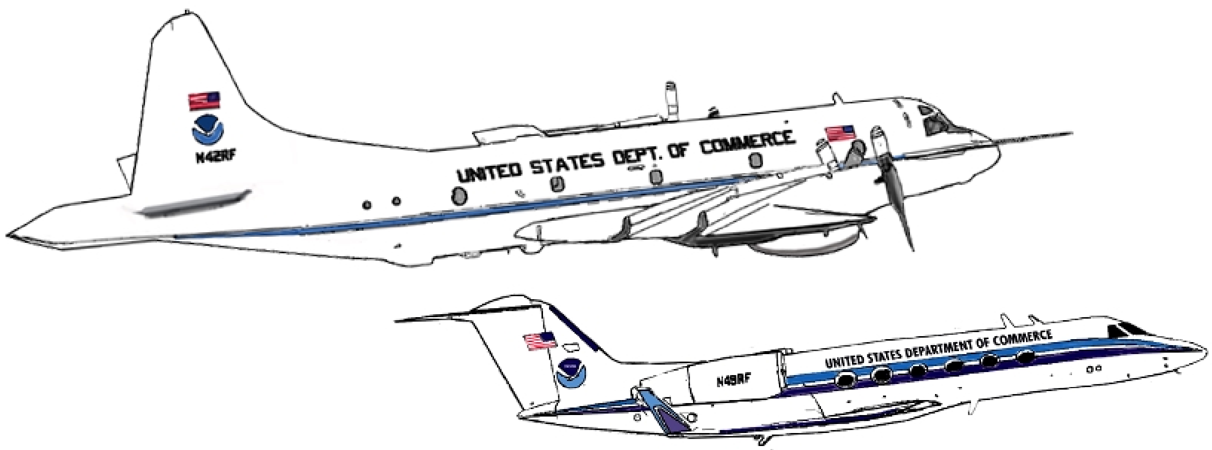
How Will NOAA's Heavy Aircraft Adapt to Programmatic and Technological Changes in the Next 5-10 Years?

—Proceedings from the NOAA Heavy Aircraft Conference—



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January 2001

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Executive Summary

The NOAA Office of Marine and Aviation Operations (OMAO) sponsored a conference on July 11, 2000 in Boulder, Colorado to address NOAA's heavy aircraft needs over the next 5-10 years. The attending members of the NOAA research and operational communities examined the future requirements, summarized the current aircraft situation and future prospects, and formulated their recommendations. The major conclusions of the Conference are as follows:

Future Requirements

- Air chemistry and air physics research within NOAA requires at least two heavy aircraft with medium to long-range endurance, and significant load-carrying capability. This is especially important for those missions requiring at least two airborne Doppler radars.
- In addition, air physics research within NOAA requires operational capability at altitudes from 30 meters to at least 12 kilometers above the surface.
- Most of the airborne mission profiles require low altitudes as well as slow operational speeds for measurements, parameters which are needs conducive to the use of turboprop aircraft.
- Furthermore, most of the airborne mission profiles require an aircraft that can accommodate a large suite of remote sensing and in-situ measurements.

Current Situation

- NOAA's two WP-3Ds are 25 years old, and despite excellent maintenance, both are approaching the end of their useful design life (30 years).
- Lockheed has not manufactured P-3s since 1986, causing some concern about future support in terms of maintenance and spare parts.
- NOAA's WP-3Ds have been extensively modified over the years and are unique in their current configuration. There are no other similarly equipped aircraft available from any other Federal agency, university, or private sector source, without considerable alterations.
- No other currently available turboprop aircraft can provide the required combination of endurance, payload, altitude and speed ranges, and power supply.

Options and Recommendations

We recommend that NOAA:

- Maintain the fleet of two WP-3D aircraft via a service-life extension program.

- Closely follow the Navy's discussions with Lockheed regarding the potential re-opening of a P-3 assembly line, which could offer NOAA the possibility of cost-effective acquisition of new aircraft in the longer term.

- Maintain the G-IV aircraft and improve its capability to support NOAA's air chemistry and physics research needs.

- Establish efforts to partner formally with other agencies to develop unmanned airborne vehicle (UAV) and remotely piloted vehicle (RPV) technologies that are relevant to NOAA's missions.

Introduction

Future Requirements

Over the next 5-10 years, the air chemistry research community requires the use of NOAA heavy aircraft in three categories: (1) air quality research and forecasting; (2) global and regional climate change; and (3) stratospheric ozone depletion. The air chemistry community within NOAA feels that two WP-3Ds are necessary to satisfy its requirements. Most current air chemistry requirements can be met by one WP-3D and a G-IV operating either independently or in concert. However future studies, for example, certain chemical flux and divergence studies could profitably utilize two WP-3Ds operating together.

Over the next 5-10 years, the meteorology and air physics communities require the use of NOAA heavy aircraft in the following five categories: (1) improvement of severe weather forecasts and warnings, (2) improvement of hurricane track and intensity forecasts, (3) improvement of winter storm forecasts and increased lead times, (4) improvement of numerical model forecasts from observations to improve representation of sub-grid scale (e.g. radiative, cloud microphysical, and turbulent) processes, and (5) improvement of satellite retrieval algorithms. All flight profiles in the meteorology and air physics community require operating from the deep tropics to the poles, operating in remote regions requiring endurance greater than eight hours, operating in a “low and slow” flight mode, as well as operating with heavy payloads that often require modifications from mission to mission.

Current Situation

For the past few years, questions about NOAA's aging WP-3Ds and related concerns over remaining design life have been discussed at the most senior levels of the agency and the Department of Commerce (DOC). For more than 25 years, NOAA's airborne research community has been dependent in large part on the WP-3Ds to provide suitable platforms for air chemistry, air physics, and hurricane research and reconnaissance missions.

During its Scheduled Depot-Level Maintenance (SDLM) in March 1999, one of NOAA's WP-3D Orion aircraft – N42RF -- was discovered to have damage to its wing structure. Specifically, the aft wing-spars were cracked and the Navy’s Naval Air Depot at Jacksonville, Florida recommended repairs, which were done immediately. It was determined that the cracks were stress fractures, as well as metal fatigue that was common for aircraft that were over 25 years old. The Aircraft Operations Center (AOC) decided to also replace the aft wing spars on NOAA's other WP-3D -- N43RF – after the Navy also found cracks in that aircraft.

The resulting unexpected expenditure of approximately $1.0M and the corresponding unexpected loss of mission availability raised questions about the future use of NOAA's WP-3Ds, and how much longer the agency could expect to keep these uniquely equipped platforms operating. With limited ability to respond to the important task of flying hurricane research and reconnaissance missions, NOAA found itself missing a critical portion of its airborne research and operations effort. The downtime experienced with the WP-3Ds validated that these aircraft are important national assets and their continued utility to the agency is of utmost importance. It should be emphasized that both of these aircraft are reaching the end of their useful design life (30 years), as defined by the Navy and Lockheed.

This document is the first of several on the topic of NOAA's heavy aircraft – their viability, their versatility, and their longevity. The Office of Marine and Aviation Operations (OMAO) and AOC will continue to seek input and guidance from the user community in order to meet the operational needs for airborne research. As additional reports on the heavy aircraft topic are written, OMAO hopes to gain consensus on a number of substantial recommendations that will support critical review. OMAO also feels it is important to emphasize that the audience for this report, and the ones to follow, will be broad reaching. The readership will not be limited to NOAA scientists and platform operators, but will also be read by senior NOAA and DOC policy makers, as well as the other Federal agencies, Congress, the Office of Management and Budget, and the commercial aviation community.

OMAO feels it is imperative that this initial effort be an instrumental element in the FY2003 Strategic Planning Process. The current FY2002 DOC budget has $500k for a detailed engineering study and cost analysis of replacement aircraft options. Right now, there is neither the time nor the technical expertise to conduct this in-depth analysis. However, OMAO feels very strongly that this replacement aircraft study should begin immediately in FY2002, whether or not the funds are approved in the FY2002 budget process. OMAO will work with the NOAA user community and the Chief Financial Officer to target funding in order to get this process moving no later than October 2001. If necessary, OMAO feels funding should be made available from other sources, including programmatic funds and the Administrator's Discretionary Fund. Strategic Planning teams such as Advance Short-Term Warnings and Forecast Services, Assess and Predict Decadal to Centennial Change, and Implement Seasonal to Interannual Climate Forecasts will benefit from the interactions put forth in this report, and succeeding analysis.

OMAO and AOC will continue to maintain the two WP-3Ds, adhering to set schedules for routine maintenance and SDLM's. These two aircraft are essential to NOAA's airborne research efforts and OMAO will continue to provide safe, cost-effective platforms for these missions.

Finally, OMAO and AOC would like to offer sincere appreciation to Dr. Daniel Albritton, Director of the Office of Oceanic and Atmospheric Research (OAR's) Aeronomy Laboratory in Boulder for hosting the initial meeting in July. Additionally, the contributions made by Drs. Fred Fehsenfeld, Frank Marks, Al Gasiewski, Naomi Surgi, and David Fahey were instrumental in compiling this initial report, and OMAO wishes to thank them for their efforts.

