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CLEAR AIR TURBULENCE

By Paul Rosenberg, M. Gould Beard,
and Henry T. Harrison

December 1965

Prepared under Contract No. NSR 33-026-001 by
FLIGHT SAFETY FOUNDATION
New York, N.Y.

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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T A B L E O F C O N T E N T S

PREFACE

This report was prepared by the Flight Safety Foundation, Inc., New York, N. Y. under NASA Contract No. 33-026-001 as the 1965 part of FSF Project CAT, to assist NASA in keeping abreast of research and development projects directed toward the alleviation of problems posed by flight in clear air turbulence (CAT).

The contents of this report are the result of conferences and corresponsence with government agencies, research institutes, manufacturers, airline accounting, safety and meteorological departments, and the science and engineering departments of universities.

Many articles, scientific reports and manufacturers proposals covering all phases of Project CAT were reviewed by the people working on this project. Direct conferences and interviews were found necessary to develop the detail information for a comprehensive understanding of the work being done by many of the organizations.

The individuals who participated in this project are: Dr. Paul Rosenberg - Consulting Physicist; Mr. Henry T. Harrison - Consulting Meteorologist; M. Gould Beard - Director, Flight Operations Research, FSF; and Jerome Lederer - Vice President and Technical Director, FSF.

F O R E W O R D

Swept-wing jet transports started operation late in 1958. Within a few months there were reports of turbulent air penetrations in which moderate to severe turbulence was encountered. Twenty of these, which occurred in the four year period from 1960 through 1963, were analyzed in Project "Upset". Eight of the twenty occurred when the aircraft were on instruments in clouds at time of upset. Six were in convective areas, but in the clear between cumulus clouds or between cloud layers. Four were in clear air with no associated convection activity. In two instances the conditions were either not clearly stated or were unknown. Fifty percent of these upsets were in clear air where the X- or C- band weather radars installed on transports could not help the pilot avoid the turbulence. Some of the most severe turbulence, which had drastic effects on passengers, structure or control of the airplane, occurred in convective areas when the aircraft were flying in the clear at altitudes between 4,000 ft. and 30,000 ft. Military swept-wing jet aircraft flying at altitudes above 40,000 ft. also have experienced moderate to severe turbulence in clear air outside of convective areas. It has been established that clear air turbulence will be experienced by the supersonic transport.

The number of CAT incidents of drastic nature occurring to transport planes reached a peak in the fall of 1963. The airline industry had become aware of the trend and had taken several corrective actions. Meteorological forecasting of CAT was improved, providing the pilot more opportunity to avoid turbulent areas or to prepare for turbulence penetrations. All pilots were given a briefing concerning the action of swept-wing high-speed transports in severe turbulence, and the best methods of controlling them in turbulence. Instruments were modified to portray clearly the attitude of the aircraft at large departures from horizontal.

In 1964 there were fewer drastic incidents and in 1965 there were only three reported to this Project by the airlines, the FAA and the CAB.

The large number of drastic CAT penetrations during the years 1962 through 1964 accelerated the efforts of the Air Force, FAA, Weather Bureau, Navy and the airlines to develop a CAT detector. The need for, and possibilities of, developing a CAT detector had been discussed in 1949 by the NACA (now NASA) Committee on

Operating Problems. In 1962 and 1963 several Government-funded study and research projects were started, and several "in-house" projects were conducted within industry toward development of a good CAT detector.

These activities became so widespread and numerous that NASA considered it advisable to fund a project for ascertaining and reporting on all the activities in this field throughout the country, on a continuing basis, as an information service to the divisions of NASA, to other government agencies interested in this field, and to the organizations within industry working in this field.

The Flight Safety Foundation was awarded Contract NSR 33-026-001 by NASA in November, 1964 and work began in December, 1964. The literature available on CAT forecasting, literature on the nature of the fine-scale structure of the atmosphere and experimental devices proposed for CAT detection were studied.

To obtain information about development projects, it was decided to poll the instrument and electronic industry and research organizations by form letter (reproduced on page 5 of this report). Based on the replies received from this letter, visits were scheduled to interview the organizations which had indicated active projects and interest in the development of CAT detectors, or that had instruments they considered adaptable to CAT detection, or which were working in the meteorological field of CAT. Frequently, these conferences developed information about projects as yet unpublished. Much of the information discussed was labeled "proprietary" and has been reported in confidence to NASA. Often we were given reports, brochures and other literature about detection devices which required considerable time to read and condense into the brief statements appearing in this report. Most of the visits were made by Dr. Rosenberg and Mr. Beard jointly. Some were made by Mr. Lederer and Mr. Beard. The meteorological studies were made by Mr. Harrison. When this project became generally known, the Flight Safety Foundation was asked for papers and to give talks on the subject. Several were given, as listed later in this report.

During the year most of the people and organizations working in the field of CAT, its forecasting and detection, were personally contacted and generally were most cooperative. Except in a few instances, there has been insufficient time to make repeat calls. However, the organizations not contacted on the first round will be visited first on the second year's renewal of the project.

One of the objectives of this contract was to evaluate the CAT detection devices as to suitability for airline use. This was impossible at this stage of development as only three principles of detection had even been flown in their research configurations and the results of the preliminary flight research of each project has been inconclusive. At this writing there are no CAT detectors which can be considered sufficiently developed for such an evaluation. Until more accurate indications of the range, reliability of indication, freedom from false warning, size, weight, cost and requirements for location on the airplane are available, it will be impossible to make an evaluation of the relative suitability of the various detection devices for airline use. In fact, at this stage of development of any of the devices, such an evaluation could unfairly curtail development of principles of detection which eventually might prove to be excellent.

The authors and consultants on this project deeply appreciate the cooperation of the organizations visited and the help and assistance of the personnel in the various government agencies interested in this project, which include NASA, U. S. Air Force, U. S. Navy, U. S. Weather Bureau, FAA and CAB.

M. Gould Beard, Director
Flight Operations Research
Flight Safety Foundation, Inc.

CLEAR AIR TURBULENCE

I. Objectives and Scope of Contract

To assist NASA in keeping abreast of research and development projects directed toward the alleviation of problems posed by flight in turbulence.

To list and critically evaluate on a continuing basis, current projects related to:

(1) Forecasting of turbulence

(2) Detection of turbulence

(3) Devices for indicating turbulence with particular emphasis on clear air turbulence (CAT), and

(4) To prepare a list of incidents involving turbulence, including their effect on airline operation.

II. Poll of Industry for Information about Development Activities on CAT Detection

Visits were made to NASA, the Air Force, the Weather Bureau, the FAA, and the Office of Naval Research about research and development contracts which are active in the field of atmospheric turbulence. The progress of these projects was followed as a part of this contract. However, it was felt that there might be other developments not on record with Government agencies. To obtain information about these, the electronics and instrument industry was polled with the following letter:

IIa. Form letter to poll industry and research organizations.

26 February 1965

Name
Address

Subject: Clear Air Turbulence (CAT)
NASA/FSF Contract NSR 33-026-001

The National Aeronautics & Space Administration (under Contract NSR 33-026-001) has assigned to the Flight Safety Foundation the responsibility for keeping NASA abreast of research and development projects relating to clear air turbulence (CAT).

As one of its tasks, FSF has been directed by NASA to list and critically evaluate, on a continuing basis, current developments of equipment, instruments and methods for advance detection, warning and forecasting of CAT.

The purpose of this communication is to ask you to advise us of any developments which your organization has completed or is now conducting along these lines; and to request that you send us all available relevant technical reports and information (at no cost to FSF, NASA or the Government). Proprietary rights will be respected by FSF and NASA, and technical reports and information will be kept in confidence, if you so stipulate.

If information concerning your projects is classified, please advise us accordingly, so that we may arrange for appropriate clearance. If pertinent documents are classified, please give us their full designations, degree of classifications, and name of the agency having cognizance over their distribution.

In the event you have no relevant projects to report, please notify us to this effect.

Please direct your reply, as well as any questions you may have, to Mr. M. G. Beard, Director of Flight Operations Research at the Flight Safety Foundation's New York office. The evaluation of the physical concepts will be done by Dr. Paul Rosenberg of 330 Fifth Avenue, Pelham, New York.

FSF is an independent, non-profit organization, established in 1945, dedicated solely to improving safety in aviation.

Your cooperation in this CAT Project will be greatly appreciated.

We look forward to your early reply.

Sincerely,

FLIGHT SAFETY FOUNDATION, INC.

Similar letters were sent to the Ministry of Aviation, Royal Aircraft Establishment, Bedford, England and to the Department of National Defense, Defense Research Board, Ottawa 4, Ontario, Canada. Replies to this circular letter uncovered many active projects and developments which had not been previously reported. During subsequent conferences and interviews, additional research and development work in the field of CAT were noted, and included in the conference itinerary.

III. Conferences and Interviews

In the middle of January, conferences were held with several government agencies to establish contacts with sources of information about active projects for research and development in the fields of atmospheric turbulence, CAT detection instrumentation, CAT forecasting and reporting of CAT penetration incidents and accidents. Shortly thereafter conferences were scheduled with industry. All conferences and interviews are listed here chronologically. Conference reports are in Section IV.

1. 14 Jan. 1965 - U. S. Weather Bureau, 24th & M Sts., N.W., Washington, D. C. 20235

   Dr. Robert M. White - Chief, U. S. Weather Bureau
   Mr. Newton Lieurance - Director, Office of Aviation Weather Affairs, Washington Science Center, Rockville, Maryland
   Mr. DeVer Colson - Chief, Synoptic Techniques Section

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2. 14 Jan. 1965 - Federal Aviation Agency, 800 Independence Ave., S.W., Washington, D. C. 20553

   Mr. James F. Rudolph - Flight Standards Service, Chief, Operations Division
   Mr. Lowell Davis - Flight Standards Service, Chief, Technical Standards Div.

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3. 14 Jan. 1965 - Air Transport Association of America, 1000 Connecticut Ave., N.W., Washington, D.C. 20036

   Mr. Roger Flynn - Manager, Domestic Operations

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4. 15 Jan. 1965 - Eastern Air Lines, Inc., Atlanta Airport, Atlanta, Ga.

Mr. J. J. George - Director Meteorology
Mr. Paul W. Kadlec - Meteorologist, Flight Weather Research, Eastern Air Lines, Inc., Crossway Airport Inn, 1850 N.W. LeJeune Rd., Miami, Fla. 33126

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5. 29 Jan. 1965 - United States Air Force, Hq. USAF, Pentagon, Washington, D. C. 20301

Mr. William J. Becker, AFORQ - Coordinator of Air Force Meteorological Research and Development Projects.

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6. 9 Feb. 1965 - Air Force Cambridge Research Labs. AFCRL, Hanscom Field, Bedford, Mass. 01731

Mr. Andrew S. Carten - Aerospace Instrumentation Senior Engineer for Meteorological Equipment
Mr. W. H. Paulsen - Chief, Indirect Probing Techniques Branch
Mr. F. W. Gibson - Physicist

(Note: At date of conference, above offices were located in Waltham, Mass.)
Mr. Walter Baginski - Acting Chief, Program Management Branch

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7. 9 Feb. 1965 - Nortronics Division, Northrop Corp., Needham Heights, Massachusetts

Mr. W. W. Smith, Director
Mr. Hugh Taylor, Chief, Electronics Systems
Mr. Bard Howes, Supervisor Radiometry

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8. 12 Feb. 1965 - Belock Instrument Corp., 112-03 14th Avenue, College Point, N. Y. 11356

Mr. Robert L. Willes - Chief, Electro Optics Dept.
Mr. Gerald J. Marks, Senior Electro Optics Engineer
Mr. Conrad Kass - Applications Engineer

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9. 18 Feb. 1965 - NASA Headquarters, 600 Independence Ave., Washington, D. C. 20546

Mr. William S. Aiken - Chief, Operations Research, Aeronautics Division
Mr. William A. McGowan - Operations Research, Aeronautics Division

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10. 18 Feb. 1965 - Second conference with Air Transport Association, 1000 Connecticut Ave., N.W., Washington, D. C. 20036

Mr. Allen Dallas, Director - Engineering Division

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11. 23 Feb. 1965 - Kollsman Instrument Company, 80-08 45th Avenue, Elmhurst, N. Y. 11373

Mr. David P. Nichinson - President
Dr. Nathan Kaplan - Director, Engineering Division
Dr. A. Robinson - Director, Research
Mr. John D. Huarisa - Chief Executive Officer
Mr. Henry Droge - Manager, Commercial Aircraft Marketing
Mr. Herbert Sandberg - Manager, Technical Staff, Avionics Division
Mr. Aaron Wallace - Senior Scientist
Mr. Elliot Kahn - Senior Scientist

12. 3 Mar. 1965 - Raytheon Company, Sudbury, Mass. 01776

Mr. Irving Goldstein - Manager, Electrical Optics Lab.

Dr. K. Seeber - Staff

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13. 17 Mar. 1965 - Lockheed Aircraft Corp., Atmospheric Physics Dept., Physical & Life Science Lab., 2555 N. Hollywood Way, Burbank, Calif. 91503

Mr. William W. Hildreth, Jr. - Meteorologist
(Conference at FSF office, New York, N.Y.)

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14. 17 Mar. 1965 - Basic Devices, P. O. Box 336, Wellesley, Mass. 02181

Mr. Robert S. Djarup - President
(Conference at FSF office, New York, N.Y.)

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15. 26 Mar. 1965 - Demonstration by RAWCO Instruments, Inc. - RAWCO Instrument Inc., 1400 Riverside Drive, Fort Worth, Texas 76104
(At Federal Bldg., Washington, D. C.)

Mr. W. D. Smith
Mr. R. B. Basham
Mr. Robert M. Sinks - Tele-Beam Corp., Dallas, Texas

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16. 26 Mar. 1965 - Second conference with FAA

Mr. James H. Muncy, RD-241

17. 26 Mar. 1965 - U. S. Navy, Main Navy Bldg., Washington, D. C. 20360

Mr. James Hughes - Atmospheric Physicist, Geophysics Branch, ONR

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18. 31 Mar. 1965 - Lear Siegler, Inc., Laser Systems Center, 2320 Washtenaw, Ann Arbor, Michigan 48104 (Conference in Washington, D. C.

Mr. J. B. Bittner - Vice President
Mr. Herbert Norder - Manager
Dr. H. Ligda of SRI attended

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19. 12 Apr. 1965 - Autonetics Division, North American Aviation, Inc., 3370 Miraloma Ave., Anaheim, California

Mr. R. A. Averitt - Dir. Commercial Avionics (Conference at FSF office)

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20. 13 Apr. 1965 - NASA - ERC, 575 Technology Square, Cambridge, Mass.

Dr. Lester C. Van Atta, Ass't Dir. for Electromagnetic Research
Mr. Irving J. Etkind - Microwave Lab.
Mr. Max R. Nagle - Chief, Space Optics Lab.
Dr. Philip L. Hanst - Space Optics Lab.
Mr. John A. Sullivan - Space Optics Lab.
Mr. Gene Manella - Chief, Instrumentation Research Lab.
Mr. Gilmore H. Trafford - Chief, Microwave Radiation Lab.

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21. 14 Apr. 1965 - Attended SAE Meeting - Operational Problems - The Jet Upset

Chairman, Mr. William M. Magruder - Lockheed, Calif.

Speakers - Mr. James F. Rudolph - FAA, Washington, D.C.
Mr. Richard A. Sliff - FAA, Washington, D.C.
Mr. R. L. Loesch - Boeing, Seattle, Washington
William S. Aiken - NASA, Washington, D. C.
Mr. Mel M. Gough - Consultant
Mr. W. E. Rhoades - United Air Lines, San Francisco, Calif.

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22. 22 Apr. 1965 - American Institute of Aeronautics and Astronautics, 1290 Avenue of the Americas, New York, N. Y. 10019

Mr. Robert R. Dexter - Corp. Sec'y and Dir. Technical Services

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23. 26-27 Apr. 1965 - Air Force-Sponsored Conference on CAT, Federal Bldg., 800 Independence Ave., Washington, D. C.

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24. 3 May 1965 - Continental Airlines, Inc., International Airport, Los Angeles, Calif.

Mr. R. H. Curtis - Manager of Meteorology
Mr. Don R. Wilson - Vice Pres., Flight
Mr. J. Coburn, Ass't Vice Pres. - Tech. Oper.

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25. 3 May 1965 - Second conference with Lockheed Aircraft Corp., 2555 N. Hollywood Way, Burbank, Calif. 91503

Mr. R. L. Thoren - Dir. of Engineering
Mr. J. F. McBrearty - Research Dir.
Mr. E. L. Joiner - Chief Research & Test Engineer
Mr. E. J. Marsh - Test Manufacturer, Systems and Analysis
Mr. A. W. East - Research & Development Engineer
Mr. W. M. Crooks, Jr. - Research Specialist, Flight Test
Mr. R. H. Cook - Group Engineer - Flight test
Mr. W. W. Hildreth - Scientist - Staff
Mr. F. M. Hoblit - Group Research & Development Engineer
Mr. T. F. Laughlin - Group Research & Development Engineer

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26. 4 May 1965 - North American Aviation, Inc. Space & Information Systems Division, Electro-Optical Laboratory, Torrance Facility, 12214 Lakewood Blvd., Downey, Calif. 90241

Mr. R. C. Breece - Clear Air Turbulence Project Eng., Electro Magnetic Systems Information Systems
Dr. H. E. Henry - Proj. Engr., E.M. SIS
Dr. D. L. Fried - Head Laser Techniques, Electro Optical Laboratory Information Systems
Mr. William Quinlivan - Mgr. Systems Safety, NAA General Office
Mr. W. E. Airth - Information Systems Programs, Advanced Programs Development

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27. 4 May 1965 - Douglas Aircraft Co., Inc.,
3855 Lakewood Blvd., Long Beach, Calif. 90801

Mr. J. H. Strom - Flight Dept. C1-273
Mr. H. E. Morphew - Supervisor, Transport Customers Service
Mr. John J. Dreher, Ph.D. - Research Scientist
Mr. M. K. Oleson - Proj. Engineer
Mr. R. T. Ross
Mr. A. G. Heimerdinger - Chief Pilot

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28. 5 May 1965 - Stanford Research Institute,
Menlo Park, Calif. 94025

Dr. M. G. H. Ligda - Manager, Aerophysics Lab.
Mr. Sidney M. Serebreny - Senior Research Meteorologist, Aerophysics Group
Mr. Roy M. Endlich - Weather Dynamics Group
Mr. R. T. H. Collis - Head, Aerophysics Group

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29. 5 May 1965 - United Air Lines, San Francisco
International Airport, San Francisco, Calif. 94128

Mr. A. F. Trumbull - Supt. Radio Engineering
Mr. O. E. Anderson - Staff Engineer
Mr. L. E. Crowell - Staff Engineer
Mr. R. E. Coykendall - Staff Engineer
Mr. T. Falbo - Engineer
Mr. C. M. Cooke - Engineer
Mr. E. S. Wagner - Staff Engineer

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30. 6 May 1965 - The Boeing Company, Transport Div., Renton, Washington 98055

Mr. R. L. Rouzie - Director of Engineering
Mr. Ray Utterstrom - Staff Engineer, Electro Dynamics
Mr. Robert A. Peterson - Engineering Supervisor, Electro Dynamics Staff
Mr. Paul R. Higgins
Mr. C. David Lundeen - Electronics R & D, Electro Dynamics Staff

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31. 6 May 1965 - Northwest Airlines, Inc., Minneapolis-St. Paul International Airport, St. Paul, Minn. 55111

Mr. Benjamin G. Griggs, Jr. - Vice Pres. Flight Oper.
Mr. Paul A. Soderlind - Manager, Flt. Oper. Dept., R & D Div.
Mr. Daniel F. Sowa - Supt. of Meteorology

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32. 6 May 1965 - Honeywell, Aeronautical Division, 2600 Ridgeway Rd., Minneapolis, Minn. 55413

Dr. W. T. Sackett, Jr. - Research Section Head
Mr. Joseph E. Killpatrick - Research Supervisor, Optics
Mr. Paul Senstad, Research Supervisor - Instrumentation
Dr. Ed Rang, Research Supervisor - Control and Guidance
Dr. Grant B. Skelton - Senior Research Scientist - Control & Guidance
Mr. Harlan C. Pringle - Special Ass't to Director of Marketing, Aeronautical Division

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33. 12 May 1965 - Flight Research Section, Uplands Laboratories, National Aeronautical Establishment, Montreal Road, Ottawa, Canada

Mr. A. D. Wood - Director
Dr. F. G. Gould - Aeronautics
Mr. M. G. Caiger - Aeronautics
Mr. G. K. Mather - Meteorology
Mr. K. G. Pettit - Meteorology

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34. 19 May 1965 - National Center for Atmospheric Research, 30th St. and Arepho, Boulder, Colo.

Dr. William Jones, Assistant Director

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35. 20 May 1965 - Attended - Flight Safety Foundation Tenth Annual Business Aircraft Safety Seminar, Denver, Colo.

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36. 21 May 1965 - Colorado State University, Department of Atmospheric Sciences, Foothills Campus, Fort Collins, Colo. 80521

Prof. Elmar R. Reiter, Ph.D.

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37. 2 June 1965 - Barnes Engineering Co., Defense and Space Division, 30 Commerce Rd., Stamford, Conn. 06902

Mr. Eric M. Wormser - Vice Pres. & General Mgr.
Mr. Robert W. Astheimer - Technical Director

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38. 8-9 June 1965 - National Severe Storms Laboratory, Norman, Oklahoma 73069

Dr. Edwin Kessler III, Director

39. 9 June 1965 - Royal Aircraft Establishment, Farnborough, Hants, England

Mrs. Anne Burns, Structures Dept. (Conference at National Severe Storms Lab.) Norman, Oklahoma

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40. 9 June 1965 - University of Michigan, Ann Arbor, Michigan

Prof. Peter Franken - Dept. of Physics (At NSSL, Norman, Okla.)
Mr. Joseph Tenney - graduate student
Mr. David Rank - graduate student

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41. 14 June 1965 - Second conference with Mrs. Anne Burns at John F. Kennedy International Airport, New York, N. Y.

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42. 18 June 1965 - Litton Guidance and Controls Systems Div. at FSF offices, New York

Mr. Roy E. Williams

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43. 24 June 1965 - TRG, Inc., subsidiary of Control Data Corp., Melville, L.I., N.Y. 11749

Dr. Lawrence Goldmuntz - President
Mr. H. L. Jennings - Contract Mgr.
Dr. David M. Chase - Physicist

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44. 29 June 1965 - Phone conference with Dr. Elmar R. Reiter, Dept. of Atmospheric Sciences, Colorado State University, Fort Collins, Colo. 80521

45. 8 July 1965 - Decker Corp., Bala Cynwyd, Pa. 19004

Mr. James C. Dell (At Flight Safety Foundation offices)

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46. 12 July 1965 - Phone conference with Sandia Corp., Albuquerque, N. M. 87108

Dr. L. Smith
Dr. Hugh Georgia

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47. 13 July 1965 - General Precision, Inc. - Link Group, Hillcrest, Binghamton, N. Y. 13902 (Conference on simulators for turbulence)

Mr. E. Darling - Aerodynamics - G.P.F.
Mr. Paul Papp - Aerodynamics - Link Div.
Mr. S. Weinstein - AAL
Mr. Bates - CAL
Mr. Romaine - P.A.L.
Mr. Coleman Donaldson - Link Div.
Mr. R. L. Garman - " "
Mr. E. Fetters - " "
Mr. John Houbolt - " "
Mr. Frank Banta - GPI
Mr. Max Bassett - "
Mr. Mack W. Eastburn - AAL
Mr. Jerome Lederer - FSF
Prof. Edward Seckel - Dept. Aerospace & Mech. Science, Princeton University

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48. 16 July 1965 - Federal Aviation Agency, 800 Independence Ave., Washington, D. C.

Mr. James H. Muncy, RD-241

49. 29 July 1965 - New York University, Geophysics Bldg., 2455 Sedgwick Ave., Bronx, N. Y. 10468

Mr. U. Oscar Lappe - Senior Research Scientist

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50. 22 July 1965 - NASA, Langley Field, Virginia 23365

Mr. Joseph Stickle
Mr. Dick Storey - Engrg. Tech.
Mr. Harvey Melfi - Aerospace Technology
Mr. Harry Hubbel
Mr. H. Pierce

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51. 30 July 1965 - Second conference with Douglas Aircraft Company, Inc., 3855 Lakewood Blvd., Long Beach, Calif. 90801

Mr. A. J. Heimerdinger - Chief Pilot
Mr. J. H. Strom - Maintenance, Human Engineering
Mr. M. K. Oleson - Engineering Dept.
Mr. H. E. Morphew - Customer Service, Transport.

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52. 30 July 1965 - Electro Optical Systems, Inc., 300 N. Halstead St., Pasadena, Calif. 91109

Dr. Arthur Alden - Vice Pres. Res. & Dev.
Mr. George White - Mgr. Optical Division
Mr. James Baum - Ass't Mgr. of Advanced Technology
Mr. Ellis Harris
Mr. Glen Cato - Senior Engineer

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53. 31 July 1965 - Meteorology Research, Inc. (M.R.I.) and Atmospheric Research Group (A.R.G.) Field Laboratory at Flagstaff Airport, Arizona

Mr. Paul MacCready, President

54. 30 July 1965 - U. S. Army Electronics Laboratory, Ft. Monmouth, N. J.

Dr. Henry Kuzemir - at Flagstaff Field Station

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55. 23 August 1965 - ITEK, Burlington, Mass. 02103

Mr. Robert Fleming

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56. 23 August 1965 - Second conference with Air Force Cambridge Research Laboratories, L. G. Hanscom Field, Bedford, Mass. 01731

Major R. W. Cowne - CREU - Chief Final Engineering Section Aerospace-Instrumentation Lab.
Mr. Andrew S. Carten, Jr. - Chief Engr. for Meteorological Equipment, Aerospace Instrumentation Lab.
Mr. Wilbur Paulsen - Chief, Indirect Probing Techniques Branch
Mr. Walter Baginski - Acting Chief, Program Management Branch

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57. 24 August 1965 - ARACON Geophysics, Virginia Road, Concord, Mass. 01742
A Division of Allied Research Associates, Inc.

Mr. Lawrence Levy - President, Allied Research Associates, Inc.
Mr. William K. Widger, Jr., Director - Satellite Meteorology Research
Mr. Earl S. Merritt - Senior Meteorologist
Dr. Ray Wexler
Dr. David Chang - Lasers

58. 24 August 1965 - MITRE Corp., Bedford, Mass. 01730

Mr. John Sullivan
Mr. Harry Schacter - Ass't Dept. Head D-81 Environmental Factors

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59. 26 August 1965 - Sperry Gyroscope Co., Division of Sperry Rand Corp., Great Neck, N.Y. 11020

Dr. W. L. Barrow - Vice Pres. Res., Dev. & Engrg.
Dr. Leonard Swern - Great Neck - Tech. Asst. to V.P. for Tech. Adm. and Planning
Dr. Leonard W. Holmboc - Great Neck - Engrng Dept. Head, Electro-Optics
Dr. W. D. Mount - Sudbury, Mass., Hd. - Atmos. Physics Dept.

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60. 4 Oct. 1965 - Convair Division of General Dynamics, 5001 Kearny Villa Rd., P. O. Box 1128, San Diego, Calif. 92112

Mr. Murray Edelstein - Flight Test Group Engineer
Mr. Frank Woffinder - Senior Dynamics Engineer
Mr. Floyd W. Wundrow - Senior Flight Test Engineer
Mr. John R. Rausch - Senior Aerodynamics Engineer

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61. 5 Oct. 1965 - Second conference with North American Aviation, Autonetics Division, 3370 Miraloma Ave., Anaheim, Calif. 92803

Mr. R. A. Averitt - Dir. Commercial Avionics
Mr. Edward F. Flint - Proj. Engr. Electro-Optical Systems

62. 5 Oct. 1965 - Second conference with Meteorology Research, Inc., 2420 N. Lake Ave., Altadena, Calif. 91001

Mr. Paul MacCready - President
Mr. Thomas R. Mee
Mr. Edwin K. Kanper

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63. 7 Oct. 1965 - Collins Radio Co., 5200 C Ave., N.E., Cedar Rapids, Iowa 52402

Dr. Eugene R. Marner - Dir. of Research
Mr. Walter R. Sliff - Head Atmospheric Physics Group
Mr. Eugene O. Frye - Senior Technical Staff - Technical Div.

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64. 14 Oct. 1965 - General Electric Company, Missile and Space Division, Philadelphia, Pa. (Conference at FSF offices, New York

Mr. H. W. Halsey

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65. 25 Oct. 1965 - Cornell Aeronautical Laboratory, Inc. Buffalo International Airport, Buffalo, N. Y. 14221

Dr. Ira G. Ross - President
Mr. Walter O. Breuhaus - Head Flight Research Dept.
Mr. Frank E. Prichard - Aeronautical Engineer, Flight Research Dept.
Mr. John M. Schuler
Dr. George E. McVehil - Meteorological, Applied Physics Dept.
Mr. Cal Easterbrook - Atmospherics
Mr. Richard J. "Dick" Clark - Electronics Engineer, Electronics Research Dept.

66. 18 Oct. 1965 - General Electric Company, Information Engineering Laboratory, Advanced Technology Labs., Research & Development Center, P. O. Box 8, Schenectady, N. Y. 12301

Mr. J. E. Bigelow - Inform. Engr., Research and Development
Dr. Kiyo Tomiyasu - Sen. Electronics Engineer

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67. 19 Oct. 1965 - Second conference with Lear Siegler, Inc., Laser Systems Center, 2320 Washtenaw, Ann Arbor, Mich. 48104

Mr. Douglas Linn - Mgr. Marketing
Mr. David Matthews - Mgr. Systems Engineering Group

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68. 26 Oct. 1965 - IIT Research Institute, 10 West 35th Street, Chicago, Ill. 60616

Mr. David Freyberger

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69. 27 Oct. 1965 - Phone conference between Dr. Elmar R. Reiter and Dr. Paul Rosenberg

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70. 10 Dec. 1965 - Southwest Research Institute, 8500 Culebra Rd., P. O. Box 2296, San Antonio, Texas 78206

Mr. Thomas E. Owen - Consultant, Dept. of Electronics and Electrical Engineering
Mr. Dale Suttle - Meteorologist

71. 27 Dec. 1965 - Second conference with Stanford Research Institute, Menlo Park, Calif. 94025; by Dr. Paul Rosenberg

Dr. Myron G. H. Ligda - Manager, Aerophysics Lab.
Mr. Ronald T. H. Collis - Head, Aerophysics Group
Mr. Roy M. Endlich - Weather Dynamics Group
Mr. Sidney M. Serebreny - Senior Research Meteorologist
Mr. J. E. Nanericz

IV. Report on Conferences and Interviews

Summaries are given of the material discussed in the various conferences except where the material was stated to be "Proprietary", in which case it has been omitted from the report. The summaries of conferences and interviews are sometimes very brief for this reason. The conference numbers corresponds to the numbers in Section III.

1. U. S. Weather Bureau - Dr. Robert M. White and Mr. Newton Lieurance.

Dr. White was informed of Project CAT and the objectives. Projects under the U. S. Weather Bureau that have a bearing on Project CAT were discussed. The full cooperation of the Weather Bureau was offered. Mr. Lieurance gave information on the Allegheny upset of 27/12/64 over Maryland.

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2. FAA - James F. Rudolph and Lowell Davis

This conference was made to inform the FAA of Project CAT and to establish working relations with Lowell Davis to receive information on all incidents and accidents of a drastic nature. Lowell Davis will forward reports on all such incidents to FSF, Project CAT.

3. Air Transport Association

To receive advice about CAT detection and forecasting projects of which the ATA has knowledge and to arrange for future information from ATA about airline projects in this field.

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4. Eastern Air Lines - Mr. J. J. George

To receive briefing and literature on CAT forecasting method developed by him and his staff to reduce the size of the block of air in which CAT was previously forecast.

Mr. Paul W. Kadlec

To get history and background about Project TRAPCAT being tried out by five airlines: EAL, AAL, Delta, UAL, and TWA, under funding by FAA, with instrumentation built by Litton.

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5. USAF - AIR FORCE OFFICES AND COMMANDS

MAC - Lt. Col. L. C. Peterson, MAOCO/AT;
OAR - Capt. Walter A. Gallie, RROSE;
AFLC - Col. J. C. Wise, MCOO Wright-Patterson;
SAC - Dr. C. A. Beck, Operations Analyst;
Norton AFB - Lt. Col. J. Creedon, Staff Officer

Coordinator of Air Force research and development projects on meteorology, weather forecasting, CAT forecasting and detection. This office coordinates all Air Force projects in this field and maintains records on funding expenditures, and periodic status reports. There are three R & D Divisions:

1. Air Weather Service (AWS)
Forecast, Climatology and Operational
Under Military Airlift Command (MAC)
Scott AFB.

2. Air Force Cambridge Research Laboratories (AFCRL)
Equipment Development and Research
Under Office of Aerospace Research (OAR)
Washington, D. C.

3. Aeronautical Systems Division (ASD)
Wright Patterson AFB
Under Research and Technology (AFSE)
Bolling Field (RTD)

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6. AFCRL - Andrew S. Carten, F. W. Paulsen and Walter Baginski.

Mr. Carten outlined the organization of AFCRL and gave a brief history of the Air Force activities in the field of CAT.

Mr. Paulsen gave a resume of the Projects now active in the field of CAT detection and research to determine in the laboratory and in the atmosphere whether laser backscatter comes from particulate matter or from air molecules. He also reviewed the laser probings of the upper atmosphere at the University of the West Indies with a ruby laser beam shooting vertically to determine the concentrations and densities of particulate matter in the air at levels above 30,000 ft.

The work at Rawlinsville, Colo., observing the mountain wave with ruby laser beams, was described, also the work at Wallops Island, Virginia with large antenna, high-power radar of 3, 10 and 70 cm. wavelengths. All of these projects are discussed in later sections of this report.

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7. Northrop Corp., Nortronics Division

Any object having a temperature different from the ambient air radiates energy which can be detected with a sufficiently sensitive detector. The air between the object and the detector will absorb this energy according to the length of path and the composition of the air.

Nortronics Div. has worked on an in-house project to develop a radiometric method of CAT detection for several years. The system operates in the 50-60 g.c. frequency band.

The Division has made a proposal to AFCRL for the development of a CAT detector based on the radiometric method in the 50 to 60 g.c. frequencies.

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8. Belock Instrument Corp.

Belock is not working on a CAT detector but does have a star tracking unit, used as a component of other instruments, which might be adaptable to a CAT detector. This unit tracks stars by night or day. It is $2\frac{1}{2}$" in diameter, 6" long. It can also track all targets in the infrared and ultra-violet. Belock has made measurements of haze particles of 2 micron size. The unit is a slit-type scanner videocon with an electric multiplier to augment the scanned image. Power requirements are 100 watts total. For CAT detection, scanning could be made slower than for star tracking down to about 20 c. per second. Display could be on a P.P.I. scope or electro-luminescent panel.

9. NASA Headquarters

Discussion of Project CAT and contents of quarterly reports.

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10. Air Transport Association

Review status of Project TRAPCAT and establish reporting of drastic CAT incidents.

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11. Kollsman Instrument Corporation

Kollsman has studied the possibilities of CAT detection based on previous work in star tracking. Proposals have been made for airborne CAT detection devices using lasers in two variations.

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12. The Raytheon Company - Space and Information Systems Division

This Division has two in-house company-funded programs for CAT detection.

(1) An airborne optical Doppler "radar" to measure relative velocity between aircraft and turbulence gusts.

(2) A high powered laser beam and receiver to measure the intensity of radiation backscatter from particulate matter concentrations in CAT.

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13. Lockheed Aircraft Corp.

Conference with William W. Hildreth, Jr. at FSF office, New York to develop plans for future conference at the Burbank plant.

14. Basic Devices

Conference at FSF offices, New York with Robert S. Djorup, Pres., Basic Devices, concerning Basic Devices' projects in the field of CAT.

Under contract AF19(628)-1677 an airborne Jet Stream detector or wind gradient meter was developed for the USAF Electronic Systems Division, Meteorological Development Laboratory. One probe mounted on each wing tip of the test plane determines horizontal wind gradient with a threshold sensitivity of 0.01 miles (52.8 ft.) per hour. The technique used is the direct sensing of air-stream velocity by a pair of heated metal films, the resistance variations of which are a function of heat transfer to the mass flow of the air-stream. This instrument has not yet been installed and test flown by the Air Force.

Currently under way is the wind-tunnel testing of a fast variant of the above instrument which was developed to permit a two point measurement of instantaneous air-stream velocity and shear components.

A nine-channel constant-temperature heated-element anemometer has been built for aircraft application.

A stripped version of the vertical turbulence measuring system will be installed in a light aircraft. A two-trace, slow-speed strip chart recorder will be used to record the data.

A zero, two-second, thirty-second and five-minute storage interval are to be provided for indicating peak values. Selection of the zero storage interval permits the display of continuous vertical velocity component, filtered only by the dynamics of the meter element. Flights over the Northeastern United States are to be made which, it is hoped, will provide information regarding the possible application of direct-sensing techniques to turbulence-warning devices. Flights are also to be made repeatedly through the mountain waves generated by the Catskills or the Greiner, New Hampshire area.

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15. RAWCO Instruments at Washington, D. C.

Demonstration was arranged by Robert M. Sinks, Sales Representative of Tele-Beam Corp. of Dallas, Texas, the firm which represents and markets products built by RAWCO Instrument, Inc. Mr. W. D. Smith of RAWCO gave the major portion of demonstration, supported by Raymond B. Basham, who has a proprietary interest in the static charge detector of this demonstration.

Mr. Smith showed and demonstrated two static charge detection units built by RAWCO and which are now being used in industry. The unit of prime interest in this demonstration is a sphere about the size of a tennis ball rotating on an axis at a moderate speed. The internal construction of this sphere was stated to be the secret of its ability to detect extremely small atmospheric static charges. The construction was not divulged at this conference. However, it is the opinion of several people at this conference that the basic operating principle of this RAWCO instrument is substantially that of the classic field mill.

It was stated that in thunderstorm areas the meter will read as high as 300,000 V/ft.; that it is not uncommon to find 40 V/ft. in factory areas where high-speed machinery and belts are in operation.

The meter was said by RAWCO to sense change in a 60° cone. Demonstrations were made to show sensitivity of the instrument by blowing a stream of warm air in the vicinity of the sensor, and also releasing a stream of CO_2 from a high-pressure CO_2 bottle.

It was stated by RAWCO that whenever a thunderstorm passed over the Fort Worth area the meter would indicate extremely high static charges; and conversely, whenever the meter indicated extremely high atmospheric charge it is an indication that a thunderstorm would occur very shortly.

Mr. DeVer Colson of the Weather Bureau stated that the U. S. Weather Bureau had done much work in areas where lumbering operations are conducted, in measuring static charge build-ups as an indication of the possibility of fire from atmospheric static charges, and that the Japanese also have done much work in measuring the static field charges in the vicinity of thunderstorms and frontal areas. A question was asked as to whether RAWCO had made any observations as to the diurnal variation in atmospheric static charges. Both DeVer Colson and Dr. Paul Rosenberg indicated that for many years much work had been done in the field of atmospheric electricity which might be useful to RAWCO.

It was stated that the spherical unit has directional sensing. Distance of the charge source cannot be measured. There was some discussion as to the circuitry and sensor units used in the UAL, SRI Static Charge Project now being flown on 10 United Air Line's aircraft.

Mr. Muncy of FAA expressed an opinion that all static sensors have to be close to the source, and that there would be insufficient warning for a Jet aircraft which needs about 40 miles warning of turbulence in order to take effective action.

Mr. Sanford of the FAA asked whether RAWCO had considered how this rotating sphere could be practically applied to an airplane for all-weather use. RAWCO replied that they had given consideration to this, but that it would be several weeks before they could give a good answer to this question. DeVer Colson suggested that

RAWCO get in touch with Mr. Kessler of the NSSL at Norman, Oklahoma, who might be able to give considerable assistance in their exploration work in correlating static charge indications with clear air turbulence.

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16. FAA - James M. Muncy at Washington, D. C.

This conference was held to develop information as to the various projects along the line of atmospheric turbulence in which FAA is interested.

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17. ONR - James Hughes at Washington, D. C.

Dr. Paul Rosenberg conferred with Mr. Hughes to develop information on CAT projects funded by Navy and to learn more about Prof. Peter Franken's project at University of Michigan, which is partly funded by ONR.

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18. Lear Siegler and FAA

To explore the potentials of applying Lear Siegler's Lidar to the measurement of runway visual range as well as visibility at the lower end of the glide slope close to the ground. In a later conference Lear Siegler made a presentation to the FAA of this use of Lidar.

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19. North American Aviation, Autonetics Div.

R. A. Averitt called to discuss in general terms the work of Autonetics Division on a radiometric sensing device for CAT, based on an underwater temperature-change sensing device which could be used in clear air.

Autonetics estimate that this would have a range greater than 25 miles. The sensor would be about 4 3/4" diameter, 12" long, and the total system would weigh about 35 lbs. The sensing is in the IR band, and the system is passive. The system scans with a 45° sweep laterally, 25 times per minute.

North American Aviation has three divisions having worked in the field of CAT detection, namely, the Autonetics Division at Anaheim, Calif., The Space and Information Division at Downey, Calif., and the Columbus, Ohio Division working on a different IR spectrum radiometric sensing device. Visits to these three divisions will be made at suitable times in the future.

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20. NASA, Cambridge Division

Conference was held to exchange information on CAT activities.

In discussing static charge correlating with clear air turbulence, it was stated that before 1959 NASA had detected r.f. signatures of electrical discharges in clear air, with no visible discharge, using 25' whip antennas. The ground system had three stations triangulated 50 miles apart. These atmospheric signatures were obtained when there was no weather within hundreds of miles. The observations were few in number and have never been followed up or repeated.

In discussing CAT in relation to jet streams, it was conjectured that a sufficient number of ground-based installations across the country capable of detecting jet streams, could keep a running watch on jet stream location, motion, thickness and speed. In clear weather star gazers or trackers might be able to spot CAT and watch the jet streams from scintillation of stars both day and night.

The thought was expressed that although the desire is to develop a CAT detection system giving similar information to that of weather radar, a passive system might be developed much sooner and with less expense, which would give valuable information to the pilot regarding proximity to CAT; and sufficient research should be done on the various passive systems to determine which principle would be most likely to give the pilot reliable information and the maximum amount of advance warning. It was agreed that research to determine the nature of CAT has not been organized to get at the basic nature of CAT on which a development program can be built.

During this conference, several valuable leads to agencies doing work in various fields of atmospheric turbulence were received.

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21. SAE Washington, D. C. meeting on Operating Problems - "The Jet Upset".

The only paper available from the session was #650251-"Operational and Design Considerations of Swept-wing Transports in Turbulence" - by F. J. Rudolph, Chief-Operations Division, FAA, and Richard S. Sliff, Assistant Chief Engrg. and Mfg. Div., Flight Standard Service, FAA.

Other papers presented were:

"Design and Prevention Factors - Airplane Upsets" by R. L. Loesch, Chief of Flight Tests, Airplane Division, The Boeing Company; "NASA Research Programs on the Problems of Operation in Turbulence" - by William S. Aiken, Jr., Chief-Operations Research Aeronautics Division, NASA Administration;

An untitled talk covering the subject, by Melvin N. Gough.

Comments by W. E. Rhoades, Vice Pres. Engrg., United Air Lines, and Paul Soderlind, Manager of Research and Operations Development Division, Northwest Airlines.

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22. AIAA conference with R. R. Dexter at AIAA Headquarters.

Discussion of the possible channels for receiving information concerning CAT research in England, France and other European NATO countries. Mr. Dexter made several suggestions and will try to find out about European CAT R & D on his next trip to Europe.

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23. Air Force-sponsored conference on CAT - 26, 27 April

A brief resume to the Government agencies working in this field, of the status of active CAT detection projects. The Air Transport Association also attended this meeting. Since Hq. USAF has published a complete report on this meeting, no report on the conference will be made here.

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24. Continental Air Lines

Conference with R. H. Curtis dealt to a large extent with mountain wave action in the western part of the United States, where strong mountain waves occasionally penetrate the tropopause. Under these conditions, moderate to severe turbulence can be expected 10,000 ft. above the terrain, and 5,000 ft. above the tropopause.

Continental is using gradient of the vertical shear in forecasting CAT. The U-2 has found convective turbulence at 30,000 ft., directly above fast-rising high-altitude cumulus clouds.

Continental experienced severe turbulence in a mountain wave near Denver on January 27th, 1965.

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25. Lockheed Aircraft Corp. at Burbank, Calif.

Lockheed's Hi and Low altitude turbulence studies and instrumentation for sensing and recording data for structural design were discussed. Lockheed's meteorological studies relative to CAT were also reviewed.

Hi Hi CAT Program - This program operates in the altitude range from 70,000 to 200,000 ft. Lockheed report No. LR-18178, dated 22 September, 1964, "Hi CAT Vehicle and Instrumentation System Study" describes the work done on this program. Lockheed also has a new seven-month contract, starting approximately the end of May, 1965, to study an unmanned vehicle traveling at Mach 5, at a constant altitude of about 40 miles, capable of traveling anywhere in the world. The flight is to be horizontal rather than in a constant Mach climb to simplify analyses of the data. The airplane will be instrumented for determination of power spectra. The vehicle will have stable platform guidance, will be booster-launched from an SST, and will be recoverable because of the expense involved. It will be several years before CAT data can come from such a project.

HiCat Program - This is a U. S. Air Force program which began in 1963, at first under Aeronautical Systems Division, and later under Flight Dynamics Laboratory, WPAFB, Ohio. The Air Force began flying a U-2 in January, 1963 in three world areas, namely: The United States, Alaska, and along the easterly jet over the equator. Primary purpose of the project is to gather statistical information for structures studies, and to gather meteorological data.

Lockheed's function in this HiCat Program is to supervise, collect and analyze the data. The altitudes of interest in this program are 50,000 to 75,000 feet. Instrumentation in the aircraft includes a gust probe, gyros, accelerometers, and equipment for 6 hours of data recordings. The gust probe is of the vane type, recording frequencies up to 20 cycles per second. The flights have experienced CAT accelerations up to plus or minus 1g incrementally (i.e. from 0 to 2g) over mountain waves. In the program to date, CAT disturbances of the aircraft were measured only up to a wave length of 2,000 feet; but a new phase of the program, using better accelerometers and stabilized platform, will measure wave lengths to 12,000 feet and longer.

During the conference, Lockheed had the following comments to make regarding CAT detection devices: The aircraft in the HiCat Program have space and weight available for more CAT instrumentation than has been installed to date, and Lockheed hopes to be able to install more instrumentation. For example, Lockheed plans to use a high-response Rosemount probe, and consideration is being given to the use of sensitive pressure transducers simultaneously recorded at ground stations, to triangulate for the turbulence. Other possible instrumentation would measure particulate matter in jet streams. Keith Biggs photographed particulate matter in jet streams in Australia during a Royal Air Force Top-Hi-Cat program; he is now at the National Center for Atmospheric Research in Boulder, Colorado.

In connection with CAT forecasting methods, Lockheed is studying to develop physical models to explain CAT and to correlate data. The study will sample small segments of the atmosphere, and expand this to worldwide forecasting on a probability basis. HiCat has shown a surprising amount of CAT in the stratosphere above areas where there is low-level activity of towering cumulus and nimbus clouds. Lockheed's theory to explain this is that vertical pulses from mountain waves and low-level convective activity are transmitted through the air into the stratosphere. Lockheed has found that methods used for forecasting CAT in the troposphere do not generally apply in the stratosphere, and they have found no good method for forecasting CAT reliably in the stratosphere. It appears necessary to develop a CAT detection device for aircraft which will fly largely in the stratosphere.

In discussing results of HiCat, it was stated that by deliberately seeking out CAT, the pilots were able to fly through CAT from 10% to 14% of the time while above 50,000 ft. In one instance the aircraft experienced true gust velocity of 30 ft. per second, and + 2g and - 1.7g at an altitude of 57,000 ft.

In discussing turbulence penetration procedures, it was stated that the SST probably will have no turbulence penetration speeds. It will be accelerating through M. 1 in the climb at about the tropopause level where it is usually mildly turbulent.

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26. North American Aviation, Space and Information Systems Division, Electro Optical Laboratory, Torrance, Calif.

Since the 4 May 1965 conference with R. A. Averitt, NAA has been awarded a contract by AFCRL for a 15-month design study of a laser radar CAT detection system.

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27. Douglas Aircraft Company, Long Beach, Calif.

Conference covered several in-house projects. In the course of theoretical studies of plasma and magnetohydrodynamics, Dr. Richard L. Moore of Douglas has developed a vector wave equation which he finds applicable to waves in stratified fluids and their methods of generation, including the effects of gravity and inertia.

Moore's equations agree with Tolstoy's equations, but Moore has a different physical interpretation of the results. Moore does not use the concept of buoyancy which Tolstoy introduces. Moore is led to propose the following mechanism for the generation of acoustic-gravity waves "In a stratified compressible non-viscous fluid at rest with a steady force field, motion is induced by gradients in heat transfer only". Dr. Moore is endeavoring to apply this to the meteorological forecasting of CAT.

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28. Stanford Research Institute

Conference with Dr. Ligda and associates working in the field of atmospheric turbulence revealed the wide scope of the work this group is doing in the field of CAT and CAT detection. AFCRL is funding the research work being done by SRI and United Air Lines on the correlation between CAT and electric fields.

(See Section V pages   for details of this project).

AFCRL has also funded a project on the analysis of U-2 photographs to determine the distribution and dimensions of cumulus clouds. U. S. Weather Bureau has funded a project which SRI is conducting on an analysis of CAT by use of rawinsonde data. AFCRL has also funded a study of the climatology of winds, temperature, and turbulence in jet streams. Lear Siegler contracted with SRI to conduct ground-based studies on detection of CAT by the use of Lidar.

29. United Air Lines, San Francisco Int'l Airport

Conference covered some of the information reported in Item #28 re conference with SRI, i.e. the program to investigate the relationship between CAT and atmospheric electric fields.

UAL is considering the possibility of detecting turbulence by means of sensing infrasonic pressure waves. Sensitive pressure transducers installed at suitable locations, free of aircraft induced pressure aberrations and having resonant responses rates that would not give false indications from pressure pulses or "noise" produced by the aircraft, would be necessary to pick up feeble infrasonic pressure waves at sufficient distance from the CAT areas to permit evasive action.

UAL's Meteorology Department is conducting continued studies in CAT forecasting for greater accuracy and closer pinpointing of moderate to severe CAT. In cooperation with Northwest Airlines, UAL is studying mountain wave generating locations in the Western Mountains for the purpose of rerouting the airways to avoid these generators.

30. The Boeing Company, Renton, Washington

The Company is investigating a radar method (for CAT detection) which is interesting and promising because:

1) The method does not require the presence of particulate matter or aerosols in the CAT;

2) Boeing considers the system can be made airborne by using a yagi antenna of practical dimensions, although the frequency is about 220 megacycles.

The Boeing method depends upon VHF radiation backscattered from refractive eddies in the turbulence. In other words, the method "sees" fluctuations of the dielectric constant of the atmosphere at VHF frequencies.

Boeing's early experiments with this method were conducted with a 75-megacycle (4 meter) bistatic CW "radar" with the transmitter and receiver separated by 10 miles over Puget Sound, using the airport's 75 MC outer fan-marker.

The ground was phased out. There was no scanning. Twenty-four hour strip-chart recordings were correlated with upper-winds and wind shears taken from rawindsoundings.

One of the difficulties in interpreting the data was that the scattering volume was roughly a cube, 3 kilometers on a side, with the result that the received signal integrated scattering from all altitude levels from approximately 20,000 to 30,000 feet. The scattering angle was about 90 degrees. The receiving antenna was a parabolic dish of chicken wire.

The results of the aforesaid 75 MC CW experiments encouraged Boeing to set up a 217 megacycle pulsed radar at Inglewood about September 1964. The antenna is a 40-ft. diameter dish scooped out of the ground and lined with chicken wire on plastic. The beam shoots straight up. Beamwidth is about 15 degrees. Pulse-width is 8 microseconds. Peak power is 300 KW; average power is 300 watts.

Operation consists of waiting until turbulence is indicated by combinations of PIREPS, upper air data, upper air wind charts, rawinsonde data, and information from the Boeing flight test center and FAA traffic controllers. Radar observations are then made when it is likely that turbulence is passing through the beam.

Twenty-five different CAT observations on this radar, between October 1964 and April 1965, were confirmed by aircraft flying near Inglewood at the altitude of the CAT indicated on the radar scope.

Boeing installed (late 1965) an airborne VHF radar on Boeing 727 aircraft E2. It consists of a yagi antenna (a series of upright vanes) along the top centerline of the aircraft, which gives a fixed beam of 20° x 20° included angle directly ahead of the aircraft. Tests of the pattern, impedence and power handling (200 kw peak) are completed, and the system is now being flight tested.

Antenna size is 480"x2"x8". Antenna weight is 100 lbs. Ground clutter and altitude return will be gated out.

The Boeing aircraft, thus equipped, is exploring CAT over the Inglewood ground-based radar, and will chase regions of jet stream CAT as they drift eastward. The investigation will seek to determine not only the practical value of this radar method of CAT detection, but also the answers to such questions as, what is the effective radar cross-section for various types of turbulence; what radar power is required; what frequency is effective.

For a number of months Boeing has been carrying on simulator studies of the effect of turbulence on Models 707, 720, and 727. Turbulence data from the work done by the NSSP is programmed into an analog simulator, and the simulator is flown with and without autopilot with fixed controls, and in other manners to study the effects of horizontal and vertical gusts on these models of Boeing aircraft.

From these studies and those with the 75 megacycle bistatic CW radar, Boeing believes that the longer wave lengths of CAT, the wave lengths that shake airplanes, are the wave lengths that a CAT detector should be designed to sense.

31. Northwest Airlines was visited by M. G. Beard, while Dr. Rosenberg visited Honeywell.

Since the Boeing 720 accident at Miami in January, 1963, Northwest Airlines has probably done more work in the area of atmospheric turbulence than any other airline, except perhaps United.

Paul A. Soderlind, Manager of Research and Development Division of the Flight Operations Department, summarized the work of the department in Northwest Airlines Flight Standard Bulletin #8-63, dated November 12, 1963 - Subject: "Jet Turbulence Penetration". This bulletin was issued to all of the Northwest flight crews, and was presented before a closed inter-airline operations group in Miami in late November, 1963. This bulletin subsequently reached all the airline and corporate pilots of the country. Paul Soderlind personally lectured the chief pilots and the flight instructors of several of the major airlines on his findings regarding turbulence penetrations and the correct method of handling the jet transport under turbulent conditions.

In 1965 Northwest Airlines issued a second bulletin, Flight Standard Bulletin #3-65, dated February 26, 1965, - Subject: "Operations in Turbulence". This bulletin is an updating of Flight Standard Bulletin #8-63, offering additional information regarding handling of the jet transport in turbulent air.

Dan Sowa, Supt. of Meteorology, has been concentrating on detailed analyses of synoptic charts with an aim towards more closely pinpointing the location of turbulent areas of all types, and instructing the pilots so they can determine locations where turbulence probably will be encountered along the flight path. Northwest's instructions to pilots have been issued in several bulletins, but are as yet not compiled into one document. Northwest does not forecast turbulence in a block of airspace, but endeavors to pinpoint the locations of turbulence more exactly. With respect to the jet stream, if the pilot begins to encounter slight chop when flying with the stream, the rule is to turn right a few degrees and the plane will fly out of the turbulent area. Similarly, if the pilot begins to encounter a slight chop when flying counter to the jet stream, on the north side outside the jet stream where turbulence may be anticipated, the rule is turn right and the plane will fly out of the turbulence.

Northwest considers the mountain wave action on its routes in the northwest part of the country more severe than in the more publicized areas of the southwest. As has been previously stated, United and Northwest are making a joint survey of their routes in an effort to change the routes sufficiently to avoid mountain wave generating ridges. In several instances changing the route by not more than 20 miles will avoid severe mountain wave generators. There are one or two places, such as Helena, Montana which lie directly in the lee of the generating ridge, where route change is not possible because landings and takeoffs must be conducted at these points.

Although mountain wave turbulence generally is encountered to the east of the generating ridge because of the westerly wind pattern in the northern hemisphere, there are places, notably Salt Lake, where northeast winds occasionally produce severe turbulence over the Great Salt Lake Valley to the west of the mountain range.

