Sailplane Flights into a Classical Appalachian Mountain Wave as Shown by the ESSA 9 Weather Satellite

By Charles V. Lindsay
Environmental Science Services Administration Weather Bureau Forecast Office, Washington, D.C., USA

Presented at the 12th OSTIV Congress, Alpine, USA (1970)

Introduction

Since the advent of the Tiros I weather satellite in 1960, photographs of many wave-cloud patterns have been observed over mountainous sections of the United States and other parts of the world.

We know that lenticular clouds, if correctly interpreted as such, are reliable evidence of the existance of mountain waves in an air stream. Reports of lenticular clouds from ground observations and by airborne pilots are of value in forecasting waves, especially as very little positive data on waves reach the aviation forecaster. Frequently pilots of powered aircraft encounter the vertical motions produced by waves when lenticular clouds are visible, although these motions occur when adequate moisture is lacking for cloud formation.

In 1965 Lindsay [1] related satellite photographs of wave-cloud patterns to wave soaring. There have been several occasions recorded [1, 2] when a sailplane was flown in a wave while a weather satellite was photographing the same area of waves. Previous examples have been rather brief in description.

On February 21, 1970 this satellite photograph relation to wave soaring occurred with much more detail than before. Very seldom are such classical mountain wave-clouds photographed by the weather satellite and also observed to be so widespread by ground observers as occurred to the lee of the Appalachian Mountains of Pennsylvania, Virginia, Maryland, and North Carolina on February 21, 1970. Not only were these clouds observed by the ESSA 9 weather satellite but they were also observed and photographed from the ground and in addition reported by a number of sailplane pilots and one powered aircraft pilot.

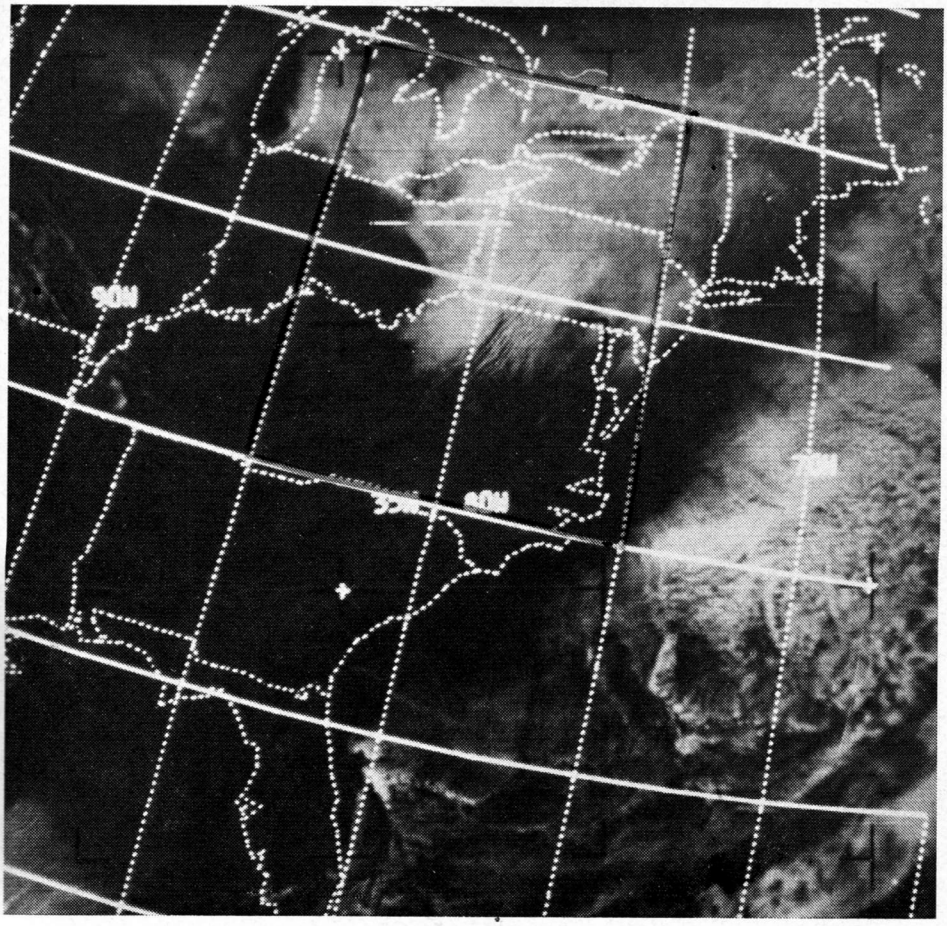


Fig. 1
Wave-cloud pattern to the lee of the Appalachian Mountains of Pennsylvania, Maryland, West Virginia, and Virginia as photographed by the ESSA 9 weather satellite at 1926 GMT (1426 EST) on February 21, 1970.

