Applications of the Space Perspective to Aviation

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More than two millenia ago, Aristotle and one of his students documented the relationships between the signs of weather and the direction from which the wind blew. Almost 250 years ago, George Hadley first hypothesized the existence of an organized global circulation cell that still bears his name. Some meteorological reporting networks were organized in Europe by the early 19th Century by Lamark, LaPlace and Lavoisier. Weather observations were gathered by mail in those days, so the data compiled were useful only in the historical sense. Such collections did, however, permit the synthesis of individual reports into a so-called synoptic picture of the weather over a wide area, and the first weather map was drawn by Heinrich Brandes for the date March 6, 1783, in 1820! Hardly a timely forecast!

M. F. Maury published maps of mean wind fields over the globe in 1848, and these were soon put to use by the sailing fleets of the day. It was not until the invention of the telegraph in the mid-19th century that rapid and reliable weather reports became available in a timely fashion. The importance of weather observations gradually became evident, and as the number of stations grew, so did the interest in weather forecasting.

Certainly the introduction and growth of aviation in the early 20th Century increased the interest in meteorology. For as we all know, aviation is clearly the form of transportation most vulnerable to the vagaries of weather.

It was in the early years of this century that significant progress in understanding weather was made with the introduction of the cyclonic and frontal models by Vilhelm and Jacob Bjerknes, Bergeron and Solberg. Their theories explained the three-dimensional aspects of the weather and made it clear that two-dimensional surface observation networks were inadequate for forecasting weather.

It was in the post World War I period that Richardson suggested that the future state of the atmosphere should be predictable from the present state using the first principles of physics. With the linearized partial differential equations of motion, the thermodynamic equation and the equation of continuity, Richardson's "primitive equation" model had to be numerically integrated by hand, a task so burdensome that he estimated it would provide a forecast for 12 hours only after many days of intensive labor!

The development of free-flying rubber balloons and an economical wireless instrument package in the 1930s made it possible to begin sounding the thermodynamics of the atmosphere in three dimensions on a wide scale. World War II provided an enormous boost to meteorology with the use of airpower becoming a significant mode of warfare. The U. S. Government poured millions of dollars into training and observations. The development of radar also gave added impetus to the science. The next major advance for meteorology came with the development of the electronic computer in the 1950s. Von Neumann and his colleagues recognized the potential for using the first computers to do what Richardson was unable to do...produce an objective forecast in time to still be a forecast!

A very significant advance in meteorology came in 1960 when the first meteorological satellite (TIROS-I) was launched. Even though it provided pictures of clouds which were difficult to interpret because its spinning orientation made navigation and registration of the images a nightmare, it was a breakthrough in elevating our perspective to a large expanse of viewing the atmosphere from above. At last, the meteorologist could see what the present cloud conditions were in great detail over a wide area at a given time.

These views were useful, but not so valuable for short-range aviation forecasting. For, as we all know, weather systems, particularly in smaller-scale weather (often the most severe), can develop over a matter of hours, and observations from a satellite once or twice per day simply miss a great many weather events. It was not until Vern Suomi developed the spin-scan camera for the ATS satellite that satellites began to have a large impact on weather forecasting in general and aviation forecasting in particular. With images of the entire disc of the earth available at 30-minute intervals, and sector scan of more limited areas available every 3 minutes, it became possible to monitor the development and movement of clouds quantitatively. This capability provides not only cloud growth and cloud height information, but cloud motions are good tracers of the wind as well. This technique was applied to the NASA SMS/NOAA GOES satellites and is operational today. These satellites provide the images we usually see on the evening television news.

When this capability to observe the atmosphere almost continuously is combined with the marvels of modern electronics, especially with an analyst in the loop, the full potential of satellite data grows enormously. With devices like the Man-Computer Interactive Data Access System (or McIDAS, for short) digitized computer images can be quantitatively manipulated to determine winds, wind shears, convergent/divergent zones, vertical growth rates of cumulus clouds, etc. These data displayed with an overlayed weather chart provide instant information to the forecaster, synthesized in virtually real-time.

But the satellite observations need not be confined to images and image manipulation. Satellite measurements of the atmosphere became three-dimensional in 1969 when instruments aboard the NASA Nimbus III satellite made vertical temperature soundings from space. These first sounders used the thermal radiation emitted by atmospheric CO_2 in the 15 μm band to determine the vertical temperature profile. Further developments in vertical temperature soundings pioneered by the experimental Nimbus series of satellites permitted us to obtain more accurate soundings by using the 4.3 μm emission band of CO_2 and then the 50-60 GHz thermal band of atmospheric oxygen. In the latter case, the soundings are not limited to cloud-free areas as they are with the infra-red. With the development of the NASA TIROS-N satellite in 1978 and its operational follow-ons, the sounding system utilizes a combination of passive infrared and microwave sensors to measure the temperature structure of the atmosphere routinely. With approximately 7000-8000 soundings per day, the satellite soundings provide important information to the numerical forecast models, especially in remote regions where no conventional soundings are available such as vast oceanic areas and over many third-world nations.

