APPLICATIONS PRODUCTS OF AVIATION FORECAST MODELS

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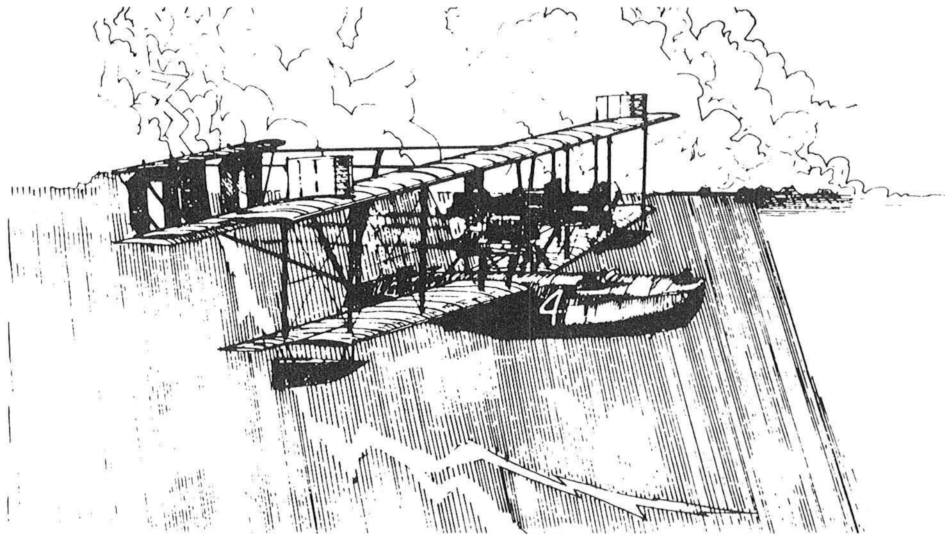
The Fleet Numerical Oceanography Center (FNOC) is a unit of the United States Navy and is located in Monterey, California. This presentation will concentrate mainly on an application of output data from FNOC's Naval Oceanographic Global Atmospheric Prediction System (NOGAPS) model run on a Cyber-205 computer. We operate a service called the Optimum Path Aircraft Routing System (OPARS). It was developed in the late 1970's and early 1980's for Navy, Marine Corps, and Coast Guard aircraft primarily to save fuel. The aircraft shown in Figure 1 is the NC-4, and it was the first aircraft to cross the Atlantic, in May 1919. several years before Lindbergh flew nonstop. Three Navy aircraft started from Rockville, New York; went to Halifax, Nova Scotia; Nova Scotia to the Azores; from the Azores to Lisbon; then from Lisbon to Portsmouth, England. Of the three that started, only one completed the trip. It took them 20 days, and navigation en route had to be assisted by several ships stationed along the flight route. They had to fly low to see the ships as there were no NAVAIDS and forecast meteorological information was nonexistent. I use this aircraft as a logo as it is acceptable by all the aviation communities of the Navy and Maine Corps. Also, this is probably the first time that the requirement for a computer-assisted flight planning program was defined. This aircraft was restored by the Smithsonian Institute and is presently on display at the Naval Aviation Museum in Pensacola, Florida.

The Cyber-205 NOGAPS model is run once each 12 hours and once the run is completed, oceanographic and meteorological forecast data are transferred to other computers for use in applications programs. OPARS is one such program. Figure 2 illustrates the Primary Environmental Processing System (PEPS) which is a bank of two computers. OPARS operates on a separate computer affectionately known as HAL. At the present time, it is a CDC-6500, but will soon be replaced by a CDC-860. People around the world will be able to dial in on value added network directly into HAL, supply input, and gain an output. If they have any difficulties, there are people on watch 24 hours a day for assistance. Another method of getting a flight plan is by use of the DOD message system. In this case, the PEPS computers process OPARS and generate a return message. A message is returned within 2–4 hours after receipt of the request. Figure 3 is a graphic which depicts the sites we service on-line (value added network). They range from the Philippines and Japan through Alaska and the Hawaiian Islands, throughout the United States, Bermuda, Puerto Rico into Spain and Europe. All these sites have direct access into our computer at Monterey.



Provide recommended optimum flight plan:

- Fuel management
- Time en route

Figure 1. Optimum Path Aircraft Routing System (OPARS).

