

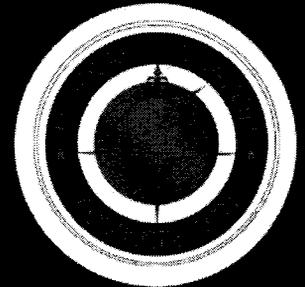


**AC 00-57**

**Hazardous  
Mountain  
Winds**



*And  
Their  
Visual  
Indicators*



AC 00-57

# **Hazardous Mountain Winds And Their Visual Indicators**

U.S. DEPARTMENT OF TRANSPORTATION  
Federal Aviation Administration  
Office of Communications, Navigation, and Surveillance Systems  
Washington, D.C.

---

## FOREWORD

This advisory circular (AC) contains information on hazardous mountain winds and their effects on flight operations near mountainous regions. The primary purpose of this AC is to assist pilots involved in aviation operations to diagnose the potential for severe wind events in the vicinity of mountainous areas and to provide information on pre-flight planning techniques and in-flight evaluation strategies for avoiding destructive turbulence and loss of aircraft control. Additionally, pilots and others who must deal with weather phenomena in aviation operations also will benefit from the information contained in this AC.

Pilots can review the photographs and section summaries to learn about and recognize common indicators of wind motion in the atmosphere. The photographs show physical processes and provide visual clues. The summaries cover the technical and “wonder” aspects of why certain things occur — what caused it? How does it affect pre-flight and in-flight decisions? The physical aspects are covered more in-depth through the text.

Comments regarding this publication should be directed to the Department of Transportation, Federal Aviation Administration, Flight Standards Service, Technical Programs Division, 800 Independence Avenue, S.W. Washington, DC 20591.

## Acknowledgments

---

Thomas Q. Carney	Purdue University, Department of Aviation Technology and Consultant in Aviation Operations and Applied Meteorology
A. J. Bedard, Jr.	National Oceanic and Atmospheric Administration Environmental Technology Laboratory
John M. Brown	National Oceanic and Atmospheric Administration Forecast Systems Laboratory
John McGinley	National Oceanic and Atmospheric Administration Forecast Systems Laboratory
Tenny Lindholm	National Center for Atmospheric Research Research Applications Program
Michael J. Kraus	National Oceanic and Atmospheric Administration Forecast Systems Laboratory

Cover photo: over Boulder, Colorado,  
winter 1988, © A.J. Bedard, Jr.

## TABLE OF CONTENTS

<p><b>FOREWORD</b> ..... v</p> <p><b>LIST OF FIGURES/TABLES</b> ..... ix</p> <p><b>PART I. REVIEW OF METEOROLOGICAL CONCEPTS</b> ..... 1</p> <p>1.0 INTRODUCTION ..... 1</p> <p>2.0 ACCIDENT STATISTICS ..... 3</p> <p>3.0 THE EFFECTS OF OROGRAPHIC WINDS AND TURBULENCE ON AVIATION OPERATIONS ..... 4</p> <p>    3.1 <i>High-Altitude Operations</i> ..... 4</p> <p>    3.2 <i>Takeoff and Landing</i> ..... 5</p> <p>    3.3 <i>Low-Level Mountain Flying</i> ..... 5</p> <p>4.0 SOURCES OF MOUNTAIN-INDUCED WIND HAZARDS FOR AVIATION ..... 6</p> <p>    4.1 <i>A Review of Key Meteorological Concepts</i> ..... 6</p> <p>    4.2 <i>A Review of Static Stability and Stable/Unstable Atmospheric Stratifications</i> ..... 8</p> <p>        4.2.1 Summary Comments on Stability ..... 10</p> <p>    4.3 <i>Elementary Theory of Gravity Waves and Shear-Induced Waves</i> ..... 11</p> <p>        4.3.1 Summary Comments on Gravity Waves and Shear-Induced Waves ..... 14</p> <p>    4.4 <i>Breaking Waves and Turbulence</i> ..... 14</p> <p>5.0 ATMOSPHERIC DISTURBANCES IN MOUNTAINOUS AREAS ..... 15</p> <p>    5.1 <i>Larger-Scale Hazards</i> ..... 15</p> <p>        5.1.1 Vertically Propagating Mountain Waves ..... 17</p> <p>            5.1.1.1 Forecast and Observed Data ..... 21</p> <p>            5.1.1.2 Charts ..... 22</p> <p>            5.1.1.3 Other Assistance ..... 23</p> <p>            5.1.1.4 Summary Comments on Vertically Propagating Mountain Waves ..... 24</p> <p>        5.1.2 Trapped Lee Waves ..... 24</p> <p>            5.1.2.1 Forecast and Observed Data ..... 30</p>	<p>                5.1.2.2 Summary Comments on Trapped Lee Waves ..... 31</p> <p>    5.1.3 Persistent Horizontal Roll Vortices (Rotors) ..... 32</p> <p>        5.1.3.1 Summary Comments on Horizontal Roll Vortices ..... 34</p> <p>    5.1.4 Kelvin-Helmholtz Waves ..... 34</p> <p>        5.1.4.1 Summary Comments on Kelvin-Helmholtz Waves ..... 38</p> <p>5.2 <i>Smaller-Scale Hazards</i> ..... 38</p> <p>    5.2.1 Lee-Side Inversion With Shear Flow (Mountain-Induced Shear With No Wave Development) ..... 38</p> <p>        5.2.1.1 Summary Comments on Lee-Side Inversions with Shear ..... 39</p> <p>    5.2.2 Non-Steady Horizontal Roll Vortices (Moving Horizontal Vortices) ..... 41</p> <p>        5.2.2.1 Summary Comments on Moving Horizontal Vortices ..... 45</p> <p>    5.2.3 Intense Vertical-Axis Vortices ..... 46</p> <p>        5.2.3.1 Summary Comments on Vertical-Axis Mountain Vortices ..... 47</p> <p>    5.2.4 Boras ..... 47</p> <p>        5.2.4.1 Summary Comments on Boras ..... 48</p> <p>    5.2.5 Other Phenomena ..... 48</p> <p>        5.2.5.1 Summary Comments on Other Phenomena ..... 49</p> <p><b>PART II. ATLAS OF VISUAL INDICATORS</b> ..... 51</p> <p>6.0 VISUAL INDICATORS OF OROGRAPHIC WIND FIELDS ..... 51</p> <p>    6.1 <i>Larger-Scale Features</i> ..... 51</p> <p>    6.2 <i>Smaller-Scale Flows</i> ..... 55</p> <p>    6.3 <i>Rotors and Other Turbulent Zones</i> ..... 58</p> <p>    6.4 <i>Interpreting Contrails</i> ..... 66</p> <p>    6.5 <i>Other Visual Indications of Air Motion Near Complex Terrain</i> ..... 73</p>
--	---