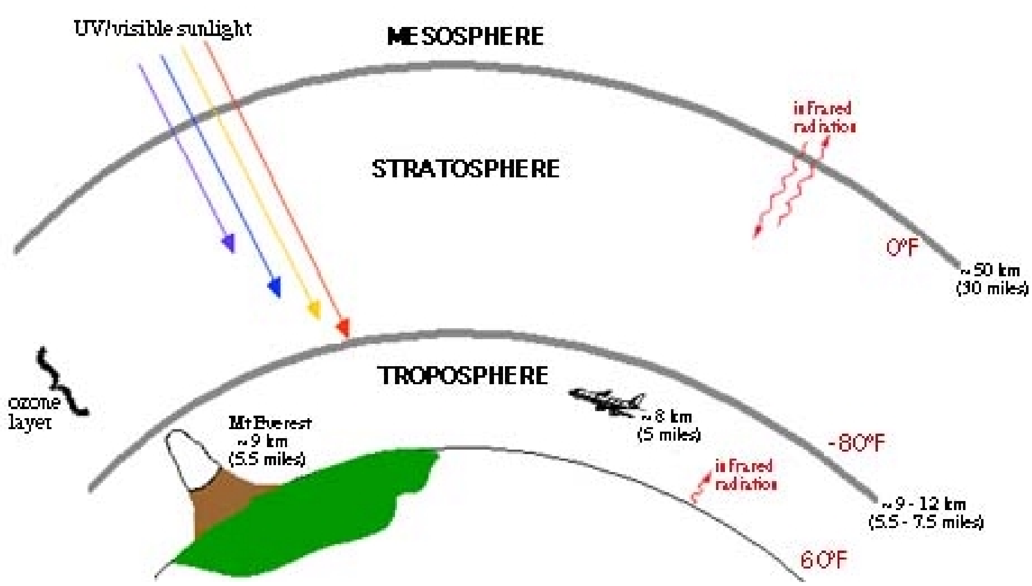
Projected Atmospheric Chemistry Needs

The principal investigators and lead scientists within the air chemistry research community were invited to Boulder, Colorado, to discuss not only their platforms needs, but also to reflect and comment on such items as: (1) How can budgeting efforts within the air chemistry community be improved? (2) How can the user community work more effectively as a whole? and (3) What are the varying operational approaches from the user perspective? What follows is their perception of basic needs for the next five to ten years.

Airborne Chemistry – Future Research Needs (next five years)

The air chemistry research in NOAA's Office of Oceanic and Atmospheric Research (OAR) that requires the use of the NOAA heavy aircraft can be placed in three categories: (1) air quality research and forecasting; (2) global and regional climate change; and (3) stratospheric ozone depletion. Each of these research areas will need one or more of the NOAA heavy aircraft, the two Lockheed WP-3D Orions and the Gulfstream G-IV, to satisfy several of the requirements for an airborne research platform. Air quality research, which is typically done in the planetary boundary layer and the lower- to mid-free troposphere, requires an aircraft with medium- to long-range and significant load-carrying capacity. These airborne studies support the current NOAA initiative in “Health of the Atmosphere” and potential new initiative in “Air Quality Research and Forecasting.” The operational requirements for three programs can largely be satisfied by the WP-3Ds. Global and regional climate change research is typically carried out in the free troposphere and lower stratosphere. The studies require long range endurance and significant load-carrying capacity that are available with the WP-3D over the lower altitudes and G-IV at higher altitudes in the troposphere.

REGIONS OF THE ATMOSPHERE



Aspects of the research that involve studies of deep convection in tropical regions and most stratospheric climate change and ozone depletion research will require an aircraft with operational altitude capabilities greater than that available in the NOAA fleet of heavy aircraft. Clearly, for this research during the next five years, we should seek cooperation with other agencies with the necessary aircraft capabilities.

In summary, for regional air-quality, global and regional climate change and stratospheric ozone depletion research the NOAA heavy aircraft capability is adequate for most of the needs of the air chemistry community in NOAA. Because of the aircraft support provided by the NOAA Aircraft Operations Center, NOAA's air chemistry programs have been able to play a significant role in promoting the understanding of the processes that shape the chemical composition of the atmosphere on regional and global scales. For these reasons the air chemistry community regards the heavy aircraft capability in NOAA to be a vital ongoing resource that must be maintained.

- Special Measurement Needs

During the next five years the NOAA chemistry community expects that special emphasis will be placed on the development and deployment of long-path optical (remote sensing) techniques aboard the NOAA heavy aircraft. Scientists in OAR have taken the lead in developing the new technology for remote sensing. These measurements are used to determine radiative properties of the atmosphere and radiation that drives atmospheric photochemistry. Recently, these measurements have become increasingly important in determining the chemical composition of the atmosphere. Some of these techniques will have the capability to measure the height-resolved concentration of species such as ozone and aerosols.

For meteorological research, such measurements will be useful to determine the structure as well as the chemical composition of the atmosphere. In addition, the remote sensing techniques carried aboard the NOAA aircraft will be invaluable for helping to ground-truth satellite measurements. During the next ten years, satellites will be deployed to measure the chemical composition of the atmosphere. These satellites will be expected to provide significant information concerning the atmospheric chemical composition to meet operational chemical forecasting needs. The deployment of satellites to provide chemical composition measurements will require extensive testing and evaluation using in-situ and remote sensing instruments carried aboard the NOAA heavy aircraft.

Because of the weight and viewing port requirements for the instruments, special arrangements may be required to place them onboard the NOAA heavy aircraft. Arrangements should be made between AOC and the scientists associated with this technology to develop a plan to accommodate these instruments on NOAA's heavy aircraft.

- Number of WP-3Ds Required for Air Chemistry

The air chemistry community feels that two WP-3Ds will be required to satisfy NOAA's air chemistry requirements. As indicated above, a WP-3D and a Gulfstream G-IV operating either independently or in concert can meet most current air chemistry requirements. A few future studies, for example certain chemical flux and divergence studies, could profitably utilize two WP-3D's operating in concert. However, in addition to the needs of the NOAA chemistry community, there are within NOAA significant additional demands for WP-3D time. Weather research and operations can severely limit aircraft availability at certain periods. WP-3D maintenance and repair can further complicate this situation. It is important to emphasize that this requirement is not in addition to existing WP-3D aircraft, but it should be noted that during non-hurricane season, air chemistry missions often require the availability of two WP-3Ds. The air chemistry community's experience suggests that if only one WP-3D is in operation, limited WP-3D availability would probably produce an untenable situation for air chemistry research.

- **Should NOAA Replace the WP-3Ds with Other Aircraft After Five Years?**

The WP-3Ds currently in operation by NOAA are more than 25 years old. However, they are well maintained and it is estimated they have at least eight to ten years of design life remaining. They are able to accommodate the large suite of air chemistry measurements that is required for investigating complex regional air-quality problems. If the WP-3Ds were to be replaced by different aircraft with similar operational capabilities, considerable expense would be involved in adapting this array of chemistry measurements that is currently being flown aboard the WP-3D to a different airframe. From the air chemistry perspective, currently there seems to be no better alternative to the WP-3Ds to justify the cost of switching.

- **Cost-effective Management of the Heavy Aircraft Capability**

The air chemistry community recognizes the need to use the NOAA heavy aircraft as cost effectively as possible. This could be achieved through increased cooperation among the air chemistry users, and NOAA's weather research and operations users. There are many examples that can be cited. The WP-3D users in OAR should cooperate to fully utilize the aircraft. This could be done in some cases by combining missions. To do this, investigators who plan to use the plane should compare their requirements and indicate their constraints well in advance so there would be ample time for accommodation. In addition, some aircraft needs could be met by piggybacking on certain missions. This would require an indication of the aim, theater of operation and instrument load planned for the host investigation to determine the feasibility of collaboration and possible payoffs. Such cooperation has been informally discussed within the air chemistry community between air chemistry and hurricane research, and between air chemistry and operations.

With regard to the G-IV, this platform is currently used principally for operational weather research and forecasting. However, many of these missions are currently flown with a lightly instrumented aircraft. Air chemistry investigators could add several chemical monitors to fly important experiments on the aircraft when it is being used. These piggyback missions could provide for use of the aircraft by the chemistry community and give potentially important information to meteorology research and operations that could use the chemical measurements as tracers.

- **Support for WP-3D Operations**

The cost of operation and maintenance for the WP-3Ds has increased steadily over the past decade. However, adequate increases to the operating budget have not been forthcoming.

First, consideration should be given to adequately funding the operation and maintenance budgets. Based on safety considerations, the maintenance of the aircraft should be adequately funded. It must be recognized that the cost of maintenance for these aging aircraft may well increase faster than inflation. With regard to the G-IV as well as the WP-3Ds, this budget should also provide funds to support the acquisition and operation of important ancillary measuring instrumentation and instrumentation infrastructure that can be made available for both chemistry and meteorology research.

Second, it may be necessary to consider that some form of partial support cost for aircraft operations are paid for by the OAR user. This approach, of course, would favor the fiscally stronger programs that are best able to partially pay for their associate external costs. Since the research budgets are equally stressed at present, further expenses without additional support could imply less research being conducted. These broad budget and support issues regarding facilities essentially cut across all of NOAA and likely will need to be addressed as such.

Third, budget proposals have traditionally been aligned with NOAA's Line Offices. Today's fiscal climate seems to imply that this approach is outdated. Budget initiatives that are developed across components have the potential to be better integrated and more broadly supported.

- **Improving Aircraft Capabilities**

The air chemistry community's use of the G-IV would be greatly helped if engineering support could be obtained through AOC. Such individuals could assist in designing instrument inlets, viewing windows and mounting arrangements for the G-IV. Since the aircraft is flown under FAA certification, significant additional steps will be required to properly integrate new instrumentation on the aircraft. The centralized assistance through AOC by an engineer familiar with FAA requirements would be of great benefit to individual projects as they prepare instrumentation to fly on the G-IV. With regards to the G-IV, the chemistry community also needs to have the flow fields around the G-IV mapped. This will assist in the design of inlets that can sample the atmosphere without interference associated with contact between the sampled air and the fuselage of the aircraft and without aerosol particle perturbation. Finally, it would be desirable to investigate the feasibility and cost of having hard points on the wings of the aircraft for mounting instrument-carrying pods. This modification, if feasible, would serve to improve the payload capacity of the aircraft and improve aerosol-sampling options. In addition, it could possibly circumvent problems associated with the shedding of ice from inlets protruding from the fuselage in front of the engines that are mounted at the rear of the aircraft.

- **Ancillary Measurements**

Several measurements were identified that the atmospheric chemistry community believes should be included in any atmospheric chemistry study. Hence, we request that AOC investigate the feasibility of acquiring the instrumentation necessary to provide these data routinely. Several measurements would be desirable, but two were identified that would be particularly helpful and timely. These are accurate and fast-response water vapor (response time ≤ 1 second) and an aerosol LIDAR. The water vapor measurement is important for both air chemistry and meteorological measurements. Although water vapor measurements are now being made routinely on the NOAA heavy aircraft, these measurements do not meet current research needs (precision, accuracy, and response time). Likewise, an aerosol LIDAR could provide information concerning the vertical structure of the atmosphere that would be vital to both air chemistry and meteorology research.

