Í	AD-A1	62 338	STO		ECIPIT IGHTNI	ATION NG_EVE	AND W	IND ST	E DUR	ING AI	RCRAFT	1/	<b>'1</b>	<b>ا</b> م جو ا
İł.	UNCLA	SSIFIE	D AFG	L-TR-8	5-012	1			 05	F/G	4/1	NL.		
			1 6.3 1											
												END Finals ptic		
														ا لنت



100000000

MICROCOPY RESOLUTION TEST CHART NATIONAL BUREAU OF STANDARDS 1963-A

AFGL-TR-85-0121 ENVIRONMENTAL RESEARCH PAPERS, NO. 917

## Storm Precipitation and Wind Structure During Aircraft Strike Lightning Events

ALAN R. BOHNE ALBERT C. CHMELA





ATMOSPHERIC SCIENCES DIVISION

PROJECT 6670

# AIR FORCE GEOPHYSICS LABORATORY

HANSCOM AFB, MA 01731

"This technical report has been reviewed and is approved for publication"

FOR THE COMMANDER

NETH M. GLOVER

Chief, Ground Based Remote Sensing Branch Atmospheric Sciences Division

ROBERT A. MCCLATCHEY

Director, Atmospheric Sciences Davision

This document has been reviewed by the ESD Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS).

Qualified requestors may obtain additional copies from the Defense Technical Information Center. All others should apply to the National Technical Information Service.

If your address has changed, or if you wish to be removed from the mailing list, or if the addressee is no longer employed by your organization, please notify AFGL/DAA, Hanscom AFB, MA 01731. This will assist us in maintaining a current mailing list.