Whenever the jet stream penetrates the tropopause, the pilots can expect turbulence 4,000 feet below, and 5,000 feet above the area of penetration. Just south of Tallahassee, Florida, there is a gravity wave which is chronic in the winter months whenever strong westerly winds are blowing in the area.

Northwest's instructions to its pilots are to stay out of known turbulent air areas, and to avoid flying in turbulence whenever possible. Northwest is developing a technique for anticipating turbulent penetrations by watching for erratic motions of the navigational doppler indicator needle.

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32. Honeywell, Aeronautical Division

Dr. Paul Rosenberg visited Honeywell. Dr. Sackett is the person at Honeywell to contact for future CAT technical matters.

Honeywell conducted an experimental study to investigate molecular backscattering with a ruby laser. They were interested in the Tatarsky model. They used a chamber, 200 feet long and 24 inches in diameter, containing baffles. Receiving aperture was approximately 8" in diameter. Turbulence was produced by heating elements.

Honeywell observed backscattering which was close to Raleigh scattering; but the results were inconclusive because the experimental conditions did not preclude the possibility of there being particulate matter in the chamber to give particulate scattering. It was suggested to Honeywell at this conference that they might have investigated the back-scattered radiation as a function of receiving aperture, i.e. as a function of angle, and thereby distinguish between some of the possible types of scattering.

Honeywell also has conducted field tests at the Minneapolis Airport, using a ruby laser of 40 to 70 megawatts peak power, with a pulse half-width of 10 to 20 nanoseconds. The receiver in the early experiments was 8 inches in diameter, and is now a 5-foot diameter searchlight. Mention also was made of the

Honeywell-Cambridge Research Labs experiments at Colorado. Backscattered radiation was re-received from clouds at ranges up to 30 miles. However, the results are as yet inconclusive with regard to CAT detection. Work continued on this project until June 1965 when the contract expired. (Honeywell's laser contract with AFCRL is No. AF 19(628)-2376).

Honeywell is studying the characteristics of autopilots in turbulence, through computer simulation, with the end purpose of developing an improved autopilot which can handle turbulence better than the human pilot (and better than existing autopilots). Honeywell (like others) believes it cannot simulate adequately the reactions of the human pilot in turbulence; hence Honeywell's computer simulation studies have dealt with autopilots only.

Honeywell is using a statistical model of turbulent wind from NASA-Langley data in an effort to determine how far ahead of the aircraft (for example, 300 feet) an autopilot needs gust prediction in order to prepare for a safe and comfortable penetration of the turbulence. The theoretical possibility of flying an angle-of-attack sensor at the end of a boom extending out in front of the aircraft is being considered.

Honeywell feels that an autopilot which is properly designed for turbulence also will function well as a general autopilot in non-turbulent flight. In other words, a two-position switch (autopilot and manual) should suffice. There need not be separate operating modes of the autopilot for turbulent and non-turbulent flight.

Honeywell is conducting an experimental research program, supported by the Army Surgeon General, to investigate the effect of laser beams upon the eyesight of primates. The program is under the direction of Dr. H. G. Sperling, and its purpose is to determine the intensity, wave length, and duration parameters in relation to both permanent retinal damage and temporary flash blindness. Monkeys are trained to perform tasks requiring certain visual acuity, and their performance is rated. Their eyes are then periodically exposed to laser radiation, and the effect upon their performance is noted.

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33. National Aeronautical Establishment, Uplands Laboratories, Flight Research Section, Ottawa, Canada.

(IATA Headquarters in Montreal recommended this contact.)

Mr. A. D. Wood, Head of the Flight Research Section, stated that most of the turbulent air work done by the personnel of Uplands Laboratories has been in the low-altitude regions, using an F-86 and a T-33 instrumented with three accelerometers to get accelerations about the three axes. Their interest is in the turbulence at altitudes from 300 ft. to 1,000 ft. over rough terrain. The roughness profile of the Laurentian Mountains has been thoroughly measured. The instrumentation on the planes is adequate to obtain the power spectrum of the turbulence.

Although Air Canada did not have recorders installed on its turbine-powered transports prior to the Montreal DC-8 accident on November 29, 1963, Air Canada now is installing recorders having 42 channels with a possible 250 channels available, on all turbine-powered aircraft.

Another project of the Uplands Laboratories is that of checking the flying qualities of helicopters for limiting design factors or turbulence operations.

Since Air Canada operates DC-8's, the National Aeronautical Establishment is very much interested in all DC-8 accidents and incidents.

The T-33 is being used to simulate the maneuvers of some of the DC-3 accidents, for example, the accident at Dulles Airport on 20 August 1963, and one at Houston on 9 November 1963.

Dr. Marshall of McGill University is carrying on a project of cross-sectioning storms at various altitudes at time intervals. Observations are being made, using 10-cm. and 5-cm. radar, with determination of hail as a major part of this project. One radar set is located in Montreal, and one in Alberta.

Just before this conference terminated, I was asked if there was any interest in an incident which occurred on a flight test of a military aircraft where violent high-speed buffet temporarily incapacitated the crew. The details of this experience tie in very closely with the human factors work being done at Johnstown in shaking pilots to determine the resonant period of the eyeballs, and NASA's project in determining the resonant period of large jet aircraft. The details of this experience were immediately reported by NASA through Mr. Aiken's office, and the information passed on to the NASA scientists working in this field.

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34. The National Center for Atmospheric Research at Boulder, Colorado is supported by the University Corporation for Atmospheric Research, whose membership is composed of 21 universities. The Laboratory of Atmospheric Sciences, to which this visit was made, is headed by Dr. William W. Kellogg - Director. In his absence Dr. William Jones, Ass't Dir., was visited.

This laboratory is carrying on two projects which have a bearing on turbulence: 1) The High Altitude Research Division doing work in solar physics in the ionosphere; and 2) The Laboratory for Atmospheric Sciences doing meteorological research from the ionosphere down to earth. Objectives are to study the large-scale circulation of the atmosphere to develop long-range forecasting, to develop more refined atmospheric models, to study the effects of radiation over mountains, frictional forces of winds over mountain areas, etc.

In a study of atmospheric physics and cloud physics, a ruby laser is to be used to detect stratospheric dust layers and density discontinuities. A study also is to be made of the size of particulate matter in the stratosphere.

In the Cloud Physics segment, drop-sonde methods are to be used by dropping instrumentation through thunderstorms to measure air currents, water droplet size, temperatures at the various levels, etc. This project was scheduled to start in June, 1965. The drop-sonde instrumentation is to be monitored by radar.

The laboratory planned to study the effects on thunderstorm hail of shock waves produced by bombs. The Italians are also carrying on a similar project.

During this interview, Dr. Jones stated that three of their laboratory scientists show signs of minor eye damage from lasers. This is in a form of minute white scars on the retina. These are not detectable by the naked eye, but require magnification to be seen. This would indicate that the threshold of retina damage is lower than previously thought. The damage was done by a gas laser.

In the winter of 1966 the laboratory will have two scientists studying mountain waves in relation to surface winds.

This summer the laboratory worked on dynamics of thunderstorms on a synoptic basis.

35. Flight Safety Foundation, Tenth Business Aircraft Safety Seminar, Denver, Colorado.

The proceedings of this conference included a paper on "Atmospheric Turbulence", by M. G. Beard.

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36. Colorado State University, Fort Collins, Colo. Professor Elmar R. Reiter heads the Department of Atmospheric Sciences.

Dr. Reiter attended the International Colloquium on "The Fine Scale Structure of The Atmosphere" in Moscow, Russia, June 1965. The conference was organized by the Inter-Union Committee on Radio-Meteorology.

Dr. Reiter has been analyzing Tiros pictures in an attempt to analyze flow over mountains to see whether these pictures revealed mountain waves. Normally, these pictures do not show mountain waves too clearly. However, by looking at the shadows on the Tiros pictures with the sun in the right position, the cloud pattern of the high-altitude clouds throws indicative shadows on the lower altitude clouds which can be seen in some pictures. Some jet streams also can be determined in this manner. A study is being made to see whether mountain waves can be determined in a similar way.

In 1964 Dr. Reiter was attached to the British and Australian groups in Australia, making measurements of turbulence to obtain information for plotting the power spectral density for aircraft design criteria. From the Australian tests, the energy or amplitude of the wave lengths of 2,000 ft. were measured. It is Dr. Reiter's theory that these long waves progressively dissipate energy into smaller waves, and finally into very short wave lengths of small scale turbulence. The longer wave lengths have the basic energy. These long waves break down into medium wave lengths which create the moderate to severe turbulence which shakes aircraft. Dr. Reiter believes these break down into smaller eddies which dissipate into heat through viscosity. Dr. Reiter states the degenerated waves have little energy and do not bother Jet transports.

Part of the purpose of the colloquium in Moscow was to try to determine the nature of Clear Air Turbulence.

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37. Barnes Engineering Company, Stamford, Conn. propose an adaptation of their Infrared Atmospheric Thermometer (IRAT) for the detection of CAT. This is based on the premise that turbulence is often associated with temperature discontinuities in the atmosphere of the order of $3^{o}c$ to $5^{o}c$. Measuring the radiation omitted at several wave lengths within an absorption band can give a range indication.

At the suggestion of FAA, Barnes is considering mounting their instrument on a mountain top in the eastern part of the U. S., while an instrumented aircraft of Pennsylvania State University (State College, Pa.) flies in the vicinity to correlate the readings of the Barnes instrument with aircraft measurements of turbulence and air temperature. Barnes estimates that equipment for these mountain-top tests could be made ready in about two months. The company estimates they could build a research instrument for aircraft evaluation in four months; after which, evaluation itself would probably take 6 months to a year. Production prototypes could be made in another 6 months; with operational instruments ready for installation in aircraft in 2 or 3 years if all went well with the development.

Barnes has an AFCRL contract to build free air thermometers for transonic military aircraft (KC135 and two other planes). The "beam shape" of these thermometers is rectangular; a total of 6 degrees up-and-down; and a total of 15 degrees left-and-right. The instrument is to be mounted on an external pod.

Barnes states that there is no fundamental limitation which would prevent their airborne instrument from eventually scanning in azimuth and elevation (using rotating mirrors or equivalent moving optical elements). Their present 2-second time for one range scan would have to be increased, but a speed-up by a factor of ten, to a 0.2 second range scan, is not out of the question, Barnes states, because the detectors have a response of the order of one millisecond. If necessary, more than one detector could be used. Therefore, it would be feasible to scan perhaps through a 30° included angle in azimuth, and a 10° included angle in elevation, to make a 3-dimensional search for CAT.

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38. U. S. Weather Bureau National Severe Storms Laboratory (NSSL), Norman, Oklahoma

This organization is successor to the NSSP formerly located in Kansas City, Mo.

The laboratory is well-equipped with several weather surveillance radars having circular sweep, sector scan, vertical scan, and scope photography. It is located in what is known as "Tornado Alley" which extends from Central Texas through Oklahoma, Arkansas, Kansas, Missouri, Nebraska, Illinois, Iowa, South Dakota, Minnesota, Wisconsin, Indiana, and Michigan. It is ideally located for surveillance of tornadoes, thunderstorms and frontals which sweep up through the western border of the Mississippi River Valley along the slopes of the high plateau, east of the Rocky Mountains.

The laboratory objectives are:

1. To gain new knowledge of the morphology and dynamics of severe storms, such as heavy rains, squall lines, thunderstorms and tornadoes, and thereby to contribute to the development and understanding of improved forecasting.

2. To discover improved methods for collecting, analyzing, and processing severe storm data, and to stimulate development of equipment, especially radar equipment, holding promise of expanded capabilities.

3. To study operating configurations of men and equipment, and thereby to contribute to the design of improved storm observing and reporting systems wherein sensors, processors and communications facilities are efficiently meshed to provide timely accurate information to the host of users.

The purpose of the visit to NSSL was twofold, namely, to make contact with the staff of the NSSL and obtain information as to any activities this laboratory is doing in the field of Clear Air Turbulence, and to interview Mrs. Anne Burns of the British project which is now terminating its mission at the NSSL. This project is to obtain data on turbulent air surrounding storm areas and inside thunderstorms in the United States.

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39. Royal Aircraft Establishment, Farnborough, Hants, England.

Mrs. Anne Burns, head of the British group in the U.S.A. obtaining data on turbulence in storms, was interviewed during the visit to NSSL. Professor Peter Franken of the University of Michigan flew his laser-equipped plane to NSSL and Mrs. Burns accompanied our inspection of the plane and the laser installation. A second conference with Mrs. Burns was held at Kennedy Airport, New York, on June 14th when she was enroute to England.

The British project, under the auspices of the British Royal Aircraft Establishment at Farnborough, was started by a visit to NSSL by Mr. Jack Burnham and Mr. Peter Bisgood of the BRAE on November 3, 1964. Purpose was to discuss participation in the NSSL Spring program. The formal invitation was extended to the British by the Chief of the U. S. Dept. of Commerce Weather Bureau on December 18, 1964.

The British at NSSL have two Canberra bombers, and one RAE Scimitar Delta Wing Fighter, all of which are equipped for recording the factors in turbulence necessary to compute the power spectrum density for use in aircraft design.

Mrs. Anne Burns of Farnborough, head of the expedition, is a structural engineer and also a British licensed glider pilot. On her staff are the three crews which man the three aircraft, a meteorologist, a staff of analysts, and office assistants.

The two Canberra bombers fly in the vicinity of frontal areas and thunderstorms to obtain turbulence data in the air surrounding major storms. The Scimitar Fighter actually probes the storm centers and records the conditions in the core of the storms.

This mission arrived in the United States during the week of April 4th, and terminated its stay after a total of about ten weeks at Norman, Oklahoma on June 11th. They obtained some good turbulent-air data, but were disappointed that during their stay there were no severe frontal storms which passed directly over Norman, Oklahoma, so that they could obtain both the inflight data and the ground radar storm surveillance data. The mission did obtain data on a large number of isolated thunderstorms within radar sighting distance of NSSL. On the afternoon of June 8th when we were scheduled to interview Mrs. Burns, there was one thunderstorm of moderate proportions to the northeast of Norman, about 30 miles distant, and Mrs. Burns was inflight with one of the Canberra bombers. The afternoon was spent interviewing Dr. Kessler, and in observing the ground radar observation procedures, and the photographing of this small thunderstorm.

Since our time was short, the British delegation was not available for interview on the afternoon of June 8, and we had an additional contact to make with the University of Michigan group, these two groups were invited to dinner on the evening of June 8th in order to continue the conference, which lasted through until about 10 o'clock that evening.

On the morning of June 9, Mrs. Burns was desirous of seeing the University of Michigan airplane and equipment. Therefore, discussion of the project was postponed to June 14 as she was returning to England.

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40. Professor Franken, University of Michigan described his project as an exploratory research experiment, using relatively simple equipment to see if he could detect radiation backscattered from particulate matter or aerosols in turbulent air illuminated by a laser beam. He realistically estimated that the chances of success in his experiment were perhaps one in ten. He stated this probability of success was usual in an exploratory scientific research experiment and amply justified the project.

In Franken's experiment, a pulsed ruby laser transmitter head, built by Lear Siegler, is mounted just outside the fuselage on the port side, fastened rigidly to the left end of a stiff 4-inch diameter aluminum tube which passes horizontally and laterally through the fuselage near the top of the cabin. The tube (which serves only to support the laser transmitter and receiver) is mounted on brackets attached to the instrument rack which is shock mounted on the floor of the cabin. The tube is not connected structurally with the fuselage side walls, although there are flexible closures around the tube at these side walls. An optical receiver head is mounted on the right hand end of the aluminum tube just outside the starboard side of the fuselage. Transmitter and receiver are about 5 feet apart. The receiver is a photomultiplier at the focus of a Questar telescope with appropriate filters which pass the laser beam frequency. The transmitter and receiver both face forward, and are aligned so that their respective axes of sight intersect at a point 700 feet ahead of the airplane. The spread of the transmitted beam and the viewing angle of the receiver are such that, theoretically, the backscattered radiation can be seen from 500 to 1,200 feet ahead of the airplane. This geometry was preferred by Franken to a coaxial configuration because it is simpler and less expensive than a coaxial arrangement which would require gating to cut out radiation backscattered from the beam close to the aircraft. Alignment of the transmitter and receiver is checked by ranging on an identifiable ground target while driving at 45° angle. No trouble has been found in keeping the transmitter and receiver in alignment.

Franken's experiment has been criticized unjustly on two counts:

(1) Through misinformation it has been erroneously stated that the relative alignment of the transmitter and receiver cannot be maintained because the transmitter and receiver are mounted respectively on the port and starboard wing tips and therefore are misaligned every time the wings flex;

(2) Franken's experiment has been misunderstood as an effort to demonstrate a proposed CAT warning instrument, rather than an exploratory research experiment. These misunderstandings may be due in part to the fact that Franken did not issue a written report of the project until December 1965:

Airborne Investigations of Clear Air Turbulence with Optical Radar

by P. A. Franken, J. A. Jenney and D. M. Rank

University of Michigan

"Of more than 1,300 experiments in severe storm areas approximately ninety percent of the observations failed to reveal either peculiar aerosol distributions or turbulence. Of the remaining ten percent, however, roughly one third exhibited turbulence and no interesting aerosol effects, one third exhibited interesting aerosol distributions, but no turbulence, and the remaining third exhibited both effects concurrently.

"A fine-grain aerosol distribution can and does exist in the atmosphere at an altitude of 20,000 ft. at least, and the presence of turbulence in these regions does not appear to mix the aerosol to the point of uninteresting homogeneity.

"The presence of aerosol discontinuities does not provide a unique signature for turbulent activity because the aerosol signals apparently can be associated with quite friendly atmospheres that simply contain sheets or striae of particulate matter."

To determine whether there are characteristic differences in distribution of particulate matter in turbulence which the "A-scope" type of presentation of optical radar one-dimensional exploration cannot distinguish, Franken is developing a PPI optical radar capable of providing a two-dimensional map of the atmosphere which can show whether there is characteristic clumping of particulate matter into several hundred-foot sized cells by turbulence. The flight equipment will be capable of carrying the tests to 30,000 ft. to probe jet streams, mountain waves and severe storm-associated CAT.

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41. Royal Aircraft Establishment (Second conference with Mrs. Anne Burns at Kennedy Airport)

During this conference Mrs. Burns reiterated that the British project is particularly interested in gusts of 500 to 1,000 feet wave length, as these appear to have the most drastic effect on the airplane. Preliminary study seems to indicate a difference in the power spectrum density between flights made in the direction of the wind as compared to crosswind. This item will be explored with Dr. Reiter.

Mrs. Burns stressed the procedure of marking turbulent air areas with smoke or colored powder so that they can be kept in sight and traversed repeatedly during turbulent air tests. This procedure was followed several times with great success in the Australian project. On one flight a turbulent area was marked each time a traverse of the area was made. The area moved with the air mass, but appeared to stay intact as a turbulent area. This area was followed for several hours. (This technique for labeling a turbulent area so that it can be used repeatedly should work well under most conditions, except the mountain wave. In the case of the mountain wave, the generating ridge is static and the air flows over the generating ridge. Marking material therefore would flow with the air and away from the mountain waves created by the generating ridge. Whenever lenticular clouds are present, they mark the mountain wave presence and structure, but lenticular clouds are only present when humidity conditions are right for their formation).

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42. Litton Guidance & Controls Systems Div.

Roy E. Williams called at FSF office at New York to report the status of Project "TRAPCAT". The instrumentation required extensive modification which was being accomplished at Litton's shops during the summer months. The sets were to be returned to the same airlines for installation in the Fall and operation during the winter months of 1965-66.

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43. TRG, Inc. subsidiary of Control Data Corp.

TRG is actively engaged in laser and radar developments for applications other than CAT. TRG made a proposal to AFCRL on the study contract for doppler laser radar CAT detector.

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44. Colorado State University, Fort Collins, Colo.

Dr. Reiter reported on the Russian meteorological colloquium with world meteorologists. Russian meteorologists were surprised at the data on turbulence flight tests which he showed them.

Dr. Reiter gained a better insight regarding the causes of CAT. The conference indicated that CAT associated with the jet stream is in the form of gravity waves which progressively break down into smaller waves, thereby dissipating their energy.

The conference considered the quantities which should be detected for determining CAT. Longer wave lengths which shake airplanes should be detected, it was stated.

45. The Decker Corp.

Proposed a ground-based differential pressure transducer which measures small barometric pressure changes, at ground level, of the order of 10^{-4} mm of Hg. The assumption is made that rapid barometric variations, thus detected, would indicate CAT at higher altitudes.

The proposed measurement would constitute an acoustic detector in the audible and ultrasonic ranges of frequencies. This detector would probably be affected by ambient noise of all kinds.

Decker Corp. has made no study of CAT as such, and has not tested its proposal experimentally.

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46. Sandia Corp.

Dr. Smith and Dr. Georgia phoned and explained that the Project Roller Coaster, funded by the U.K. and U.S.A. in 1963, does not apply to the CAT at higher altitudes in which Project CAT is interested.

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47. General Precision, Inc.

Link Group called this conference to discuss simulators for training pilots in handling turbulence. The pros and cons of simulators with and without motion were discussed. Visual displays were described. Simulator requirements for training on turbulent air and unusual maneuvers were outlined. Turbulence measurements for simulator design received considerable discussion. No conclusions were drawn.

48. FAA Conference

Jim Muncy discussed Project TRAPCAT findings for the first phase of the operation. Only three airlines actually operated the instrument during the Spring of 1965. Modifications were being made in the recording instruments which were to be reinstalled by the same five airlines, beginning about Jan. 1966. The project will continue through the winter months of greater jet stream and mountain wave turbulence activity, and terminate in March or April 1966.

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49. New York University

Mr. Lappe discussed his paper, presented before the AIAA January 1965 meeting in New York, "A Low Altitude Turbulence Model For Estimating Gust Loads on Aircraft" (#65-14 by U. Oscar Lappe, New York University).

The paper deals with power spectral density, a generalized harmonic analysis of turbulence effects on flexible and rigid body modes varying from 0.4 to 1 c/sec. Discussing the wave length spectrum, if the short wave lengths are present and measured it may be assumed the long wave lengths are there also or have been there, based on the theory of the breakdown of the gravity wave into viscous dissipation.

New York University is working with comparative measurements of P.S.D. quantities of the B-52, B-56, F-106 and B-58.

New York University also worked with the Rough Rider Project.

The data for the AIAA paper came from measurements made on the B-56 project.

Mr. Lappe is coordinating on turbulence projects with Mr. Muncy and Mr. Sanford of the FAA.

50. The NASA Langley Field Conference

This was primarily to see and get information on the Lear Siegler ruby pulse laser installation on the T-33 for flight tests to correlate laser backscatter-return with CAT.

The installation instrumentation consists of:

1) A resistance-thermometer temperature probe similar to a Rosemount probe.

2) A "continuous particle sampler" built by Meteorology Research, Inc. at Altadena, Calif. This is a moving film passing around a small radius curve under a slit. The frontside of the Mylar 15-mm. film is gummed with a sticky substance just before passing under the slit. Particulate matter which passes through the slit is imprinted on the sticky surface. The imprint is permanent and can be examined and measured in the laboratory even if the particle happens to be an ice crystal which has melted.

3) A 6-channel recorder.

4) Recording camera to photograph the laser system oscilloscope.

5) Laser transmitter and receiver.

6) Oscilloscope, Tektronix, high response.

7) Control boxes for laser.

8) Accelerometer located at c.g., the signals fed into the recorder.

9) Airspeed transducer, fed into recorder.

10) Altitude " " " "

Laser characteristics:

Peak power - 10 megawatts (Set rated for 20 m.w.)
Rep. Rate 1 p.p.s.
Pulse width 20-30 nanoseconds
Wave length 6943 A^{o} $\pm$ 1A^{o} (Ruby)
Switching - Passive fuse switch or rotating prism.
Beam divergence - 1 milliradian (total) $\pm$ .5 m.r.
Beam diam. - 1 1/4" from 1/4".
Receiver Acceptance Angle - 1 m.r.

With varying peak power there will be difficulty in obtaining repeatable results from flight to flight. Lear Siegler is redesigning the gain sequencing or will get a new power supply.

Receiver and transmitter are 7 3/4" apart. They are essentially coaxial.

Range 100 ft. to 100 miles (hopefully).
Signal-to-noise ratio = 10 at 5 miles and 40,000 ft. in clear air. A nitrogen laser noise level is much lower. Lear Siegler maintains this laser can detect Raleigh scattering.

At 10 miles the attenuation is said to reduce the laser beam intensity to 1/2 the eye damaging intensity. (From Medical College of Virginia report on rabbit eye damage.)

Plexiglass in the windshield will absorb wave length of 3514 A^{o} and might be a protection against eye damage from lasers using this frequency.

The project will use lower power at start of flight tests.

The purpose of the project is to coordinate the laser returns with response of aircraft to the turbulence encountered and measure the particulate matter size and density from which the laser return was received. Also to coordinate temperature changes with turbulence encountered.

The plan is to locate turbulent areas and return back through the area by ground radar vectoring.

The Wallops Island radar has been contracted for by AFCRL to monitor and guide the NASA T-33 on this project.

The physical characteristics of the shock wave on leading edges of the SST were discussed with Mr. Hubbel and Mr. Pierce. We have discussed the effects of the shock wave on the various proposed detectors with their proponents and have received answers of varying degrees of optimism as to whether the device would work on the SST through the shock wave. None of the detection principles have been tested in a supersonic wind tunnel to determine their effectiveness under this condition.

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51. Douglas Aircraft Company

The company has plans to completely instrument an A3D for flight research in atmospheric turbulence. This is an "in-house" project.

Douglas has been studying methods of computerizing weather data to derive quantity rapidly and mathematically in three dimensions. Mr. Marphew believes CAT is a microscopic structure of the atmosphere that can be so analyzed.

(See Part II for further information)

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52. Electro-Optical

The organization is working with optical doppler radar and hopes to get backscatter from aerosols or particulate matter. The optical probings have two goals:

1) To develop a research tool for upper atmospheric research; and

2) To develop a probe for mounting on airplanes which will reach 1,000 meters or more ahead of the plane to detect CAT. The unit will be a pulse laser of about 10 joules peak output. Electro-Optical has a NASA, Ames contract for research on the nature of backscatter. The first research study is to sort out and discriminate between the types of backscatter, molecular and aerosols. A pulsed PLIDAR (Polychromatic Lidar) having two scopes will be used, one showing 6943 A°; the other, 3472 A°. The second study will be on scattering from CW laser with no attempt to correlate with CAT. Maximum distance Electro-Optical expects to get for CAT detection is 10 km for any system with power up to 10 joules. Electro-Optical's studies indicate 1,000 photons would have to be received to detect CAT usefully. Electro-Optical also is working on a coherent doppler radar called MOPA (Master Oscillator Amplifier).

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53. Meteorology Research, Inc.

This is a profit research organization. In order to be eligible for national research grants, Atmospheric Research Group, a non-profit organization, has been formed.

At the Flagstaff field laboratory, research in cloud physics and cloud seeding is conducted.

A.R.G. has research grants in the field of atmospherics from the National Science Foundation; in the field of air pollution, from the U. S. Public Health Service; and on wind shear, vertical and horizontal, from NASA, Huntsville.

Paul MacCready stressed the need for funding a long-term research project in CAT which would permit complete instrumentation of a plane of sufficient size to carry full automatic recordings of all sensors installed, and several research engineers and scientists. This also was stressed by others with whom we conferred. Operating through the winter months of peak jet stream and mountain wave activity, such a project could provide the data necessary to fill gaps and unknown areas in the fine-scale structure of the atmosphere and the breakdown of gravity waves. This data and information are necessary to determine the best principles for design of a good CAT detector. An even greater benefit would be to the science of meteorology in general.

M.R.I. has developed a "universal turbulence meter" which they believe could standardize reporting of degrees of turbulence. The instrument is said to be simple, adaptable to any aircraft, and not expensive. It compensates for all characteristics of the aircraft so that the turbulence rating would be the same whether taken in a jet transport or a small plane. The cockpit indicator has a scale from 0 to 10 on which the degree of turbulence is indicated. The instrument is compensated for each model. If it becomes desirable to obtain more accurate turbulence reporting, this instrument is a possible solution.

The wind-shear studies for NASA - Huntsville, indicate the simplicity of forecasting CAT. Radiosonde must be improved and readings taken more frequently.

M.R.I. is interested in weather modification and is optimistic that increased rainfall can be accomplished over an extended period in local areas.

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54. The U. S. Army Electronics Laboratory

Conference with Dr. Kuzemir was held while waiting for MacCready to return from a cloud-seeding mission.

Dr. Kuzemir is studying thunderstorms at the Flagstaff field laboratory. This project has been conducted for several years, during the months of

July and August.

A ground installation, with range of 500 miles built by Litton (SPARSA), triangulates on thunderstorms in the area and automatically locates their positions.

One objective of this research has been to determine whether seeding of cumulus clouds with chaff needles will prevent them from developing into thunderstorms. Electrical fields in the vicinity of thunderstorms are measured by a field mill mounted on a DC-3. Two components of the electric field are measured. The installation cancels out the residual charge on the airplane which comes largely from the engine exhausts. Gliders do not acquire these residual charges which are independent of tribo electric charges from particulate matter.

A field mill centered on the nose of the aircraft usually will be in the electrical symmetry of the plane. The installation on the C-47 will measure 2 volts/meter in a noise level of 50 mv/m.

It is estimated that the field mill used on the C-47 is 2×10^6 times more sensitive in measuring atmospheric static charge than that used on the DC-8 in the SRI-UAL static charge detection for correlating with CAT.

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55. ITEK

ITEK's interest in CAT primarily is in the optical effect of turbulence in aerial photography. They are interested in photographing changes and non-uniformities in the optical density of air between a plane flying at 60,000 ft. and the ground.

ITEK also has an "in-house" project on optical scattering as a function of wave length. This is covered in their report #5240, "Atmospheric Effects on Aerial Photography" - by W. D. Davis.

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56. AFCRL

Wilbur Paulsen listed the following projects funded by the Indirect Probing Techniques Branch:

1) Laboratory project at Honeywell, Minneapolis, Minn. - A study of laser backscatter from molecular motion or particulate matter. The final report is being completed.

2) Rawlinsville, Colo. - A ground-based laser, operated by Honeywell, to probe the upper air to correlate backscatter from particulate matter in mountain waves with CAT. Technical difficulties prevented conclusive findings during winter of 1964-1965.

3) An airborne laser installed in a T-39 - To correlate backscatter from particulate matter with CAT. This project has not been initiated but is contemplated.

4) SRI-UAL - An atmospheric electric charge project, with SRI recorders installed in ten DC-8's, to correlate static charge buildup with CAT. The first report has been completed and is ready for distribution by SRI.

5) University of West Indies - From the ground, laser probings of upper atmosphere to determine the concentration of particulate matter at high altitudes. A scientific report on the first phase has been completed: "A Study of the Feasibility of Measuring Atmospheric Density by Using A Laser - Searchlight Technique." Contract #AF AFOSR 616164 - University of the West Indies, Department of Physics. Scientific Report for period - 1 April 1964 to 31 March 1965.

6) North American Aviation - Doppler Lidar development for airborne use. Project in process.

7) Atmospheric electric field correlation with CAT - A study begun in July by Honeywell; and extension of the contract is contemplated.

8) An IR detector, built by Barnes Engineering Co., Stamford, Conn. to be installed in a T-39 or a C-130, Jan. 1966 - This instrument to be evaluated primarily as a temperature sensor for CAT correlation.

9) An Ozone (O_3) detector for correlation of O_3 concentrations with CAT - This project is in the Research Laboratory under Mr. Sam Penn. The U-2 in which the O_3 detector is mounted made a few flights in the Spring of 1965 but no correlations with CAT have been made.

10) Spherics, Position, Azimuth, Ranging, Systems Analyzer (SPARSA) - This system was built by Litton's Applied Science Division to be installed at Cape Kennedy. It is designed to determine position and intensity of electrical storms in the vicinity at Cape Kennedy.

Since the SPARSA project is designed to study detection of thunderstorms from the weakest electrostatic charge formation through to complete dissipation, certain aspects of this project may be applicable to detection of CAT, especially if the SRI-UAL project finds good correlation between static charge buildup and CAT. During the data processing, attention should be given to indications of static charge buildup when no thunderstorms are indicated.

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57. ARACON Geophysics, Division of Allied Research

Dr. Wexler is working on AFCRL contract studying precipitation detection with doppler radar. Under storm conditions, measurements were taken every twelve minutes for six-hour periods. Every time there was a breakdown or dropping of air at high velocities, the Richardson number at that point was less than 1. However, there also were areas where the Richardson number was less than 1 when there was no dropping air current.

Mr. Merritt thinks the passive radiometric principle, with horizontal scanning in the H_2O vapor-absorption band, is promising for CAT detection. Water vapor is always present at all levels now flown. Mr. Merritt cites Pan American pilots' observations with X-band radar in which the radarscope showed a distinct but faint mottled effect one to two minutes before encountering CAT. The CO_2 band also can be used.

Optimistically, range-precision with a radiometric detector would be about $\pm$ 5 miles. The scanning sweep would be 3 cycles/mile at M.82 cruise. The range of the detector would be shorter at higher air densities at lower altitudes, and longer at lower densities at higher altitudes.

A second method was proposed, that of sensing $\frac{d\phi}{dv}$. Two beams, one above the other would sweep horizontally for an arc of two miles at a 20-mile range, and 3,000 ft. apart vertically at 20 miles. The two beams would measure the vertical temperature shear, there being a correlation between strong winds and strong vertical shear. This method would develop a turbulence-index similar to a Richardson number which could indicate degree of turbulence.

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58. MITRE CORP.

While Mitre Corp. has no project on CAT detection, their engineers believe the work they are doing with refractometers is applicable to CAT detection. They have been working with a refractometer which will measure the refractive index for purposes of missile control. Measuring the difference in travel times of two frequencies through the tropopause determines the total refractivity over the two paths.

These experiments have been made by shooting two frequencies between mountain ranges across Lake Winnepesaukee, New Hampshire; a 1-cm slowing in their paths from turbulence has been measured. The power spectrum of the turbulence gives indication of CAT intensity. They ultimately intend to put the apparatus into a fast-moving airplane. Frequencies of 15, 30, 45 and 90 kc. are used. On windy days when the lower air is turbulent, the rapidity of fluctuation increases and the amplitude of fluctuation is proportional to the wind speed which gives indication of turbulence intensity.

There are difficulties in height-finding in missile tracking caused by refractive bending. MITRE instrumented an airplane to measure the refractive index and has written a report on backscatter from refractive index. Dr. David Atlas has worked on this with MITRE at Wallops Island. MITRE has a dual cavity refractometer mounted on the wing of an airplane, the two units separated vertically by 1 meter. Tests are being conducted to measure the refractive index difference in the vertical plane.

Other organizations and scientists who have done work with refractometers are:

Bureau of Standards
M.I.T.
Dr. Moody C. Johnson at Boulder, Colo. has worked with dual cavity refractometers.

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59. Sperry Gyroscope Company

Sperry's CAT activities include research and development work with passive microwave radiometers and with laser radiation in the infrared and visible portions of the spectrum.

Its microwave radiometry work is conducted at Clearwater, Fla., and at Sudbury, Mass., not primarily for CAT purposes but with possible applications. Sperry is studying atmospherics with radiometers in three frequency ranges: 18 to 26 GC (water vapor absorption band); 35 GC (window region for control purposes); and 55 to 65 GC (O_2 absorption band).

Sperry considers 60 GC a promising frequency for the detection of CAT from aircraft. The signal-to-noise ratio will be higher at 60 GC than at infrared or optical frequencies because signals in this O_2 absorption band will not be obscured by noise from other sources such as radiations from water vapor or clouds. In general, very little atmospheric work has been done in this 60-GC band because most such work has been done by communications researchers who steer clear of the noise from O_2 absorption bands because this limits the range in communications work. Sperry's observations in this band to date have been made with ground-based equipment, taking atmospheric temperature profiles vertically and horizontally.

One method for CAT detection which Sperry is considering, is to use a radiometer to look ahead of the aircraft to measure total integrated radiation received. Ninety-nine percent of this radiation would come from ranges of 1.25 km to 20 km, depending upon the frequency used.

For research purposes, Sperry now uses radiometer integration times from 10 to 240 seconds; but this could be cut down to less than one second to permit scanning in azimuth ahead of the aircraft.

The ability of microwave radiometry to see through fog is demonstrated by Sperry's ability to see icebergs from aircraft through fog at 15 GC.

With ground-based equipment at Clearwater, Sperry has seen rising currents of air that form clouds, at 35 GC.

In order to determine range of CAT from an aircraft, Sperry proposes scanning in frequency, using several discrete frequencies.

Sperry's present microwave radiometers are all ground-based, with no attempt made to minimize size and weight. Even so, the present equipment is approximately 12"x16"x18", including the antenna. This size could be reduced considerably for airborne use. The microwave radiometer could share the present radome on an aircraft, thus minimizing the modification required on the aircraft structure if this CAT detector were installed. It is also possible that the radiometer could share the present X-band dish.

In addition to the aforesaid microwave work, Sperry is also conducting atmospheric studies with ground-based lasers, both pulsed and CW, looking up into the atmosphere. Sperry also has experimented with Doppler laser in the laboratory.

Their equipment has detected particles 1 micron and smaller in clear atmosphere at Sudbury, Mass. Laser developments in progress at Sperry may enable them to go down to 5,000 Angstroms, giving more sensitive detectors which can detect even smaller particles.

Sperry used pulsed ruby lasers in their atmospheric experiments, varying the receiving angle (e.g. 1 milliradian), the output power, and the separation between transmitter and receiver up to 6 feet.

In the laboratory at Great Neck, Sperry is studying CW-laser scattering by particles in liquid suspension, to simulate scattering by atmospheric particles. Scattering is being measured as a function of angle up to 360 degrees, giving scattering cross-sections.

Sperry's atmospheric visibility studies are funded in part by FAA.

Laser anemometers, with a sensitivity of the order of 1 foot/second, using CW gas lasers, are being studied by Sperry. The anemometers require powers of the order of 10 watts, and range in size from 5 inches to 2 feet.

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60. Convair Division of General Dynamics

Convair has conducted a high-altitude CAT project and completed an AF report on an F-106 in turbulence between 8,000' and 35,000 ft.

Wright Patterson conducted tests on the F-102 to determine the types of turbulence the F-106 would encounter on its missions.

General Dynamics Report
GEC-62-64
25 June 1962

Convair has made proposals AF ASP PR 20618-KNA to Wright Patterson for a low-altitude turbulence project on the F-106. A proposal WA3R-5-670 (proprietary) also has been made to FAA to completely instrument a jet transport to study airplane response, and pilot reaction and response in severe turbulence.

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61. North American Aviation, Autonetics Div.

This division has an in-house proprietary project on CAT detection.

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62. Meteorology Research, Inc.

A second conference was held at M.R.I.'s Altadena offices. Paul MacCready stated that the FAA is to receive a joint proposal for a turbulence meter, the proposal to be sponsored by four organizations:

Meteorology Research, Inc.
Desert Research Institute of University of Nevada
Sierra Research of Buffalo, N. Y.
Computer Development Corp.

This unit will weigh about 3 lbs. and cost about $2,500. MRI have been conducting cloud-seeding tests with the X-21.

MRI conducted flight tests and wrote reports to Northrop Norair about X-21A tests. These were:

An investigation of Atmospheric Factors that May Effect Laminar Flow Control.

Report PO #615-4425392
by Thomas R. Mee

and

Atmospheric Factors During LFC Flights
1 Dec. 1964 to 30 April 1965
Report PO #506-556-692L
by Thomas R. Mee
Edwin K. Kanper

The X-21A is instrumented for collecting data on particulate matter, size, shape and concentration in the atmosphere.

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63. Collins Radio Company

Using electromagnetic radiation in the 5-6 mm O_2 absorption lines, Collins Radio Company is studying meso-scale meteorology. They are now flying a 6-mm radiometer at high altitudes, for vertical sensing of the atmosphere; and they are trying to develop an horizon sensor.

Their antenna is 6" diameter, giving a 3-degree beam (3 deg. to half power). They could share an 18" diameter antenna in an airborne radome to give a .7-degree beam.

Azimuth scanning would seem to be ruled out since Collins detection equipment gives a reading only every 10 to 15 seconds because of fluctuations in the received signals which must be integrated.

The beam could be broadened in azimuth, but this would decrease the sensitivity to turbulence in small areas.

This radiometer method would not be affected by water vapor in the atmosphere, but would be affected by clouds if they were very dense, e.g. the top of cumulus nimbus. In other words this method would be affected by the same conditions that affect weather radar. The system would be good at altitudes above 5,000 ft.

As a research tool, this system could measure vertical lapse rates, looking down vertically from the aircraft into turbulence.

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64. The General Electric Company, Missile and Space Division.

This division of G.E. has no CAT detection projects. They have been doing experimental work with lasers in atmospheric transmissivity by measuring laser backscatter, using pulsed ruby lasers. This work is described in a paper - "Determination of Atmospheric Transmissivity from Laser Backscatter Measurements," by H. W. Halsey - presented before the Conference on Atmospheric Limitations to Optical Propogation, at Boulder, Colorado on March 17, 1965.

The Missile and Space Division has been exploring the use of pulsed ruby lasers for missile tracking and as atmospheric probes. Laser backscatter from clear air, clouds, and miscellaneous atmospheric matter has been analyzed. This work is reported in the proprietary report:

Technical Information series
No. 64SD276
THE USE OF A LASER AS AN
ATMOSPHERIC PROBE
by H. W. Halsey and G. L. Snyder

65. Cornell Aeronautical Laboratory (CAL)

CAL has an AFCRL contract to build a mathematical model of atmospheric turbulence, using all applicable data from former flight testing and new flight testing. Data from Lockheed's HiCat, Low Cat and Cornell's variable stability aircraft flight tests will be used.

In past years CAL has studied turbulence below 5,000 ft., measuring the quantities for computing power spectral densities. About 1954, CAL and NASA devised a direct method for measuring turbulence by measuring angle of attack, side-slip, and airspeed and accelerations about the three major axes. This gives air-motions relative to the aircraft. Combining these with aircraft-motions relative to the ground, gives motions of the air with respect to the ground. Much of the advanced instrumentation is located in the probe or boom.

CAL has measured the effect of turbulence on aircraft in both CAT and convective or weather turbulence, but has more data on convective turbulence than on CAT. There is good statistical correlation of data with turbulence up to an altitude of about 1,500 ft. At higher altitudes there is no good correlation between cause and effect.

CAL has a contract with the Structures Division, Air Force Flight Dynamics Laboratory, Wright Field, to study turbulence for purposes of aircraft structural design.

Edgewood Arsenal has funded a classified project for the exploration of atmospheric parameters by lasers. CAL hope to be able to use data collected on this project for correlation with CAT.

CAL has found considerable difference between monochromatic and polychromatic or white light in their studies on distribution of particulate matter in the atmosphere, and has built a white-light radar for these studies. In some respects the white light gives superior results. In connection other work, CAL has detected backscatter radiation from clear water vapor at a range of 3/4 mile, using a pulsed ruby laser at about 1 megawatt. CAL is building a resonant cavity interferometer to measure particle size in aerosols.

CAL believes there is a need for a much better mathematical model of turbulence than is presently available. The turbulence models, such as those used by Reiter, have shortcomings and have not been demonstrated to be correct in the opinion of many. CAL has endeavored to improve the mathematical models based upon the meager data available in their reports. More flight observation and recorded data are needed and more study of the mathematical models of turbulence is strongly indicated.

The CAL group expressed several viewpoints regarding CAT detection. Some felt a ground-based doppler radar a possible solution to CAT detection; another opinion was that a detector, based on sensing the refractive index, would be difficult to develop to portray the turbulence on a radarscope; while a third opinion was that the return from the refractive index would be the best principle for a meaningful indication of CAT.

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66. General Electric

G.E.'s Advanced Technology Labs have been working on CAT detection, using the laser doppler shift principle. A proposal for a detector based on this principle was made to AFCRL in July, 1965. It was titled:

"Design Study of Doppler Laser Radar for Clear Air Turbulence Detection"
by J. E. Bigelow
Report No. 65GL116 - July 1965

67. Lear Siegler

Lear Siegler's Laser Systems Center built the ruby pulse laser now being flown in the NASA T-33 at Langley Field, and it supplied SRI with several ground lasers for probing the atmosphere.

The Laser Systems Center also built the laser flown by Professor Franken in his preliminary flight tests to try to correlate particulate matter with ruby pulse laser backscatter.

(Refer to Part II for further information)

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68. IIT Research Institute

IITRI has no projects on CAT detection, but Mr. Freyberger has projects allied with several aspects of CAT detection.

1. For AFCRL: A contract in Detection of Atmospheric Electricity to evaluate schemes and proposals for locating (bearing and range) concentrations of atmospheric electricity. This is in the field of sferics, is entirely analytical and uses the experimental results of others.

2. For AFCRL: Weather Radar for locating weather. All analytical.

3. For AFCRL: Analysis of data obtained by University of Texas to meet III specifications on radiometric measurements of atmospheric temperatures; these measurements made in 62 kilomegacycles (kmc) because O_2 absorbs in this frequency; also in 22 kmc. because H_2O absorbs in this frequency.

4. A project related to Project TRAPCAT, which detects CAT by temperature rate of change and total temperature change, for obtaining range information by comparing intensity of two

frequencies. Frequencies used are 62 kmc, 22 kmc and 10-15 kmc.

5. Investigation of Lightning Discharges.

The static charge buildup in thunderstorms above the freezing level causes static discharges or lightning. The lower frequencies from these discharges carry for thousands of miles through the atmosphere and can be detected at great distances. Most of the energy is in the audio range which does not get through the ionosphere. The positive charge radiates out of the top of the cloud and sometimes can be seen visually. The current may be as strong as 1 amp. The ambient atmospheric field charge may be as high as 100 V/meter. This makes smaller field charges, such as are measured from CAT, hard to detect.

IITRI's future research program is work on the feasibility of CAT detectors using radiometric techniques, thermal gradients and CO_2 concentrations. This will be funded by AFCRL.

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69. Telephone conference: Dr. Reiter and Dr. Rosenberg

The phone conference at New York between Dr. Reiter and Dr. Rosenberg concerned Dr. Reiter's research on CAT which has been the subject of several articles by Dr. Reiter. (Refer to Section IV. No. 36, p. 46)

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70. Southwest Research Institute

While making measurements of sound coming from the atmosphere in the shorter wave lengths and higher frequencies, it was found that large amounts of noise came from cells or areas of turbulence.

Microwaves were projected from the ground into these areas of turbulence and the backscatter was measured. These turbulent cells or areas gave an appreciable backscatter return.

Southwest proposed to White Sands, a device to measure turbulence at lower levels for their missile work, but so far has not received a favorable reply. They are now using 20-40 kc. Phase modulation of receivers gave considerable range of frequency return. With suitable apparatus, it is possible to get angle of arrival of backscatter and range. Southwest has also proposed to the U. S. Weather Bureau, a project to measure turbulence with apparatus in the 20-40 kc band.

Mr. Owen stated that the National Bureau of Standards in Boulder, Colo. has detected tornadoes by using acoustical detectors. They made two directional fixes on tornadoes this past season. Southwest is endeavoring to get funds for tracking by using acoustical apparatus from a ground-based station located at San Antonio.

Southwest also is working on the influence of turbulence on communication carrying laser light beam. Turbulence in the atmosphere causes aberrations in the signal beam which affects the fidelity of the communications. A 1/4" light beam is being used, shooting through 20 feet of air. Artificial turbulence is created with air blasts and hot air currents. The aberrations in signals are compared and correlated with observed signals from atmospheric tests outdoors between the buildings.

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71. Stanford Research Institute

This conference, visited by Paul Rosenberg in December 1965, brought up to date SRI's CAT research work reported during the visit of 5 May 1965.

(a) SRI-United Air Lines-AFCRL Electric Discharge Project

The airborne installations have been modified by installing a time-delay circuit to place a distinctive CAT-event mark on the current-recorder chart to distinguish the CAT event from other events recorded on the flight recorder. This facilitates and speeds up data reduction, and tends slightly to improve the apparent correlation between CAT and electrical discharge from the tail fins.

A total of roughly 28,000 hours of discharge-current records have been obtained from the ten United Air Lines DC-8 aircraft equipped with the SRI instruments. Only 10,000 hours of this could be properly time-correlated with flight recorders. Roughly, 3,100 hours of this were available with the distinctive CAT-event mark modification.

In all, 82 CAT-event marks were recorded. Forty-seven of these marks had to be disregarded for such reasons as malfunction of equipment. The remaining 35 event marks were analyzed with the following results: Twenty-seven were judged to show correlation between CAT and current discharge; while eight were judged to show no correlation.

SRI reported this was a significant, although not conclusive, correlation. However, SRI also states that their project produced no information to answer the question: "What is the false-alarm rate of this method of CAT detection?" In other words, this project has not yet produced data on the number of times clear-air electrical-activity would be detected without the presence of CAT.

In almost all of the 35 cases studied, the polarity of the charge leaving the fin-cap was negative, before, during and after the CAT. SRI show that this does not prove whether the electric discharge is caused by electric fields associated with CAT, or whether the discharge is caused by the tribo-electric effect of fine particles in or near CAT.

It is estimated by SRI that total currents as high as 350 microamperes were discharged from the entire aircraft.

TRAPCAT has not been installed as yet on any of the ten DC-8's equipped with the tail electric-discharge recorders. For the present winter season, United plans to install a TRAPCAT with a Rosemount probe and doppler radar on one DC-8. Doppler radar is on all the overseas DC-8's equipped with electric-discharge recorders, but Doppler data has not yet been tied in with the electric-discharge project.

(b) SRI Lidar

At present, SRI has two ground-based Lidar systems available for CAT and other atmospheric studies.

V. Airborne CAT Detection Devices Undergoing Active Flight Testing

Six CAT detection projects involving five principles of detection were being flight tested during 1965. Correlation of CAT with laser backscatter from particulate matter concentration is the principle of both the Lear Siegler Lidar installed in NASA's T-33 and Professor Franken's optical radar. The instrumentation reliability and suitability for operational use is of interest in most of these tests with the possible exception of the ozone correlation project. Should one of these six principles prove acceptable, most of the instrumentation being test flown will require various degrees of modification to become operationally suitable. Project TRAPCAT and the electrical field principles have large portions of the instrumentation common with the instrumentation and components already in the airplanes. If the TRAPCAT or the electrical discharge principle is found to be effective, revisions to make these systems operational should be minor. The circuitry in the electrical field project being flown is unique to the DC-8 and major revisions will be required to adopt the instrumentation to the Boeing 707 and other transports. A brief description of the six detection principles and instrumentation and the status of each project follows.

1. Project TRAPCAT

The relationship between atmospheric temperature change and CAT (the Kadlec, EAL, Litton Project); funded by FAA.

Ten sets have been built by Litton. Four airlines were to have installed two sets each, i.e. EAL, AAL, Delta and UAL; TWA installed one set, leaving one spare. Originally, it was intended to have the installations made by Jan. 1965 in order to catch the period of peak jet stream and mountain wave activity. However, because of difficulties with aircraft air-data systems which supplied airspeed and temperature information, only EAL, AAL and TWA finally completed the installations, and operated them starting about March and April 1965.

The Project TRAPCAT method consists of watching for a rate of change of temperature of .7°C per minute and a total change of 3.5°C. An amber light warns the pilot when the rate of temperature-change reaches or exceeds .7°C per minute and if the prescribed rate of .7°C per minute continues until 3.5°C total-change occurs in five minutes, a red warning light is activated. When both lights appear, the method predicts that the pilot can expect a CAT penetration in one to three minutes. The temperature rate of change is based on a cruise speed of .85M. Therefore the system is only usable in cruise level flight.

Air Force Cambridge Research Laboratory made a study of this method and issued a report of an analysis made on thirty B-47 flights picked at random to test the validity of the temperature gradient method for warning of CAT penetration. This report is titled, "An Investigation Into the Use of Temperature Gradient as an In-flight Warning of Impending Clear Air Turbulence," Project 6020 TASK 602004, by George I. McLean.

The AFCRL study shows that the TRAPCAT method had a low reliability of prediction of CAT. The study explains the high percentage of failure of the TRAPCAT method in terms of an analysis of temperature profiles and the locations of areas of turbulence in the vicinity of an idealized model of jet streams.

(It should be noted that the temperature-change rate of .7°C per minute of the TRAPCAT method is based on a .83M cruise speed whereas the B-47 cruise speed is more nearly .74M).

The TRAPCAT project was designed to use the units of the Kollsman KIFIS System already installed in the DC-8 and the Boeing 707 transports. The temperature sensor is the flush-skin type which is rugged and durable for airline operation but which has a relatively large temperature lag. Eastern Air Lines is trying a "Rosemount" total air temperature sensor, which is stated to have less temperature lag, on one of the EAL DC-8's to evaluate the effect of probe-temperature characteristics and sensitivity on the indication reliability of this system. An Edison temperature sensor also is installed on the same DC-8. It was found necessary to overhaul the Kollsman KIFIS System before starting these trials as the temperature errors, caused by backlash of component parts, gave errors of a magnitude equal to the 3.5°C criteria of this method.

During the summer of 1965, certain modifications were made to the recorders. The rate of temperature-change was increased from .7°C per minute to 1.0°C and the total temperature-change reduced from 3.5°C to 1°C. Since the data is all that is desired in this project, the warning lights for pilot information were disconnected. An effort will be made to reinstall the recorders in the same aircraft as in Phase 1 and continue recordings through March 1966.

Eastern Air Lines has prepared a report on the first phase of Project TRAPCAT:- "Flight Data Analysis of Relationship Between Atmospheric Temperature Change and Clear Air Turbulence" by Paul W. Kadlec, June 1965, Contract No. Cwb-10888.

2. Correlation Between Clear Air Turbulence and Electric Fields Discharge

This project is funded by AFCRL, contract AF 19(628)-3308, to Stanford Research Institute.

United Air Lines is donating the installation of instrumentation, and flight observations in schedule operation. Ten UAL DC-8 jet transports (four in domestic service, three in Hawaiian service, and three DC-8F cargo aircraft in world-wide service) have been equipped with the instrumentation. The upper part of the fin on the DC-8 is insulated from the rest of the aircraft so that it can be used as an HF antenna. United does not use the fin cap VHF antenna; therefore the unused coaxial cable from fin cap to cockpit is available for instrumentation. Six precipitation static dischargers with sharp tungsten points are located (two) on the fin cap and (four) on the upper part of the rudder trailing edge. The fin cap is connected to the rest of the airframe through a 1.5-megohm static drain resistor. Another 1.5-megohm resistor is located on the line from fin cap to the instrumentation. Thus, only half the current discharged through the static dischargers flows through the coaxial cable to the instrumentation.

Instrumentation records discharge current, speed, acceleration, heading, altitude; an event marker is actuated by the pilot when CAT is encountered. By March 1965 the project had accumulated about 13,000 flight hours. It will continue for a total of about 30,000 hours.

SRI issued an interim report on the first 1,300 hrs. of flight recordings: Report No. AFCRL 65-112, "Correlation Between Clear Air Turbulence and Electric Fields," by J. E. Nanevicz, E. F. Vance, and S. Serebreny - Contract AF 19(628)3308.

During the first phase of this project, the "G" records were taken from the aircraft crash recorder. When analyzing the data on the tapes of the two recorders, great difficulty was experienced in indexing the events on the crash-recorder tapes with those on the SRI static-charge recorder. Another difficulty was built into the SRI recorder. The pilot was provided an event-marker button to push to indicate when turbulence had been encountered. This marker also was used to indicate other events. In the analysis, it was sometimes impossible to determine what event the marker indicated. For the second phase of this project, the "G" trace was recorded on the SRI recorder tape, and the pilot's event-marker will be removed.

In order to sample turbulence conditions over the widest possible area, four of the ten DC-8's have been used exclusively for domestic passenger service; three have been used on the Hawaiian-to-Mainland service; and the three DC-8F freighters have been used world-wide. DC-8 #2927 is equipped with a Rosemount temperature probe having a digital readout indicator which indicates total temperature (static + rain) to tenths of a degree C.

(See Conference Report No. 71, Page 75, for the latest status of this electric-discharge project.

3. Lear Siegler Airborne Lidar installed in NASA T-33 for CAT detection.

The Lear Siegler airborne Lidar is being tested in flight to prove both the principle of CAT detection and the instrument for detection.

