EFFECT OF SONIC BOOMS of VARYING OVERPRESSURES on SNOW AVALANCHES

Tests Conducted 18 - 20 March 1965

COOPERATIVE PROGRAM BETWEEN

- Federal Aviation Agency
- U. S. Forest Service
- U. S. Air Force
- National Aeronautics & Space Administration

REPORT SUBMITTED

by

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NOTICES

The information contained herein is a part of the supersonic transport research program sponsored by the Federal Aviation Agency with technical support provided by the Department of Defense and the National Aeronautics and Space Administration.

ABSTRACT

On 18 - 20 March 1965, a sonic boom program was conducted in the Star Mountain area near Leadville, Colorado, in the San Isabel National Forest. Objective was to determine the effects of sonic boom overpressures on snow avalanches. A total of 18 combined F-104 and F-100 runs were made with overpressures ranging from 1.5 to 5.2 measured. No avalanche was observed as a direct result of the sonic booms. Forest Service personnel rated the avalanche hazard as "low" during the test period, resulting in the recommendation for further tests during periods of "high" avalanche hazard.

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I. INTRODUCTION

The effects of sonic booms are important considerations in the operation of supersonic aircraft over land areas. In addition to the related problems of community reaction and ground-structure response in regard to the operation of supersonic aircraft, the Federal Aviation Agency and the U. S. Forest Service are examining the possibility of snow-avalanche triggering by sonic booms during certain critical periods immediately following snow accumulations. This could be an operational problem in any developed mountainous area subjected to heavy snowfall. To determine the effects of sonic boom on snow avalanches, an experiment sponsored by the FAA and participated in by several other agencies was conducted 18 through 20 March 1965. The responsibilities of these agencies were:

A. Federal Aviation Agency - Program Management.

B. National Aeronautics & Space Administration - Technical Support and Pressure Signature Recording.

C. United States Air Force - Aircraft & Communications, Damage Claims.

D. United States Forest Service - Technical Assistance including Site Selection, Condition of Snow and Avalanche Hazard, Analysis of Results.

E. United States Weather Bureau - Forecasts.

II. PROGRAM OBJECTIVES

The objectives of this study were to determine the effects of various sonic boom overpressures from 1.5 to 5.0 pounds per square foot on potential snow "slab" avalanches during periods of high hazard.

If avalanching can be induced by sonic booms:

A. Pressures at which avalanches occur must be identified.

B. Potential avalanche areas should be avoided by scheduled supersonic operations during periods of high hazard, at overpressures of potential triggering.

C. Sonic boom overpressures could be utilized by the Forest Service in controlling potential avalanche hazards in developed areas.

III. AVALANCHE CHARACTERISTICS

The snow avalanche is a result of a build up of snow on steep slopes. Avalanches occur throughout the winter in mountainous terrain. However, an avalanche is considered a "hazard" only when it threatens human beings or valuable improvements such as buildings, highways, power lines, etc.

Slopes 25° (47%) and steeper can be expected to avalanche when conditions are right. Slopes from 15° - 25° may, on rare occasions, avalanche. Avalanching is most prevalent on terrain which includes steep gullies and open slopes.

Characteristics of snow deposited on mountain slopes vary as conditions change. Snow is a plastic substance and tends to stretch and conform. Most avalanches result from a layer of new snow which has poor adhesion to the snow under it. This layer is called a "slab". Because of its plastic nature, snow will creep downhill. This results in a "stretching" near the top of a slab and, like a stretched rubberband, extreme tensions can be developed. The tension or stress of a slab depends on a number of factors -- weight of snow in the slab, temperature changes, etc.

The bond between the slab and the surrounding snowpack is known as the "shear strength". When the stress on the snowpack exceeds the shear strength, the snow is broken and flows downhill. This release may occur naturally or may be induced artificially if conditions are right. During certain periods of high tension or stress, a slab may be easily released or this same slab may settle in place and become stabilized without sliding. When a slab stabilizes in place, this indicates the shear strength was sufficient to prevent release. Hence, the period during which avalanches can be released artificially may be relatively short.

The Forest Service now employs three methods of reducing avalanche hazards. These are:

A. Hand-placed high explosive charges.

B. Artillery such as the 75 m.m. pack howitzer and the 75 m.m. and 105 m.m. recoilless rifles.

C. High explosive projectiles launched by compressed gas (avalauncher).

An avalanche hazard area that is subjected to high explosives will react in one of three ways:

A. The slab will release and flow down the hill.

B. The slab will stabilize in place and rupture cracks will appear over the surface of the slab.

C. The explosives will produce only a hole in the snow. In this case, it is probable that a slab was not present in the snowpack.

IV. DESCRIPTION OF TEST AREA

The following criteria were set for the selection of the test area:

A. The site must be a location where an avalanche hazard build up can be expected as a result of an average winter storm.

B. The area must have few, if any, improvements that could be damaged by anticipated overpressure or avalanching.

C. The area must be accessible to an instrumentation vehicle during the test period.

The area chosen was the Lake Creek Drainage above Twin Lakes, Lake County, Colorado on the San Isabel National Forest. (See maps in Appendix) This site is located about 16 miles southwest of Leadville. The general topography of the region is indicated in the contour map in the Appendix. The specific target chosen was Star Mountain with a summit elevation of 12,941 feet. This area met the above criteria and is representative of the terrain and snow conditions found in the Rocky Mountains along the Continental Divide. Snow conditions vary somewhat in other parts of the United States such as the Pacific Northwest, California Sierras, etc.

It should be kept in mind that the base operations (instrumentation, communications, etc.) were located at an elevation of 10,300 feet. During the winter, this area is subjected to very severe climatic conditions. Daytime temperatures here frequently run between 0° F. and -10° F., and occasionally -10° F. to -15° F. Severe conditions such as this result in many tactical problems for both equipment and personnel.

V. OPERATIONAL PROCEDURES AND TEST DATA

A. General

Plans called for fighter aircraft to make twenty (20) supersonic passes over the target area at varying calculated overpressures from 1.5 to 5.0 pounds per square foot. The amount of overpressure created by the sonic booms was recorded by NASA instrumentation.

The first tests were conducted on March 18, 1965. Four supersonic passes over the slide area were made with an F-100 aircraft. The flight conditions are indicated in table I for runs 1 through 4. Due to navigational and communication problems associated with the initial scheduled sorties, the first two runs were 1-2 miles east of the target area. Only flights 3 and 4 were positioned over the target area as reported by ground observers. No avalanches were observed during these flights; however, following the flights a small avalanche was triggered with a high-explosive projectile fired from an avalauncher into the avalanche area. Due to generator failure, no overpressures could be measured for these flights; thus, the values of the table are based on theoretical calculations of aircraft type, altitudes, and Mach number designed for 2 pounds per square foot.

On March 19, two flights with an F-104 aircraft were made over the area at altitudes of 16,000 feet and at a Mach number of 1.4 (runs 5 and 6). Due to communication failure, tests were discontinued on that day; however, one pressure signature was measured which indicated an overpressure of approximately 1.5 psf.

