Smart Heads in the Clouds

Airborne Atmospheric Research by SOAR

The SOAR Cheyenne II is an airborne platform for atmospheric research. Its instrumentation has the capability of measuring properties of clouds and their surrounding environment.

Photo courtesy of SOAR

by Mike Haenggi

Imagine you're in the market for a twin turbine aircraft. Your needs are pretty simple. The aircraft has to be fast, have good range, icing certification and pressurization to fly comfortably in the flight levels. A big color GPS moving map with terrain and traffic displays would be nice.

What else... oh yes, definitely lasers under the wings! It also needs a sulfur hexafloride detector. Of course you'll want it to be able to sample air isokinetically in an aerodynamically focused laminar stream. And why not a tandem differential mobility analyzer while we're at it?

Science fiction? Nope. It's just what you need if you're trying to conduct airborne atmospheric research. And if you're a meteorologist studying cloud physics, these tools are necessary to do your job. Duncan Axisa, a professional meteorologist who lives in Texas, always dreamed of having a research aircraft like this. Now he has one with all this equipment and much more. And the way he got it is a story in itself.

It all started because west Texas is dry. Too dry. Most of the rain

Photo courtesy of SOAR

When the team was flying in the Houston area along rain bands associated with former tropical depression Ivan, the research pilot kept making requests to fly in an area of deep convection. The air traffic controller gave them a vector and changed their call sign to "361 Just Clouds" instead of "361 Juliet Charlie". "Just Clouds" is now a SOAR slogan.

typically falls between May and October, and the total precipitation averages fewer than 19 inches per year. The Ogallala (pronounced "oh-ga-la-la") underground aquifer is one of the few sources of water. The Ogallala is one of the largest aquifer systems in the world. It stretches across eight states, generally from north to south, and includes South Dakota, Nebraska, Wyoming, Colorado, Kansas, Oklahoma, New Mexico and Texas and underlies about 174,000 square miles. Most of the communities in west Texas count on it for daily consumption. Farmers rely on it heavily to water their crops.

Monitoring of the aquifer has revealed rapid declines in the water table on the Texas High Plains since the early 1940s. Declines of a foot or more per year have been recorded; and at the peak of irrigation development, some monitoring wells lost as much as five feet in a single year. The trend of rapid decline started slowing in the mid-1970s and in the 1980s even began to stabilize. But then a drought hit in the mid-1990s, and agricultural producers, out of necessity, increased pumpage of water for irrigation. Meanwhile, everyone prayed for more rain.

When it does rain in west Texas, it's usually the result of moisture that comes in from the south from the Gulf of Mexico or from the west via air masses from the eastern Pacific Ocean. In the spring and summer months, there are cumulus clouds that build overhead. The trouble is they often don't produce rain before drifting on to the east.

The Texas Legislature recognized the need for additional measures to augment the water conservation efforts in the west. At the same time, communities were clamoring for support for local cloud-seeding operations. The gears of democracy worked their magic, and the Legislature passed a bill to license, fund and regulate precipitation-enhancement programs. Water conservation districts around the state now had a mechanism to put cloud-seeding operations into place, and many of them did.

SOAR is Born

Three underground water conservation districts in west Texas – the Sandy Land, the South Plains and Llano Estacado Water Conservation Districts – banded together in 2002 to create a project for rainfall enhancement for 5.8 million acres of the Texas-New Mexico border area. They named it the Southern Ogallala Aquifer Rainfall (SOAR) program. Today, SOAR has a dedicated research staff of three, including a project director and two research pilots.

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Photo courtesy of SOAR

The SOAR crew, from left to right: Duncan Axisa, project director, flight scientist and chief meteorologist; David Prentice, research pilot; and Gary L. Walker, research pilot and manager.

Gary Walker, who was integral to the founding of SOAR, is its research pilot and manager. A cattle rancher-turned-pilot, Walker got a degree in animal science from Texas A&M University and did some graduate work at West Texas A&M. After graduating, he spent some time in the U.S. Navy flying T-34s before going on to spend 20 years in the cattle business. Ranching in west Texas got him involved in water conservation with the Sandy Land Underground Water Conservation District, which ultimately led him to SOAR. Once he left ranching, flying became a regular part of his life, for business and pleasure. He's owned a Cherokee 180, a Comanche 250, a Cessna 310 and two Piper Aztecs.