Satellite photograph of wave clouds on February 21, 1970

Figure 1, an ESSA 9 weather satellite photograph over the eastern United States at 1926 GMT (1426 EST) on February 21, 1970 shows the classical wave pattern in the clouds over Pennsylvania, Maryland, eastern West Virginia, and into West Virginia. This photograph shows that the waves extended 70 to 100 miles downwind from the mountains and about 240 miles in a general northeast-southwest direction along the mountains. The wave lengths were measured to be 6 to 8 miles. Figure 2, an enlargement of the previous figure, shows these waves more clearly and in more detail.

Previous work by Lindsay [2] from the results of 36 satellite wave photographs over the Appalachians showed the wave lengths to average 10 nautical miles, varying from 7 to 15 miles. In that study the waves extended downwind an average of 115 miles and 187 miles along the ridges in a general northeast-southwest direction. The area of the waves observed on the 21st of February was also the area where the frequency of waves indicated by the 36 weather satellite photographs showed a maximum over the Appalachian area.

The 26 cases on Corby's (1957) graph [3] relating the average wind speed in the troposphere to the observed wave length of lee waves produced a correlation coefficient of 0.91. On February 21st the mean wind speed in the troposphere over the area of the waves at 12 Z was 57 knots which (using Corby's graph) gave a wave length of 7 nautical miles. At 00 Z on the 22nd the mean wind speed was 64 knots which gave a wave length of 8 nautical miles. This compares almost exactly with the wave lengths as indicated by the photograph in figure 2.

Fritz [4] has used satellite pictures of mountain waves to estimate the average wind speed in the troposphere using Corby's graph with good results. On days when waves are likely but due to a lack of moisture wave clouds would not be expected, Corby's graph could be used to estimate the wave length.

Ground photographs of the same wave clouds shown by the weather satellite

At 1300 EST on February 21st the photograph of the wave clouds in figure 3 was taken from the west side of the City of Alexandria, Virginia looking west. Alexandria is some 45 miles east of the first mountain ridge. At this time

the wave clouds were well developed to the west of the city. By 1500 EST the lenticular clouds were seen everywhere even to the east of the City of Alexandria about 6 miles further east. Figure 4 was taken from the east side of Alexandria looking southeast. Later in the afternoon the clouds continued to increase in amount until only wave windows could be seen and finally it became overcast.

Over and close to the Appalachian Mountains lenticular clouds are frequently observed when conditions for wave development are present. These wave-cloud patterns are also frequently photographed by the weather satellites. November 30, 1959 was the last time that wave clouds were observed from the ground to be so well developed and widespread in the Washington area [5].