On March 20, marginal communications were restored and, by means of an elaborate relay system, useful overpressure data were obtained on 8 out of 12 flights of an F-104 aircraft. Scheduled altitudes/Mach numbers ranged from 13,000 to 16,000 feet and 1.3 to 1.5 Mach. Typical measured pressure signatures are shown in figure 6(a, b, c). As could be expected for these flight conditions, the wave shapes reveal near-field effects as well as appreciable disturbances following the tail wave in some cases similar to those measured in references 1 and 2. Also, the weather conditions and terrain may have had some effect on the wave shapes, especially with regard to the rise time for the signature of figure 6c (see references 1 and 3). Based on the measurements and estimates of the airplane track position, estimates have been made of the overpressures for the release zones of the avalanche areas at 13,000 fee and are tabulated in table I, column 10. Also included in table I, column 9 are the theoretical overpressures at the measuring station (altitude 10,300 feet) for the proposed flight tracks based on the volume theory of reference 4.

TABLE I - SUMMARY OF FLIGHT CONDITIONS AND ESTIMATED OVERPRESSURES

Run No.	Aircraft Type	Date	Time (hours)	Mach No.	Altitude (MSL) ft.	Heading, Degrees Magnetic	Δp Measured lb/ft^2	Δp Theory	Target Δp Estimated
1	F-100	3-18-65	1500	1.30	28,000	204	-	-	-
2	↓	↓	1510	1.30	28,000	204	-	-	-
3	↓	↓	1520	1.25	25,000	204	-	1.90	-
4	↓	↓	1540	1.25	25,000	204	-	1.90	-
5	F-104	3-19-65	-	-	16,000	192	-	-	-
6	↓	↓	1255	1.40	13,000	250	1.15	8.96	1.20
7	F-104	3-20-65	1000	1.50	16,000	193	-	-	-
8	↓	↓	1010	1.50	16,000	193	1.63	5.00	1.70
9	↓	↓	1017	1.50	16,000	192	3.78	5.00	4.85
10	↓	↓	1043	1.00	16,000	191	-	-	-
11	↓	↓	1052	1.50	16,000	191	1.87	5.00	1.98
12	↓	↓	1115	1.40	15,000	192	2.13	6.00	2.20
13	↓	↓	1120	1.40	15,000	192	4.00	6.00	4.90
14	↓	↓	1125	1.40	15,000	245	4.58	6.00	6.50
15	↓	↓	1128	1.40	13,000	245	4.53	8.96	5.15
16	↓	↓	1145	1.30	16,000	192	-	-	-
17	↓	↓	1153	1.30	16,000	245	5.02	5.00	9.50
18	↓	↓	1157	1.30	12,500	245	-	10.35	-

After March 20 supersonic sorties during which no slides were observed, Forest Service personnel attempted to trigger slides by utilizing standard techniques of firing into the release zone with an avalauncher. No avalanches were released.

B. Aircraft

Aircraft utilized in support of the snow-avalanche program consisted of an F-104, F-100, T-29, and the Forest Service Beech Baron. The F-100 was programmed for boom overpressures of 1.5 and 2.0 pounds per square foot and the F-104 to generate up to and including 5.0 psf. A T-29 photography aircraft, as provided by the U. S. Air Force, was scheduled to photograph Star Mountain and surrounding potential avalanche areas prior to and after each run to provide information pertaining to areas inaccessible by ground transportation, and not visible to ground observers. Although this aircraft did fly, weather precluded obtaining aerial photographs as desired. The U. S. Forest Service provided a Beech Baron aircraft as a further precautionary method of assuring a target area free of tourists and/or other unauthorized persons. This aircraft was utilized prior to daily scheduled sonic boom activities.

C. Instrumentation

Two microphones were placed as close as possible to the main slide path using 450 feet of cable /Figure 3(A)/ Two channels of instrumentation were used consisting of two dynagage units and a direct-write recording oscillograph, which made possible on-location examination of recorded pressure signatures. The main components of the measurement systems used for sonic boom pressures are the same as those described in more detail in reference 1. Each channel of the system as used in the experiments consisted of a specially modified microphone, tuning unit, d-c amplifier, and oscillograph recorder. The useable frequency range was from 0.1 to 5,000 cycles per second, and this range applies to all the data presented herein. The microphones have a dynamic range from about 70 to about 150 DB. They were field-calibrated statically before each test by means of a pressure bellows and a sensitive manometer. Prior to field installation, frequency response curves were obtained for all microphones. The instrumentation was powered by a 110-volt, 1.5 kilowatt portable generator. A schematic, plan-view diagram of the test location and equipment layout is shown in appendix A.

D. Communications

Air route traffic control and handling was provided by Denver Air Route Traffic Control Center and provided safe separation of snow-avalanche project aircraft from other activities. F-100 aircraft operated under control form Buckley Air Force Base, Denver, and the F-104 aircraft were staged from Ent Air Force Base, Colorado Springs, Colorado. Air/Ground communications were established on UHF frequency of 296.7 with an Air Force communications van located in the target area with HF/UHF and VHF capabilities. As outlined in the program plan, all flights were conducted under VFR conditions and air route traffic control provided approximate positions only; navigation to exact target area was provided by sortie pilot. Due to line-of-sight operating limitations of UHF and VHF communications, it was necessary to relocate the van approximately 7 miles from the NASA measuring equipment. HF communications was not possible because this equipment was not available in the fighter aircraft. By utilizing two Forest Service communications trucks, a relay system provided adequate aircraft positioning and location for instrumentation turn-on.

E. Safety

The safety of personnel and improvements was the prime consideration in these tests. Reconnaissance flights were made prior to testing each day as discussed above under Aircraft. Standard safety procedures were used during the firing of the avalauncher. Details of safety measures employed during the study can be found in the Operations Plan in the Appendix.

VI. SUMMARY OF PROGRAM RESULTS

A. No avalanche was observed as a direct effect of the sonic booms conducted 18-20 March 1965.

B. During the test, two avalanches were observed in the general area of the target. One was released on the lower slopes of Star Mountain /Figure 3(B)/ with a high explosive projectile from an avalauncher. The second was approximately one mile west of Star Mountain in Negro Gulch /Figure 3(C)/ and occurred sometime between 1730 hours, 18 March and 1330 hours, 20 March. This avalanche was not visible from the instrumentation site, but was observed while driving up Highway 82. Cause of release is unknown.

C. During the tests, avalanche hazards were rated by the Forest Service to be "low". No avalanches are known to have been caused by sonic booms of overpressures from 1.5 to 5.0 pounds per square foot during these snow conditions.

VII. RECOMMENDATIONS

A. That further tests be conducted during a period of "high" avalanche hazard with scheduled increased overpressures in an attempt to determine exact overpressures required for avalanche release.

B. If additional tests are conducted, the U. S. Forest Service will provide technical assistance to include an alert when high hazard conditions are anticipated. Adequate personnel, equipment, and support aircraft should be maintained in the test area to enable program initiation with a minimum elapsed time and prior to avalanche stabilization.

C. Tests should be performed by NASA to determine overpressure measurements of high explosives presently utilized by the Forest Service to produce slides. These tests could be conducted in conjunction with flight test in the same flight test area.

D. Consider obtaining overpressure readings adjacent to the actual avalanche release zone to establish a comparison between these readings and those obtained at the bottom of the avalanche paths near the road.