As I indicated, the early satellite soundings demonstrated that we could obtain soundings from space, but they left much to be desired in terms of accuracy. Thus, their early use sometimes made a forecast worse and they were not used operationally for almost 10 years. NASA continued to develop methods to retrieve more accurate soundings and to assimilate these data into models that were designed to accept synoptic measurements. Introducing asynoptic satellite observations "shocked" the models and caused other problems in the numerical stability of the computations as well. These problems have been virtually eliminated now. We have even developed techniques to remove the contamination of the temperature sounding by clouds, water vapor, unwanted minor constituents, aerosols, etc. Most important, we have demonstrated that adding satellite-derived temperature soundings and winds significantly improves mid-range weather forecast accuracy (3 - 10 days).

You may recall the Global Atmospheric Research Program's (GARP) Global Weather Experiment which was conducted in 1978-79. It involved over 140 countries, cost $300 million, and provided us with the most complete set of observations of the atmosphere ever made. The experiment used five geosynchronour satellites, two polar orbiters and a multitude of special ships, buoys, drifting superpressure balloons and aircraft observing systems. We are intensively investigating this data set to discover the limits of predictability and to define the optimum global observing system we need. We, in NASA, are spending over $7 million per year to support this research which is being done with strong participation by the academic community. In addition, we have made a substantial commitment to the analysis of satellite data and the development of improved models of the atmosphere by acquiring a new vector processor, the Cyber 205. This machine and its attendant systems comprise a computing facility which will have a speed of over 100 million instructions per second, and an on-line memory of 110 billion words. We anticipate that this tenfold increase in computing power will enable us to run models that were simply too long and costly to run previously. These models will have more realistic physics formulated in them and will have much higher vertical and horizontal resolution as well.

We have already learned a great deal from our work with the Global Weather Experiment data sets. For example, we have shown that: satellite observations positively impact the range and accuracy of weather forecasts; tropical observations must be included in 3-4 day forecasts at mid-latitudes; the current conventional upper air observing system is inadequate for even 6-hour forecasts except over North American and Eurasia; and we have discovered several new aspects of the South Hemisphere circulation that we didn't know existed (standing Rossby waves, and a more intense circumpolar frontal circulation than the North Hemisphere counterpart).

With the launch of GOES-4, temperature soundings from geosynchronous altitudes became a reality. The NASA-developed VAS (VISSR Atmospheric Sounder) instrument which uses the infrared emission of the atmosphere to sense temperature and water vapor permits us to observe the time evolution of convective storms in detail. These kinds of data will hopefully lead to improved detection and short-term forecasts of thunderstorms and tornadic activity. It is important to note that for atmospheric phenomena which occur on the temporal and spatial scales involved in thunderstorms, space observations (used together with ground-based measurements) offer the only economically viable approach to obtaining not only the repeated coverage needed, but also the dense grid of observations, as well.

There is one other area of satellite applications to aviation I wish to mention. You are probably familiar with the location and tracking of mobile platforms capabilities available from satellites. This technique, which was developed by NASA on the early Nimbus satellites, has now been adopted operationally by NOAA on the TIROS-N class spacecraft and even by the U.S.S.R. This system can be an invaluable aid to airmen in distress. For example, in 1977, there were 4286 aircraft crashes with 1440 of these requiring a search. In 1978, the U. S. Coast Guard responded to 3348 calls for aid in areas 25 or more miles from shore. Rescue is vital to survival of crash victims, and over half can be saved if they are rescued within 8 hours. Emergency transmitters are installed in 200,000 U. S. civil aircraft and 6,000 vessels. Sarsat (for search and rescue) will provide 10 - 20 or 2-5km location accuracy depending on frequency used, and can handle up to 10 simultaneous transmissions. Spacecraft will be launched in the February 1983 time frame and begin a joint demonstration with COSPAR (Committee on Space Research) in September 1983. The problem at present is that an U.S.S.R. satellite is receiving 15 - 20 reports each day from false alarms. Two rescues have been effected, but high false-alarm rate precludes use of the SAR (synthetic aperture radar) signal as an indicator. The planes/vessel must be listed as missing before a search is initiated. This could be costly to people who have an emergency.

The future for satellite applications to aviation looks very bright. Satellite instrumentation will contribute to better wind measurements, improved aircraft/ship routing, improved short-range and medium-range weather forecasting and better communications, including search and rescue capabilities.