up with forceps and sealed in a specially cleaned nylon bag. The season's take is kept frozen until it arrives at the Johnson Space Center in Houston, Texas. If a sample were to thaw earlier, water could enter, rusting and dissolving the minerals the meteorite contains.

A rock from Mars that Harvey is currently studying—"my favorite Martian," as he calls it—was found in Antarctica's Allan Hills. It contains carbonate, an unusual mineral for a meteorite. "The carbonate might have been deposited by fluids traveling through the Martian crust—an explanation with staggering implications for what Mars is like," Harvey says. "We know that at some time in the past, Mars had an active system of rivers, and today we see polar caps, vapor clouds, and frost on the planet's surface. But we don't know what kinds of fluids these are, or how warm Mars was in the past. Carbonates left by these fluids can tell us how warm and wet Mars might actually have been."

After six field seasons in Antarctica, working with meteorites has transformed Harvey's view of Earth. "I now look at our planet as a giant wrecking ball crashing through the Universe, sampling whatever happens into its path," he says. "Antarctic meteorites are providing new and exciting ideas about our solar system."

Based on material by Lynn Simarski, Public Affairs Specialist, NSF, Office of Legislative and Public Affairs.

Pegasus: A glacial-ice runway for wheeled flight operations at McMurdo Station

The U.S. Antarctic Program (USAP) relies heavily on aircraft support between Christchurch, New Zealand, and McMurdo Station. The austral summer field season begins in early October when the smooth annual sea ice in McMurdo Sound is thick enough to support heavy aircraft. Wheeled C-130 Hercules, C-141 Starlifters, and C-5 Galaxy airplanes operate routinely from this runway until mid-December when near-melting air temperatures and intense 24-hour-per-day sunshine combine to deteriorate the sea-ice surface and force abandonment of the runway.

For the remainder of the season, which ends in late February, flight operations are shifted to a semi-permanent, groomed skiway located on a deep snow field on the Ross Ice Shelf (figure 1). Only airplanes with very low-ground-pressure tires or those that are ski-equipped can operate from this skiway because of its low bearing strength. The USAP uses specialized LC-130 Hercules (equipped with both skis and wheels) to satisfy the logistics needs of the more than 1,000 people using McMurdo Station as a support base at this time of year. Only nine LC-130s exist; five are under the control of the USAP. Demand for these few airplanes has typically been so great that a backlog of personnel and crucial cargo often has occurred. This backlog severely constrains the USAP from the middle to the end of the season.

In 1989, the Cold Regions Research and Engineering Laboratory (CRREL) initiated a study to determine how a runway on the Ross Ice Shelf near McMurdo Station could be created. The proposed glacial-ice runway had to be capable of supporting heavy wheeled aircraft during the period after the sea ice deteriorated. Using historical records and air photos, the study group chose a site 13 kilometers south of McMurdo Station in an area that has a thin, but permanent and complete, snow cover. The snow at the site is underlain by a contiguous mass of glacial ice about 30 meters (m) thick.

Runway construction

During the 1991–1992 field season, the snow cover was stripped from a surveyed 3,000- by 90-m area to expose the undulating ice surface. Large ice blisters were rough graded, and low areas were filled by flood water from a portable snow melter. In August 1992, following the austral winter, accumulated winter snow was removed, and a survey of the ice surface was used to establish the desired grade for the runway to minimize construction. A laser-guided grader (figure 2) with a specially built chisel-tool blade (figure 3) was used to level the ice surface to a high standard for smoothness. A high-capacity snowblower was used to remove the graded ice (figure 4). Grading and clearing were completed by the end of October 1992.

Protection during peak solar period

In December and the first half of January, warm air temperatures predominate (–7°C to +1°C), and exposed glacial ice often experiences enough heating due to absorbed radiation to cause melting. Melting usually occurs slightly below the surface of the ice. When melt pools form, they are generally large and widespread enough to render a runway useless before complete refreezing in March or later.