The installation in the T-33 is described in Section IV, #50. The transmitter and receiver antennas are essentially coaxial. Detection of backscatter from particulate matter is the principle of detection.

Although this project was started early in 1965, it has met with several misfortunes. The Lidar was dropped in shipment from Ann Arbor, Mich. to Langley Field, and was returned to the factory for extensive repair. With all the other instrumentation in the T-33, the generator capacity would not permit the Lidar to operate at full power. After six flights, several of the components needed replacement, and the Lidar was returned to the factory for repair and modification. It was scheduled for reinstallation in the T-33 in Jan. 1966. None of the six flights were in turbulent air and no findings or conclusions can be made at this date.

4. Pulsed laser (optical radar) with separated and converging Transmitter-Receiver axes.

This system, being tested by Prof. Franken of the University of Michigan, is composed of a Lear Siegler Q-switched ruby laser on the left end of a 4" tube, five feet long, with a receiver at the other end consisting of a Questar telescope coupled to an EMI 9558A photo-multiplier tube via a 10A^{O} band pass-interference filter and a camera shutter automatically opened before the laser is fired. This project is reported in Section IV, #40, of this report.

The system was devised to determine whether radar backscatter from particulate matter could be correlated with CAT. The conclusions are excerpted in Section IV, #40. This apparatus has more flying time and has performed more experiments (1300) in CAT than any other airborne laser at this date.

5. Ozone associated with CAT

AFCRL Meteorological Laboratory instrumented a U-2 with a standard ozone detector to further explore the findings of past research that ozone concentrations are frequently found in the vicinity of CAT, especially where the jet stream penetrates downward from the tropopause. The U-2 is equipped with accelerometers and all instrumentation necessary for correlating Ozone with CAT.

About six flights were made early in 1965 but no good CAT was found. The plane was then diverted to other research for a few months. More flights were made in the Spring and Fall of 1965. Over 100 hours of flight research have been made on this project. The Meteorology Laboratory is in the process of compiling a report on the findings of the project to date. Some correlations of ozone and CAT have been found.

The U-2 is to be equipped with a more sensitive Ozone detector for further research in the vicinity of jet streams in Jan. and Feb. 1966.

6. The Boeing VHF radar installed in the Boeing 727 E-2 test plane is now being flight tested. No conclusions have been published. See Section IV, No. 30, page 38 for description of this device.

VI. CAT INCIDENTS

Reports of turbulence penetrations of moderate-or-greater degrees for the years 1960 through 1965 have been screened. All incidents occurring when the pilot was on instruments were eliminated. Incidents in convective or storm areas when the pilot was definitely in the clear, flying around cumulus clouds, dodging thunderstorms, or over, under or between cloud layers have been listed with the strictly clear air incidents. A CAT detector could help pilots in all these situations. Notations of the conditions are given. The only incidents listed were those in which structural damage, loss of control, large loss of altitude, or severe personal injury were factors. Incidents have been eliminated where any weather or severity criteria was in doubt. All the incidents listed in Table I involved turbine-powered high-speed, swept-wing commercial aircraft.

This detailed screening resulted in a relatively small number of incidents of drastic nature, which could give the impression that CAT is not a serious problem. To obtain a better understanding of the CAT problem to aviation in general, the U. S. Weather Bureau's tabulation of CAT reports, received from traffic control reporting stations throughout the U. S. for the year 1964, has been screened. The Weather Bureau tabulation includes pilot's reports of all degrees of turbulence encountered by all types of commercial and military aircraft. There are a total of 8,507 pilot reports of CAT for the year 1964. Of these, 671 were reports of moderate-or-greater turbulence encountered by turbine-powered aircraft, both commercial and military; i.e. DC-8, B-707, B-720, CV-880, L-188, C-135, B-47, B-57, B-52, B-58.

Further classification of these 671 CAT incidents - into Commercial and Military and degree of CAT encountered - reveals the following:

TYPE A/C			Deg. Turbulence		
Com'l.	Mil.	Unknown	Mod.	Sev.	Extreme
259	344	68	497	163	11
38.6%	51.3%	10.1%	74.1%	29.3%	1.65%

Interpreting these figures another way, approximately once every hour throughout the year there was a CAT report from an aircraft somewhere over the U. S.; a commercial jet transport encountered moderate-or-greater CAT once every 34 hours; and a military jet encountered moderate-or-greater CAT once every 25.5 hours.

T A B L E I

DATE	CARRIER	PLACE	A/C	TYPE WEATHER	DEGREE TURB.	G's	ACCIDENT CLASS	WARNING	ALT.	COMMENTS
5/24/60	UAL	Denver, Colo.	DC-8	Convective Pilot VFR	Mod-Sevr	-	Pass. + Stew. injury	None	29,000 cruise	Cruising between tops cu clouds sharp jolts - 10 sec. 288 k
5/12/60	DELTA	Miami, Fla.	DC-8	CAT	Sevr	-2.99 to +2.5	Pass. injury, cabin damage	None	10,700 descending	Seat belts not on one belt failure
12/4/60	UAL	Wolbach, Neb.	B-720	Convective Pilot VFR	Mod.	-	Pass. injury	Yes	23,000 descending	Descending in clear between cumulus
8/21/61	NW.	Mason City, Iowa	B-720B	Convective Pilot VFR	Sevr	-	Pass. + Stew. injury	Yes	39,000	Flying in clear parallel to leading edge of squall line 25 miles away
6/14/62	PAA	Marco, Fla.	DC-8	Convective Pilot VFR	Mod.	-	Pass. injury	No	27,000	Descending in clear between cumulus

TABLE I

DATE	CARRIER	PLACE	A/C	TYPE WEATHER	DEGREE TURB.	G's	ACCIDENT CLASS	WARNING	ALT.	COMMENTS
9/23/62	UAL	Albany, N.Y.	B-720	CAT	Mod.	+.75 to +1.5	Pass. + Stew. injury	Yes by ATC	25,000	Seat belt sign on but not in time for belts be fastened when turb. hit
11/9/62	PAA	Kingston, Jamaica	B-707	Convective Pilot VFR	One Severe bump	-	Stew. injury	Only by cloud form-ations	20,000	Descend-ing between cumulus. Belt sign not on. Stew. not seated.
2/12/63	NW	Miami, Fla.	B-720B	Convective Pilot VFR	Sevr to Extrm	+3 -4.7 at 480+k	Fatal	Yes	17,000 climb-ing	Vectored around storms on SW depart-ure. Recorder shows severe updraft; then pitched over into dive. A/C dis-integrated in dive at -4.7 g.

TABLE I

DATE	CARRIER	PLACE	A/C	TYPE WEATHER	DEGREE TURB.	G's	ACCIDENT CLASS	WARNING	ALT.	COMMENTS
4/30/63	NW	Albany, Ga.	B-720	CAT	Mod. to Sevr	0 to +2.2 for 1 min.	-	-	-	Rough
5/27/63	UAL	Anniston, Ala.	Cara-velle	Convect-ive Pilot VFR	Sevr	-	Pass. injury	-	14,000	Saw alto cumulus cloud ahead and turned to avoid it. Turb. en-countered while turn-ing for 5 sec.
6/23/63	EAL	Norfolk, Va.	DC-8	CAT	Sevr for 15-20 sec.	+.3 to -1.2	Pass. injury	None	27,000	Seat belt sign not on and belts not fastened.
7/8/63	PAA	Wilmington, N.C.	B-707-121	Convect-ive Pilot VFR	Sevr	-	Pass. injury	Yes	33,000	Pilot entered haze line 40 miles south of storm. Shear line ahead of the front.

TABLE I

DATE	CARRIER	PLACE	A/C	TYPE WEATHER	DEGREE TURB.	G's	ACCIDENT CLASS	WARNING	ALT.	COMMENTS
7/28/63	UAL	Des Moines Iowa	DC-8	Convective Pilot VFR	Sevr	-	Pass. injury	Yes	35,000	Passing between two cumulus top 37,000 ft. Belt sign on. Pass. returning to seat.
8/20/63	EAL	Dulles Airport, Va.	DC-8	Convective incipient tornado Pilot VFR	Sevr	-1.05 to +4.5	Child injury; skin wrinkles	Only by clouds	4,000	Under overcast. In clear between storms. Rolled beyond vertical. Child slipped out of mother's arms.
11/9/63	EAL	Houston, Texas	DC-8	Convective Pilot VFR	Sevr	-0.9 to +2.9	Pass. injury and a/c damage, lost engine	Not from ground but in storm area.	18,000 climbing	Between cloud layers and looking at blue sky to West. Seat belts not fastened.
12/4/63	EAL	Lakeland, Fla.	DC-8	CAT	Mod.	-	Pass. injury	None	33,000	Cruising in clear air.

TABLE I

DATE	CARRIER	PLACE	A/C	TYPE WEATHER	DEGREE TURB.	G's	ACCIDENT CLASS	WARNING	ALT.	COMMENTS
1/10/64	AAL	38 n. mi. west of Denver	B-707	CAT Mountain Wave	Chop then one sevr bump	-	Pass. injury	No	28,000	Turbo com-pressors became inop-erative. Lost 1,000 ft.
1/10/64	USAF	Sangre de Cristo, Colo.	B-52	CAT Mountain Wave	Extrm	Vert. gust est. 120' sec	Struct-ural damage	No	14,200	Looking for turbu-lent air at low alt. Gust took most of vertical fin and all of rudder off.
1/18/64	UAL	La Veta Alamosa, Colo.	B-720	CAT Mountain Wave	Sevr	-	Pass. & Stew. injuries 4	Yes by ATC	31,000	Cruising westbound at 38,000; requested lower alt. when warned. Given 31,000
1/18/64	AAL	La Veta Alamosa, Colo.	B-707-123	CAT Mountain Wave	Mod.	-	None	Yes by ATC	37,000	Cruising eastbound at 37,000; elected to stay at that alt.

T A B L E I

DATE	CARRIER	PLACE	A/C	TYPE WEATHER	DEGREE TURB.	G's	ACCIDENT CLASS	WARNING	ALT.	COMMENTS
1/18/64	AAL	La Veta Alamosa, Colo.	B-707-123	CAT Mountain Wave	Sevr two periods 45 sec each over 3 min.	+3.26 to -0.35	Pass. injury and #4 eng. pylon cracked	Yes by ATC	27,000	Cruising at 37,000; requested lower alt. when warned. Given 27,000 two ladies had neck injuries.
1/18/64	23 other airplanes	same	all types	CAT Mountain Wave	Mod. to sevr	-	Some minor	Yes	7,000 to 39,000	All from the same Mountain Wave over a 5 hour period.
3/17/64	NW	Elk Mt., Mont.	Jet 720B	CAT Mountain Wave	Sevr	+1.9 to -0.1	Pass. + Stew. injured	No	37,000	Elk Mt. south of Big Belt Mts.
4/5/64	12 reports by carriers and private	over Salt Lake, Utah	One B-57	CAT Mountain Wave	Mod. to Sevr	-	Uncon-trollable	Yes	35,000 to 7,500	Mountain Wave rotor formed over Salt Lake City
10/8/64	Royal Air MAROC	Over Gulf of Lions, France	Cara-velle	CAT	Sevr	+3.7 to -0.6	Pass. + Stew. injury	No	28,000	Approach-ing Marseilles, France, A/C gained 1,100 ft. in 8 sec. A/S varied from 280 k to 298 k.

TABLE I

DATE	CARRIER	PLACE	A/C	TYPE WEATHER	DEGREE TURB.	G's	ACCIDENT CLASS	WARNING	ALT.	COMMENTS
10/13/64	Panair do Brazil	Between Rio and San Paulo	Cara-velle	CAT	Sevr	-	Pass. injury and structure damage	No	-	Cruise level on flight from Rio to San Paulo
10/15/64	AAL	40 mi. east of Cleveland, Ohio	B-720B	CAT	Sevr	+2 to -0.4	Pass. + Stew. injured	No	29,000	Climbed to 33,000 out of Detroit. Encountered chop and descended to 29,000. Later de-scended to 21,000 remainder flight.
1/23/65	NW	South of Chicago	B-720	CAT on low press. side of jet stream	Sevr	-	11 pass. injured	No	24,000	Horizontal and vert-ical shear except-ionally great.
1/24/65	UAL	East Texas, Penn.	Caravelle	CAT on low press. side of jet stream	Sevr	-	Stew. broken ankle	No	19,000	Horizontal and vert-ical shear except-ionally great.

T A B L E I

DATE	CARRIER	PLACE	A/C	TYPE WEATHER	DEGREE TURB.	G's	ACCIDENT CLASS	WARNING	ALT.	COMMENTS
1/27/65	Conti-nental	Pueblo, Colo.	B-720B	CAT Mountain Wave	Sevr	-	No in-juries; seat belts on	Yes	23,000	A/P had just been turned on before jolt en-countered. Shaking of plane made instru-ments difficult to see.

VII. METEOROLOGICAL DEVELOPMENTS RELATIVE TO CAT

Prepared by

Henry T. Harrison

1. Recent Progress In Forecasting High-Level Clear Air Turbulence

2. The Mountain Wave

   The Clear Air Turbulence Situation at LaVeta, Colo., Jan. 18, 1964

   The Clear Air Turbulence Situation West of Denver, Colo., Jan. 10, 1964

   The Clear Air Turbulence Situation at LaVeta, Colo., Jan. 10, 1964

   The Clear Air Turbulence Situation Near Elk Mountain, north of Ringling, Montana on JR 90, Mar. 17, 1964

   The Clear Air Turbulence Situation at Salt Lake City, Utah, April 3, 1964

   The Clear Air Turbulence Situation near Crazy Woman, Wyoming, Sept. 25, 1964

   The Clear Air Turbulence Situation over the Rocky Mountains, Jan. 27, 1965

3. Analysis of a Classical Type I CAT Incident

1. RECENT PROGRESS IN FORECASTING HIGH LEVEL CLEAR AIR TURBULENCE

History

High-level clear air turbulence forecasting has been practiced routinely in this country only since 1959 when the first turbo-jet aircraft went into service. Mountain wave forecasting was routine with one airline two years before that. It, therefore, may be premature to expect any large degree of perfection in the techniques with which meteorological knowledge is being applied to the problem today.

It is true that both basic researcher and practitioner have put out exceptional effort in this area. Recent literature contains many studies performed by the Air Force, by the Weather Bureau and by the airlines. It is not unlikely that we have attempted to assimilate too much in too short a time, that possibly what we need now is to take time out to expose the scientist and the forecaster to one another and to encourage them to find a more common meeting ground.

Dr. Robert D. Fletcher, Director of Aerospace Sciences for the Air Weather Service, feels that the vast amount of effort that has been expended in this area in the past five years or so has yielded only marginal returns. His analysis is that we have hit a plateau of forecasting capability from which we are unlikely to climb much higher until more basic research is accomplished. One approach would be to assign two-man scientist-forecaster teams to work together for a year or two at a time with each one trying to help the other stay in realistic, productive channels.

The Picture Today at the End of 1965

In the area of forecasting the general wind shear type of CAT, two airlines, Eastern and United, have reported on new methods which they are now applying regularly in their meteorology departments. Eastern is placing great emphasis on the existence of an isotherm trough at the 250 millibar surface, United on the tendency for the thermal gradient to tighten at the 700 or the 500 millibar surface. Both companies are satisfied that they can now do a better job of pinpointing the occurrence and location of moderate or severe turbulence, that the size of the forecast boxes has been reduced considerably. Tests by Eastern suggest that the two methods may be closely related.

In the field of mountain wave forecasting, the Air Weather Service is in the forefront with a system which makes routine forecasts covering the occurrence and specific intensity of 25 mountain waves over the forty-eight states plus Alaska and southwest Canada. The AWS modestly reports that they have done nothing more than adapt the ideas of others but the fact is that their approach to the problem shows a great deal of ingenuity and imagination. In view of the controversy today over whether or not there is a significant operating problem for the turbojet in the mountain wave, it would be of universal interest if the Air Weather Service would publish findings on how well this service is being received by their pilots and operations people.

The summaries on the following pages cover some of the more prominent studies of the past year on the broad subject of high level clear air turbulence.

U. S. WEATHER BUREAU

"On the Analysis of Clear Air Turbulence by Use of Rawinsonde Data"

R. M. Endlich and R. L. Mancuso. Monthly Weather Review. Vol. 93. January 1965. U.S. Weather Bureau Contract No. Cwb-10624.

Substantial agreement was found between reports of turbulence and computed quantities of vertical shear, lapse rate, Richardson's number and a turbulence index (the product of wind speed and change of wind direction with height). All quantities were determined objectively from rawinsonde data over the United States by electronic computer.

One exception was recommended by the authors. The high pressure side of jet streams should be ignored even when the Ri and the turbulence index call for turbulence.

A strong recommendation was made that turbulence sensors should be flown with each radiosonde ascent.

"The Significance of Mountain Lee Waves as Seen from Satellite Pictures"

Sigmund Fritz. Journal of Applied Meteorology. Vol. 4. February 1965. U. S. Weather Bureau research.

Satellite cloud photographs showed remarkable mountain wave cloud formations on a synoptic scale over the appalachians, the Cascades, the Andes and the Sierra Nevada. On May 2, 1963 a complex mountain wave system was shown by parallel bands of wave clouds extending from the Cascades and Sierras eastward to Utah and southwestern Idaho.

U. S. WEATHER BUREAU

"Objective Analysis and Forecasting of Clear-Air Turbulence"

R. M. Endlich and R. L. Mancuso. Stanford Research Institute Final Report under Cwb-10871. SRI project 5031. June 1965.

Endlich and Mancuso tested numerous meteorological parameters for the special turbulence reporting period February 4 to 9, 1963 but reached the discouraging conclusion that persistence is nearly as reliable as the use of any variable. Their recommendation was that the most promising approach to the forecasting problem at the moment is through a combined use of actual turbulence reports and meteorological data.

Of the meteorological parameters tested, vertical wind shear vector was found to be as good a single criterion as any. The Richardson Number and wind direction shear were nearly as effective. They concluded that much more work is needed to improve forecasts of upper tropospheric winds and of meteorological indicators of turbulence.

"The Distribution of Clear Air Turbulence Reports and Cloud Patterns As Seen in Satellite Photographs"

Eldon J. Wiegman. Stanford Research Institute. Final Report under Cwb-10791. SRI Project 4842. January 1965.

Wiegman found that satellite cloud pictures are of some assistance in locating areas of clear air turbulence risk but only when certain cloud patterns are visible. Jet streams and mountain waves can often be identified but many CAT situations had no associated cloud formations.

"Flight Data Analysis of the Relationship Between Atmospheric Temperature Change and Clear Air Turbulence"

Paul W. Kadlec. Eastern Air Lines Meteorology Department. Final Report under Contract No. Cwb-10888. June 1965.

This report was summarized under Eastern Air Lines.

In addition to the contract research performed for the Weather Bureau by Stanford Research Institute and by Eastern Air Lines, the clear air turbulence research unit under DeVer Colson has conducted continuous studies by the staff and has performed a most useful service for the profession by editing, compiling and publishing monthly printouts of CAT PIREPS over the whole country. These latter have provided the basic data for a large number of studies in forecasting clear air turbulence.

In response to a direct inquiry, Mr. Colson advised that there are no formal or organized procedures in the Weather Bureau for forecasting mountain waves nor are there any plans for collecting statistics for a climatology on waves.

"Correlation Between Clear-Air Turbulence and Electric Fields"

J. E. Nanevicz, E. R. Vance, S. Serebreny. Stanford Research Institute. Contract AF 19(628)-3308. SRI Project 4690. February 1965.

This is another project which was designed to test the reliability of an airborne sensor to detect clear air turbulence but it has synoptic implications because it is also testing the relationship between CAT and still another meteorological parameter, the atmospheric electric field.

The preliminary finding is that there is a significant correlation between clear air turbulence encounters and periods of electrical discharge as measured by precipitation static dischargers installed on the fins of DC-8 aircraft. The suggestion is made that these discharges may be caused by electric fields in the region of clear air turbulence or by particulate matter in the region that charges the aircraft, or by a combination of both.

(Many have felt that meteorological observations will never be complete until the existing electric field is built into them. A new element for the RAWINSONDE, inflight pilot observations or some method of sensing the field from ground instruments are all possibilities.)

"Empirical Relationships Between Gust Intensity in Clear-Air Turbulence and Certain Meteorological Quantities"

R. M. Endlich and G. S. McLean. Journal of Applied Meteorology. Vol. 4. April 1965. Contract AF 19(628)-3304.

Endlich and McLean examined measurements of turbulence, wind and temperature made by B-47 aircraft of Air Force Cambridge Research Laboratories during jet stream explorations and found that -

> A quantity which is the product of wind speed and turning of the wind with height is more closely related to turbulent gust intensity than either vertical wind shear or Richardson's Number.

"Jet Stream Structure over the Central United States Determined from Aircraft Observations"

R. M. Endlich and C. S. McLean. Journal of Applied Meteorology. Vol. 4. February 1965. Contract AF 19(628)-3304.

Two conclusions dealing with clear air turbulence were -

1. A pronounced minimum of turbulence is found at the maximum wind level immediately south of the jet core.

2. Secondary centers of turbulence, found about 3° south of the jet core, are due in part to turbulence in cirrus clouds.

The Air Weather Service has long been in the forefront in the pursuit of knowledge about clear air turbulence. It is believed to be the only agency to establish an independent unit charged with complete responsibility for the issuance of CAT forecasts and directed to develop new and better forecast techniques. Set up initially in Kansas City, this unit quickly became operational by borrowing methods developed first by others, modifying them as experience dictated, and then experimenting with some of their own. Some of their best work has been in the field of mountain wave forecasting.

Starting out with the United Air Lines method developed in 1957, the AWS extended the geographical coverage, refined some of the techniques and added a few new ones. Today, this is the only service on the continent, as far as is known, which issues routine forecasts individually for all major mountain wave zones. Coverage includes Alaska, southwest Canada and the forty-eight states. Here are a few of the AWS developments;

1. Modification of the original UAL forecasting nomogram.

2. Master overlays showing wind vectors required for producing significant waves in 25 mountain complexes.

3. Development of sea level pressure pairs for use in all of the 25 zones.

4. Requirement for a short wave trough at 500 mb. within 300 miles upwind.

Mountain Wave Forecasting

The forecasting techniques described on the preceding page are in routine use at the Global Weather Central at Offutt Air Force Base today. The methods are largely empirical but so completely objective that little human judgment is required except in the prediction of the individual parameters that go into the nomogram. No information was supplied by the Air Weather Service on how effective the wave forecasts have proven to be.

General CAT Forecasting

Dr. Robert D. Fletcher, Director, Aerospace Sciences for AWS, had the following to say on the state of the art in general CAT forecasting:

> "Our current techniques developments (we avoid the use of the term 'research') in forecasting CAT are shown in Inclosure 2. Needless to say, this is an area in which we have expended considerable effort over the past several years with rather marginal returns. It appears that we are reaching the current state of the art in forecasting CAT until more basic research is accomplished."

Fletcher listed the following areas in which AWS forecasting studies are being conducted:

1. Evaluation of Dr. Moore's parameter which measures the rate of generation of kinetic energy.
2. Evaluation of Dr. Saucier's CAT potential parameter.
3. Change in kinetic energy along three-dimensional trajectories.
4. Analysis of RAWINSONDE data with increased vertical resolution (10 readings per minute).
5. Comparative study of simultaneous FPS-16 and GMD-1 observations at Eglin AFB.
6. Comparative study of Jimsphere data with conventional RAWINSONDE data in same area to define limitations in computing wind shears which are inherent in the system and which are introduced by coding procedures.

AMERICAN AIRLINES

American Airlines has developed no new CAT forecasting methods and has no plans for any future research.

Colonel A. F. Merewether, Manager of Weather Service for American, reports that they are concentrating on a program of collecting pilot reports of turbulence, negative as well as positive, from their flights all over the country. AAL pilots have been trained to report wind component, temperature and turbulence in addition to flight condition. A sample collection for one hour on November 1, 1965 included 28 complete AAL jet PIREPS made at flight levels 240 to 390 at check points between Memphis and Salt Lake City. These collections go automatically to Continental and Western Air Lines at Los Angeles and to the Weather Bureau at Suitland.

Merewether feels that the PIREPS program has improved the quality of the standard forecasting procedures but concedes that "-it still leaves much to be desired".

DELTA AIR LINES

Mr. C. L. Chandler, Supervisor-Weather Analysis for Delta Air Lines, reported on October 26, 1965 that his group has developed nothing radically new during the past two years but that they are more than ever convinced that the "frontal contour method" gives eminently satisfactory results when used for forecasting clear air turbulence. Chandler summed up their status in this single paragraph;

> "As to our CAT forecasting, we are still improving on our Frontal Contour method and still think that this is the best for our way of flight planning and find it hard to understand why more others don't do the same thing. Go to this method for 30-60 days and you will never leave it that is for sure. We think that 95% of moderate or greater CAT will be found in

1. Upper fronts

2. Tropopause surfaces

3. Trough lines and ridge lines."

Chandler feels that the mountain wave is overrated as a forecasting and flight planning problem, pointing out that no Delta flight has ever reported moderate or severe turbulence under wave conditions. (Note: a relatively slight exposure to major mountain waves could well be a factor in this and semantics could also be involved).

EASTERN AIR LINES

"CAT Evening of March 4, 1965"

J. J. George. EAL Met Bulletin 65-5. March 5, 1965.

George found that a critical zone for the occurrence of clear air turbulence is where a 125k isotach maximum intersects a thermal trough at 250 mb.

EAL meteorologists were directed to draw 250 mb. temperature maps whenever strong isotherm troughs are present and especially when they are crossing or paralleling jet streams. Temperature data is to be entered to tenths of a degree and isotherms drawn for 2° or $2\frac{1}{2}^{\circ}$ intervals. Jet streams are then superposed from the LMW charts and careful continuity established.

"Flight Data Analysis of the Relationship Between Atmospheric Temperature Change and Clear Air Turbulence"

Paul W. Kadlec. EAL Meteorology Department. Final Report Contract No. Cwb-10888 for U. S. Weather Bureau. June 1965.

Although this research was designed to test the reliability of an airborne temperature change sensor in detecting clear air turbulence, it also carried direct forecasting implications.

Data collected by Kadlec on 146 jet flights indicated that a rate of temperature change of at least 1° C per minute with a minimum total change of at least 1.0° C was the most useful value for detecting turbulence ahead. Average values in turbulence incidents were between 2.5° and 3.0° C per 2 minutes. It should be noted that these figures sample the existing thermal gradient and are independent of physical changes taking place.

"Eastern Airlines Revised CAT Forecasting Procedures"

J. J. George. EAL Met Bulletin 64-18. December 29, 1964.

George found that an axis of low temperature (isotherm trough) at 250 or 300 mb is a CAT producer if it occurs in conjunction with one or more of the following:

1. A major jet stream, preferably with an isotach maximum of 125 knots or greater.
2. At its intersection with a 250 or 300 mb trough line.
3. Where it crosses the center 2 isotachs of a vertical wind shear area of 6 k per 1,000 feet or greater or any wind shear area greater than 10 k per 1,000 feet.
4. When the axis of low temperature becomes isolated as an area of low temperature and there is at least some other supporting symptom for turbulence.

Met Bulletin 64-18 was modified slightly by Met Bulletin 65-5 which will be found described separately.

"A Different Synoptic Look at Some Cases of Clear Air Turbulence"

J. J. George. Eastern Air Lines Meteorology Department. April 7, 1965.

George used the 15 Sorenson CAT case clusters (see United Air Lines) and applied the EAL method of analyzing the 250 mb. isotherm trough in each case. The results showed that the EAL procedure would have predicted CAT in all but one instance. In the remaining 14 cases, all occurred near isotherm trough lines.

NORTHWEST AIRLINES

Mountain Wave Investigations

Under the direction of Superintendent of Meteorology D. F. Sowa, Northwest Airlines has concentrated their studies on mountain wave turbulence in the northwestern part of this country and southwestern Canada. Northwest is experimenting with two alternate routings for jet aircraft on wave days in Montana as recommended by Mr. Sowa. These are on Jet Route 90 near Helena and on JR 16 from Whitehall to Billings.

Northwest pilots are cooperating with these studies by taking inflight photographs of mountain wave clouds and by making meso scale (or smaller) observations of turbulence. Sowa has long maintained that minor detours of as little as 10 nautical miles will often avoid significant wave activity.

Northwest is collaborating with United Air Lines in a joint study of jet route exposure to mountain wave activity in the western part of the country. This study has already isolated 165 mountain wave zones west of longitude 100° which look to be capable of producing significant wave activity at jet aircraft cruising levels. This will be completed on December 31, 1965.

TRANS WORLD AIRLINES

Mr. E. J. Minser, Director of Meteorology for Trans World Airlines, submitted the following status report on CAT forecasting procedures in their meteorology department:

> "During the past two years TWA has not initiated any new advances in the study or forecasting of clear air turbulence. The procedures used by our forecasters and pilots have been quite reliable in pinpointing turbulent areas, particularly those producing moderate or heavy turbulence.

One of our real problem areas are those conditions where turbulence occurs at 'all levels' and changes in altitude fail to locate smooth air. These conditions are not only a problem vertically, but frequently extend 500 or more miles horizontally. We are establishing a study of this type of CAT for this winter."

UNITED AIR LINES

"Synoptic Patterns for Clear Air Turbulence"

J. E. Sorenson. UAL Meteorology Circular No. 56. December 1964

Sorenson developed several procedures which modify earlier United Air Lines CAT forecasting methods and are considered to be capable of reducing the size of the geographical blocks in which turbulence is predicted. Four salient changes were made in the routine methods prescribed for use by UAL meteorologists;

1. Forecast CAT in zones where horizontal wind shear is 40 k per 150NM but only when the thermal gradient in the zone is tightening (isotherm packing is taking place). Further restrictions were made that this must occur in a trough and that one or more additional specifications must be met.

2. Forecast CAT in sharp ridges when the LMW speed is at least 40k and when the radius of curvature is smaller than 4^{o} of latitude at 700 mb or at 500 mb and tending to sharpen further.

3. Forecast mountain wave CAT when thermal gradients along mountain ranges are tightening and the other specifications of the UAL forecasting nomogram are met. (*)

4. Limit CAT forecasts to no more than 5,000 feet above the tropopause in mountains and 3,000 feet elsewhere.

(*) Note: this agrees nicely with the Air Weather Service requirement for a short wave trough at 500 mb., developed entirely independently.

UNITED KINGDOM

"Association of Clear Air Turbulence With 300 Millibar Contour Patterns"

A. A. Binding. Meteorological Magazine. Vol. 94, No. 1,110. January 1965.

This study is of interest chiefly from the point of the statistical results of one of the largest samples ever investigated. Binding looked at 100,000 PIREPS over the North Atlantic and found that only 230 reported moderate or heavier turbulence. All turbulence occurred with three basic synoptic types;

Ridge	140
Sharp trough	62
Instability area	28
	230

This would imply that CAT is never found with straight contours or with weak troughs over the North Atlantic. The ratio of ridge to trough is quite surprising. Other investigators have dealt with the ridge type of CAT before but no one has ever suggested that anticyclonic contours would outnumber cyclonic by more than two to one.

2. THE MOUNTAIN WAVE

Aircraft experience four basic types of turbulent air:

1. Convective
2. Wind shear
3. Low level orographic
4. Mountain wave

Synoptic meteorologists will recognize how different the situations are under which those four types occur, yet the unfortunate circumstance is that each is capable of generating turbulence outside of clouds "in the clear". The result is that there is a certain tendency to categorize all turbulence outside of clouds as a unique weather phenomenon. This has been true in the areas of analysis, forecasting and reporting, and sometimes even research.

While strong mountain wave activity is relatively rare at turbojet cruising levels, it happens often enough to warrant attention. The monumental Bishop Wave Project yielded useful knowledge about the mountain wave in this country but left a number of questions unanswered. Among these was the uncertainty about how much of a hazard or an annoyance the wave would prove to be for jet aircraft operating above 25,000 feet. Kuettner's studies at Bishop did suggest that a wave can occasionally break down into a chaotic state of turbulence up to extremely high levels but it was not determined where and when this will happen. Since that time, most of the research in this country has been in the area of empirical forecasting methods developed by the airlines and by the Air Weather Service. These forecasting methods have been helpful but have fallen short of providing a complete answer, mainly because they have been limited to a few well known wave locations like Bishop, Reno, Helena, Denver and Yakima.* In Europe some useful contributions have come from Larsson in Sweden, Berenger and Gerbier in France, Forchtgott in Czechoslovakia and by Corby, Scorer and Wallington in England; yet little is known about the climatology of the wave and how often it will be a factor in jet operations.

(*) Preliminary results of a joint Northwest Airlines-United Air Lines study of mountain wave exposure have isolated 165 locations on 30 jet routes west of longitude 100° where moderate to strong mountain waves are possible.

There is a tendency to discount wave occurrence at turbojet cruising levels. Earlier rules of thumb such as "fly fifty percent higher than the height of the mountain to avoid rough air" may be partly responsible for this. Such rules overlook the role played by the tropopause in generating or intensifying latent turbulent situations. Statistics show a higher incidence of rough air at 35,000 feet than at 25,000 at mid latitudes and individual case histories of airline incidents provide even more convincing evidence that the tropopause zone is a favored one for turbulence.

The report which follows consists of seven case histories of severe to extreme clear air turbulence. All were recent, all affected jet aircraft and all were mountain wave situations.

The Clear Air Turbulence Situation at LaVeta, Colorado

1800GCT

January 18, 1964

The Incident

The airline jet aircraft experienced severe clear air turbulence at LaVeta, Colorado within 18 minutes of one another on January 18, 1964. Seven persons were reported slightly injured on each flight and the Boeing 707 suffered structural damage as the recorder on this downwind flight gave extreme g load readings of +3.33 and -0.35. Both flights were in cruise configuration with seat belt signs reported as being turned on, the B-707 at FL 270 and the B-720 at FL 310.

In addition to the two incidents just mentioned, there were four other pilot reports of severe turbulence, seven of moderate to severe and ten of moderate clear air turbulence within a five-hour period from 1700 to 2200GCT in that general area of the Sangre de Cristo Mountains on that day.

General Weather Type

A strong mountain wave was in progress in the lee of the Sangre de Cristo Mountain Range. Using the UAL mountain wave nomogram, the sea level pressure differential across the mountains between Pueblo and Farmington was 14 millibars and the wind speed was 65 knots at 20,000 feet perpendicular to the mountain ridge. This would place the wave well into the moderate to strong area. This conclusion was further evidenced by mountain wave lenticular and rotor clouds reported at Colorado Springs, Pueblo and Trinidad. The B-720 flight reported that their turbulence occurred just as they passed under an elongated lenticular cloud lying parallel to and in the lee of the mountain range. Marked stability was shown in the upwind air mass by the sounding at Grand Junction where a nearly isothermal layer was reported between 16,000 and 18,000 feet and an inversion of 3°C at 20,000 feet.

Features of Interest

1. This was one of the worst cases of mountain wave turbulence ever reported in this country. There were 23 known cases where pilots reported moderate or worse turbulence from 7,000 feet all the way up to Flight Level 390.

2. The element of surprise should not have been involved. Both airline meteorology departments predicted mountain wave conditions.

3. This case focused attention on the exposure of JR 54 and JR 64 to mountain wave turbulence east of Alamosa. (Today JR 64, JR 102 and JR 110 converge on Alamosa from the east and pass directly over the LaVeta Pass zone in the lee of Mt. Blanca at 14,390 and Culebra Peak at 14,090.)

4. This case also supports the idea that flights should be planned to the north via Cheyenne when active waves threaten over southern Colorado and via Las Vegas, New Mexico as they develop over northern Colorado.

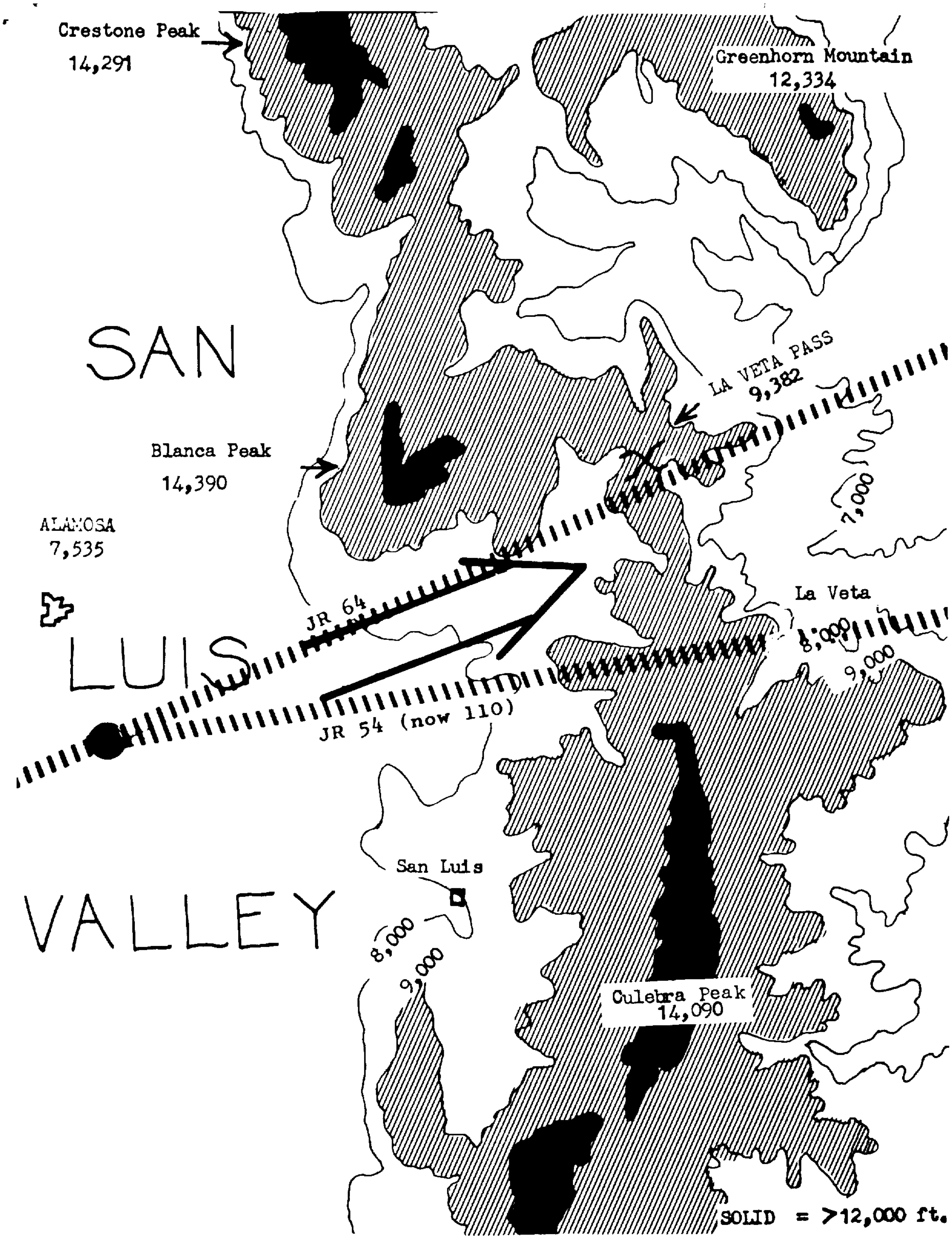


Figure 1. Plan view of the topography crossed by Jet Routes 54 (now JR 110) and 64 over the Sangre de Cristo Mountains in Colorado.

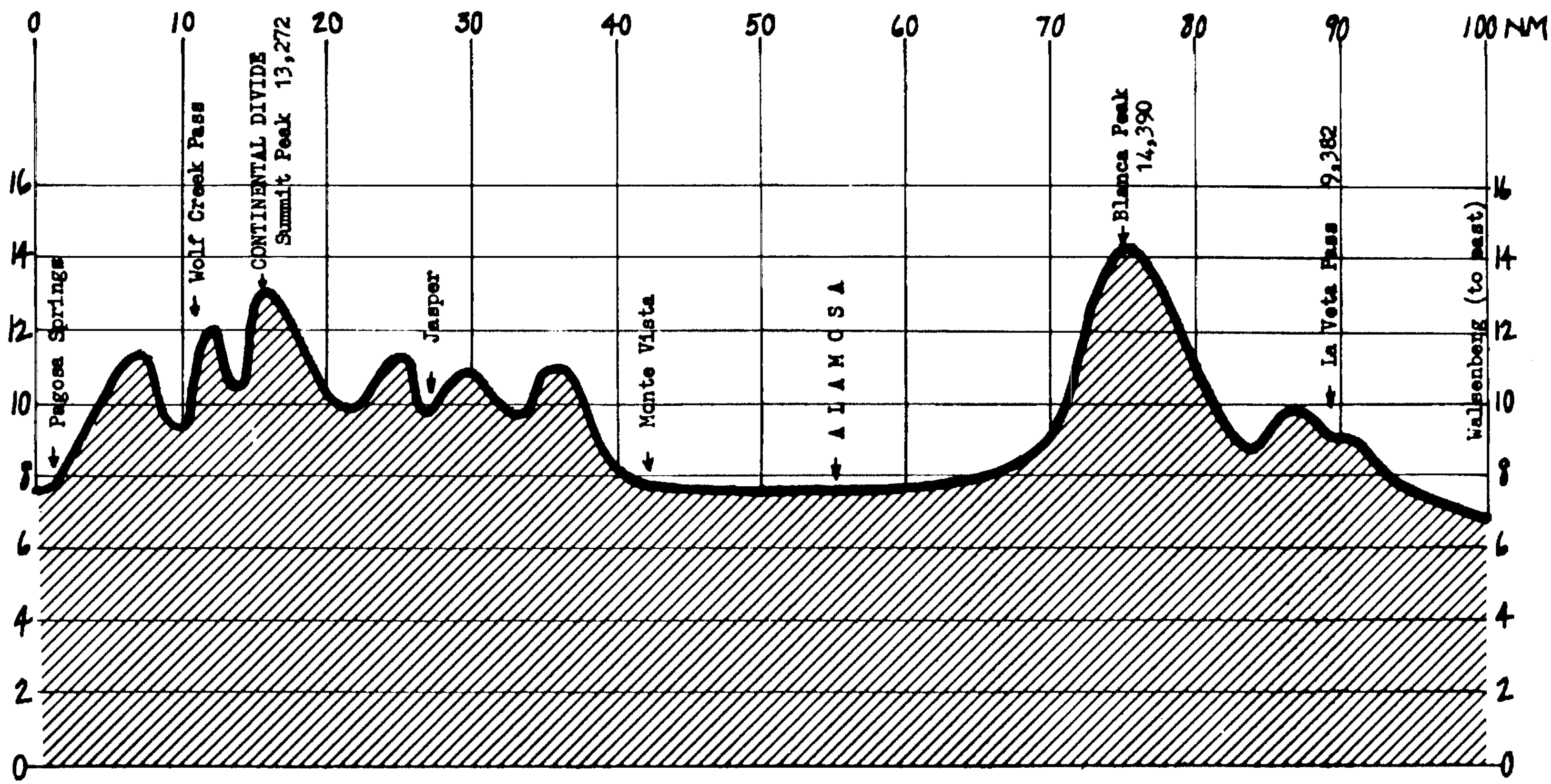


Figure 2. Terrain profile across the continental divide and the Sangre de Cristo Mountains along Jet Routes 54 (now 110) and 64.

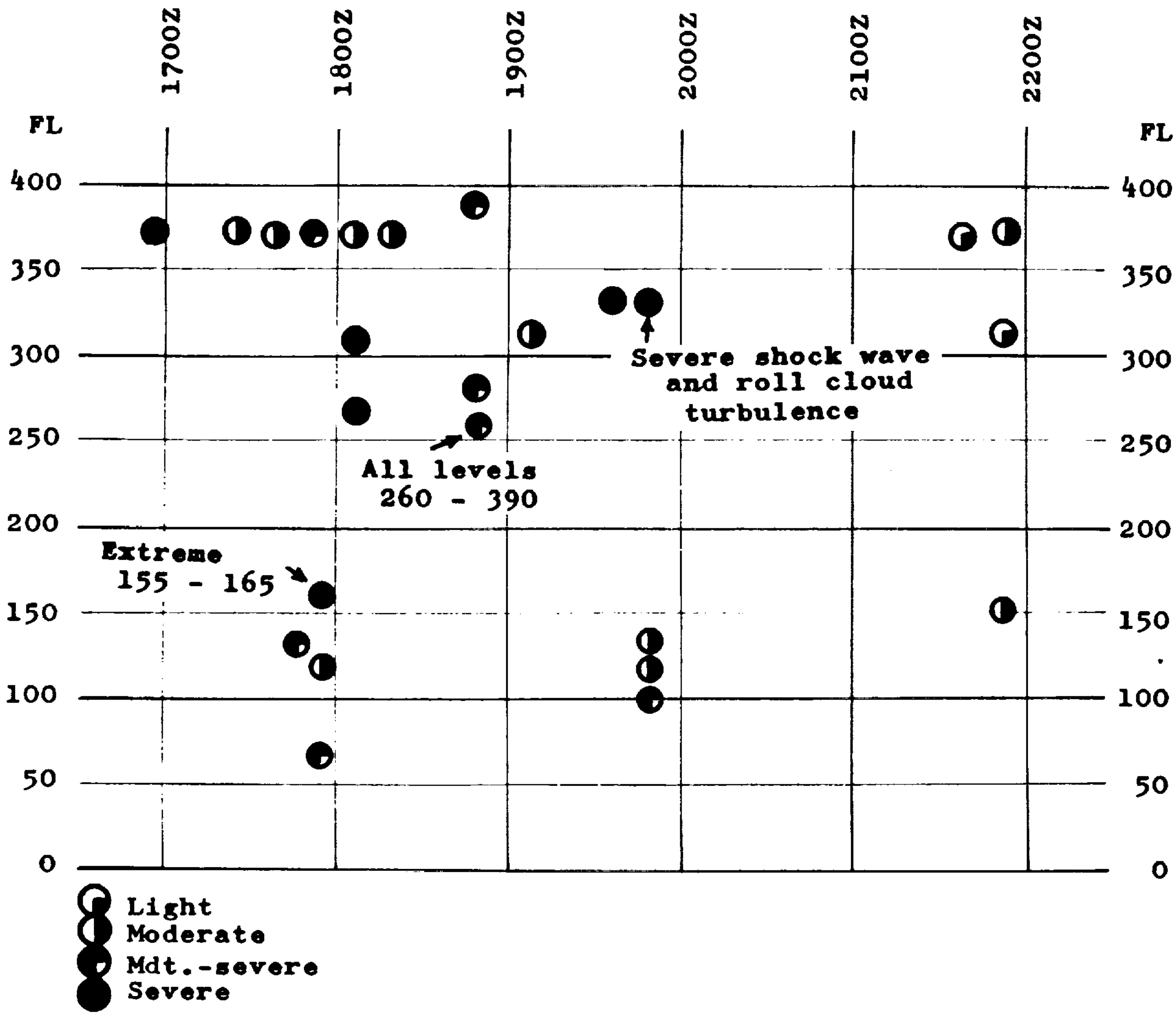
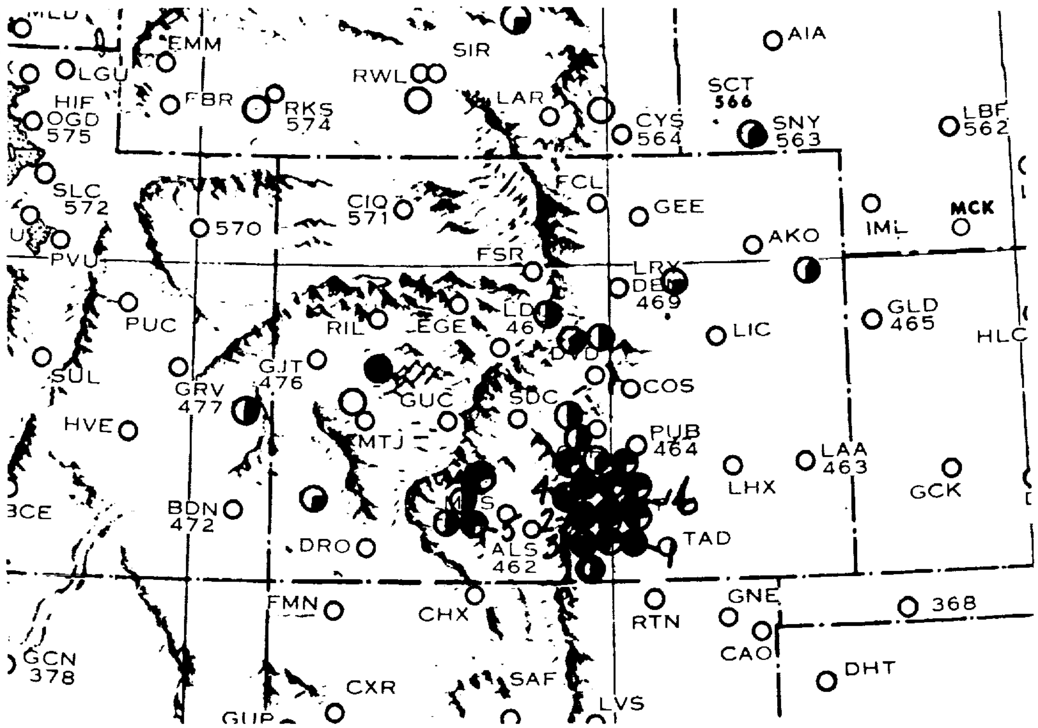


Figure 3. Time cross section of mountain wave turbulence reports west of Walsenberg, Colorado on January 18, 1964.



LEGEND

Smooth

LIGHT

LIGHT TO MODERATE

MODERATE

MODERATE TO SEVERE

SEVERE TO EXTREME

INDIVIDUAL REPORTS

1. "Severe shock wave and roll cloud turbulence · FL 330 32 E of ALS to 42 E of ALS". B-707

2. "Severe turbulence-unable maintain altitude" B-720 at FL 330 30 E of ALS

3. "Extreme turbulence vcnty Spanish Peaks-unable VFR westbound" 155-165

4. "Heavy side gust from left - then felt as though a bulldog had hold of the nose and was shaking it violently-lasted 70 seconds then smooth for 70 seconds then by slightly lesser turbulence for another 70 seconds-control maintained mainly by lateral control and reference to visual horizon". B-707 at FL 270 30 E of ALS. Recorder showed +3.33 to -0.35g

5. "Moderate to severe turbulence at FL 370 41 W of ALS to 38 E of ALS. Temperature varied -64° C to -56° C." DC-8.

6. "Two severe jolts at FL 310 34 NE of ALS at 1806Z Only light chop prior to this so had seat belt sign on." B-720 UAL #773

Figure 4. Pilot reports of turbulence over Colorado and southern Wyoming during a five-hour period on January 18, 1964.

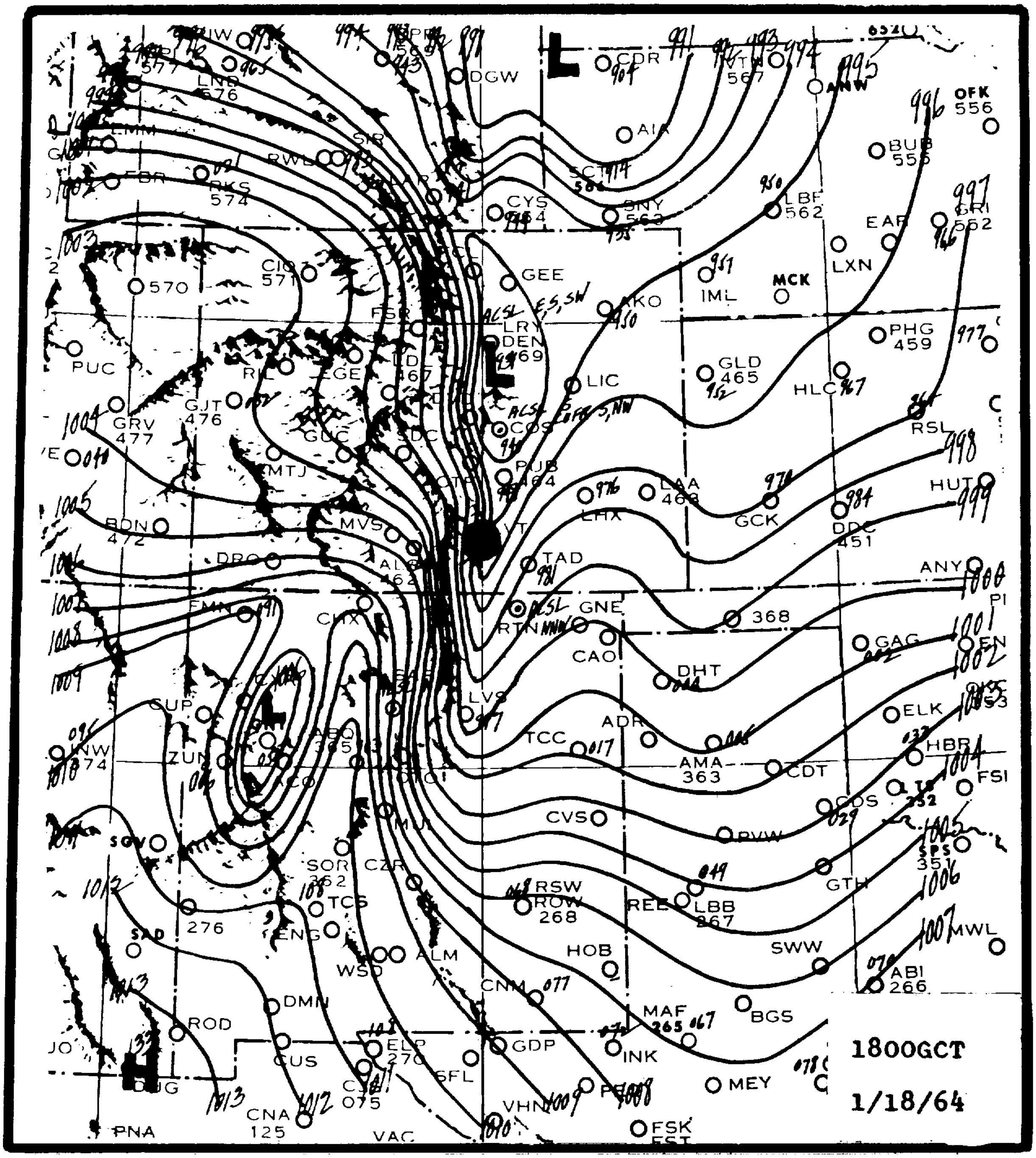


Figure 5. Sea level isobars drawn at 1-millibar intervals for 1800GCT on January 18, 1964. The sharp trough in the lee of the continental divide is a characteristic of prominent mountain waves in Colorado. It is a fingerprint which is useful in detecting wave developments along the divide from Montana down to New Mexico.