Photo courtesy of SOAR

Unlike most pilots who try to avoid weather, Gary Walker spends his time working with ATC to get routings and altitudes near convective activity.

David Prentice is also a research pilot. After high school, he obtained a B.S. degree from Tulane University followed by an M.D. from the University of Texas Medical School in Houston. He retired from medicine and went back to school to get an MBA from the University of Houston. Prentice is an ATP with type ratings in the CitationJet and Beech 1900. He has amassed over 5,000 hours in a wide variety of civilian aircraft.

Duncan Axisa came on as the project meteorologist. Axisa knows more than most about the weather. He earned his post bachelor's degree from Texas A&M University in Meteorology after coming to the United States from the Mediterranean island nation of Malta, where he worked as an airport meteorological assistant. He received his bachelor's degree in education there, too, where he focused his dissertation on curriculum development in aviation meteorology at the University of

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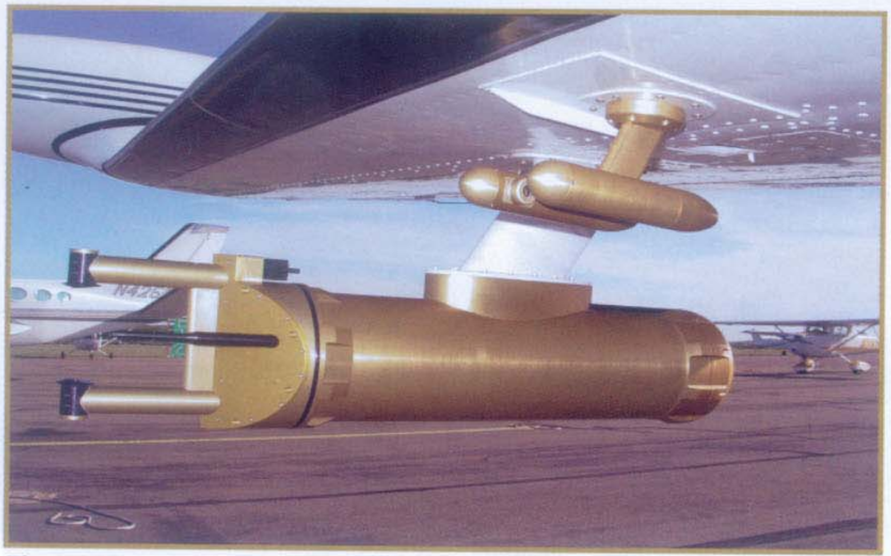
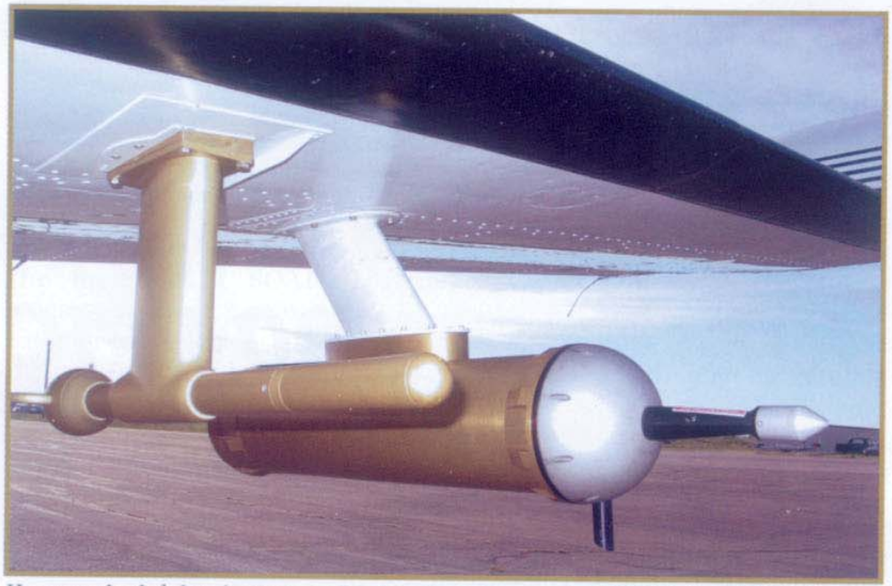


The Droplet Measurement Technologies Cloud Imaging Probe and Cloud Droplet Probe are shown here on the Cheyenne's right wing hardpoint.