---

<b>PART III. SUMMARY .....</b>	<b>83</b>
<b>7.0 REVIEW OF MAJOR CONCEPTS .....</b>	<b>83</b>
<b>GLOSSARY OF KEY TERMS .....</b>	<b>87</b>
<b>REFERENCES.....</b>	<b>90</b>

## LIST OF FIGURES/TABLES

### Figure 1-1.

Figure 1-1. States with general aviation accident rates over 3.0 per 100,000 operations, Fiscal Year 1992.

### Table 2-1.

Turbulence-related accidents and incidents occurring in the vicinity of mountains.

### Figure 4-1.

Example of a large-scale atmospheric wave pattern as seen on a National Weather Service constant pressure chart (500 mb). The solid lines are approximately parallel to the wind flow at this level. Rawinsonde observations are plotted. This example happens to be a few hours before a DC-8 experienced engine separation west of Denver, Colorado (see Table 2-1).

### Figures 4-2a-c.

Determination of atmospheric stability: (a) unstable case; (b) neutral case; (c) stable case.

### Figure 4-3.

Oscillations associated with a gravity wave.

### Figure 4-4.

Growth and breakdown of waves induced by vertical wind shear in a stable layer of the atmosphere.

### Figure 4-5a-b.

Clouds associated with Kelvin-Helmholtz waves over Laramie, Wyoming (photograph ©, B. Martner).

### Figure 5-1.

Schematic of a vertically propagating mountain wave (after Durran and Klemp, 1983).

### Figure 5-2.

Schematic showing locations of jump and wave breaking region (after Durran and Klemp, 1983).

### Figure 5-3.

Aircraft flight tracks and turbulence encounters associated with a wave-induced high-wind event (taken from Lilly, 1978).

### Figure 5-4.

Schematic of the strong shear zone associated with a hydraulic jump in a mountain wave.

**Figure 5-5.**

The Fohn cloud and rotor clouds associated with a jump at the downstream edge of a region of strong downslope winds near Boulder, Colorado (photograph ©, 1991, R. Holle).

**Figure 5-6.**

Computer simulation of trapped lee waves behind a 300-meter-high mountain.

**Figure 5-7.**

Lenticular clouds associated with a trapped lee wave (after Durran and Klemp).

**Figure 5-8.**

Clouds associated with a trapped lee wave (photograph ©, 1988, R. Holle).

**Figure 5-9.**

Conceptual view of a mountain lee wave rotor zone (1993, A.J. Bedard, Jr.).

**Figure 5-10.**

View from aloft of a wave cloud and associated rotor (photograph ©, NCAR).

**Figure 5-11.**

Clouds associated with gravity-shear (Kelvin-Helmholtz) waves (photograph ©, 1985, P. Neiman).

**Figure 5-12.**

Clouds associated with gravity-shear (Kelvin-Helmholtz) waves (photograph ©, 1990, A.J. Bedard, Jr.).

**Figures 5-13a-c.**

A developing upslope flow associated with an approaching cold frontal boundary (photographs ©, 1990, A.J. Bedard, Jr.).

**Figure 5-14.**

Development of a strong roll vortex associated with a wind surge down the lee slope of a mountain (1993, A.J. Bedard, Jr.).