- **Long-Term Additions to NOAA's Fleet**

The atmospheric chemistry community has requirements in one area where the present NOAA heavy aircraft fleet cannot satisfy current air chemistry research needs. This is research that requires an aircraft capable of carrying an integrated payload of measurements over longer distances and/or at higher altitude than is available with NOAA's current heavy aircraft. Atmospheric research and NOAA weather service operations also indicated the need for such an

aircraft. Aircraft that could potentially meet these requirements are currently in the design and testing stage. These aircraft are primarily unmanned aerial vehicles (UAV's) (see Appendices C, D and E for additional information.) The air chemistry community would urge AOC to determine future NOAA research and operations needs in this regard and investigate the possibility of securing the use of such an aircraft possibly through a cooperative arrangement with another agency.

Projected Meteorology and Air Physics Needs

The principal investigators and lead scientists within the air physics and meteorological research and operational community were invited to Boulder, Colorado, to discuss not only their platforms needs, but also to reflect and comment on such items as: (1) How can budgeting efforts within the meteorology and air physics community be improved? (2) How can the user community work more effectively as a whole? and (3) What are the varying operational approaches from the user perspective? What follows is their perception of basic needs for the next five to ten years.

Projected NOAA Requirements:

The meteorology, oceanography, and air physics communities in NOAA's National Weather Service and Office of Oceanic and Atmospheric Research, which require the use of the NOAA heavy aircraft, defined nine mission profiles to address research and operational issues. These topics fall primarily under the NOAA Strategic Goal for Environmental Assessment and Prediction, and in particular the Advanced Short-term Warning and Forecast Services theme. Additionally, these topics are critically important to the successful achievement of the U.S. Weather Research Program (USWRP) objectives. Of the nine mission profiles identified, six address research problems and three address operational problems. These mission profiles can be placed in five categories:

- Improvement of severe weather forecasts and warnings (two mission profiles) designed to collect observations to improve understanding of storm dynamics (storm defined as scales from tens of meters [m] to hundreds of kilometers [km]), and to improve understanding and warnings of tornadoes and supercell thunderstorms.
- Improvement of winter storm forecasts (one mission profile) designed to collect dropsonde data over targeted regions (defined as scales of 2500-4500 kilometer) of the Northeast Pacific. This mission is tied to the strategic goal to increase lead-time and probability of detection of winter storms over the continental U.S. and Alaska, as well as to provide West Coast forecasts as accurately as for the rest of the country.
- Improvement of hurricane track and intensity forecasts (two mission profiles) designed to collect observations to improve understanding and forecasts of hurricane tracks, and hurricane intensity change. These missions are tied to the strategic goal to increase the average lead-time for hurricane landfalls and improve hurricane wind speed forecasts.
- Improvement of numerical weather prediction model representations of sub-grid scale effects (two mission profiles) designed to collect observations to guide improved parameterization of radiative, cloud microphysical, and turbulent processes.
- Improvement of satellite retrieval algorithms (microwave, short wave, long-wave) for temperature, humidity, precipitation, and wind (one mission profile) designed to collect observations to calibrate and validate satellite remote sensed retrievals. This mission includes satellite calibration and validation campaigns associated with NOAA POES, DMSP, and NPOESS sensors, as well as microwave sensors development for NOAA GOES.

The last two categories have implications on the Seasonal and Interannual Variability and Decadal/Centennial Variability Themes as the improvement of the numerical models and satellite retrievals are essential elements to the atmospheric portions of these themes.

For the meteorological and atmospheric physics operational and research requirements outlined above, the NOAA heavy aircraft capability is adequate for the vast majority of the needs of the meteorology and atmospheric physics community in NOAA. Because of the aircraft support provided by AOC, NOAA's meteorological and atmospheric physics programs have been able to play a significant role in promoting the understanding of the processes that govern the atmosphere on scales ranging from individual thunderstorms to regional and global scales. For these reasons the meteorological and atmospheric physics community regards the heavy aircraft capability in NOAA to be a vital ongoing resource that must be maintained.

Platforms:

A. Observation Requirements from Mission Profiles

The nine mission profiles were also used to determine the platform requirements in terms of the operating environment characteristics. These requirements point to a need for one or more of the current NOAA heavy aircraft, the two Lockheed Orion WP-3Ds and the Gulfstream G-IVSP, to satisfy several of the requirements for an airborne operational and research platform. These aircraft must have heavy-lift capacity such as the WP-3Ds, long-range capabilities such as provided by both WP-3D and G-IV platforms, and operational capability at altitudes from 30 m (WP-3D) to 12 km altitude (G-IV). The altitude requirements suggest the need for at least two aircraft given the optimal operating characteristics of turboprop and jet aircraft. Turboprops operate optimally at altitudes less than seven km altitude, whereas, jet aircraft with their high-bypass engines have an optimal operating altitude greater than seven km. These platforms require flexible payload configurations to carry the large variety of instruments for the different missions. The specific platform requirements are:

- All profiles require operating environments from the deep tropics to the poles.
- All profiles require sampling of remote regions thousands of nautical miles (nm) away from base (long range: 3000-4000 nm) requiring endurance greater than eight hours to be able to get to the target region and loiter for four-six hours.
- In-situ flight-level data needed from near the surface (30 m) to top of the troposphere (15 km)
- Most of the profiles require low (30-3000 m) and slow (100-150 meters/second [m s^{-1}]) sampling, while some require rapid sampling at high altitude (10-20 km) over large domains.

- All profiles require heavy payload capacity (>300 kilograms) and flexible payload configurations that can be modified from mission to mission.

B. Airborne Instrumentation

The nine mission profiles were also used to determine the platform requirements in terms of the instrumentation characteristics. These requirements point to a need for high-frequency in-situ data sampling up to 40 Hertz (Hz), radiometer-based imaging of clouds, water vapor, and precipitation at high spatial resolution, and radar-based precipitation mapping around the aircraft either for weather avoidance, or to choose precipitation targets for sampling. Besides these key instrument capabilities, many profiles required a varying array of in-situ and remote sensing instruments. The specific instrumentation requirements are:

- All profiles require in-situ state variables (pressure [P], temperature [T], humidity [H], east-west wind component [u], north-south wind component [v], vertical wind component [w], location, altitude) at data rates up to 40 Hz and available to other data systems via intraplane telecommunication.
- All profiles require in-situ cloud microphysics observations from a few m to 10 cm.
- All profiles require airborne radars to either map precipitation out to 100 nm from the aircraft or for weather avoidance.
- Many profiles require in-situ short wave and long-wave radiation observations.
- Many profiles require three-dimensional mapping of precipitation and winds over short time intervals around the aircraft by a vertically scanning airborne Doppler radar.
- Many profiles require ability to launch expendables (GPS dropsondes, airborne expendable ocean probes, e.g., bathythermographs, current probes, and conductivity temperature and depth probes-AXBT, AXCP, AXCTD, respectively) to sample the atmosphere to the ocean surface, and to 200m below the ocean surface. Launch capability to deploy GPS dropsondes at rates up to one per minute.
- Many profiles require capability to carry a number of remote sensors (passive and active) at the same time in a suite (e.g., radiometers, scatterometers, Lidars, interferometers).
- Both research and operational profiles require at least moderately high bandwidth communications with the ground (>9600 baud).

The WP-3D aircraft currently in operation by NOAA are extremely useful. They are able to accommodate the large suite of remote sensing and in-situ measurements that are required for investigating meteorological and atmospheric physics problems. In fact, in terms of the ability to make airborne radar measurements, the WP-3D aircraft are unique. No other modern aircraft platform can support the vertically scanning tail Doppler radar system. Also, the desire for three-dimensional mapping of the wind field over short time intervals requires at least two airborne Doppler radars. If the WP-3D aircraft were to be replaced by different aircraft with similar operational characteristics, this capability would vanish. Given the certain demise of the National Center for Atmospheric Research Electra, this capability would no longer be available anywhere. From the meteorology and atmospheric physics perspective there is no better alternative to the WP-3D platform. Additionally, given the significant and growing demands for WP-3D aircraft, use can severely limit aircraft availability at certain periods of time, such as hurricane season. Aircraft maintenance and repair can further complicate this situation. Our experience suggests that if only one WP-3D is in operation, limited WP-3D availability would probably produce an untenable situation for the NOAA research community.

The Gulfstream G-IV aircraft currently in operation is a valuable addition to the NOAA fleet. However, as currently configured, it is capable of making only a few of the remote sensing and in-situ measurements that are required for investigating meteorological and atmospheric physics problems from altitudes higher than the WP-3D aircraft can reach. Currently, the aircraft can only provide operational support to the National Weather Service (NWS) through deployment of GPS dropsondes. However, it has little or no capability to support much of the meteorological and atmospheric physics research requirements mentioned above. Also, one of the operational mission profiles required the development of a high-altitude (10-12 km) tropical cyclone reconnaissance aircraft capability including the instruments needed to demonstrate this reconnaissance capability, which was an operational specification for the G-IV acquisition. **Currently, the G-IV has little or no capability to support this operational reconnaissance requirement**.

Future Needs:

A number of the mission profiles demonstrated a need for new instrumentation and operational capability over the next five-ten years. These instrumentation needs include, but are not limited to:

- Improved measurements of moisture in the atmosphere from the surface to the tropopause. This capability will require improved in-situ humidity and moisture variable measurements at temperatures from +30°C to -50°C. The capability of dropsondes may be greatly improved by the addition of passive microwave remote sounding equipment.
- Improved capability to remotely map the precipitation and wind fields in convective storms with temporal resolution of a few minutes through the addition of a rapid-scanning Doppler radar and polarimetric microwave imaging radiometers.
- Improved capability to remotely map the microphysics fields in convective storms through the addition of polarization diverse radars.
- Improved capability to remotely map the wind fields where there are no precipitation targets, both in the pre-convective environment and near convective storms, through the increased sensitivity of the X-band tail radar and the addition of Doppler LIDAR and polarimetric microwave imaging radiometers.
- Improved capability to map the cloud-top and cloud-base fields through the addition of vertically pointing LIDAR.