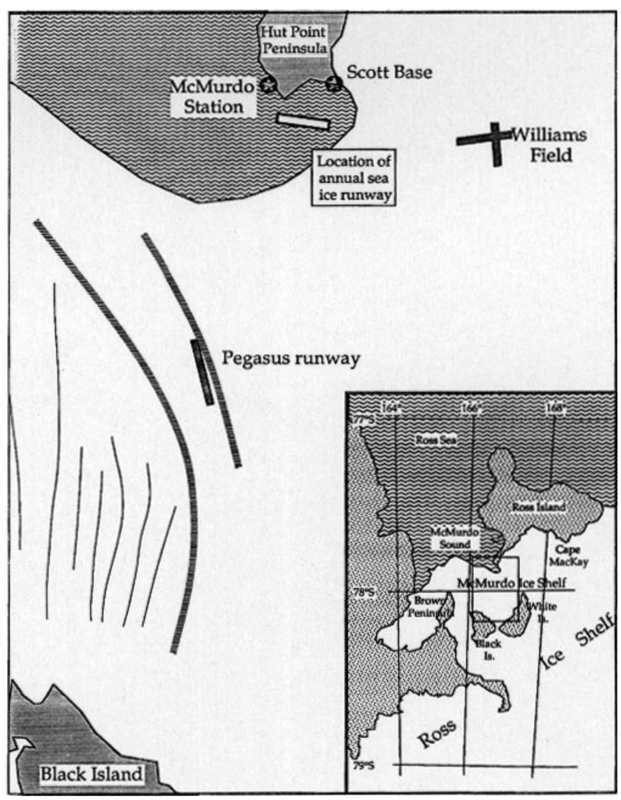

Figure 1. Map of McMurdo Station area showing location of airfields.

Figure 2. Laser-controlled grader used to level natural ice surface for runway.

To protect against melting, the graded ice surface was covered with a 25-centimeter (cm) layer of snow. During the construction phase (1992–1993), material from along the sides of the runway was blown back onto the graded ice surface to provide protection. During subsequent seasons, snow present on the runway following the winter provided the source for this cover. The protective snow cover must be in place by the end of November, just before the peak of the austral summer.

Throughout December and the first week of January, the snow cover required compaction (accomplished with heavy, rubber-tired rollers) to increase its ability to attenuate penetrating solar radiation. Planing and dragging were also done to provide a highly reflective, porous surface. Measurements of air, snow, and subsurface ice-temperature profiles, together with the intensity of the incoming solar radiation, were used to monitor snow-cover performance and to govern snow maintenance activities.

Sometime between 7 and 15 January, the air temperature in the McMurdo Station region begins its downward trend. Within several days of the onset of cooling, the average daily air temperature drops below the highest temperature measured within the ice for that day. With the annual cooling trend thus established, the protective snow cover could be stripped from the runway.

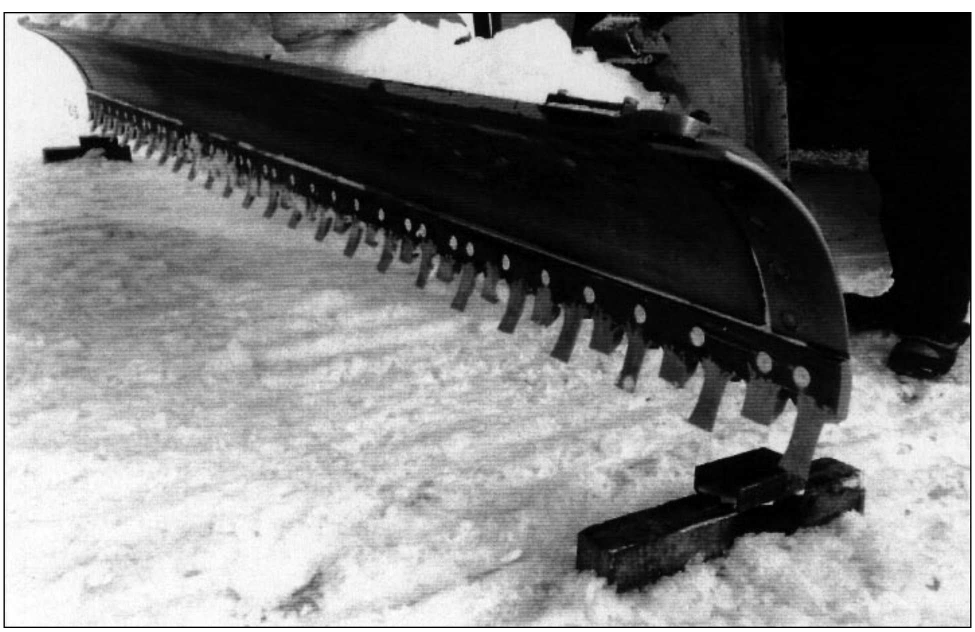

Figure 3. Custom-built grader blade for leveling glacial ice.