UNCL	ASSIFIED
------	----------

-10-A162 33	5
-------------	---

REPORT DOCUMENTATION PAGE     11 AFORT SECURITY CLASSIFICATION   10 AESTRICTIVE MARKINGS     Unclassified   10 AESTRICTIVE MARKINGS     22 SECURITY CLASSIFICATION AUTHORITY   10 OSTRIBUTION-AVALABILITY OF REPORT     25 DECLASSIFICATION DOWNGRADING SCHEDULE   10 AESTRICTIVE MARKINGS     26 CLASSIFICATION DOWNGRADING SCHEDULE   10 MONITORING ORGANIZATION REPORT NUMBERSI     26 THE ORMING ORGANIZATION REPORT NUMBERSI   2 MONITORING ORGANIZATION REPORT NUMBERSI     26 NAME OF PERFORMING ORGANIZATION   10 OFFICE SYMBOL     26 NAME OF PERFORMING ORGANIZATION   10 OFFICE SYMBOL     26 NAME OF PENDING FORMORG   10 OFFICE SYMBOL     26 NAME OF PENDING FORMORGING   10 OFFICE SYMBOL     27 NAME OF PUNCHONG FORMORG   10 OFFICE SYMBOL     28 ADDRESSINGLY, SIZE and ZIP Code:   10 SOURCE OF FUNCTION NUMBER     28 ADDRESSINGLY, SIZE and ZIP Code:   10 SOURCE OF FUNCTION NUMBER     29 ADDRESSINGLY, SIZE and ZIP Code:   10 SOURCE OF FUNCTION TO NUMBER     20 OFFICE SYMBOL   10 SOURCE OF FUNCTION NUMBER     20 OFFICE SYMBOL   10 SOURCE OF FUNCTION TO NUMBER     20 OFFICE SYMBOL   10 SOURCE OF FUNCTION NUMBER     20 OFFICE SYMBOL   10 SOURCE OF FUNCTION NUMBER     20 OFFICE SYMBOL   10 S	SECURITY CLASSIFICATION OF THIS PAGE			<u>-10-7</u>	162	<u>))8</u>	
BEFORT SECURITY CLASSIFICATION     ID     HESTRICTIVE MARKINGS       UDCLASSIFICATION AUTHORITY     DISTRIBUTION.AVAILABILITY OF REPORT       SECURITY CLASSIFICATION AUTHORITY     DISTRIBUTION.AVAILABILITY OF REPORT       SECURITY CLASSIFICATION AUTHORITY     DISTRIBUTION.AVAILABILITY OF REPORT       DISTRIBUTION.AVAILABILITY OF REPORT     Approved for public release;       DISTRIBUTION.AVAILABILITY OF REPORT     Approved for public release;       DISTRIBUTION.AVAILABILITY OF REPORT     Approved for public release;       ATTE FORCE     DISTRIBUTION.AVAILABILITY OF REPORT       APPORT SECURITY CARACTER     DISTRIBUTION.AVAILABILITY OF REPORT       APPORT SECURITY CARACTER     DISTRIBUTION.AVAILABILITY OF REPORT       APPORT     DISTRIBUTION.AVAILABILITY OF REPORT       Security Character     DISTRIBUTION.AVAILABILITY OF REPORT       APPORT     DISTRIBUTION.AVAILABILITY OF REPORT       Security Character     DISTRIBUTION.AVAILABILITY OF REPORT       APPORT     DISTRIBUTION       BARACT CARACTER     DISTRIBUTION.AVAILABILITY OF REPORT       Security Character     DISTRIBUTION       SECURITY OF REPORT     DISTRIBUTION       SECURITY OF REPORT     DISTRIBUTION       SECURITY OF R		REPORT DOCUM	ENTATION PAGE	E			
Unclassified   1   Distribution Authority     2: SECURITY CLASSIFICATION AUTHORITY   2   Distribution Authority     2: SECURITY CLASSIFICATION AUTHORITY   2   Distribution unlimited.     2: DECLASSIFICATION REPORT NUMBERSI   3   MUNITORING ORGANIZATION REPORT NUMBERSI     3: AFGL-TR-65-0121 ERP, No. 917   5   MUNITORING ORGANIZATION REPORT NUMBERSI     3: ADME OF PERFORMING ORGANIZATION   b) OFFICE SYMBOL   7: NAME OF MONTORING ORGANIZATION     4: ADME OF PERFORMING ORGANIZATION   b) OFFICE SYMBOL   7: NAME OF MONTORING ORGANIZATION     4: ADMEDS FCIN, SHE MED (IFC OFFICE SYMBOL)   1: ADME OF MONTORING ORGANIZATION   1: O OFFICE SYMBOL     4: ADMEDS FCIN, SHE MED (IFC OFFICE SYMBOL)   1: ADME OF FUNDING ORGANIZATION   1: O OFFICE SYMBOL     4: ADMEDS FCIN, SHE MED (IFC OFFICE SYMBOL)   1: O ADDRESS (CIN, SHE MED (IFC OFFICE SYMBOL)   1: O ADDRESS (CIN, SHE MED (IFC OFFICE SYMBOL)     4: ADMEDS FCIN, SHE MED (IFC OFFICE SYMBOL)   1: O ADDRESS (CIN, SHE MED (IFC OFFICE SYMBOL)   1: O ADDRESS (CIN, SHE MED (IFC OFFICE SYMBOL)     5: ADDRESS (CIN, SHE MED (IFC OFFICE SYMBOL)   1: O ADDRESS (CIN, SHE MED (IFC OFFICE SYMBOL)   1: O ADDRESS (CIN, SHE MED (IFC OFFICE SYMBOL)     5: ADDRESS (CIN, SHE MED (IFC OFFICE SYMBOL)   1: O ADDRESS (CIN, SHE MED (IFC OFFICE SYMBOL)     6: ADDRESS (	18 REPORT SECURITY CLASSIFICATION		16 RESTRICTIVE MARKINGS				
Secontry classification subtronity     Distribution Additability of the second distribution and distribution and the second distribution and distributis distretis and distribution and distribution distribution and d	Unclassified						
boccassification/downgrading Screbule distribution unlimited. Approved for public relation distribution unlimited. Approved for public relation distribution unlimited. AFGL-TR-85-0121 ERP, No. 917 anAut of repromise organization borrice symbol distribution unlimited. AFGL-TR-85-0121 ERP, No. 917 anAut of repromise organization borrice symbol distribution unlimited. AFGL-TR-85-0121 ERP, No. 917 anAut of repromise organization borrice symbol distribution unlimited. AFGL-TR-85-0121 ERP, No. 917 anAut of repromise organization borrice symbol distribution unlimited. AFGL-TR-85-0121 ERP, No. 917 another of the optic symbol distribution unlimited. AFGL-TR-85-0121 ERP, No. 917 another of the optic symbol distribution unlimited. AFGL-TR-85-0121 ERP, No. 917 another of the optic symbol distribution unlimited. Air Force Geophysics I.YR ADDRESS (cir), show and //P Code: Hanscon AFB Massachusetts 01731 another of the optic symbol dif applicable second and the optic symbol dif applicable second and the optic symbol dif applicable another of the optic symbol dif applicable another of the optic symbol dif applicable another of the optic symbol another of the optic symbol another of the optic symbol dif applicable another of the optic symbol dif applicable another of the optic symbol another optic symbol another of the optic symbol anoth	2. SECURITY CLASSIFICATION AUTHORITY		3 DISTRIBUTION/A	VAILABILITY O	F REPORT		
definition difference of the definition of	Th DECLASSIFICATION/DOWNGBADING SCHEE		distribution	or public r	elease;		
a reproduind on Canuzation Report Numerals:   5. MUNITORING ORGANIZATION REPORT NUMERAL:     AFGL-TR-85-0121 ERP, No. 917     Sea NAME OF PERFORMING ORGANIZATION Air Force Geophysics Laboratory   Be OFFICE SYMBOL ("supported")   1. NAME OF MONITORING ORGANIZATION Air Force Geophysics Laboratory     Sea ADDRESS (Cir, State and ZIP Code)   If applicable   1. NAME OF MONITORING ORGANIZATION ("supported")     Sea ADDRESS (Cir, State and ZIP Code)   Be OFFICE SYMBOL (If applicable)   9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER (If applicable)     Sea ADDRESS (Cir, State and ZIP Code)   Be OFFICE SYMBOL (If applicable)   9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER (If applicable)     Storm Precipitation and Wind Structure During Aircraft Strike Lightning Events     Storm Precipitation and Wind Structure During Aircraft Strike Lightning Events     Storm Precipitation and Chmela, Albert C.     Tis TYPE OF REPORT     Storm Precipitation Report     Its SUBJECT TERMS (continue on storie d'accuser and dealt) by Back sumber     Scientific Interim     Its SUBJECT TERMS (continue on storie d'accuser and dealt) by Back sumber     Its SUBJECT TERMS (continue on storie d'accuser and dealt) by Back sumber     Its SUBJECT TERMS (continue on storie d'accuser and dealt) by Back sumber     Its SUBJECT TERMS (continue on storie d'accuser and dealt) by Back sumber     Its SUBJECT TE					•		
AFGL-TR-85-0121 ERP, No. 917 AFGL-TR-85-0121 ERP, No. 917 Air Force Geophysics LyR Address constant and UP Code: Hanscon AFB Massachusetts 01731 Address cons AFB Massachusetts 01731 Address cons AFB Massachusetts 01731 Address cons AFB Massachusetts 01731 Address constant and UP Code: The Address consthere and UP Code: The Address	4. PERFORMING ORGANIZATION REPORT NUM	BER(S)	5 MUNITORING OR	GANIZATION R	PORT NUMBER	\$)	
See Andle OF PERFORMING ORGANIZATION Air Force Geophysics Laboratory   Is NAME OF MONITORING ORGANIZATION ("Implement" I.YR     See ADDRESS (City, State and Cit Code)   Is ADDRESS (City, State and Cit Code)     Hanscom AFB Massachusetts 01731   Is OFFICE SYMBOL (If applicable)   Is ADDRESS (City, State and Cit Code)     NAME OF FUNDING/SPONSORING ORGANIZATION   Is OFFICE SYMBOL (If applicable)   Is ADDRESS (City, State and Cit Code)     NAME OF FUNDING/SPONSORING ORGANIZATION   Is OFFICE SYMBOL (If applicable)   Is ADDRESS (City, State and Cit Code)     NAME OF FUNDING/SPONSORING ORGANIZATION   Is OFFICE SYMBOL (If applicable)   Is ADDRESS (City, State and Cit Code)     IT TITLE Unclude Security Clamboling Storm Precipitation and Wind Structure During Aircraft Strike Lightning Events   Is OFFICE Strike Codent     Is Extended Authonis Bohne, Alan R., and Chmela, Albert C.   Is Date of mergort (Finder)   Is Proceed and the Codent     Is SUPPLEMENTARY NOTATION   Is Subject TERMS (Calings on more of Action for the off) for the codent Field Group   Is Subject TERMS (Calings on more of Action for the off) for the codent for the off action for the off action for the off for the off) for the off action for the off action for the off for the off for the off) for the off action for the off for	AFGL-TR-85-0121 ERP, 1	No. 917					
Air Force Geophysics LYR Laboratory LYR 6c ADDRESS (Cir, Start and CIP Code: Hanscom AFB Massachusetts 01731 6c ADDRESS (Cir, Start and CIP Code: 6c ADDRESS (Cir, Start and CIP Code: 6c ADDRESS (Cir, Start and CIP Code: 6c ADDRESS (Cir, Start and CIP Code: 700 ADDRESS (Cir, Start and Circle Code: 700 ADDRESS (Cir, Start and Circle Code: 700 ADDRESS (Circ, Start Code:	6. NAME OF PERFORMING ORGANIZATION	60 OFFICE SYMBOL	78 NAME OF MONI	TORING ORGAN	ZATION		
Laboratory   1111     ADDRESS (Ciry Side and ZIP Code)   10 ADDRESS (Ciry Side and ZIP Code)     Massachusetts 01731   10 ADDRESS (Ciry Side and ZIP Code)     Bradderst Ciry, Side and ZIP Code)   10 Source of Funding Formation     Bradderst Ciry, Side and ZIP Code)   10 Source of Funding Formation     Bradderst Ciry, Side and ZIP Code)   10 Source of Funding Formation     Bradderst Ciry, Side and ZIP Code)   10 Source of Funding Formation     Bradderst Ciry, Side and ZIP Code)   10 Source of Funding Formation     Storm Precipitation and Wind Structure During Aircraft Strike Lightning Events   10 Source of Funding Events     Storm Precipitation and Wind Structure During Aircraft Strike Lightning Events   10 Source of Funding Events     Storm Precipitation   10 Oct 820 30 Sep 84   1985 May 24   40     Scientific Interim   From 10 Oct 820 30 Sep 84   1985 May 24   40     10 Supplementary NOTATION   11 Subject TERMS (Continue on started direction and dealth by Mark number)   11 Structure and dealth by Mark number)     11 Field Group   Subject TERMS (Continue on started direction and dealth by Mark number)   12 Structure and dealth by Mark number)     12 Event Cooks   10 Oct 820 30 Sep 84   1985 May 24   40     13 Supplementary NOTATION <td< td=""><td>Air Force Geophysics</td><td>t VB</td><td></td><td></td><td></td><td></td></td<>	Air Force Geophysics	t VB					
Hanscom AFB Massachusetts 01731     Image: And the first of t	E- ADDRESS (City, State and ZIP Cude)		75 ADDRESS (City	State and ZIP Cod			
Massachusetts 01731     Intervention of the structure of	Hongoom AFP						
In ADM C OF FUNDING SPONSORING   B: OFFICE SYMBOL   I PROCURT MENT INSTRUMENT OF THE CATION NUMBER     B: ADDRESS (City, State and ZIP Code)   III SOURCE OF FUNDING MOS   PROGRAM   PROJECT   TASK     B: ADDRESS (City, State and ZIP Code)   III SOURCE OF FUNDING MOS   PROGRAM   PROJECT   TASK   MOGRAUNIT     B: ADDRESS (City, State and ZIP Code)   III SOURCE OF FUNDING MOS   PROGRAM   PROJECT   TASK   MOGRAUNIT     Storm Precipitation and Wind Structure During Aircraft Strike Lightning Events   III SOURCE OF REPORT   III DATE OF REPORT IS   III DATE OF REPORT IS FORM TO OCCURRED   IIII  DATE OF REPORT IS FORM TO OCCURRED   IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII	Massachusetts 01731						
Bar ANDRE OF FUNDING/SPONSORING ORGANIZATION   Bb OFFICE SYMBOL If applicable.   D PROCURE OF FUNDING NOS     Bar ADDRESS (City, State and ZIP Code)   Is Source OF Funding Nos   PROGRAM   PROJECT     Bar ADDRESS (City, State and ZIP Code)   Is Source OF Funding Nos   No   No   No     Bar ADDRESS (City, State and ZIP Code)   Is Source OF Funding Nos   PROGRAM   PROJECT Nos   No   OI     It TITLE (Include Security Clautification)   Storm Precipitation and Wind Structure During Aircraft Strike Lightning Events   No   OI     Iz PERSONAL AUTHORIS:   Bohne, Alan R., and Chmela, Albert C.   Is Date OF REPORT   Is Prove I Doct 820 30 Sep B4   1985 May 24   40     Iz COSATI CODES   Is SUBJECT TERMS (Continue on recent direction and density by Mere aumber)   Actional Strikes   Turbulence     Iz COSATI CODES   Is SUBJECT TERMS (Continue on recent direction and density by Mere aumber)   Actional Strikes   Actional Strikes     Iz COSATI CODES   Is SUBJECT TERMS (Continue on recent direction and t and anditand andite and direction and direction and direction a		·····					