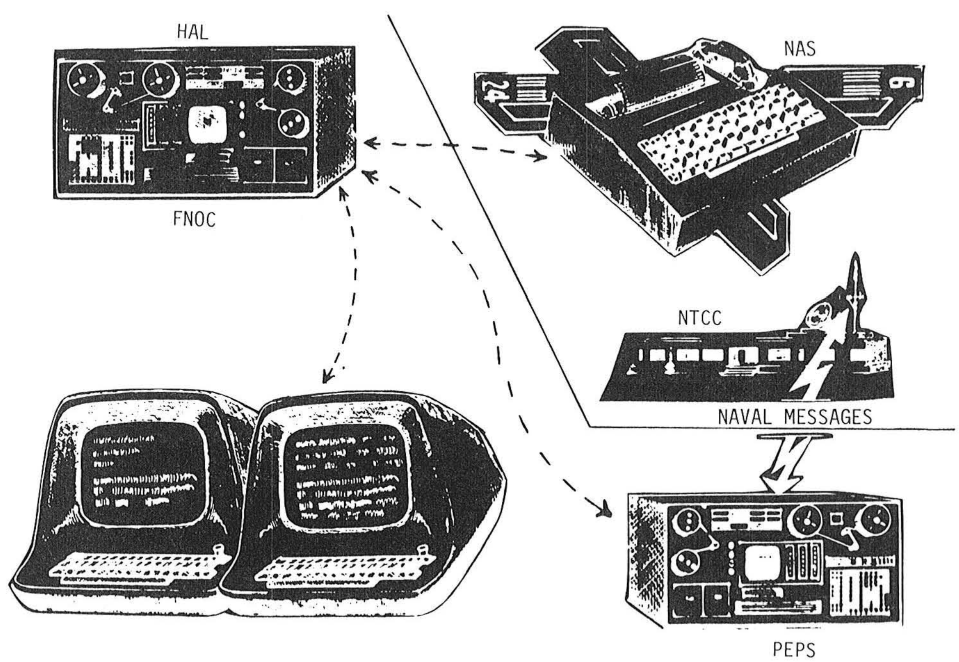


Figure 2. Optimum Path Aircraft Routing System (OPARS).

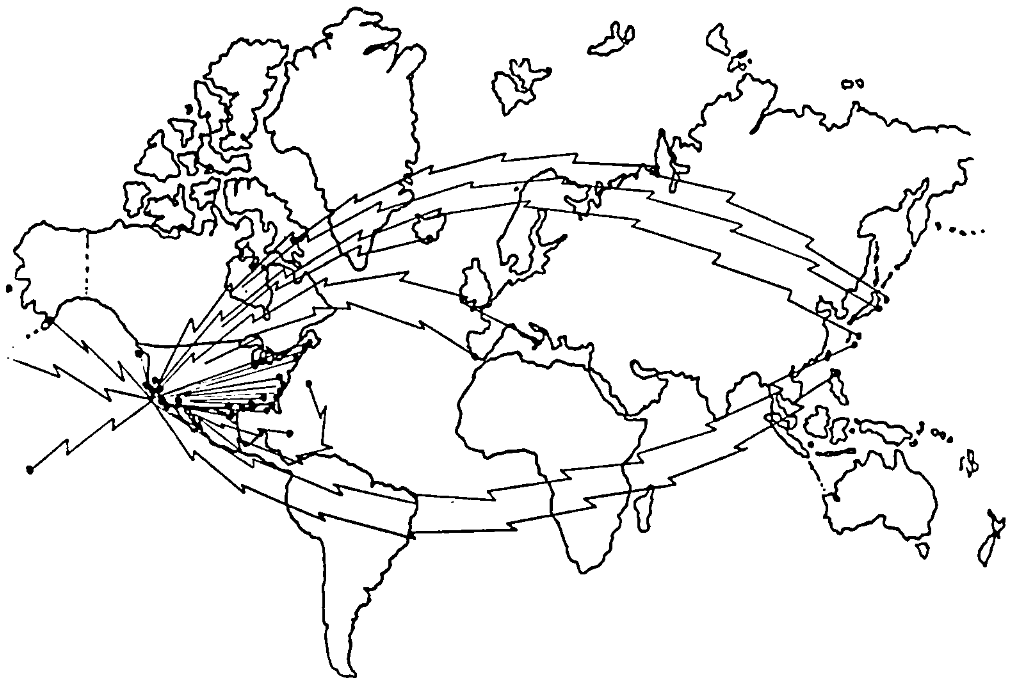


Figure 3. Sites regularly served by OPARS from FNOC.