Here on the left hardpoint are the Aventech Research AIMMS-20 and PMS Passive Cavity Aerosol Spectrometer Probe.

Photos courtesy of SOAR

Another configuration option for the Cheyenne's left hardpoint pairs the Aventech Research AIMMS-20 with the FSSP by Particle Measuring Systems.

Malta. Today, Axisa is SOAR's project director, flight scientist and chief meteorologist. And due to his specialized occupation, he is now a permanent resident of the United States.

Describing SOAR's original mission, Walker said, "Our primary responsibility is to help conserve and preserve the groundwater of our district. Since the largest use of water in this district is irrigation, our goal of conserving and preserving water has lead us to try to help produce more rainfall from seedable clouds, therefore allowing agricultural producers an opportunity to turn their irrigation wells off for longer periods of time."

The target of SOAR's seeding operations is supercooled liquid water, found in the cloud above freezing level. The seeding agent used is silver iodide, which is released in clouds to empower the formation of ice aggregates. SOAR uses two methods of cloud seeding, cloud-base and cloud-top seeding. Base seeding is accomplished by burning silver iodide flares near the bases of clouds along predetermined tracks, letting the updraft of the cloud pull the seed up into the plume. Top seeding is accomplished by ejecting silver iodide flares into the top of growing cumulus clouds and letting gravity take them down into the heart of the updraft. Both methods are typically done 10 to 30 miles upwind of the target area.

The SOAR program has used a variety of specially modified aircraft for cloud-seeding operations. Several Cessna 340s, a Piper Comanche 250 and a Cessna 188B Ag Wagon were all modified with special flare dispensers for cloud seeding at one time or another. However, none of these aircraft were specifically equipped for airborne atmospheric research.

Beginning in 1997, the State of Texas jointly funded cloud-seeding operations in conjunction with local municipalities. These heady days saw as many as 51 million acres included in cloud-seeding "target" areas. In 2004, budget deficits forced the state to cancel all funding for cloud seeding. Weather modification operations had to get their funding from local municipalities. Most were curtailed by half in the wake of the change. Today, there are nine cloud-seeding projects that cover about 37 million acres (about 20 percent of the land area of the state).

The Seeds of Research

Despite budget ups and downs, the SOAR crew constantly tried to figure out ways to improve seeding operations. Naturally this led them to focus on scientific weather research and cloud physics, which soon became a program specialty and transformed the organization from a regional seeding operation to a national research program. Axisa recalled, "With the help of Gary Walker and the directors of the Sandy Land Underground Water Conservation District, my dream of having a research aircraft became a reality."

Axisa selected a 1977 Piper Cheyenne II to transform into a cloud physics aircraft. "The Piper Cheyenne II is a twin-turboprop aircraft capable of over six hours of endurance when operated long range cruise," he said. "Designed for long-range and high-altitude flight, the aircraft has a pressurized cabin for maximum safety and comfort, and it is certified for flight into known icing conditions. Two 620-shp Pratt & Whitney PT6A-28 turboprops driving three blade constant speed propellers power it. With its scientific equipment, the aircraft has research speeds between 130 and 195 knots, a climb rate up to 2,800 feet per minute and a service ceiling of 25,000 to 30,000 feet. Range at our research speeds is around 1,500 nautical miles."

But getting the platform was just the beginning. Installing the research equipment is what would make this aircraft special. It was modified to accommodate two hard points, each designed for a