B: ADDRESS (City, State and ZIP Code)   10. Sounce OF Punching Not   In Sounce OF Punching Not     B: ADDRESS (City, State and ZIP Code)   10. Sounce OF Punching Not   In Sounce OF Punching Not     B: ADDRESS (City, State and ZIP Code)   In Sound Structure During Aircraft Strike Lightning Events   In Sound Structure During Aircraft Strike Lightning Events     11 TITLE (Include Security Classification)   Storm Precipitation and Wind Structure During Aircraft Strike Lightning Events     12 PERSONAL AUTHORIS:   Bohne, Alan R., and Chmela, Albert C.     13 TYPE OF REPORT   13b TIME COVERED   14 Date OF REPORT No. Device State Strike Structure Interview (Increase) and dramth, by Mechanimer's Address State Structure State State Structure State State Structure Structure Structure State Structure State Structure State S	80. NAME OF FUNDING/SPONSORING ORGANIZATION	8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT	NSTRUMENT ID	ENTIFICATION N		
ADDRESS (City, State and ZIP Code)   10 SOURCE OF FUNDING NOS     PROGRAM   PROJECT   TASE     NO   62101F   6670   19     11 TITLE /Include Security Classification:   Storm Precipitation and Wind Structure During Aircraft Strike Lightning Events   01     12 PERSONAL AUTHORS:   Bohne, Alan R., and Chmela, Albert C.   130 TIME COVERED   14 DATE OF REPORT.   15 PAGE COUNT     12 Scientific Interim   FROM 10 Oct 820 30 Sep 84   1985 May 24   16 PAGE COUNT     12 COSATI CODES   18 SUBJECT TERMS (Continue on micris / Increases and dentify by Mark number)   16 DATE OF REPORT.   16 PAGE COUNT     12 COSATI CODES   18 SUBJECT TERMS (Continue on micris / Increases and dentify by Mark number)   16 Precipitation   Radar     12 COSATI CODES   18 SUBJECT TERMS (Continue on micris / Increases and dentify by Mark number)   16 Precipitation   Radar     13 TITLE (Interim   FROM 10 Oct 820 30 Sep 84   1985 May 24   20   20     14 SUBJECT TERMS (Continue on micris / Increases and dentify by Micris number)   16 Precipitation   Radar     14 SUBJECT TERMS (Continue on micris / Increases and dentify by Micris number)   19 Precipitation   Radar     15 Alimited set of in -situ aircraft and ground-based radar data acquired during the 1981 and 19							
PROGRAM   PROACT   Take   NOR   NOR     Elevent No   62101F   6670   19   01     11 TITLE Include Security Claumidication:   Storm Precipitation and Wind Structure During Aircraft Strike Lightning Events   01     12 PERSONAL AUTHORS:   Bohne, Alan R., and Chmela, Albert C.   130 Diff Events   130 Diff Events   130 Diff Events     132 TYPE OF REPORT   130 Diff Events   130 Diff Events   14 Date of REPORT. Yr. No. Dari   16 Page Count     132 TYPE OF REPORT   130 Diff Events   130 Diff Events   14 Date of REPORT. Yr. No. Dari   16 Page Count     134 TYPE OF REPORT   130 Diff Events   130 Diff Events   14 Date of REPORT. Yr. No. Dari   16 Page Count     135 Supplementary Notation   130 Diff Events   130 Diff Events   14 Date of REPORT. Yr. No. Dari   16 Page Count     136 SUPPLEMENTARY NOTATION   130 Diff Events   14 Date of REPORT. Yr. No. Dari   16 Date   16 Date     137 Diff Events   UP   COSATI CODES   18 SUBJECT TERMS (Continue on recent diff Events   16 Date     148 Date 1981   1982 Joint Agency Turbulence   Wind Shear   17 Date   18 Date     159 Alstract (Continue on recent diff In gents and ground-based radar data ac	Bc. ADDRESS (City, State and ZIP Code)		10 SOURCE OF FUNDING NOS				
11   TITLE include Security Clautification:     Storm Precipitation and Wind Structure During Aircraft Strike Lightning Events     12   PERSONAL AUTHORIS:     Bohne, Alan R., and Chmela, Albert C.     13a trive or REPORT   13b trive covered     Scientific Interim   13b trive covered     read   10 Oct 82o 30 Sep 84     1985 May 24   40     10   10 Oct 82o 30 Sep 84     11   1985 May 24     12   COSATI CODES     13   13b SUBJECT TERMS Continue on recent of accuses and identify by Merk number:     14   Date of REPORT.     15   SUPPLEMENTARY NOTATION     12   COSATI CODES     13   TIS SUBJECT TERMS Continue on recent of accuses and identify by Merk number:     14   Date of REPORT.     15   SUPPLEMENTARY NOTATION     12   ABSTRACT (CONUME on metric if accuses and identify by Merk number:     13   ABSTRACT (Continue on guerie if accuses and identify by Merk number:     19   ABSTRACT (Continue on guerie if accuses and identify by Merk number:     19   ABSTRACT (Continue on guerie if accuses and identify by Merk number:     19   ABSTRACT (Continue on guerie if accuses and i			PROGRAM ELEMENT NO	PROJECT	TASK	NORE UNIT	
ITTLE finctude Security Clautification:     Storm Precipitation and Wind Structure During Aircraft Strike Lightning Events     12. PERSONAL AUTHORIS:   Bohne, Alan R., and Chmela, Albert C.     13. TYPE OF REPORT   13b TIME COVERED   14 DATE OF REPORT V. No. David     Scientific Interim   FROM 10 Oct 820 30 Sep 84   1985 May 24   40     12 COSATI CODES     Is SUBJECT TERMS (Continue on reverse direction and density by block number)     FIGLD GROUP SUB OR     Lightning     Precipitation     Radar     Aircraft Strikes     Wind Shear     19 ABSTRACT (Continue on groups of accurate and density by block number)     FA limited set of in-situ aircraft and ground-based radar data acquired during the 1981 and 1982 Joint Agency Turbulence Experiment are used to study the relationship of aircraft lightning strikes to storm precipitation, turbulence severity, and wind shear. The strikes are found to be strongly correlated with vertical drafts, predominantly downdrafts. The strikes were also well correlated with regions of strong turbulence. However, since most strong turbulence episodes were not associated with lightning, use of lightning location methods to locate hazardous turbulence within storms is considered unreliable. The strikes occurred in storm regions having radar reflectivity factor between 25 to 35 dBZ. These regions were generally on the boundaries			62101F	6670	19	01	
Storm Precipitation and Wind Structure During Aircraft Strike Lightning Events     12. PERSONAL AUTHOR(S) Bohne, Alan R., and Chmela, Albert C.     13. TYPE OF REPORT     14. DOTE     14. DOTE     15. SUBJECT TERMS (Continue on more of demoty by Book number)     14. Type OF REPORT     15. SUBJECT TERMS (Continue on more of demoty by Book number)     14. Lightning     15. Precipitation     16. SUBJECT Contes     17. Astract (continue on more of demoty by Book number)     18	11 TITLE Include Security Classificationi		<u></u>		<u> </u>		
12   PERSONAL AUTHOR(S) Bohne, Alan R., and Chmela, Albert C.     13a TYPE OF REPORT Scientific Interim   13b TIME COVERED FROM 10 Oct 820 30 Sep 84 1985 May 24   16 FAGE COUNT 40     12   COSATI CODES FIELD   13b SUBJECT YEAMS (Continue on reverse of memory and density by block number) Lightning   1985 May 24   10     12   COSATI CODES FIELD   18 SUBJECT YEAMS (Continue on reverse of memory and density by block number) Lightning   198 Free cipitation   Radar     14   Alightning   Precipitation   Radar     15   SUB FRACT (Continue on reverse of density) by block number( Storms   Wind Shear     19   ABSTRACT (Continue on reverse of density) by block number( The strikes are found to be strongly correlated with vertical drafts, predominantly downdrafts. The strikes to storm precipitation, turbulence severity, and wind shear. The strikes are found to be strongly correlated with regions of strong turbulence. However, since most strong turbulence episodes were not associated with lightning, use of lightning location methods to locate hazardous turbulence within storms is considered unreliable. The strikes occurred in storm regions having radar reflectivity factor be- tween 25 to 35 dBZ. These regions were generally on the boundaries of the dominant storm precipitation cores. Storm wind shear was frequently high in regions near air- craft strikes. The strong correlations with strong turbulence, downdraft boundaries, and precipitation core boundaries suggest that the strikes occurred in regions of charge separation.	Storm Precipitation and Wine	d Structure Dur	ing Aircraft S	Strike Ligh	tning Even	ts	
13a type of REPORT   13b type covered   14 bate of REPORT type basis   14 bate of REPORT type basis     13a type of REPORT   13b type covered   14 bate of REPORT type basis   16 bate of REPORT type basis   16 bate of REPORT type basis   16 bate of REPORT type basis     13a type of REPORT   13b type covered   14 bate of REPORT type basis   16 bate of REPORT type basis   16 bate of REPORT type basis   16 bate of REPORT type basis     13a type of REPORT   10 Oct 820 30 Sep 84   1985 May 24   16     14b type basis   10 Oct 820 30 Sep 84   1985 May 24   16     15b type basis   15b type basis   16 basis   16 basis   16 basis     15c control   15b type basis   16 basis   1985 May 24   16     15c control   15b type basis   15b type basis   1985 May 24   16     15c control   15b type basis   15b type basis   1985 May 24   16     15c control   15b type basis   15b type basis   15b type basis   16 basis     15c control   15b type basis   15b type basis   16 basis   16 basis     15c and 1982 Joint Agency Turbulence type type basis   16 basis   16 basis   16 basis   16 b	12. PERSONAL AUTHOR(S) Bohne Alan B and ('hmela	Albert C					
Scientific Interim   FROM 10 Oct 820 30 Sep 84   1985 May 24   40     18 SUPPLEMENTARY NOTATION   18 SUBJECT TERMS (Continue on receive diagrams) by Merk number:   40     FIELD   GROUP   SUB GR   Lightning   Precipitation   Radar     Aircraft Strikes   Turbulence   Storms   Wind Shear   1981 and 1982 Joint Agency Turbulence Experiment are used to study the relationship of aircraft lightning strikes to storm precipitation, turbulence severity, and wind shear.     The strikes are found to be strongly correlated with vertical drafts, predominantly downdrafts. The strikes were also well correlated with regions of strong turbulence.   However, since most strong turbulence episodes were not associated with lightning, use of lightning location methods to locate hazardous turbulence within storms is considered unreliable. The strikes occurred in storm regions having radar reflectivity factor between 25 to 35 dBZ. These regions were generally on the boundaries of the dominant storm precipitation cores. Storm wind shear was frequently high in regions near aircraft strikes. The strong correlations with strong turbulence, downdraft boundaries, and precipitation core boundaries suggest that the strikes occurred in regions of charge separation.	13. TYPE OF REPORT	OVERED	14 DATE OF REPOR	NT .Yr No Dev	16 PAGE		
12   COSATI CODES   18 SUBJECT TERMS (Continue on received decrease) and density by block number;     FIELD   GROUP   SUB GR   Lightning   Precipitation   Radar     Aircraft Strikes   Turbulence     Storms   Wind Shear     19. ABSTRACT (Continue on received decrease) and density by block number;     FA limited set of in-situ aircraft and ground-based radar data acquired during the 1981 and 1982 Joint Agency Turbulence Experiment are used to study the relationship of aircraft lightning strikes to storm precipitation, turbulence severity, and wind shear. The strikes are found to be strongly correlated with vertical drafts, predominantly downdrafts. The strikes were also well correlated with regions of strong turbulence. However, since most strong turbulence episodes were not associated with lightning, use of lightning location methods to locate hazardous turbulence within storms is considered unreliable. The strikes occurred in storm regions having radar reflectivity factor between 25 to 35 dBZ. These regions were generally on the boundaries of the dominant storm precipitation cores. Storm wind shear was frequently high in regions near air-craft strikes. The strong correlations with strong turbulence, downdraft boundaries, and precipitation core boundaries suggest that the strikes occurred in regions of charge separation.	Scientific Interim FROM 10	Oct 820 30 Sep	84 1985 M	lay 24	40		