APPENDIX A

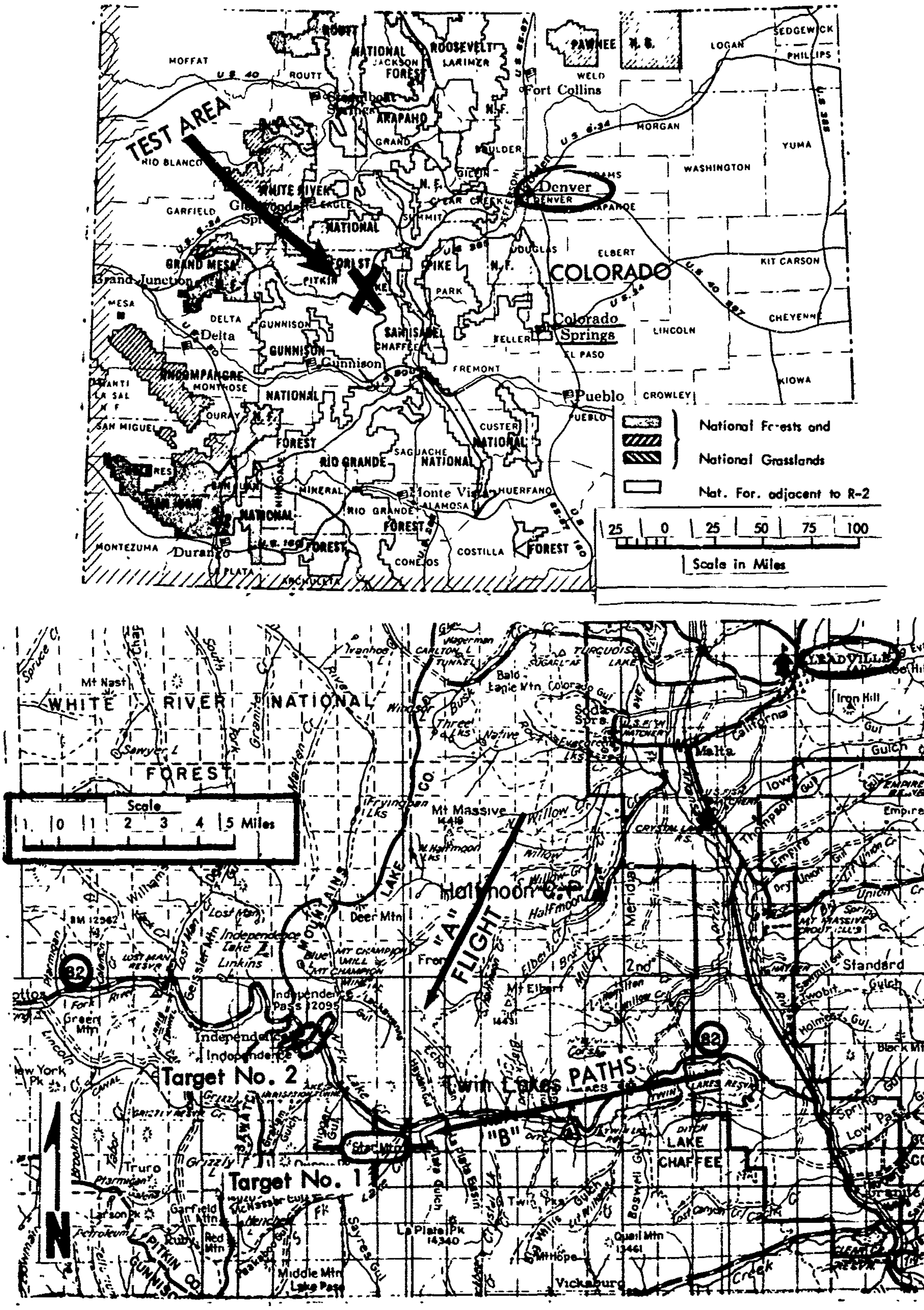


Figure 1   LOCATION MAPS

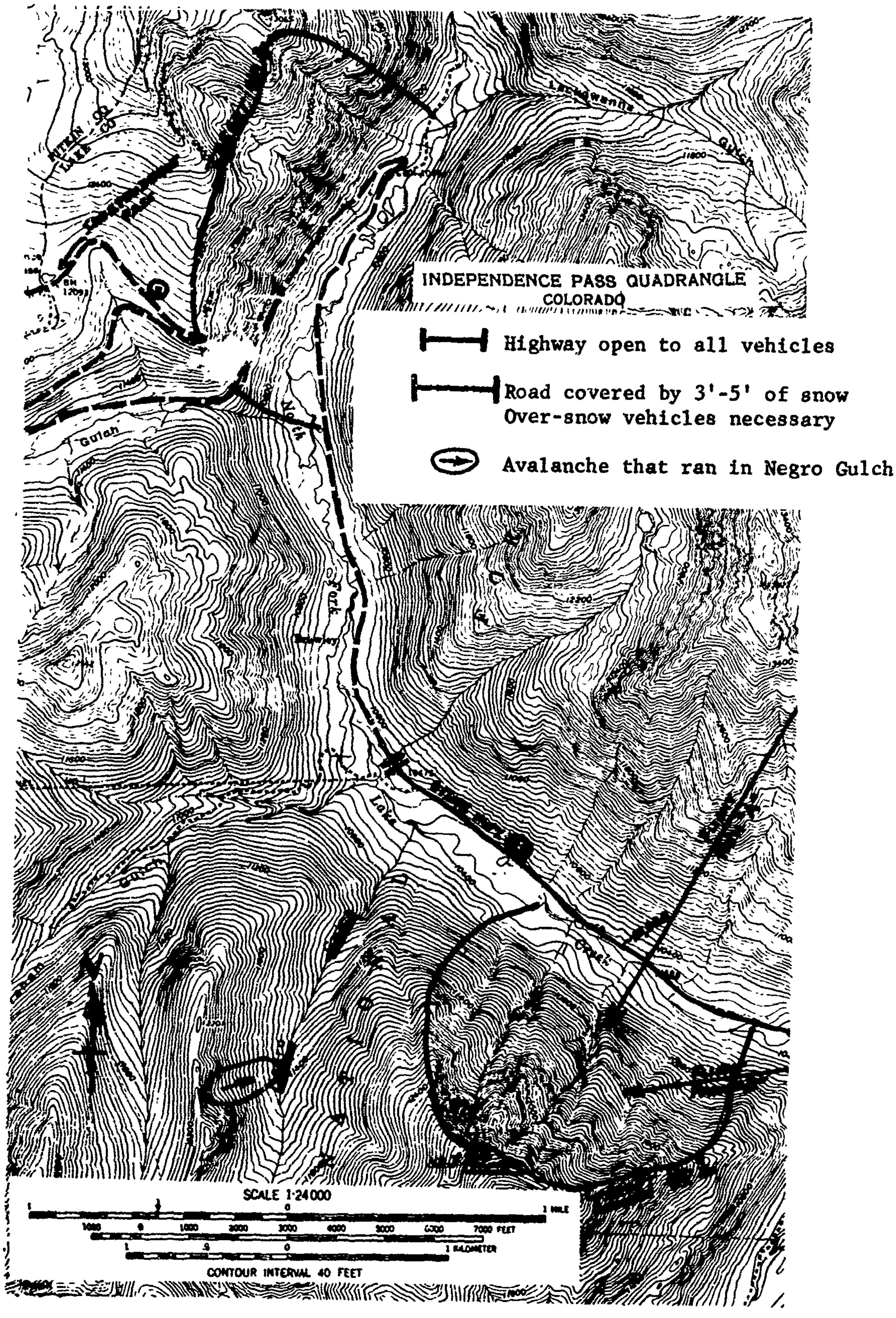


Figure 2 TOPOGRAPHIC MAP OF TEST AREA