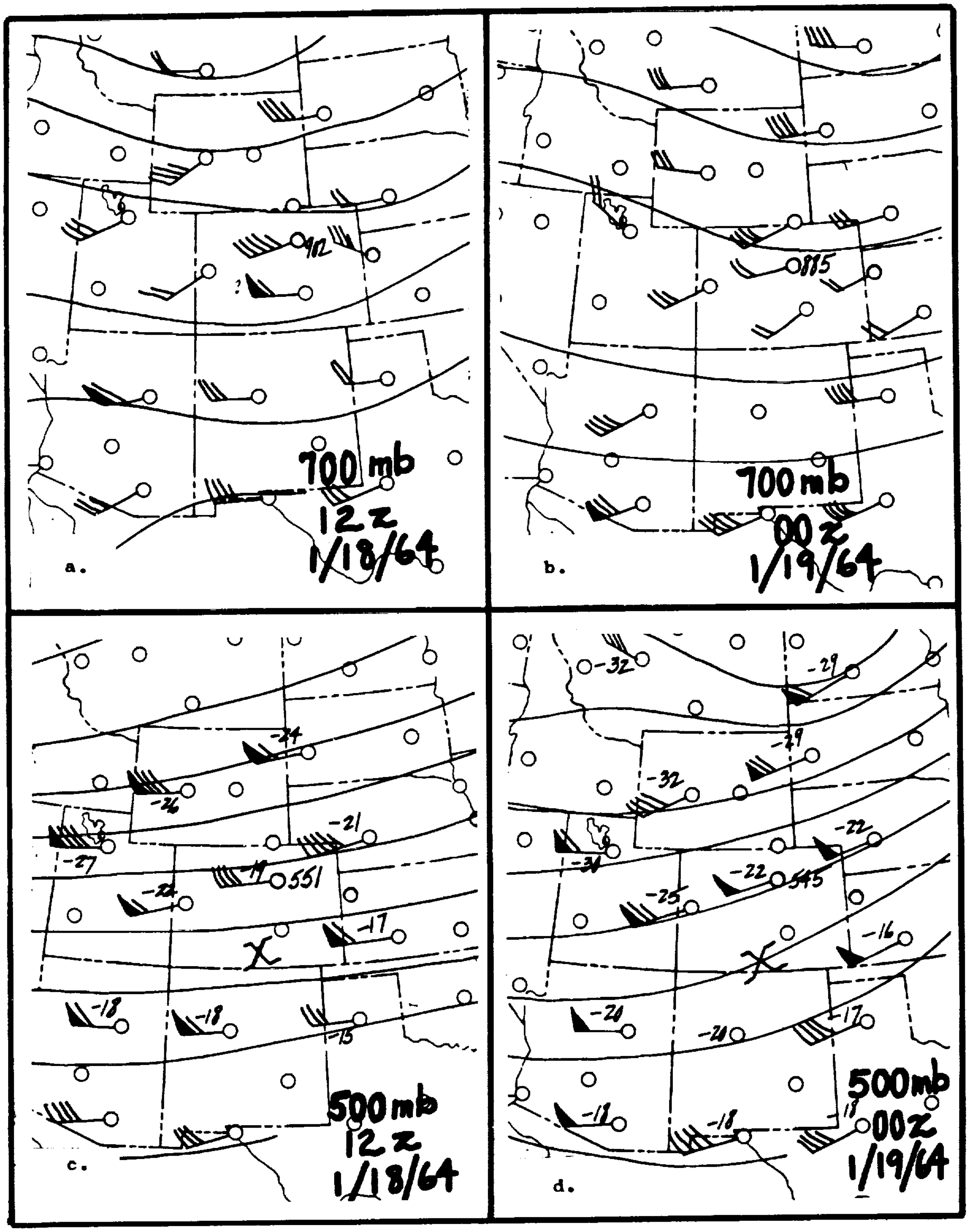


Figure 6. a. 700 mb. chart for 1200GCT on January 18, 1964; b. 700 mb. chart for 0000GCT on January 19, 1964; c. 500 mb. chart for 1200 GCT on January 18, 1964; d. 500 mb. chart for 0000GCT on January 19, 1964.

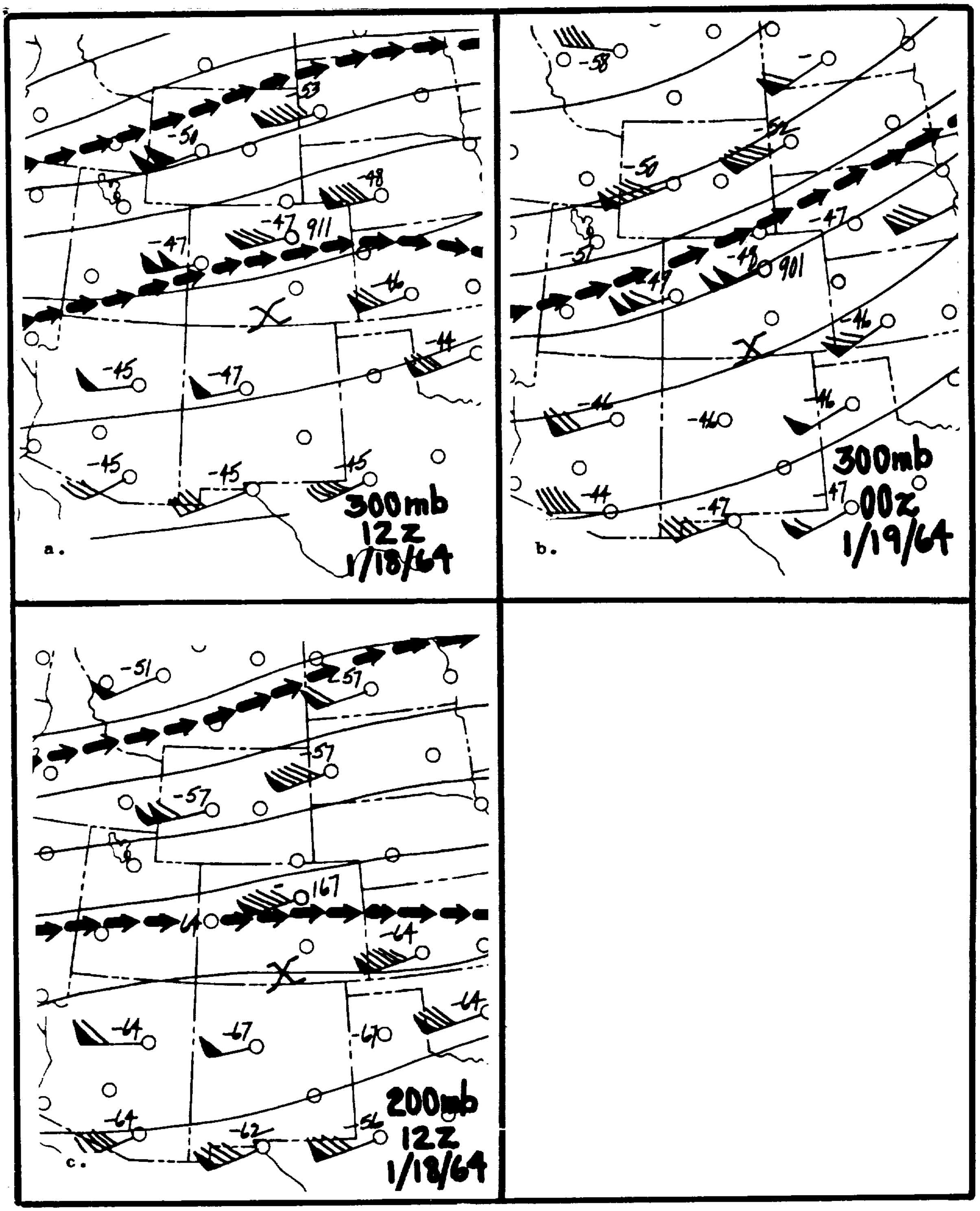


Figure 7. a. 300 mb. chart and jet stream positions for 1200 GCT on January 18, 1964; b. 300 mb. chart and jet stream position for 0000GCT on January 19, 1964; c. 200 mb. chart for 1200GCT on January 18, 1964 with jet stream positions.

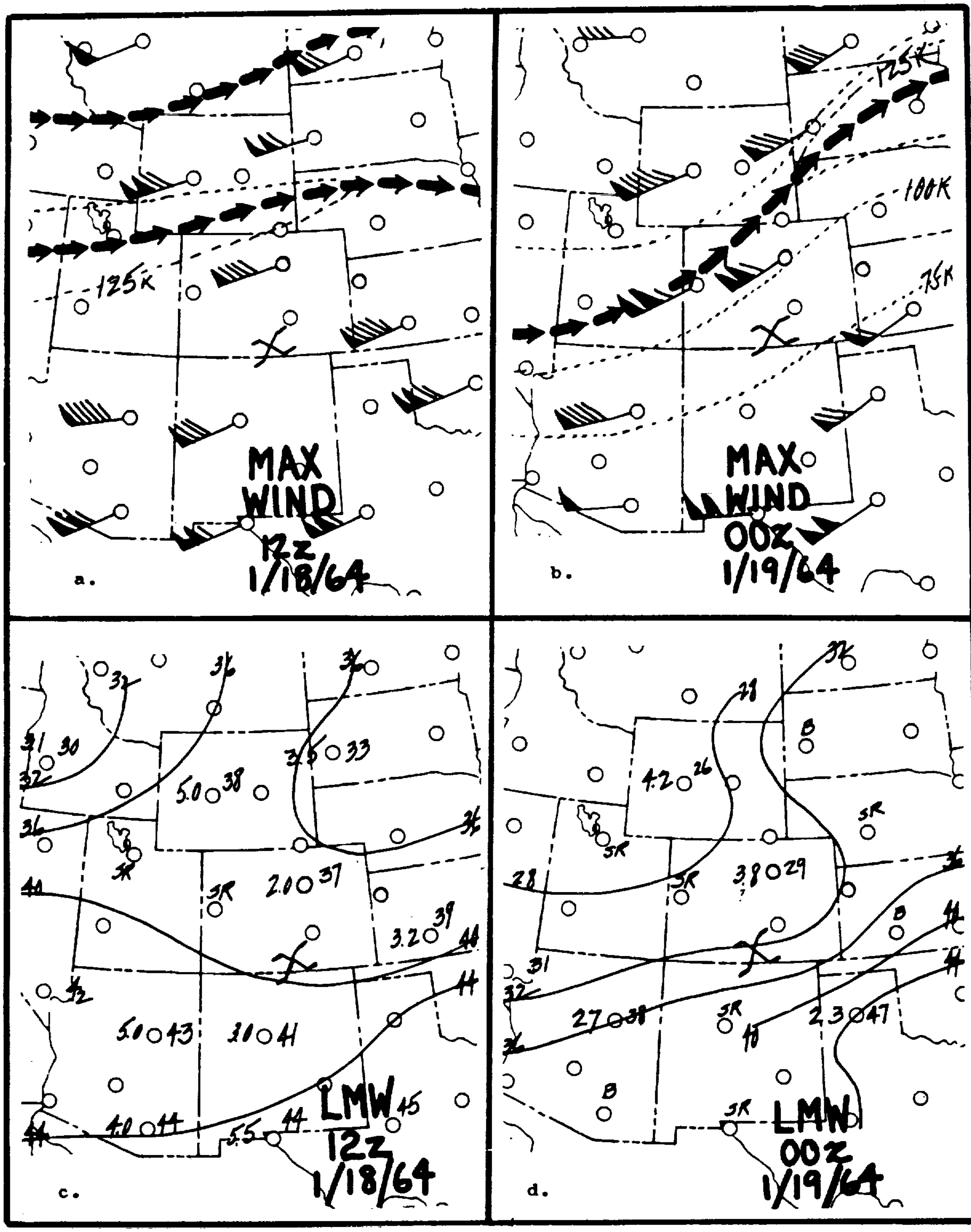


Figure 8. a. Section of maximum wind chart for 1200GCT on January 18, 1964; b. Section of maximum wind chart for 0000GCT on January 19, 1964; c. Level of maximum wind for 1200GCT on January 18, 1964; d. Level of maximum wind for 0000GCT on January 19, 1964.

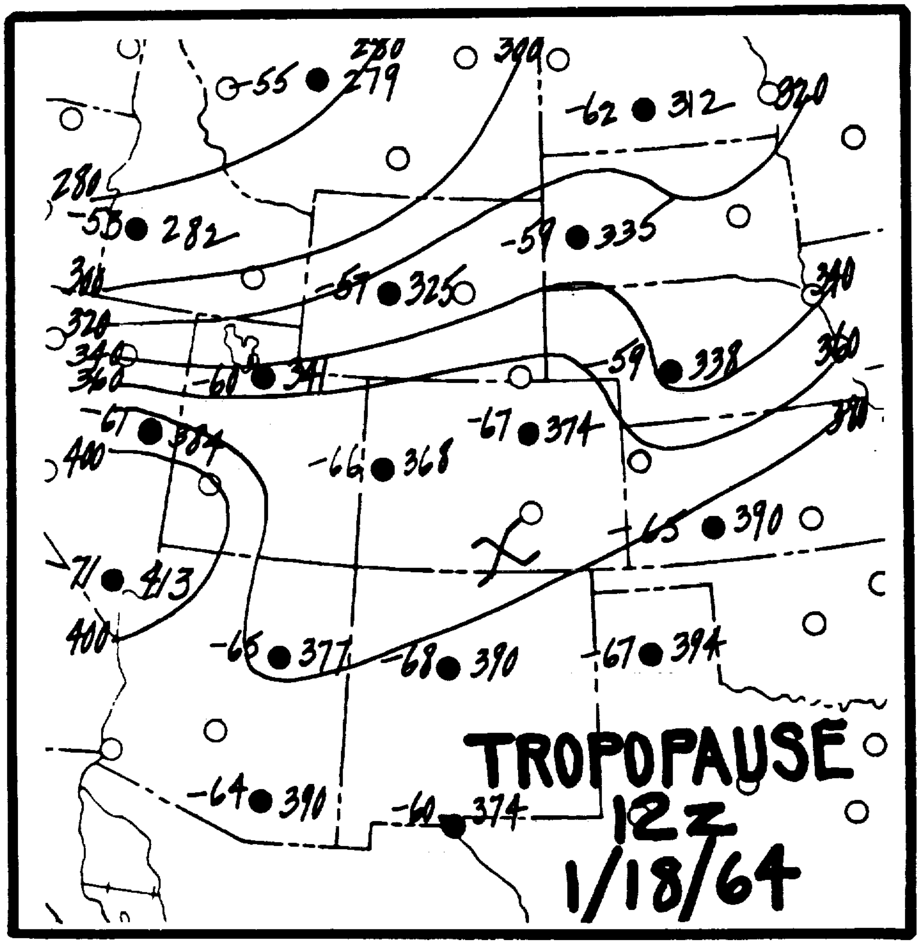


Figure 9. Section of the tropopause chart for 1200GCT on January 18, 1964. "X" marks the location of the turbulence incidents.

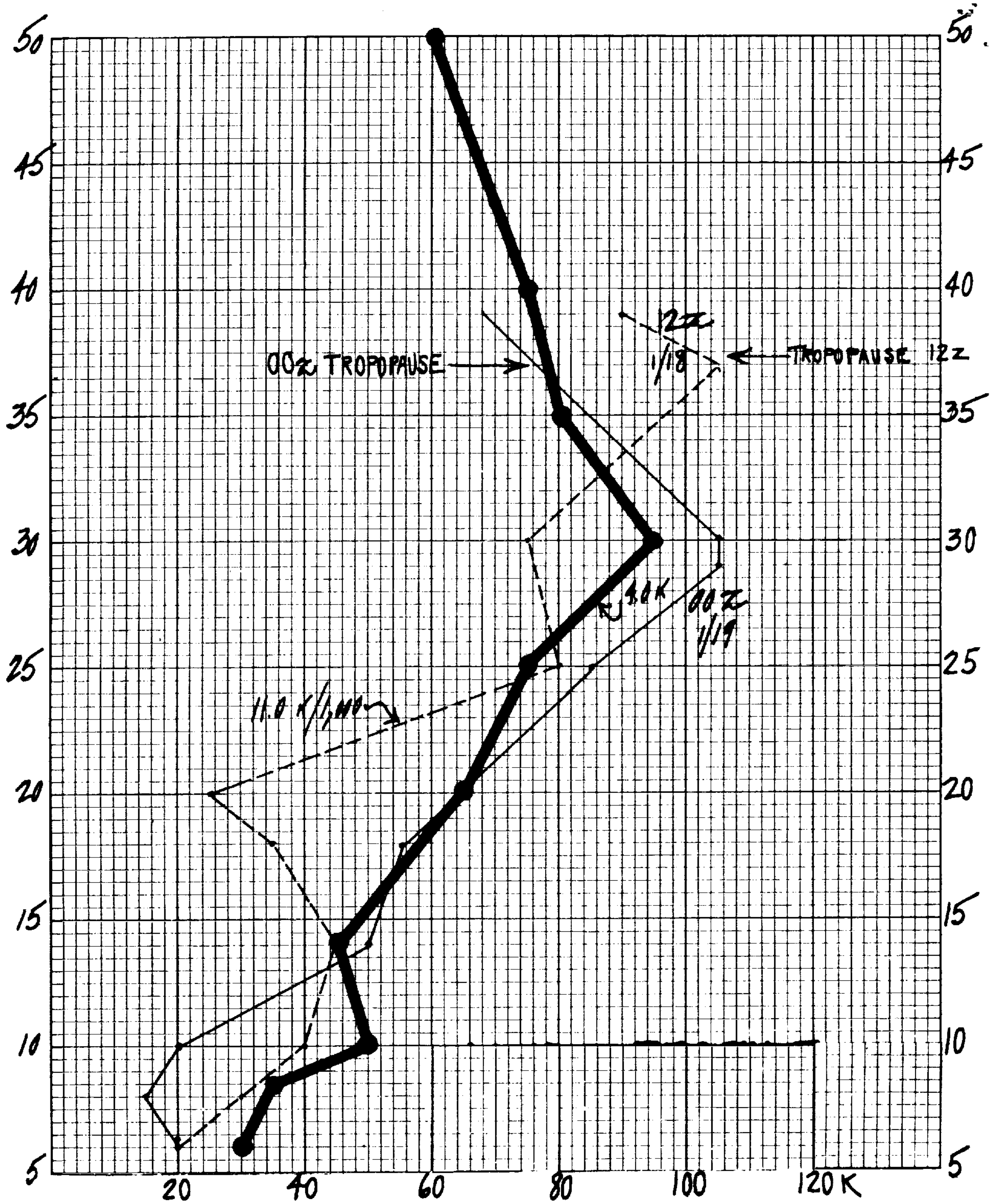


Figure 10. Wind speed profile at Denver for 1800GCT on January 18, 1964. The speed profile for six hours earlier is shown by dashed line and profile for six hours later by the solid, thin line.

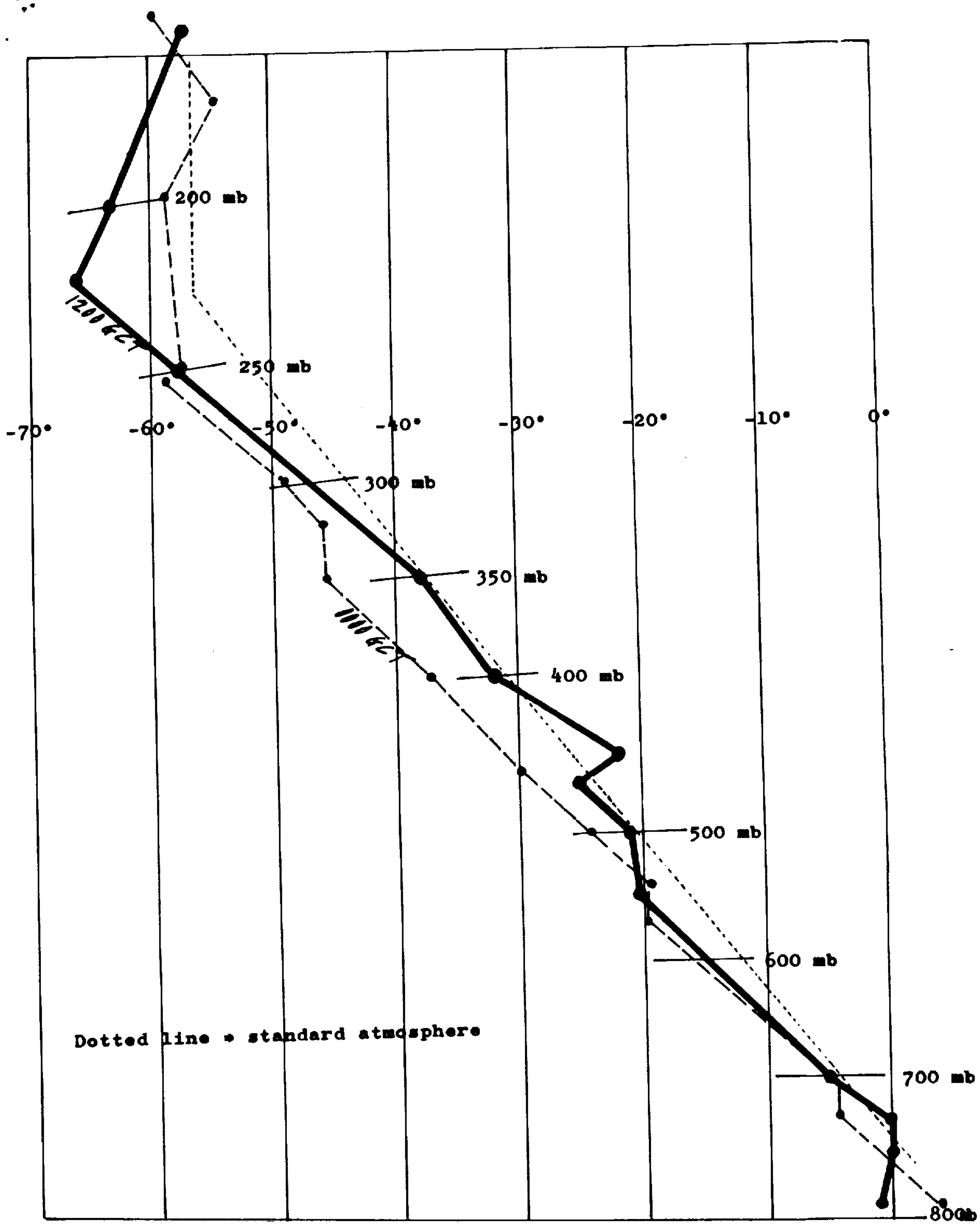


Figure 11. The upwind air mass sounding at Grand Junction, Colorado at 1200GCT on January 18, 1964. The sounding twelve hours later is shown by dashed curve. Note the stable layers between 15,000 and 28,000 feet in the troposphere.

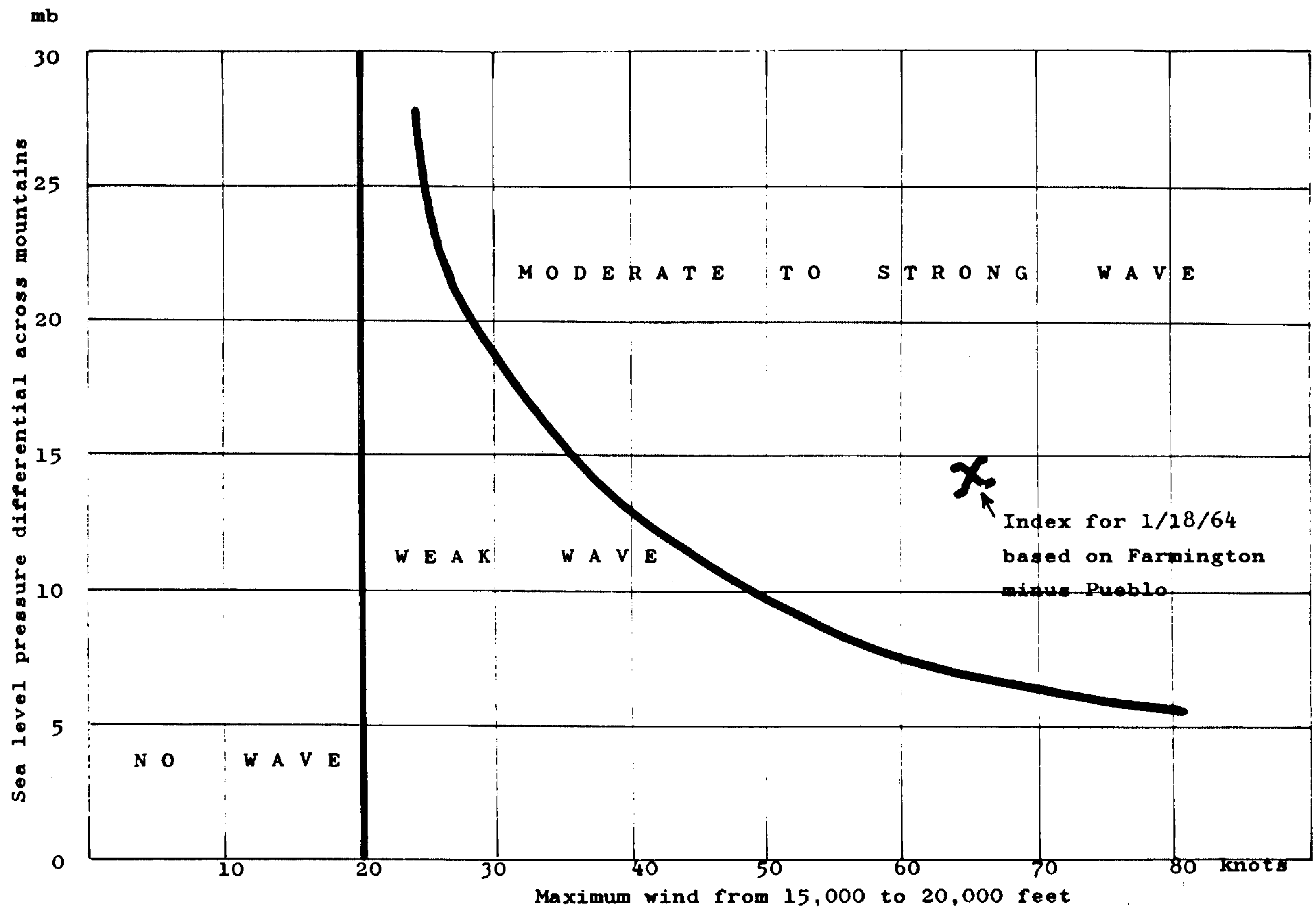


Figure 12. Index of mountain wave intensity for Sangre de Cristo Mountain Range on January 18, 1964 based on UAL system of identification and rating.

The Clear Air Turbulence Situation West of Denver

0300GCT

January 10, 1964

The Incident

A Boeing 707 encountered severe clear air turbulence at FL 280 while 38 NM west of Denver, Colorado. Mountain wave effects had not been reported but had been anticipated after the headwind component on this westbound flight increased to 80 knots. The airplane shook violently and then encountered a terrific bump - turbo-compressors became inoperative - lost a thousand feet of altitude - flight control was no unusual problem - there was no recovery maneuvering - cabin was found in disarray and several passengers had minor cuts and bruises. The pilot felt that "an unreported wind shear existed on the west edge of the mountain wave which caused the extreme turbulence we found there." (Time estimated 0300GCT)

This was the only major turbulence report received near this time but a series of cases happened later in the day farther south in the lee of the continental divide.

General Weather Type

A strong mountain wave was in progress in the lee of the continental divide over northern Colorado. The UAL mountain wave forecasting nomogram showed a wind speed of 60 knots at 18,000 feet and a sea level pressure differential of 16 millibars at the time the incident is estimated to have happened. Darkness prevented the reporting of any mountain wave clouds. In addition to the high wave index, the upwind air mass sounding at Grand Junction showed an inversion of 3°C at 6,000 feet and another of 3°C between 10,000 and 12,000 feet. This air mass stability therefore completed all of the requirements for a strong wave in the lee of the divide west of Denver.

Features of Interest

Of the four jet routes fanning out to the west of Denver, JR 30-56 and JR 60-80 catch the brunt of wave developments because they lie across Corona Pass west of Rollinsville and Loveland Pass west of Georgetown and Idaho Springs. The former is notorious as one of the biggest wave breeders in the country. The flight on January 10, 1964 was on one of those two routes, probably the one over Corona Pass since the distance given as 38W of Denver would have put it just west of Rollinsville along the average position of the first mountain wave.

Typical of big waves in the lee of the continental divide, a sharp trough in the sea level isobars appeared in the usual position about fifty miles to the east of the divide. Like many mountain waves over the Rockies, this one was a migratory wave that advanced gradually southward during the day. It will be noted, from reference to the next situation, that major turbulence occurred over southern Colorado later in the day.

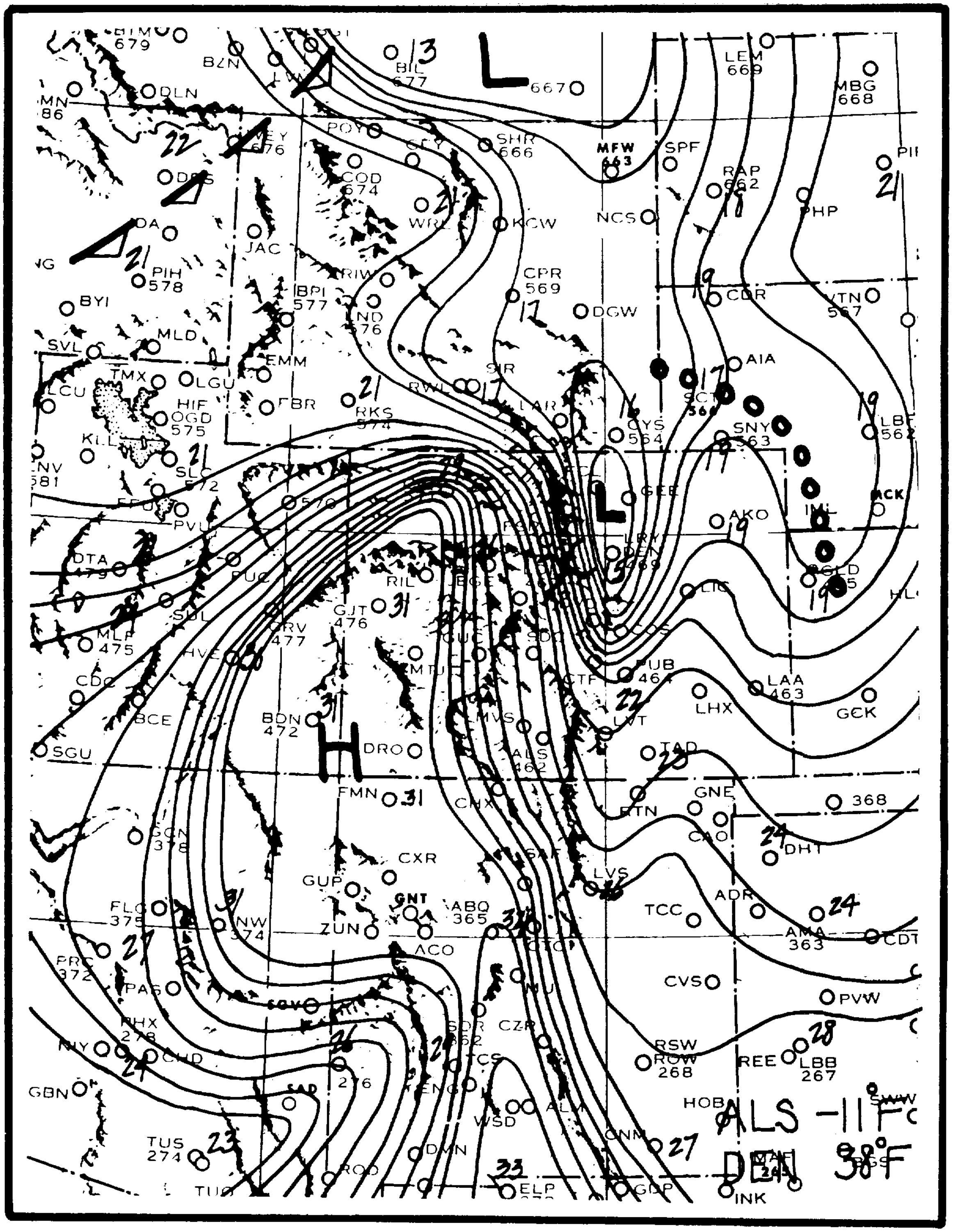


Figure 13. One-millibar sea level isobars along the middle continental divide for 0300GCT on January 10, 1964. Note the sharp lee trough in the usual position and the unusual packing of the isobars across the mountains.

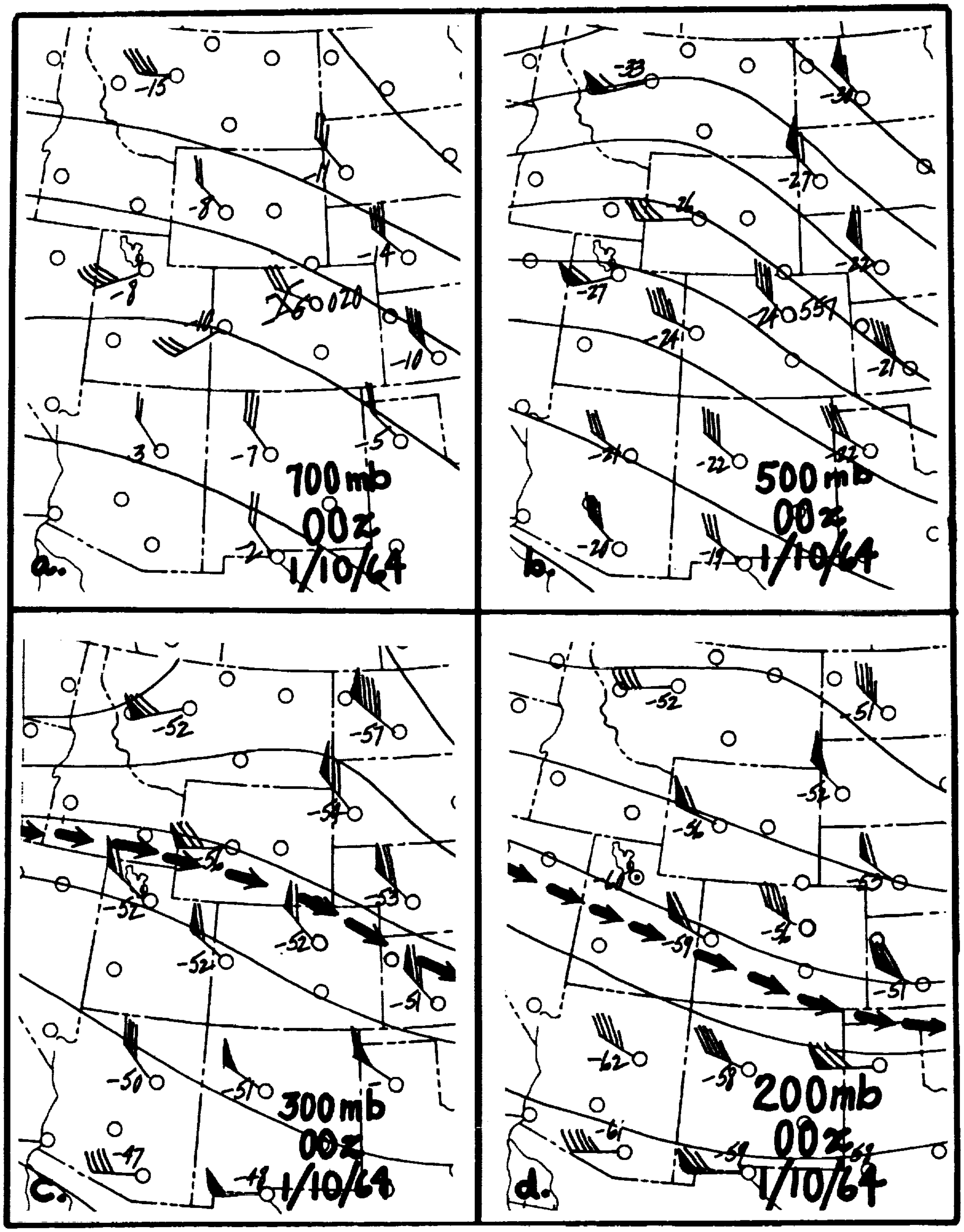


Figure 14. Sections of upper air charts for 0000GCT on January 10, 1964. a. 700 mb. chart; b. 500 mb. chart; c. 300 mb. chart; d. 200 mb. chart. NWAC jet stream positions are shown on the last two charts.

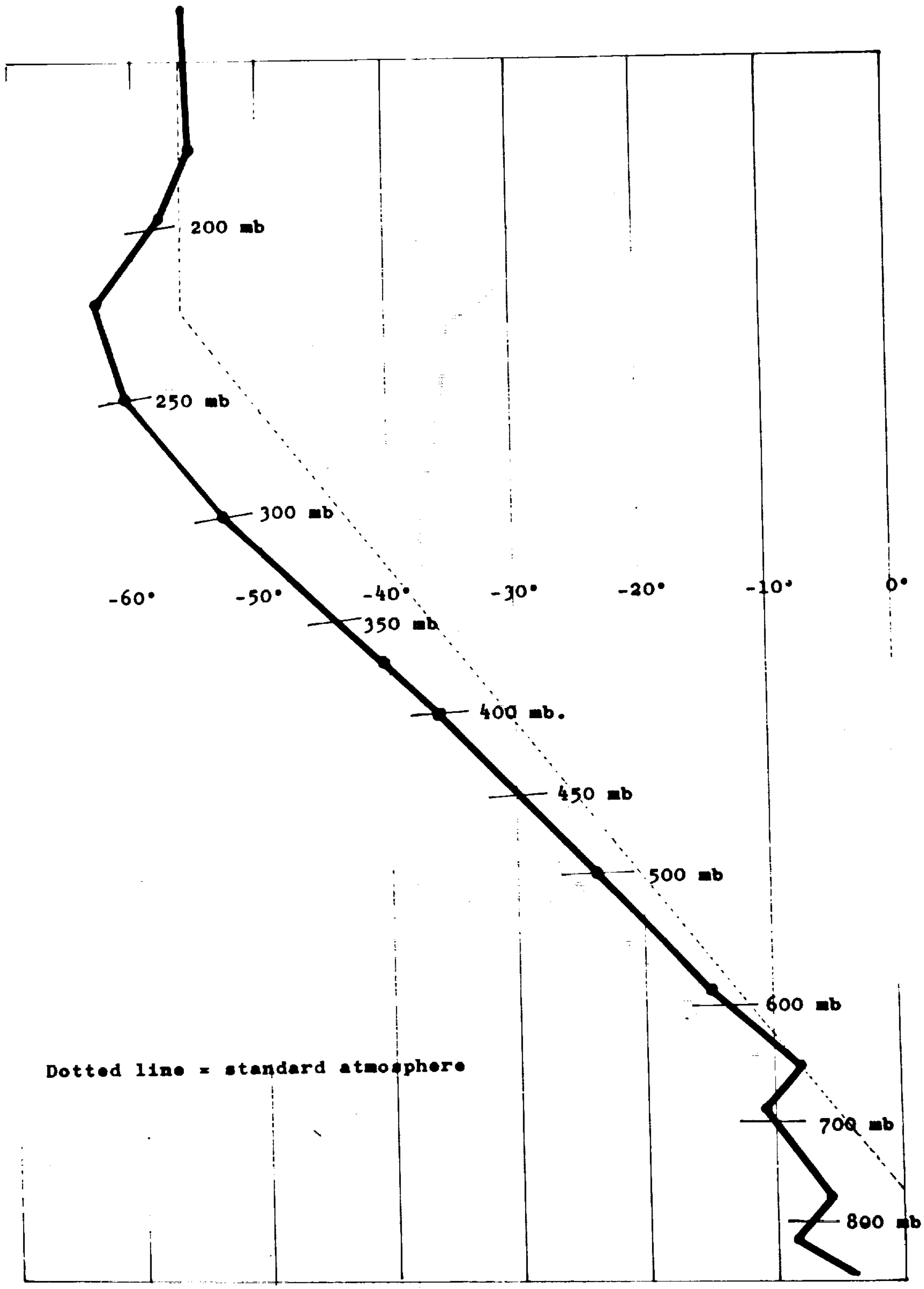


Figure 15. Radiosonde plot for Grand Junction, Colorado at 0000GCT on January 10, 1964. Note the marked stability shown in this upwind sounding.

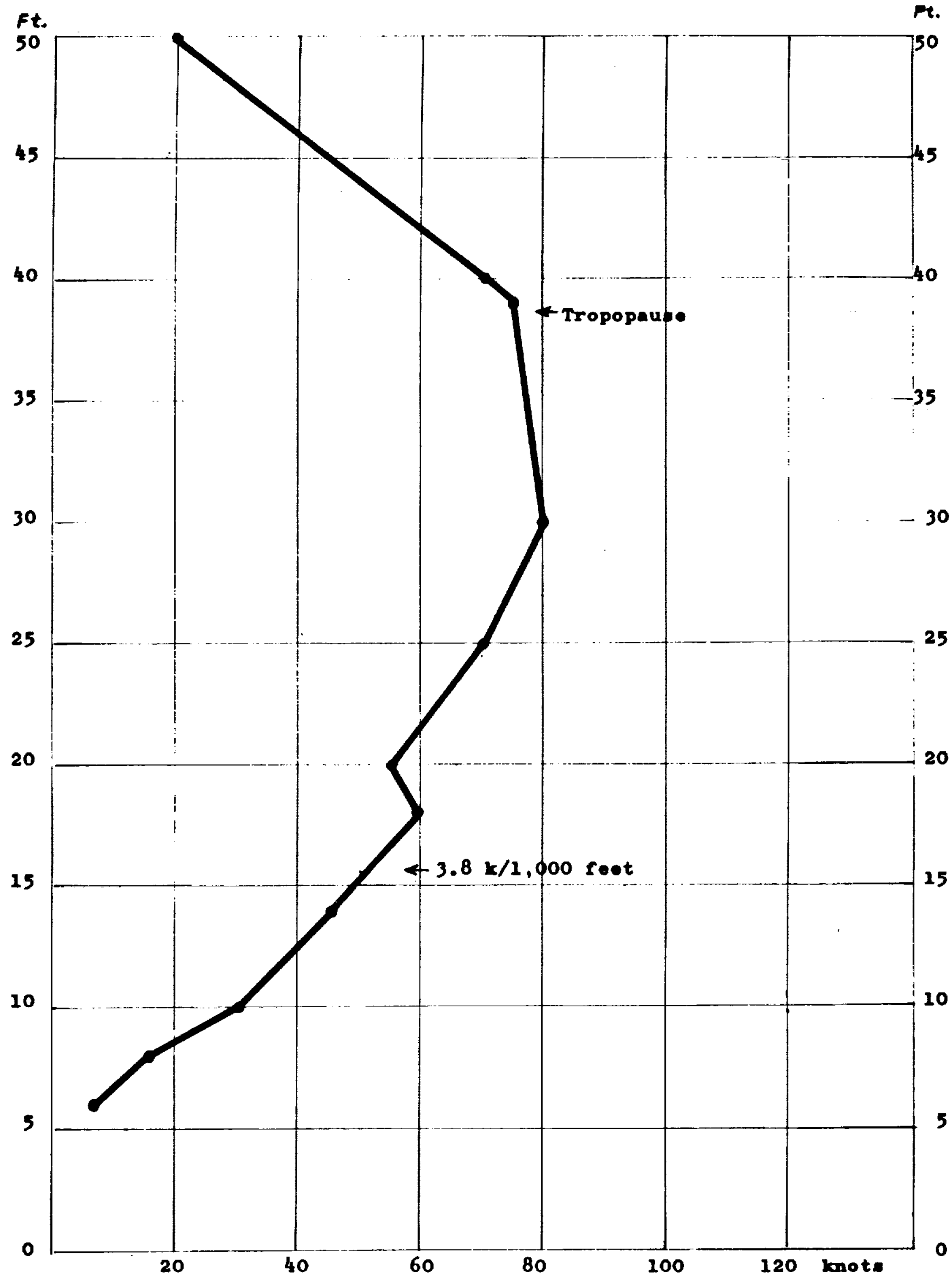


Figure 16. Vertical wind speed profile at Denver, Colorado for 1200GCT on January 10, 1964.

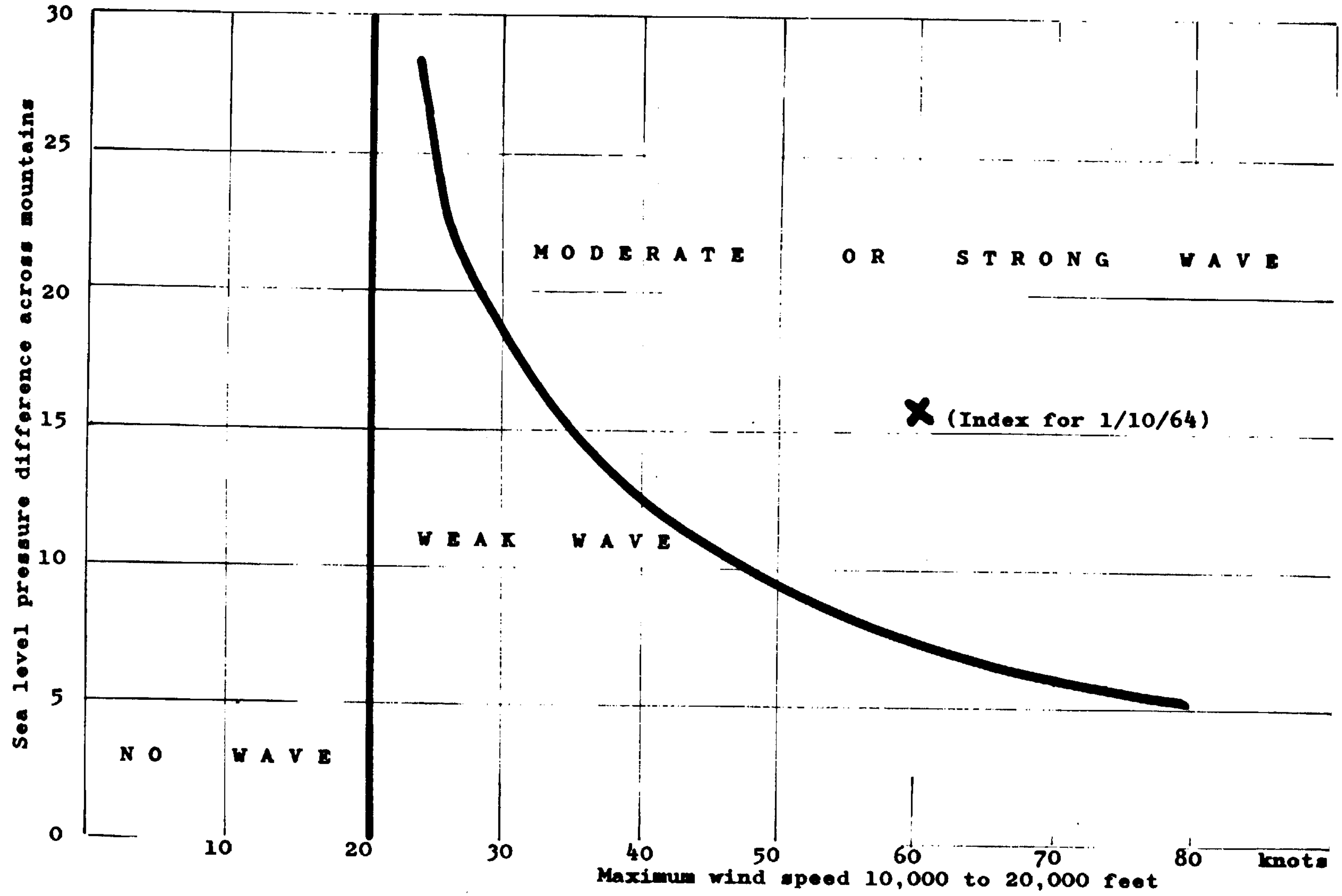


Figure 17. Mountain wave index for January 10, 1964 along continental divide west of Denver. Based on United Air Lines forecasting method for the Colorado wave.

The Clear Air Turbulence Situation at LaVeta, Colorado

1549GCT

January 10, 1964

The Incident

An Air Force experimental B-52, making test runs at low levels along the east face of the Sangre de Cristo Mountains, encountered extreme turbulence at 14,300 feet while passing adjacent to East Spanish Peak which is just southeast of LaVeta, Colorado. Vertical gusts computed at 120 feet per second tore the vertical fin from the aircraft but the crew kept it flying and eventually made a safe landing at Blytheville, Arkansas.

General Weather Type

All indications, based upon the UAL system of identification and rating, pointed to a strong mountain wave being in progress in the lee of the Sangre de Cristo Mountains starting at about 1400GCT on this date. Wind speed was 55 to 60 knots near 20,000 feet and sea level pressure differential was 9 millibars between Farmington and Trinidad. (Use of Alamosa would have made the differential 20 millibars but there is some question about how valid this pressure would be for the purpose). The upwind air mass sounding at Grand Junction showed a surface inversion and then a stable, isothermal layer near 12,000 feet which indicated that the requirements for stability were met. The index on the UAL nomogram plotted out as calling for a moderate to strong mountain wave.

Positive evidence for the existence of a wave came from the official ground observations of mountain wave lenticular clouds in this section starting at 1400GCT on this date (nearly two hours before the incident) and continuing each hour from then until 1900GCT when they were no longer reported. It is conceivable that wave clouds were present prior to 1400GCT but could not be identified because of darkness. The other incident on this date occurred in a strong mountain wave west of Denver twelve hours earlier and evidence there pointed to the wave being a migratory one which was moving southward.

Further evidence that the LaVeta incident was not an isolated case came from pilot reports of moderate CAT at FL390 near La Junta at 1600GCT, of moderate to severe CAT between Flight Levels 320 and 390 near Santa Fe at 2100GCT and a report of moderate CAT between Flight Levels 310 and 390 near Grants, New Mexico at 2200GCT.

Features of Interest

While the extreme turbulence on this date happened down near the mountain tops, other flights did experience moderate and heavier turbulence in the clear at normal jet cruising levels. When we pair this incident with the one of the two airline jet aircraft at the same spot on January 18, 1964 it becomes evident that we are dealing with one of the worst jet exposures in the country to mountain wave activity. Waves in the lee of LaVeta Pass evidently equal the intensity of those at Corona Pass west of Denver and the most notorious of all, Bishop in California.

This case again focuses attention on the advisability of flight planning around this spot on days of known or suspected wave activity. The three Jet Routes which converge on Alamosa from the east, 64-102-110, should be avoided on days when some or all of these wave symptoms are reported:

1. Wind direction 250° to 270° at 40 knots or more between 15,000 and 20,000 feet.

2. Sharp sea level pressure differential across the mountains resulting in a distinct lee trough when the isobars are drawn carefully. If in doubt, draw one-millibar isobars exactly to every sea level pressure reported.

3. Stable air noted in upwind air mass soundings

When surface stations at Colorado Springs, Pueblo, Trinidad or Alamosa start reporting lenticular clouds (ACSL's) or rotors, the wave is already in progress.

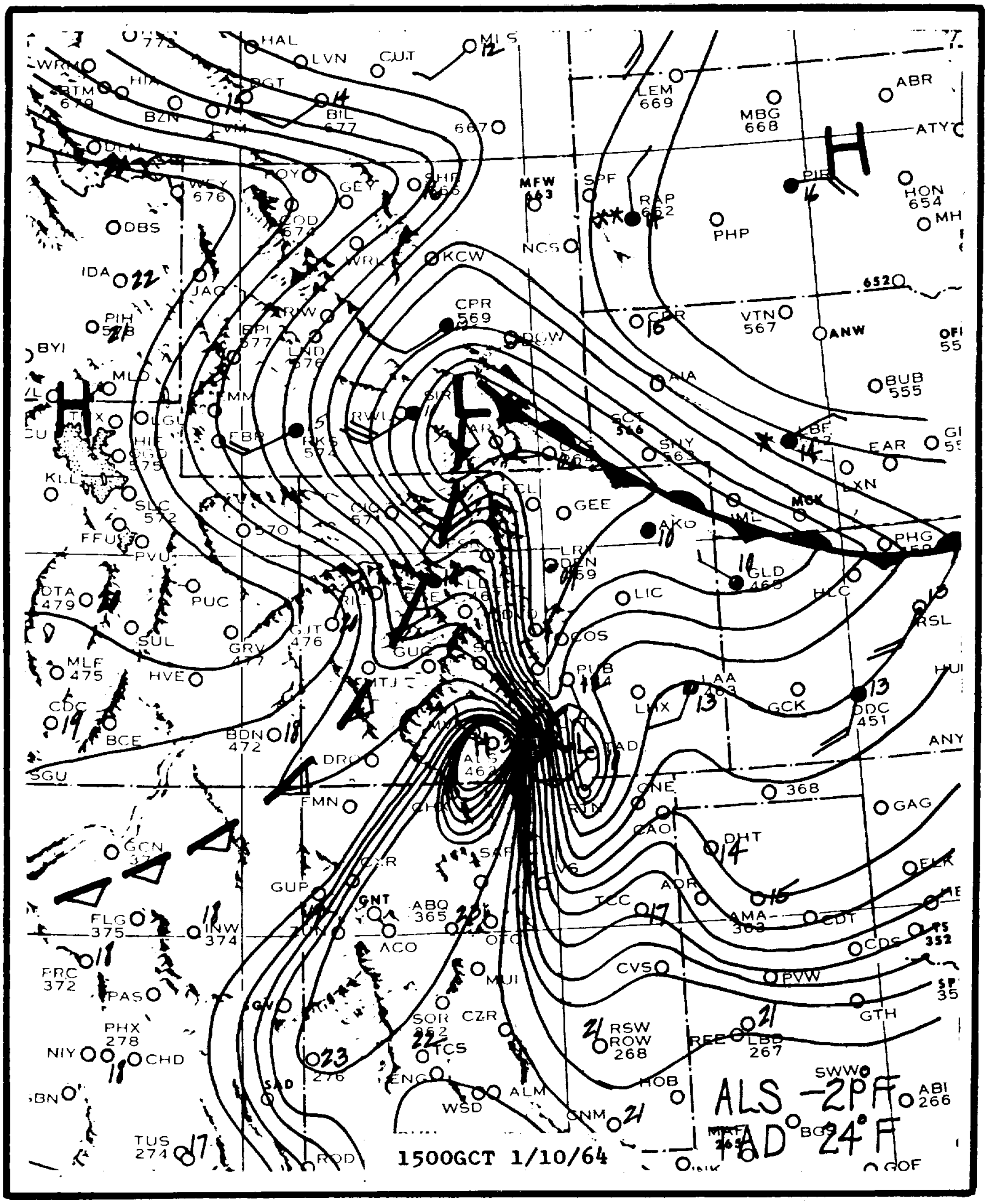


Figure 18. One-millibar sea level isobars over the continental divide area in Colorado and New Mexico at 1500GCT on January 10, 1964. Note the extreme packing of the isobars across the Sangre de Cristo Mountains. In the Denver incident twelve hours earlier the isobar packing was concentrated at that point.

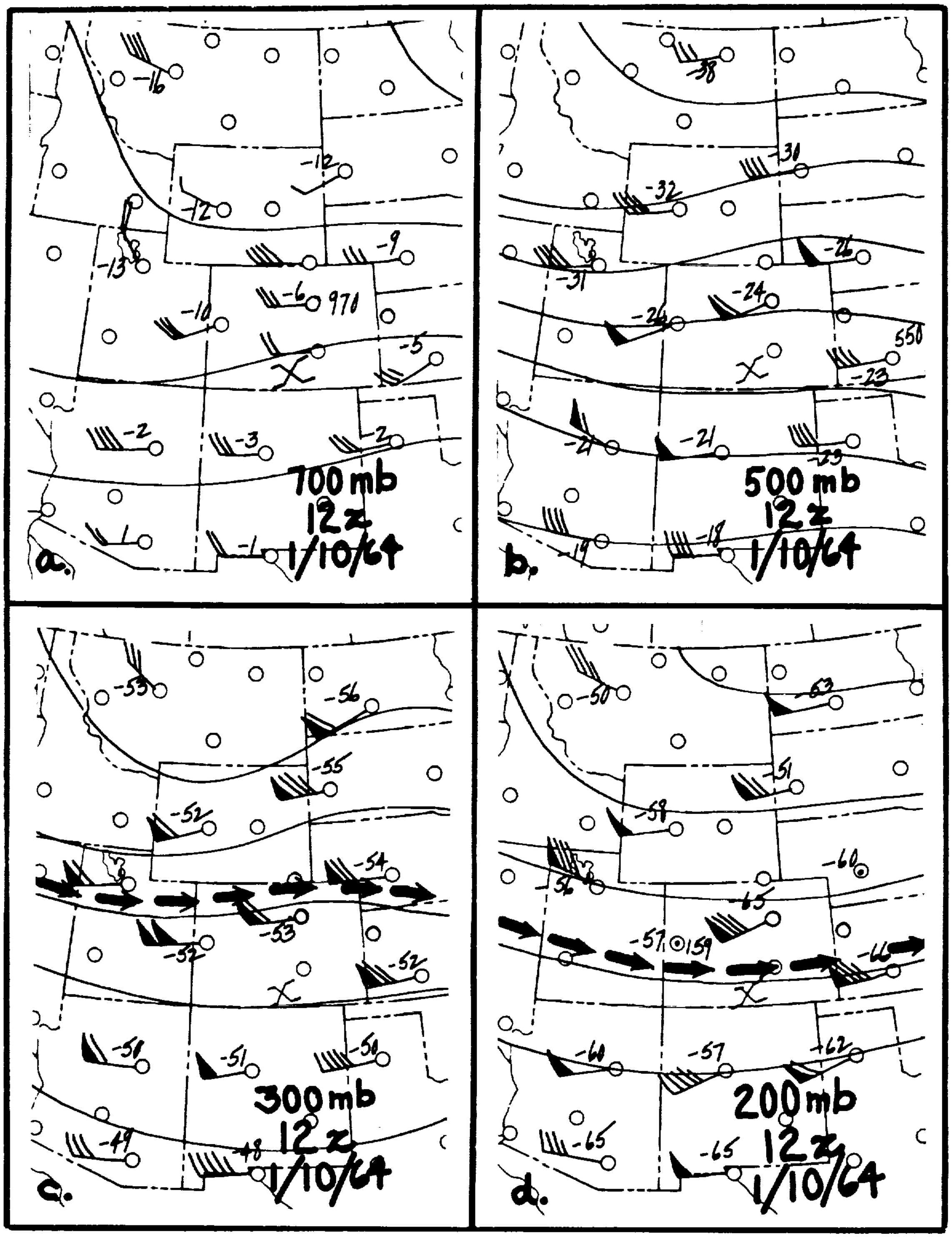


Figure 19. Sections of upper air charts for 1200GCT on January 10, 1964. a. 700 mb.; b. 500 mb.; c. 300 mb.; d. 200 mb. NWAC jet stream positions appear on last two charts.