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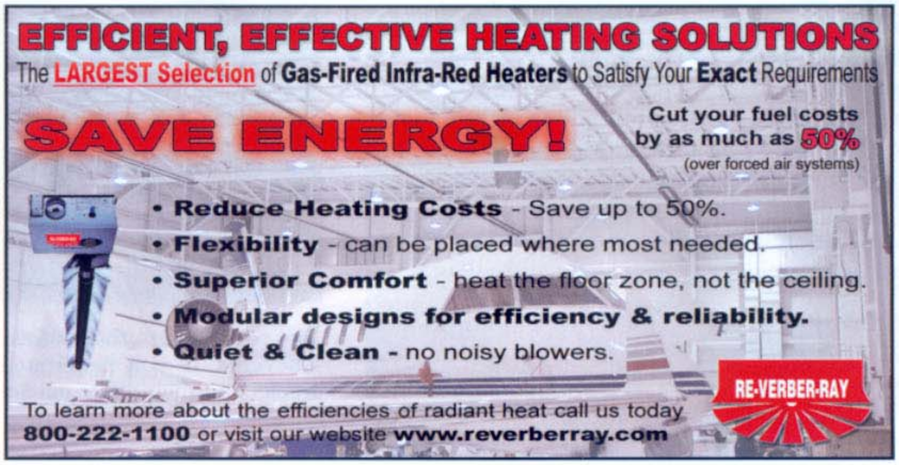


SOAR Cloud Physics Aircraft Equipment

Passive Cavity Aerosol Spectrometer Probe – Atmospheric particles in the temporarily suspended aerosol range are measured by a laser in the Passive Cavity Aerosol Spectrometer Probe. Light scattered by a particle entering the laser beam is collected and focused onto a photodetector where it undergoes three stages of amplification to cover the range between 0.1 µm and 3.0µm.

Cloud Droplet Probe – The Cloud Droplet Probe (CDP) is a new forward light-scattering spectrometer that can measure cloud particles in the range of 2 µm to 50 µm. The instrument counts and sizes individual cloud droplets as they traverse a laser beam. The CDP is mounted below the right wing adjacent to the Cloud Imaging Probe.

Cloud Imaging Probe – The Cloud Imaging Probe (CIP) measures cloud particles in the range of 25 µm to 1.55 mm. Whenever a detector diode is shadowed by a passing particle, the on-board digital electronics begin storing diode information at the true airspeed (TAS) frequency. The TAS is determined using an on-board pitot tube mounted adjacent to the sampling area, providing accurate airspeed at the instrument itself. The CIP also incorporates a Liquid Water Content detector.

Cloud Condensation Nuclei Counter – The Cloud Condensation Nuclei (CCN) counter samples aerosols from outside the aircraft to measure their capability to act as cloud condensation nuclei. An air sample is introduced in the CCN chamber via a 0.25-inch diameter inlet on top of the aircraft fuselage and non-conductive tubing that is plumbed from the CCN instrument to the aircraft fuselage.

Aircraft Integrated Meteorological Measurement System – Also known as the AIMMS-20AQ, this instrument is used to take research-grade atmospheric soundings from the clouds under study. It gives up-to-the second, real-time, three-dimensional wind conditions with better than 0.5m/s accuracy. It also measures the flow direction, true heading, barometric pressure, altitude, temperature and relative humidity.

SF6 Detector – The Sulphur Hexaflouride (SF6) detector senses trace levels of SF6 gas that are released by the seeder aircraft during the seeding experiments.

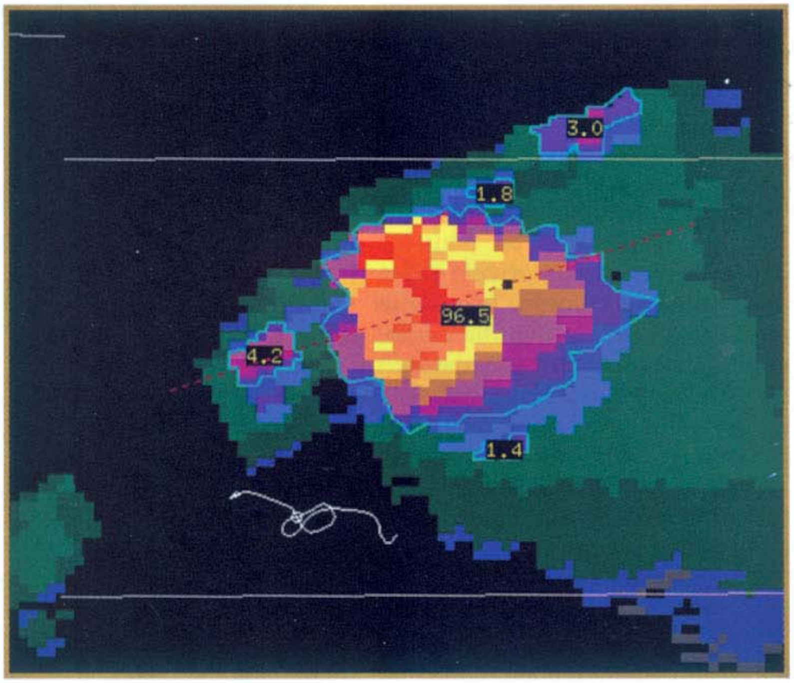
maximum weight of 60 pounds. The wing was strengthened locally to provide six mounting locations. Each hard point consists of a strut that attaches to a canister containing research equipment. The canisters are wired so that the aircraft can be quickly reconfigured with different instruments according to the research objective.