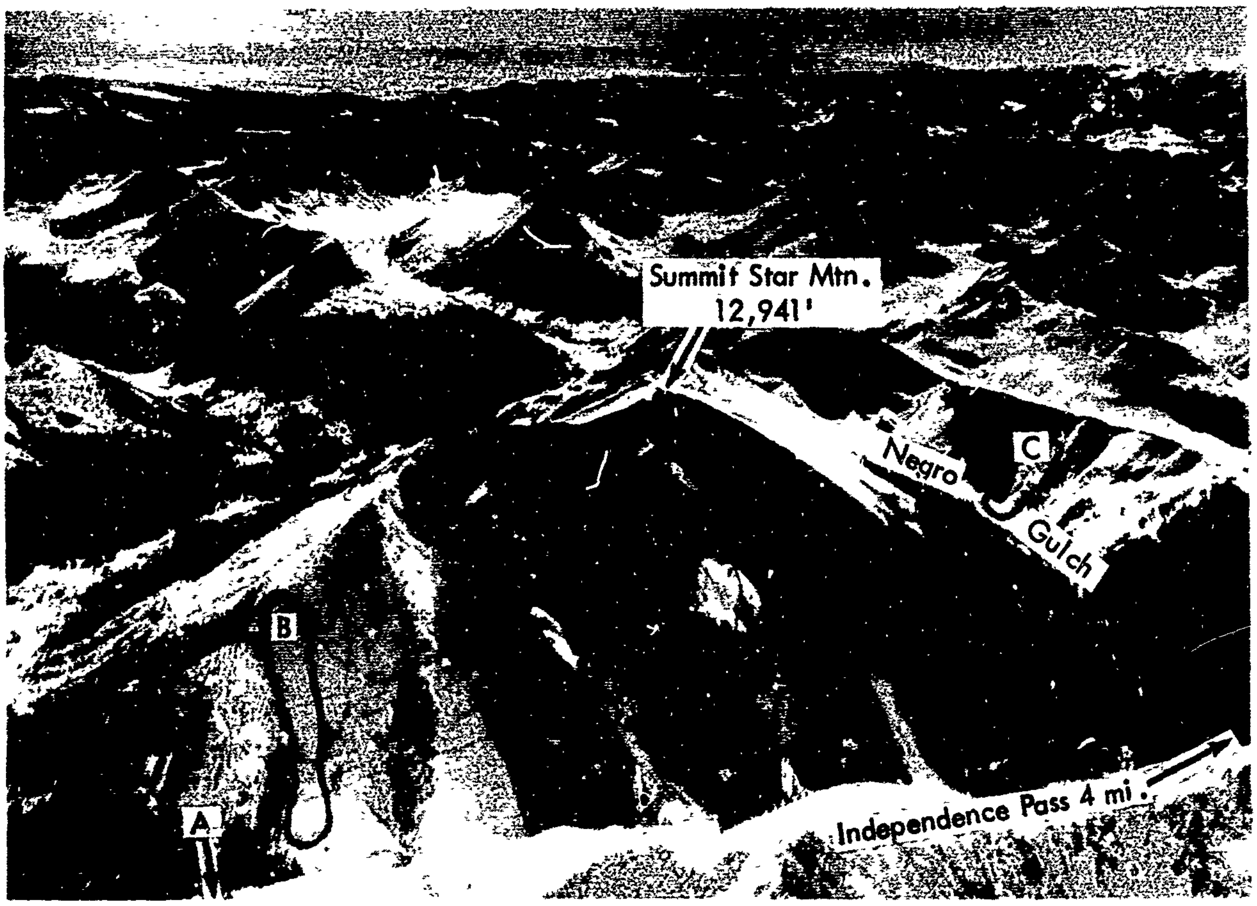


Figure 3 OBLIQUE AERIAL PHOTO OF STAR MOUNTAIN AND VICINITY

Figure 4 STAR MOUNTAIN, COLORADO