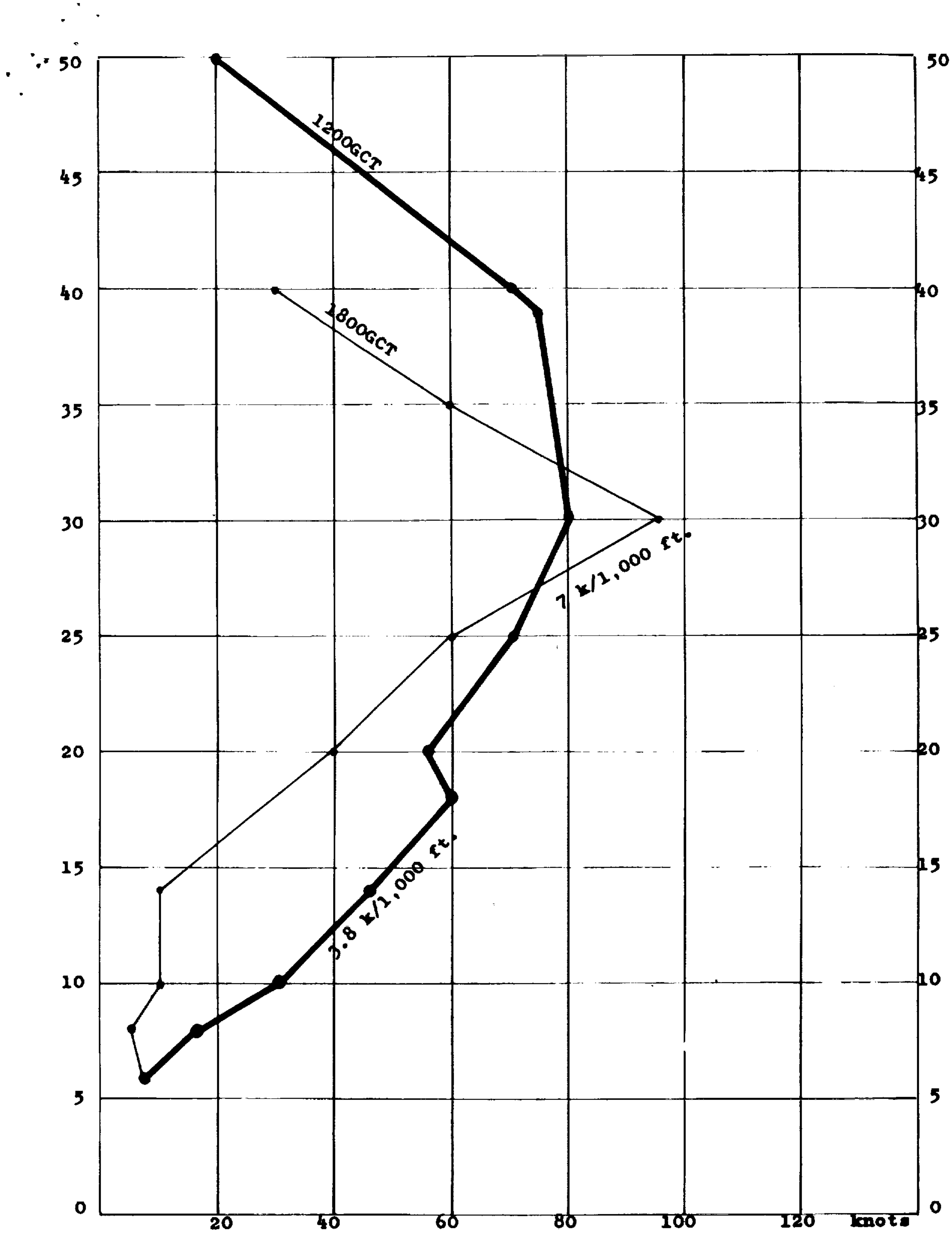


Figure 20. Wind speed profile at Denver, Colorado on January 10, 1964. Heavy curve is for 1200GCT (before the incident) and light curve is for 1800GCT (after the incident).

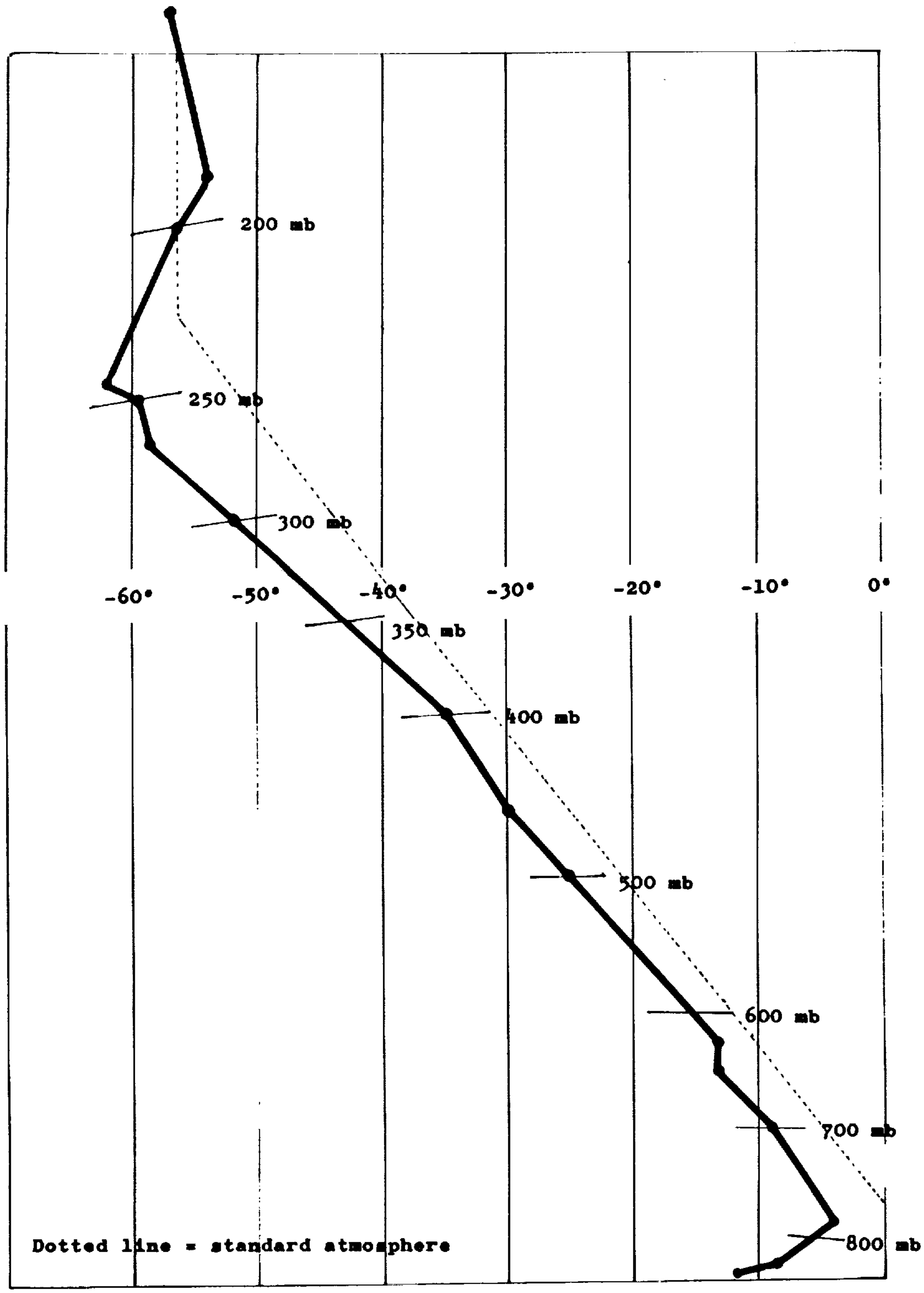
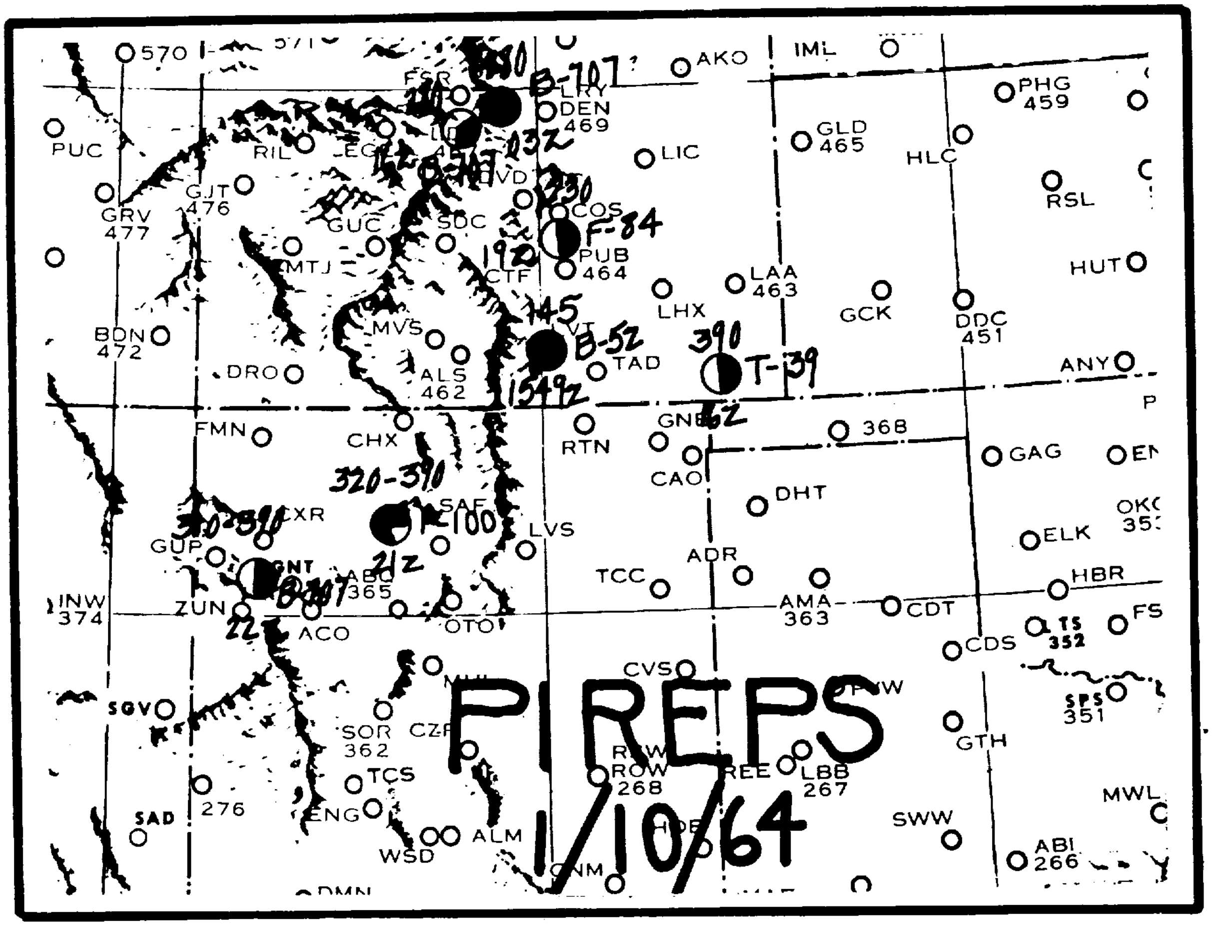


Figure 21. Air mass sounding at Grand Junction, Colorado for 1200GCT on January 10, 1964. Note that this upwind sounding from the incident shows a surface inversion plus an isothermal layer around 12, 000 feet msl.



Light to moderate

Moderate

Moderate to severe

Severe

Figure 22. Location of pilot reports of clear air turbulence in Colorado and northern New Mexico on January 10, 1964.

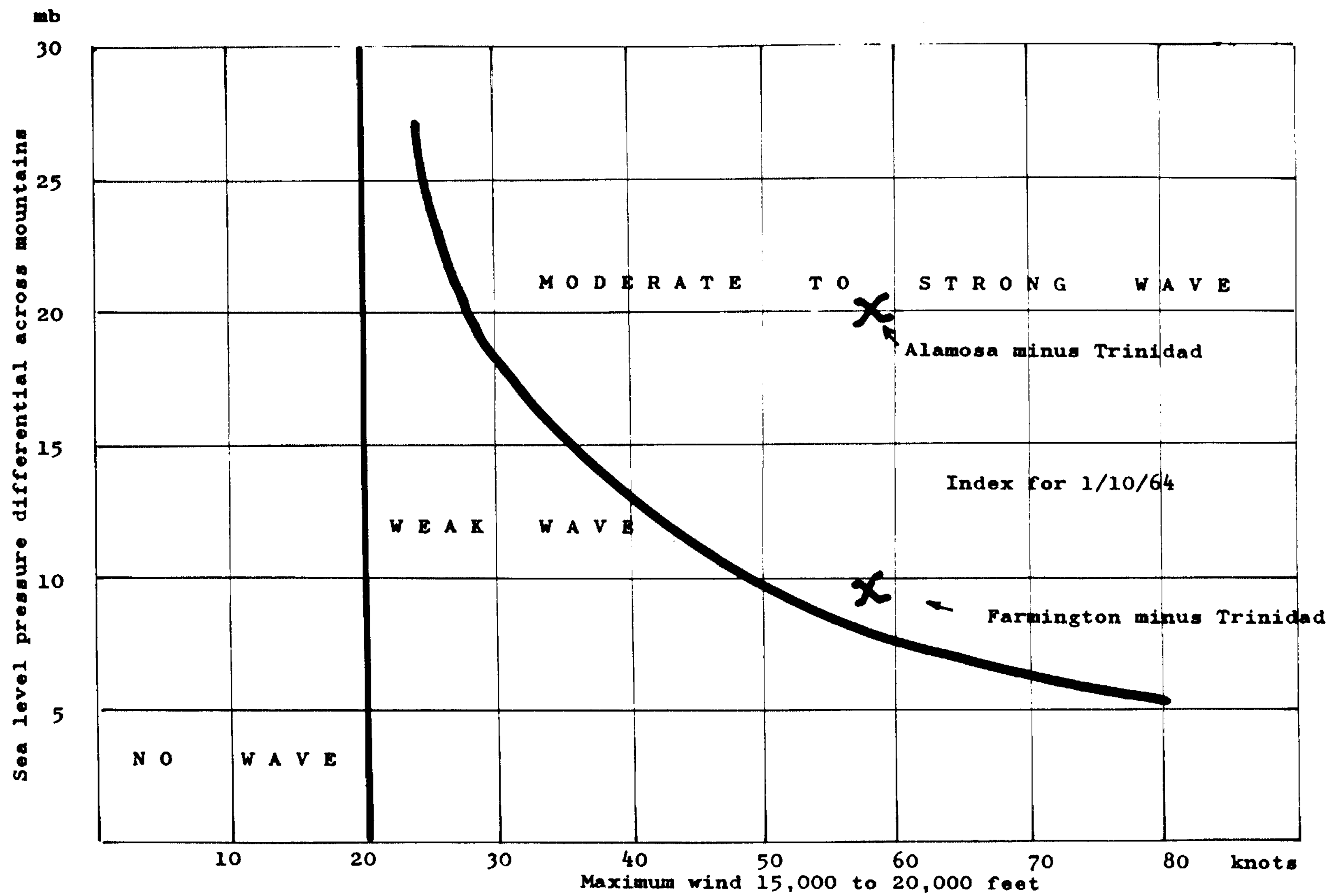


Figure 23. Index of mountain wave intensity based on UAL forecasting nomogram for Sangre de Cristo Mountain Range on January 10, 1964.

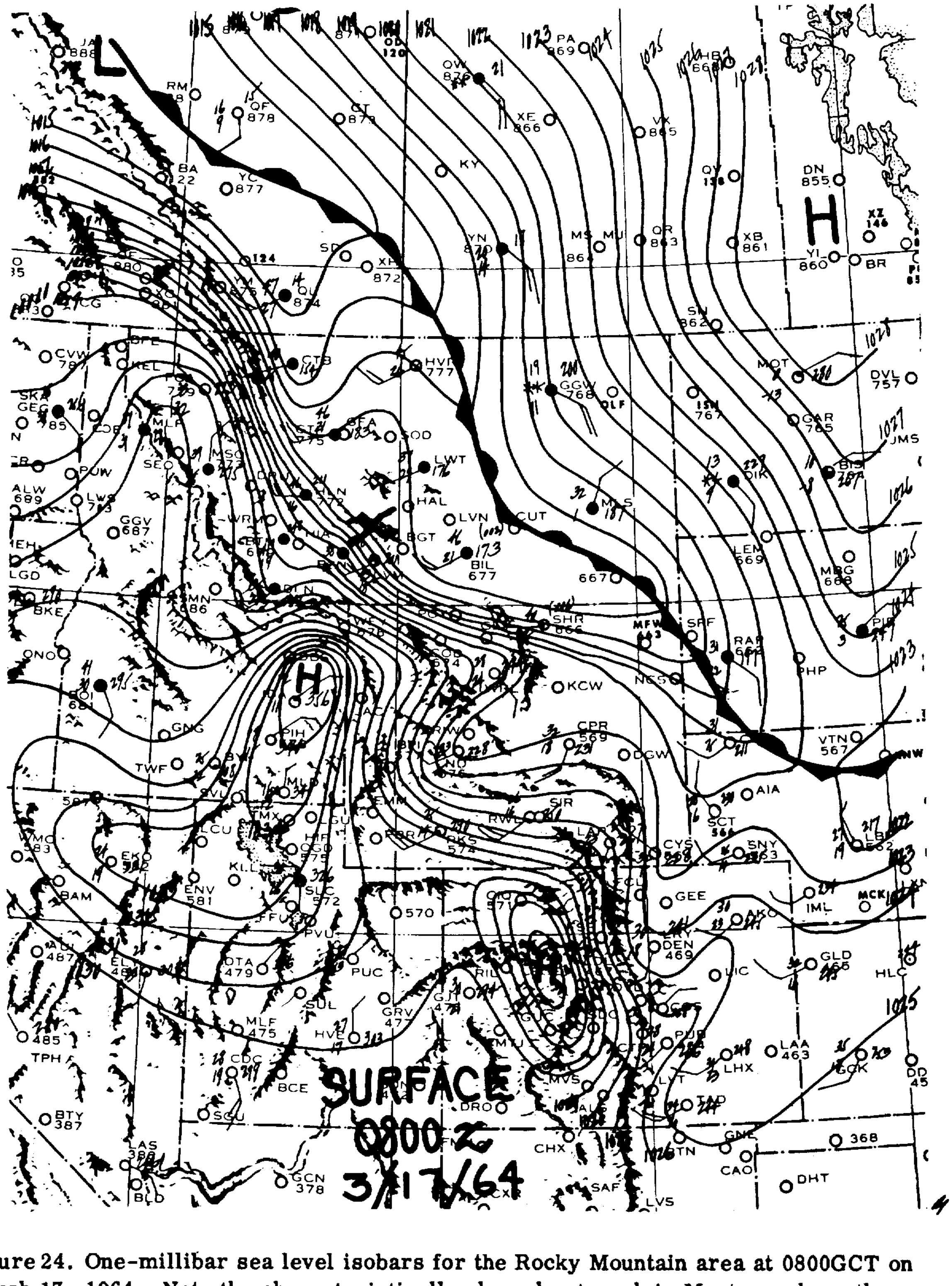


Figure 24. One-millibar sea level isobars for the Rocky Mountain area at 0800GCT on March 17, 1964. Note the characteristically sharp lee trough in Montana where the mountain wave was in progress at this time. Stability of the air mass is evidenced by the low surface temperatures west of the divide.

The Clear Air Turbulence Situation Near Elk Mountain

North of Ringling, Montana on JR 90

0800GCT

March 17, 1964

The Incident

A four-engine jet transport encountered moderate to severe clear air turbulence at FL 370 on Jet Route 90 while 95 NM WNW of Billings, Montana. The location was just south of Elk Mountain in the lee of the Big Belt Mountains which rise to 9,700 feet at this point in Mt. Baldy. The flight recorder revealed a range of gusts between +1.9 g and -0.1 g. One passenger and a stewardess were reported injured.

General Weather Type

A mountain wave was in progress in the lee of the Big Belt Mountains as well as along other mountain ridges in Montana starting near 2200GCT on March 16th. This was when standing lenticular clouds (ACSL) began to be reported along JR 70 west of Great Falls and JR 90 WNW of Billings. Sea level pressure differential across the mountains had been increasing during the preceding twelve hours and the usual sharp lee trough in the sea level isobars had appeared along the east face of the continental divide.

While the UAL mountain wave nomogram was designed for forecasting in Colorado, the topography in Montana is so similar that it should be applicable there also, possibly with some minor adjustments for distance between pairs of pressure difference stations. The nomogram, in this case, did give an index calling for a moderate to strong wave and this index continued to increase up to the time of the turbulence incident. Mountain wave clouds were no longer reported after 0200GCT on the 17th but this would have been expected because of darkness, there being no known method of identifying such cloud forms at night unless moonlight is brilliant.

Wave clouds were actually reported during this period by Great Falls, Helena, Livingston, Lewistown and Dillon which gives some idea of the extensive nature of the wave developments in spite of the quartering wind from the northwest. Colson and others have commented on the unusual intensity to be found in some of these waves in Montana where the windflow is far from being perpendicular to the ridges. Another characteristic of the quartering wave is that it generally is a migratory system which advances progressively southward and sometimes reaches from Montana down to Colorado in twenty-four hours or less. Other positive evidence for the existence of the wave came from a jet pilot at FL 390 about 160 NM west of Billings who reported "moderate occasionally severe chop mountain wave" at 0212GCT on the 17th.

Features of Interest

This was another example of the tendency for mountain wave turbulence to be worse for jet aircraft at levels near and below the tropopause. On this date the average position of the tropopause was close to 37,500 feet in western Montana and the two mountain wave turbulence cases occurred at FL 370 and FL 390. On the other hand, flights down at FL 250 and FL 270 reported no turbulence across Montana.

This case is also a good example to show that significant mountain waves occur in the lee of many ranges and are far from being limited to the popular locations in the lee of the continental divide, the Sierras and the Cascades. A look at the terrain profile across the Big Belt Mountains lying north-south across JR 90 just to the east of the Missouri River will show why this is so. Mt. Baldy at 9,700 feet is higher than anything to the west along the divide, there is a wide open sweep for the surface air mass to gather momentum in moving southeastward from Helena down the broad Missouri Valley, and a dropoff of 4,000 feet on the lee side for the cascading air. Finally, there is a secondary lift of 2,000 feet imparted to the airmass 12 miles east of the ridge line which should have the effect of being a built-in hydraulic jump. This terrain feature is found in many of the big mountain wave profiles (Corona, LaVeta, Bishop) and it is strange that meteorologists have failed to pay any attention to it.

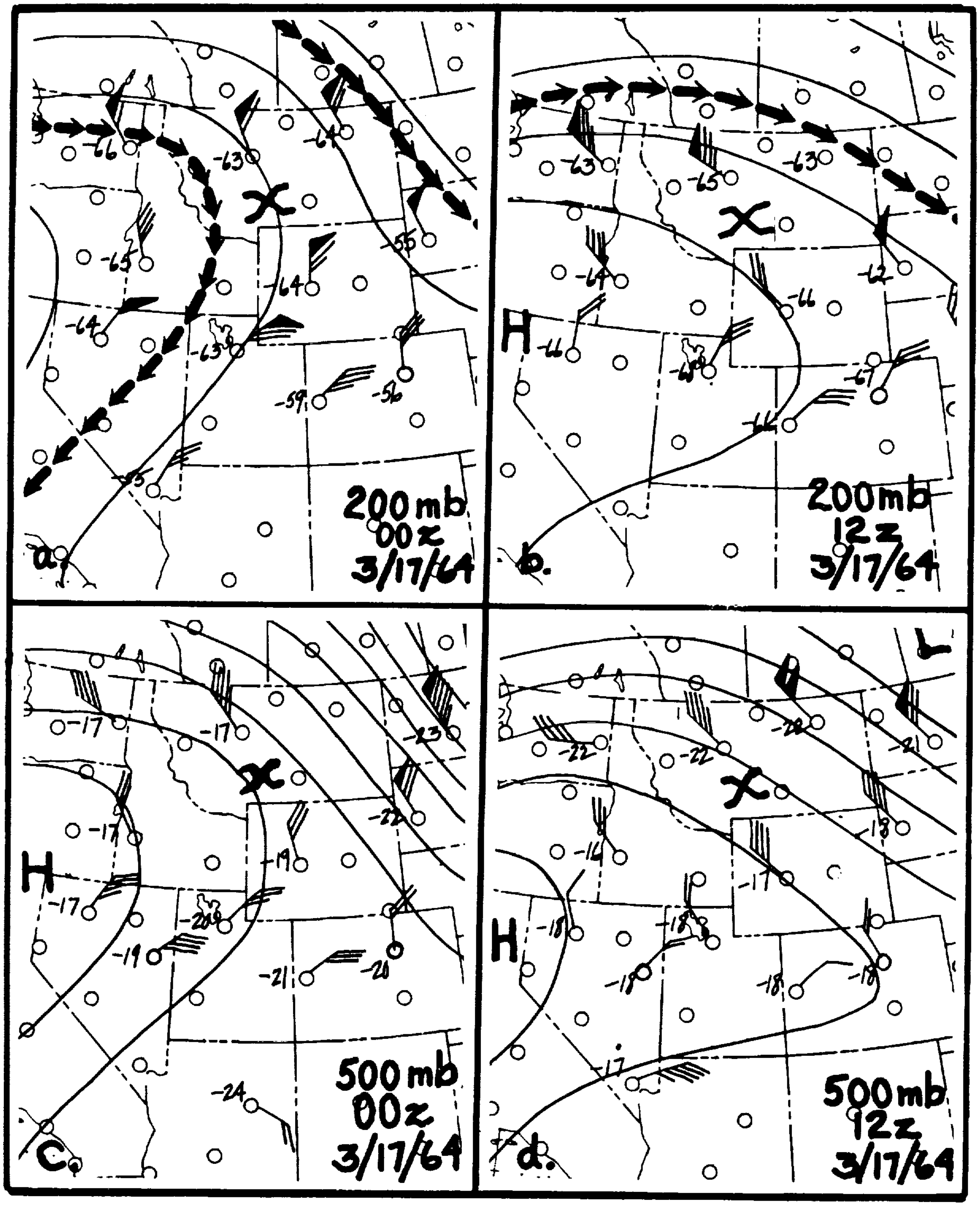


Figure 25. Sections of upper air charts for the Rocky Mountains on March 17, 1964.
a. 200 mb. for 0000GCT; b. 200 mb. for 1200GCT; c. 500 mb. for 0000GCT;
d. 500 mb. for 1200GCT. NWAC jet stream positions are shown on the 200 mb. charts.

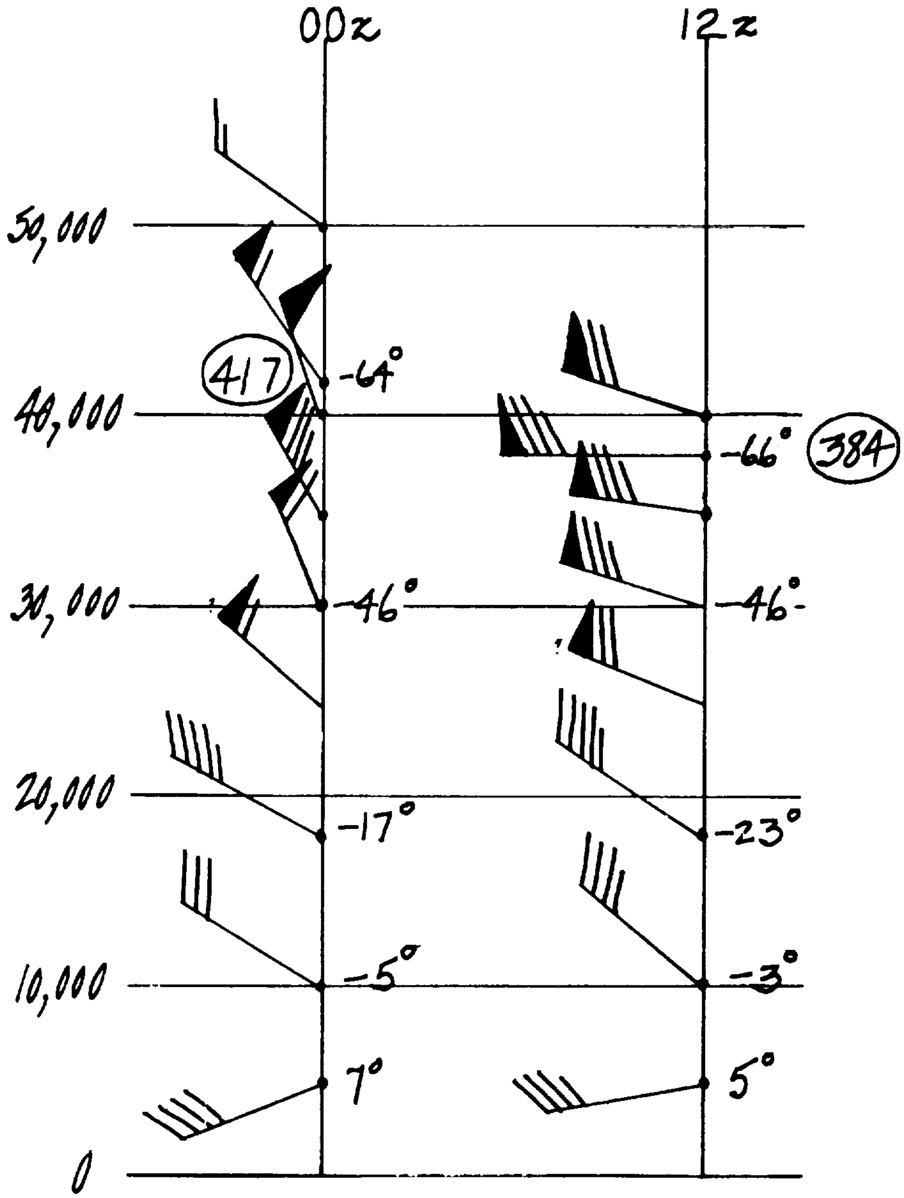


Figure 26. An abbreviated plot of the rawinsonde observations at Great Falls, Montana for 0000GCT and 1200GCT on March 17, 1964. Several features should be noted; (a) lowering and cooling tropopause, (b) increased instability above 30,000 feet, (c) increased stability between 18,000 and 30,000 feet and (d) backing of wind direction at high levels to give a more ideal mountain wave profile in the vertical.

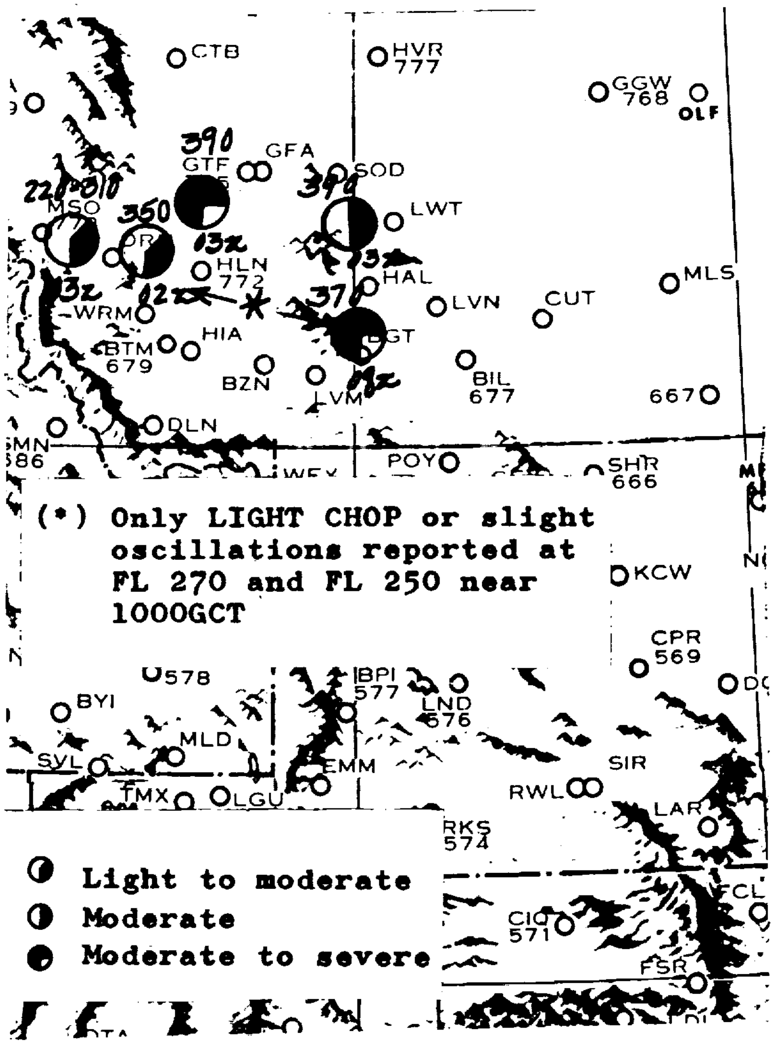


Figure 27. Location and intensity of known clear air turbulence in Montana on March 17, 1964.

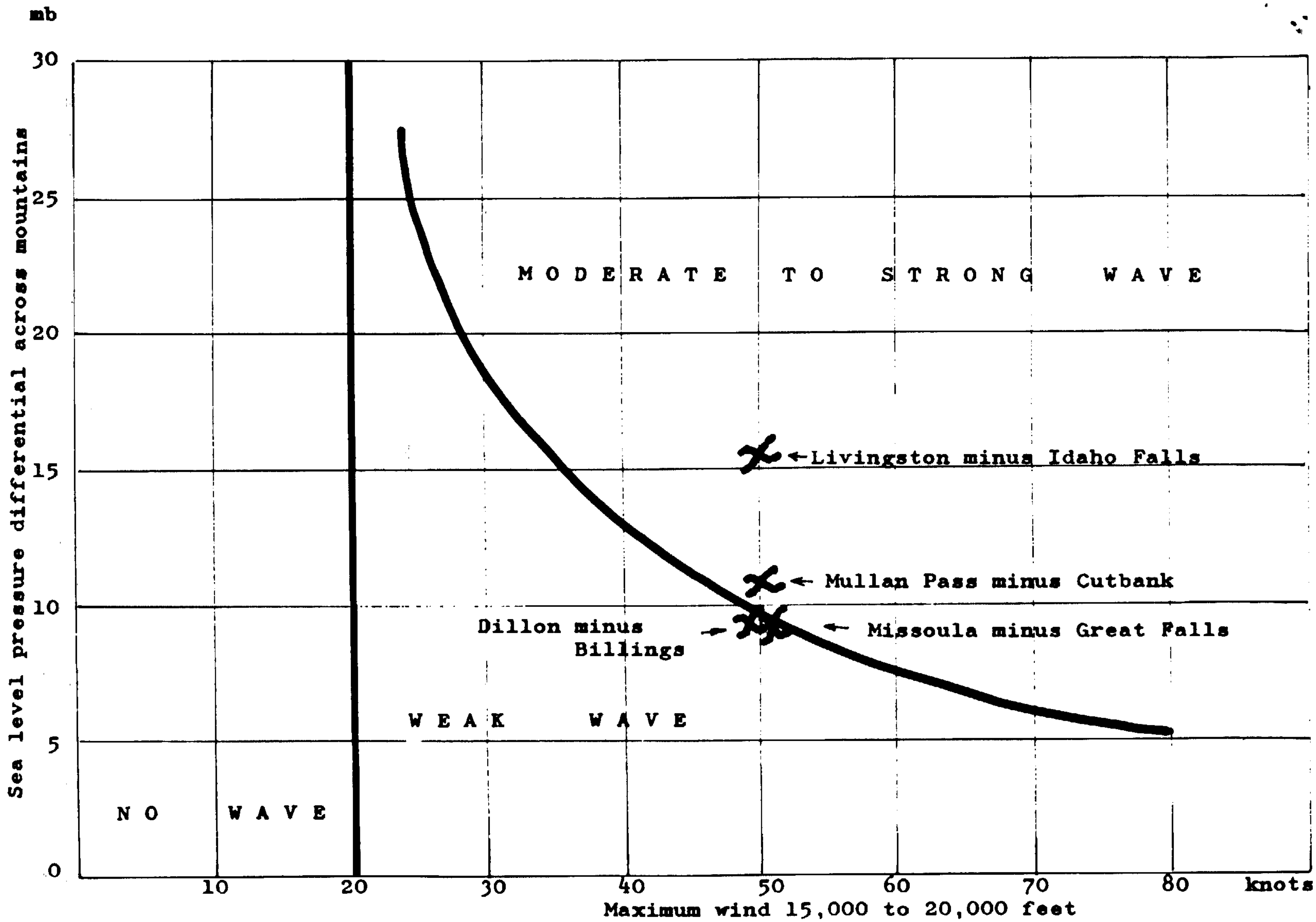


Figure 28. Intensity of the mountain wave in Montana at 0800GCT on March 17, 1964 based on index obtained from the UAL forecasting nomogram.

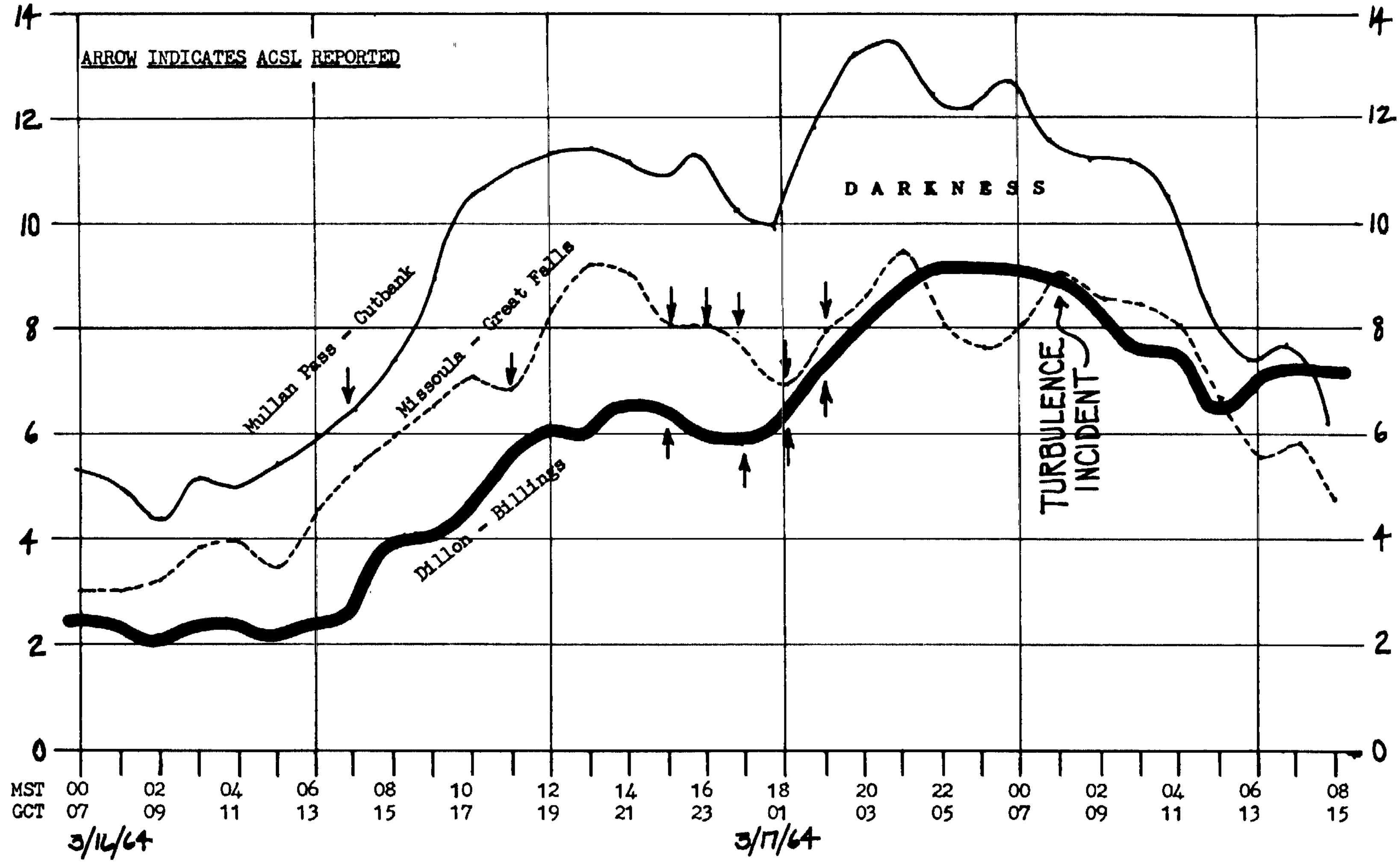


Figure 29. A plot of sea level pressure differences across the mountains in Montana on March 17, 1964. Note the general increase in the gradient as the lee trough sharpened and mountain wave lenticulars began to be reported.

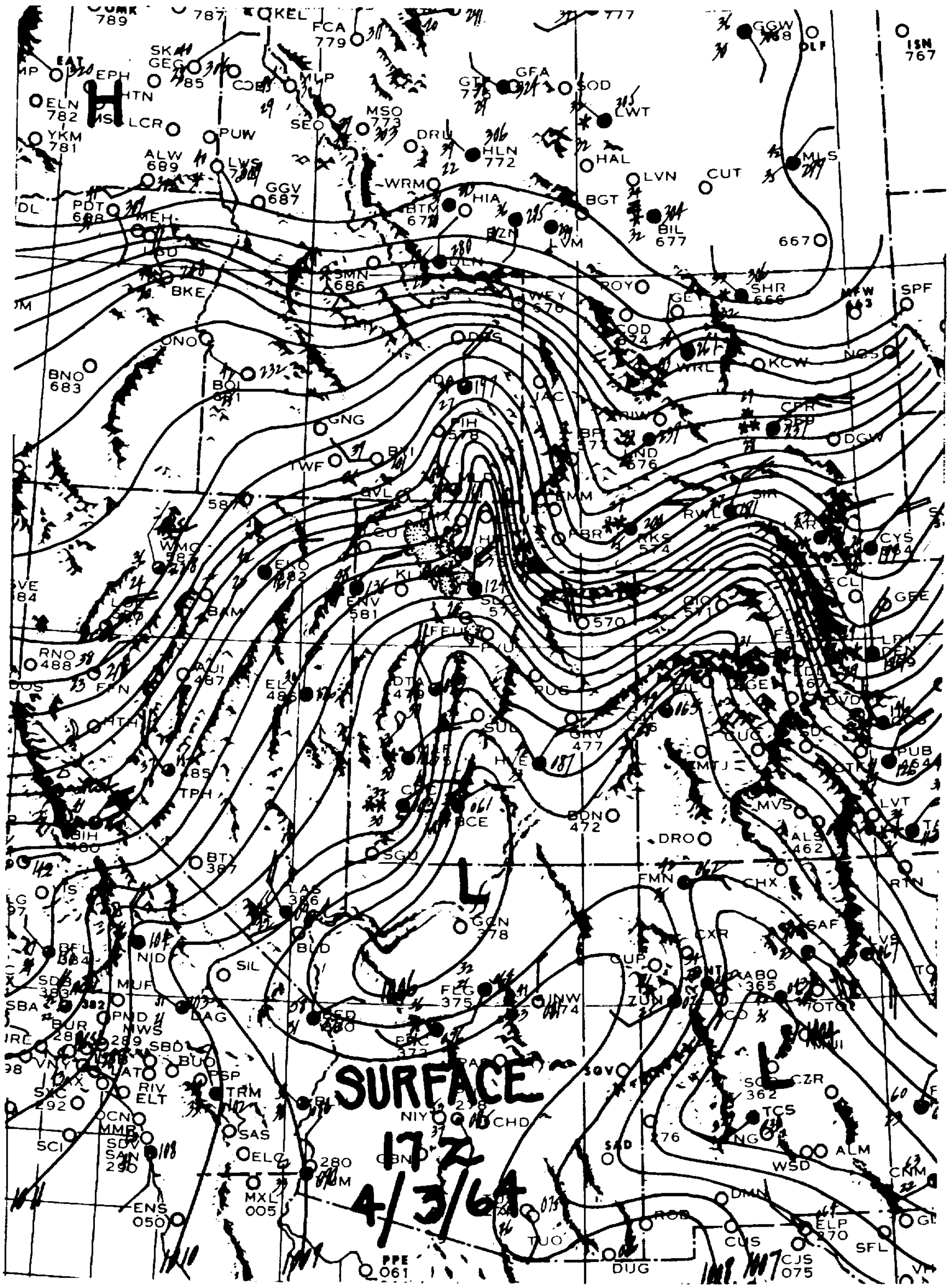


Figure 30. One-millibar sea level isobars over the Rocky Mountains at 1700GCT on April 3, 1964. Note the sharp lee trough induced to the west of the Wasatch Range by east winds of 40 to 50 knots blowing against the east side.

The Clear Air Turbulence Situation at Salt Lake City

1800GCT

April 3, 1964

An extraordinary type of turbulence which caught everybody by surprise, caused delays to airline jet flights and much turbulence to Air Force jets operating in and out of Hill Field. Twelve separate pilot reports of turbulence running from light to moderate to extreme were received over the Salt Lake Valley near midday (local time) on April 3, 1964. One B-57 reported "extreme turbulence at 7,500 feet 5N of Salt Lake City - almost uncontrollable" and there were three other cases of severe clear air turbulence reported. While most was low level there was one case of moderate turbulence at FL 350 by a B-707. Mountain wave rotor clouds formed directly over Salt Lake City Airport causing airline flights to be held on the ground.

General Weather Type

A strong east-wind type of mountain wave was in progress in the lee of the Wasatch Mountains over Salt Lake Valley. Winds were easterly at 45 knots between 10,000 and 20,000 feet and 50 to 65 knots between 25,000 and 38,000 where the tropopause was found. The Salt Lake City Weather Bureau is to be commended for an excellent job of reporting the wave because the suddenness of the appearance of the lenticular clouds and the rotors after daylight with an east wind blowing must have been something of a shock. Lenticulars were reported throughout the day until darkness cut them off. "Roll clouds" were reported along the mountains to the east at 1800GCT which was at about the height of the wave.

While the UAL nomogram was not designed for reverse mountain waves from the east, the index on this day did in fact put the wave in the edge of the moderate to strong category with a wind speed of 45 to 50 knots at 18,000 feet and a sea level pressure difference of 12 millibars between Lander and Salt Lake City.

This spectacular mountain wave was photographed in color by Mr. Philip Williams, meteorologist in charge at the Salt Lake City Weather Bureau, and in black-and-white by Mr. W. B. Beckwith of United Air Lines. Some of Beckwith's Polaroids were taken from a DC-8 cockpit in flight.

Features of Interest

The lesson to be learned from this case is that east winds can produce just as vigorous mountain waves as the conventional west wind types if they are deep enough vertically, if the air mass has at least one stable layer, and provided the terrain profile meets wave requirements. Moreover, it means that east-wind waves will occur several times every winter somewhere over the western part of the country when deep cold LOWS are centered to the south of a N-S mountain range which has a sharp dropoff to the west. The Santa Ana complex in southern California is one example. The case is also proof of the critical role played by the terrain profile. There are numerous instances every winter when strong west winds carry stable air up over the Wasatches but the mountain wave activity that develops on the east side of the range is minor compared to that which resulted in the wave of April 3, 1964. The reason is that the cascading air falls 2,000 more feet on the west side than it does on the east slope.

Steady light to heavy snow fell all day at Evanston on the east side of the Wasatches.

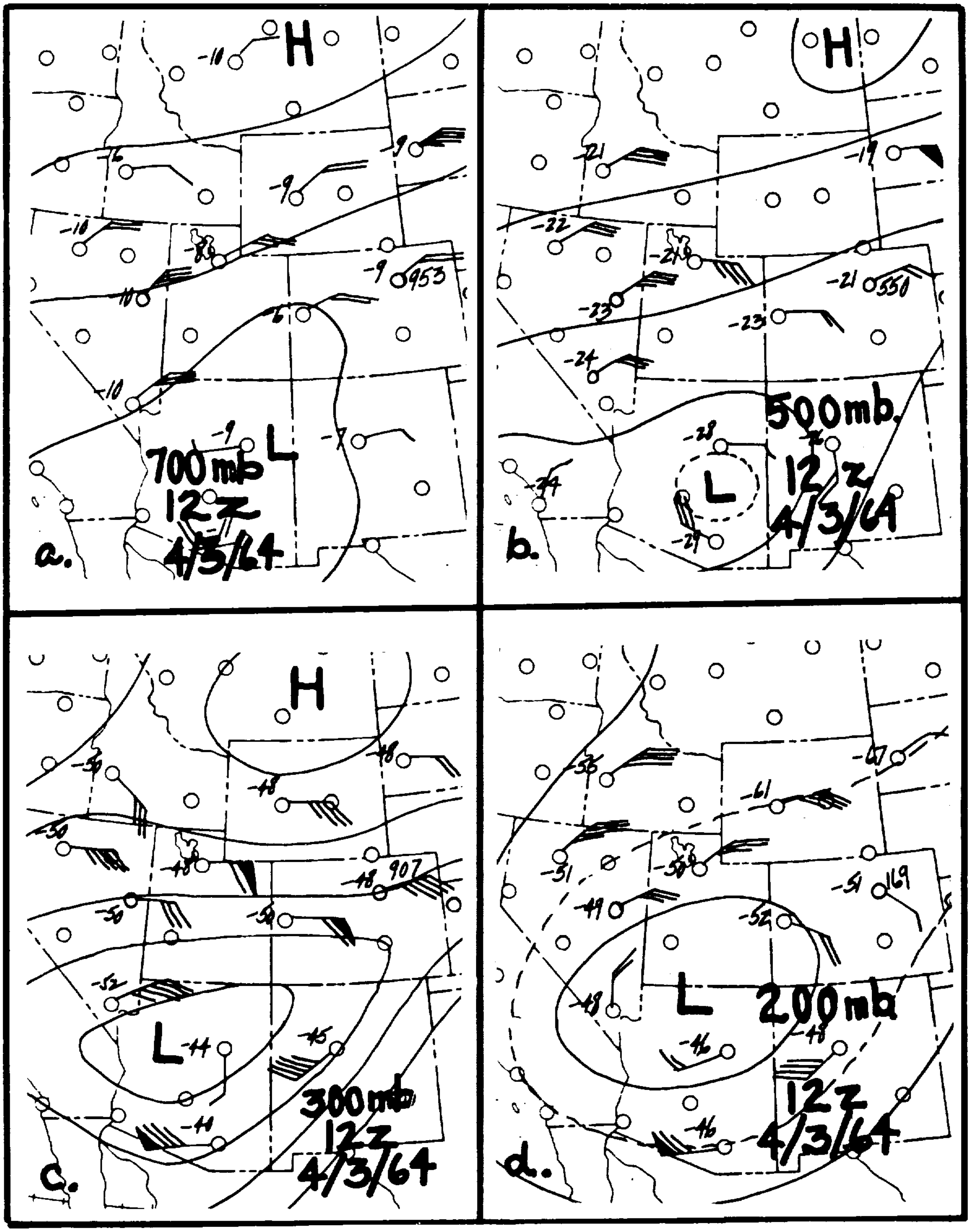


Figure 31. Upper air charts over the Rocky Mountains at 1200GCT on April 3, 1964.
a. 700 mb; b. 500 mb.; c. 300 mb; d. 200 mb.

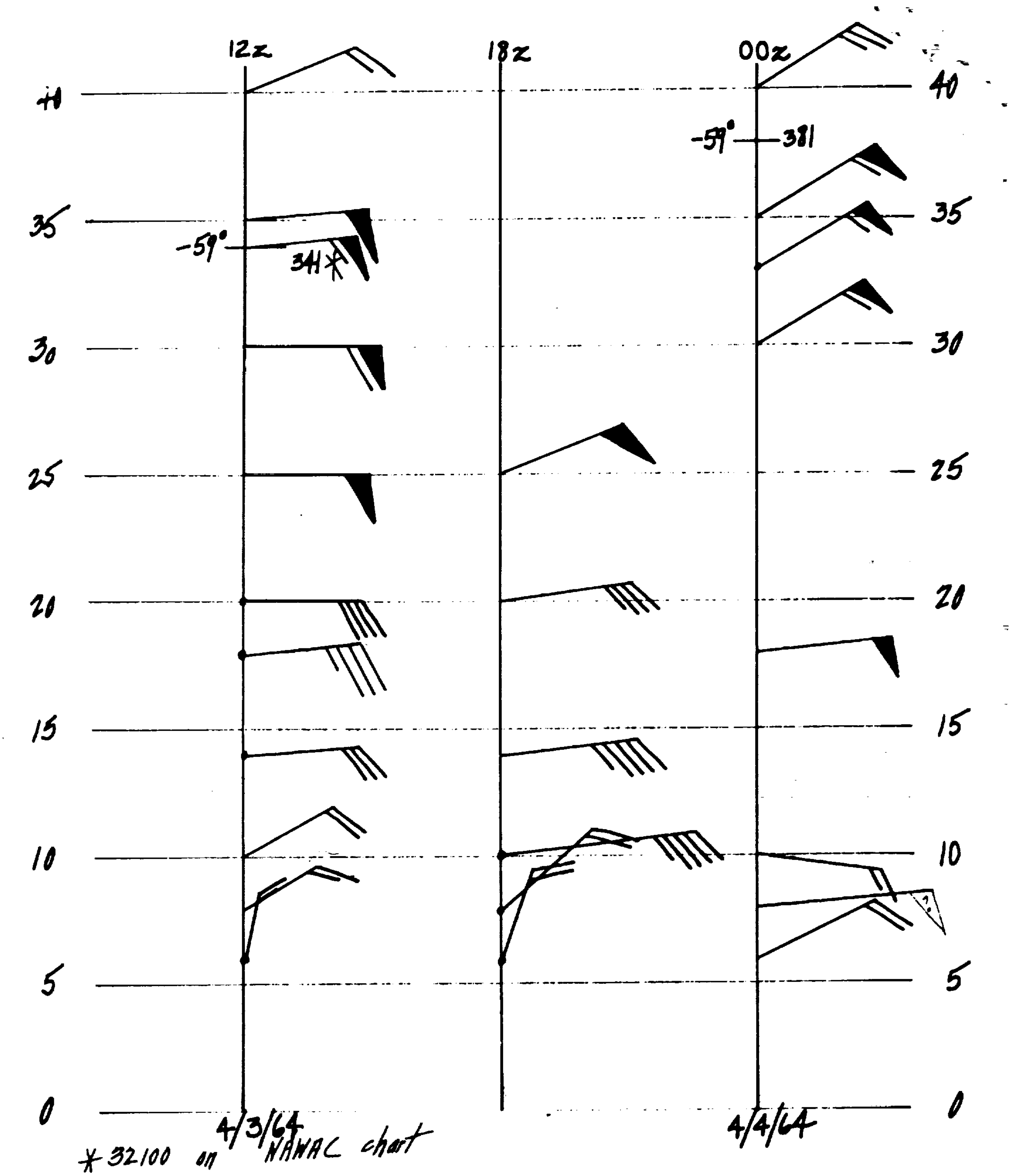


Figure 32. The vertical wind speed profile at Salt Lake City on April 3, 1964. Note the vertical shear of 25 knots in 2,000 feet starting at 8,000 at 1800GCT.