Certification of runway strength

In preparation for wheeled aircraft operations, the integrity of the runway was tested with a proof cart. The cart, which replicates the main landing gear of a C-130 or C-141, has a flat deck for ballast to simulate the load, plus a factor of safety, on the aircraft's main landing gear (figure 5). The runway was tracked with the proof cart along its entire length, plus overrun areas at either end. Tire tracks were placed no more than 1 m apart.

During proof testing for C-130 aircraft in January 1993, approximately 30 weak spots were found. In these locations, the ice failed by crumbling, leaving a slight depression in the surface. Excavation of failed points revealed that they had an average size of 2.8 square meters and were 15–45 cm deep. In nearly every case, failure points were associated with a thin (2.5- to 6-millimeter) gap below the ice surface. This gap was most likely caused during refreezing of melt pools that were known to have been present at this site during the 1991–1992 field season when initial construction activities exposed the ice surface and melt pools formed.

Each failure point was excavated, and all of the fractured ice around the edges was dislodged. The ice chunks were broken into fist-sized pieces and packed into the cavity. Cold water was used to flood the cavity, making an ice bath that froze completely within 48 hours. Numerous patched spots were re-tested, and all were found to be sound. On 1 February 1993, the runway was certified for operation of wheeled Hercules aircraft.

During the following season (1993–1994), the proof cart, reconfigured to duplicate C-141 main landing gear, was ballasted to a load of 174,300 kilograms (kg), approximately 25 percent greater than the maximum take-off load on the main landing gear. The tires were inflated to 1,800 kilopascals (kPa), compared to the 1,375-kPa maximum pressure for the C-141.

Proof testing of the runway for C-141 aircraft was completed immediately after the protective snow cover was stripped away on 10 January. No ice failures occurred. After 2 days of proof testing, the runway was dragged and planed to provide an extremely smooth operating surface. The runway was certified for both C-130 and C-141 aircraft and opened for air operations.

Test flights and operations

Before wheeled aircraft could operate on the runway, flight tests were performed to determine the high-speed characteristics and surface traction of the runway. On 6 February 1993, an LC-130 operating on wheels performed a series of landing, taxi, steering, braking, and take-off tests. All test flight results were deemed excellent by the flight crew, and no ill effects were noted on the runway surface.

Full flight operations began from the glacial-ice runway on 8 February 1993. LC-130 aircraft were used to fly cargo from McMurdo Station to Amundsen–Scott South Pole Station allowing an extra 3,600 kg of payload by taking off on wheels. LC-130s operating on wheels and a standard C-130 (figure 6) also used the runway to fly passengers to Christchurch. This change made it possible to increase the number of passengers carried on each flight to 30–50, compared to the usual 15–30 when the plane used skis for take off. The runway was closely inspected following each of the first 15 flights. No damage or wear could be detected, and no ice failures occurred.

In preparation for the 1994 flight season, an LC-130 was again used to certify runway integrity. On 25 January 1994, a wheeled landing, high-speed taxi test, braking test, and a take-off were completed. The flight crew reported that the runway had a superb operating surface, stating that the surface was smoother than most of the concrete runways from which they operate.

Figure 4. Large-capacity snowblower used to remove snow and graded ice from runway.

Figure 5. Proof cart configured and ballasted for C-141 aircraft proof testing.

Figure 6. C-130 Hercules performing routine operations from the glacial-ice runway.

The 1994 operating season began on 26 January and extended through 27 February. Numerous LC-130 flights (on wheels) were operated in supplying the South Pole, and a conventional C-130 was operated between Christchurch and McMurdo Station on an every-other-day basis starting on 1 February. In total, more than 55 flights were operated.