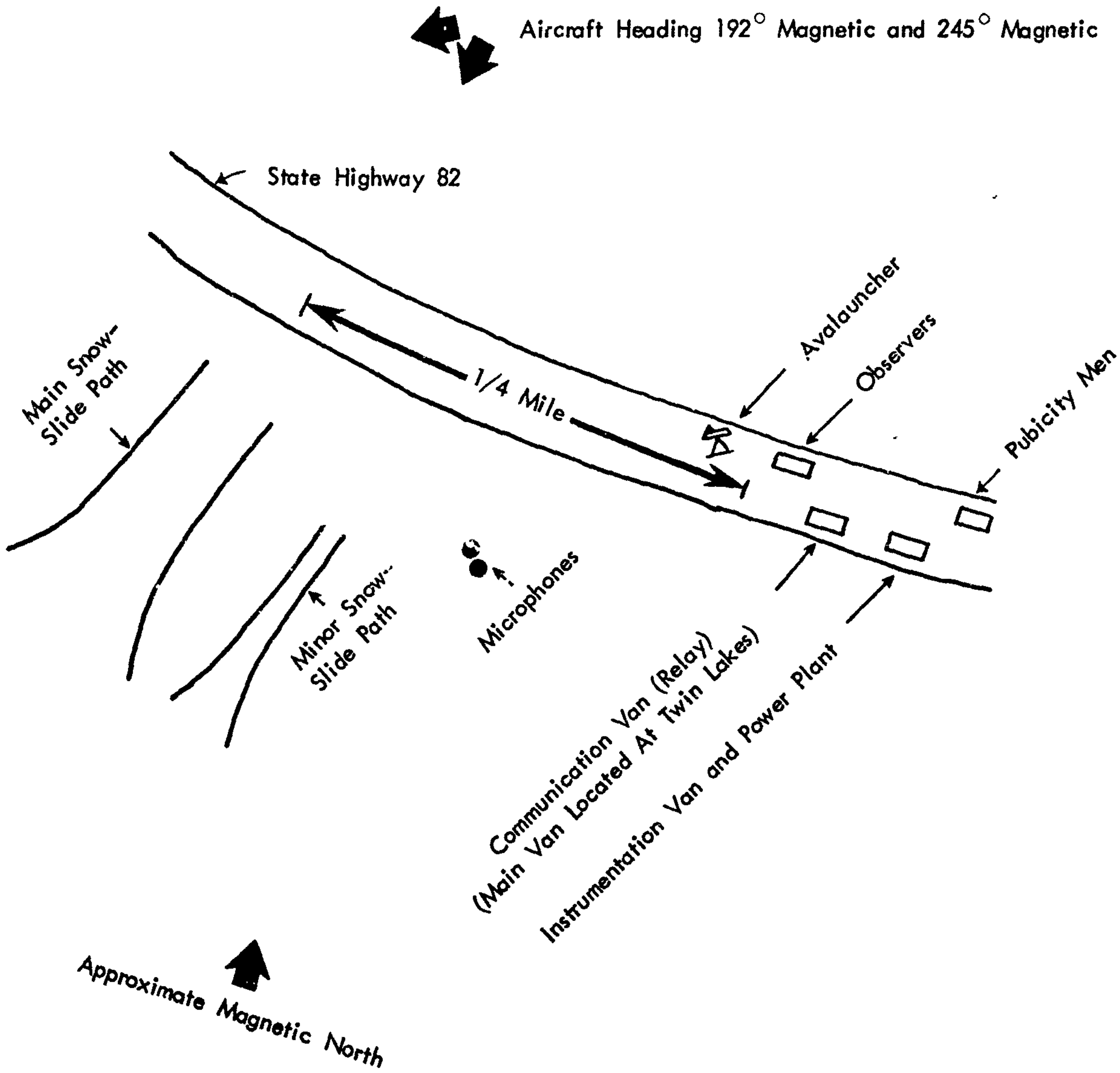
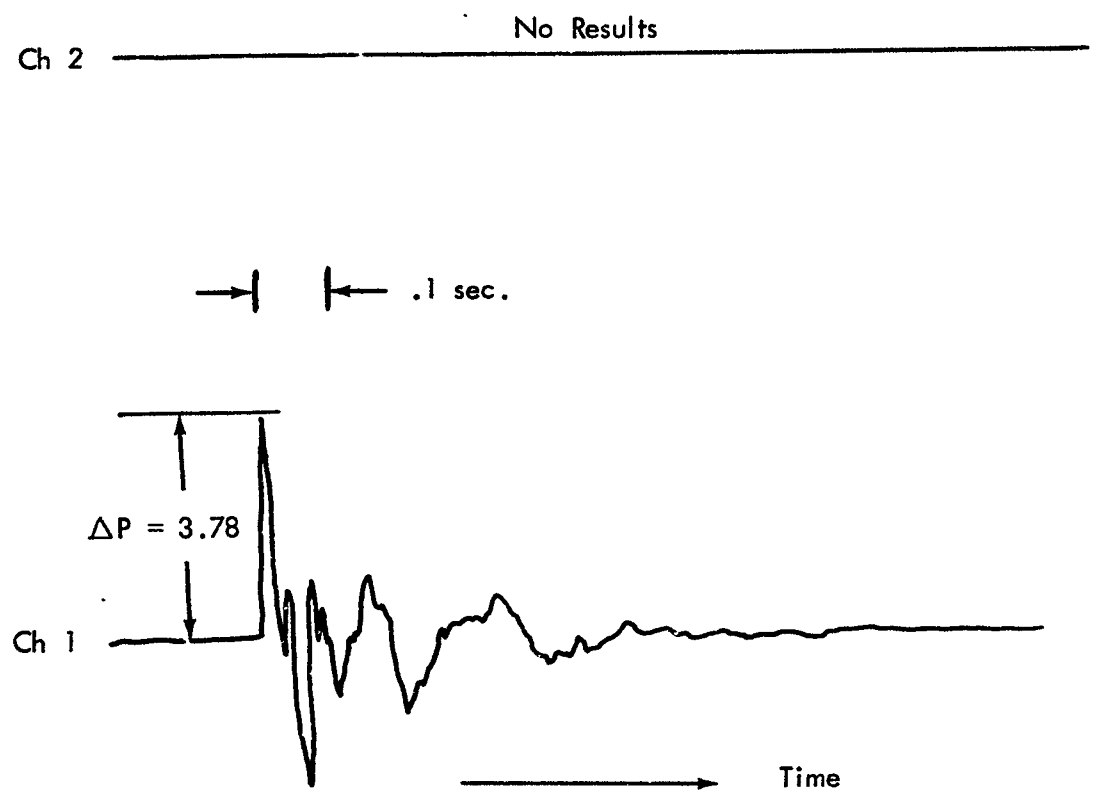
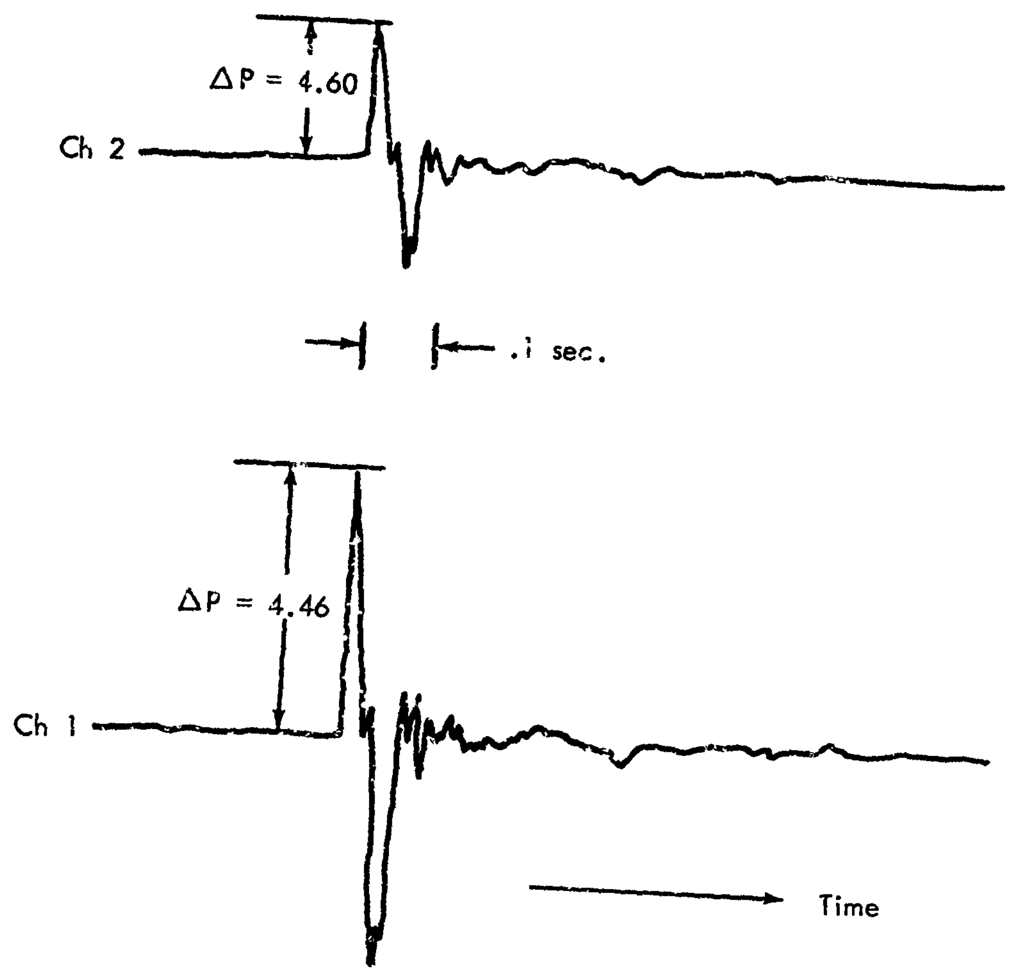


Figure 5. - Schematic diagram of equipment location.