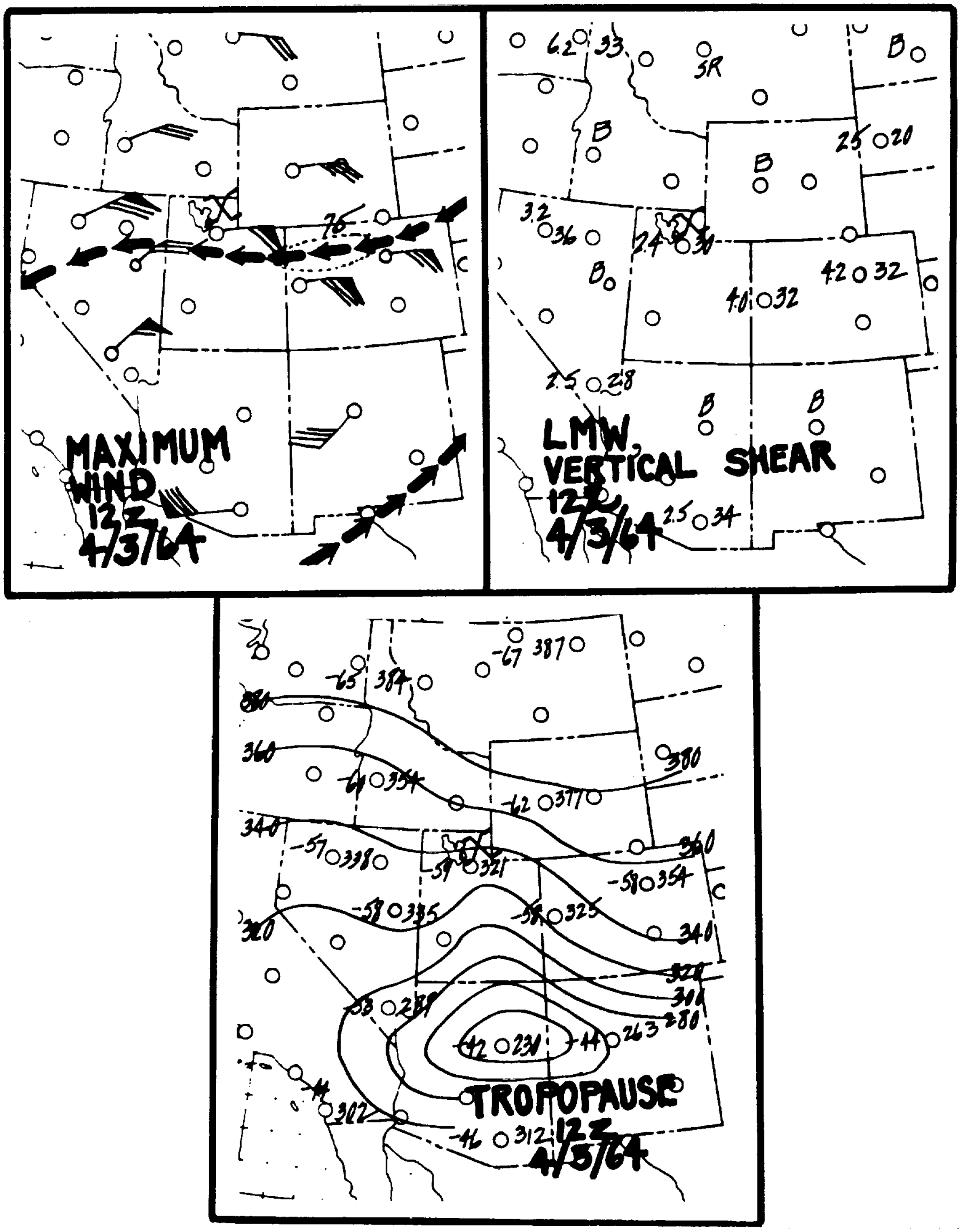


Figure 33. Additional upper air analyses for 1200GCT on April 3, 1964. a. Maximum wind chart; b. Level of maximum wind-vertical shear; c. Tropopause.

SEVERE

B-52 at low levels vicinity SLC
B-57 reported EXTREME at 7,500 5 N of SLC-"almost uncontrollable"
F-101 below 6,500 at 1725Z
C-47 on the approach to Hill AFB at 1725Z

MODERATE TO SEVERE

F-101 surface to 9,000 at 1604Z
T-39 surface to 12,000 at 1415Z
B-727 surface to 10,000 at 21Z

MODERATE

DC-8 surface to 10,000 SLC to 10 west
B-707 at 35,000 near Bonneville at 22Z

LIGHT TO MODERATE

C-47 SW of MLD at 12,000 at 18Z
B-720 SLC to OGD at 11,000 at 16Z
B-57 at 43,000 OGD to SLC

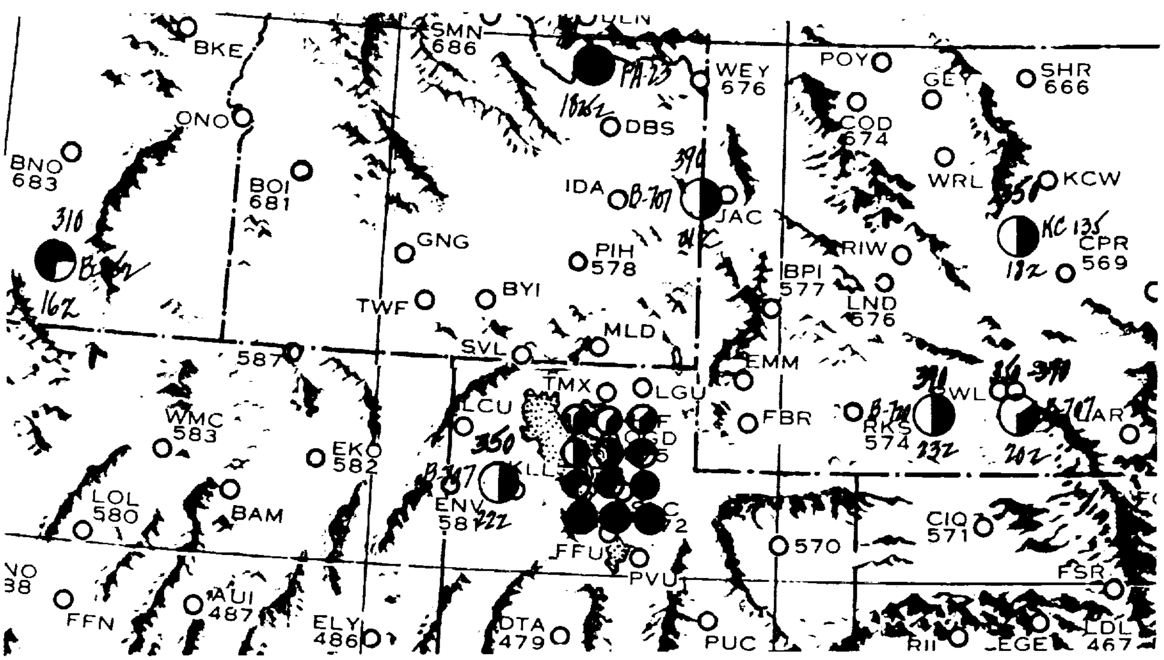


Figure 34. Pilot reports of clear air turbulence over the central Rocky Mountains near midday on April 3, 1964. Note the cluster of 12 reports in the Salt Lake Valley ranging in intensity from light-moderate to extreme.

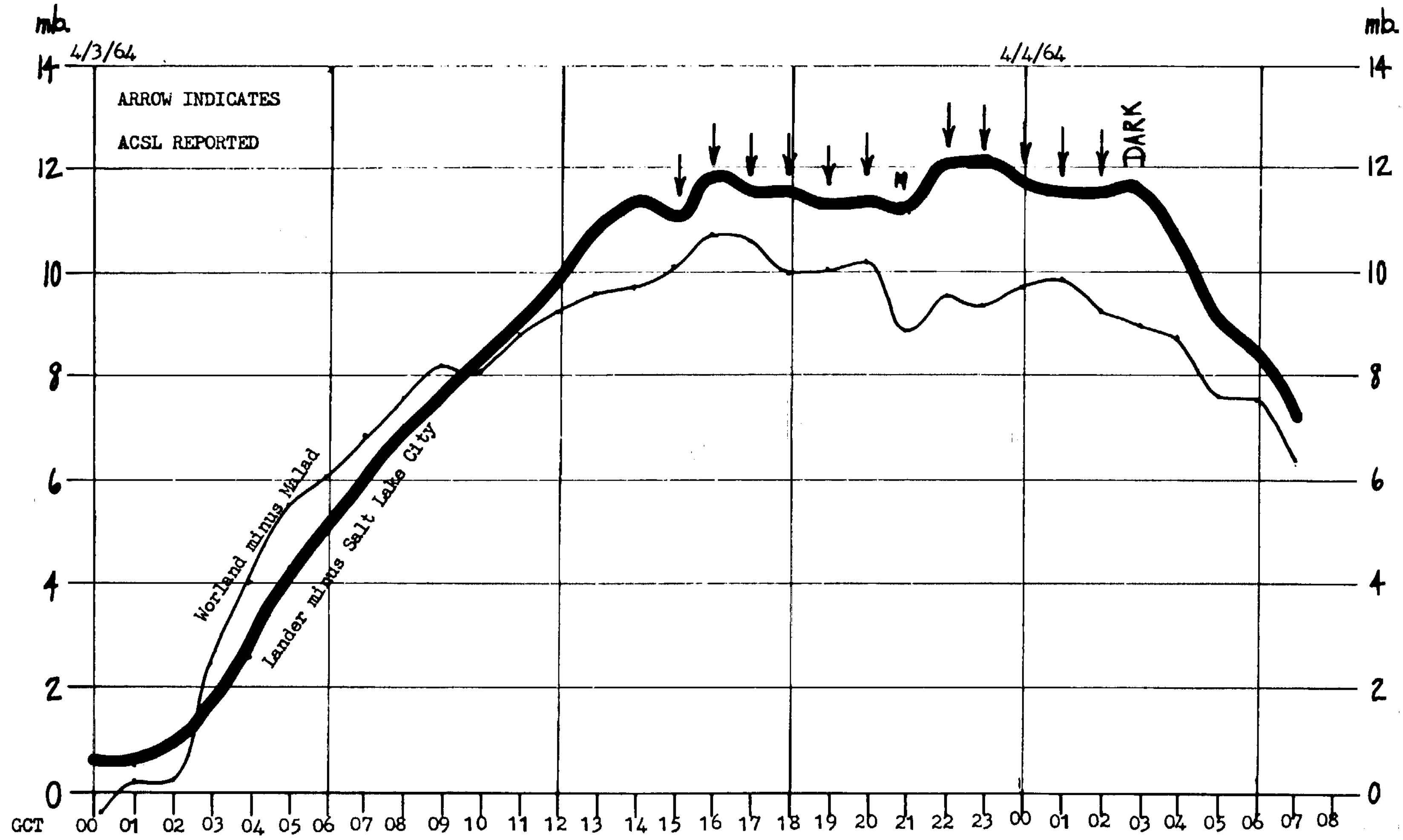


Figure 35. A plot of sea level pressure difference trends across the Wasatch Mountains on April 3, 1964.

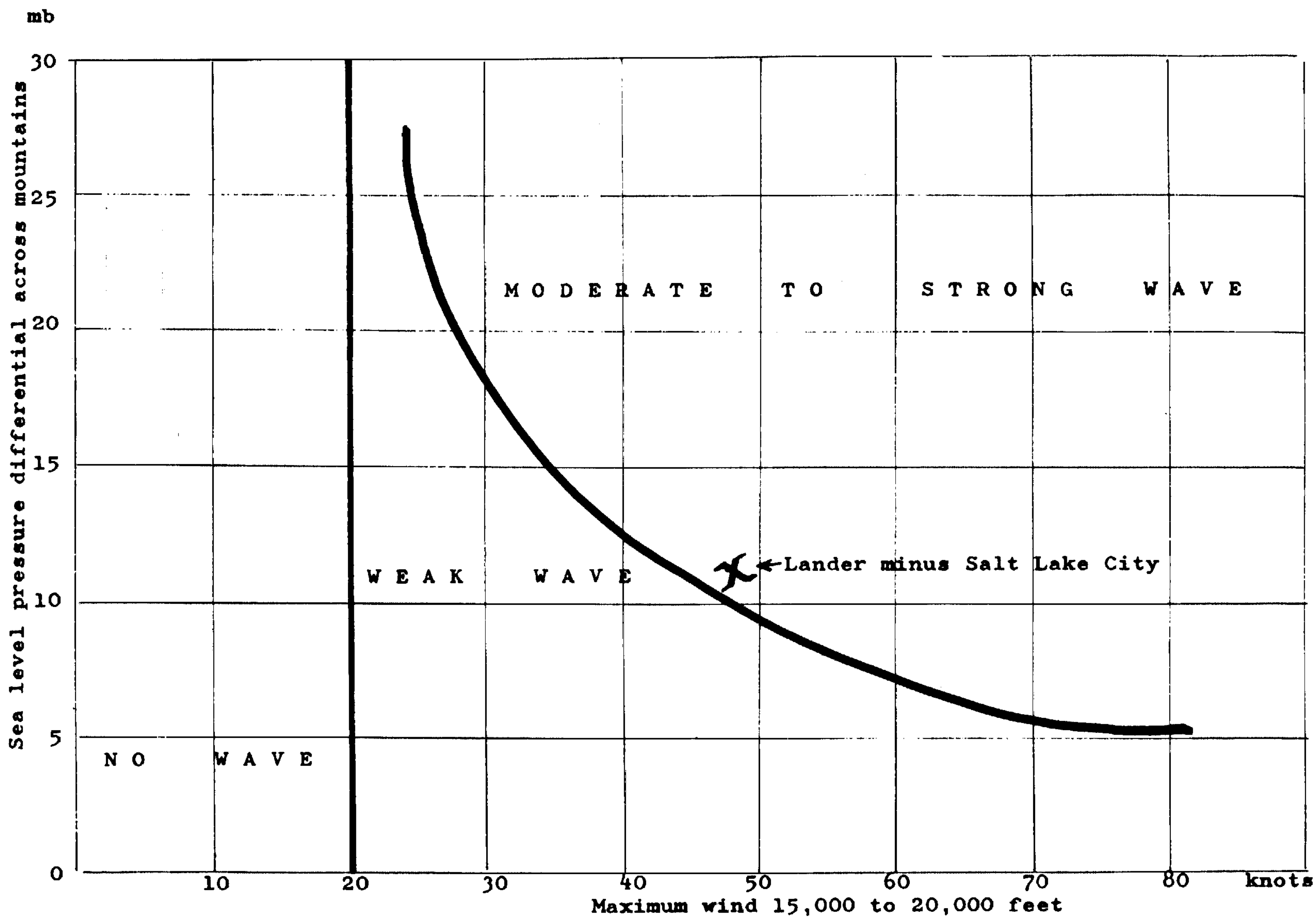


Figure 36. Index of mountain wave intensity at Salt Lake City on April 3, 1964 based on reference to UAL mountain wave forecasting nomogram.

NASA-Langley, 1965 CR-315

The Clear Air Turbulence Situation Near Crazy Woman, Wyoming

2000GCT

September 25, 1964

The Incident

A four-engine airline jet transport "encountered one jolt" at FL 310 or 290 while near Crazy Woman, Wyoming at 2000GCT on September 25, 1964 which is reported to have caused the injury of one woman passenger who was not belted in. In addition to this one severe case of turbulence, there was a moderate turbulence report by a B-707 at 2200GCT and another moderate turbulence report by a C-135 at 2100GCT in this section. The B-707 occurred at FL 350 and the C-135 was found between FL 290 and 370.

General Weather Type

A mountain wave was in operation on this date in the lee of the continental divide and the eastern Rockies in Colorado, Wyoming, Montana and Idaho as evidenced by ACSL (lenticular) clouds reported by hourly weather stations in those states. The incident probably occurred about 20 miles west of Crazy Woman in the lee of the Big Horn Mountains which rise at this point to 10,555 at Mt. Hazleton and the dropoff to the lee is nearly 6,000 feet. These mountains are oriented N-S and the chain is concave for west winds.

Further evidence for mountain wave at this spot was provided by reference to the United Air Lines mountain wave nomogram where a plot of the sea level pressure difference of 13 millibars and a maximum wind speed of 61 knots below 20,000 feet called for a moderate to strong wave over northern Wyoming. The wind direction of 270^{o} was perpendicular to the Big Horn Mountains and the upwind air mass sounding at Lander showed stable air below the mountain top level.

The polar front jet stream was lying 175 miles to the north across Montana and was showing a steady southward progression during the day. Wind speeds were between 80 and 90 knots at 30,000 to 40,000 feet. Both horizontal and vertical wind shear were slight at upper levels but a vertical shear of 8 knots per 1,000 feet was measured below 19,000 feet on the Lander sounding for 0000GCT on the 26th.

The date was early for a moderate to strong mountain wave but this is not unusual at this latitude. Waves are known to occur regularly throughout the twelve months in Montana and northern Wyoming.

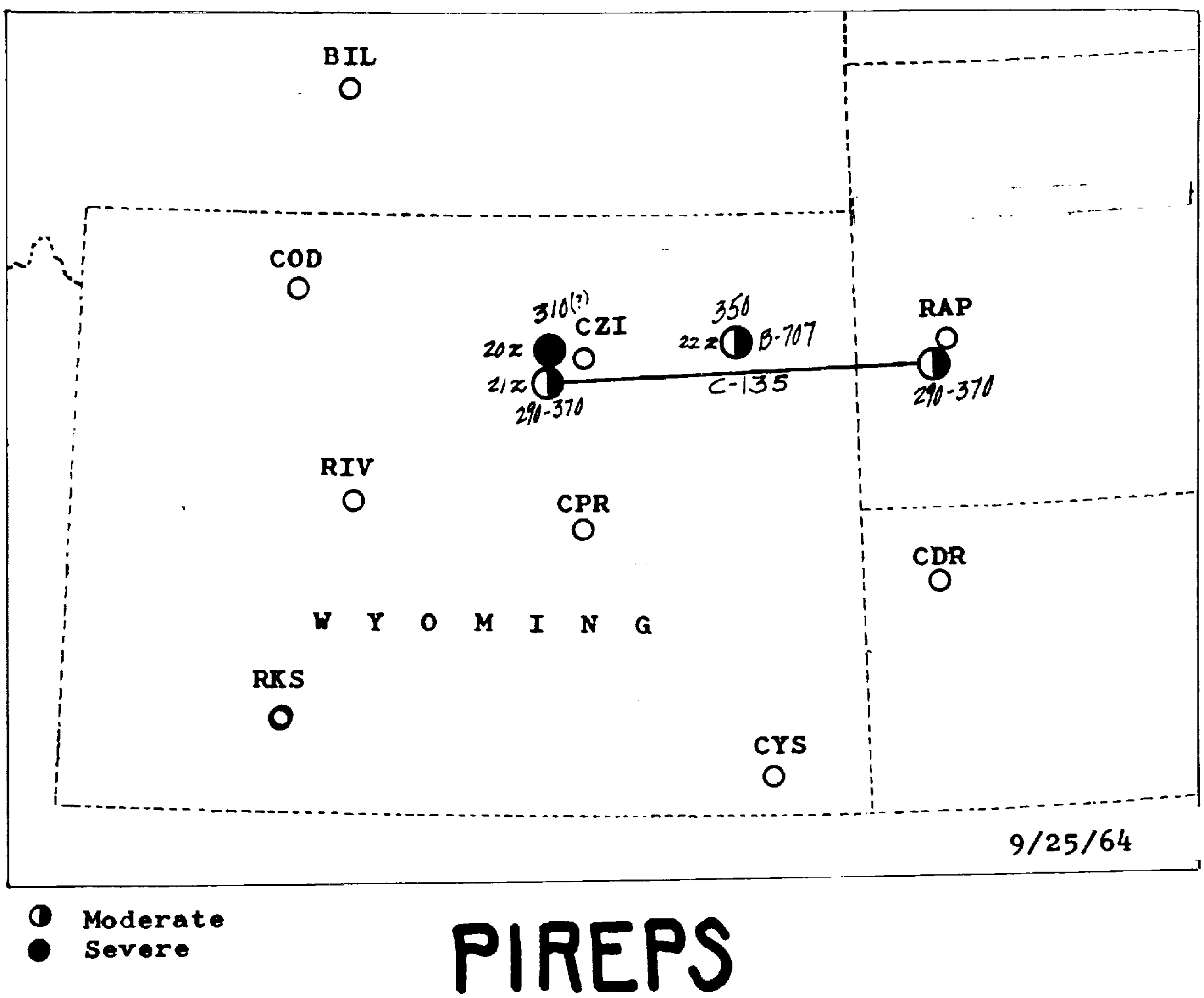


Fig. 37 Pilot reports of clear air turbulence over northeastern Wyoming on September 25, 1964.

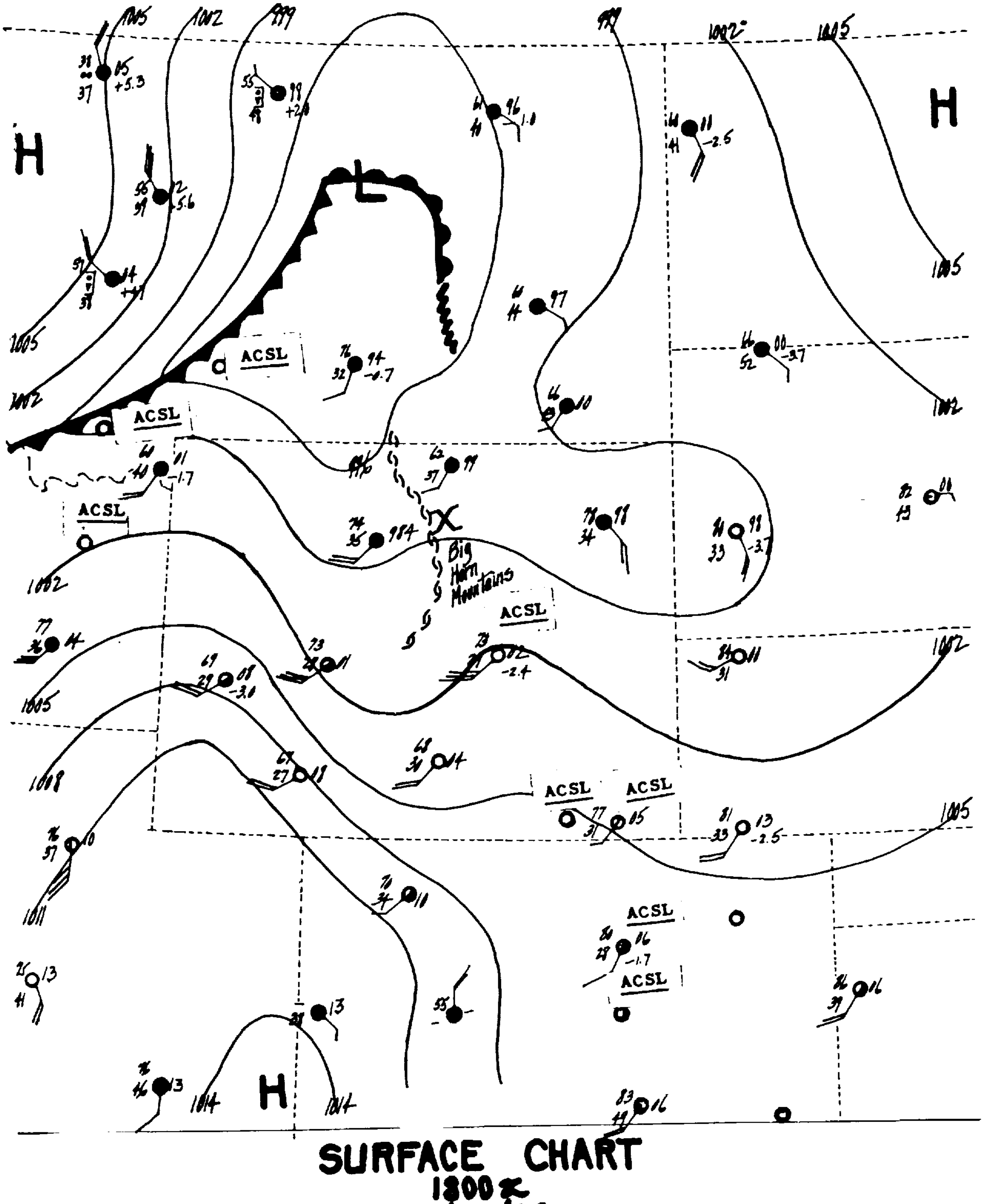


Fig. 38 Panel of the surface chart for 1800GCT on September 25, 1964. Note the typical lee trough and the wave cloud reports.

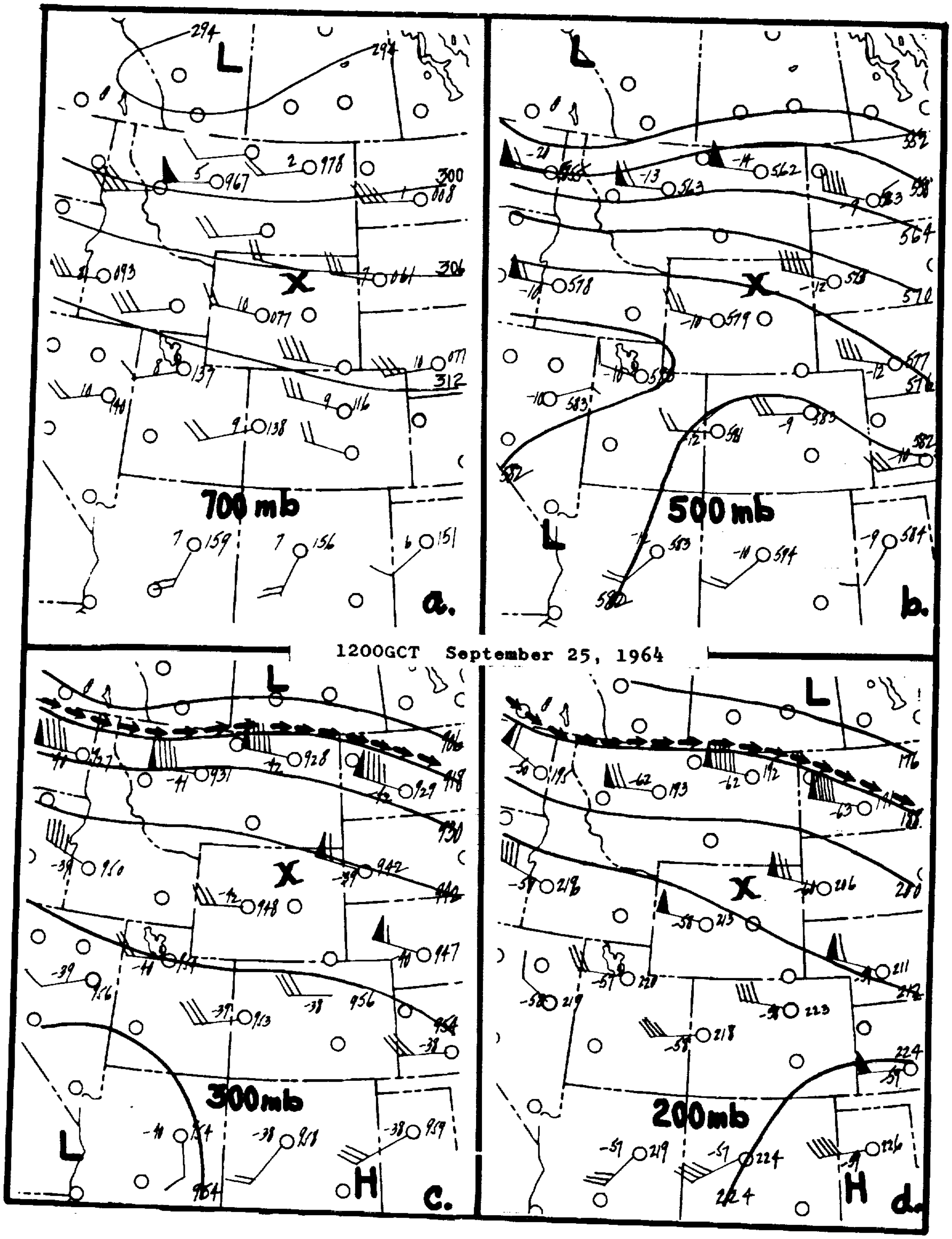


Fig. 39 Panels of upper air charts at 1200GCT on September 25, 1964. a. 700 mb.; b. 500 mb.; c. 300 mb.; d. 200 mb.

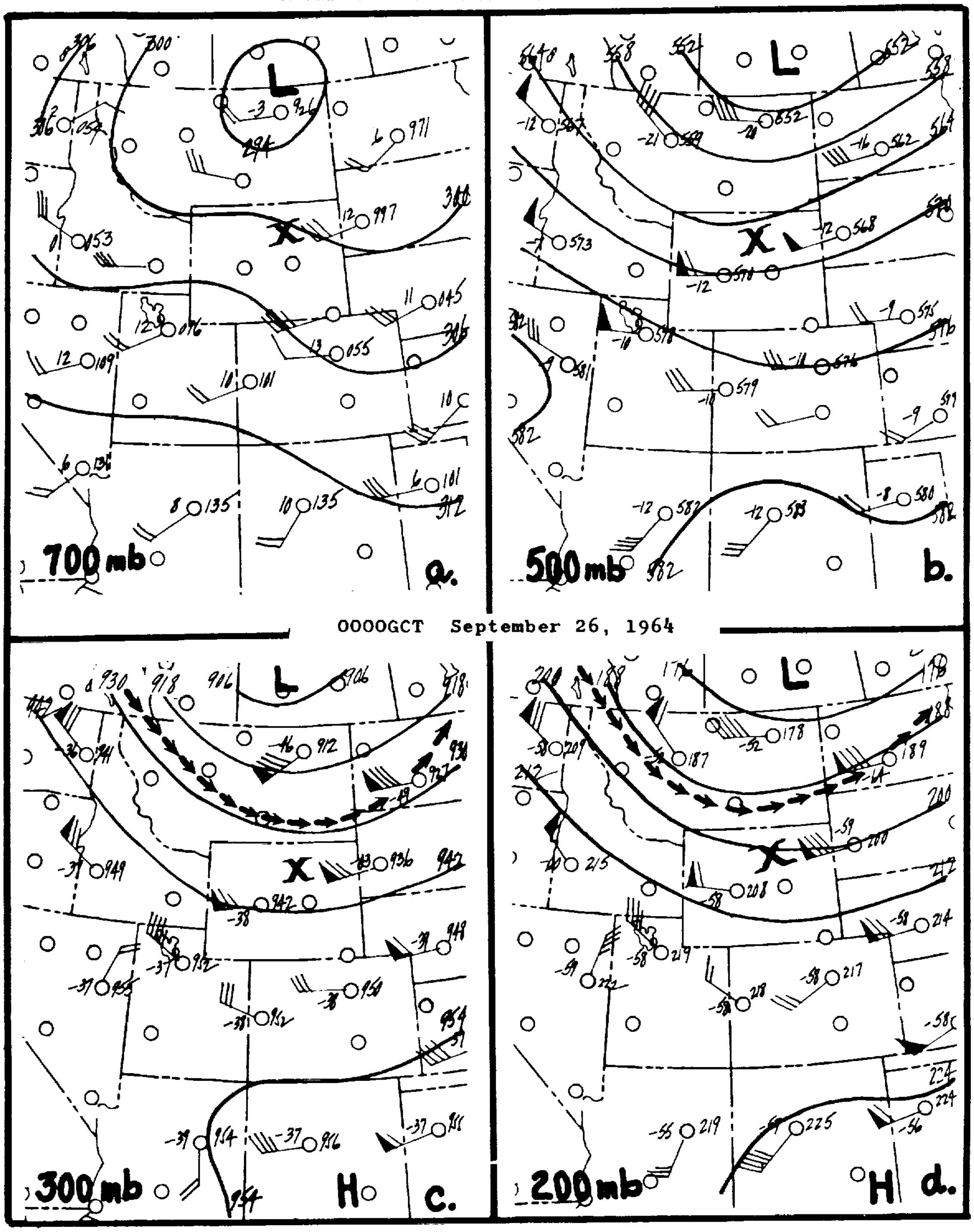


Fig. 40 Panels of upper air charts at 0000GCT on September 26, 1964. a. 700 mb.; b. 500 mb.; c. 300 mb.; d. 200 mb.

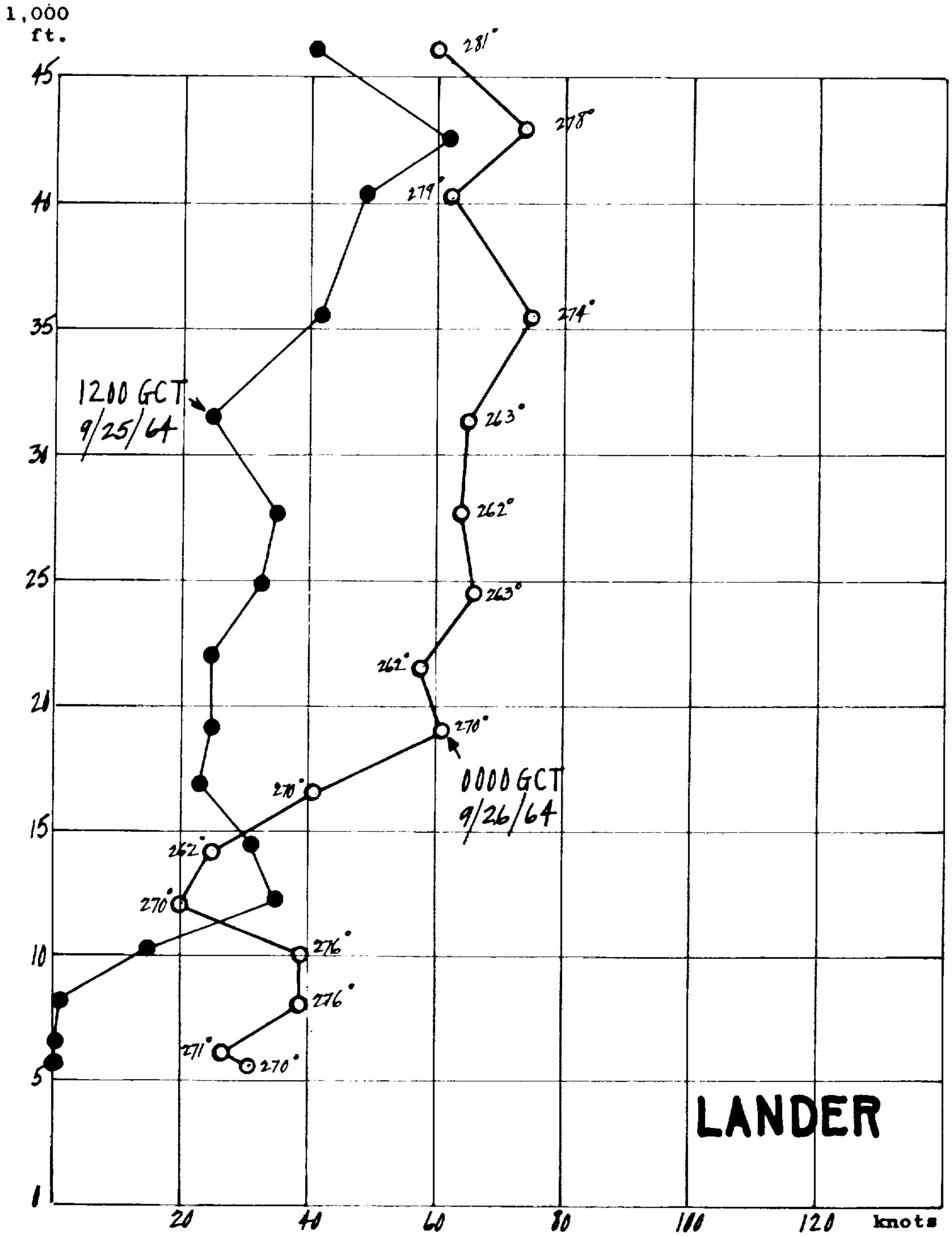


Fig. 41 Vertical wind speed profiles at Lander, Wyoming at 1200GCT on September 25, 1964 and at 0000GCT on September 26, 1964.

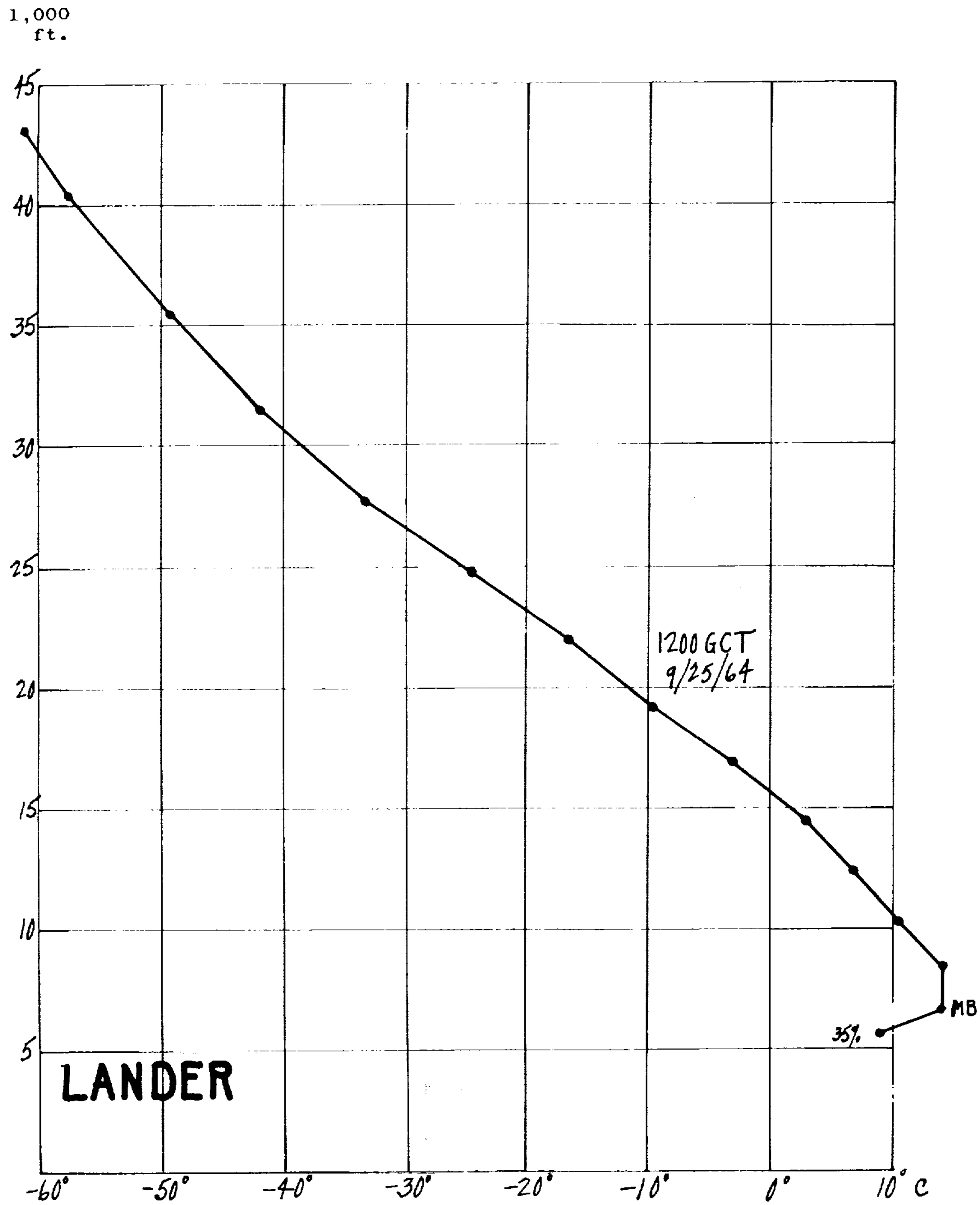
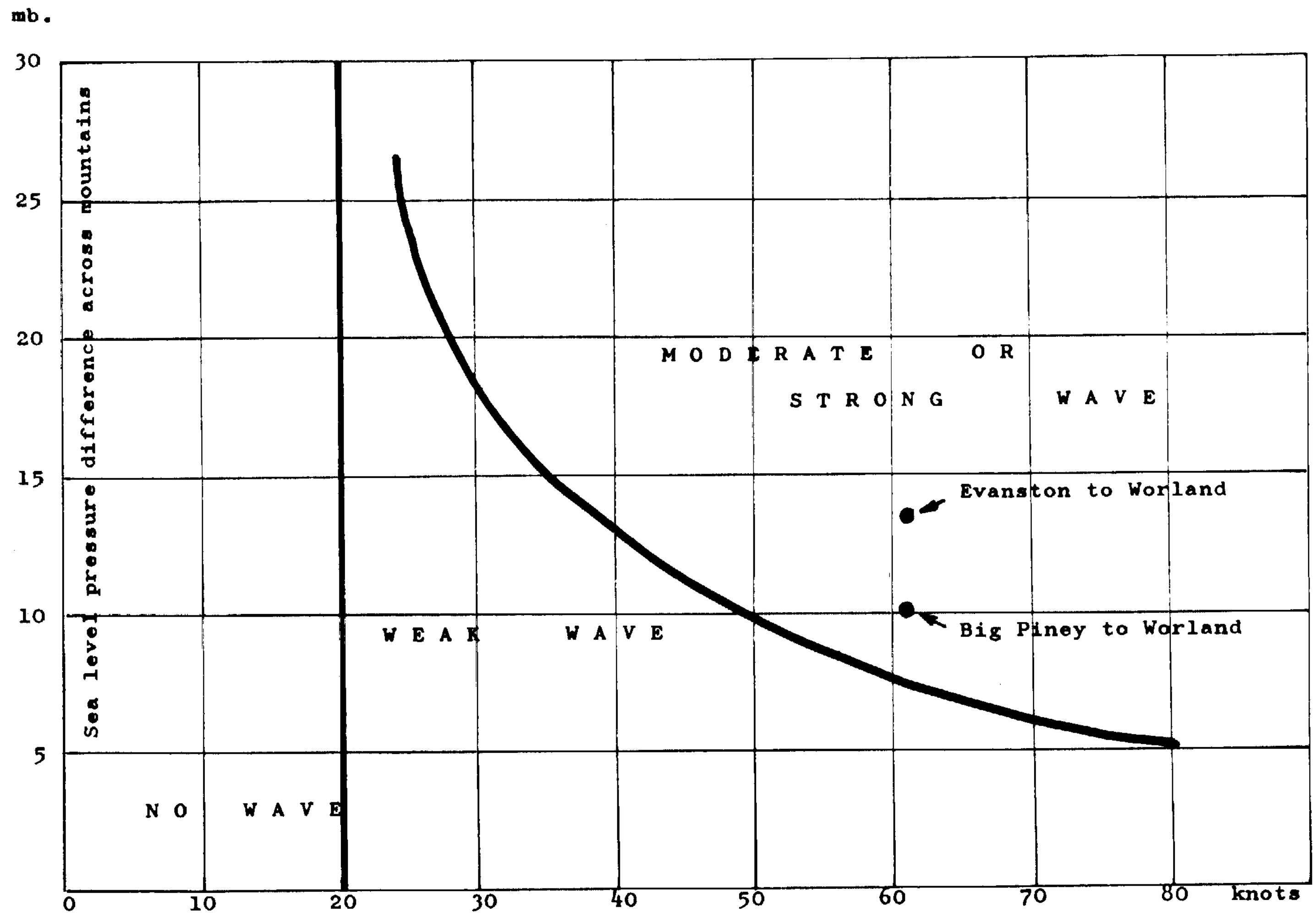


Fig. 42 Temperature-moisture sounding above Lander, Wyoming at 1200GCT on September 25, 1964. This upwind air mass sounding shows stable air beneath the mountain top level from 9,000 down to the surface.



MOUNTAIN WAVE NOMOGRAM
(United Air Lines)

Fig. 43 Mountain wave index over northern Wyoming on September 25, 1964 as obtained by plotting maximum wind speed up to 20,000 feet of 61 knots against the sea level pressure difference across the mountains on the United Air Lines mountain wave nomogram.

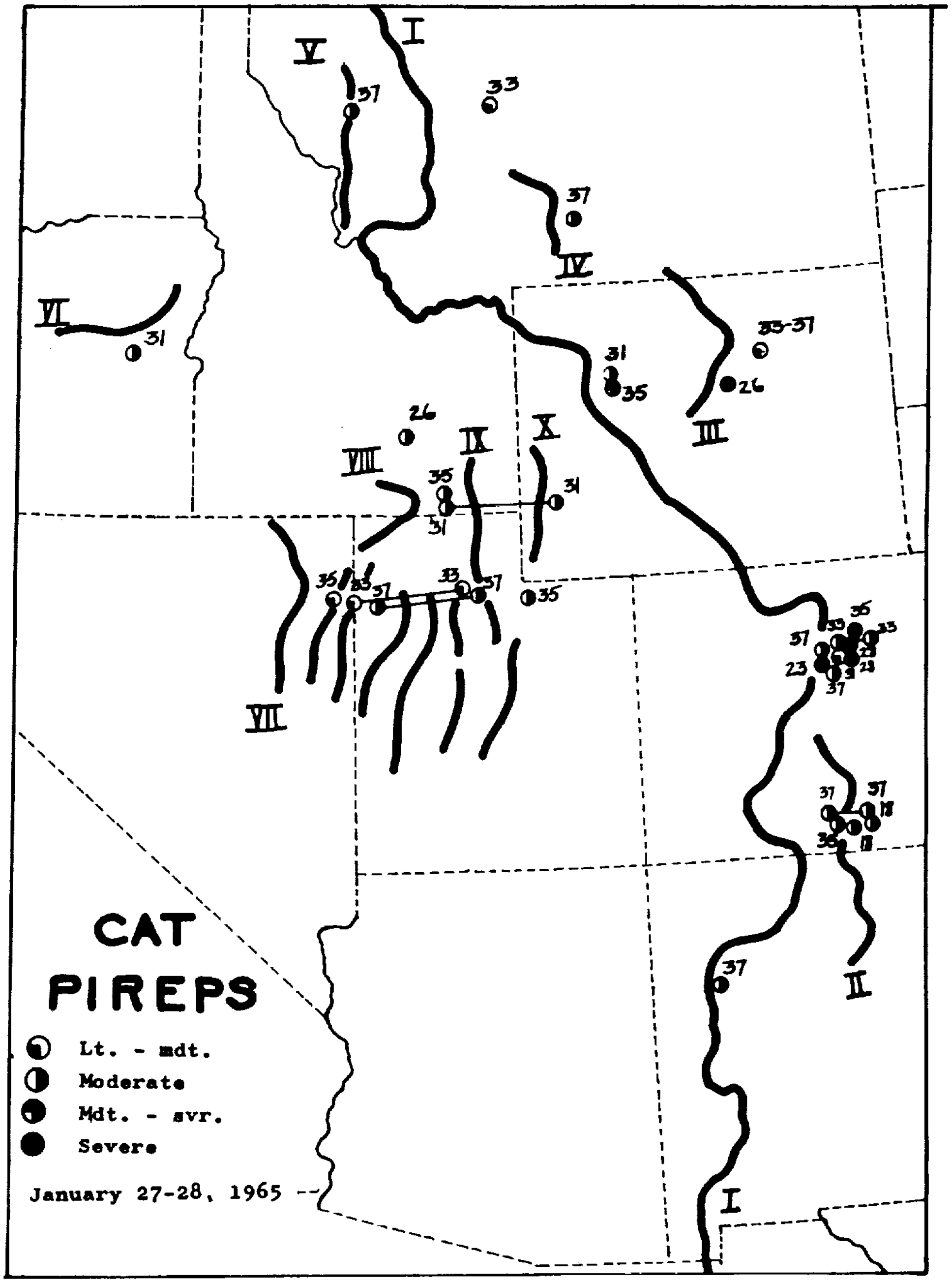


Fig. 44 Location and flight level of civil and military CAT PIREPS from 0000GCT on January 27, 1965 to 1000GCT on January 28, 1965. Note that all except the case near Pocatello might be explained by lee of the mountain effect. Mountains and ridges that were involved, all of them meeting requirements of major wave breeders, were; I) Continental divide; II) Sangre de Cristo; III) Big Horn; IV) Crazy; V) Mission-Bitterroot; VI) Blue; VII) Series of N-S ridges; VIII) Raft River; IX) Wasatch; X) Salt River

The Clear Air Turbulence Situation Over the Rocky Mountains

2325GCT

January 27, 1965

The Incident

An airline B-720 reported "severe mountain wave turbulence" for $1\frac{1}{2}$ minutes while climbing through FL 230 in the lee of the continental divide west of Denver at 2325GCT on January 27, 1965. No damage and no injuries resulted but the captain reported that "the shaking of the plane made it difficult to reach the controls and to read the instruments", that vision and observation of the instruments were impaired by the G forces.

This case was only one of more than two dozen turbulence encounters on this date over an eight-state area which stretched from New Mexico to Montana and westward through Utah, Idaho, Nevada and Oregon. From reference to Fig. 44, it will be seen that all of these reports carry a strong mountain wave suggestion because they occurred in the lee of prominent ridges which meet topographical requirements for major wave breeders. All of these reports were above FL 150 and most were above FL 300. In addition to these predominantly jet aircraft cases, numerous other reports were received from piston-engine flights of severe to extreme turbulence at lower levels.

General Weather Type

Synoptic conditions were ideal to create extensive mountain wave activity over the eastern Rockies. A well established warm HIGH covered the southern Plateau Region from Nevada to western Colorado with a pronounced lee side trough in the sea level isobars along the continental divide from Montana to New Mexico. (Next to the ACSL cloud reports on the hourly sequences, this sharp frontless trough in the lee of the divide is probably the most positive identifier of the wave that we have.) In Colorado, where the wave was analyzed in some detail, upper winds were strong, but not excessive, from west-northwest and the usual stable layer was found in the upwind sounding at Grand Junction below the mountain top level from 10,000 to 13,000 feet. The deviation of the wind from the perpendicular-to-the-mountain at Denver is a common occurrence. Some of the strongest waves there have been observed to show up suddenly as the upper wind flow backs from 350° to about 330°.

At Denver there was a moderately strong vertical shear shown below 14,000 feet but, outside of this, both horizontal and vertical wind shear were negligible. On the United Air Lines nomogram, the wind speed of 58 knots plotted against a sea level pressure difference of 18 millibars between Grand Junction and Denver called for a moderate to strong wave.

ACSL lenticulars were reported in the lee of the divide in Colorado and in the lee of the N-S ridges in eastern Nevada. To the north, across Wyoming and Montana, lower cloud sheets would probably have prevented observation of any lenticulars above.

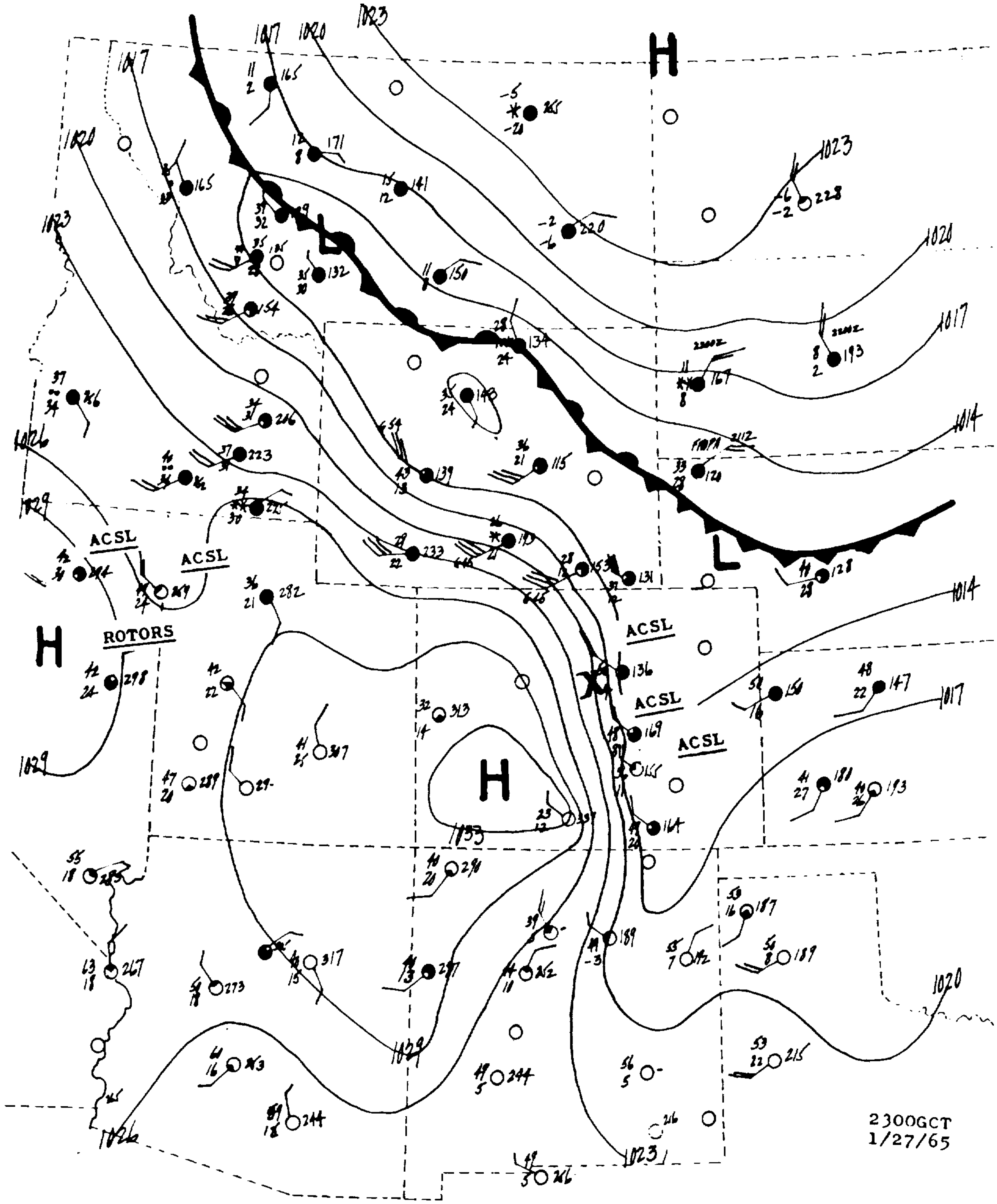


Fig. 45 Panel of surface chart for 2300GCT on January 27, 1965. Note the characteristic lee trough along the length of the continental divide and the warm HIGH over the Plateau Region.