17   COSATI CODES   18 SUBJECT TERMS (Continue on review if accesses and identify by block number)     FIELD   GROUP   SUB GR   Lightning   Precipitation   Radar     Aircraft Strikes   Turbulence   Wind Shear   19     19   ABSTRACT (Continue on reverse if necesses) and identify by block number:   Wind Shear     19   ABSTRACT (Continue on reverse if necesses) and identify by block number:     19   ABSTRACT (Continue on reverse if necesses) and identify by block number:     19   ABSTRACT (Continue on reverse if necesses) and identify by block number:     19   ABSTRACT (Continue on reverse if necesses) and identify by block number:     19   ABSTRACT (Continue on reverse if necesses) and identify by block number:     19   ABSTRACT (Continue on reverse if necesses) and identify by block number:     1981 and 1982 Joint Agency Turbulence Experiment are used to study the relationship of aircraft lightning strikes to storm precipitation, turbulence severity, and wind shear. The strikes are found to be strongly correlated with vertical drafts, predominantly downdrafts. The strikes were also well correlated with regions of strong turbulence. However, since most strong turbulence episodes were not associated with lightning, use of lightning location methods to locate hazardous turbulence within storms is considered unreliable. The strikes occurred in storm regions having radar reflectivity factor between 25 to 35 dBZ. These regions were generally on the boundaries of t	16. SUPPLEMENTARY NOTATION						
17   COSATI CODES   18 SUBJECT TERMS (Continue on receive directions and identify by block number)     FIELD   GROUP   SUB GR   Lightning   Precipitation   Radar     Aircraft Strikes   Turbulence   Storms   Wind Shear     19   ABSTRACT (Continue on receive if necessary and identify by block number)   Field   Aircraft Strikes     19   ABSTRACT (Continue on receive if necessary and identify by block number)   Field   Wind Shear     19   ABSTRACT (Continue on receive if necessary and identify by block number)   Field   Field     19   ABSTRACT (Continue on receive if necessary and identify by block number)   Field   Field     19   ABSTRACT (Continue on receive if necessary and identify by block number)   Field   Field     19   ABSTRACT (Continue on receive if necessary and identify by block number)   Field   Field     1981 and 1982 Joint Agency Turbulence Experiment are used to study the relationship of aircraft lightning strikes to storm precipitation, turbulence severity, and wind shear. The strikes are found to be strongly correlated with vertical drafts, predominantly downdrafts. The strikes were also well correlated with regions of strong turbulence. However, since most strong turbulence episodes were not associated with lightning, use of lightning location methods to locate hazardous turbulence within storms is considered unreliable. The strikes occurred in							
FIELDGROUPSUB GRLightningPrecipitationRadarAircraft StrikesTurbulenceStormsWind Shear19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by block number)19. ABSTRACT (Continue on overse if necessary and identify by		TH SUBJECT TERMS	Continue on receive of ne		/. b. black auth		
Aircraft Strikes Turbulence Storms Wind Shear NABSTRACT (Continue on average if accurate and identify by block number) A limited set of in-situ aircraft and ground-based radar data acquired during the 1981 and 1982 Joint Agency Turbulence Experiment are used to study the relationship of aircraft lightning strikes to storm precipitation, turbulence severity, and wind shear. The strikes are found to be strongly correlated with vertical drafts, predominantly downdrafts. The strikes were also well correlated with regions of strong turbulence. However, since most strong turbulence episodes were not associated with lightning, use of lightning location methods to locate hazardous turbulence within storms is considered unreliable. The strikes occurred in storm regions having radar reflectivity factor be- tween 25 to 35 dBZ. These regions were generally on the boundaries of the dominant storm precipitation cores. Storm wind shear was frequently high in regions near air- craft strikes. The strong correlations with strong turbulence, downdraft boundaries, and precipitation core boundaries suggest that the strikes occurred in regions of charge separation.	FIELD GROUP SUB GR	Lightning	Precip	itation	Radar		
Storms Wind Shear 19. ABSTRACT (Continue on receive if receivery and identify by block number) A limited set of in-situ aircraft and ground-based radar data acquired during the 1981 and 1982 Joint Agency Turbulence Experiment are used to study the relationship of aircraft lightning strikes to storm precipitation, turbulence severity, and wind shear. The strikes are found to be strongly correlated with vertical drafts, predominantly downdrafts. The strikes were also well correlated with regions of strong turbulence. However, since most strong turbulence episodes were not associated with lightning, use of lightning location methods to locate hazardous turbulence within storms is considered unreliable. The strikes occurred in storm regions having radar reflectivity factor be- tween 25 to 35 dBZ. These regions were generally on the boundaries of the dominant storm precipitation cores. Storm wind shear was frequently high in regions near air- craft strikes. The strong correlations with strong turbulence, downdraft boundaries, and precipitation core boundaries suggest that the strikes occurred in regions of charge separation.		Aircraft Str	ikes Turbul	ence			
A limited set of in-situ aircraft and ground-based radar data acquired during the 1981 and 1982 Joint Agency Turbulence Experiment are used to study the relationship of aircraft lightning strikes to storm precipitation, turbulence severity, and wind shear. The strikes are found to be strongly correlated with vertical drafts, predominantly downdrafts. The strikes were also well correlated with regions of strong turbulence. However, since most strong turbulence episodes were not associated with lightning, use of lightning location methods to locate hazardous turbulence within storms is considered unreliable. The strikes occurred in storm regions having radar reflectivity factor be- tween 25 to 35 dBZ. These regions were generally on the boundaries of the dominant storm precipitation cores. Storm wind shear was frequently high in regions near air- craft strikes. The strong correlations with strong turbulence, downdraft boundaries, and precipitation core boundaries suggest that the strikes occurred in regions of charge separation.		<u>Storms</u>	Wind S	hear			
1981 and 1982 Joint Agency Turbulence Experiment are used to study the relationship of aircraft lightning strikes to storm precipitation, turbulence severity, and wind shear. The strikes are found to be strongly correlated with vertical drafts, predominantly downdrafts. The strikes were also well correlated with regions of strong turbulence. However, since most strong turbulence episodes were not associated with lightning, use of lightning location methods to locate hazardous turbulence within storms is considered unreliable. The strikes occurred in storm regions having radar reflectivity factor be- tween 25 to 35 dBZ. These regions were generally on the boundaries of the dominant storm precipitation cores. Storm wind shear was frequently high in regions near air- craft strikes. The strong correlations with strong turbulence, downdraft boundaries, and precipitation core boundaries suggest that the strikes occurred in regions of charge separation.	19. ABSTRACT (Continue on reverse if necessary and	didentify by block number	windebagod ma	dan data a	covirad du	ring the	
of aircraft lightning strikes to storm precipitation, turbulence severity, and wind shear. The strikes are found to be strongly correlated with vertical drafts, predominantly downdrafts. The strikes were also well correlated with regions of strong turbulence. However, since most strong turbulence episodes were not associated with lightning, use of lightning location methods to locate hazardous turbulence within storms is considered unreliable. The strikes occurred in storm regions having radar reflectivity factor be- tween 25 to 35 dBZ. These regions were generally on the boundaries of the dominant storm precipitation cores. Storm wind shear was frequently high in regions near air- craft strikes. The strong correlations with strong turbulence, downdraft boundaries, and precipitation core boundaries suggest that the strikes occurred in regions of charge separation.	1981 and 1982 Joint Agency 1	furbulence Exp	eriment are u	sed to stuc	iv the relat	ionship	
The strikes are found to be strongly correlated with vertical drafts, predominantly downdrafts. The strikes were also well correlated with regions of strong turbulence. However, since most strong turbulence episodes were not associated with lightning, use of lightning location methods to locate hazardous turbulence within storms is considered unreliable. The strikes occurred in storm regions having radar reflectivity factor be- tween 25 to 35 dBZ. These regions were generally on the boundaries of the dominant storm precipitation cores. Storm wind shear was frequently high in regions near air- craft strikes. The strong correlations with strong turbulence, downdraft boundaries, and precipitation core boundaries suggest that the strikes occurred in regions of charge separation.	of aircraft lightning strikes	o storm precip	itation. turbu	lence seve	rity, and w	ind shear.	
downdrafts. The strikes were also well correlated with regions of strong turbulence. However, since most strong turbulence episodes were not associated with lightning, use of lightning location methods to locate hazardous turbulence within storms is considered unreliable. The strikes occurred in storm regions having radar reflectivity factor be- tween 25 to 35 dBZ. These regions were generally on the boundaries of the dominant storm precipitation cores. Storm wind shear was frequently high in regions near air- craft strikes. The strong correlations with strong turbulence, downdraft boundaries, and precipitation core boundaries suggest that the strikes occurred in regions of charge separation.	The strikes are found to be s	trongly correl	ated with vert	ical drafts	, predomín	antly	
However, since most strong turbulence episodes were not associated with lightning, use of lightning location methods to locate hazardous turbulence within storms is considered unreliable. The strikes occurred in storm regions having radar reflectivity factor be- tween 25 to 35 dBZ. These regions were generally on the boundaries of the dominant storm precipitation cores. Storm wind shear was frequently high in regions near air- craft strikes. The strong correlations with strong turbulence, downdraft boundaries, and precipitation core boundaries suggest that the strikes occurred in regions of charge separation.	downdrafts. The strikes we	re also well com	rrelated with	regions of	strong turt	oulence.	
of lightning location methods to locate hazardous turbulence within storms is considered unreliable. The strikes occurred in storm regions having radar reflectivity factor be- tween 25 to 35 dBZ. These regions were generally on the boundaries of the dominant storm precipitation cores. Storm wind shear was frequently high in regions near air- craft strikes. The strong correlations with strong turbulence, downdraft boundaries, and precipitation core boundaries suggest that the strikes occurred in regions of charge separation.	However, since most strong	turbulence epis	sode <mark>s</mark> were no	t associate	ed with ligh	tning, use	
unreliable. The strikes occurred in storm regions having radar reflectivity factor be- tween 25 to 35 dBZ. These regions were generally on the boundaries of the dominant storm precipitation cores. Storm wind shear was frequently high in regions near air- craft strikes. The strong correlations with strong turbulence, downdraft boundaries, and precipitation core boundaries suggest that the strikes occurred in regions of charge separation.	of lightning location methods	to locate haza	rdous turbuler	nce within a	storms is a	onsidered	
tween 25 to 35 dB2. These regions were generally on the boundaries of the dominant storm precipitation cores. Storm wind shear was frequently high in regions near air- craft strikes. The strong correlations with strong turbulence, downdraft boundaries, and precipitation core boundaries suggest that the strikes occurred in regions of charge separation.	unreliable. The strikes occu	urred in storm	regions havin	g radar re	flectivity f	actor be-	
craft strikes. The strong correlations with strong turbulence, downdraft boundaries, and precipitation core boundaries suggest that the strikes occurred in regions of charge separation.	tween 25 to 35 dBZ. These is	regions were g	enerally on the	e boundari	es of the do	ominant	
and precipitation core boundaries suggest that the strikes occurred in regions of charge separation. $\checkmark$	craft strikes The strong co	prorin wind she	ar was freque estrong turbul	lence dow	n regions n ndraft bour	ear air- dariee	
separation.	and precipitation core bounds	aries suggest fl	hat the strikes	cocurred	in regione	of charge	
	separation.		une ou nice	- occurred		or climine	
	· γ-						