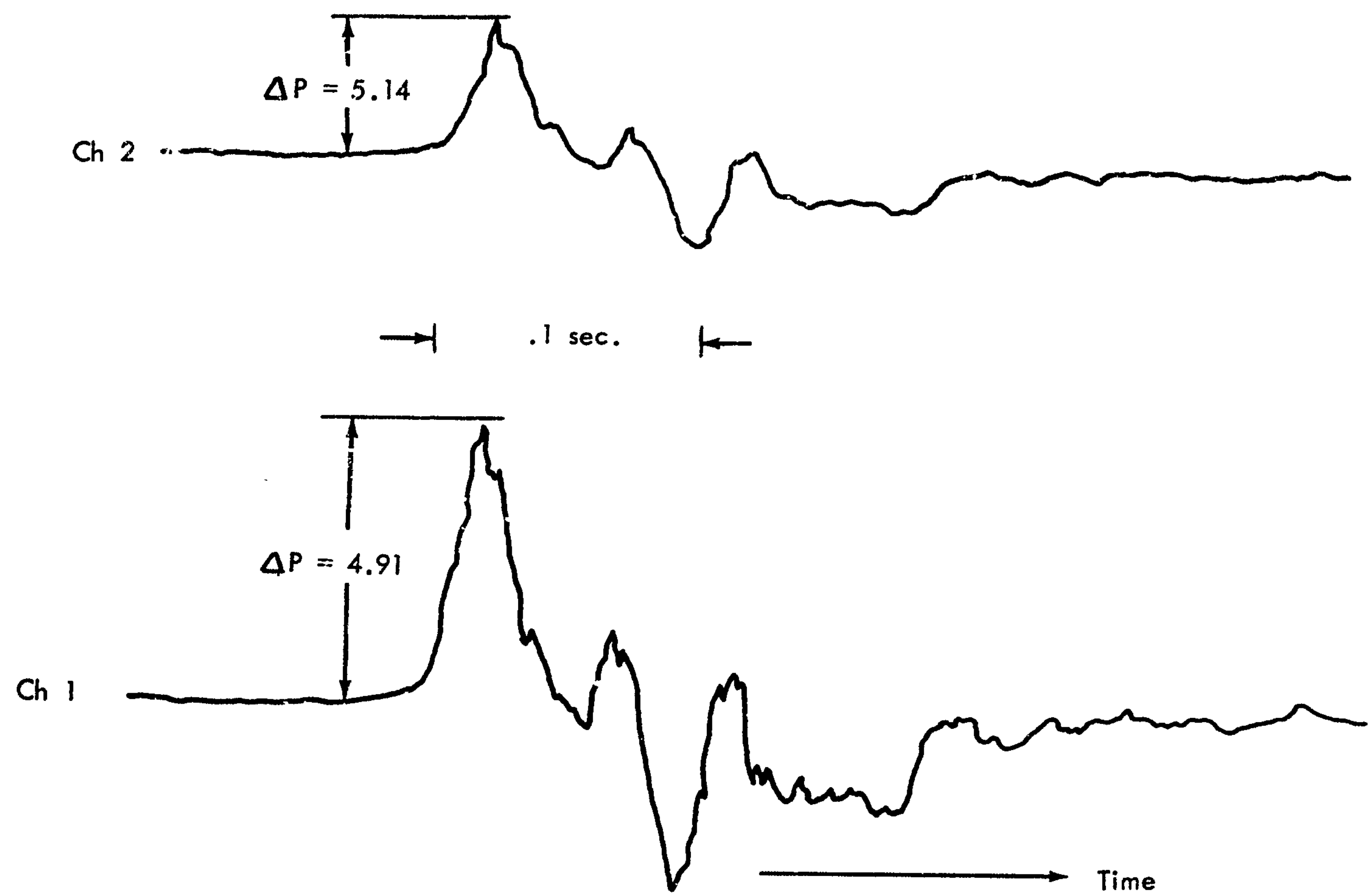
(a) Run No. 3

Figure 6A - Sample sonic-boom preassure-time histories recorded from each microphone at ground level during snow-avalanche investigation.



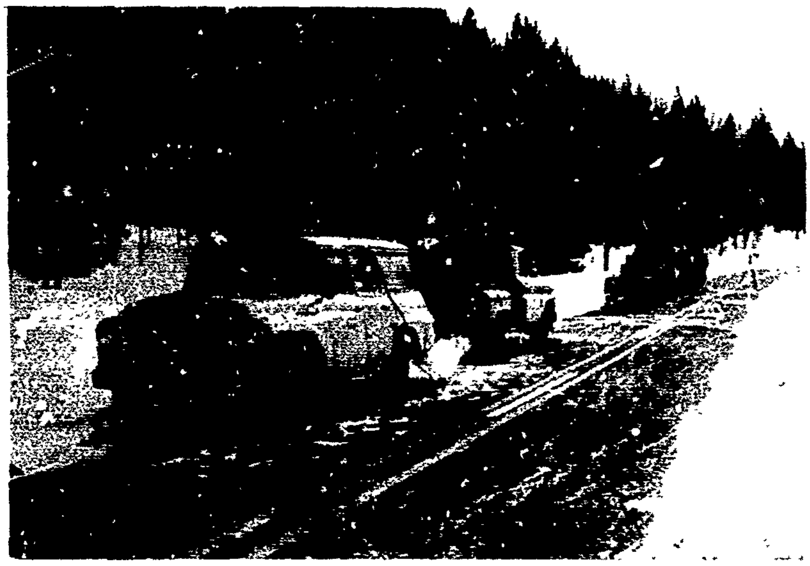
(b) Run No. 9

Figure 6B



(c) Run No. 11

Figure 6C



Left to Right - N.A.S.A. instrumentation truck; with generator furnishing power for instruments; U.S.A.F. radio communications truck with generator trailer.

Figure 9

Readying avalauncher to fire on "Test Area No. 2". Over-snow vehicles necessary to gain access to site.
"Cristy" snow cat on left, and "Ski-Do" snow scooter on right.

Figure 10

"Avalauncher" ready for firing. Compressed nitrogen gas is put into cylinder. High explosive charge is put down barrel. Trigger is pulled and a special valve releases the gas almost instantaneously pushing charge to range of 1000 yards.