Another area that all of the mission profiles suggested needs attention was improved telecommunications within the aircraft, between the aircraft and the ground, and from aircraft to aircraft. Research needs mentioned the addition of an onboard local area network and server to connect all of the instruments together on the aircraft. Additionally, both research and operational mission profiles required improved broadband telecommunications (>9600 baud) between aircraft, and between the aircraft and the ground. It is expected that digital INMARSAT links will be able to satisfy the mission bandwidth requirements.

Finally, a couple of mission profiles expressed the need for access to unmanned and remotely piloted aircraft (UAV, RPV) to operate in environments unsafe or inaccessible to manned aircraft (see Appendices C, D and E). Given the lack of NOAA experience with UAV and RPV platforms, it was felt that NOAA needs to partner with other agencies or private sector entities that are using these platforms to alert them to NOAA's requirements and needs.

Cost-effective Management of the Heavy Aircraft Capability

The meteorological and atmospheric physics community recognizes the need to use the NOAA heavy aircraft as cost effectively as possible. We feel that a more cost-effective use of the aircraft could be achieved through increased cooperation among the various aircraft users, such as the air chemistry users and the meteorological and atmospheric physics research and operational users. There are many examples of this type of cooperation that could be cited. The WP-3D users in OAR should cooperate to fully utilize the aircraft. This could be done in some cases by combining missions or piggybacking some instruments onto other experiments. To do this, investigators who plan to use the aircraft should compare their requirements and indicate their constraints well in advance so there would be ample time for accommodation. This would require an indication of the aim, theater of operation and instrument load planned for the host investigation to determine the feasibility of collaboration and possible payoffs. Such cooperation has been informally discussed between air chemistry and hurricane research and operations.

A more versatile use of the WP-3Ds could also be achieved by developing a means to swap the belly Doppler radars with other NOAA sensors, for example, the Polarimetric Scanning Radiometer (PSR) series of imaging microwave radiometers. Currently, there is no simple way to download the radar and upload the PSR equipment. However, the capability to reconfigure the WP-3D bomb bay with a versatile fairing suitable for housing a wide range of remote sensing equipment has been demonstrated on the NASA WFF P-3 and a Navy P-3. A similar fairing and swap-out scheme could be developed for at least one of the WP-3Ds.

While the G-IV currently is used principally for operational support, many of these missions are flown with a lightly instrumented aircraft – dropsonde capability only. Other researchers could add instruments to conduct experiments on the aircraft when it is being used for the operational missions. These piggyback missions could provide potentially important information for use in operations.

Options and Limitations Affecting NOAA Heavy Aircraft

The results of a Heavy Aircraft Conference held with NOAA programs in Boulder in July 2000 strongly indicated a continuing need over the next 5-10 years for four-engine turboprop aircraft to conduct NOAA's research. Both air chemistry and air physics/meteorology researchers within NOAA agreed that there is still a great need for airborne research at altitudes of 10,000 feet and less, that is, at altitudes where four engine turboprops are the most efficient and effective airframe design. The requirements to fly "low and slow" with heavy scientific payloads are ideally met by turboprop aircraft but are not operational modes conducive to turbine jet engine aircraft which were designed to operate efficiently at higher altitudes and higher speeds.

What turboprop aircraft are currently available and what does NOAA have?

- Currently, there are only two (2) types of four-engine turboprop aircraft in wide use anywhere in the world: the P-3 Orion and the C-130 – both manufactured by Lockheed. Both of these aircraft were originally designed for military missions and have since been modified for other Federal (non-military) and commercial uses. Lockheed stopped production of the P-3 Orion in 1986, except for a small order of eight produced between 1995 and 1996 for South Korea.

- <u>P-3 Orions</u>

  ◊ NOAA has two WP-3D Orion aircraft which are uniquely equipped to conduct hurricane reconnaissance and hurricane research missions and air chemistry research. NOAA's P-3 Orions were built in the mid 1970s and are currently over 25 years old. NOAA's P-3s are the only aircraft that conduct hurricane reconnaissance and research over Cuba and are capable of collecting data that allows for hurricane landfall predictions over the United States. The planes do this through a uniquely adapted instrumentation system designed into the plane, such as lower fuselage C-band research radars, X-band Doppler tail research radars, and C-band and K_u-band scatterometers.

  ◊ The Navy does operate a few aircraft configured similarly to the NOAA WP-3Ds. They have two squadrons of EP-3's which are used for intelligence and electronic warfare missions. The EP-3's have similar belly radomes; however, the IEW mission is critical to the Navy and these aircraft have a very high priority to remain mission ready. Therefore, it is very doubtful the Navy would be willing to part with one of its EP-3's. In addition to military missions and training purposes, the U.S. Navy uses P-3's for research as well, primarily in direct support of the Naval Research Laboratories (NRL) research requirements (specific details of NRL's aircraft follow in the section on "NOAA WP-3D Design Life"). The Naval Air Warfare Center (NAWC) also operates P-3's that are equipped for remote sensing applications, and have operated with NOAA microwave sensors onboard. However, their primary mission is national defense related, and these planes are heavily booked.

  ◊ The only other Federal agencies flying P-3's are NASA (Wallops Fight Facility), which has one, and U.S. Customs, which has approximately 10-12. NASA's P-3 would also have to be reconfigured in order to accommodate NOAA's belly and tail radomes, although this place has many times carried NOAA microwave sensors, LIDARs, surface imaging radars, and dropsondes. The NASA P-3 is typically heavily booked for earth science missions, but has been used on occasion for NOAA research. NASA also flies five heavy jet aircraft – a Boeing 737, a DC-8, two WB-57F's, and an ER-2 – none of

which would be able to support NOAA's lower altitude missions. The DC-8 is used for joint NOAA/NASA hurricane experiments every three years as part of the NASA Convection and Moisture Experiment (CAMEX). The DC-8 is similarly heavily booked for NASA earth science projects. The WB-57F is not heavily booked, but allows only a single scientist on board for observations or instrument control. Customs Department's P-3's are the older "Alpha" and "Bravo" models that were disposed of by the Navy, and have been modified for law enforcement and surveillance missions. It is important to note that customs has had serious problems with corrosion and airframe cracks with their older aircraft.

- <u>C-130s</u>

◊ C-130s, a more modern turboprop aircraft, also manufactured by Lockheed, are built as heavy duty cargo planes used for military as well as commercial purposes around the world and by many countries. The newest model from Lockheed is the C-130J, of which the US Air Force operates a squadron for weather reconnaissance. The "J" has newer, more efficient engines, higher altitude capability, longer range, larger payload, smaller flight crew, and over-all reduced operational costs. Some concerns have been expressed about the capability of the new "J" models' composite propellers to withstand penetration through heavy rain bands. Additionally, it should be noted that all C-130's – by virtue of their fundamental design as cargo aircraft – have a very low ground clearance and thus are not amenable to easy integration of large nadir-looking remote sensing equipment (see below).

◊ Other Federal agencies operate C-130s – Navy and Coast Guard. However, due to the C-130's design as a cargo plane, i.e., built very low to the ground, NOAA's existing lower fuselage C-band radar ("belly radome") will not fit underneath their aircraft. An additional $20M-$25M (per aircraft) (NOTE: these estimates are very crude, as there are currently no known modifications that would allow for a vertically scanning radar on a C-130, based primarily on extensive work conducted by NCAR) would be needed to re-engineer the lower fuselage of their C-130, just as it would for any model C-130. Also, due to the C-130's design as a cargo plane, i.e., cargo ramp door in the tail section, NOAA's existing X-band tail radar ("airborne Doppler") will not fit on their aircraft. An additional $20M-$25M (per aircraft) (NOTE: these estimates are very crude, as there are currently no known modifications that would allow for a X-band tail radar on a C-130) would be needed to re-engineer the tail section of their C-130. These same re-engineering issues and related costs would apply even if NOAA "contracted" with other Federal agencies to fly the research missions for NOAA. With existing (and near-term) future radar technology, modifications to any C-130 aircraft is cost-prohibitive.

◊ The private sector operates dozens of C-130 aircraft around the world on a daily basis. Seeking contractor support would require the owner/operator to modify their aircraft to accommodate NOAA's required research equipment at an estimated cost of \$25M-\$30M (per aircraft) for the aforementioned lower fuselage radar, and \$25M-\$30M (per aircraft) for the aforementioned X-band tail radar. It is estimated (after discussions with the Department of Interior's Office of Aircraft Services (OAS), which handles hundreds of private sector contracts annually) that a private sector vendor would require a long-term, exclusive-use contract of 10-15 years, and NOAA would probably be required to pay all airframe modification costs mentioned above in the initial year of the contract – estimated to be \$50M-\$60M. Although private sector aircraft are routinely involved in airborne research with light aircraft and helicopters, there is very little precedent for private sector support in airborne research with heavy aircraft – due primarily to the extreme airframe modifications required. Finally, the contract costs associated with hiring the private sector to fly into hurricanes and other severe storm research missions is considered to be prohibitively expensive, due to the liability and insurance requirements placed upon the contract operator. The only heavy aircraft contracts that OAS is aware of are those large aircraft modified and dedicated as exclusive use for forest fire missions.

◊ The academic community, generally speaking, operates light aircraft rather than heavies. However, the National Center for Atmospheric Research operates a C-130 and a Lockheed Electra (an Electra is the commercial predecessor to the P-3) in support of research projects for the National Science Foundation and the Department of Energy. Based on the same airframe limitations and associated costs as referenced in the Federal aircraft section above, it is not practical to assume that academic research aircraft can fully support NOAA's requirements. NCAR frequently augments and supports NOAA missions – such as this year's effort with the Texas Ozone Project -- but it would require major modifications to their C-130 or Electra in order fly NOAA's full suite of equipment. Currently, NOAA's aircraft are uniquely equipped and no other Federal agency, private sector firm, or academic institution in the U.S. or internationally has the C-band and X-band radars, and the C-band and K_u-band scatterometers needed for NOAA's airborne research programs.