The Cheyenne's suite of instruments is impressive and gives the team the capability of measuring microphysical properties of clouds and their thermodynamic environment, documenting the composition of clouds and diagnosing the physical processes within them. The combination of systems gives the aircraft the capability of measuring the size distribution of cloud particles ranging from 0.1µm to 1.55mm in diameter. (See the equipment sidebar for a full list.)

By adding research capabilities to its repertoire, SOAR was able to undertake research projects funded by the U. S. Bureau of Reclamation, the National Science Foundation, the National Oceanic and Atmospheric Administration and other federal and state government entities. To better reflect the new work, the SOAR acronym was changed to stand for Seeding Operations and Atmospheric Research.

Down to a Science

It wasn't long before the advanced research capabilities of the SOAR project team and the Cheyenne II were put to work. Axisa recalled, "Our first project was called the Southern Plains Experiment in Cloud Seeding of Thunderstorms for Rainfall Augmentation (SPECTRA). This was an experiment designed to study convective clouds in the southern plains in Texas, southeastern New Mexico, and Oklahoma. The objectives of this first phase of the SPECTRA project were to document the cloud condensation nuclei distribution and their effect on the cloud drop size distribution."



The white line to the southeast of this storm shows the flight path of the Cheyenne II as it penetrated clouds to document Cloud Condensation Nuclei and their effect on cloud drop size during the SPECTRA project.

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Next the team flew repeated flights over the California Sierra Nevada for a study of the Suppression of Precipitation (SUPRECIP) caused by pollution aerosols. SOAR used its cloud physics aircraft to document the suppressive effects of pollution on winter orographic clouds (formed by upsloping terrain) and precipitation in that area.

"Time series analyses show that the orographic enhancement factor of precipitation is decreasing with time and remained unchanged where no pollution sources were to be expected. According to that, the precipitation loss is between 15 to 25 percent in these thirsty and densely populated parts of the world," said Axisa.

Aircraft Icing – A Scientific Look

On the morning of the Feb. 7 2005, the SOAR Cheyenne II research aircraft departed the Sacramento Executive Airport (KSAC) on a research flight. After climbing to the northeast to a point west of Lake Tahoe and abeam the crest of the Sierra Nevada mountains, the team descended westward to the lowest possible minimum vectoring altitude while penetrating an orographic cloud layer and continued northward along the Sierra foothills towards Chico.

Photo by Prof. Daniel Rosenfeld

This picture was taken immediately before entering the cloud layer while the aircraft was heading 250 degrees, descending west of the Sierra crest. Outside air temperature was –8.2 degrees C.

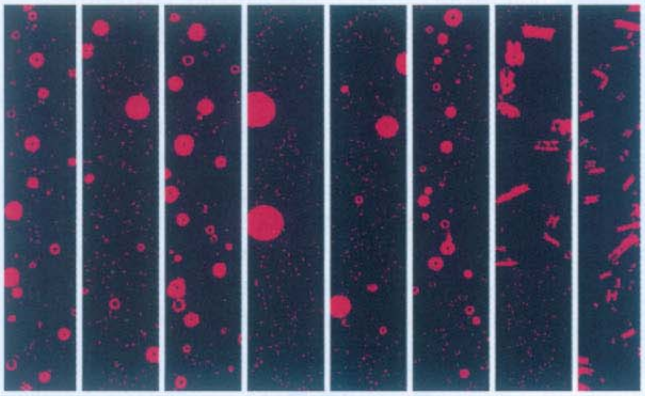

Photo courtesy of SOAR

This is a series of Cloud Imaging Probe (CIP) probe images of cloud particles taken over a 12-minute period as the aircraft descended into the cloud layer. The CIP records up to 10,000 images per second of cloud particles as they stream through the viewing area of the instrument at the aircraft air speed. Notice the transition from drizzle particles to ice particles.