Figure 11

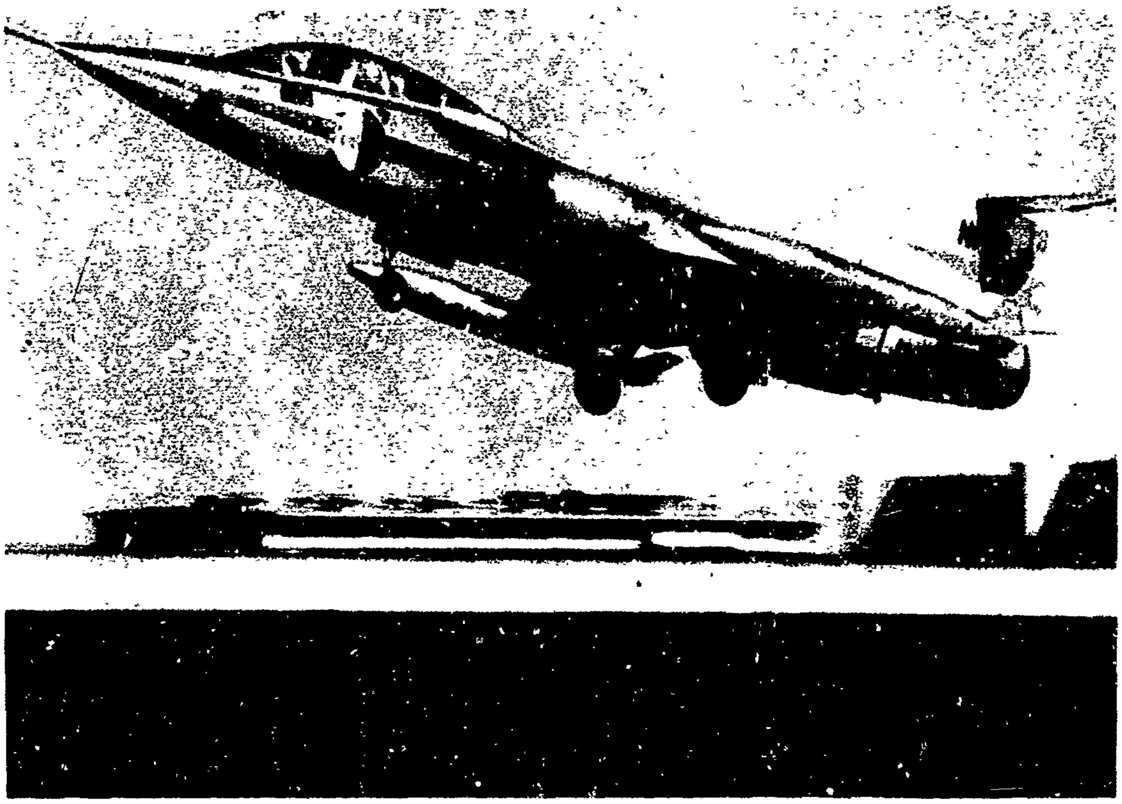


Figure 12A F-104 TEST AIRCRAFT

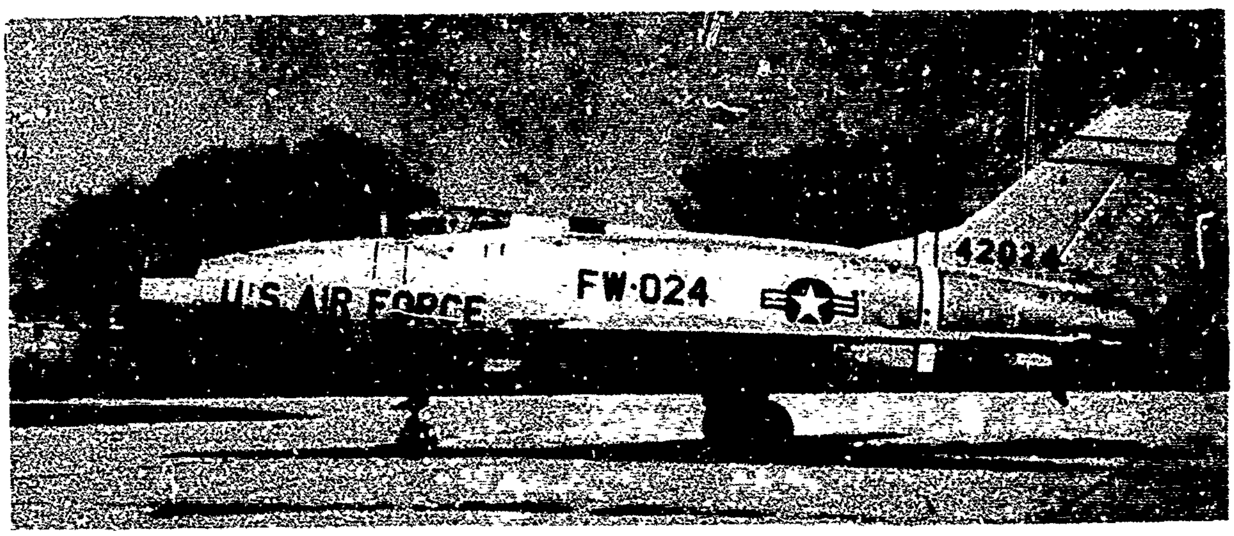


Figure 12B F-100

APPENDIX B

OPERATIONS PLAN FOR DETERMINING THE EFFECT OF SONIC BOOMS OF VARYING OVERPRESSURES ON SNOW AVALANCHES

I. INTRODUCTION

The snow avalanche is a result of a buildup of snow on steep slopes. The characteristics of the snow deposited on the slopes vary as conditions change. At times snow can be under great tension. When the stress on the snowpack exceeds the shear strength, the snow is broken and flows downhill. This release may occur naturally or may be induced artifically if conditions are right.

Most avalanches result from a layer of snow which has poor adhesion to the snow under it. This layer is called a "slab." The stress or tension of a slab depends on a number of factors -- weight of snow in the slab, temperature changes, snow creeping downhill, etc. During certain periods of high tension a slab may be easily released, but later this same slab may settle in place and become stabilized without sliding. Here the stress never exceeded the shear strength. Hence the period during which avalanches can be released artifically may be relatively short.

A. Avalanche Characteristics

An avalanche source area that is subjected to high explosives will react in one of three ways:

1. The slab will release and flow down the hill.
2. The slab will stabilize in place. Rupture cracks will appear over the surface of the slab.

3. The explosives will produce only a hole in the snow. In this case it is probable that a slab was not present in the snow pack.

Slopes 25° (47%) and above can be expected to avalanche when conditions are right. Slopes form 15° - 25° may, on rare occasions, avalanche. Terrain which includes steep gullies and open slopes are most prevalent to avalanching.

Avalanches occur throughout the winter, but because they do not threaten valuable improvements (buildings, highways, power lines, etc.) or humans. they do not constitute a "hazard." Hence "avalanche hazard" constitutes a threat to life and/or property from cascading snow.

II. AGENCIES INVOLVED

The following agencies will be involved in this study:

1. The United States Air Force.
2. Federal Aviation Agency.
3. National Aeronautics and Space Administration.
4. United States Forest Service.

III. PURPOSE OF THE STUDY

These tests will be conducted to answer the following:

1. To determine the effects of various sonic boom overpressures 1.5 to 5.0 psf on snow slides and avalanches in various stages of development.

2. United States Forest Service -- The U.S. Forest Service desires to know if avalanches can be triggered by the use of sonic booms during times when the hazard is high. If avalanches can be induced by this method it may be used as a means of reducing the "avalanche hazard" on National Forest lands.

The safety of personnel and improvements will be the prime consideration in these tests. All personnel operating on this program, prior to departure for the site, will be equipped with adequate Artic clothing and survival equipment acceptable to the U. S. Forest Service.