On 7 February 1994, a C-141 flew from Christchurch to McMurdo Station, marking the first-ever C-141 landing on glacial ice. Two to 7 cm of processed snow covered the runway surface, and the C-141's small, high-pressure tires appeared to displace the snow only where more than 5 cm was present or where prior C-130 wheel tracks existed. The C-141 taxied and com-

Figure 7. C-141 completing take-off after successful tests on the glacial-ice runway.

pleted turn-around without difficulty. The C-141 pilot and his crew indicated extreme satisfaction with the runway.

The C-141 was fueled and loaded with three pallets of priority science cargo. Fifty-four passengers boarded and the C-141, at a weight of 127,100 kg, proceeded with take-off, pulling clear of the runway at the 1,500-meter mark (figure 7). The runway suffered no damage from the C-141 operation.

Conclusions

The McMurdo Station glacial-ice runway was developed over a 5-year period and now provides access to heavy wheeled aircraft for much of the austral summer field season. Benefits of the runway include reduced wear and tear on airframes, more efficient use of aircraft and flight crews, less wasted time by science and support personnel, enhanced morale, assurance of stocking South Pole before station closings, increased efficiency for cargo handlers, and timely station close-out. Access by much of the world's aircraft and the potential for winter flights are also gained.

To date, about 78 flights have operated from the glacial-ice runway yielding a savings of 39 flights. This translates to a cost savings of close to 2 million dollars.

The successful completion of this project was the result of cooperation, interest, and hard work by many organizations and agencies including Antarctic Support Associates, the U.S. Navy, and the U.S. Air Force.

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The Arctic and Antarctic Research Center: Support for research during 1994–1995

Since 1988, the Arctic and Antarctic Research Center (AARC) at the Scripps Institution of Oceanography (SIO) has maintained viable satellite data collection facilities for the polar regions and has ensured that full-resolution satellite data of the greatest possible geographic and temporal coverage are available to the research community, both for real-time polar operations and retrospective research purposes (Van Woert et al. 1992). In October 1994, the AARC became part of the California Space Institute, one of the research divisions of SIO. As of mid-1995, the AARC received both high-resolution picture telemetry (HRPT) from the National Oceanic and Atmospheric Administration (NOAA) polar orbiters and Defense Meteorology Satellite Program (DMSP) telemetry from the U.S. Air Force polar orbiters from two land-based, antarctic sites (McMurdo and Palmer Stations) and from the U.S. Coast Guard icebreakers *Polar Sea* and *Polar Star* when these ships are operating north or south of 50° latitude. These four satellite-tracking facilities, as well as the AARC image-processing laboratory at SIO, are based on the TeraScan hardware and software manufactured by the SeaSpace Corporation of San Diego, California, although AARC usually supports scientific users who do not themselves possess the TeraScan software. The table lists the total number of HRPT and DMSP overpasses in the AARC archive that cover part of the antarctic continent and/or the southern oceans. Between the two land-based sites, geographic coverage of the continent is nearly complete with some gaps on the Indian Ocean side. As of 1995, AARC was recording 10 HRPT and 10 DMSP satellite overpasses per day from each land-based site.

In addition to providing the historical archive outlined in the table, AARC offers real-time services in three ways. With the TeraScan software at each shipboard or land-based site, a researcher in the field is able to work with the data using any of the standard TeraScan functions and also his or her own algorithms because the TeraScan software allows export of data to other formats. Real-time services are also available at the AARC image-processing laboratory at SIO via the T1 line out of McMurdo Station. On any given day, a user at SIO can readily access the most recent 24–36 hours of satellite imagery (NOAA or DMSP) tracked by the antenna at McMurdo Station. If additional recent data are required by a user at

The number of HRPT and DMSP overpasses covering high southern latitudes archived at the AARC as of 18 July 1995

Year	HRPT	DMSP
1985	46	0
1986	78	0
1987	123	0
1988	594	0
1989	598	0
1990	1,512	0
1991	2,854	1,133
1992	3,645	1,873
1993	3,987	2,513
1994	4,930	5,166
1995	3,708	3,638