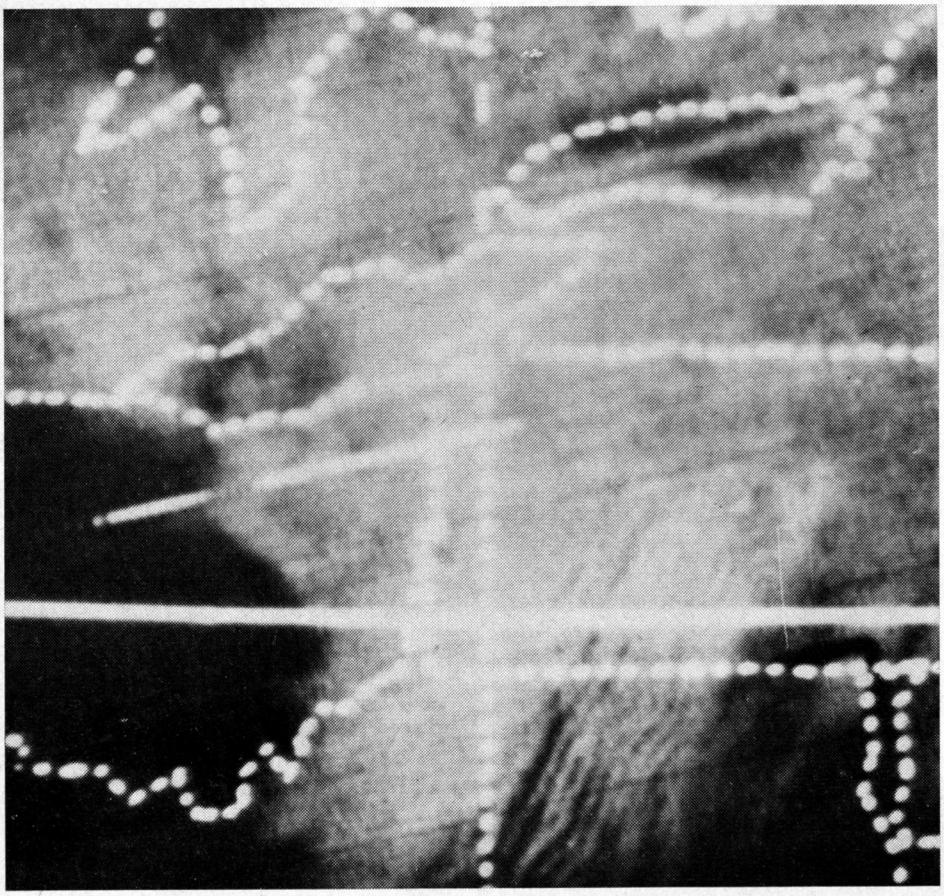


Fig. 2
Enlarged area of the wave-cloud pattern as shown in fig. 1.

Fig. 3
Photograph of mountain wave clouds taken from the west side of the City of Alexandria, Virginia at 1300 EST on February 21, 1970 looking west.

Surface observations and powered aircraft pilot reports of the waves on February 21, 1970

Very often wave clouds are present over the area of weather stations and observers either do not recognize them as such or fail to report them. Stations nearer to the mountains usually do a better job. This is also true when weather satellites show that wave clouds are over the same area. On February 21st weather observers at a number of weather stations noted these lenticular clouds (ACSL) and reported them on the hourly observations in the remarks. These observations are noted on figure 5 showing the time they were observed and the directions from the stations. Also included are reports by pilots of powered aircraft. At 1900 EST an AA-1 Yankee reported severe turbulence with up and down drafts at an altitude of 6,500 feet between Shenandoah Valley, Virginia and Elkins, West Virginia. On this day 10 aircraft reported moderate to severe turbulence below the wave clouds and two of them are noted on figure 5. One pilot reported severe turbulence over the Roanoke, Virginia area at 7,500 feet and smooth air at 8,500 feet. Three pilot reports of cloud tops are noted on figure 5 over southern Pennsylvania.

Reports by sailplane pilots flying in these waves

On February 21st a number of sailplane flights were made in waves from four locations in Virginia and Maryland as indicated by the four large solid circles on figure 5. The most significant flights were made from near Lexington, Virginia which was nearest the area where the jet stream passed over as indicated on figure 9 and is in the center of the wave area as shown by the weather satellite photograph. Pilots reported that wave flight was even better the following day, the 22nd of February, but the wave clouds were reported by these pilots only near the mountains. February 21st happened to be on a Saturday therefore sailplane pilots were out in force hoping for a wave flight.

Flight reports
from Lexington, Virginia

The following report was made by Allen R. Dresner on February 21, 1970 flying a Schweizer 1–23. At 1450 EST Dresner was towed off the 'L. B. Gliderport' located near Lexington, Virginia. The field elevation was 1,200 feet ASL and the surface wind was from the west at 15 to 20 knots. After a turbulent tow 6 miles due west, Dresner released at 6,000 feet ASL. A brief search for lift resulted only in sink so he retreated to an eight mile long ridge which was oriented NNE-SSW

with elevations ranging from 2,300 to 2,800 feet ASL. After working back and forth the length of the ridge for an hour using ridge lift he encountered thermal lift just west of the south end of the ridge. Climbing at 500 to 800 fpm in moderate turbulence he encountered smooth wave lift at 5,800 feet and climbed at 600 fpm initially with lift reducing gradually until his climb peaked out at 12,200 feet. He reported that it was apparent that the westerly wind had increased as he climbed and that he had backed out of the peak of the wave lift. The wind was 60 knots at 12,000 feet.

Radio advice from Jim Smiley flying a Libelle, who had earlier reached 17,000 feet, prompted Dresner to dive for penetration speed and he advanced 2 miles to an area of strong lift. Leveling off at 9,700 feet he started to climb in strong lift while maintaining 60 knots indicated airspeed. At 14,000 feet, lift at this high airspeed was down to 100 fpm. In the absence of oxygen equipment and approaching dusk he descended at 85 knots using some spoiler. At 8,000 to 9,000 feet he was dodging the many lenticular clouds which covered approximately 50 % of the sky.

Upon return to the field at 1728 EST and having made the Gold Altitude gain Dresner learned that several Gold Altitude attempts had failed because pilots were on tow until entering the wave at 6,000 to 6,500 feet ASL and then climbing to maximum altitude. Since lift apparently peaked out at 14,000 to 15,000 feet they just missed the required altitude gain of 3,000 meters.