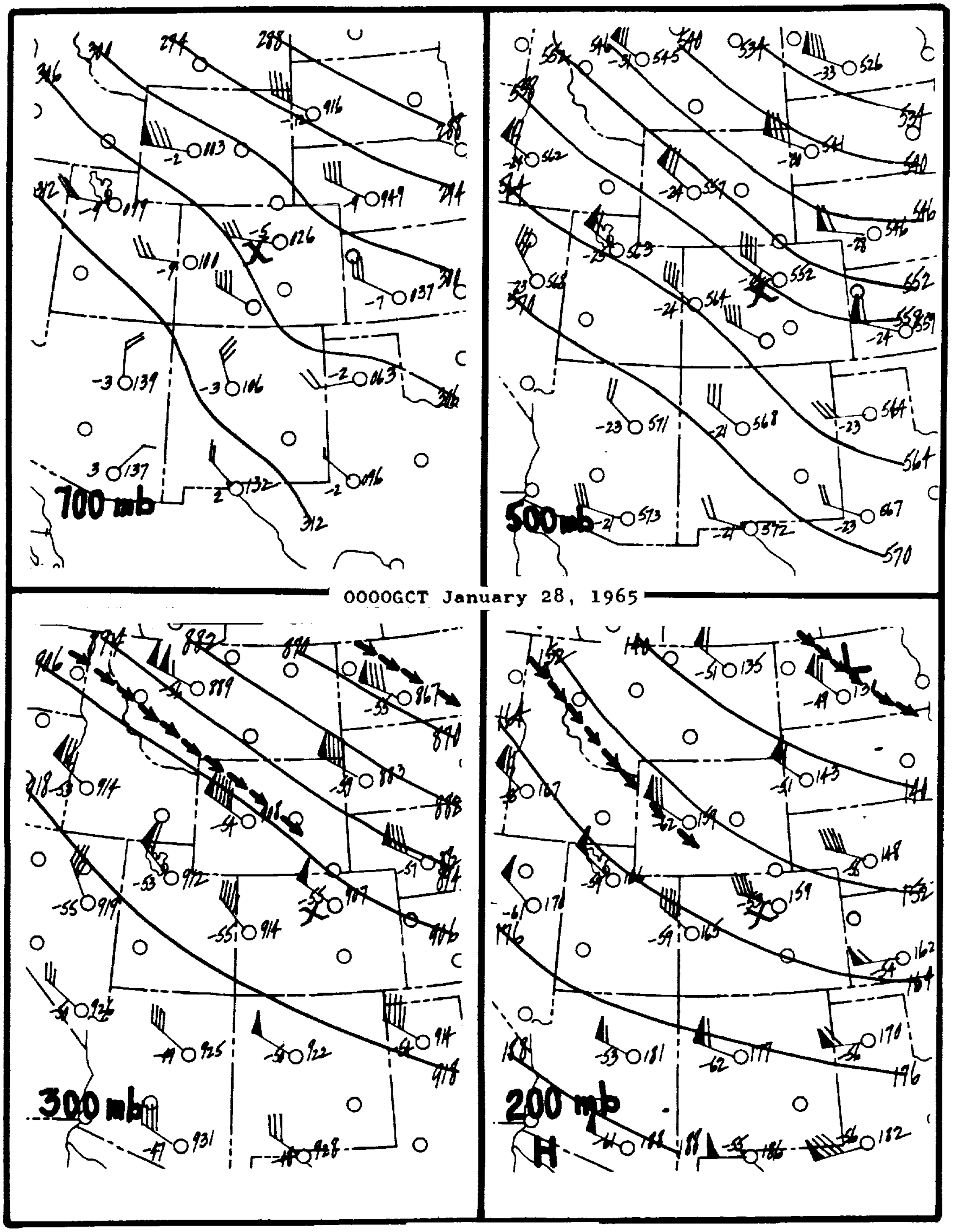


Fig. 46 Panels of upper air charts at 0000GCT on January 28, 1965. Jet stream positions are NMC analyses.
a. 700 mb.; b. 500 mb.; c. 300 mb.; d. 200 mb.

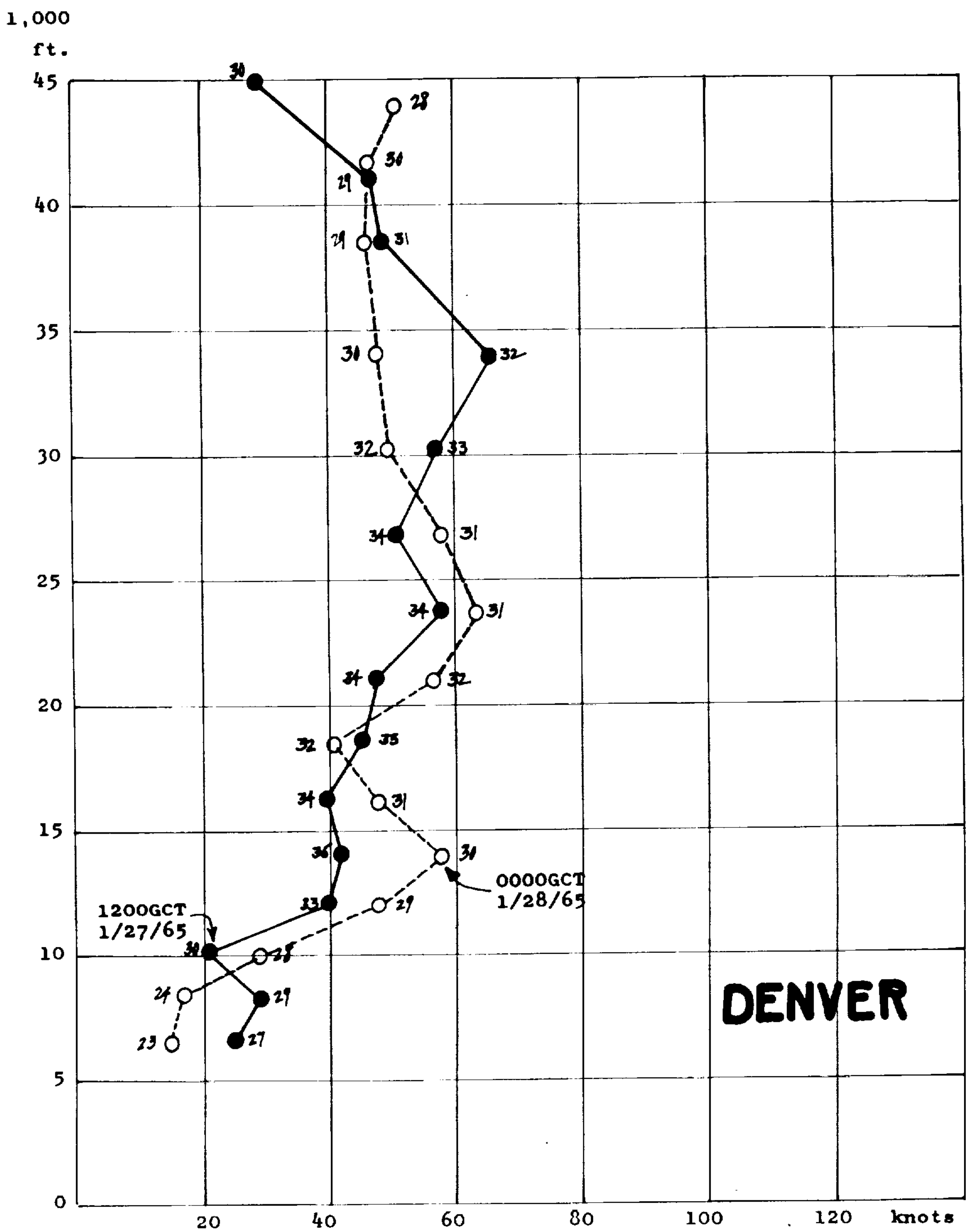


Fig. 47 Wind speed profiles above Denver, Colorado at 1200GCT on January 27, 1965 and at 0000GCT on January 28, 1965. Note that vertical wind shear is negligible above 14,000 feet.

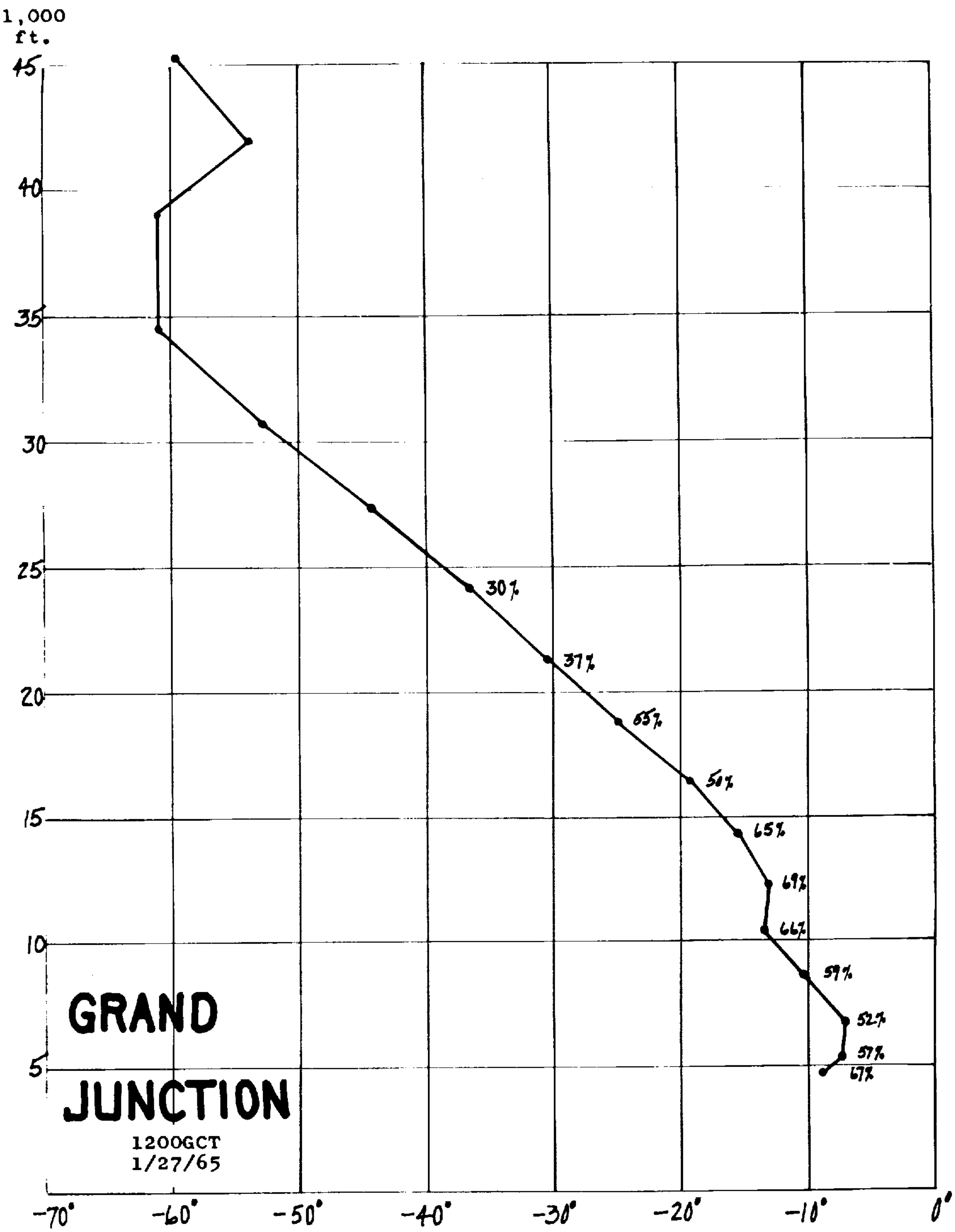
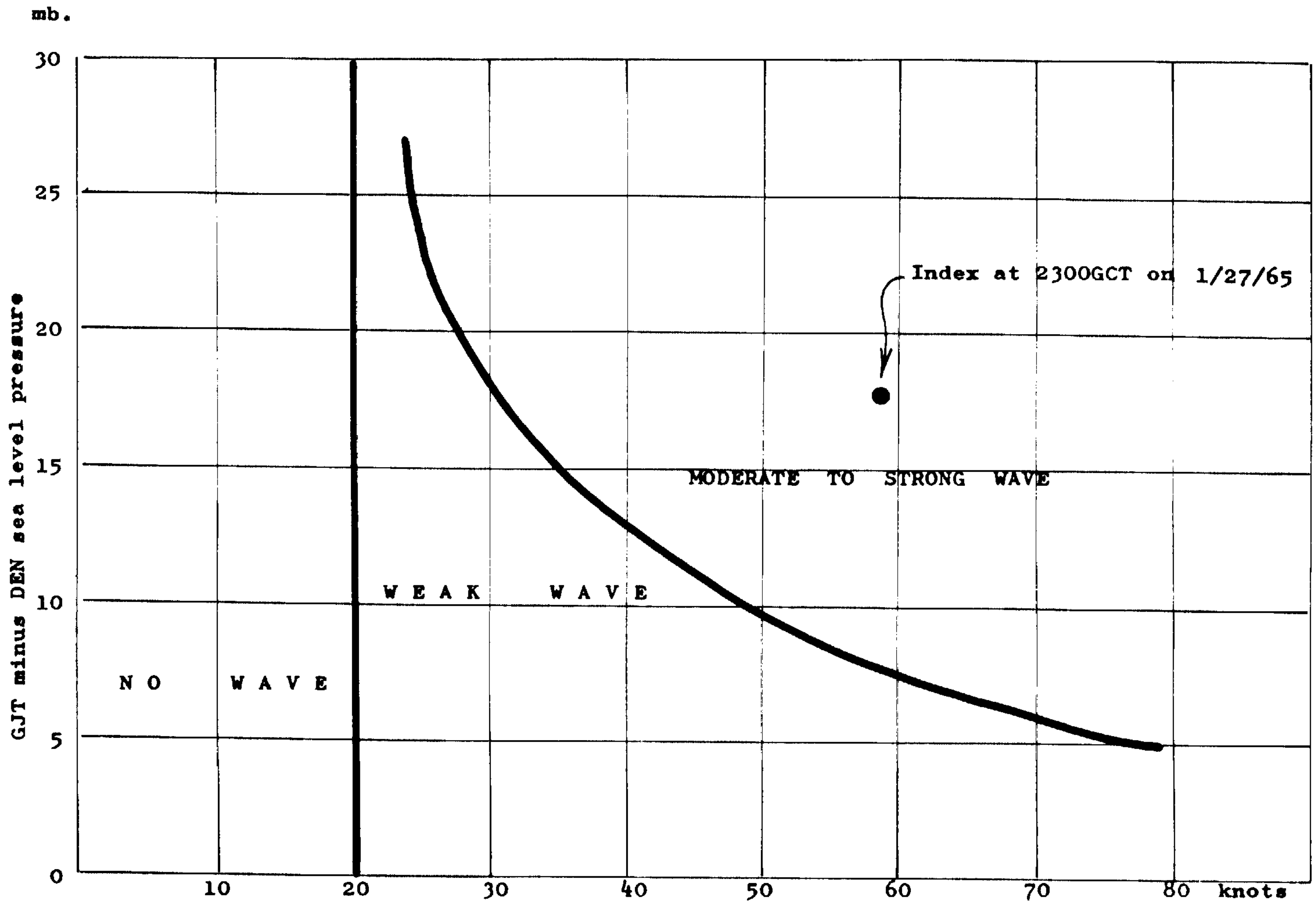


Fig. 48 Temperature-moisture sounding above Grand Junction, Colorado at 1200GCT on January 27, 1965. The characteristic stable layer is found in this upwind airmass sample between 10,000 and 13,000 feet.



UAL MOUNTAIN WAVE NOMOGRAM

Fig. 49 Mountain wave index at Denver on January 27, 1965 as obtained by plotting maximum wind speed up to 20,000 feet against the sea level pressure difference across the mountains on the United Air Lines mountain wave nomogram.

3. ANALYSIS OF A CLASSICAL TYPE I CAT INCIDENT

The Turbulence Situation Near Reading, Pennsylvania

Near 1800GCT

January 24, 1965

The Incident

An airline jet transport experienced severe turbulence at FL 190 while 15 miles west of East Texas, Pennsylvania at a time estimated to have been close to 1800GCT on January 24, 1965. The incident may have happened later than this. One stewardess suffered a fractured ankle as a result of this turbulence.

Roughly 24 hours prior to this incident, there was another and more serious airline jet aircraft incident which happened under the same relative synoptic conditions just south of Chicago at FL 240. As reported by the Chicago TRIBUNE, this was a B-720 which experienced "severe clear air turbulence" that caused injuries to 11 passengers, two of whom were hospitalized. Again quoting the TRIBUNE, officials who "inspected the damaged plane at O'Hare Field said that its interior 'was a complete mess'". Time was not given.

General Weather Type

The synoptic situation was a classical Type I CAT case as studied and reported by United Air Lines (1959) and by others. Both incidents occurred on the low pressure side of a strong jet stream where both horizontal and vertical wind shear were exceptionally great.

Features of Interest

Based on the New York City RAWIN for 000GCT on 1/25/65, the vertical wind shear was 23 knots per 1,000 feet between 18,000 and 21,000 feet. The horizontal shear was 85 knots in the 150 nautical miles between Pittsburgh and Washington on the 300 mb. surface. The New York balloon at 0000GCT on 1/25/65 was lost at

27,000 feet after indicating a peak wind of 150 knots at 21,000.

At the surface, a strong arctic HIGH was retreating down the St. Lawrence Valley and giving way to a pair of major LOWS in its wake. One storm, the primary center, was moving northeastward over the Great Lakes while a rapidly developing secondary way taking shape off the coast of Delaware. A general ice storm was in progress from eastern Pennsylvania to New England.

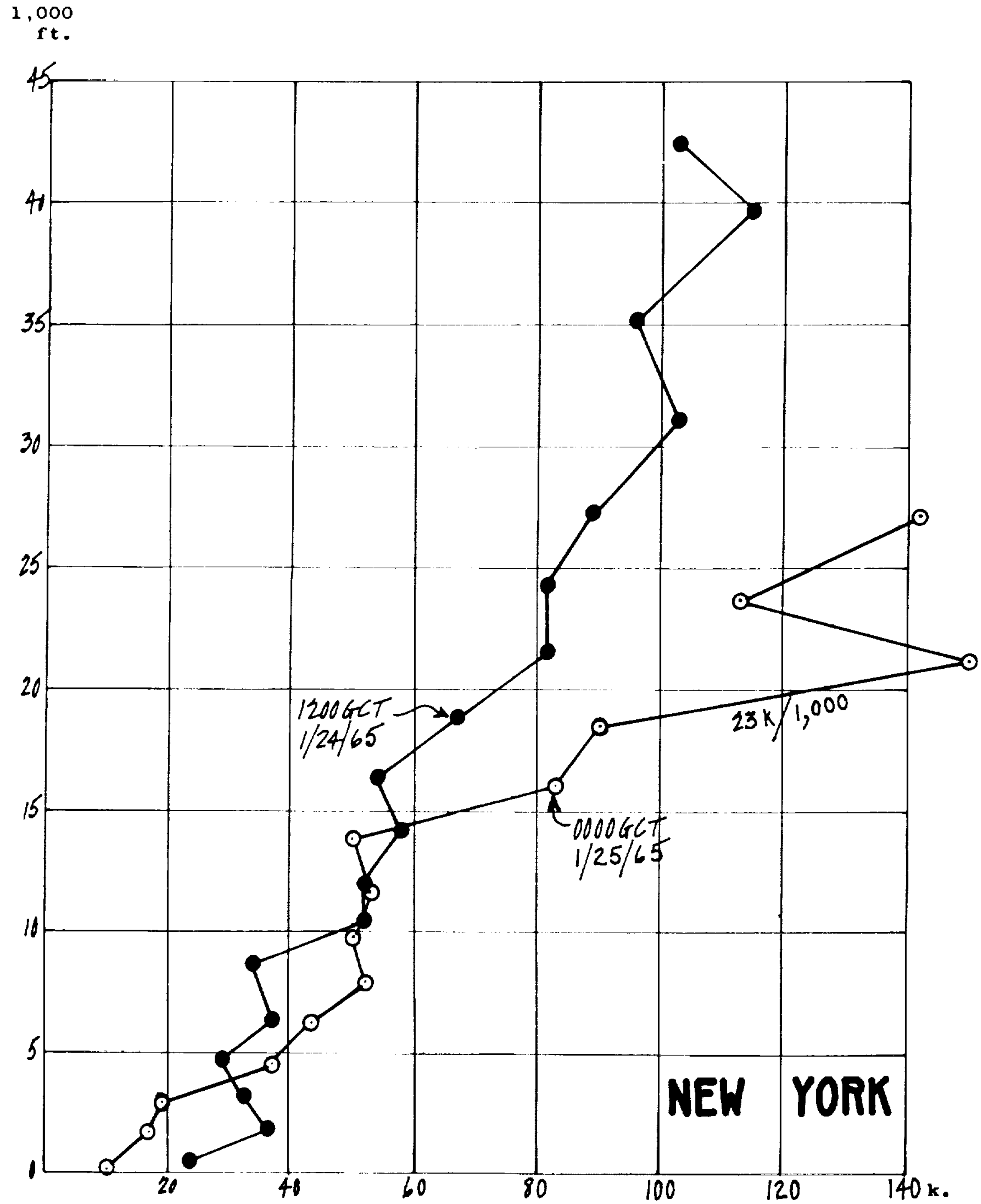


Fig. 50 Wind speed profiles above New York City at 1200GCT on January 24, 1965 and at 0000GCT on January 25th.

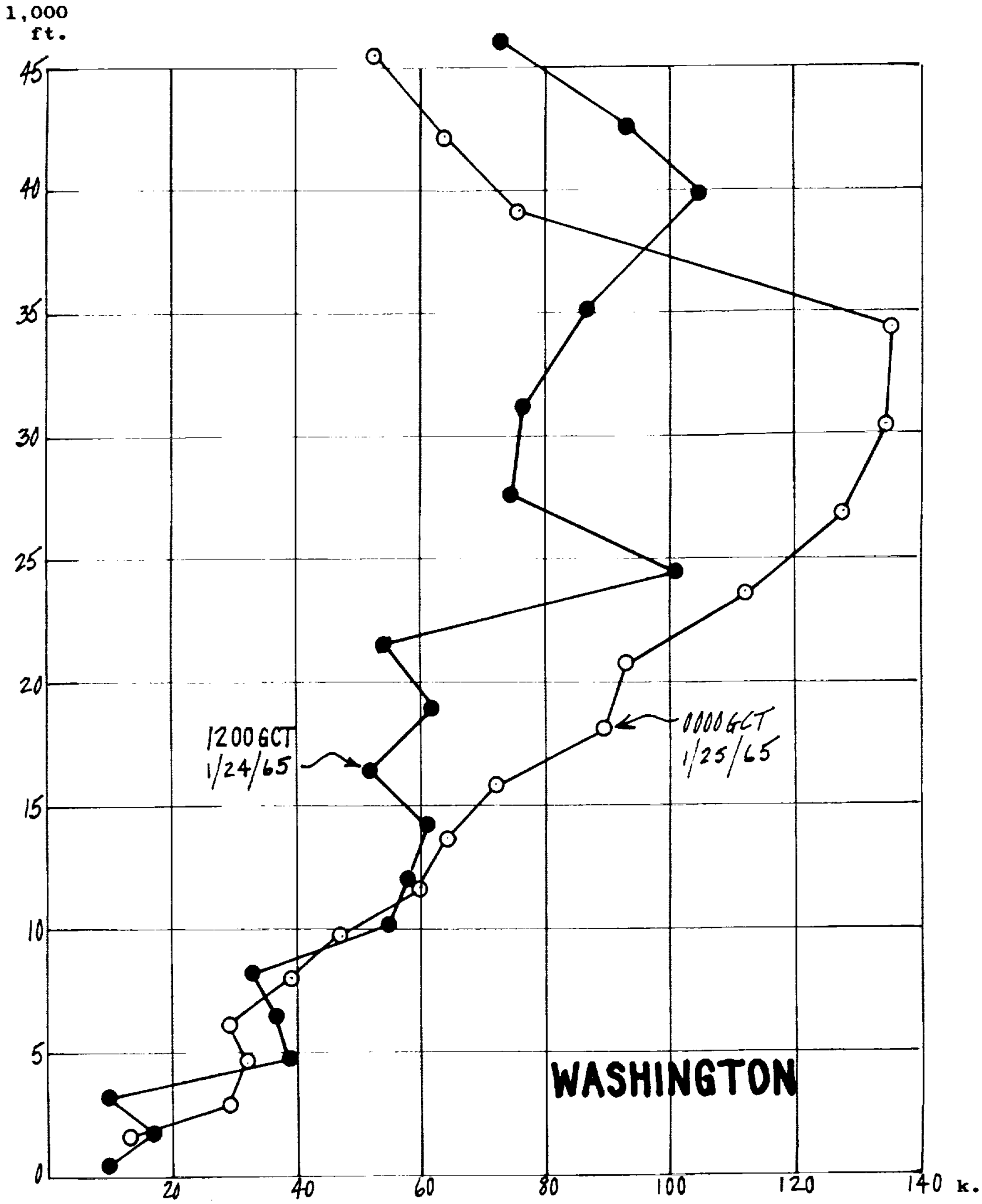


Fig. 51 Wind speed profiles above Washington, D. C. at 1200GCT on January 24, 1965 and at 0000GCT on January 25th.

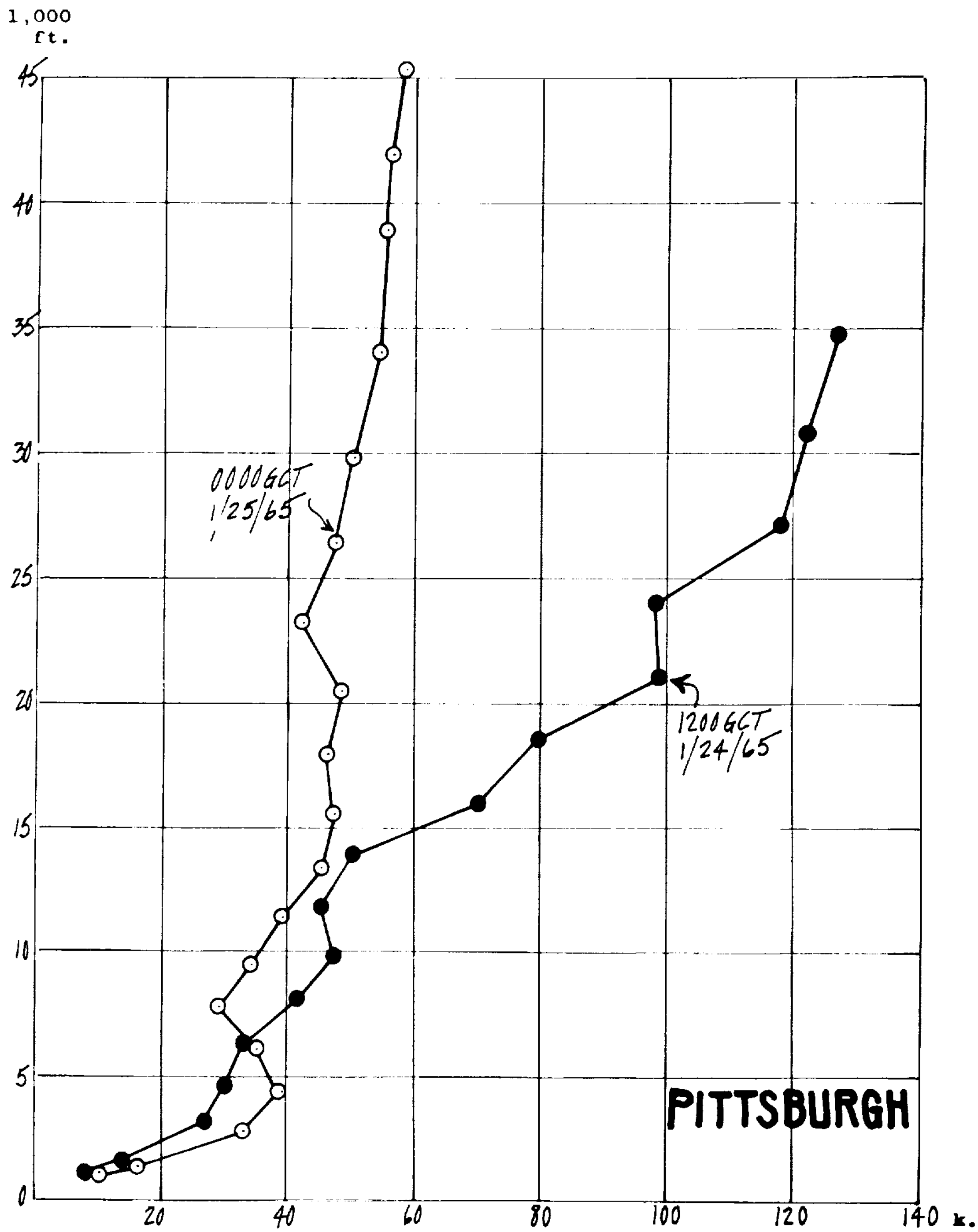


Fig. 52 Wind speed profiles above Pittsburgh at 1200GCT on January 24, 1965 and at 0000GCT on January 25th.

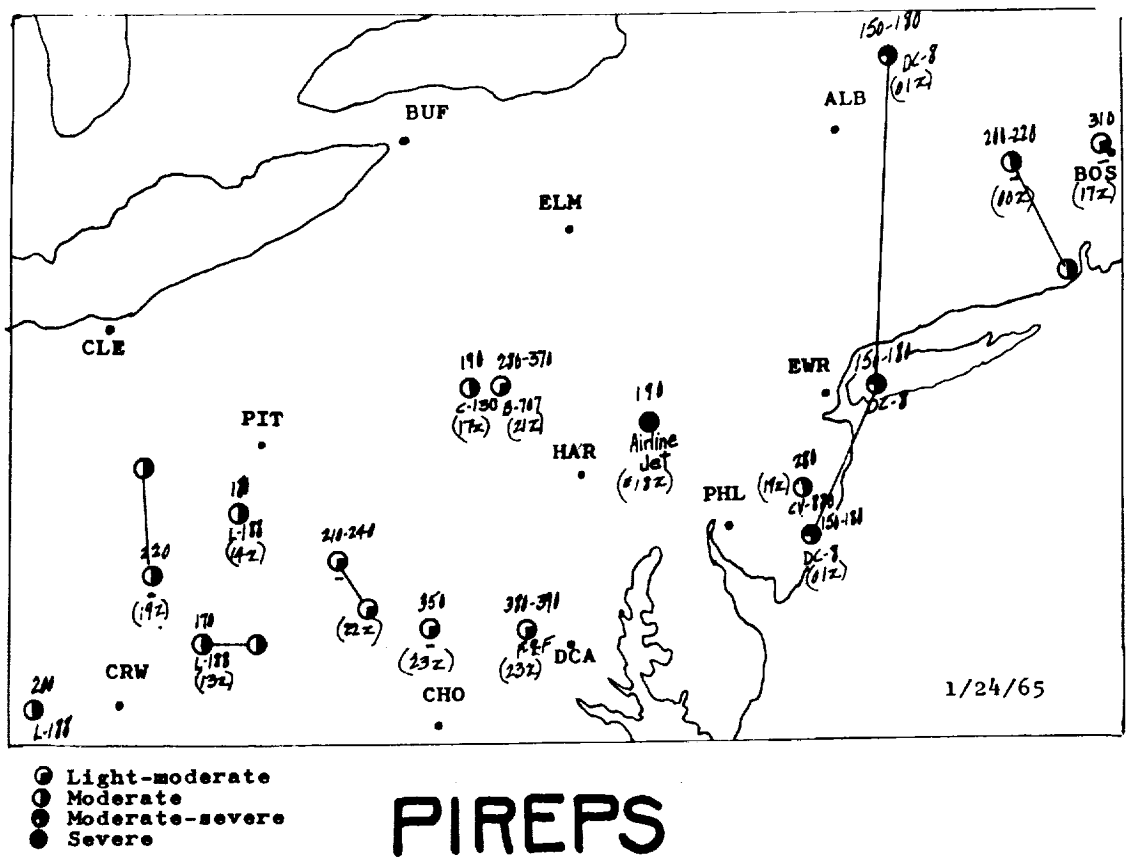


Fig. 53 Pilot reports of clear air turbulence above 15,000 feet over northeastern United States near 1800GCT on January 24, 1965.

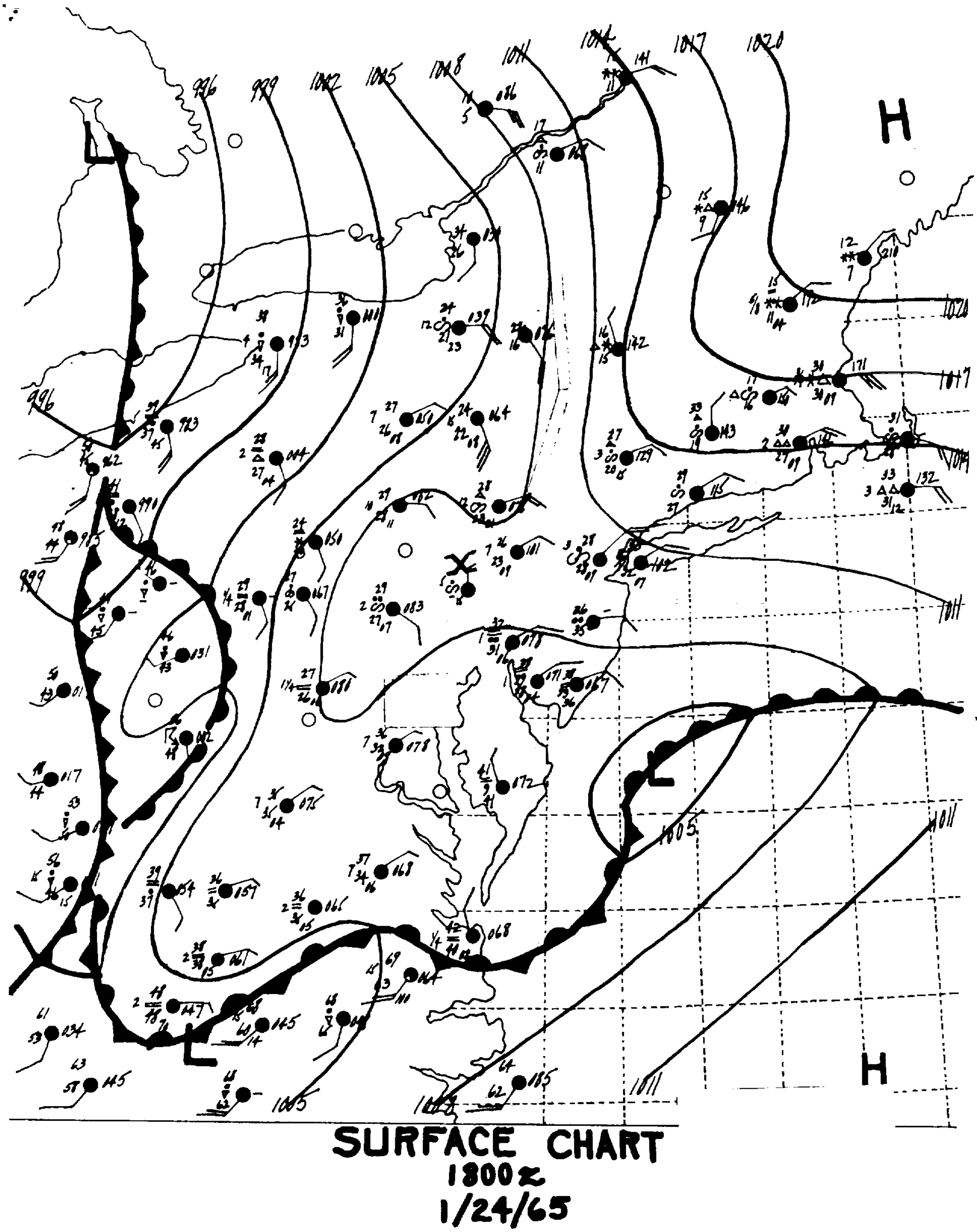
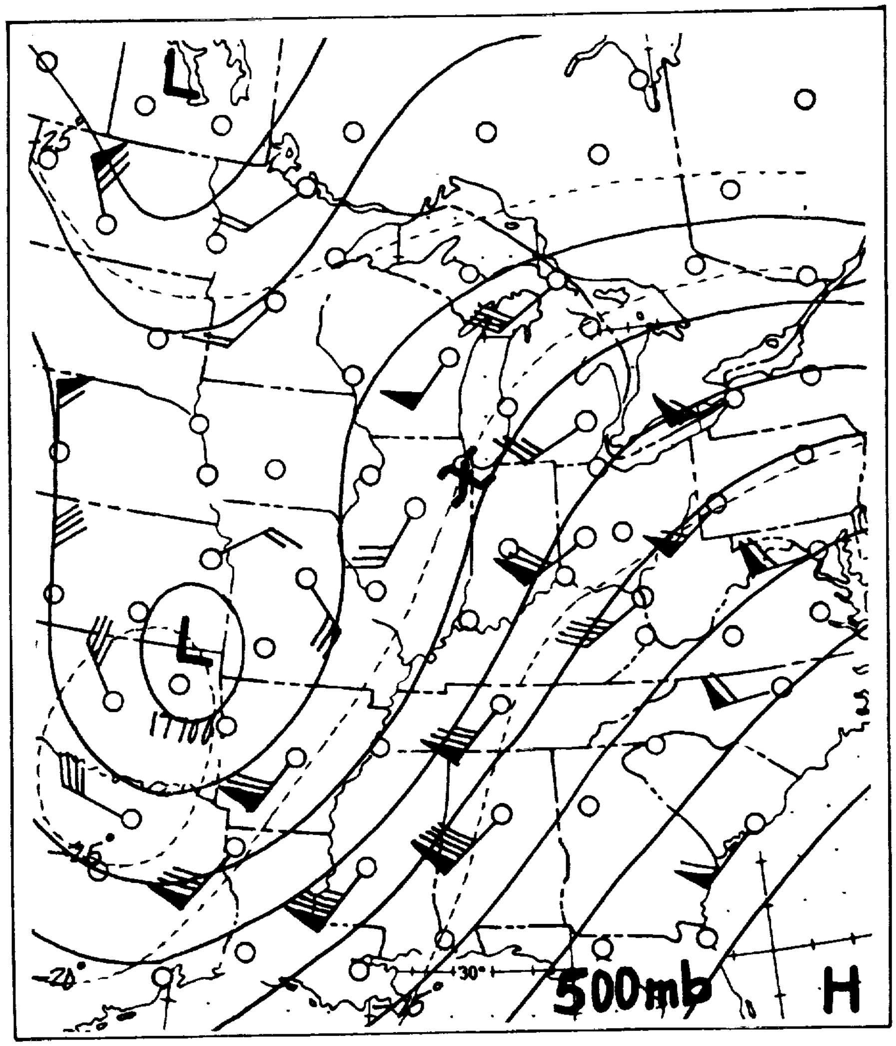


Fig. 54 Panel of the surface chart for 1800GCT on January 24, 1965.



0000GCT January 24, 1965

Fig. 55 A section of the 500 mb. chart for 0000GCT on January 24, 1965. The "X" marks the location of a serious airline CAT incident at FL 240 at an unknown hour on January 23rd, local time.

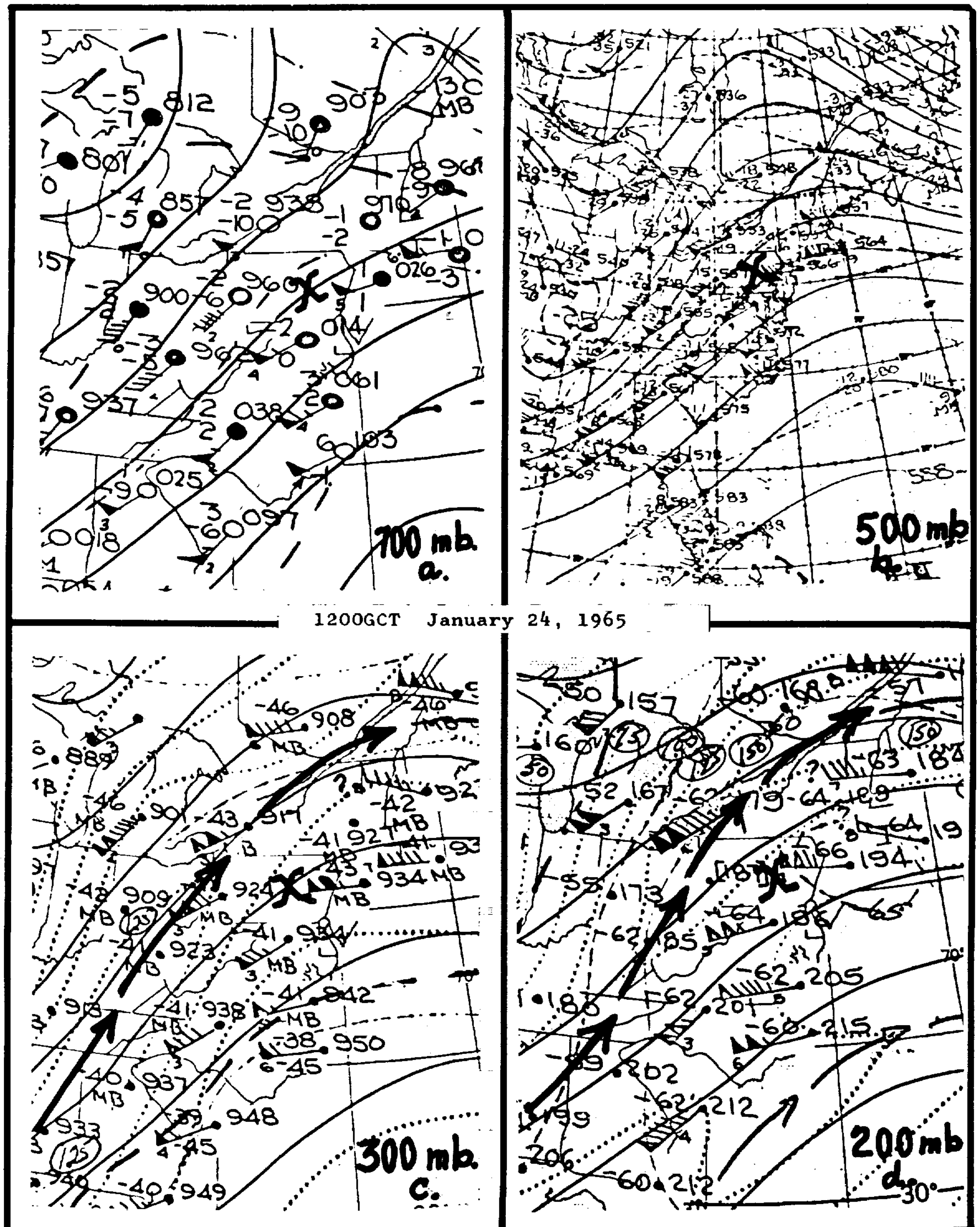


Fig. 56 Panels extracted from upper air charts for 1200GCT on January 24, 1965. a. 700 mb.; b. 500 mb.; c. 300 mb.; d. 200 mb. Jet streams are NMC analyzed positions.

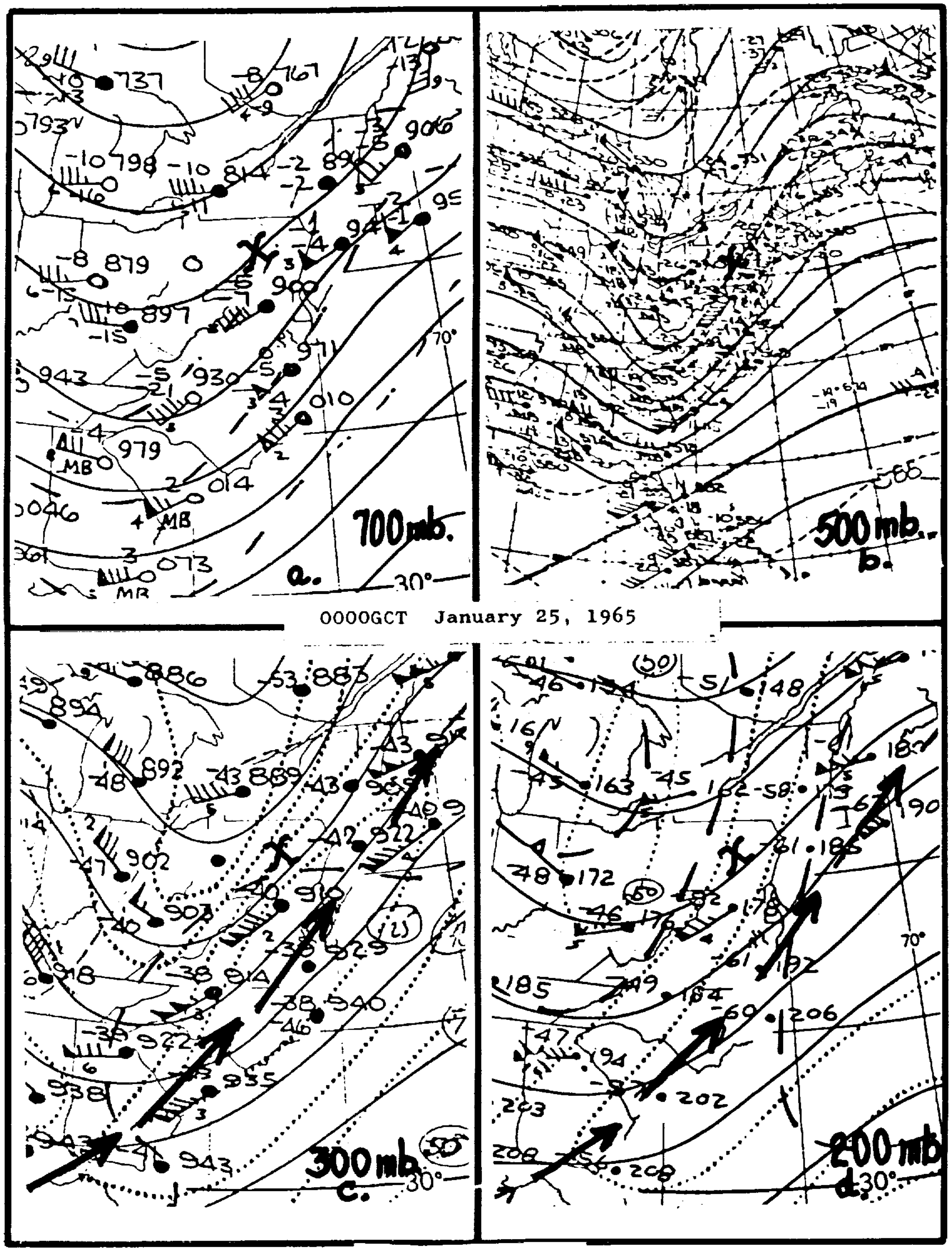


Fig. 57 Panels extracted from upper air charts for 0000GCT on January 25, 1965. a. 700 mb.; b. 500 mb.; c. 300 mb.; d. 200 mb. Jet streams are NMC analyzed positions.

VIII. ECONOMIC ASPECTS OF FLIGHT IN TURBULENCE

Prepared by Jerome Lederer

The avoidance of turbulence is a goal of flight operations not only because of discomfort to passengers and crew but also because turbulence reduces the life of the aircraft structures, may require grounding of aircraft for inspections and repairs, results in injuries to aircraft occupants, loss of control, upsets and total destruction of aircraft with its occupants. These incur costs.

An investigation was made to obtain a rough estimate of the economic consequences of turbulence. Several airlines were asked to report on the costs of diversions to avoid turbulence, the cost of inspections and repairs caused by flight in turbulence, the extent of injuries to passengers and crews. In addition, they were requested to provide estimates of the costs of training aircrews to control aircraft in turbulence and the cost of forecasting and disseminating information on probability of turbulence.

The information was requested by the following letter:

"As you know we have a NASA project to keep NASA advised of developments in detecting turbulence with emphasis on clear air turbulence.

"One phase of this project is to obtain information on the effect of turbulence on airline operations. We are considering the following points:

a) Number of groundings of aircraft for inspection after turbulence encounter; cost of grounding for inspection.

b) Cost of repairs due to turbulence.

c) Injuries to crew and passengers caused by turbulence. (We believe there was a turbulence fatality in airline operation in 1964).

d) Effect on passengers.

e) Cost of special training of crews to detect and avoid; techniques to retain control.

f) Cost of ground organization to forecast or obtain information on turbulence areas and disseminate the information.

g) Costs of diversions to avoid turbulence.

"We would appreciate your comments and criticisms of these factors. Perhaps there are others.

"Your response to items a), b), e), f), g) will we know require some digging. If you prefer that this be done by personal visit, we could arrange for it.

"Thank you for your cooperation in this interesting work."

The airlines that were selected covered a broad geographical area and included short haul as well as long haul operations. Northwest Airlines operates across the northern section of the United States and over the Pacific. It deals with strong mountain wave turbulence in its winter flights across the North. National Airlines operates across the southern section of the United States and along the east coast from Florida to New York. United Air Lines operates across the central portion of the United States along the west coast from San Diego to Seattle and has a complex of operations in the eastern area of the United States. Trans World Airlines operates generally across areas between United and National and also has a complex of operations in eastern and central United States as well as overseas. American Airlines overlaps several of these regions. Piedmont Airlines was also selected to obtain input from an airlines operating with frequent flights in very hilly terrain. Air Canada operates across the lower portion of Canada into the Carribean and over the Atlantic to Europe.

Information was requested for the year 1964 but one airline included information on injuries from 1959 through July 1965.

There was considerable inconsistency in the replies received from the airlines in connection with costs of training, diversion, and dissemination of information. This is understandable because of the dovetailing of training routines, the availability of alternate routes on long distance flights, the melding of the dissemination of various types of weather information. The blending of activities within each area of interest creates difficulty in separating component costs. However, enough information was obtained to determine that appreciable costs are incurred for training, diversions and weather dissemination. Costs of groundings for repairs and inspection appeared easier to obtain. Costs of injuries were obtained from insurance sources.

THE COST OF INJURIES- The average medical cost of an injury due to inflight turbulence was found to be about $1,156. This was based on 497 injuries which occurred on two airlines for the period 1958 through 1964.

Forty-seven injury claims reported by two airlines in 1964 averaged $1.357 per claim.

The number of injuries reported to the Civil Aeronautics Board was found to be far below those reported by passengers for recovery of medical costs.

The CAB reported that a total of 48 passengers and 15 crew members were injured by turbulence in 1964 in accidents and incidents (one of these was a fatal passenger injury).

Five of the United States Air Carriers from whom FSF requested information reported 99 passenger injuries and three airlines reported 42 crew injuries in 1964. This discrepancy between the injuries reported to the CAB and the number of injuries reported by passengers may be due to the definition of an injury required by regulation to be reported to the CAB by the airlines.

This definition reads:

April 1, 1963
Revision-SIR-4
CAB SAFETY INVESTIGATION REGULATIONS
SUBPART B
Initial Notification of Aircraft Accidents, Inflight Hazards and Overdue Aircraft
320.5 Immediate Notification.

"The operator of an aircraft shall immediately, and by the most expeditious means available, notify the Civil Aeronautics Board, Bureau of Safety Field Office nearest the accident or occurrence when;
(a) As a result of the operation of an aircraft, any person (occupant or non-occupant) receives fatal or serious injury or any aircraft receives substantial damage.

320.2 Definitions- "Serious injury" means any injury which (1) requires hospitilization for more than 48 hours, commencing within seven days from the date the injury was received; (2) results in a fracture of any bone (except simple fractures of fingers, toes or nose); (3) involves lacerations which cause severe hemmorhages, nerve, muscle or tendon damage; (4) involves injury to any internal organ; (5) involves second or third degree burns, or any burns affecting more than five percent of the body surface."

It is obvious that minor injuries could be sustained which need not be reported to the CAB. Apparently many claims of injury due to turbulence are made by passengers who are not injured seriously enough to be reported to the CAB but nevertheless result in medical costs which the air carriers pay directly or through their insurance companies.

The CAB reported one passenger fatality due to turbulence but the airline involved contests this, asserting that the passenger died from another cause three days after the incident; medical examinations had shown no injuries. One passenger was fatally injured by turbulence in Canada.

The CAB reported that four injuries occurred in clear air turbulence that was worse than forecast, six in clear air turbulence that was substantially as forecast.

Injuries sustained by crew members, almost always stewardesses, are treated by company medical services.

The 48 passenger cases reported to the CAB by all scheduled air carriers would presumably cost about $55,000.

The total number of injuries sustained in turbulence, other than those reported to the CAB, is not known.

However, a rough estimate can be made of the number of passengers injured in 1964 by obtaining the total number injured per million passengers carried by the reporting airlines used in the sample (4 per million) and multiplying this by the total number of passengers carried by all the scheduled airlines, 83 million. This comes to 332 injured passengers, or roughly $383,792 (say $384,000) for the year 1964 at $1,156 per claim. This does not include time lost from work, overhead costs for processing the claims or other miscellaneous costs.

TRAINING COSTS- One airline with 100 jet aircraft reported $103,661 spent in training for turbulence ($1,036 per jet). Another airline with 83 jets estimates that $100,000 would be a conservative estimate for the cost of training its crews for turbulence encounters ($1,200 per jet). A small airline with 25 jets reports $16,400 ($650 per jet).

A Canadian airline with 16 jets reported $2,500 ($156 per jet).

Another airline with 14 jets reported a cost of $13,255.54 ($900 per jet).

Obviously there is a lack of uniformity among airlines in estimating costs of training for turbulence encounters.

The four United States airlines which made special estimates of these costs have 222 jets and spent $233,316 or approximately $1,000 per jet. There were 517 jets in operation among scheduled U. S. air carriers in 1964. Thus, the cost of training for turbulence could have been $517,000.

DIVERSIONS- As in the case of training, there is no set pattern by which the airlines estimate the cost of diversions caused by turbulence. One airline with 502,880 flights estimates that it costs $300,000 for diversions to avoid weather phenomena of all types. A transcontinental airline does not maintain separate records. Another airline reports that other variables in flight planning, such as best ride, best time, coupled to alternate routes, make diversions relatively inconsequential.

However, one airline which operated 100,742 flights in 1964 reported a cost for diversions of $891,900. See Appendix A for the way this and other costs were calculated by this airline.

Another airline reported a diversionary cost "conservatively" estimated at $420,950. This airline operated 122,461 flights. The average cost per flight for diversions due to turbulence was approximately $6.00 for these two airlines.

There were 3,933,821 scheduled air carrier flights, excluding helicopters, in 1964.

In view of the absence of specific data from the other airlines, the cost of $6.00 per flight will be applied to the four million flights, totaling approximately $24 million.

However, it may be argued that local service airlines with their short hops often penetrate instead of divert for turbulence. They totaled 1,310,767 flights, leaving 2,673,054 flights for the trunk airlines or a cost of about $16 million for diversions for 1964 for the major airlines.

DISSEMINATION OF INFORMATION ON TURBULENCE- The airline with 122,461 flights reported a cost of $115,927 for its ground organization to forecast and obtain information on turbulent areas and to disseminate the information. This is 94 cents per flight.

An airline with 203,339 flights reported $401,258 for maintaining two offices that forecast significant enroute weather, including turbulence. The cost of disseminating turbulence forecast information per se is included as part of the overall cost.

Another airline with 100,742 flights estimates that .5 hour per man shift of dispatchers is devoted to turbulence. In this operation it amounted to 6,205 hours at $6.00 per hour or $37,230.00. This would be 37 cents per flight. Using the previous figure of 2,673,054 flights for all major airlines, the yearly cost might be about $989,000. The validity of this approach is open to question but in the absence of better data it appears to be acceptable and conservative in light of the definite cost of 94 cents per flight disclosed in the first paragraph.

COST OF GROUNDING, INSPECTION, REPAIRS- One airline points out that while it has not "grounded" an airplane for inspection after encountering turbulence, it conducted eleven structural inspections for turbulence reasons on jet aircraft since the inception of jet operations in 1959. "It is our feeling that other more costly structural repairs found by routine inspection are at least partially attributable to clear air turbulence exposure, incidents which are probably completely unrecorded. Each inspection runs about one man-hour in direct labor at about $4.00, exclusive of any time spent in moving the aircraft and situating it for inspection. Man hours for mechanical repairs are additional."

The airline which operated 122,461 flights experienced eight groundings for inspection after turbulence encounters in 1964. The cost of grounding for inspection amounted to $6,314.44 including cost of inspection. Cost of repairs was $114.40. This amounts to about 5 cents per flight.

An airline which operated 256,487 flights spent $4,500 in labor and $12,004.25 for repairs (one incident). This amounts to about 6 cents per flight. In addition there were 12.5 aircraft days of lost service for inspection. There appears to be consistency in these two estimates: five cents for one airline, six cents for the other.

It seems logical to include all flights, less helicopters, to estimate the costs of inspection and repairs due to turbulence. At 5 cents per flight this amounts to .05 x 4 million flights or $200,000.

Thus, these rough estimates total:

Injury	384,000
Diversions	$16,000,000
Training	517,000
Information	989,000
Inspection	200,000
	$18,900,000

or about $6.00 per flight, for 2,673,054 flights as the cost of turbulence in 1964. This does not include loss of use of grounded aircraft, loss of employable time by injured occupants and overhead involved in settling claims for injuries.

There are other intangible losses: disgruntled passengers and structural fatigue. There is also the occasional fatal accident caused by turbulence.

The parameters used in arriving at these cost estimates are numbers of passengers, number of jet aircraft, number of flights. In view of the inability of several airlines to separate these specific costs from their overall costs, there appears no way to obtain greater accuracy in getting total costs incurred for turbulence in the past.

A preplanned attempt to secure more accurate and complete information would be desirable if a study of the economics of turbulence is to be continued.