FLIGHT PLAN FORMULATOR

RSU - Request Set Up
FPF - Flight Plan Formulator
PRA - Post Route Analyzer
OPA - Output Preparation = Archival

COMMUNICATIONS

Interactive
Request

ENVIRONMENTAL DATA

Global Update Every 12 Hours
Time/Space Interpolation Every Flight

DATA BASE MANAGER

Aircraft Performance Curves
Routes - Airports - Navaids
Restricted Areas

Figure 4. Major subsystems of OPARS.

The computer program is divided into four major subsystems (Figure 4): 1) the Flight Plan Formulator does the actual processing, by calling upon several data bases to enable the system to run properly. 2) The Communications subsystem allows the user to interface with the computer to enter the request and receive the flight plan. 3) The Data Base Manager stores the data bases that remain relatively static such as aircraft. For Navy aircraft we use performance data depicted in the Naval Air Training and Operating Procedures Standardization Program (NATOPS) manuals provided for each aircraft. The air routes, airports, and NAVAIDS are provided in computer-readable format by the Jeppessen Sanderson Corporation of Denver, Colorado. This data base is updated every 28 days and consists of all the air routes, NAVAIDS, waypoints, and all airports (with hard surface runways 5,000 ft. or longer) in the Northern Hemisphere and selected areas in the Southern Hemisphere. The prohibited area data base is static as most prohibited areas remain constant. Input options will either allow or not allow aircraft to fly through these areas. 4) The Environmental Data subsystem consists of winds and temperatures extracted from the NOGAPS model which is run once each 12 hours. OPARS primarily uses the 12- to 48-hour forecast winds. Temperatures and winds are extracted from the surface to 100 mb, approximately 55,000 ft. We also have a level of maximum winds which approximates the tropopause level. NOGAPS is usually complete within four and one-half hours after observation time, and processing the wind/temperature data takes another hour, so the first available winds for OPARS come from the 12-hour forecast. Most flight plans are processed using the 12- to 36-hour forecast winds. For the flight simulation we use a time and space interpolation (space being the proper altitudes for the most efficient (optimum) flight profile). Time is the forecast winds nearest the actual time of flight. Forecast winds are available in six-hour time steps; i.e., 12-hour, 24-hour, 30-hour forecasts, etc. For a while we toyed with the idea of interpolating right down to the actual forecast minute that an aircraft would transmit a position, but found that it was difficult to obtain a viable method of averaging the wind vectors to depict accurate winds (average velocity is normally too low). We decided to go with the 6-hour time step since it is a direct extract from the NOGAPS model.

For the past 14 months we have been verifying winds over regions where we feel the NOGAPS model is most likely to be weak, and where radiosonde station sites are located so we can verify forecasts with observations. The regions are the east coast of Asia; off the west coast of the U. S., where a trough can migrate west or east of actual position (winds potentially 180° in forecast error); a track across the northern U. S.; another across the mid-United States, to pick up any errors in jet stream migration; along the east coast of the U. S.; across the North Atlantic; and through the Mediterranean area. During these 14 months, we concentrated our effort on the 24-hour forecast at the 300 mb level. We simulate flight in both directions through each area. Flights are about 2,000 miles long, and we use a

Navy C-9 Aircraft. The results to date have been very good as we have about 99% probability of being within 15 minutes of estimated fuel (1000 - 1200 lbs.) using the 24-hour forecast winds and temperatures. As the NOGAPS model improves, I feel we also will improve.