◊ Scaled Composites, Inc. Of Mojave, CA has developed a prototype version of a lightweight composite (Proteus) that could potentially be integrated with the remote and in-situ sensing equipment to satisfy some of the NOAA mission goals, particularly those of high-altitude reconnaissance. However, the Proteus has limited payload and low-altitude storm penetration capabilities, and would require installing all equipment in pods. Moreover, FAA certification of Proteus is expected to exceed \$10M.

◊ AirPlatforms, Inc. of Moffett Field, CA is seeking to commercialize at least two Canberra B-6 high-altitude aircraft for environmental reconnaissance purposes. One of these aircraft has demonstrated dropsonde capability from 53,000 feet, and the aircraft model has the capability to be modified at a cost of approximately \$0.5-\$1.0M to fly NOAA sensors in its bomb bay. However, the limitations for low-altitude operation and rain band penetration are similar to those of the NASA WB-57F, and would not satisfy NOAA low-altitude requirements.

- ◊ Smaller, twin-engine turboprop aircraft are not suitable replacement options for NOAA's airborne research requirements. While it is true that many more platform options exist in twin-engine aircraft, there are no aircraft currently available that would provide the needed combination of duration, payload, altitude and power supply of a four-engine turboprop aircraft. NOAA currently operates, as well as having available via the private sector, a number of twin-engine aircraft that are extensively used for airborne research. However, for safety considerations, it would be ill advised to attempt to conduct hurricane and severe storm research in smaller aircraft.

- ◊ NOAA does not operate any C-130 aircraft.

Why does NOAA need to replace its aging aircraft and what are the options?

- As stated above, NOAA researchers have said research requirements in air physics/meteorology and air chemistry, which utilize the unique capabilities of the P-3, will continue into the next decade.

- Both of NOAA's P-3 aircraft are over 25 years old. With aging aircraft, like anything mechanical, the planes require more maintenance, parts become harder to find, and consequently operational costs increase.

- Finding suitable replacements for NOAA by utilizing Navy "cast-offs" is not a likely solution. The Navy P-3s are older, have more flight time, and more landings on their aircraft than do NOAA's P-3s. The Navy's newest aircraft, a P-3C model, would still be 15+ years old. Even if one or two suitable airframes were identified from the Navy, considerable costs (estimate - $15M-$20M each) would be incurred by NOAA to modify the Navy aircraft to accommodate the:
  - ◊ Lower fuselage C-band research radar
  - ◊ X-band Doppler tail research radar
  - ◊ C-band and K_u-band scatterometers

- The U.S. Navy's fleet of P-3's has shrunk from 300 to approximately 200. Their primary mission – antisubmarine warfare/patrolling – has disappeared. The Navy is wrestling with replacement issues related to their own P-3 fleet, with no clear choice in sight. It will likely take the Navy two to three years to reach a decision on any P-3 replacement or modernization.

- NOAA might save money due to "economies of scale," if NOAA's WP-3D replacement option is tied closely to what the Navy decides to do. If the Navy decides to re-open the Lockheed production line for new P-3s with current technologies, e.g., "glass cockpit," newer engines, etc., NOAA should be ready to commit to acquiring two new aircraft while in production. These aircraft would likely satisfy NOAA's low-altitude needs for the next three decades, and represent a major investment in environmental research and operations.

- On the other hand, preliminary discussions of the Navy choosing a Boeing 737-300 jet as their P-3 replacement will not provide any realistic, cost-effective support for NOAA's research flight regime. Operating a jet aircraft at low altitudes and low speeds is extremely inefficient due to extremely poor engine performance and increased fuel consumption.

- A new C-130J model with no NOAA scientific equipment on board would cost $25M-$30M (per aircraft).
  - ◊ An additional $25M-$30M (per aircraft) is needed to equip a C-130J to existing WP-3D capability.
  - ◊ Due to the C-130J's design as a cargo plane, i.e., built very low to the ground, NOAA's existing lower fuselage C-band radar ("belly radome") will not fit underneath. An

additional \$20M-\$25M[1] (per aircraft) would be needed to re-engineer the lower fuselage of the -J model.

◊ Due to the C-130J's design as a cargo plane, i.e., cargo ramp door in the tail section, NOAA's existing X-band tail radar ("airborne Doppler") will not fit. An additional \$20M-\$25M[2] (per aircraft) would be needed to re-engineer the tail section of the -J model.

◊ NOAA currently has no flight crews trained to fly this aircraft. An additional \$250K (per aircraft) would be needed to train two full crews to fly the -J model.

So how will NOAA continue to provide heavy aircraft service in support of NOAA's mission with an aging fleet?

- One recommendation would be to conduct a study of the aircraft to determine their material condition for comparison with others that need replacement to more accurately determine the potential remaining life.
- Watch closely to see what the U.S. Navy will do to replace its P-3 aircraft.
- If the Navy decides to replace its P-3s with Boeing 737-300 jets, NOAA may be forced to look at a service life extension program for its P-3s as the jet will not meet NOAA requirements.
- If the Navy decides to service-life-extend its P-3s, or build new P-3s, NOAA should be prepared to commit to the resources to buy two new aircraft or extend the life of the two NOAA aircraft.
- Modifying a C-130J appears cost prohibitive. It would cost twice as much to modify a new aircraft for NOAA's use than the cost to build it.
- However, it is important to note that if, and only if, radar technology changes drastically within the next few years, the size of the radars units themselves may "shrink." But it is very doubtful that the required antenna will be reduced in size such that they can be mounted onboard a C-130J without the prohibitive re-engineering modifications needed to the airframe.

Specific Options Related to NOAA WP-3D Design Life

NOAA's WP-3Ds, the agency's primary research aircraft, are now more than 25 years old. Similarly, P-3 operators worldwide are faced with addressing corrosion and its impact on airframe fatigue, cracking, and overall airframe life. The major concern from AOC's perspective is the stress cracking from excessive g-loading encountered in the flight environment of NOAA's research and operational missions.

A comparison of NOAA's two WP-3Ds, and between NOAA's aircraft and research P-3s of the U.S. Navy follow:

[1] These estimates are very crude and may vary by an order of magnitude, as there are currently no known modifications that would allow for a vertically scanning radar on a C-130.
[2] These estimates are very rough, as there are currently no known modifications that would allow for a vertically scanning radar on a C-130.

NOAA's WP-3Ds

Date Delivered	Tail Number	Flight Hours	Landings
1975	N42RF	8404	1121
1976	N43RF	7315	1781

Naval Research Laboratory (NRL) P-3 Fleet

Date Delivered	Tail Number	Flight Hours	Landings
1963	674	22,107	7418
1968	587	18,877	12,268
1971	227	20,087	3911
1978	764	15,333	9139

The positive considerations for NOAA's WP-3Ds are:

- ◊ Relatively low number of total flight hours and number of landings;
- ◊ Aircraft have been hangared for the last eight years;
- ◊ Superior maintenance practices, including full Scheduled Depot-Level Maintenance every 44 months at NAS Jacksonville, Florida;
- ◊ Both WP-3Ds have new rear wing spars

Options for Continued Mission Support:

A. Service Life Extension Program (SLEP)

A Service Life Extension Program deserves serious consideration as an option for continuing the use of NOAA's WP-3Ds, as the NOAA airborne research community has indicated that the vast majority of its research and operational mission profiles require the use of heavy turboprop aircraft. NOAA's WP-3Ds, which were manufactured by Lockheed in the 1970's as part of an overall U.S. Navy maritime patrol aircraft production line, are no longer available. Lockheed has not produced new P-3s since 1986 (other than a brief production run for South Korea between 1995 and 1996). Additionally, Congress has not appropriated funds to support any new naval maritime patrol aircraft as a replacement for existing U.S. Navy P-3s. Finally, only jet aircraft are available on the civilian aircraft market – there are no heavy turboprop aircraft manufactured in the world other than for military missions. The benefits associated with SLEP are: (1) lower costs for engineering and modification, (2) no loss of mission continuity, (3) proven reliability of the platform, and (4) opportunity to incorporate technology developed for newer platforms at lower cost. The related risk is NOAA would be losing technology now being developed for newer platforms.

The various options under the overall SLEP heading are:

• Sustained Readiness Program (SRP) – estimated cost -- $10M

The U.S. Navy cancelled its SRP contract after 13 aircraft were overhauled due to: (1) poor quality control, (2) wing and surface contours not maintained due to poor workmanship, (3) costs doubled from $5M to $10M, and (4) SRP aircraft were expected to have excessive fatigue problems and fuel leaks even after repairs, due to poor quality workmanship and faulty rivets in each wing.

• Service Life Assessment Program (SLAP)

The U.S. Navy will begin an assessment program to determine what critical factors will be involved in the eventual SLEP. The SLAP will consist of a test program to assess the current fatigue and corrosion problems of their P-3 fleet, and should to be completed during 2002-2003. SLAP is designed to "shake" a P-3 airframe until it breaks from fatigue; and using this information, the SLEP will be defined based on what failed during SLAP. The Navy may decide to ultimately replace entire sub-assemblies rather than individual components.

• Service Life Extension Program (SLEP)

After the U.S. Navy completes the SLAP phase of the inspections, they will begin a SLEP in 2006, and is designed to capture 120% of fatigue life issues to postpone the Navy's P-3 attrition. Additionally, the Navy has not yet determined the complete costs per airframe; and will have to define the parameters and extent of the program, based on which components failed during the SLAP.

• Kestrel Program – Hawker Pacific, Ltd.