The method used by one airline to determine the cost of training crews, cost of diversions, cost of forecasting and disseminating information on turbulence follows:

YEAR 1964

a) Cost of special training of crews to detect and avoid; techniques to retain control.

Jet Model A Captain

$2,600.00 month	=	$ 32.50 hour	
	x	2.65 hour	
		$ 86.13	
	x	68	
		$5,826.84	$ 5,826.84

Jet Model A Co-Pilot

$1,700.00 month	=	$ 21.31 hour	
	x	2.65 hour	
		$ 56.31	
	x	70	
		$3,741.70	$ 3,741.70

Chief Pilot's Preparation Time	1,446.00
Chief Pilot's GS Time	823.00
Check Pilot's GS Time	1,396.00
Total	13,233.54

b) Costs of diversions to avoid turbulence

Jet Model A

4700 hours month x 12	=	56,400 year	
1% of 56,400 hours	=	564 hours	
	x	$ 750 "	
		$423,000.00	$ 423,000.00

Turboprop

4700 hours month x 12	=	56,400 hours/year	
$1\frac{1}{2}$% x 56,400	=	846 " "	
	x	$ 500 "	
		$423,000.00	423,000.00

Piston

4 months x 8 airplanes	=	32 months	
4 " x 4 "	=	16 "	
		48 "	
	x	120 hour/month	
		5,760 hour	
$1\frac{1}{2}\%$ x 5,760 hours	=	86.4 hours	
	x	$ 500	
		$43,200.00	43,200.00

Jet Model B

1 month x 2 airplanes	=	540 hours	
1% of 540 hours	=	5.4 "	
	x	$ 500 "	
		$ 2,700.00	$ 2,700.00
		Total	$891,900.00

Paragraph a)	$ 13,233.54
Paragraph b)	891,133.54
	$905,133.54

c) Cost of ground organization to forecast or obtain information on turbulence areas and disseminate the information.

Year round average dispatcher shifts/day:

Station A - 6 months 8		365	
" A - 6 " 15	x	34	
Station B - 6 months 6		12,410 man shifts year	
" B - 6 " 5		.5 hour per shift	
		6,205	
		$ 6.00 hour	
		$37,230.00	$ 37,230.00

IX. CONCLUSIONS

1. a. There is a need for a practical, operationally useful method for CAT detection and warning for aircraft.

   b. It appears likely that the SST likewise will need a CAT detector.

2. There is a widespread activity in industry, Government Departments and the Armed Services, concerning the CAT problem.

3. A wide variety of physical methods have been proposed for CAT detection and warning. These include: electromagnetic radiation methods, active and passive; electric field measurements; air temperature sensors; air pressure sensors; and chemical sensors.

4. There are only five principles and devices that have been in flight-test to date: i.e.- lasers, temperature sensor (on the aircraft), electric discharge monitor, VHF radar and ozone detector.

5. No one method of CAT detection and warning has yet been demonstrated to be operationally useful and practical. There is insufficient data on any detection device to make a comparative evaluation concerning its suitability for operational use.

6. Despite many commonly quoted theories about the nature and meteorology of CAT, not enough is actually known and proven about the phenomenon to enable the practical value of proposed CAT detection methods to be predicted with any useful degree of confidence.

7. Considerable further research is needed to determine the physical characteristics and parameters of CAT.

X. Recommendations

Recommendation No. 1 of this project's Second Quarterly Report 15 June 1965, is reiterated.

1. "It is recommended that a Clear Air Turbulence Advisory Board (CATAB) be established for the following purposes:

   a. To provide a broad scientific overview of research and development of methods and devices for the advance detection and warning of CAT.

   b. Through advice and recommendations, to coordinate the diverse R&D work sponsored and planned by Government agencies in the area of CAT detection and warning.

   c. To recommend neglected areas of CAT R&D.

   "The individual members of CATAB should be physicists and environmental scientists of interdisciplinary capabilities who have no conflict of interest as regards CAT R&D or CAT detection methods or devices. Such men can be found in Government agencies, among independent consultants, on the staffs of colleges and universities, and in research foundations.

   "In order to preserve CATAB's objectivity and impartiality, only men who have no preconceived or pet ideas about CAT detection should be invited to serve on CATAB.

   "The need for CATAB has revealed itself as a result of the country-wide survey and study being conducted under this contract. We find that CAT R&D lacks much basic information about the structure of the atmosphere which should be known in order to develop a good CAT detector. In many instances a "solution" has been developed for which a problem is sought. CATAB, with a broad scientific viewpoint and with no axe to grind, could maintain a balanced perspective in the matter, and could advance the day when the CAT problem will be alleviated or solved.

2. It is recommended that the study and survey project, of which this is the final report, be continued in order to:

   a. Complete the survey of CAT work in this country. (It was not possible to do so in this first phase of the project).

   b. Continue the reporting of current CAT investigation and development work in progress.

   c. Critically evaluate the potentialities and merits of the diverse CAT detection and warning methods now being developed.

XI. Bibliography

AIR TURBULENCE

A BIBLIOGRAPHY COVERING

PHYSICAL, METEOROLOGICAL AND OPERATIONAL ASPECTS

The first part of the Bibliography (204 items) consists largely of reports prepared by NASA and other scientific groups up to 1964. It was prepared by the Flight Safety Foundation as part of a report for the FAA, entitled "Survey of Occurrences Involving Loss of Control of Swept Wing Aircraft (Project Upset)".

The second part, (items 204-274) is made up of reports and articles in general, published in 1964 and 1965. This portion of the Bibliography has been prepared, in part, by the Flight Safety Foundation on Contract NSR 33-026-001 with the NASA. In the interest of making the bibliography available at an early date, the entries are arranged alphabetically by author, and not classified by sections as in the first part.

BIBLIOGRAPHY

A. GUST RESEARCH

1. Donely, Philip: Summary of Information Relating to Gust Loads on Airplanes. TR 997, 1950.

2. Gust Loads Brahch: Notes on the Gust Problem for High-Speed Low-Altitude Bombers. NACA RM L52E22, 1952.

3. McDougal, R., Coleman, T. L., and Smith, P. L.: The Variation of Atmospheric Turbulence With Altitude and Its Effect on Airplane Gust Loads. RM L53G15a, 1953.

4. Donely, Philip, and Gillis, Clarence L.: Some Design Considerations Pertinent to the Rough-Air Behavior of Airplanes at Low Altitude. RM L53J01b, Nov. 1953.

5. Press, Harry, Meadows, May T., and Hadlock, Ivan: Estimates of Probability Distribution of Root-Mean-Square Gust Velocity of Atmospheric Turbulence From Operational Gust-Load Data by Random-Process Theory. TN 3362, October 1954.

6. Press, Harry, and Meadows, May T.: A Reevaluation of Gust-Load Statistics for Applications in Spectral Calculations. TN 3540, 1955.

7. Press, Harry, Meadows, May T., and Hadlock, I. K.: A Reevaluation of Data on Atmospheric Turbulence and Airplane Gust Loads for Application in Spectral Calculations. NACA Rpt, 1272, 1956.

8. Steiner, Roy: Statistical Approach to the Estimation of Loads and Pressures on Seaplane Hulls for Routine Operations. RM L57A15, March 1957.

9. Press, Harry: Atmospheric Turbulence Environment With Special Reference to Continuous Turbulence. Rep. 115, AGARD, NATO (Paris), April-May 1957.

10. Coleman, Thomas L., Press, Harry, and Meadows, May T.: An Evaluation of Effects of Flexibility on Wing Strains in Rough Air for a Large Swept-Wing Airplane by Means of Experimentally Determined Frequency-Response Functions with an Assessment of Random-Process Techniques Employed. NASA TR R-70, 1960. (Also NACA TN 4291, March 1958.)

11. Press, H., and Steiner, R.: An Approach to the Problem of Estimating Severe and Repeated Gust Loads for Missile Operations. NACA TN 4332, September 1958.

12. Press, Harry, and Tukey, J. W.: Power Spectral Methods of Analysis and Their Application to Problems in Airplane Dynamics. Vol. IV of AGARD Flight Test Manual, Pt. IVC, Enoch J. Durbin, ed., North Atlantic Treaty Organization (Paris), pp. IVC: 1-IVC:41.

13. Zbrozek, J. K.: The Relationship Between the Discrete Gust and Power Spectra Presentation of Atmospheric Turbulence, With a Suggested Model of Low-Altitude Turbulence. R.A.E. Tech. Note No. Aero. 2682 R and M 3216 (March 1960) ARC 21,874.

14. Coleman, Thomas L., and Stickle, Joseph W.: Turbulence Environment for Supersonic Transports. Presented at the 5th Annual Symposium of the Society of Experimental Test Pilots, Beverly Hills, California, September 29-30, 1961.

15. Wright Air Development Division: B-66 Low Level Gust Study, WADD Technical Report 60-305, Vol. I, "Technical Analysis." March 1961.

16. Hunter, Paul A., and Coleman, Thomas L.: Operational Experience of Jet Transports. SAE National Aeronautic Meeting, New York, N.Y., April 3-6, 1962.

17. WADD TR60-398: Optimum Fatigue Spectra. Mar. 1962.

18. Operational Experiences of Turbine-Powered Commercial Transport Airplanes. NASA TN D-1392. October 1962.

19. Aeronautical Systems Division, AF Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio: High Altitude Gust Survey. Rpt. Nr ASD-TDR-63-145, Vol. 1. NB-66B. June 1963.

20. Aeronautical Systems Division, AF Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio: High Altitude Gust Survey: Power Spectra. Rpt. Nr ASD-TDR-63-145, Vol. II. NB-66B. June 1963.

21. Aeronautical Systems Division, AF Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio: High Altitude Gust Survey: Time Series. Rpt. Nr ASD-TDR-63-145, Vol. III. NB-66B. June 1963

B. OPERATIONAL VG AND VGH DATA - GUST RESEARCH

22. Walker, W. G.: An Analysis of the Airspeeds and Normal Accelerations of Douglas DC-2 Airplanes in Commercial Transport Operation. TN 1754, Nov. 1948.

23. Steiner, Roy: An Evaluation of Air-Borne Radar as a Means of Avoiding Atmospheric Turbulence. RM L8I01, November 1948.

24. Walker, W. G., and Hadlock, I. K.: An Analysis of the Airspeeds and Normal Accelerations of Boeing B-247 and B-247D Airplanes in Commercial Transport Operation. TN 1783, December 1948.

25. Steiner, Roy: An Analysis of Airspeeds Attained by a Douglas DC-4 Airplane in Commercial Operations During the Early Months of 1947. RM L8K24, October 1949.

26. Steiner, Roy, and McDougal, R.: Summary of Normal Accelerations, Gust Velocities, and Operating Practices from April to August 1949 of a Twin Engine Airplane in Commercial Transport Operations. RM L50B02.

27. Coleman, T. L.: An Analysis of the Normal Accelerations and Airspeeds of Several Lockheed Constellation L-649 Airplanes in Postwar Commercial Transport Operations Over the Eastern Part of the United States. RM L9E18a, 1950.

28. McDougal, R.: Summary of the First Sample of VGH Data of Normal Accelerations and Associated Operating Conditions on Two Four-Engine Transport Airplanes in Commercial Operations. RM L50D28a.

29. Coleman, T. L., and Schumacher, P.: An Analysis of the Normal Accelerations and Airspeeds of a Four-Engine Airplane Type in Postwar Commercial Transport Operation on Trans-Pacific and Caribbean-South American Route. TN 2176, 1950.

30. Walker, W. B., and Steiner, Roy: Summary of Acceleration and Airspeed Data From Commercial Transport Airplanes During the Period from 1933-1945. TN 2625, February 1952.

31. Steiner, Roy, and Persh, Doris A.: Normal Accelerations and Associated Operating Conditions on Four Types of Commercial Transport Airplanes From VGH Data Available as of September 1951. RM L52A28, May 1952.

32. Press, H., and McDougal, R.: The Gust and Gust-Loads Experience of a Twin-Engine Low-Altitude Transport Airplane in Operation. TN 2663.

33. Walker, W. B., and Schumacher, P.: An Analysis of the Normal Accelerations and Airspeeds of a Two-Engine Type of Transport Airplane in Commercial Operations on Routes in the Central United States From 1948-1950. TN 2735, July 1952.

34. Steiner, Roy: An Analysis of Normal Accelerations and Airspeeds of One Type of Twin-Engine Transport Airplanes in Commercial Operations Over a Northern Transcontinental Route. TN 2833, November 1952.

35. Coleman, T. L., and Schumacher, P.: An Analysis of Normal-Acceleration and Airspeed Data From a Four-Engine Type of Transport Airplane in Commercial Operation on an Eastern United States Route From November 1947 to February 1950. TN 2965, August 1953.

36. Walker, Walter G.: Summary of Revised Gust-Velocity Data Obtained from V-G Records Taken on Civil Transport Airplanes From 1933 to 1950. NACA Rep. 1206, November 1953.

37. Walker, Walter G.: Gust Loads and Operating Airspeeds of One Type of Four-Engine Transport Airplane on Three Routes From 1949 to 1953. TN 3051, (DC-6), November 1953.

38. Coleman, Thomas L., and Copp, Martin R.: Maneuver Accelerations Experienced by Five Types of Commercial Transport Airplanes During Routine Operations. TN 3086, April 1954.

39. Walker, Walter G.: Gust-Load and Airspeed Data From One Type of Four-Engine Airplane on Five Routes From 1947 to 1954. TN 3358, October 1954.

40. Coleman, T. L., Copp, M. R., Walker, W. G., and Engel, J. N.: An Analysis of Accelerations, Airspeeds, and Gust Velocities From Three Commercial Operations of One Type of Medium-Altitude Transport Airplane. TN 3365, November 1954.

41. Coleman, T. L., and Walker, W. G.: Analysis of Accelerations, Gust Velocities, and Airspeeds From Operations of a Twin-Engine Transport Airplane on Transcontinental Route From 1950 to 1952. TN 3371.

42. Copp, Martin R., and Coleman, T. L.: An Analysis of Acceleration, Airspeed, and Gust-Velocity Data From One Type of Four-Engine Transport Airplane Operated Over Two Domestic Routes. TN 3475, June 1955.

43. Coleman, T. L., and Fetner, Mary W.: An Analysis of Acceleration, Airspeed, and Gust-Velocity Data From a Four-Engine Transport Airplane in Operations on an Eastern United States Route. TN 3483, June 1955.

44. Copp, Martin R., and Coleman, T. L.: An Analysis of Acceleration, Airspeed, and Gust-Velocity Data From One Type of Four-Engine Transport Airplane Operated Over Two Domestic Routes. TN 3475, Oct. 1955.

45. Walker, W. G.: Gust-Load and Airspeed Data From One Type of Two-Engine Airplane on Six Civil Airline Routes From 1947 to 1955. TN 3621, Nov. 1955.

46. Copp, Martin R., and Fetner, Mary W.: An Analysis of Airspeed, Altitude, and Acceleration Data Obtained From a Twin-Engine Transport Airplane Operated Over a Feeder Line Route in the Rocky Mountains. NACA TN 3750, June 1956.

47. Copp, Martin R., and Walker, Walter G.: Analysis of Operational Airline Data to Show the Effects of Airborne Weather Radar on the Gust Loads and Operating Practices of Twin-Engine Short-Haul Transport Airplanes. TN 4129, November 1957.

48. Engel, J. N., and Copp, M. R.: Analysis of Acceleration, Airspeed, and Gust-Velocity Data From a Four-Engine Transport Airplane Operating Over a Northwestern United States - Alaska Route. NASA Memo. 1-17-59L.

49. Walker, W. G., and Copp, M. R.: Summary of VGH and VG Data Obtained from Piston-Engine Transport Airplanes From 1947 to 1958. NASA TN D-29, 1959.

50. Copp, Martin R., and Fetner, Mary W.: Analysis of Acceleration, Airspeed, and Gust-Velocity Data From a Four-Engine Turboprop Transport Operating Over the Eastern United States. NASA TN D-36, 1959.

51. Coleman, Thomas L., Copp, Martin R., and Walker, Walter G.: Airspeed Operating Practices of Turbine-Powered Commercial Transport Airplanes. NASA TN D-744, 1961.

52. Hunter, Paul A., and Fetner, Mary W.: Maneuver Accelerations Experienced During Routine Operations of a Commercial Turbojet Transport Airplane. NASA TN D-1801, March 1963.

53. Hunter, Paul A., and Walker, Walter G.: Analysis of VG and VGH Operational Data From a Twin-Engine Turboprop Transport Airplanes. NASA TN D-1925, April 1963.

C. ENVIRONMENTAL STUDIES - GUST RESEARCH

54. Thompson and Press: An Analysis of the Relations Between Horizontal Temperature Variations and Maximum Effective Gust Velocities in Thunderstorms. TN 1917.

55. Clementson, Gerhardt C.: An Investigation of the Power Spectral Density of Atmospheric Turbulence. Ph.D. Thesis, M.I.T., 1950.

56. Thompson, J. R.: A Relation of Wind Shear and Isolation to the Turbulence Encountered by an Airplane in Clear Air Flight at Low Altitudes. RM L51H07.

57. Tolefson, H. B.: Preliminary Results From Gust Velocity Measurements at High Altitudes. RM L51L12a.

58. Chippendale, G. R., and Clement, W. F.: A Statistical Study of Atmospheric Turbulence by Flight Measurements. Report No. 6822-2-T-2, (S.M. Thesis), Instrumentation Laboratory, M.I.T., Cambridge, Mass., May 1951.

59. Tolefson, H. B., Pratt, K. G., and Thompson, J. R.: An Experimental Study of the Relation Between Airplane and Wing-Vane Measurements of Atmospheric Turbulence. RM L52L29b.

60. Connor, Roger J., Hawk, John, and Levy, Charles: Dynamic Analysis for the C-47 Airplane Gust Alleviation System. Rep. No. SM-14456, Douglas Aircraft Co., Inc., July 29, 1952.

61. Press, H., Schindler, M., and Thompson, J. R.: Summary of Pilots' Reports of Clear-Air Turbulence at Altitudes Above 10,000 Feet. RM L52L30a, Mar. 1953.

62. Panofsky, H. A.: Statistical Properties of the Vertical Flux and Kinetic Energy at 100 Meters. Scientific Rep. No. 2 (Contract No. AF19(604)-166), Div. of Meteorology, Pennsylvania State College, July 1, 1953.

63. Copp, Martin R.: Evaluation of Turbulence Measurements Obtained From a Flight Investigation of the Jet Stream, December 10, 1953 to March 26, 1954. RM SL54F07, 1954.

64. Chilton, Robert G.: Some Measurements of Atmospheric Turbulence Obtained From Flow-Direction Vanes Mounted on an Airplane. NACA TN 3313, 1954.

65. Summers, Robert S.: A Statistical Description of Large-Scale Atmospheric Turbulence. Sc. D. Thesis, M.I.T., 1954. (Also Rep. T-55, Instrumentation Lab., M.I.T., May 17, 1954.)

66. Notess, Charles B., and Eakin, Geady J.: Flight Test Investigation of Turbulence Spectra at Low Altitude Using a Direct Method for Measuring Gust Velocities. Rep. No. VC-839-F-1 (Contract AF33 (616)174), Cornell Aero. Lab., Inc., July 1, 1954.

67. Lappi, V. O.: A Direct Method of Utilizing Flight Data to Determine Space and Spectrum Gust Velocity Distributions and Airplane Gust Performance Function (Low Level Turbulence Study). Rep. No. GM-776-T-45 (Contract AF18(600)-1550), Cornell Aero. Lab., Inc., August 1955.

68. Tolefson, H. B.: Summary of Derived Gust Velocities Obtained From Measurements Within Thunderstorms. Rept. No. 1285, 1956.

69. Fetner, Mary W.: Summary of Locations and Extents of Turbulent Areas Encountered During Flight Investigations of the Jet Stream From October 1953 to May 1954 and November 1954 to July 1955. RM L55H04a, April 1956.

70. Tolefson, H. B.: An Investigation of Vertical-Wind Shear Intensities From Balloon Soundings for Application to Airplane- and Missile-Response Problems. TN 3732, July 1956.

71. Crane, H. L., and Chilton, R. G.: Measurement of Atmospheric Turbulence Over a Wide Range of Wavelength for One Meteorological Condition. NACA TN 3702, June 1956.

72. Coleman, T. L., and Funk, Jack: Initial Measurements of Atmospheric Turbulence at High Altitudes as Determined From Acceleration Measurements on Lockheed U-2 Airplane. NACA RM L57A11, Dec. 1956.

73. Coleman, T. L., and Coe, Emilie C.: Airplane Measurements of Atmospheric Turbulence for Altitudes Between 20,000 and 55,000 Feet Over the Western Part of the United States. RM L57G02.

74. Tolefson, H. B.: Atmospheric Temperature Observations to 100,000 feet for Several Climatological Regions of the Northern Hemisphere. TN 4169, August 1957.

75. Copp, Martin R.: Summary of Locations, Extents, and Intensities of Turbulent Areas Encountered During Flight Investigations of the Jet Stream from January 7, 1957, to April 12, 1957. RM L57L12, December 1957.

76. Notess, Charles B.: A Study of the Nature of Atmospheric Turbulence Based Upon Flight Measurements of the Gust Velocity Components. WADC Tech. Rep. 57-259, ASTIA Doc. No. AD118242, U. S. Air Force, May 1957.

77. Coleman, T. L., and Meadows, May T.: Airplane Measurements of Atmospheric Turbulence at Altitudes Between 20,000 and 55,000 Feet for Four Geographic Areas. NASA Memo. 4-17-59L.

78. Henry, Robert M.: A Study of the Effect of Wind Speed, Lapse Rate and Altitude on the Spectrum of Atmospheric Turbulence at Low Altitude. Inst. Aero. Sci. Rep. No. 59-43, January 1959.

79. Panofsky, H. A., and McCormic, R. A.: The Spectrum of Vertical Velocity Near the Surface. Inst. Aero. Sci. Rep. 59-6, January 1959.

80. Lappe, U. O., Davidson, B., and Notess, C. B.: Analysis of Atmospheric Turbulence Spectra Obtained From Concurrent Airplane and Tower Measurements. Inst. Aero. Sci. Rep. 59-44, January 1959.

81. Coleman, Thomas L., and Steiner, Roy: Atmospheric Turbulence Measurements Obtained From Airplane Operations at Altitudes Between 20,000 and 75,000 ft. for Several Areas in the Northern Hemisphere. NASA TN D-548, 1960.

82. Zbrozek, J. K., and Ridland, D. M.: A Measured Power Spectrum of the Vertical Component of Atmospheric Turbulence. R.A.E. Tech. Note Aero. 2681, ARC 21875, March 1960.

83. Wright Air Development Division: B-66 Low Level Gust Study, WADD Technical Report 60-305, Vol. I, "Technical Analysis." March 1961.

84. Steiner, Roy, and Rhyne, Richard H.: Some Measured Characteristics of Severe Storm Turbulence. American Meteorological Society, Conference on Severe Storms. Norman, Oklahoma, February 13-16, 1962.

85. Wells, E. W.: Low Altitude Gust Measurements Over Three Routes in the U.K. R.A.E. (Farnborough) T.N. Structures 320, Oct. 1962.

86. Steiner, Roy, and Rhyne, Richard H.: Atmospheric Turbulence and Airplane Response in Convective-Type Clouds. Presented at Joint AIAA and AMS Meeting on Meteorological Support for Aerospace Testing and Operation, Fort Collins, Colo., July 1963.

87. DeVer Colson: Analysis of Special C-A-T Data Collection Program, Feb. 4-9, 1963. U. S. Weather Bureau, Washington, D. C.

88. Panofsky, H. A., and McLean, J. C., Jr.: Physical Mechanisms of Clear-Air Turbulence. Scientific Report No. 1, Penn. State University, October 1963.

89. Reiter, Elmer R.: CAT and SCAT. AIAA May 1964.

90. National Advisory Committee for Aeronautics: Meteorological Problems Associated With Commercial Turbojet-Aircraft Operation. NACA RM 54L29, June 1955.

91. Colorado State University Research Foundation, Fort Collins: Occurrence and Causes of High-Level Turbulence. Technical paper No. 45, July 15, 1963.

92. Paul, Philip I., 1st Lt, USAF: F-102 High-Altitude Flameouts in and Around Thunderstorms. WADD TN 60-296, January 1961.

IV. FLIGHT INVESTIGATIONS - GUST RESEARCH

93. Funk, Jack, and Binckley, E. T.: A Flight Investigation of the Effects of Compressibility on Applied Gust Loads. TN 1937, August 1949.

94. Thompson and Lipscomb: An Evaluation of the Use of Ground Radar for Avoiding Severe Turbulence Associated with Thunderstorms. TN 1960, October 1949.

95. Shufflebarger, C. C., and Mickleboro, H.: Flight Investigation of the Effect of Transient Wing Response on Measured Accelerations of a Modern Transport Airplane in Rough Air. TN 2150, Aug. 1950.

96. Mickleboro, H., and Shufflebarger, C. C.: Flight Investigation of the Effect of Transient Wing Response on Wing Strains of a Twin-Engine Transport Airplane in Rough Air. TN 2424, July 1951.

97. H. B. Tolefson and C. A. Gurtler: An Investigation of a Method to Indicate Atmospheric Turbulence From an Airplane in Flight. NACA RM L50K29a, July 1951.

98. Press, H., and McClanahan, H. C.: Flight Investigation of the Effect of Atmospheric Turbulence on the Climb Performance of an Airplane. TN 2498, October 1951.

99. Funk, J., and Binckley, E. T.: A Flight Investigation of the Effect of Center-of-Gravity Location on Gust Loads. TN 2575, December 1951.

00. Murrow, H. N., and Payne, C.: Flight Investigation of the Effect of Transient Wing Response on Wing Strains of a Four-Engine Bomber Airplane in Rough Air. TN 2951, June 1953.

01. Mickleboro, H., Fahrer, R., and Shufflebarger, C.C.: Flight Investigation of Transient Wing Response on a Four-Engine Bomber Airplane in Rough Air With Respect to c.g. Accelerations. TN 2780, Sept. 1952.

02. Payne, C.: A Flight Investigation of Some Effects of Automatic Control on Gust Loads. RM L53E14a.

103. Funk, Jack, and Mickleboro, Harry C.: A Comparison of Gust Loads Measured in Flight on a Swept-Wing Airplane and on an Unswept-Wing Airplane. RM L52L02, June 1953.

104. Vitale, James A., Press, H., and Shufflebarger, C.C.: An Investigation of the Use of Rocket Models for Gust-Load Studies With an Application to a Tailless Swept-Wing Model at Transonic Speeds. RM L53L08, June 1954.

105. Coe, E. C., and Fetner, M. W.: Summary of Turbulence Data Obtained During United Air Lines Flight Evaluation of an Experimental C Band (5.5 cm) Airborne Weather Radar. NACA RM L54F07, 1954.

106. Mickleboro, H. C., and Funk, Jack: A Flight Study of Compressibility Effects on the Gust Loads of a 35° Sweptback-Wing Airplane. NACA RM L54G09a, 1954.

107. Funk, Jack, and Rhyne, Richard H.: An Investigation of the Loads on the Vertical Tail of a Jet-Bomber Airplane Resulting From Flight Through Rough Air. NACA TN 3741, October 1956.

108. Coleman, T. L., Press, Harry, and Shufflebarger, C.C.: Effects of Airplane Flexibility on Wing Bending Strains in Rough Air. NACA TN 4055, July 1957.

109. Shufflebarger, C. C., Payne, Chester B., and Cahen, George L.: A Correlation of Results of a Flight Investigation with Results of an Analytical Study of Effects of Wing Flexibility on Wing Strains Due to Gusts. TN 4071, May 1957.

110. Rhyne, R. H., and Murrow, H. N.: Effects of Airplane Flexibility on Wing Strains in Rough Air at 5,000 Feet as Determined by Flight Tests of a Large Swept-Wing Airplane. TN 4107, Sept. 1957.

111. Rhyne, Richard H.: Effects of Airplane Flexibility on Wing Strains in Rough Air at 35,000 Feet as Determined by a Flight Investigation of a Large Swept-Wing Airplane. TN 4198, Jan. 1958.

112. Engel, J. N.: Experimental Measurements of the Effects of Airplane Motions on Wing and Tail Angles of Attack of a Swept-Wing Bomber in Rough Air. NACA TN 4307, August 1958.

113. Rhyne, R. H.: Measurements of the Motions of a Large Swept-Wing Airplane in Rough Air. NACA TN 4310, Sept. 1958.

114. Murrow, H. N.: An Analysis of Flight-Test Measurements of the Wing Structural Deformations in Rough Air of a Large Flexible Swept-Wing Airplane. NASA Memo. 12-3-58L. January 1959.

115. Funk, J., and Cooney, T. V.: Some Effects of Yaw Damping on Airplane Motions and Vertical-Tail Loads In Turbulent Air. NASA Memo. 2-17-59L.

116. Coleman, Thomas L., Murrow, Harold N., and Press, Harry: Some Structural Response Characteristics of a Large Flexible Swept-Wing Airplane in Rough Air. Jour. Aero/Space Sci., Vol. 25, No. 8, pp. 515-521, August 1959.

117. Gracey, William, and Shipp, Jo Ann: Random Deviations From Cruise Altitudes of a Turbojet Transport at Altitudes Between 20,000 and 41,000 feet. NASA TN D-820, 1961.

118. Pearson, H. A.: Acceleration, Stress, and Deflection Measurements of the X-15 Bomber in Gusty Air. NACA Memo Report, Langley Memorial Aeronautical Laboratory, Langley Field, Va., June 1939.

119. Kraft, Christopher C., Jr.: Flight Measurements of the Velocity Distribution and Persistence of the Trailing Vortices of an Airplane. NACA TN 3377, March 1955.

120. Roys, George P., 1st Lt, USAF: Operation of an F-106A In Thunderstorms at Supersonic and High Subsonic Airspeeds. ASD TN 61-97, Oct. 1961.

V. THEORETICAL STUDIES - GUST RESEARCH

121. Mazelsky, B., and Diederich, F. W.: Two Matrix Methods for Calculating Forcing Functions From Known Responses. NACA TN 1965, July 1949.

122. Press, Hary: The Application of the Statistical Theory of Extreme Values to Gust Load Problems. TR 991, 1950.

123. Mazelsky, B.: Charts of Airplane Acceleration Ratio for Gusts of Arbitrary Shape. TN 2036.

124. Mazelsky, B., and Diederich, F. W.: A Method of Determining the Effect of Airplane Stability on the Gust Load Factor. TN 2035.

125. Mazelsky, B.: Numerical Determination Indicial Lift of a Two-Dimensional Sinking Airfoil at Subsonic Mach Numbers From Oscillatory Lift Coefficients With Calculations for Mach Number 0.7. TN 2562, July 1951.

126. Mazelsky, B.: Determination of Indicial Lift and Moment of a Two-Dimensional Pitching Airfoil at Subsonic Mach Numbers From Oscillatory Coefficients With Numerical Calculations for a Mach No. of 0.7. TN 2613, February 1952.

127. Mazelsky, B., and Drischler, J.: Numerical Determination of Indicial Lift and Moment Function for a Two-Dimensional Sinking and Pitching Airfoil at M = 0.5 and 0.6. TN 2739, July 1952.

128. Press, Harry: An Approach to the Prediction of the Frequency Distribution of Gust Loads on Airplanes in Normal Operations. TN 2660, April 1952.

129. Pratt, K.: A Revised Formula for the Calculation of Gust Loads. TN 2964, June 1953.

130. Pratt, K. G., and Walker, W. G.: A Revised Gust-Load Formula and a Reevaluation of VG Data Taken on Civil Transport Airplanes From 1933 to 1950. TR 1206, 1954.

131. Houbolt, John C.: Correlation of Calculation and Flight Studies of the Effect of Wing Flexibility on Structural Response Due to Gusts. NACA TN 3006, 1953.

132. Press, H., and Mazelsky, B.: A Study of the Application of Power-Spectral Methods of Generalized Harmonic Analysis to Gust Loads on Airplanes. NACA Rept. No. 1172, 1954. (Also TN 2853, Jan. 1953.)

133. Houbolt, John C., and Kordes, Eldon E.: Structural Response to Discrete and Continuous Gusts of an Airplane having Wing-Bending Flexibility and a Correlation of Calculated and Flight Results. NACA Rep. 1181, 1954. (Supersedes NACA TN 3006; also contains essential material from TN 2763 and TN 2897.)

134. Mazelsky, B.: Extension of the Power Spectral Methods of Generalized Harmonic Analysis to Determine Non-Gaussian Probability Functions of Random Input Disturbances and Output Responses of Linear Systems. Jour. Aero. Sci., Vol. 21, No. 3, March 1954.

135. Press, Harry, and Houbolt, John C.: Some Applications of Generalized Harmonic Analysis to Gust Loads on Airplanes. Jour. Aero. Sci., Vol. 22, No. 1, January 1955, pp. 17-26.

136. Zbrozek, J. K.: A Study of the Longitudinal Response of Aircraft to Turbulent Air. R.A.E. Rept. No. Aero 2530, ARC 17612, January 1955.

137. Zbrozek, J. K.: Longitudinal Response of Aircraft to Oscillatory Vertical Gusts. R.A.E. Rept. No. Aero. 2559, November 1955.

138. Diederich, F. W.: The Dynamic Response of a Large Airplane to Continuous Random Atmospheric Disturbances. Journal of the Aeronautical Sciences, Vol. 23, Oct. 1956.

139. Eggleston, John M.: Calculation of the Forces and Moments on a Slender Fuselage and Vertical Fin Penetrating Lateral Gusts. NACA TN 3805, October 1956.

140. Pratt, Kermit G., and Bennett, Floyd V.: Charts for Estimating the Effects of Short-Period Stability Characteristics on Airplane Vertical Acceleration and Pitch-Angle Response in Continuous Atmospheric Turbulence. NACA TN 3992, June 1957.

141. Eggleston, John M.: A Theory for the Lateral Response of Airplanes to Random Atmospheric Turbulence. NACA TN 3954, May 1957.

142. Diederich, Franklin M.: The Response of an Airplane to Random Atmospheric Disturbances. NACA Rep. 1345, 1958. (Supersedes NACA TN 3910.)

143. Thorson, Kenneth R., and Bohne, Quentin R.: Application of Power Spectral Methods in Airplane and Missile Design. Inst. Aero. Sci. Report No. 59-42, January 1959.

144. Houbolt, John C., and Steiner, Roy: Prediction of Gust Loads in Airplane and Missile Operations. WADC TR 59-507, Proc. of Fatigue of Aircraft Structures. August 11-13, 1959, Dayton, Ohio.

145. Bennett, Floyd V., and Yntema, Robert T.: Evaluation of Several Approximate Methods for Calculating the Symmetrical Bending-Moment Response of Flexible Airplanes to Continuous Atmospheric Turbulence. NASA Memo. 2-18-59L, March 1959.

146. Bennett, Floyd, and Pratt, Kermit G.: Calculated Responses of a Large Swept-Wing Airplane to Continuous Turbulence with Flight Test Comparisons. NASA TR R-69, 1960.

147. Eggleston, John M., and Phillips, William H.: The Lateral Response of Airplanes to Random Atmospheric Turbulence. NASA TR R-74, 1960.

148. Bunham, J.: Aircraft Response to Tubulent Air. R.A.E. Tech. Note No, Aero 2791. October 1961.

149. Zbrozek: J. K.: Aircraft and Atmospheric Turbulence. R.A.E. Tech. Note No. Aero 2790, October 1961.

150. Houbolt, John C., Steiner, Roy, and Pratt, Kermit G.: Flight Data and Considerations of the Dynamic Response of Airplanes to Atmospheric Turbulence. Pres. to the Structures and Materials Panel and to the Flight Mechanics Panel, Advisory Group for Aeronautical Research and Development, Paris, France, July 3-13, 1962. (Presently being made into a TR, same title).

151. Pearson, Henry A.: Study of Inadvertent Speed Increases in Transport Operations. NACA Report 1138, 1953.

VI. GUST-ALLEVIATION

152. Boucher, Robert W., and Kraft, Christopher C., Jr.: Analysis of a Vane-Controlled Gust-Alleviation System. NACA TN 3597, 1956.

153. Phillips, William H., and Kraft, Christopher C., Jr.: Theoretical Study of Some Methods for Increasing the Smoothness of Flight Through Rough Air. NACA TN 2416, 1951.

154. Russell, Walter R., Sjoberg, S. A., and Alford, William L.: Flight Investigations of Automatic Stabilization of an Airplane Having Static Longitudinal Instability. NASA TN D-173, 1959.

155. Hunter, Paul A., Kraft, Christopher C., Jr., and Alford, William L.: A Flight Investigation of an Automatic Gust-Alleviation System in a Transport Airplane. NASA TN D-532, January 1961.

156. Kraft, Christopher C., Jr.: Initial Results of a Flight Investigation of a Gust-Alleviation System. NACA TN 3612, April 1956.

157. Payne, Chester B.: A Flight Investigation of Some Effects of Automatic Control on Gust Loads. NACA RM L53E14a, July 1953.

VII. GUST TUNNEL INVESTIGATIONS

158. Donely, Phillip: An Experimental Investigation of the Normal Acceleration of an Airplane Model in a Gust. NACA TN 706, May 1939.

159. Reisert, T. D.: Gust-Tunnel Investigation of a Wing Model With Semichord Line Swept Back 30°. TN 1794, January 1949.

160. Pierce, Harold B.: Tests of a 45° Sweptback-Wing Model in the Langley Gust Tunnel. NACA TN 1528, February 1948.

161. Reisert, D.: Gust-Tunnel Investigation on a Flexible Wing Model With Semichord Line Swept Back 45°. TN 1959, October 1949.

162. Pierce, H. B.: Gust-Tunnel Investigation of a Wing Model With Semichord Line Swept Back 60°. TN 2204, 1950.

163. Cahen, G. L.: Gust-Tunnel Investigation to Determine the Load at the Joint of a Coupled Airplane Configuration Encountering a Gust. RM SL51E01a.

164. Pierce, H. B., and Johns, S.: Gust-Tunnel Investigation of a Delta-Wing Model with the Leading Edge Swept back 60°. RM L52B04, April 1952.

165. Reisert, D., and Maglieri, D.: Gust-Tunnel Investigation to determine Effects of Center-of-Gravity Position on the Gust Loads of a Delta-Wing Model With Leading Edge Swept Back 60°. RM L53A30, June 1953.

166. Cahen, Geoge L.: A Preliminary Gust-Tunnel Investigation of Leading-Edge Separation on Swept Wings. RM L52C20, June 1952.

167. Cahen, George L.: Gust-Tunnel Investigation of the Effect of Leading-Edge Separation on the Normal Accelerations Experienced by a 45° Sweptback-Wing Model in Gusts. RM L53J07, November1953.

168. Maglieri, Domenic J., and Reisert, Thomas D.: Gust-Tunnel Investigation of the Effect of a Sharp-Edge Gust on the Flapwise Blade Bending Moments of a Model Helicopter Rotor. TN 3470, May 1955.

169. Croom, Delwin,R., Shufflebarger, C. C., and Huffman, J. K.: An Investigation of Foward-Located Fixed Spoilers and Deflectors as Gust Alleviators on an Unswept-Wing Model. TN 3705, June 1956.

VIII. INSTRUMENTATION - FLIGHT RESEARCH

170. Tolefson, H. B., and Gurtley C. A.: An Investigation of a Method to Indicate Atmospheric Turbulence From an Airplane in Flight. RM L50K29a.

171. Richardson, Norman R.: NACA VGH Recorder. NACA TN 2265, 1951.

172. Taback, Ismael: The NACA Oil-Damped VG Recorder. NACA TN 2194, 1950

173. Flight Standards Service, FAA: "Project Race" Recorder and Control Evaluation, Boeing 707/720. January 1963.

174. FAA Altimeter Systems Survey. Contract FAA ARDS-445. Proj. No. 307-16-SD.

IX - AIRCRAFT FLIGHT CHARACTERISTICS

175. Tynczyszyn, J. J., and Spiess, Paul C.: The Effects of Supersonic Transport Flight Characteristics on Performance Requirements. SAE 674D, Wash. D. C., April 1963.

176. O'Harrah, Ralph C.: Low Altitude, High Speed Handling and Riding Qualities. AIAA June 1963.

177. Campbell, George S., and Weil, Joseph: The Interpretation of Nonlinear Pitching Moments in Relation to the Pitch-Up Problem. NASA TN D-193. Supersedes NACA RM L53I02).

178. Fischel, Jack, Butchart, Stanley P., Robinson, Glenn H.; and Tremant, Robert A.: Flight Studies of Problems Pertinent to Low-Speed Operation of Jet Transports. NASA Memo. 3-1-59H, April 1959.

179. Butchart, Stanley P., Fischel, Jack, Tremant, Robert A., and Robinson, Glenn H.: Flight Studies of Problems Pertinent to High-Speed Operation of Jet Transports. NASA Memo. 3-2-59H, April 1959.

180. Tambor, Ronald: Flight Investigation of the Lift and Drag Characteristics of a Swept-Wing, Multijet, Transport-Type Airplane. NASA TN D-30, Nov. 1959.

181. Williams, Walter C., and Phillips, William H.: Some Recent Research on the Handling Qualities of Airplanes. NACA RM H55L29a, February 1956.

182. Wright Air Development Center: Phase V (Adverse Weather) Flight Tests of the KC-135A Aircraft. WADC TN 57-303, ASTIA Doc. AD 130999.

183. Davis, Don D., Jr.: The Problem of Reducing the Speed of a Jet Transport in Flight. NACA TN 3613, Dec. 1955.

184. Phillips, William H., Brown, B. Porter, and Matthews, James T., Jr.: Review and Investigation of Unsatisfactory Control Characteristics Involving Instability of Pilot-Airplane Combination and Methods for Predicting These Difficulties From Ground Tests. NACA RM L53F17a, August 1953.

185. Koven, W. and Wasicko, R.: Flying Quality Requirements for United States Navy and Air Force Aircraft. NATO-AGARD R-336, April 1961

186. Allwright, H. J.: Design Aims for Stability and Control of Piloted Aircraft. NATO-AGARD R-337, April 1961.

X. POWER PLANTS

187. Conference on Environmental Effects on Aircraft Propulsion. U. S. Naval Air Turbine Test Station, Trenton, New Jersey, Jan. 22-23, 1961.

188. Second Annual Conference on Weather Effects on Aircraft Systems. U. S. Naval Air Turbine Test Station, Trenton, N. J., Sept. 18-19, 1962.

189. Stawski, Edward: Altitude Operation of a J57-P-20 Turbojet Engine under Water and Ice Ingestion Conditions; Part 3: Evaluation of Anti-Ice System. U. S. Naval Air Turbine Test Station, Trenton, N.J. March 1962.

190. Paul, Philip I., 1st Lt, USAF: F-102 High-Altitude Flameouts in and Around Thunderstorms. WADD TN 60-296, January 1961.

191. Factors that Affect Operational Reliability of Turbo-jet Engines. NASA TR R-54, 1960.

XI. AIRCRAFT INSTRUMENTATION

192. Zalovcik, John A.: Summary of Stall-Warning Devices. NACA TN 2676, May 1952.

193. Myers, C. E., Jr.: Alpha is For Angle of Attack. Society of Experimental Test Pilots. Vol. 2, No. 3, Quarterly Review, Spring 1958.

194. Anderson, Seth B.: Correlation of Pilot Opinion of Stall Warning With Flight Measurements of Various Factors Which Produce the Warning. NACA TN 1868, April 1949.

195. Hogan, Lt. Edward J.: Toward An Optimum Approach The Naval Aviation Safety Review "Approach", Aug. 1963

196. McFadden, N. M.: Rathert, George A., Jr., and Bray, Richard S.: Flight Calibration of Angle of Attack and Sideslip Detectors on the Fuselage of a 35° Swept-Wing Fighter Airplane. NACA RM A52A04, February 1952.

XII. WEATHER

197. Perkins, Porter J., and Kline, Dwight B.: Analysis of Meteorological Data Obtained During Flight in a Supercooled Stratifom Cloud of High Liquid Water Content. NASA RM E51D18, July 11, 1951.

198. Schumacher, Paul W. J.: Free Water At High Altitudes. Reprint 63-293, AIAA-AMS. Meteorological Support for Aerospace Testing and Operation Meeting, Fort Collins, Colorado, July 10-12, 1963.

199. Weather Bureau - U. S. Dept. of Commerce: Severe Storm Detection and Circumnavigation. Final Report FAA Contract ARDS-A-176, National Severe Storms Project, June 1963.

200. 8th Weather Group, Technical Services, Seminar #43: C-135A Data and Information for Forecasters. January 1962.

201. Roys, George P.: Thunderstorm Penetrations by an F-106A Aircraft at High Speed and High Altitude. WADD TN 60-274, December 1960.

202. Schumacher, Roys, and Binckley: USAF Operations in 1960 National Severe Local Storm Research Project (Rough Rider). WADD TN 60-282, January 1961.

203. Aeronautical Systems Division, Dir/Flight Test, Wright-Patterson AFB, Ohio: Airborne Instrumentation System for Measuring Meteorological Phenomena Inside Thunderstorms. Rpt. No. ASD-TDR-63-231, May 1963.

204. Wicker, Arthur R., Captain USAF: Turbulence and Radar Photographic Studies of Thunderstorms. WADD TN 60-303, January 1961.

BIBLIOGRAPHY - UPDATED AND EXTENDED THRU 1965

205. Arguella, R. J.: Clear Air Turbulence Investigation. Kollsman Instrument Corp., #389930-1, Aug. 4, 1964.

206. Dir. of Aero. Safety: CAT Again. Aerospace Safety, USAF Dec. 1963.

207. Beard, M. G., Flight Safety Foundation: Status Report on Latest Developments in Clear Air Turbulence. AIAA paper 65 - 800 Nov. 1965.

208. Beckwith, W. B.: Analysis of the Severe Weather Factors in Automatic Control of Air Route Traffic. UAL Meteorological Circular No. 54, 1962.

209. Best Jr., Col. William H.: War Against CAT. Combat Crew, Nov. 1964.

210. Bigler, Stewart A.: Ground Based Radar as a Means of Detecting Areas of Turbulence and Hail. Flight Safety Fdn. Seminar, Nov. 1964.

211. Binding, A. A.: Association of Clear Air Turbulence With 300 MB Contour Patterns. The Meteorological Magazine, Met. 0.762 Meteorological Office, Jan. 1965.

212. Blackmer, R. H. and Serebreny, S. M.: Dimensions and Distributions of Cumulus Clouds as Shown by U-2 Photographs. Geophysics Research Directorate, AFCRL-62-609- July, 1962.

213. Burns, A. and Rider, C. K.: Project "TOPCAT", Power Spectral Measurements of Clear Air Turbulence Associated with Jet Streams. Royal Aircraft Establishment, Technical Memo. No. Structures, 1965.

214. Chaney, Robert E.: Subjective Reaction to Whole-Body Vibration. The Boeing Co., Wichita, Kan., Rpt. D3-6474, Sept. 1964.

215. Clark, Capt. John B.: Turbulence -- Hidden Giant in The Sky. Rebuttal to Life Mag. article, Dec. 21, 1964.

216. Collis, Ronald T. H.: The Possibility of Detecting Clear Air Turbulence Using Laser Radar. Occasional Paper #18, Stanford Res. Inst., May 1964.

217. Colson, Dever: Analysis of Clear Air Turbulence During April 1960. Monthly Weather Review, Mar. 1961.

218. Colson, Dever: Analysis of Clear Air Turbulence Data for March 1962. Monthly Weather Review, Vol. 91, #2, Feb. 1963.

219. Endlich, R. M. and Mancuso, R. L.: On The Analysis of Clear Air Turbulence by Use of Rawinsonde Data. Monthly Weather Review, Vol. 93, #1, Jan. 1965.

220. Endlich, R. M. and McLean, G. S.: Studies of the Climatology of Winds, Temperature and Turbulence in Jet Streams. Stanford Res. Inst. Final Report, AFCRL-64-834.

221. Fusca, James A.: Clear Air Turbulence. Space Aeronautics, Aug. 1964.

222. George, J. J.: Prediction of Clear Air Turbulence. Reprint from issue #273, Shell Aviation News.

223. Gould, D. G. and Wood, A. D.: Engineering Considerations of Low Altitude Flight in Turbulence. Reprint from article DME/NAE quarterly Bulletin No. 1965 (1).

224. Harrison, H. T.: Mountain Wave Zones in the United States. UAL Meteorology Circular #43, Sept. 1, 1957.

225. Harrison, Henry T.: Progress in Forecasting High Level Clear Air Turbulence. UAL Meteorology circular #52, Mar. 1, 1961.

226. Hildreth, Jr., W. W.: High Altitude Clear Air Turbulence. Lockheed-Calif. Co., Technical Documentary Report No. ASD-TDR-63-440. 1963.

227. Kadlec, Paul W.: A Study of Flight Conditions Associated with Jet Stream Cirrus, Atmospheric Temperature Change, and Wind Shear Turbulence. U.S. Dept. of Commerce Weather Bureau, June 1964.

228. Klass, Philip J.: Airborne Turbulent Sensors Under Test. Av. Wk., 31 Aug. 1964.

229. Lappe, U. Oscar: Low Altitude Turbulence Model for Estimating Gust Loads on Aircraft. AIAA paper 65-14, Jan. 1965.

230. Lear, Siegler: A Lidar System for Detecting Clear Air Turbulence. Engineering Proposal GR5552, Oct. 1964.

231. McLean, George: An Investigation into the Use of Temperature Gradients as an In-Flight Warning of Impending Clear Air Turbulence. Air Force Cambridge Res. Labs., AFCRL 65-117, Feb. 1965.

232. Meeker, Jr., Ralph I.: Some Quantitative Aspects of Clear Air Turbulence. A.A.L. Forecaster LAX, Jan. 31, 1962.

233. Merritt, Earl S. and Raymond, Wexler: Radiometric Detection of Clear Air Turbulence. Aracon Geophysics Co., Concord, Mass., Oct. 14-16, 1964.

234. Mizon, E. A.: Forecasting Aspects of the First Phase of the TOPCAT Trials. Project TOPCAT Meteorological Reports, University of Melbourne, Meteorology Dept. 1964.

235. Naneviez, J. E., Vance, E. F., Serebreny, S.: Correlation between Clear Air Turbulence and Electric Fields. Stanford Res. Inst., AFCRL 65-112, Feb. 1965.

236. NASA: Report to Comm. on Aircraft Operating Problems. 14 Dec. 64.

237. National Center for Atmospheric Research: Reports of Research and Facilities Programs. 1964.

238. Panofsky, H. A., and McLean, Jr., J.C.: Physical Mechanism of Clear-Air Turbulence. Research Report to U.S. Weather Bureau, Dept. of Meteorology, Pennsylvania State U., 1964.

239. Partl, Willibald: Troposphere or Stratosphere? Navigation - 1961, Vol. 8 #1.

240. Partl, Willibald: Clear Air Turbulence at the Tropopause Levels. Navigation - Winter 62-63, Vol. 9 #4.

241. Pchelko, I. G.: Aero Synoptic Conditions of Airplane Bumpiness. Gidromet, Moscow. 1962.

242. Pinus, N. S. and Shmeter, J. M.: Atmospheric Turbulence Affecting Aircraft Bumping. Gidromet, Moscow. 1962.

243. Radok, U.: Project TOPCAT, Meteorological Reports. University of Melbourne, Meteorology Dept., 1964.

244. Reiter, E. R.: Turbulenz in Wolkenfreien Raum. (Clear Air Turbulence.) Berichte des Deutschen Wetterdienstec No. 61. 1960.

245. Reiter, E. R.: Meteorologie der Strahlstrome. (Jet Streams.) Springer-Verlag, Vienna. 1961.

246. Reiter, E. R.: On The Nature of Clear-Air Turbulence. Aerospace Engineering 21 (11): 39 - 46. 1962.

247. Reiter, E. R.: A Case Study of Severe Clear-Air Turbulence. Archiv Meteorol., Geophysik, Bioklimatol., Ser. A. 13 (3-4): 379-389. 1963.

248. Reiter, E. R.: Nature and Observation of High-Level Turbulence Especially in Clear Air. Colorado State University, Atmospheric Science Tech. Paper No. 41, and U.S. Navy Weather Research Facility, Report No. NWRF 15-1262-071. 1963b.

249. Reiter, E. R. and Hayman: The Nature of Clear-Air Turbulence. Colorado State University, Atmospheric Science Tech. Report No. 28. 1962.

250. Reiter, E. R.: Jet-Stream Meteorology. University of Chicago Press, 1963c.

251. Reiter, E. R.: Nature & Observations of High-Trend Turbulence, Especially in Clear Air. Journal of Aircraft, Mar.-April 1964, Vol. 1 #2.

252. Reiter, E. R.: CAT and SCAT. Astronautics and Aeronautics, 2 (5): 60-65. 1964a.

253. Reiter, E. R.: Jet Streams and Turbulence. Australian Meteorol. Magazine, No. 45: 13-33. 1964b.

254. Reiter, E. R.: Nature and Observation of High-Level Turbulence especially in Clear Air. J. of Aircraft, 1 (2): 94-96. 1964c.

255. Reiter, E. R.: Progress in Clear-Air Turbulence Research and Forecasting. American Institute of Aeronautics and Astronautics, Paper no. 64-311, given at Annual Meeting, Washington, D.C. June 29-July 2, 1964.

256. Reiter, E. R.: Clear-Air Turbulence Models and Forecasting for Project TOPCAT, Second Phase. Project TOPCAT, Meteorological Reports, University of Melbourne, Meteorology Department. 1964e.

257. Reiter, E. R. and Nania, A.: Jet-Stream Structure and Clear-Air Turbulence. J. Applied Meteorol. 3(3): 1964.

258. Rhyne, R. H. and Steiner, R.: Turbulence and Precipitation Problems Associated with Operation of Supersonic Transports. Paper presented at 4th Conference on Applied Meteorology, Hampton, Va., Sept. 10-14, 1962.

259. Serebreny, Sidney M. and Weigman, Eldon J.: The Distribution of Clear Air Turbulence Reports and Cloud Patterns As Seen in Satellite Photographs. Stanford Research Institute.

260. Simpson, Leroy and Serebreny, Sidney M.: Meteorology & Jet Transport Operations. Stanford Res. Inst., 1960.

261. Smigielski, Frank J.: A Note on Clear Air Turbulence During April & May, 1960. Monthly Weather Review, Mar. 1961.

262. Soderlind, Paul A.: Jet Turbulence Penetration. The Airline Pilot, Dec. 1963.

263. Soderlind, Paul: Jet Transport Operation in Turbulence. AIAA paper #64-353, June 1964.

264. Sorenson, John E.: Synoptic Patterns For Clear-Air Turbulence. UAL Meteorology Circular #56. Dec. 21, 1964.

265. Spillane, K. T.: A Survey of the Subtropical Jet Stream and Clear-Air Turbulence Models. Project TOPCAT, Meteorological Reports, University of Melbourne, Meteorology Department. 1964.

266. Steiner, Roy: Review of NASA High Altitude Clear-Air Turbulence Sampling Programs. AIAA paper 65-13, Jan. 1965.

267. Tyster, H. N. C. and Pettit, K. G.: Low Altitude Turbulence Over Hilly Terrain Counting Accelerometer Data From Jet Aircraft. National Aeronautical Establishment, National Research Council of Canada, Ottawa, Dec. 1964.

268. Vickers, Tirey K.: Living With Vortices. The Controller, Jan. 1965. Vol. 9 #1.

269. Vonnegut, Bernard: Electrical Behavior of an Airplane in a Thunderstorm. Arthur D. Little, Cambridge, Mass. (FAA-ADS-36) Feb. 1965.

270. Weihe, Vernon I.: Airborne Sensing of Clear Air Turbulence. Navigation, 1963. Vol. 10, #3.

271. Wimbush, M. H.: Optical Astronomical Seeing. Reference to IRE Transactions, Oct. 1961.

272. Young, John B. and Corwin, H. Glenn: Turbulence Forecasting for Transatlantic Jet Flights. TWA Technical Bulletin No. 63-1, May 1963.

273. Zbrozek, J. K.: Atmospheric Gusts - Present State of the Art and Further Research. Journal of the Royal Aeronautical Society, Vol. 69, Jan. 1965.

274. Zbrozek, J. K.: A Study of the Longitudinal Response of Aircraft to Turbulent Air. Royal Aircr. Estab., Farnborough, Eng., RAE-Aero-2530, Jan. 1955.

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NASA-Langley, 1966 CR-62028