Figure 5 is an example of a typical input into the OPARS system. There are multitudes of possible input combinations, of course, but the one shown in Figure 5 was chosen because it is a short flight and easy to read. The input consists of a C-9B aircraft using a normal rate of climb, maximum range cruise, idle descent, and a specified output mode for a one-leg flight plan. We can run up to three legs at one time with any combination of refuel options. A leg is defined as from one point of departure to one point of arrival. In this case a $\$R$ was selected which is defined as flying on jet routes, if possible, but it is permissible to fly NAVAID direct between jet routes. We have an option forcing OPARS to remain on jet routes, and it is primarily used in the European areas. We can also fly inertial direct, inertial optimize, and any other combination that may be appropriate, but $\$R$ seems to be the most popular. Since we climb out and descend on course, we provide for additional fuel/time estimates in the departure and arrival bias inputs. In Figure 5, the point of departure was San Francisco arriving at KNZY, which is Navy North Island in San Diego.

Figure 6 shows the output calculated from the input shown in Figure 5. The cargo/fuel mix for the aircraft in this flight was determined for maximum load capability, and the time of flight was calculated to be one hour and fourteen minutes requiring 7,349 lbs. of fuel, a 45-minute reserve (at FL 100) calculated at 4,800 lbs. which totaled a 12,149-lbs. required fuel onload. The computer calculated a maximum cargo of 29,197 lbs. The routing was from San Francisco direct to Salinas then direct to North Island, and did not select any jet routes in this example. The captions across the bottom of Figure 6 represent the checkpoint, flight level, temperature deviation, winds, true course, true heading, mag heading, true airspeed, ground speed, zone distance, cumulative distance, estimated time en route, estimated time remaining, estimated fuel usage, and estimated fuel remaining. This is one of eight possible output formats.

The wind printed on this plan is not the same wind used to calculate the fuel usage and time between checkpoints. After trying several averaging methods, we settled on a simplified trapezoidal interpolation between checkpoints which is more accurate than simply averaging end point winds. The winds printed in the example in Figure 6 are derived by going back into the environmental data base and interpolating the wind at the checkpoint location and altitude. This can be verified by the pilot by reading actual winds on his inertial navigation/Doppler system. If the winds are right on, then he knows that the forecast is good and the fuel/time data from OPARS is accurate. If the winds are a little off, then he has to take

```
USER        =U,OPFO
PILOT       =LT JONES
ACTYPE      =C9BFNF
OMODE       =2KB
LEG         =1
POD         =KSFO
TOD         =04OCT1983  ,2100Z
OPWT        =65000
CARGOCH     =C
ROUTING     =$R
DBIAS       =500,5
ABIAS       =500,5
POA         =KNZY
RESERVE     =C
COMMAND-
```

Figure 5. Example of typical OPARS input.

J,6S

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FLIGHT PLAN FOR LT JONES               COMPUTED 1332Z

BASED UPON 8310040000 WEATHER DATA

LEG01 STANDARD KSFO   TO KNZY

ACFT TYPE C9BFNF          10/04/83

PLANNED FOR ETD 2100Z INITIAL CRUISE FLIGHT LEVEL 290

           FUEL   TIME  DIST ARRIVE TAKEOFF  LAND   CARGO   OPNLWT
FOA       007349  1/14 0391  2214Z  106345 098997 029197   065000
ALT         ...
RES       004800  0/45
TOT       012149  1/59

FUEL BIAS:    0   DBIAS:  500   ABIAS:  500   IBIAS:    0

ROUTING USED FOR THIS LEG
KSFO .. SNS .. NTD .. KNZY



CPT    F/L TMP WIND  T/C T/H  M/H  TAS G/S ZD   CD   ETE  ETR EFU  EFR
KSFO     1  00 00000 000 000 ***** *** *** 000 0000 0/01 1/14 000 0121
KSFO   N37372W122225
SNS    199 P11 09023 147 144 127.0 *** *** 066 0068 0/13 1/00 023 0098
SNS    N36398W121361
TOC    290 P10 07529 142 138 122.0 *** *** 079 0147 0/16 0/44 020 0078
TOC    N35378W120354
NTD    290 P09 14509 141 140 124.7 436 426 116 0263 0/16 0/28 016 0062
NTD    N34074W119073
SDP    290 P09 20515 132 133 117.9 434 428 035 0298 0/05 0/23 005 0057
SDP    N33442W118361
KNZY     0 P01 12510 132 132 118.6 *** *** 093 0391 0/23 0/00 010 0047
KNZY   N32420W117129

TOTAL WIND FACTOR    -4KTS


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Figure 6. Example of OPARS output from input format shown in Figure 5.

alternate action. Since the beginning of our operation in 1980, I do not know of anyone's having to divert due to inaccurate environmental data. In this example, the total wind factor is shown to be -4 kn.