The next morning (February 22nd) sailplanes were lined up at 0830 EST to try the wave again. Though surface winds were calm and no lenticulars were in evidence, every flight was towed directly into wave lift 6 miles northwest of the field at about 6,000 feet ASL. Wind velocities at altitude were only 40 knots but lift was steady and strong peaking out at 16,000 to 17,000 feet. At 1000 EST, lenticulars began to appear and were in evidence all day. Eight Gold Altitude gains were made on Sunday compared to two on Saturday.

The following flight report was related by J. C. Kellett. On Saturday, February 21st, Kellett launched twice. The first time he launched about 1030 EST and the second time about 1300 EST. The wave was present both times. In the early flight the sky was clear, although from his high point of about 11,500 feet he could see what appeared to be lenticular clouds forming west and north of the site. Before the second launch, lenticular clouds were forming all around. He flew out in front of one on the second flight for an altitude of 14,100 feet. The lenticular clouds were

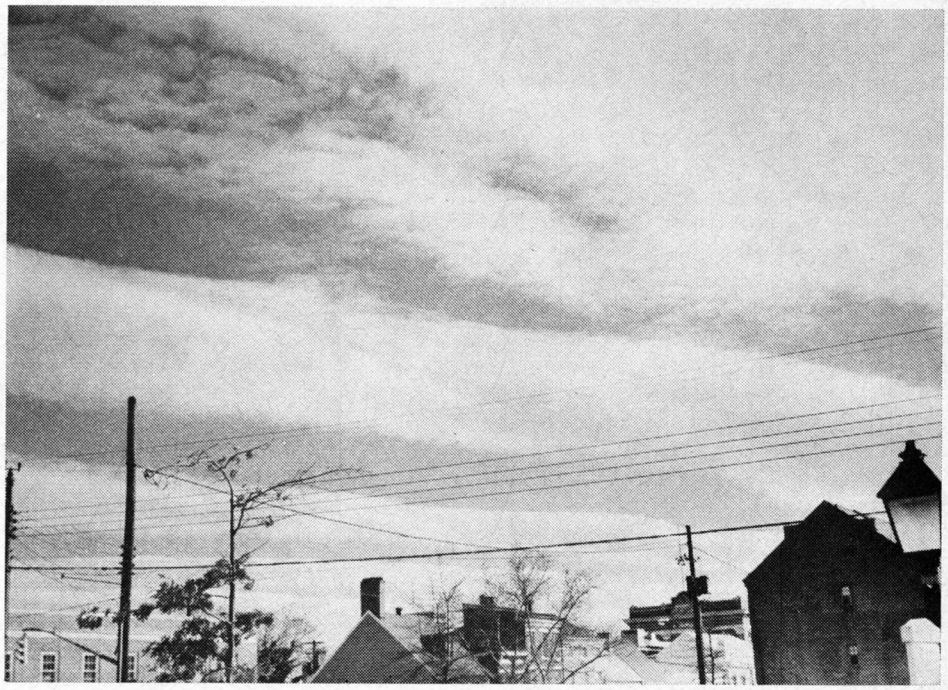
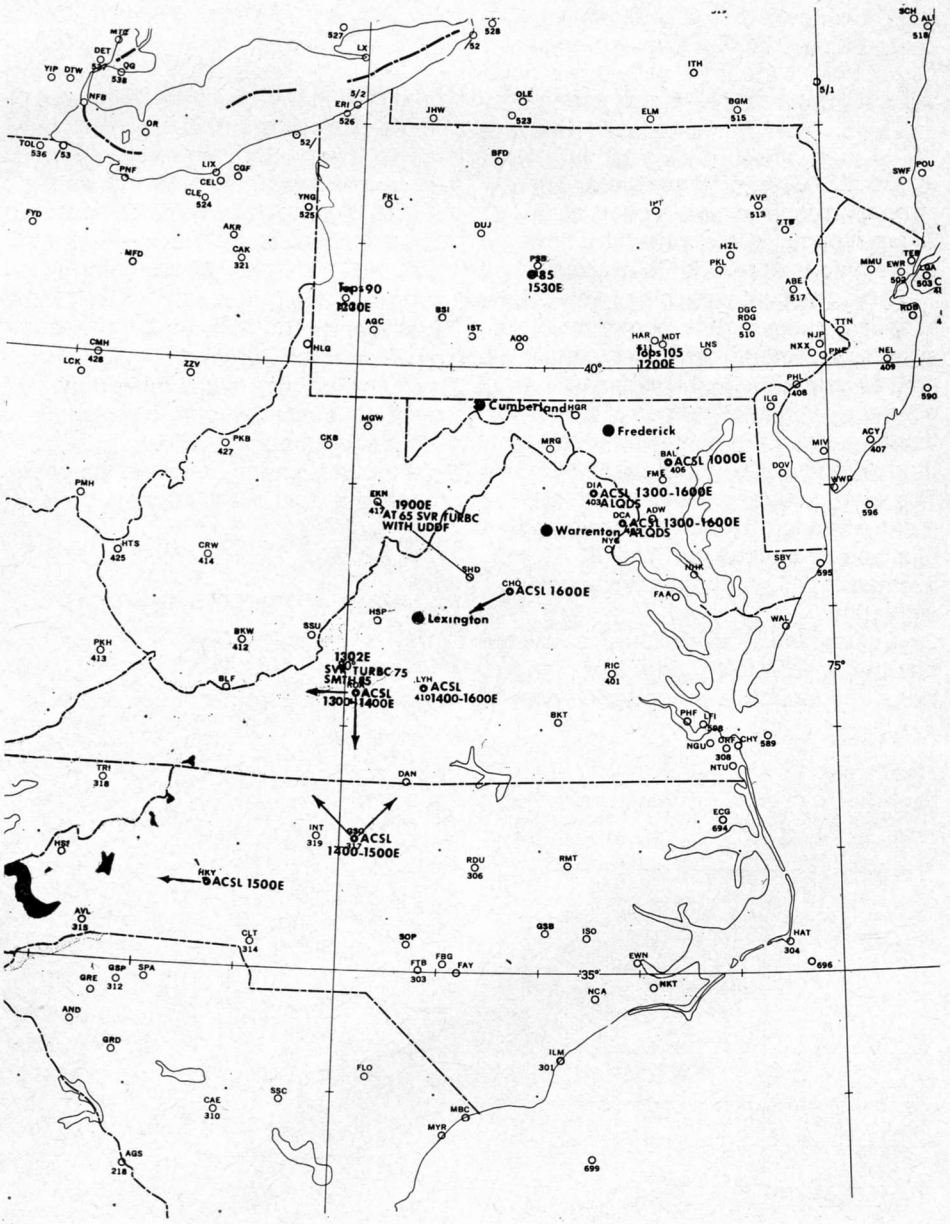