. •

DD FORM 1473, 83 APR EDITION C	F 1 JAN 73 IS OBSOLETE	UNCLASSIFIED				
Alan R. Bohne	(617) 861-4405	LYR				
22. NAME OF RESPONSIBLE INDIVIDUAL	22b TELEPHONE NUMBER include Area Code;	226 OFFICE SYMBOL				
UNCLASSIFIED/UNLIMITED 🖾 SAME AS RPT 🗆 DTIC US	ERS D UNCLASSIFIED					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21 ABSTRACT SECURITY CLAS	21 ABSTRACT SECURITY CLASSIFICATION				

SECURITY CLASSIFICATION OF THIS PAGE

### Contents

Ì

1.	INTRODUCTION	1
2.	DATA ANALYSIS	3
3.	OBSERVATIONS	5
4.	CONCLUSIONS	25
RE	EFERENCES	31

1.2.2.2

**NUMBER** 

25056523 3500053 15000533

### Illustrations

1.	Contours of Reflectivity Factor for 1 July 1981 on a Constant Height Surface at Penetration Altitude of 4.57 km msl	6
2.	Aircraft Gust Data Along the (a) Longitudinal, (b) Lati- tudinal, and (c) Vertical Directions for 1 July 1981	7
3.	Estimates of Turbulence Severity for Aircraft Relative (a) Longitudinal, (b) Transverse, and (c) Vertical Directions for 1 July 1981	8
4.	Contours of Reflectivity Factor for 17 July 1982 on a Constant Height Surface at an Altitude of 6.0 km msl	9
5.	Contours of Reflectivity Factor for 17 July 1982 on a Constant Height Surface at an Altitude of 6.0 km msl	9

### Illustrations

voor al attende die andere aan die stad die die die oorde die die stad die oorde die die stad die oorde die die

6.	Contours of Reflectivity Factor for 17 July 1982 on Track Surface for Penetration A	10
7.	Aircraft Gust Data Along the (a) Longitudinal, (b) Lati- tudinal, and (c) Vertical Directions for 17 July 1982 for Penetration A	11
8.	Estimates of Turbulence Severity for Aircraft Relative (a) Longitudinal, (b) Transverse, and (c) Vertical Directions for 17 July 1982 for Penetration A	12
9.	Contours of Reflectivity Factor for 17 July 1982 on Track Surface for Penetration B	13
10.	Aircraft Gust Data Along the (a) Longitudinal, (b) Lati- tudinal, and (c) Vertical Directions for 17 July 1982 for Penetration B	14
11.	Estimates of Turbulence Severity for Aircraft Relative (a) Longitudinal, (b) Transverse, and (c) Vertical Directions for 17 July 1982 for Penetration B	15
12.	Contours of Reflectivity Factor for 17 July 1982 on Track Surface for Penetration C	16
13.	Aircraft Gust Data Along the (a) Longitudinal, (b) Lati- tudinal, and (c) Vertical Directions for 17 July 1982 for Penetration C	17
14.	Estimates of Turbulence Severity for Aircraft Relative (a) Longitudinal, (b) Transverse, and (c) Vertical Directions for 17 July 1982 for Penetration C	18
15.	Contours of Reflectivity Factor for 28 July 1982 on a Constant Height Surface at an Altitude of 3.0 km msl	19
16.	Contours of Reflectivity Factor for 28 July 1982 on Track Surface	19
17.	Aircraft Gust Data Along the (a) Longitudinal, (b) Lati- tudinal, and (c) Vertical Directions for 28 July 1982	20
18.	Estimates of Turbulence Severity for Aircraft Relative (a) Longitudinal, (b) Transverse, and (c) Vertical Directions for 28 July 1982	21
19.	Contours of Reflectivity Factor for 30 July 1982 on a Constant Height Surface at an Altitude of 7.2 km msl	22
20.	Contours of Reflectivity Factor for 30 July 1982 on Track Surface	22
21.	Aircraft Gust Data Along the (a) Longitudinal, (b) Lati- tudinal, and (c) Vertical Directions for 30 July 1982	23
22.	Estimates of Turbulence Severity for Aircraft Relative (a) Longitudinal, (b) Transverse, and (c) Vertical Directions for 30 July 1982	24
23.	Contours of Reflectivity Factor for 31 July 1982 on Constant Height Surface at an Altitude of 7, 19 km msl	25

L

20202	
N. 491/198	
ALL BURER	
1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1	
100 A	
Ţ	

i	11		-	٠.	-	٠	:_	_	-
l	н	υ	ъ		O	T.	10	n	2

24.	Aircraft Gust Data Along the (a) Longitudinal, (b) Lati- tudinal, and (c) Vertical Directions for 31 July 1982	26
25.	Estimates of Turbulence Severity for Aircraft Relative (a) Longitudinal, (b) Transverse. and (c) Vertical Directions for 31 July 1982	27

222.22

Tables

1.	Wind and Reflectivity Factor Structure	28
2.	Turbulence Severity (cm <sup>2/3</sup> s-1)	29

Accesion For	
NTIS CRA&I DTIC TAB U. anno.1::ced Justification	-
By Di_t_ib_tio_/	
Availability Codes Dist Avair a g / or Special	
A-1	

.-

. . .



### Storm Precipitation and Wind Structure During Aircraft Strike Lightning Events

#### I. INTRODUCTION

During the spring and early summer periods of 1981 and 1982 the Air Force Geophysics Laboratory participated in the Storm Hazards Program of NASA Langley Research Center and NASA Wallops Flight Center, Virginia. The Air Force effort was termed the Joint Agency Turbulence Experiment, and was primarily directed towards developing radar techniques for detecting and classifying turbulence in storms. Radar measurements of reflectivity factor, Doppler radial velocity, and in-phase and quadrature return data were obtained with AFGL Doppler processing equipment, which was incorporated into the NASA Wallops SPANDAR radar. Estimates of turbulence severity derived from the pulse-topulse data were compared with the in-situ aircraft estimates of turbulence severity. Methods were developed that enabled the radar to enjoy considerable success in locating the nonhazardous and hazardous turbulence zones within the thunderstorms penetrated by the instrumented aircraft. The results of the AFGL effort are presented in the Final Report of the Joint Agency Turbulence Experiment.<sup>1</sup>

<sup>(</sup>Received for Publication 23 May 1985)

<sup>1.</sup> Bohne, A. R. (1985) Joint Agency Turbulence Experiment--Final Report, AFGL-TR-85-0012.

While the AFGL effort was directed towards turbulence detection, the NASA effort was directed towards studying the effects of lightning strikes to aircraft, and the general meteorological effects of lightning events on the local atmosphere. The aircraft lightning strike events were correlated with aircraft penetration altitude, temperature, precipitation, and turbulence structure. Their observations showed that lightning strikes to the aircraft occurred most frequently in the upper portions of storms, high above the freezing level. Peak strike rates were observed at altitudes between 38 to 40 kft, with ambient temperatures well below - 40°C. Relatively few strikes were obtained near the freezing level. Lightning strikes were not well correlated with regions of heavy precipitation or turbulence.

The lightning strike activity observed by the NASA aircraft may, in some cases, reflect events that were triggered by the aircraft itself. It is unlikely that the aircraft penetrated existing lightning currents, although these triggered events did appear similar to naturally occurring intracloud flashes. In addition to direct strikes there were a small number of nearby flashes, generally within a few km of the aircraft, which triggered onboard equipment but did not intercept the aircraft. Whether these were a result of modification of the local electric field by the presence of the aircraft is unknown. Thus, the observations here may reflect both natural and triggered lightning activity within the storms. The results of the NASA effort are summarized in a final report.  $^2$ 

Other researchers have investigated the occurrence of lightning in storms, with frequently differing results. These efforts were generally performed with remote UHF, VHF, or sferic measurement equipment. Generally, the results indicated that naturally occurring lightning originates in layers, usually 2 to 3 km thick and located in midlevel to upper level storm regions. <sup>3-5</sup> Most lightning events are mainly horizontal in extent. <sup>3,6</sup> They frequently originate near the

- MacGorman, D. R., Taylor, W. L., and Few, A. A. (1983) Some spatial and temporal relationships between lightning and storm structure and evolution, <u>Proceedings Addendum, Eighth Inter. Aero. and Ground Conf. on Lightning</u> and Static Elec., Ft. Worth, Texas.
- 4. Fitzgerald, D. R. (1985) <u>Thunderstorm Activity</u>, <u>The Handbook of Geophysics</u> and the Space Environment, Chapter 20.2, (in press).
- Taylor, W. L., Rusi, W. D., MacGorman, D. R., and Brandes, E. A. (1983) Lightning activity observed in upper and lower portions of storms and its relationship to storm structure from VHF mapping and Doppler radar, Proceedings, Eighth Inter. Aero. and Ground Conf. on Lightning and Static Elec., Ft. Worth, Texas.
- Proctor, D. E. (1983) Lightning and precipitation in a small multicellular thunderstorm, J. Geophys. Res. 88(No. C9):5421-5440.