As can be seen in the CIP images, the aircraft started to experience aircraft icing at the beginning of the series when large drops of supercooled drizzle at –1.1 degrees C were in contact with the sub-zero temperature of the airframe. During this time and the subsequent 2 minutes and 41 seconds until the aircraft accumulated ice on the windshield, the aircraft flew through cloud liquid water content as high as 0.8 g/m3, with cloud droplets as large as 42 micrometers and drizzle drops as large as 619 micrometers (1000 micro meters = 1 millimeter).

Photo by Prof. Daniel Rosenfeld

This picture was taken after the aircraft had flown for about 10 minutes in cloud at temperatures ranging from –8.8 degrees C to 0.4 degrees C. After this point, the ice started shedding from the aircraft as the temperatures warmed up to around freezing. It was also observed that during the airframe ice-shedding phase the aircraft was not flying through supercooled drizzle but through ice hydrometeors. Although the liquid water content was as high as 1.03 g/m3, the warmer temperatures and the ice phase of the hydrometeors were not conducive to airframe icing.

This event demonstrates why pilots should avoid flying in winter clouds in areas where supercooled (liquid phase) drizzle is present or forecast.

SPECTRA, Phase II came a few months later. In this study, the SOAR crew conducted several seeding experiments using milled salt released from an agricultural aircraft into cloud bases, simulating how ocean spray puts salt into the atmosphere. At the same time, they released Sulfur Hexafloride gas into the updraft. Then the Cheyenne II research aircraft conducted penetrations above the seeding site to see if the gas was detected on subsequent passes, which would indicate the aircraft had penetrated the seeded plume. The system worked.

"The detection of the gas was successful in part due to a software program that ingests the seeder coordinates and directs the research aircraft towards the location of the seeding. More research is needed in order to draw definitive conclusions, but the study showed promise of broadening of the precipitation particle spectrum."

The most recent study was The Houston Environmental Aerosol Thunderstorm Project (HEAT). It was designed to address the factors responsible for the observed enhancement in lightning frequency over Houston, Texas. "An array of surface and airborne equipment was operated during this study to characterize the thermodynamic, environmental, and cloud properties of the atmosphere of Houston. It has been speculated that enhanced aerosol concentrations arising from urban emissions suppress precipitation and deepen the mixed layer within urban clouds, which may alter cloud electrification, and possibly increase lightning frequency.

To address the merit of this hypothesis, detailed measurements of aerosol and cloud properties were necessary. Cloud condensation nuclei concentrations immediately downwind of Houston were observed to be as much as 10 times higher than that measured on the upwind side of the urban plume. The dramatic increase in number concentration indicates that large numbers of small particles were added to the air mass as it passed over the Houston area. The data is still being analyzed to investigate whether this change has an affect on precipitation and lightning."

To New Heights

SOAR's research directly benefits all of us in the aviation community by offering a better understanding of the atmosphere and its processes. Over the last year, Axisa and his team have accumulated more than 200 hours of atmospheric research mission time in the Cheyenne II.

"We pride ourselves in being a small elite group with an emphasis on sound scientific research plans that are conducted efficiently, professionally and safely," he said. "My goals are to continue researching precipitation and aerosol interactions, and to improve the capabilities of atmospheric research aircraft with new instrumentation."

More science, more airplanes and better cloud-shooting lasers. Who needs science fiction?

For more information or to contact SOAR, see: www.just-clouds.com

Mike Haenggi has ten years' experience in aviation publishing. He is the author of two books and many aviation articles. As a former senior aviation editor, he helped put together more than 100 books on the history of aviation. Mike holds an MBA in Aerospace Business from Embry-Riddle Aeronautical University, and is also a CFII and an Aviation Safety Counselor. During normal business hours, he manages marketing programs at Pilatus Business Aircraft for the PC-12. You can email him at flightmike@hotmail.com.