IV. <u>AREA</u>

The following criteria were set for the selection of the test area:

1. The site should be a location where an avalanche hazard buildup can be expected as a result of an average winter storm.
2. The area must have few, if any, improvements that could be damaged by anticipated overpressure or avalanching.
3. The area must be accessible by an instrumentation vehicle during the test period.

The area chosen is the Lake Creek Drainage above Twin Lakes, Lake County, Colorado on the San Isabel National Forest. This site is generally located about 16 miles southwest of Leadville. This area meets the above criteria and is representative of the terrain and snow conditions found in the Rocky Mountains along the Continental Divide. Snow conditions will vary somewhat in other parts of the United States such as the Pacific Northwest, California Sierras, etc.

The Forest Service is presently conducting a study to determine methods of increasing water yields in mountain watersheds such as Lake Creek. As a part of this study, the effect of induced avalanching on water yield has been undertaken. Triggering avalanches by sonic booms will contribute to the study as presently being conducted.

V. CURRENT AVALANCHE CONTROL METHODS

The Forest Service now employs three methods of controlling avalanche hazards. These are:

1. Hand-placed high explosive charges.
2. Artillery such as the 75 m.m. pack howitzer and the 75 m.m. and 105 m.m. recoilless rifles.
3. High explosive projectiles launched by compressed gas.

VI. GENERAL STUDY PLAN

1. Schedule -- Project to be completed by 1 April 1965. Exact time of tests will depend upon weather conditions.
2. General methods -- Supersonic flights will be made across the test area in F-100 and F-104 aircraft. The amount of overpressure created by the sonic boom will be recorded by instruments and analyzed by the NASA.

If avalanching is not induced by the sonic boom, the avalanche paths will be shot with a recoilless rifle or avalauncher as a check on the effectiveness of the sonic boom.

3. Responsibilities of Participating Agencies:

   1. Federal Aviation Agency. - Program Management
   2. National Aeronautics and Space Administration. - Technical & Recording
   3. United States Air Force.- Aircraft & Communications , damage claims
   4. United States Forest Service. - See Item XIIIA
   5. United States Weather Bureau. - Forecasts
   6. Colorado Department of Highways.- Safety

VII. SAFETY PLAN

The primary consideration of this study will be the safety of the personnel involved and the local residents and their property.

1. Operators, advisers and observers on the ground will be located in a position where they will not be in danger either by the overpressures or avalanches. This will undoubtedly require some "remote control" instrumentation.
2. All access routes leading into the test zone will be closed to public use during the test period.
3. Prior to any sonic boom tests, aerial reconnaissance of the area will be made to assure that no unauthorized personnel are in the vicinity. The aircraft to be supplied by the FAA.
4. Residents within the immediate area will be notified in advance of testing.
5. Air traffic control safety for this plan is found in Section 9.

VIII. DETAILS OF TEST PROGRAM

Basically 20 supersonic flights will be made over the test area with overpressures varying from 1.5 to 5 pounds per square foot.

If these overpressures do not produce avalanching, lower flights with higher overpressures may be necessary to complete the Forest Service portion of the test.

IX. AIR TRAFFIC CONTROL

F-100 aircraft operating from Buckley Air Force Base, Denver, will file IFR flight plans in accordance with established procedures. The operating frequency for the USAF ground station located in Leadville, Colorado and communications with the ARTCC Denver will be 296.7. No runs of the F-100 aircraft will be made until communications have been established with the above two centers. Radar and advisory service will be provided by the Denver ARTCC. Suitable NOTAMS and aircraft advisory service for supersonic flights operating in the area will be the responsibility of the ATC coordinator located in Denver, Colorado. Normal flight safety procedures will be in effect at all times.

X. MEASUREMENT INSTRUMENTATION

General Description

Instrumentation for measuring sonic boom overpressures on this project will consist of two Dynagage pressure measuring systems with appropriate amplifyers for operating an oscillograph which will use direct-write recording paper for determination of overpressures at the test location.

Detailed Description

The Dynagage units are dynamic pressure transducint devices which have a usable frequency range from .1 to 5000 CPs. The dynamic range is from 70 to 170 decibels or about 40 pounds per square foot. These units operate on a capacitance principle and therefore must be kept dry. Also, due to the low frequency response capability, they must be shielded from pressure fluctuation due to the wind. The output from the Dynagage systems will be fed into Burr Brown galvanometer amplifiers for the purpose of providing sufficient signal gain to drive the oscillograph galvanometers. The recording oscillograph uses direct-write recording paper which makes use of the ambient light for developing the pressure traces. Estimated paper speed will be about 20 inches per second which will give 60 seconds recording time per roll of paper. Twenty rolls are available for the initial tests and it is conservatively estimated that one record per roll will be obtainable.

It will be necessary, due to the sensitivity of the instrumentation, to estimate probable overpressure levels in order to properly adjust amplifier settings. The estimation procedure will necessitate close communication between the aircraft pilot and personnel at the measurement station.

Ideally the project manager will determine the overpressure which he wishes to obtain in the test area on a given test run. On location, calculations will then be made to determine the altitude which the aircraft must maintain and the distance along the flight path which the aircraft must maintain steady flight conditions to obtain the calculated overpressure. It is estimated that about 20 minutes will be needed between test runs. The pilot should know when he passes over the measuring station and should at that time communicate his altitude Mach number and heading to the personnel at the measuring station.

XI. COMMUNICATION AND NAVIGATION

Operating communications frequencies between aircraft and ground is 297.5 and the HF single-side van point to point frequency is 14.5 MC. All operations will be conducted VFR day.

XII. ANALYSIS OF DATA

Results of the tests will be jointly analyzed by the National Aeronautics and Space Administration and the United States Forest Service.

The final report will be jointly prepared by NASA, FAA and the Forest Service.

XIII. MISCELLANEOUS

A. Financial Arrangements

A written agreement between the following agencies has been accomplished to provide that the Forest Service will furnish to or procure for the Federal Aviation Agency the following:

1. The services of Mr. Dale Gallagher and Mr. Richard M. Stillman on a reimbursable basis including per diem and travel expenses.
2. The services of other Forest Service employees on a non-reimbursable basis as considered necessary by the Forest Service for the success of the project. Per diem and travel expenses for these employees will be reimbursed by the FAA.
3. Purchase, rent, or contract for supplies, equipment and services pertinent to the project.
4. Removal of snow and a debris from public roads, if deemed necessary, provided such snow and debris resulted from the Sonic Boom Avalanche Project.

B. Aircraft Use

Aircraft will be necessary for the study. It will be utilized for reconnaissance in the upper area of the avalanche slide paths (after the snow has been subjected to the sonic boom).

C. Because of the magnitude and various exposures in the test area it is recommended that low-altitude aerial photographs be taken of the site prior to and after the testing. This will be the most efficient means of checking avalanche occurrence and the different shock wave angle incidents.

Gordon M. Bain
Deputy Administrator
Supersonic Transport Development

B. K. Crane
U. S. Forestry Service
Deputy Regional Forester

APPENDIX C

References

1. Hubbard, Harvey H.; Maglieri, Domenic J.; Huckel, Vera; Hilton, David A.; Ground Measurements of Sonic Boom Pressures for the Altitude Range of 10,000 to 75,000 Feet. NASA TR R-198, July 1964.

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