Originated by the Royal New Zealand Air Force (RNZAF) to upgrade its fleet of six P-3K Orion maritime patrol aircraft. RNZAF felt that over time, fatigue damage becomes increasingly difficult to quantify. By aggressively attacking fatigue and repair issues, the RNZAF's Kestrel program avoids the complexities and uncertainties of precisely calculating the likely fatigue damage. Additionally, the Kestrel program had the following advantages: (1) known fixed price of assemblies, (2) assembly costs are significantly less than the cost of new airframes ($7M - $11M/aircraft in current dollars), (3) 90 – 180 day turn-around time, and (4) limits the risk of any additional cost as all suspect items have been replaced.

B. Replacement With a New Platform

Replacement of NOAA's existing WP-3Ds with new platforms has the advantages of: (1) state-of-the-technology, (2) longer initial service life, and (3) lower initial operating costs. The risks associated with replacement are: (1) very high up-front engineering costs, and (2) loss of mission continuity until new platforms are designed, tested, equipped, and certified.

The various replacement options are:

• U.S. Navy MMA (Multi-mission Maritime Aircraft) – costs not yet determined

The program's development would start around 2004 and is to be completed no later than 2015. Navy would like to minimize the number of P-3s it puts through the structural renewal process; they would rather spend funding on MMA. Upgrades would include new Rolls-Royce/Allison AE2100 engines, with Pratt and Whitney's PW150 as an alternative. Lockheed-Martin proposes to also replace wings, empennage and nacelles, similar to RNAZF's Kestrel project. Northrop Grumman is proposing to augment Navy P-3s with the Global Hawk UAV, claiming that six Global Hawks can provide same coverage as 18 P-3s. Boeing is proposing that Navy adopt the 737-700, since DOD is already buying a similar aircraft (737-300, known in DOD as the C-40) as a replacement for C-9's. Boeing claims that 737-700 has a larger payload than the currently max-load P-3 and that its higher transit speed will allow more time on station. Boeing is also quoted as saying, "the fuel economy at low altitude is very nearly the same" as for the P-3. The 737 would allow the Navy to reduce staffing requirements as the 737 has a cockpit of only two versus the five currently deployed with the P-3. Additional considerations are being given to the Gulfstream G-V. Australia and Japan both are monitoring the MMA program and hope to take an active role in the results.

Boeing C-40A (737-300)

- <u>Lockheed C-130J – estimated cost $55M</u>

The C-130J is a new airplane with increased performance capability. Compared to the earlier production C-130E, maximum speed is up 21%, climb time is down 50%. Cruising altitude is 40% higher, range 40% longer. With new engines and new props, the -J can reach 28,000 feet in 14 minutes. For low altitude maneuvers, new avionics and dual head-up displays make it easier and safer to operate. It also offers reduced manpower requirements, lower operating costs, support costs and life-cycle costs.

USAF C-130J

Features: A new propulsion system, featuring four powerful Allison AE2100D3 engines, generates 29% more thrust while increasing fuel efficiency by 15%. An all-composite six-blade Dowty Aerospace R391 propeller system is lighter in weight and has fewer moving parts than previous Hercules propellers. Advanced avionics technology includes Liquid Crystal Display instrument readouts for aircraft flight control, operating systems, and navigation. Besides its two holographic head-up displays, the C130-J has four multi-functional head-down LCD displays. Additionally, some concern has been expressed about the reliability of the composite blades during heavy rain penetration, although little long-term reliability data is currently available.

- <u>Possibility of Re-opening the Lockheed P-3 Orion Production Line</u>

Lockheed-Martin estimates that it would take four-five years for the first aircraft to be delivered once the production line is reactivated at an estimated cost of $40M - $50M.

Summary Comments:

All of these options will take a considerable amount of time, as well as significant funding, in order to make them happen. Therefore, NOAA should begin considerations of the advantages and disadvantages of either a SLEP or platform replacement now. NOAA's WP-3Ds are within five years of their design life, and it is imperative that NOAA, through OMAO and AOC, verify the material condition of both of the WP-3Ds by inspection of the aircraft (during SDLM) to determine fatigue life used.

Appendix A

Guidance Provided to the User Group at the Initial Meeting

In July of this year, the Director of the Office of Marine and Aviation Operations invited the principal investigators, lead scientists, laboratory directors, and other interested parties to meet in Boulder, Colorado to discuss the anticipated needs for airborne research and operations from the users' perspective. The OAR's Aeronomy Laboratory hosted the two-day conference, which was attended by approximately 25 scientists representing air chemistry, air physics, and the operational side of the National Weather Service and the National Center for Environmental Prediction/National Hurricane Center. The conference participants engaged in a broad discussion on the programmatic needs expected in the next five to ten years. Additionally, the participants were asked to consider such non-technical topics as: (1) How can budgeting efforts within the air physics community be improved? (2) How can the user community work more effectively as a whole? and (3) What are the varying operational approaches from the user perspective?

It was decided that a call for papers would be initiated along two themes: "Projected Heavy Aircraft Needs for Air Chemistry" and "Projected Heavy Aircraft Needs for Air Physics." These two papers were then compiled into the document that follows. Additionally, AOC added information regarding the current physical condition of the WP-3Ds, along with service life extension efforts undertaken by other P-3 operators such as the U.S. Navy and the Royal New Zealand Air Force. The conference participants also heard presentations that dealt with NOAA's Gulfstream G-IV and future considerations with regard to UAV's. (Information related to these presentations is included in Appendices C, D and E of this report.)

With regard to the G-IV, it is important to note that the focus of this report is the WP-3Ds and the options and/or limitations for their replacement. Both OMAO and the NOAA user community view the G-IV and its capabilities as a compliment to the projects of the WP-3Ds – not as a replacement to their missions. And in fact, the G-IV offers new capabilities such as high altitude long-range surveillance missions, that are not available from the WP-3Ds. Additionally, the G-IV is a much newer platform and has not experienced the corrosion and airframe concerns encountered by the WP-3Ds. The G-IV is discussed in some detail in Appendix B of this report.

What are the basic questions?

- What changes in technology will impact how NOAA's airborne missions are conducted?
- Will satellite technology provide duplicate or supplemental capability to our aircraft?
- What changes in other remote sensing technology will impact aircraft requirements?
- What changes in the size, weight, power requirements, and data formats of instrumentation will impact aircraft requirements?
- What changes in communications and data transmission technology will have impacts?
- What are other Federal agencies doing in their heavy aircraft fleets?
- What are the trends in airborne research that might – programmatically speaking – impact our efforts?

Appendix B

Heavy Research Aircraft Meeting Attendees: 18-19 July 2000

Name	Affiliation
NESDIS	
Laurence Connor	NESDIS
OAR	
Dan Albritton	Aeronomy Laboratory
John Daniel	Aeronomy Laboratory
David Fahey	Aeronomy Laboratory
Fred Fehsenfeld	Aeronomy Laboratory
Gerd Hübler	Aeronomy Laboratory
Andy Langford	Aeronomy Laboratory
Daniel Murphy	Aeronomy Laboratory
Michael Trainer	Aeronomy Laboratory
Frank Marks	AOML/Hurricane Research Division
Dennis Wellman	Air Resources Laboratory
John Ogren	Climate Monitoring Diagnostics Laboratory
Al Gasiewski	Environmental Technology Laboratory
Bill Neff	Environmental Technology Laboratory
Mel Shapiro	Environmental Technology Laboratory
John Daugherty	National Severe Storms Laboratory
Dave Jorgensen	National Severe Storms Laboratory
José Meitín	National Severe Storms Laboratory
Conrad Ziegler	National Severe Storms Laboratory
Nick Bond	Pacific Marine Environmental Laboratory
NWS	
Naomi Surgi	National Center for Environmental Prediction/EMC
OMAO	
Jim DuGranrut	Aircraft Operations Center
Phil Kenul	Aircraft Operations Center
Bob Maxson	Aircraft Operations Center
Jim McFadden	Aircraft Operations Center
Debora Barr	Headquarters
Evelyn Fields	Headquarters
Michael Henderson	Headquarters
Beth White	Headquarters

Appendix C

NOAA's Gulfstream IV-SP (G-IV)

The Gulfstream IV-SP (G-IV) is a high-altitude, high-speed, twin turbofan jet aircraft acquired by AOC in 1996. The G-IV is currently configured for operational support of the National Hurricane Center's synoptic surveillance hurricane and winter storm surveillance missions, and is expected to provide support for these NOAA programs through the next 15-20 years. These missions are designed to collect, process and transmit vertical atmospheric soundings in the hurricane and winter storm environments. The G-IV high-altitude surveillance missions are designed to complement the critical low-level storm data gathered by the NOAA WP-3D aircraft.

As originally outfitted, the G-IV was equipped with the following systems:

- Main Aircraft Data System
- Two Data System Modules for instrument interface and data collection
- Four Networked Sun Sparc5 Workstations
- Extensive atmospheric instrumentation

- Airborne Vertical Atmospheric Profiling System
- Dropsonde Data System for drop execution, data collection and storage
- Dropsonde Launch Chute
- GPS dropwindsonde

- Hurricane Analysis and Processing System
- Workstation accomplishes data analysis, processing, and message formatting

- Internal/External communication system
- VHF, UHF, ADF, Flight Phone, SATCOM and Passenger Communication System

- Rockwell Collins WXR-700C C-Band Weather Radar w/ 30-inch antenna

Driven by the desire to increase high-altitude multi-mission capability, AOC utilized the limited funds remaining from the aircraft acquisition and developed experimental external pods and window blanks through a third-party vendor. Additional testing, evaluation, and certification will continue as AOC strives to further develop the capabilities of the G-IV for research and operations.

The operational data collected by the G-IV has already helped improve hurricane track forecast by 15-25% as claimed in its original acquisition justification. Continued development and upgrade of the aircraft's instrumentation will enable unprecedented advances in improving hurricane intensity forecasts, as well as advance meteorological, air physics, and air chemistry research. Also, the G-IV data obtained over the northeast pacific for winter storm surveillance has improved winter storm forecasts by 10% over the West Coast of the U.S. and Alaska. Moreover, this improvement in forecast skill has been shown to propagate downstream and improve forecasts across the entire continental U.S.