Fig. 4
Photograph of mountain wave clouds taken from the east side of the City of Alexandria, Virginia at 1500 EST on February 21, 1970 looking southeast.

Fig. 5
Surface observations of wave clouds indicated from weather stations and reports from pilots of powered aircraft on February 21, 1970.



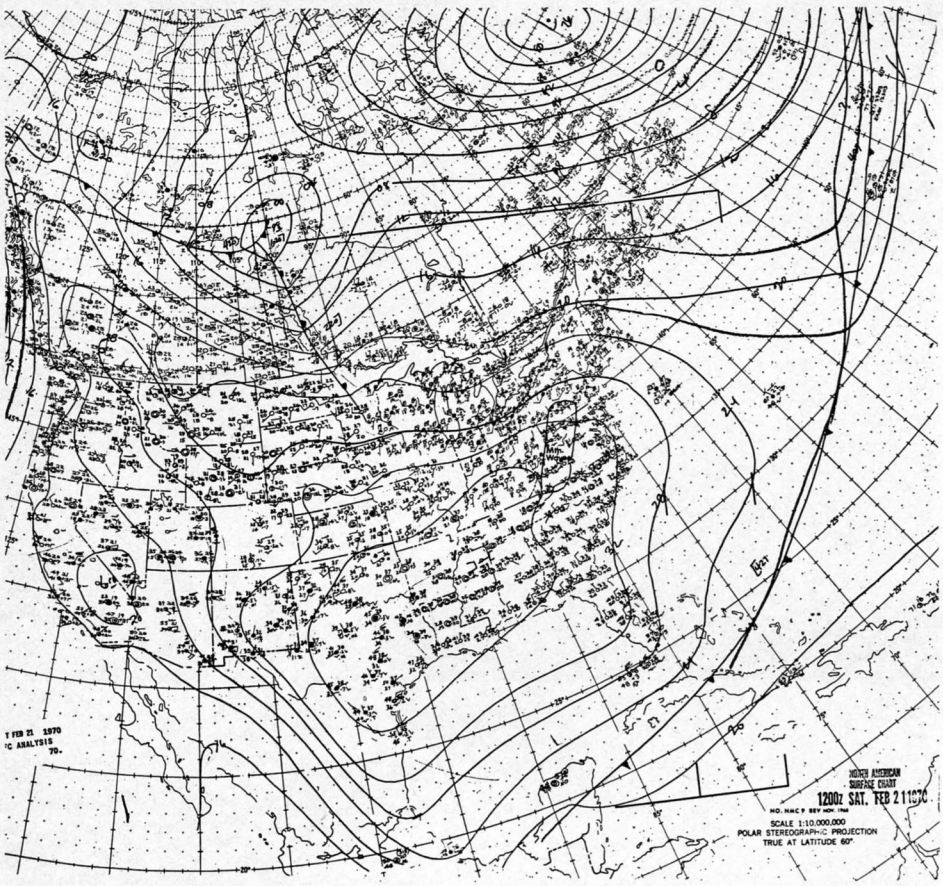


Fig. 6
Surface weather chart for 0700 EST February 21, 1970.

at about 7,000 feet. Winds were very strong, it required an airspeed of 65–70 mph to stay in the wave lift. This made it difficult for the Schweizer 1–26 because lift was rather weak. At speeds high enough to penetrate the system, his sinking speed was too high to gain altitude. Lift was strongest at ½ to 1 mile in front of the lenticular cloud. Lift was strong at low altitudes (about 900 fpm at 5,000 feet). The wind component was so strong that he had to dive into the wave and climb as he backed out. The lift seemed to fall off in direct relationship with altitude.

On Sunday the 22nd, the sky was clear and the wave was stronger and higher. Kellett had much less head wind component and flew at 38 to 45 mph and still had to 'crab' to stay in. He had a gain of 11,500 feet and flew as high as 16,200 feet for Gold Altitude gain.

Flight reports
from Warrenton, Virginia

The following report was related by Ernest Klimonda flying a Schweizer 1–26 on February 21, 1970.

On the 21st Klimonda entered the base of the wave at about 4,000 feet above ground and flew to 12,000 feet. He dared not go higher as the wave windows were closing up. He noted the cloud base at 9,000 feet and tops at 9,500 feet. He was not in the primary wave. There were a number of wave clouds observed to the west of the wave he was flying in. Warrenton is about 22 miles east of the nearest mountain ridge.

On February 22nd Klimonda flew to 15,000 feet with clear skies. At 15,000 feet he had 400 fpm lift and had to pull the spoilers and descend as he was not equipped with oxygen. His maximum lift on this flight was 700 fpm. Klimonda flew from one wave upwind to another wave and noted the wave length to be about 6 miles. Dave Tuttle flew to 14,400 feet on this day.

Flight report
from Frederick, Maryland

On February 21st Gene M. Wilburn flying an HP-11 towed off at about 1300 EST and released in the wave at 4,000 feet with 1,000 fpm lift. His lift tappered off above 8,000 feet as he flew to 13,300 feet. At that altitude he still had lift but left it as he was not oxygen equipped. Wilburn noted the wave length to be about 3 miles early in the day and that it increased to about 5 miles later in the day. He also noted the increase in the clouds later that afternoon. Wilburn said the base of the clouds were 8,000 feet and the tops about 10,000 feet. He reported that about 1430 EST to 1500 EST it began to cloud over. He flew for about 2½ hours.

Flight reports
from Cumberland, Maryland

On February 21st several flights were made in wave to 11,000 to 12,000 feet. On February 22nd, at 0800 EST, Billy

Fig. 7
Washington, D.C. Upper air soundings for 1200 GMT on February 21st and 0000 GMT February 22, 1970.