Fisher, B. D., Brown, P. W., and Plumer, J. A. (1985) <u>NASA Storm Haz-ards Lightning Research</u>, Flight Safety Foundation Thirteenth Corporate Aviation Safety Seminar, 14-16 April, 1985, Dallas/Fort Worth Apt, Texas.

precipitation cores and extend towards areas of lighter precipitation.  $^{7-9}$  Occasionally, however, no clear association of lightning source regions and precipitation are observed.  $^{10, 11}$ 

There have been a small number of observations correlating lightning activity with storm wind fields. These data were usually obtained through use of Doppler radar in addition to the traditional lightning mapping techniques. A very loose pattern emerged showing lightning sources somewhat correlated with divergent storm flows, regions of strong wind shear, and updraft and downdraft regions.<sup>3, 5, 12</sup>

The data presented here represent the storm wind, turbulence, and precipitation reflectivity factor structure during periods of aircraft lightning strike events. Since the AFGL effort was directed towards turbulence measurement, only a very limited number of lightning episodes are available for discussion. Nonetheless, a strong correlation of lightning activity is found with storm downdrafts, heavy precipitation core boundaries, and strong turbulence regions.

#### 2. DATA ANALYSIS

The aircraft and radar data presented are storm reflectivity factor, aircraft gust measurements, and estimated turbulence severity. During operations the radar operated in two distinct scan modes. During storm penetrations the NASA Wallops SPANDAR radar tracked the NASA instrumented aircraft. In between penetrations the radar performed a general series of sector scans, sequentially elevated. The storm reflectivity data are plotted on either constant height surfaces or on track surfaces. The constant height plots were generated by traditional methods of interpolating the reflectivity data from the elevated scan sequences onto constant height surfaces, using a linear trivariate weighting function

- MacGorman, D. R., Few, A. A., and Teer, T. L. (1981) Layered lightning activity, J. Geophys. Res. 86(No. C10):9900-9910.
- 8. Ligda, M. G. H. (1956) The radar observation of lightning, <u>J. Atmos. Terr.</u> Phys. 9:329-346.
- 9. Rust, W. D., and Doviak, R. J. (1982) Radar research on thunderstorms and lightning, <u>Nature 297</u>:461-468.
- Fitzgerald, D. R. (1967) Probable aircraft "triggering" of lightning in certain thunderstorms, <u>Mon. Wea. Rev.</u> 95(No. 12):835-842.
- Mazur, V., Fisher, B. D., and Gerlach, J. C. (1983) Conditions conducive to lightning striking an aircraft in a thunderstorm, <u>Proceedings</u>, Eighth <u>Inter. Aero. and Ground Conf. on Lightning and Static Elec.</u>, Fort Worth, <u>Texas</u>, pp. 90-1 - 90-7.
- 12. Carte, A. E., and Kidder, R. E. (1977) Lightning in relation to precipitation, J. Atmos. Terr. Phys. 39:139-148.

to determine the proper contribution to the surface grid points. These, when shown, usually represent the storm reflectivity at aircraft penetration altitude. The aircraft tracks are time adjusted to properly place them relative to the storm structure at plot time. Frequently, however, due to the rapid turnaround of the aircraft from the exit of one penetration to the start of the next penetration, a coordinated sector scan sequence was not obtained. In this instance, the storm reflectivity factor along the aircraft track surface is presented. The track surface is a planar surface defined to include the straight aircraft penetration at penetration altitude, and a parallel line at the ground, passing through the radar position. In this instance, a linear bivariate interpolation scheme was used to interpolate the radar reflectivity data to the surface grid points.

The aircraft gust data represent the three orthogonal longitudinal, latitudinal, and vertical wind components. They have not been decomposed into aircraft relative longitudinal, transverse, and vertical components. The horizontal data are used to show the horizontal storm gust structure, a composite of the relatively stationary storm wind structure, and the smaller scale turbulence structure. The vertical gust data clearly indicate the presence of significant updraft and downdraft regions. The vertical wind speed values occasionally appear to need adjustment to remove a bias that may be present in the data. This may be accomplished by averaging the trace along its full extent and assuming that the mean vertical velocity should be approximately zero, or assuming that the vertical current should be close to zero near the radar storm boundary. Both methods may themselves be inaccurate however, particularly when performed over only a portion of a storm penetration. Suggested corrections will be noted where applicable.

The aircraft turbulence severity data were obtained from analysis of the gust data. Here, however, the horizontal gust components have been transformed into aircraft relative coordinates, parallel (longitudinal) and transverse to the penetration tracks. This coordinate system was found most useful in the turbulence study.<sup>1</sup> The manner of obtaining the turbulence severity from the aircraft gust data is fully outlined in the Joint Agency Turbulence Experiment Final Report. Simply stated, the aircraft data were used in a structure function analysis. A segment of gust data, centered about the track location in question, served as input data to the structure function analysis. The segment was increased in size until the structure function and turbulence severity estimates, for separation distances considered to lie in the inertial subrange, became stable. That is, these quantities become essentially constant even though the data segment size was increasing. A data segment length of about 1200 m was generally found sufficient to ensure this condition was met. Larger segment lengths were not employed for it was found that with continued increase in segment length, the quasi-stationary storm wind field structures would eventually contaminate the turbulence severity

estimates. In these instances the estimates were not constant, but changed continuously with increasing segment size. Thus, the turbulence severity estimates presented here are believed to represent well the turbulence environment, with relatively minor contribution from the more stationary, larger scale storm wind field.

The aircraft gust data were also employed to estimate the maximum storm wind shear near lightning strike periods. One-second gust velocity averages were formed. The maximum and minimum values, which were located within about 5 sec of lightning strike time, were used to estimate the local maximum shear value. Care was taken to ensure that the gust excursions signified a true alteration in the structure of the storm wind field, and were not simply a result of a sudden turbulent burst.

#### 3. OBSERVATIONS

The first period for consideration occurred during penetration of a small storm located approximately 124 km to the southwest of the SPANDAR radar. The aircraft penetration altitude is 4.57 km msl. The environmental winds are light, being 21 m/sec from the southeast. Figure 1 presents the storm reflectivity factor at the penetration altitude. The aircraft passes through the northern portion of the single storm core in regions of 10 to 30 dBZ. It is seen that the nearby lightning event occurs when the aircraft was in a region near 25 dBZ. The aircraft is just beginning to exit the storm core and is approximately 4 km from the center of the core.

Figure 2 portrays the aircraft gust data during this storm penetration. The lightning event is seen to occur within 4 sec of a strong storm wind shear feature. This shear zone is relatively small in horizontal extent, occurring over a distance of roughly 800 m (about 4 sec). The estimated storm shears in the E-W and N-S directions are quite large, being about  $2.8 \times 10^{-2}$  sec and  $2.2 \times 10^{-2}$  sec, respectively.

The vertical gust trace indicates that this wind shear was coincident with a downdraft of about 6 m/sec. The aircraft was in a second small downdraft of about 5 m/sec when the nearby flash occurred. It also appears that a small, but sharp, upward air current was located in between these two downdraft regions. Although there may be a bias in the gust speed values, it is highly unlikely that any adjustment would alter the observation that the lightning event occurred when the aircraft had been in a region of moderate downdraft.

The turbulence severity estimates are presented in Figure 3. The plots indicate that the lightning event occurred when the severity was about 6 cm $^{2/3}$ /sec, which would generally be considered moderate to heavy in value. The lightning



Figure 1. Contours of Reflectivity Factor for 1 July 1981 on a Constant Height Surface at Penetration Altitude of 4.57 km msl. Time is 18:17:00 GMT

event is seen to lie within about 400 m from a turbulence severity maximum of about 10 to 12 cm<sup>2/3</sup>/sec. This value would be characterized as heavy to severe turbulence. It should also be noted that this nearby severity maximum represents the region of greatest severity along this storm track.

The next three lightning events to be presented were observed on 17 July 1982. Figures 4 and 5 depict the storm reflectivity factor on constant height surfaces during the first two and last penetrations. During these observations the storm was entering the dissipating stage, as evidenced by the decrease in maximum storm reflectivity factor, number of cores, and areal extent of the dominant storm cores, between these two periods. The maximum reflectivity factor was near 45 dBZ during the first two penetrations and had decreased to about 35 dBZ at the time of the third. The penetration altitudes were 7.8, 9.3, and 9.3 km msl, respectively. The environmental wind is out of the southwest at approximately 3.5 m/sec at these heights.

Figure 6 portrays the storm reflectivity factor structure along the track surface for the first lightning event. It is seen that the strike occurred when the aircraft was just entering the easternmost storm core. The reflectivity factor is about 25 dBZ, and the aircraft is about 4 km away from the center of this core.









alateration of the second of the second of the second second second in the second of the second of the second o

Figure 3. Estimates of Turbulence Severity for Aircraft Relative (a) Longitudinal, (b) Transverse, and (c) Vertical Directions for 1 July 1981





لكندينينك



Figure 5. Contours of Reflectivity Factor for 17 July 1982 on a Constant Height Surface at an Altitude of 6.0 km msl. Time is 20:40:35 GMT





Figure 6. Contours of Reflectivity Factor for 17 July 1982 on Track Surface for Penetration A

The aircraft gust data (Figure 7) indicate that the aircraft had just entered a region of strong downdraft, with maximum vertical windspeed greater than 14 m/sec. The downdraft speed at time of strike is also greater than 14 m/sec. It is seen that this northern edge of the storm core is dominated by a downdraft region, broken into two segments of approximately 2.8 and 1.0 km width. The horizontal storm wind structure shows fairly sharp changes on scales of a few km. The smaller scale turbulence fluctuations are also seen to increase in strength in this downdraft region.