Figure 7 is an example of an abbreviated output format used for planning purposes, and has basically the same summary information as that in Figure 6. Figure 7, however, was from Travis to Hickam AFB. It does not show all the checkpoint navigation, but does indicate the planned route, penetrated airspaces, and total wind factor. Its primary use is for planning purposes (i.e., run several with different cargo loads, etc.). Figure 8 is a popular output for pilots, a "how goes it" type of output. The flight crew must connect the dots to complete the graph. Then during the flight, the pilot plots actual fuel at each checkpoint. If it plots on the line or to the right side of the line, then fuel usage is as (or better than) predicted. If the plot is to the left, then more fuel is being expended than planned for and some corrective action or a divert is in order.

Figure 9 lists some of the other benefits of the OPARS system. Within the military, entire squadrons of aircraft are deployed from time to time, and this system is used to plan time and fuel requirements for the deployment. The system is also used to plan aircraft carrier wing fly on/off scenarios which can be extremely complicated (up to 70 aircraft at a time). One main benefit for the C-9 transport community is for planning maximum flight time versus crew rest requirements. This enables a schedule to be followed to make sure an aircraft is back at home base and ready for the next day's mission rather than somewhere else, because a lot of time was saved by letting the computer help plan the flight. The crew spent most of their workday in the air and not in Base Operations planning the flight.

Figure 10 shows the areas covered by the OPARS system in a representation flight from Jacksonville, Florida, to Spain. All the winds are loaded into this entire area at/around the optimum altitude that the aircraft should fly. Flight is simulated through all altitudes to deduce the best fuel usage.

```
FLIGHT PLAN FOR AIR FORCE              COMPUTED 1804Z

BASED UPON 8401040000 WEATHER DATA

LEG01 STANDARD KSUU   TO PHHI

ACFT TYPE C9BFNF             1/04/84

PLANNED FOR ETD 2200Z INITIAL CRUISE FLIGHT LEVEL 310

          FUEL   TIME  DIST ARRIVE TAKEOFF  LAND   CARGO   OPNLWT
POA       029368  5/34 2125  0334Z  109998 080630 009630  065000
ALT        ...
RES       006000  1/06
TOT       035368  6/40

FUEL BIAS:    0   DBIAS:  500   ABIAS:  500   IBIAS:    0

ROUTING USED FOR THIS LEG
KSUU .. SAU D230 BEBOP R64 PHMAGGI V12 PHJOELE .. PHHI



TOTAL WIND FACTOR   -36KTS


FOLLOWING AIRSPACES PENETRATED

FIR BOUNDARY         KZ  /KZOA    AT 2231Z
FIR BOUNDARY         KZOA/PHZH    AT 0239Z
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Figure 7. Example of abbreviated format from data shown in Figure 6.

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FLIGHT PLAN FOR AIR FORCE              COMPUTED 1804Z

BASED UPON 8401040000 WEATHER DATA

LEG01 STANDARD KSUU   TO PHHI

ACFT TYPE C9BFNF           1/04/84

PLANNED FOR ETD 2200Z INITIAL CRUISE FLIGHT LEVEL 310

          FUEL   TIME DIST ARRIVE TAKEOFF  LAND   CARGO   OPNLWT
POA      029368  5/34 2125  0334Z  109998 080630 009630   065000
ALT        ...
RES      006000  1/06
TOT      035368  6/40

FUEL BIAS:    0   DBIAS:  500   ABIAS:  500   IBIAS:    0

ROUTING USED FOR THIS LEG
KSUU .. SAU D230 BEBOP R64 PHMAGGI V12 PHJOELE .. PHHI
```