Appendix D

"A Vectored Earth Observing System (VEOS) for the New Millenium"

The demonstration of a "Vectored" Earth Observing System (VEOS) for severe weather forecasting, disaster management, and environmental monitoring is being studied by an interagency team led by the National Oceanic and Atmospheric Administration's Environmental Technology Laboratory. The Peacewing Prototype Project (PPP) will demonstrate the unique capabilities of an unmanned aerial vehicle (UAV) using passive microwave and hyperspectral optical imagers to provide targeted high-resolution maps of developing weather along with post-event assessment of ecosystem change and infrastructural damage caused by severe environmental events. The PPP is designed as a precursor effort leading to an operational version of the Peacewing UAV - as modeled upon the vision proposed by the U.S. State Department for the Global Disaster Information Network. The Peacewing platform will ultimately be capable of providing spatio-temporal sampling both greatly exceeding and complimentary to that available from satellites, and at a fraction of the infrastructural, operating, and human-risk costs.

The prototype project will use AeroVironment's Pathfinder Plus (PF+) UAV in a major field experiment to study aerosol, cloud, and rain relationships, ocean wind vector imaging, coral and crop change assessment, and land surface wetness. As part of the project, very high-resolution optical imagery will be collected over time-sensitive ground targets selected by disaster managers, thus emulating near-real-time observational capabilities in support of rescue exercises. The instruments to be flown include NOAA/ETL's Airborne CMIS Emulator and Advanced Power Technology, Incorporated's Aurora 6000 hyperspectral imaging system.

The field phase of the project will be focused on three scientific experiments. The aerosol, cloud, and rain experiment study will focus on the determination of the effects of natural aerosols on the inhibition of orographically-induced rainfall. The regional-scale numerical weather prediction experiment will focus on the predictability of precipitation using sub-mesoscale surface wind data, moisture, temperature, and cloud liquid data. The coral, crop, and land wetness experiment will focus on the spectral changes associated with vegetation and environmental stress and on the estimation of standing water and infrastructural damage.

Successful demonstration of Peacewing on Pathfinder+ will provide the basis for the development of a permanent VEOS based on, e.g., Helios-class UAVs, providing extreme endurance, all-weather operation, and broad societal application in the 2007-2010 time frame. A briefing describing the potential for using UAVs for operational targeted weather observations, disaster management, and ecosystem monitoring was presented to the NOAA North American Observing Systems council on September 7, 2000.

Support for the risk-reduction phase of the PPP is being provided by NASA under its UAV-based science demonstration program. Co-investigators on the PPP include personnel from the following agencies, institutions, and companies:

NOAA Research/Environmental Technology Laboratory
NOAA National Ocean Service
NOAA/NESDIS National Geophysical Data Center
NASA Goddard Space Flight Center
U.S. State Department
Aerovironment, Inc.
Advanced Power Technologies, Inc.
University of Colorado/CIRES
University of Oklahoma
Pacific Missile Range Facility

The risk reduction phase of the PPP project will be ongoing through the end of calendar year 2000. Further information on the project can be obtained through the principal investigator, Dr. Al Gasiewski at: al.gasiewski@noaa.gov or (303) 497-7275.

Appendix E

Global Hawk UAV

The NOAA Aeronomy Laboratory is proposing to use the Global Hawk Unmanned Aerial Vehicle to make measurements related to the dynamical, chemical, and radiative properties near the tropical tropopause of the Pacific Ocean in a program titled the Global Hawk Tropical Tropopause Experiment. The proposed flights will take advantage of the large payload capacity, the high cruise altitude, and long endurance of the Global Hawk and will demonstrate its value for atmospheric research. The payload instruments will provide *in situ* measurements of total water, cirrus, aerosols, ozone, carbon dioxide, methane, pressure and temperature; and remote profiles of temperature. Four mission flights are planned for the Pacific Ocean basin from Dryden Flight Research Center (34°N). The flights rely on the ability of the Global Hawk to fly 11000 nm in flights up to 32 hours in duration. The flights will include long transects along the equator (7°N) and cross-equatorial transects extending into the extra-tropics (35°S) of the Southern Hemisphere. Both transects will be explored during northern winter and northern summer.

The knowledge and insights gained with the acquired data set will address climate processes acting in the upper troposphere/lower stratosphere. Specific scientific issues to be addressed include particle production at the tropical tropopause, mixing between and within the upper troposphere and lower stratosphere, and scales of variability in the UT/LS. This unique data set should allow us to explore the existence of a circulation in the lower stratosphere that is the "mirror image" of the Walker circulation in the underlying troposphere. Additionally, gravity wave characterizations and transport modeling studies using the data collected will provide opportunities for increasing our understanding of transport processes in these under-sampled regions of the atmosphere.

The Global Hawk is a UAV developed for the U.S. Air Force by Ryan Aeronautical Center of the Northrop Grumman Corporation. Global Hawk, which first flew in February 1998, is a jet-powered aircraft with a conventional aluminum fuselage and graphite composite wings and appendages. The maximum estimated range of the aircraft is one-half of the Earth's circumference (11000 nm). The maximum operating altitude is 65,000 feet. The current payload capacity exceeds 1000 pounds. Global Hawk flies an integrated synthetic aperture radar and electro-optic/infrared reconnaissance payload for the U.S. Air Force.

Global Hawk

The Global Hawk has been designed to fit seamlessly into the national airspace system. It has a standard mode 3/A and mode C transponder, and a satellite communication relay that allows the command and control operator (CCO) to talk to ATC over VHF and UHF radio even though the CCO is hundreds of miles away in the command and control shelter. It is currently operated out of Edwards Air Force Base (co-located with NASA Dryden Flight Research Center) for the U.S. Air Force, by Ryan Aeronautical, under a FAA-issued certificate of authorization. Global Hawk has undergone an extensive series of taxi and flight tests to establish its flight envelope. The flight test approval has been governed by the standards and processes established by the U.S. Air Force. The Global Hawk fleet has accumulated a total of 585.5 flight hours so far, including two flights from Edwards AFB to Alaska and back and one to Eglin AFB in Florida. Flights to Portugal and Australia are also planned.

More details about the Global Hawk UAV are available at
http://www.northgrum.com/Corp_web/news/rev_mag/review09_18.html

Appendix F

Remotely Piloted Vehicles (RPV's)

The National Severe Storms Laboratory (NSSL), in collaboration with Wyndemeere, Inc. and the University of Colorado in Boulder, is in the process of engineering a rapid-deployment airborne mesonet of Remotely Piloted Vehicles (RPVs). The ability of RPVs to operate at low speeds and low levels make them uniquely suited to studies of the structure and evolution of the preconvective boundary layer and storms. The planned capabilities of the airborne RPV network include the following:

- Flight plan of one (lead) RPV dictated from the ground;
- A variable number of aircraft (presently configured at five) will remain locked in formation with the lead aircraft;
- Geometry of formation continuously modifiable;
- Quick-launch capability;
- Transportable to field in a pickup-size vehicle;
- Smart aircraft that monitor their state and are able to maintain directed flight, eliminating need for RPV "pilot";
- In-situ sensors appropriate for scales to be measured and aircraft speed;
- Sensor housing/shielding appropriate for RPV operation.

Future mission profiles are being designed for studies of convective initiation in clear air, dynamical forcing mechanisms in the rear-flank downdraft region of supercell thunderstorms, and other related problems of high relevance to USWRP and NOAA goals. Further information on this project can be obtained through the principle investigator, Dr. Erik Rasmussen, at: erik.rasmussen@nssl.noaa.gov, or (303) 497-6886.

Appendix G

The Role of Aircraft in Improving Winter West Coast Storm Forecasts

Motivation

- Winter storms strike the U. S. West Coast each winter with hurricane force winds and flooding rains, and yet are difficult to predict partially due to their oceanic origin.
- Forecasters are challenged to make detailed forecasts of these storms in spite of the absence of critical data in the region just upstream of the coast, and models are initialized with larger errors in this region due to the dearth of data.
- These storms cause loss of life and property in the West Coast states at an annually averaged rate comparable to the impacts of earthquakes in this earthquake prone region (roughly 10 lives lost and $1 billion damage annually).
- The National Research Council of the National Academy of Sciences has concluded that flooding along the American River of California represents the single greatest flash flood threat in the nation, largely due to the vulnerability of Sacramento.
- Improvements in mesoscale quantitative precipitation forecasts and wind could have major payoffs in terms of emergency response, water supply, flood control, and maritime industries.

Selected lessons from the CALJET experiment (1997-98)

The California Land-falling Jets experiment (CALJET) was designed to aid NWS' California flood forecasting during the strong El NiZo of 1997/98. A NOAA P-3, wind profilers, and new satellite observations were the foundation of the effort. The value of this joint effort of NOAA Research and NWS is reflected in the reactions of emergency managers.

"CALJET helped save lives in the devastating floods during the 1998 El NiZo."- *Tom Maruyama, Director of Emergency Response in the San Mateo Co. Sheriff's Office, California*.

"CALJET made a major impact on California emergency response in the strong El NiZo of 1998 by improving weather guidance for the key 12-36 hour lead times." - *Dr. Richard Andrews, Director, California Governor's Office of Emergency Services.*

- The NOAA P-3 aircraft measurement of hurricane force winds in the low-level jet in a storm approaching the coast allowed 6-hour lead time in a flash flood forecast.
- Because of the real-time value of CALJET P-3 data to California's emergency management communities, the experiment was extended by one month at the State's request.
- While the coastal wind profiler array deployed during CALJET was able to observe the low-level jet when the storms struck the coast (thereby filling in a gap in coastal NEXRAD coverage), the P-3 provided measurements of this key feature well offshore where it can improve lead time in forecasts.
- The airborne radar capabilities of the P-3 (specifically, the combination of the lower-fuselage radar and the tail Doppler radar) allow it to act as a "NEXRAD in the Sky" that can be

deployed to critical areas of approaching storms to measure the distribution and intensity of the precipitation and other key storm features. This is illustrated in Figure 1, which shows the location of rainfall from the aircraft's lower-fuselage radar (Fig. 1a) relative to a satellite image. Based on input from forecasters, researchers, and forecast users a prototype message was devised that could be sent from the P-3 using its in situ and radar data (Fig. 1b). This is based on CALJET experience and will be tried for the first time in PACJET, which will use a new satellite communications link being installed on the P-3 for this purpose.