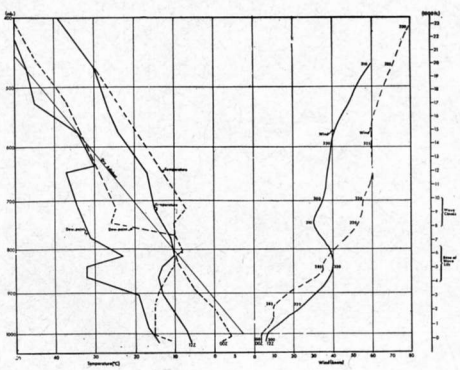
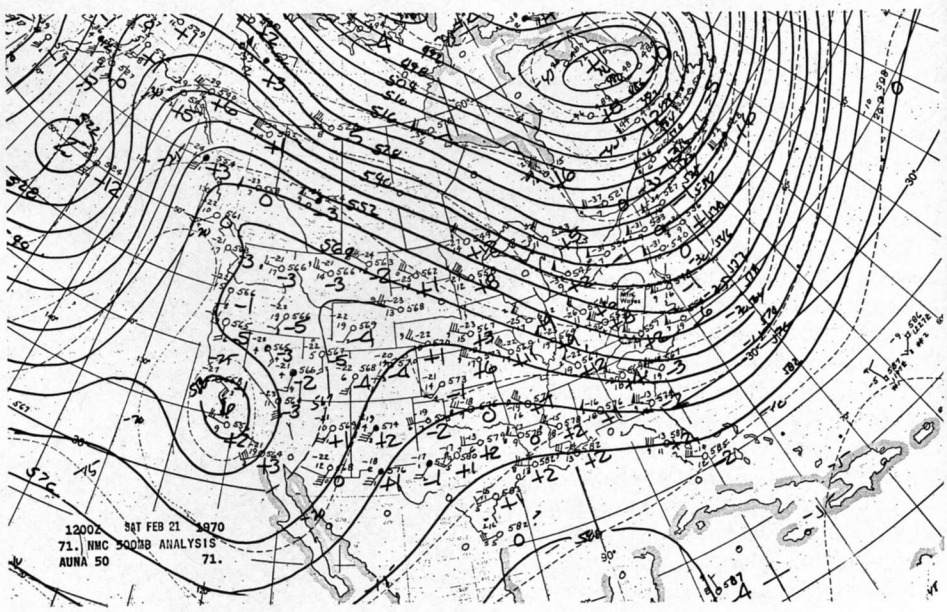


Fig. 8
500 mb chart for 1200 GMT February 21, 1970.



Thomas released at 3,400 feet in wave lift and flew to 12,600 feet. He encountered lift of 300 fpm.

Synoptic conditions associated with these waves

Surface conditions

Mountain waves to the lee of the Appalachian Mountains usually develop after the passage of a cold front as this is the situation that produces the wind and stability conditions necessary for wave development. On February 19th a strong cold front passed through the area and on the 20th a secondary cold front passed through. Figure 6 shows the surface weather chart for 0700 EST February 21st. The chart shows the post cold frontal condition on this date and the area where the waves were observed is outlined.

Stability and moisture

The soundings from Dulles International Airport just west of Washington and about 16 miles east of the first mountain ridge are shown on figure 7 for 12 Z on the 21st of February and 12 hours later at 00 Z on the 22nd.

The 12 Z sounding shows an inversion above 4,000 feet to about 7,000 feet and by 00 Z the base of the inversion was about 5,500 feet and the top 9,000 feet. The wave was observed by Kellett to be stronger and higher on the 22nd. Note the increase in moisture at the level of the inversion from 12 Z to 00 Z. This increase was noted in the increase in cloudiness in the afternoon from the ground and by the sailplane pilots as previously mentioned. The soundings show a layer of low stability below the inversions (nearly dry adiabatic). Above the inversions a layer of lower stability is present.

Winds aloft

The winds aloft at about the mountain top level were from about 300 degrees at 25 knots at 12 Z. The direction remained fairly constant with altitude varying from 290 to 320 degrees and the speed increased to 40 knots at 5,000 feet and to 60 knots at 20,000 feet. By 00 Z on the 22nd the winds had become more northwesterly above 8,000 feet and they had increased somewhat in speed above 6,000 feet while decreasing in speed below that level. This wind change also is in the direction for the better wave conditions on the second day.

The altitudes of the base of the wave lift is indicated to the right of the figure as reported by the sailplane pilots and the altitudes of the wave clouds reported are noted just above.

Figure 8 the 500 mb chart for 12 Z February 21st shows the broad general flow perpendicular to the mountains, the wave area is outlined.

Presence of a jet stream

The presence of a jet stream with high wind speeds and strong vertical wind shear has been pointed out by Colson [6] to be an important factor in the formation of mountain waves. Figure 9 shows a jet stream extending from the northwest through southern West Virginia and Southeast Virginia. The area where the waves were observed is outlined. In a previous study of waves over this area [7] 80 % of the pilot reports of waves were within 200 miles of a jet stream.