The storm wind shear estimates for the E-W and N-S directions are  $4 \times 10^{-2}$  see and  $3.5 \times 10^{-2}$  sec, respectively. These values are indicative of strong shear, larger than that usually observed within general storm regions.

The turbulence severity estimates are presented in Figure 8. They indicate very mild turbulence away from this storm core, but increasing severity as the aircraft penetrates the 25 dBZ boundary. The three components exhibit severity values ranging from 6 to 9 cm<sup>2/3</sup>/sec at strike time, and the lightning event is within 1200 m of the location of the severity maximum for this penetration. It is also observed that the turbulence severity is very strong throughout the entire storm core with maxima ranging from 9.5 to 14 cm<sup>2/3</sup>/sec. These severity values indicate heavy to severe turbulence within the storm region.

The storm reflectivity factor on the track surface for the second lightning event is shown in Figure 9. Here the aircraft penetrates the northern portion of a storm core exhibiting a maximum reflectivity factor just over 35 dBZ. The lightning strike occurs at the 35 dBZ boundary as the aircraft is departing this high reflectivity region.



いたいないたいとうないということ



Figure 10 shows the lightning strike to occur in a region where the aircraft measured gusts are undergoing their most dramatic change along this penetration. The horizontal data are undergoing very strong fluctuations on a scale of 1 km or less. The vertical trace shows the aircraft is once again in a very strong down-draft at time of strike, with windspeeds in excess of 11 m/sec for both maximum downdraft and speed at time of strike. It is also noted that these strong gust fluctuations occur near the radar storm boundary. Most of the storm core is imbedded in a vertical draft structure varying from light updraft to moderate downdraft. The very strong vertical current resides on the outer boundary of the storm core. Overall, the downdraft region is roughly 3.2 km wide, with the intense portion, encountered at strike time, about 2.0 km wide.



12.2

965 Y 197 C

102.66.58

ĥ

Figure 8. Estimates of Turbulence Severity for Aircraft Relative (a) Longitudinal, (b) Transverse, and (c) Vertical Directions for 17 July 1982 for Penetration A



Figure 9. Contours of Reflectivity Factor for 17 July 1982 on Track Surface for Penetration B  $\,$ 

The storm wind shear values are  $1 \times 10^{-2}$  sec and  $1.6 \times 10^{-2}$  sec for the E-W and N-S directions, respectively. Once again, these values are quite large and are representative of strong shear zones not typically observed in general storm regions.

Figure 11 shows the turbulence severity at strike time is clearly at a maximum for this entire penetration. The turbulence severity estimates range from 9.5 to  $15 \text{ cm}^{2/3}/\text{sec}$ , once again clearly in the range of heavy to severe turbulence. It is also noted that the severity is rather high for the entire penetration. This may be a result of precipitation induced downdraft mixing with local environmental air, resulting in the dramatic fluctuations observed on the edge of this storm.

The track surface plot of storm reflectivity factor for the third strike is shown in Figure 12. The strike occurs as the aircraft is just about to penetrate the 25 dBZ contour, which represents the northern boundary of this storm core.

Figure 13 displays the aircraft gust data. The lightning strike is seen to occur within a region where the horizontal winds are undergoing significant modification. The initial strong increase in speed in the northern component on the western side of this storm may represent environmental flow around the storm



Figure 10. Aircraft Gust Data Along the (a) Longitudinal, (b) Latitudinal, and (c) Vertical Directions for 17 July 1982 for Penetration B

core, the core representing an obstacle to the oncoming air. The sudden decrease in windspeed just before the strike, adjacent to the western boundary of the 25 dBZ contour, may represent a divergent zone behind the core on the downwind side. The variation in the horizontal wind structure is more pronounced at this time than during the rest of the penetration. The vertical gust data show that the strike occurred in a region of slight upward moving air. Also note that is occurred within about 300 m of a very narrow downdraft. The downdraft region is pronounced for its sharpness, being less than 400 m in width. The maximum downward airspeed is only about 3 m/sec (assuming a bias of about 1 m/sec in the data). Finally note that the turbulent fluctuations are greater in magnitude during this period than at any other time along the aircraft track.

The estimated storm shear values for the E-W and N-S directions are effectively zero and  $8.0 \times 10^{-3}$  sec, respectively. These values are significantly smaller than those observed during previous strike episodes.

The turbulence severity estimates in Figure 14 show the severity to be about 5 to 9 cm<sup>2/3</sup>/sec at lightning strike time. The strike is essentially coincident with the period of strongest severity along the entire penetration. The maximum severity values lie in the range of 6 to 11 cm<sup>2/3</sup>/sec. Once again these values lie in the heavy to severe range.



Figure 11. Estimates of Turbulence Severity for Aircraft Relative (a) Longitudinal, (b) Transverse, and (c) Vertical Directions for 17 July 1982 for Penetration B



Figure 12. Contours of Reflectivity Factor for 17 July 1982 on Track Surface for Penetration C

The next penetration day for discussion is 28 July 1982. Here, an extensive line of storms, stretching about 200 km southwest to northeast, moved through the region. Figure 15 shows a constant height display of the southern portion of this line at an altitude of 3.0 km. The plan view of the aircraft track is shown to pass parallel to and along the northern side of this line. Figure 16 shows the storm structure on the track surface, which here is essentially a vertical side (RHI surface) along an azimuth of about 251°. The penetration altitude is about 8.8 km. The strike occurs at the location of the 35 dBZ contour, within 2 km of the highest reflectivity factor for this particular storm core.

Figure 17 shows the aircraft gust data. Oddly, little significant fluctuation in the horizontal field components is observed. The changes in the horizontal components are not distinct from any other period along the penetration. The vertical trace, however, shows that the strike occurred when the aircraft was in a weak and narrow (less than 400 m wide) downdraft. More significantly, the strike occurs within 800 m of the edge of a pronounced downdraft. This downdraft is a minimum of 24 sec wide (nearly 5 km). Since most of the vertical gust for this track is downward moving, it is possible that there is a negative bias in the vertical gust data along the penetration. It is very unlikely that the indicated downward moving air could be sustained for a penetration length of roughly 40 km



Figure 13. Aircraft Gust Data Along the (a) Longitudinal, (b) Latitudinal, and (c) Vertical Directions for 17 July 1982 for Penetration C

(200 sec) as shown here. It therefore is assumed that there is a negative bias of about 4 m/sec. Thus, the maximum downdraft speed is estimated to be about 13 m/sec.

The E-W and N- $\omega$  components of storm wind shear are estimated to be negligible and 2.3  $\times 10^{-2}$  sec, respectively, once again indicating a strong shear zone near the lightning strike location.

Figure 18 shows the turbulence severity to range from 8 to 9 cm<sup>2/3</sup>/sec at strike time, clearly in the heavy to severe range. The strike event is somewhat removed from the very strong severity region near 22:27:04 GMT (about 3.6 km away), where the severity would be considered extreme. This strike episode thus occurred in a highly turbulent region lying adjacent to a strong downdraft and regular settling precipitation core.

The next day for discussion is 30 July 1982. Here a rather dissociated systen, was penetrated. The constant height reflectivity plot for an altitude of 7.2 km is shown in Figure 19. The environmental wind is from the west southwest and the maximum storm reflectivity factor at this altitude is about 35 dBZ. The two strikes, which occurred at 6.9 km altitude, are shown on the track surface plot (Figure 20). They occur very close to the center of the 35 dBZ core, in a region



Figure 14. Estimates of Turbulence Severity for Aircraft Relative (a) Longitudinal, (b) Transverse, and (c) Vertical Directions for 17 July 1982 for Penetration C



Figure 15. Contours of Reflectivity Factor for 28 July 1982 on a Constant Height Surface at an Altitude of 3.0 km msl. Time is 22:56:48 GMT





Figure 16. Contours of Reflectivity Factor for 28 July 1982 on Track Surface



Figure 17. Aircraft Gust Data Along the (a) Longitudinal, (b) Latitudinal, and (c) Vertical Directions for 28 July 1982

of 30 to 35 dBZ. The two strikes occurred within 10 sec, or about 2 km, of one another.

The aircraft gust data, displayed in Figure 21, indicates no truly significant differences at strike times than from any other period along the penetration. The variations in the horizontal are, in fact, less severe than at other periods along the track. The only consistent feature noted is that the strikes occurred adjacent to, and within, downward moving air currents. The first strike is at a location exhibiting zero vertical air motion. The second strike occurs within a downdraft about 1 km width, and having maximum downward speed of 6 m/sec. A significant downward moving current is seen to occur about 10 sec, or 2 km, after the second strike. Similarly, a broad current of downward moving air is seen about 2 km before the first strike. This association of aircraft strike and downdraft storm region is by now a familiar pattern.

The shear components along the E-W and N-S directions are estimated to be about  $2.0 \times 10^{-3}$  sec and negligible for the first strike event, and  $1.5 \times 10^{-3}$  sec and negligible for the second strike, respectively. These values are not indicative of very strong sheared zones and may generally be considered typical of those values commonly observed in storms. They are also somewhat smaller than those observed during previous strike episodes.



search the determined the back of the second field

Figure 18. Estimates of Turbulence Severity for Aircraft Relative (a) Longitudinal, (b) Transverse, and (c) Vertical Directions for 28 July 1982





CONTOURS OF DBZ







Figure 21. Aircraft Gust Data Along the (a) Longitudinal, (b) Latitudinal, and (c) Vertical Directions for 30 July 1982

The turbulence severity, displayed in Figure 22, indicates that the first strike occurred in severity of about 3 to 6 cm<sup>2/3</sup>/sec, and the second strike was in somewhat heavier turbulence, with severity values in the range of 5 to 10 cm<sup>2/3</sup>/sec. These severity episodes are not truly distinct from other periods observed along the track. Nonetheless, the severity at strike times still generally lie in the moderate to heavy range.