The Pacific Land-falling Jets experiment (PACJET) of 2001 and 2002

A two-part experiment has been planned that will extend the coverage of CALJET to include Oregon and Washington (based on forecaster requests), and will incorporate science-driven studies and operational forecasting applications development through collaborations between NOAA Research, Universities, and NWS Forecast Offices and NCEP. Not only does the P-3 plays a key role in this effort, as described above and in Fig. 1, it is also clear that a high-altitude aircraft for dropsonde deployment for assimilation into numerical models and for testing of new airborne remote sensors is also required. Remotely piloted vehicles (RPVs), such as the low-altitude Aerosonde, which will test its North-Pacific, winter-season capabilities in PACJET-2001, and the Peacewing high altitude aircraft, which is under NASA consideration and includes participation in possible PACJET operations in 2003, also hold great promise for the future.

Looking beyond PACJET-2001/02 to an annual integrated research-operations effort

CALJET in 1997/98 and outreach efforts conducted in planning for PACJET-2001 have revealed that many forecasters and forecast users strongly believe that an annual aircraft deployment is needed on the West Coast each winter as part of a sustained effort to address their greatest weather problem. This is analogous to the hurricane program for the south and east coasts, which uses aircraft each summer and fall. Key groups who have expressed a need for a winter season West Coast deployment to aid in forecasting and decision making include NWS Weather Forecast Offices in the West Coast states, three centers at NCEP, broadcast meteorologists, the reservoir management community, the emergency response community, and the fishing industry. Finally, research is poised to advance West Coast storm prediction through physical process studies, exploring how to make better use of existing observing systems, assessments of new or potential observing systems, and development of forecast applications.

Experience has shown that deployment of NOAA research aircraft is a catalyst for new ideas and major advancements in science and forecast applications development. Annual deployments and investment in new airborne platforms for this purpose will fill a critical gap in NOAA's ability to provide services to the nation and would exploit the innovative capabilities of its laboratories and the dedication of its operational teams.

- **In short, the CALJET and PACJET experiments have identified a new and critical annual mission for NOAA's heavy aircraft that compliments their warm-season mission for hurricane prediction with a cold-season mission for West Coast storm prediction.** **

**The PACJET experiment web page can be found at http://www.etl.noaa.gov/programs/pacjet/*
***Contact: Dr. F. M. Ralph, NOAA/Environmental Technology Laboratory, 303-497-7099,* marty.ralph@noaa.gov.

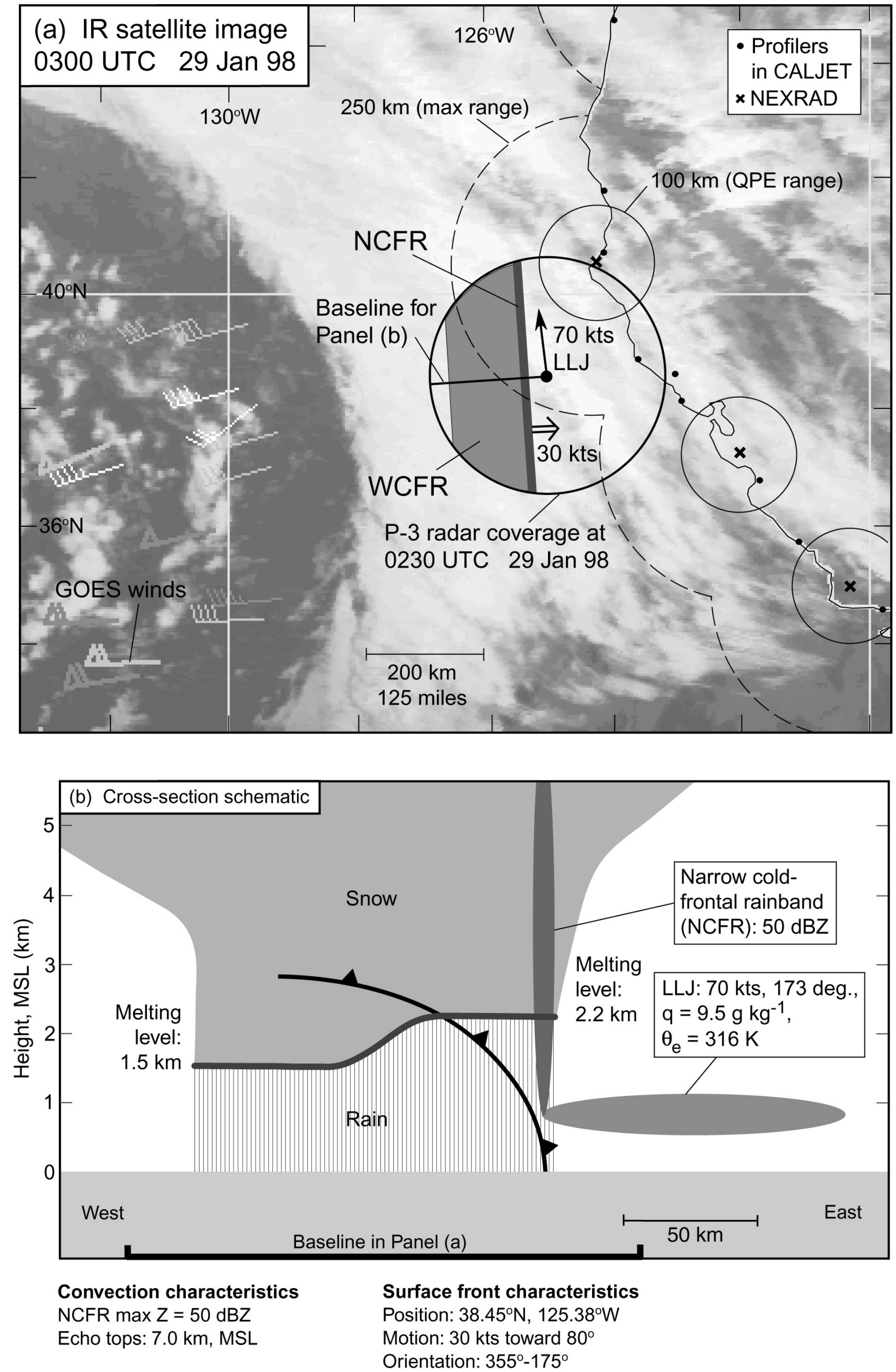


Fig. 1. The operational NEXRAD Doppler radars along the West Coast of the United States provide information on storms up to 250 km offshore. However, at ranges beyond about 150 km

the radar beam shoots over key precipitating areas of the storm, beyond roughly 100 km they are currently unable to provide useful quantitative precipitation estimates (QPE), and even at the coast they often overshoot the low-level jet. The NOAA P-3 research aircraft provides a means to extend the range of the NEXRAD array farther offshore with its lower-fuselage and tail Doppler radars and its in situ measurements, and complements satellite and profiler observations. Ideally, the P-3 would interrogate land-falling systems far enough offshore to provide additional information and significant lead-time to forecasters, but close enough to reduce the chance that the precipitation systems would evolve significantly before landfall. This goal defines a "Storm Surveillance Area" from roughly 300-1000 km west of the coast that will be tested in the Pacific Land-falling Jets experiment (PACJET). (a) Schematic P-3 radar coverage in plan view showing the wide cold frontal rain band (WCFR), the narrow cold frontal rain band (NCFR) and its propagation (30 knots), as well as the wind speed (70 knots) and direction in the low-level jet (LLJ) in an event observed during CALJET. The coastal NEXRAD radar coverage, experimental wind profiler locations during CALJET, and new winds derived from feature tracking in GOES satellite images are also shown. (b) A schematic cross section along the baseline shown in (a) through a cold-frontal system illustrates the types of quantitative information needed by forecasters that are typically unavailable offshore, but that could be provided by the P-3 aircraft.

Appendix H

List of Acronyms

ADF	Automatic Direction Finder
AFB	Air Force Base
AL	Aeronomy Laboratory
AOC	Aircraft Operations Center
AOML	Atlantic Oceanographic and Meteorological Laboratory
ARL	Air Resources Laboratory
ATC	Air Traffic Control
AXBT	Airborne eXpendable Bathythermograph
AXCP	Airborne eXpendable Current Profiler
AXCTD	Airborne eXpendable Conductivity, Temperature, Density Profiler
CAMEX	Convection and Moisture Experiment
CCO	Command and Control Operator
CMDL	Climate Monitoring and Diagnostics Laboratory
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
ETL	Environmental Technology Laboratory
FAA	Federal Aviation Administration
GPS	Global Positioning System
HRD	Hurricane Research Division
LIDAR	LIght Detection And Ranging
MMA	Multi-mission Maritime Aircraft
NAS	Naval Air Station
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction
NESDIS	National Environmental Satellite, Data, and Information Service
NHC	National Hurricane Center
NOAA	National Oceanic and Atmospheric Administration
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSSL	National Severe Storms Laboratory
NWS	National Weather Service
OAS	Office of Aircraft Services
OAR	Office of Oceanic and Atmospheric Research
OMAO	Office of Marine and Aviation Operations
OMB	Office of Management and Budget
PMEL	Pacific Marine Environmental Laboratory
RNZAF	Royal New Zealand Air Force
RPV	Remotely Piloted Vehicle
SATCOM	Satellite Communications

SDLM	Scheduled Depot-Level Maintenance
SLAP	Service Life Assessment Program
SLEP	Service Life Extension Program
SRP	Sustained Readiness Program
UAV	Unmanned Airborne Vehicle
USAF	U.S. Air Force
USCG	U.S. Coast Guard
USWRP	U.S. Weather Research Program
UHF	Ultra-High Frequency
VHF	Very High Frequency

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Number of Pages: 44

Number of Words: 13,003 (approx.)

Number of Characters: 74,119 (approx.)