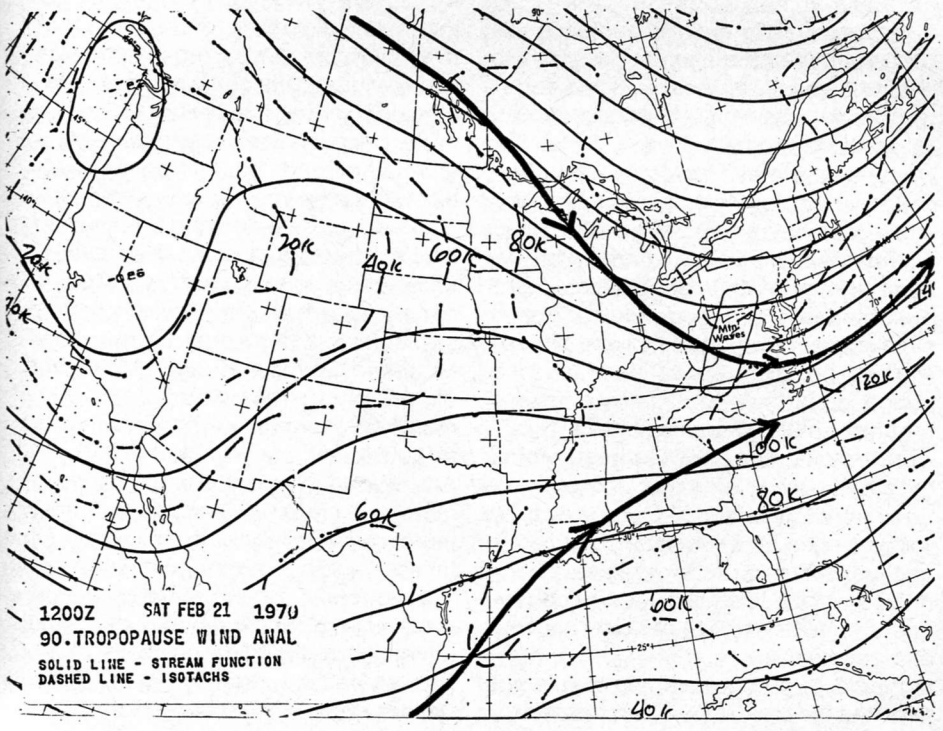
Conclusions

Over the past 6 years a great deal has been learned about mountain waves over and to the lee of the Appalachians from New England to the Carolinas, due mainly to flights made by sailplane pilots and from photographs from weather satellites along with some observations by pilots of powered aircraft. Data collected during this period indicate that these waves are rather significant not only to glider flight but to flights by powered aircraft also. Vertical currents of 1,000 to 2,000 fpm are not uncommon and 2,000 to 3,000 fpm have been reported on occasion [7]. Sailplane flights in waves have been made to 20,000 feet or higher all along the Appalachians from New England to the Carolinas.

A more ambitious study of waves over this area with better communications between sailplane pilots and pilots of powered aircraft and the Weather Bureau using satellite data along with the conventional upper air data could produce worthwhile results. The results could be useful not only in forecasting low level turbulence but more could be learned of the waves and their relation to clear air turbulence.

One final question of foremost importance to the soaring pilot is: how can he receive information on satellite photographs of wave patterns to aid in soaring flight? The most efficient way wuold be to incorporate this information in a forecast of waves in the routine aviation area forecast. This would not only benefit the soaring pilots but pilots of powered aircraft as well.

Fig. 9
Tropopause wind analysis for 1200 GMT February 21, 1970 showing a jet stream over area where waves were observed.



Acknowledgments

The author would like to thank Mr. Frank Smigielski of the National Environmental Satellite Center for the satellite photographs and helpful suggestions. Without the pilot reports from Allen R. Dresner, Jim Kellett, Ernie Klimonda, Gene Wilburn, and Billy Thomas this paper would not be possible.

References

1 Lindsay, C. V.: Satellite Wave Observations Used as an Aid to Wave Soaring. OSTIV Publication VIII.

2 Lindsay, C. V.: Satellite Observations Used as a New Tool in Developing Wave Climatology. Soaring Magazine, vol. 32, no. 1, Jan. 1968, pp. 8–12.

3 Corby, G. A.: Preliminary Study of Atmospheric Waves Using Radiosonde Data. Quarterly Journal of the Royal Meteorological Society, vol. 83, Oct. 1957, pp. 49–60.

4 Fritz, S.: The Significance of Mountain Lee Waves as Seen from Satellite Pictures. Journal of Applied Meteorology, A.M.S., vol. 4, no. 1, Feb. 1965, pp. 31–37.

5 Colson, D. and Lindsay, C. V.: Unusual Wave Cloud Over Washington, D.C. Monthly Weather Review, vol. 87, no. 12, Dec. 1959, pp. 451–452.

6 Colson, D.: Meteorological Problems in Forecasting Mountain Waves. Bulletin of the American Meteorological Society, vol. 35, no. 8, Oct. 1954, pp. 363–371.

7 Lindsay, C. V.: Mountain Waves in the Appalachians. Monthly Weather Review, vol. 90, no. 7, July 1962, pp. 271–276.