE
	6	123348	WSW	31	158434	SSE	56	165243	NNE
	7	124108	E	32	153054	S	* 57	165313	NNE
	8	125520	NE	33	153947	SW	58	165539	NNE
	9	130620	SW	34	154208	SW	59	165855	NNE
	10	130910	SW	35	154938	SW	60	170518	NNE
	11	131322	SW	36	155100	NE	61	174440	NNE
	12	131700	SW	37	155741	N	62	172021	---
	13	131755	NE	38	155848	N	63	173235	SSE
	14	132615	NNE	39	160400	S	64	173724	SSE
	15	133208	---	40	160921	S	65	174142	SSE
	16	133751	NE	41	161743	NE			
	17	134828	SW	42	161753	NE			
	18	135208	SW	43	162535	NW			
*	19	135443	NE	44	163930	NE			
	20	135517	NE	45	164013	NNE			
	21	135841	NE	46	164041	NNE			
	22	140208	NE	47	164142	NNE			
	23	140424	NE	48	164312	NNE			
	24	141832	SSW	49	164442	NNE			

Table X. List of photographs taken by Ushijima on board DC-6(40C), May 25, 1962. * indicates the frame which was synchronized with 35-mm time-lapse shutter.

Time	Visual Fixes	Time	Visual Fixes
123740	Cross Red River 6 SM ENE of Tuttle	150810	On railroad 5 SM S of Winslow
124001	Depart Oklahoma City VOR	152100	19 SM W, 1 SM S of Siloam Springs
124855	On highway due W of Crescent	152707	On railroad 3 SM NNE of Pryor
125450	4 SM W of Covington	153018	On highway 3 SM SW of Chelsea
125718	3 SM W, 1 SM N of Garber	153325	On railroad 5-1/2 SM S of Nowata
130020	1/4 SM W of railroad bridge, 3-1/2 SM SSW of Lamont	153620	On highway US 60 10-1/2 SM W of Nowata
131100	3 SM N, 5 SM W of Wellington	155018	2 SM S of Cambridge
131258	6 SM W of railroad bridge, 5 SM N of Riverdale	160214	Wichita VOR
131706	Over Wichita VOR	160535	Cross railroad 2 SM E of Carden Plain
131832	On highway 17 SM S of Newton	160715	Cross railroad 6 SM NE of Viola
132205	6 SM E of McConnell AP	161035	2-1/2 SM N of Mulvane
132925	On highway bend 12 SM E of Winfield	161725	2 SM W, 1 SM S of Cambridge
133250	2 SM W, 2 SM S of Cedar Vale	162605	1 SM SW of Hulah Res. dam
133737	On highway 12 SM S of Chautauqua	163145	On railroad 5-1/2 SM N of Nowata
134002	Over Bartlesville VOR	163700	1 SM S, 2 SM W of Vinita
134455	On highway 4 SM SSW of Nowata	164000	1 SM E of Lake of the Cherokees dam
134755	Cross railroad 2 SM SW of Chelsea	164700	On highway 3 SM SW of Siloam Springs
135230	Cross Neosho River 11 SM S of Pensacola	165030	2 SM N of Prairie Grove
140615	1 SM E of highway, 5 SM S of Winslow	171235	2 SM N, 1 SM E of Morrilton
140855	Cross river 10 SM NE of Mulberry	171355	2 SM S of Perry
141420	1 SM E, 2 SM N of Scranton	171836	8 SM S, 8 SM E of Dardanelle
141853	Cross Arkansas River 1 SM SE of Dardanelle	172600	6 SM E, 6-1/2 SM S of Paris
142535	13 SM due W of Mayflower	172725	Due S of Paris
143236	Little Rock VOR	173255	5-1/2 SM W, 4-1/2 SM N of Charleston
143725	5 SM W' 30 S' Little Rock VOR	173446	Fort Smith VOR
143900	3 SM due W of downtown Little Rock	173600	2 SM S of Van Buren
144155	4 SM W, 6 SM S of Mayflower	174203	On highway 2-1/2 SM S of Sallisaw
145230	1 SM SE of Dardanelle	174942	Cross railroad 2-1/2 SM SE of Warner
145830	3 SM N, 1 SM E of Scranton	183000	Will Rogers Field

Table XI. List of visual fixes by Fujita on board DC-6(39C), May 25, 1962.

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MESOMETEOROLOGY PROJECT ---- RESEARCH PAPERS

1. Report on the Chicago Tornado of March 4, 1961 - Rodger A. Brown and Tetsuya Fujita

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3. Outline of a Technique for Precise Rectification of Satellite Cloud Photographs - Tetsuya Fujita

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