The last period to be discussed occurred during penetration of a long line of storms to the southwest of the SPANDAR radar. Figure 23 shows the reflectivity factor on a constant height surface at an altitude of 7.19 km msl. The maximum reflectivity factor is just over 30 dBZ, and the strike occurred at the 30 dBZ boundary at an altitude of 7.0 km.

The gust data, presented in Figure 24, shows the horizontal wind components exhibited considerable variation all along the penetration track. The variations near lightning strike time are not significantly different from any other period.



DEPENDENT LAN

Recting to the second second

Figure 22. Estimates of Turbulence Severity for Aircraft Relative (a) Longitudinal, (b) Transverse, and (c) Vertical Directions for 30 July 1982





Figure 23. Contours of Reflectivity Factor for 31 July 1982 on Constant Height Surface at an Altitude of 7.19 km msl. Time is 20:14:52 GMT

What is significant, however, is that the aircraft is once again in a region of downward moving air. The downdraft is about 2 km wide, has a maximum downward speed of about 6 m/sec, and lies at the boundary of the precipitation core. The estimated E-W and N-S storm shear components are  $1.75 \times 10^{-2}$  sec for both directions and are indicative of a strongly sheared environment.

The turbulence severity values at strike time are 5 to 8 cm<sup>2/3</sup>/sec, in the range of moderate to heavy turbulence severity (Figure 25). The strike occurred during, or near (10 sec, or about 2 km), peaks in turbulence severity. Although these peaks are not distinct from those observed in other portions of the track, they do represent strong turbulence episodes.

#### 4. CONCLUSIONS

an Analast analysis therein

The data presented here detail the storm reflectivity factor, wind, and turbulence structure along aircraft storm penetrations during which lightning strikes to, or near to, the aircraft occurred. Certain persistent features were noted, and these are summarized in Tables 1 and 2. Table 1 describes the correlations of aircraft strike episodes with the storm wind and reflectivity features, while



F



Table 2 concentrates on the turbulence severity structure. The nearby nonstrike lightning episodes are indicated by the inclusion of N under the episode date.

As indicated in Table 1, all strikes occurred in storm regions where the reflectivity factor was near 25 to 35 dBZ. These episodes also occurred with the aircraft adjacent to primary precipitation cores. This suggests that charge centers are in close proximity. The strikes were also found to consistently occur when the aircraft was in a region of downward or upward moving air, or within 2 km of a significant downdraft. Table 1 shows that downdraft regions are strongly favored. The strength of the vertical currents ranged from very weak to strong. As detailed in the general discussion, the lightning episodes usually occurred near a draft edge, and not near the draft center. The association with distinct downdraft zones suggests the aircraft was near a region of charge separation. This could perhaps be verified with analysis of aircraft electric field mill data.



Figure 25. Estimates of Turbulence Severity for Aircraft Relative (a) Longitudinal, (b) Transverse, and (c) Vertical Directions for 31 July 1982

在《月末,**在1999年19月,19月**,19月1日(19月1日)(19月1日)(1999年19月)(1999年19月)(1999年11日)(1999年19月)(1999年19月)(1999年19月)(1999年19月)(1999年19月)

Structure
Factor
Reflectivity
Vind and
- -
Table

ݽݜݤݜݤݞݱݵݥݻݸݻݤݱݻݥݻݾݻݾݻݚݻݾݑݚݾݻݥݾݻݥ ݞݜݤݥݜݤݤݞݱݵݥݻݸݻݤݱݻݥݻݻݸݻݤݻݸݻݾݻݚݻݕݾݻݥݾݻݥ

1. **1**. 1. 1. 1.

<u>\_\_\_\_</u>

3.00

STELL LAND

Ę

and that the

Procession of the second s

	1 July 81 N	17 July 82 A	17 July 82 B	17 July 82 C	28 July 82	30 July 82 A	30 July 82 B	31 July 82 N
Vertical Gust Data Character	Downdraft	Downdraft	Downdraft	Updraft	Downdraft	Downdraft	Downdraft	Downdraft
Speed at Light- ning Event (ms-1)	ŝ	> 14	> 11	ę	-	0.5	ß	Q
Maximum Speed of Draft (ms-1)	ġ	> 14	> 11	2	11	0	ß	۲
Horizontal Shear Data								
Character	Distinct	Distinct	Distinct	Distinct	Distinct	Not Distinct	Not Distinct	Not Distinct
Shear E-W (s-1)	0.028	0.04	0.01	0	0	0.002	0.0015	0.0175
Shear N-S (s-1)	0.022	0.035	0.016	0.008	0.023	0	0	0.0175
Reflectivity Factor at Lightning Event (dBZ)	25	25	35	25	35	25	30	25

28

 $\mathcal{S}$ 

Table 2. Turbulence Severity  $(\text{cm}^{2/3} \text{ s-1})$ 

	1 July 81 N	17 July 82 A	17 July 82 B	17 July 82 C	28 July 82	30 July 82 A	30 July 82 B	31 July 82 N
Character of Severity	Not Distinct	Distinct	Distinct	Distinct	Not Distinct	Not Distinct	Not Distinct	Not Distinct
Vertical Component								
At Lightning Event	5	6	8	10	8	9	9	8
At Local Maximum	10	14	15	11.5	11	6.5	7	8
Time of Local Max- imum Relative to Lightning (sec)	-4	9	- 2	-2	-4	1-	9	0
Latitudinal Component								
At Lightning Event	5	9	6	6	6	ę	8	7
At Local Maximum	12	11	10.5	σ.	10	10	7.5	8
Time of Local Max- imum Relative to Lightning (sec)	٦Ĵ	3	-2	0	-3	- 6	0	- 2
Longitudinal Component								
At Lightning Event	7	7	13	5	8	4	7	ß
At Local Maximum	10	8	9.5	9	10	5	10	7.5
Time of Local Max- imum Relative to Lightning (sec)	4-	°, '	-2	-2	-2	5	5	Q

₹.

الم الم الم

المراجع والمحاجز وال

Local shear of the horizontal storm winds was often found to be most significant in a region very close to the strike location. Table 1 indicates that the shear regions were often distinctly stronger than those observed over the remainder of the penetration. There appears to exist a weak correlation of moderate to strong shear for the distinct episodes, with the nondistinct events being somewhat weaker.

The turbulence severity structure, summarized in Table 2, consistently indicates moderate to severe turbulence at strike time. Furthermore, the events generally occurred near regions of significant turbulence, of heavy to severe severity, within 2 km of the strike event. The data also indicate that the turbulence strength was essentially equal in all three orthogonal directions, suggesting the turbulence may be considered reasonably isotropic.

The correlation with significant turbulence must be tempered by the knowledge that the strike episodes were not generally in a local region where the turbulence was distinctly more severe than during the remainder of the penetration. Thus, although there is good correlation between aircraft strikes and strong turbulence for these few penetrations, observation of these and other 1981 and 1982 data demonstrates the overwhelming occurrence of strong turbulence with no associated lightning. This suggests that use of lightning locating devices are inadequate for locating the broad distribution of hazardous turbulence to be encountered within storms.

The striking correlations of strikes with precipitation cores, downdraft regions, and high turbulence severity are significant findings. It must be noted, however, that the data sample size here is extremely small. The consistency observed, nonetheless, does suggest some correlations that may be expected to occur during periods of lightning strikes to aircraft in regions of light to moderate precipitation intensity at mid to high storm levels.

#### References

- 1. Bohne, A. R. (1985) Joint Agency Turbulence Experiment--Final Report AFGL-TR-85-0012.
- Fisher, B. D., Brown, P. W., and Plumer, J. A. (1985) <u>NASA Storm</u> <u>Hazards Lightning Research</u>, Flight Safety Foundation Thirteenth Corporate Aviation Safety Seminar, 14-16 April, 1985, Dallas/Fort Worth Apt, Texas.
- MacGorman, D. R., Taylor, W. L., and Few, A. A. (1983) Some spatial and temporal relationships between lightning and storm structure and evolution, <u>Proceedings Addendum</u>, <u>Eighth Inter. Aero. and Ground Conf.</u> on Lightning and Static <u>Elec.</u>, Ft. Worth, Texas.
- 4. Fitzgerald, D. R. (1985) Thunderstorm Activity, The Handbook of Geophysics and the Space Environment, Chapter 20.2, (in press).
- Taylor, W. L., Rust, W. D., MacGorman, D. R., and Brandes, E. A. (1983) Lightning activity observed in upper and lower portions of storms and its relationship to storm structure from VHF mapping and Doppler radar, <u>Proceedings</u>, Eighth Inter. Aero. and Ground Conf. on Lightning <u>and Static Elec.</u>, Ft. Worth, Texas.
- Proctor, D. E. (1983) Lightning and precipitation in a small multicellular thunderstorm, J. Geophys. Res. 88(No. C9):5421-5440.
- MacGorman, D. R., Few, A. A., and Teer, T. L. (1981) Layered lightning activity, J. Geophys. Res. <u>86</u>(No. C10):9900-9910.
- Ligda, M. G. H. (1956) The radar observation of lightning, J. Atmos. Terr. Phys. 9:329-346.
- 9. Rust, W. D., and Doviak, R. J. (1982) Radar research on thunderstorms and lightning, <u>Nature</u> 297:461-468.
- Fitzgerald, D. R. (1967) Probable aircraft "triggering" of lightning in certain thunderstorms, Mon. Wea. Rev. 95(No. 12):835-842.

- Mazur, V., Fisher, B. D., and Gerlach, J. C. (1983) Conditions conducive to lightning striking an aircraft in a thunderstorm, Proceedings, Eighth <u>Inter. Aero. and Ground Conf. on Lightning and Static Elec.</u>, Fort Worth, Texas, pp. 90-1 - 90-7.
- 12. Carte, A. F., and Kidder, R. E. (1977) Lightning in relation to precipitation, J. Atmos. Terr. Phys. 39:139-148.

Martin - Marting

-

لىت مىد