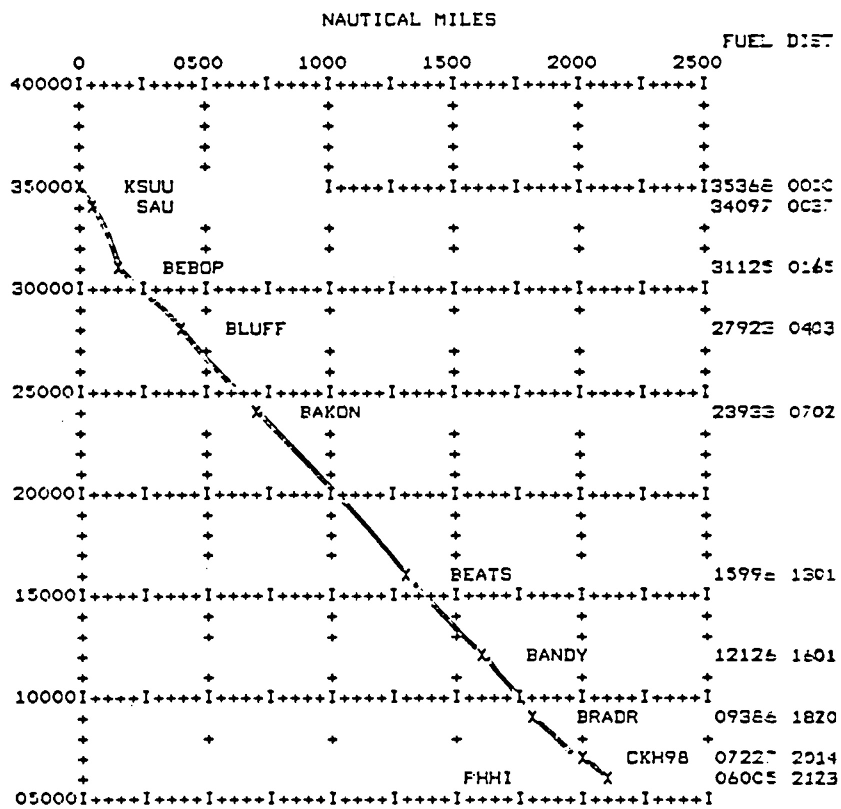

Figure 8. Graphic data display for pilots using same data as Figure 6.

TACTICAL MISSION PLANNING

AIR-TO-AIR REFUEL PLANNING

DEPLOYMENT PLANNING

AIRCRAFT CARRIER FLY ON/OFF PLANNING

OPTIMIZE FUEL LOAD/CARGO MIX

MAXIMUM FLIGHT TIME VS. CREW REST

Figure 9. Additional benefits of the OPARS system.

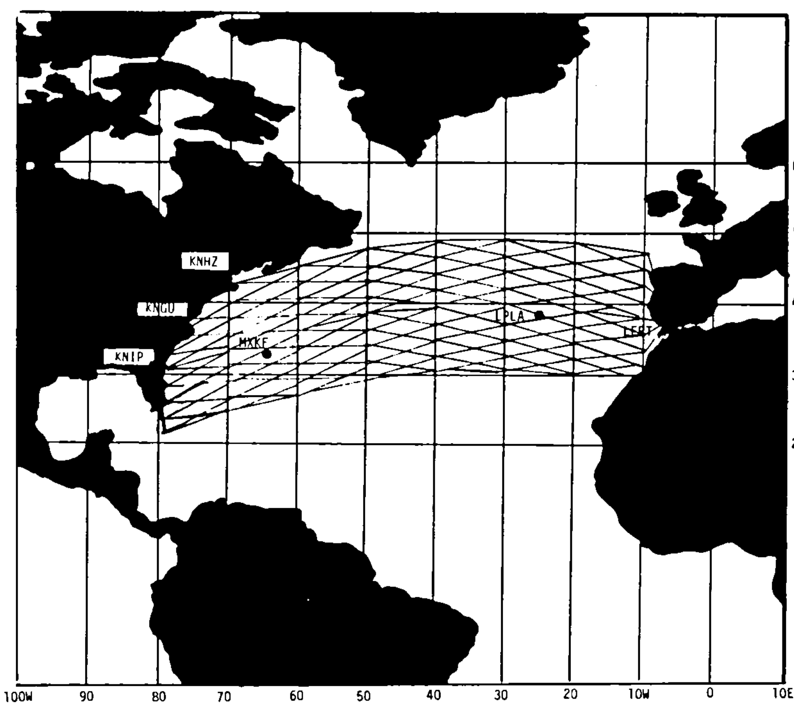

Figure 10. Areas covered by the OPARS system in representation flight.