**Figure 5-15.**

Strong horizontal vortex (photograph ©, 1984, E. Richter).

**Figure 5-16.**

Schematic of vertically oriented vortices generated in the lee of an isolated mountain peak.

**Figures 6-1a-b.**

An isolated lenticular cloud near Pikes Peak, Colorado (photograph ©, 1990, R. Holle).

**Figure 6-2.**

A wave cloud over Laramie, Wyoming (photograph ©, B. Martner).

**Figures 6-3a-b.**

A wave cloud over Nederland, Colorado (photograph ©, 1993, P. Neiman).

**Figure 6-4.**

A wave cloud oriented parallel to the upper-level flow looking west from Dillon, Colorado (photograph ©, R. Reinking).

**Figures 6-5a-b.**

Circular lenticular clouds produced by a pair of eddies in the lee of an isolated mountain peak near Nederland, Colorado (photograph ©, 1990, P. Neiman).

**Figure 6-6.**

A three-dimensional lenticular cloud that has developed in the strong flow around Mt. McKinley, Alaska (photograph ©, 1981, B. Martner).

**Figure 6-7.**

A field of circular lenticular clouds that have developed in the complex flow around a number of mountain peaks in Mt. McKinley National Park, Alaska (photograph ©, 1979, B. Martner).

**Figure 6-8.**

A view of three-dimensional lenticular clouds taken from an aircraft (photograph ©, NCAR).

**Figure 6-9.**

A view of three-dimensional lenticular clouds north of Boulder, Colorado, taken from an aircraft (photograph ©, 1988, S. Holle).

**Figure 6-10.**

A lenticular cloud over Boulder, Colorado, at sunset (photograph ©, B. Martner).

**Figures 6-11a-b.**

Clouds associated with vertically suppressed trapped lee waves at Boulder, Colorado (photograph ©, 1987, P. Neiman).

**Figures 6-12a-b.**

Vertically enhanced clouds associated with a trapped lee wave at Boulder, Colorado (photograph ©, 1992, P. Neiman).

**Figures 6-13a-b.**

Rotor cloud near State College, Pennsylvania (photograph ©, 1985, P. Neiman).

**Figure 6-14.**

Schematic of the flow associated with a rotor zone in the lee of a mountain.

**Figures 6-15a-b.**

A group of rotor clouds over Boulder, Colorado, one of which has developed a helical structure (photograph ©, 1992, F.M. Ralph).

**Figure 6-16.**

A small vortex structure formed near a turbulent mixing zone (photograph ©, A.J. Bedard, Jr.).

**Figure 6-17.**

Turbulent cloud structures near the tropopause over Boulder, Colorado (photograph ©, 1993, P. Neiman).

**Figure 6-18.**

A linear contrail showing relatively smooth air (photograph ©, 1991, A.J. Bedard, Jr.).

**Figure 6-19.**

A contrail in the vicinity of mountain wave activity near Boulder, Colorado, showing areas of turbulence (photograph ©, 1988, R. Holle).

**Figure 6-20.**

A contrail showing a significant area of turbulence aloft (photograph ©, K. Langford).

**Figure 6-21.**

Contrail with turbulent zone, over Boulder, Colorado (photograph ©, F.M. Ralph).

**Figure 6-22.**

Contrail associated with lenticular and rotor clouds, showing very turbulent conditions aloft (photograph ©, K. Langford).

**Figure 6-23.**

Contrail located above rotor and lenticular clouds, indicating smooth conditions aloft (photograph ©, 1988, R. Holle).

**Figures 6-24a-b.**

Smokestack plumes with an inversion layer in Boulder, Colorado (photograph ©, 1992, P. Neiman).

**Figure 6-25.**

Blowing snow near mountain peaks, indicating likely wave activity (photograph ©, R. Reinking).

**Figure 6-26.**

Low-level wind indicators on a lake surface (photograph ©, 1988, A.J. Bedard, Jr.).

**Figure 6-27.**

Wave cloud occurring above a layer of weak instability (photograph ©, NCAR).

**Figure 6-28.**

Cap cloud over Mt. Shasta, California, with low-lying weak convection (photograph ©, 1972, R. Reinking).

**Figure 6-29.**

Banner and cap clouds occurring in the Grand Tetons, Wyoming (photograph ©, B. Martner).

**Figures 6-30a-c.**

Cap cloud, or cloud associated with a bora (photograph ©, K. Langford).

**Figure 6-31.**

A Foehn wall near Boulder, Colorado (photograph ©, 1988, R. Holle).

**Figure 6-32.**

Cap clouds over Owens Valley, California (photograph ©, 1974, R. Reinking).

**Figure 6-33.**

Banner clouds and blowing snow (photograph ©, 1967, R. Reinking).

**Figure 6-34.**

Cap cloud over Mt. Rainier, Washington (photograph ©, K. Langford).

**Figure 7-1.**

Clouds associated with a complicated flow regime in the lee of Long's Peak, Colorado (photograph ©, A.J. Bedard, Jr.).