In order to efficiently carry out our proposed research we looked into a variety of aircraft in the Hawaii area. After discussions with various aircraft owners, we decided to use a twin engine Piper Seneca for our research (see Fig. 1). The plane is run by a well regarded local pilot who has many years of flying experience. The Seneca plane can climb up to 16,500 feet (~5.5 km) allowing us to climb well above the trade wind inversion (~2.1 km). Although we will not fly for long durations at these heights, an oxygen tank has been purchased and will be used for the pilot and crew at these high altitudes. The plane has six seats and the center two are removed for installation of the scientific equipment. The plane is owned by Air Olomana and is used for flight training and is being rented to us at a reasonable rate. As this plane is routinely used for training, any modifications must first be approved by the FAA which involves significant time and effort. Our approach has been to purchase extra Seneca doors on which we mount our scientific equipment. In the front door we have installed an aerosol inlet and exhaust venturi. In the back two doors we have installed the radiation equipment.

Figure 1. The owner/pilot (Hank Bruckner) and the Piper Seneca we are using to make radiation and aerosol measurements.
Current and Proposed Radiation Measurements: Contact - J. Porter, 808-956-6483

1) Aerosol optical depth (380, 440, 500, 675, 870, 1020 nm) (Available now)
2) Upwelling radiance from spectrometer (400-1050 nm) (scanning √ 45 degrees from nadir) (fall 1998)
3) Sky radiances from spectrometer (400-1050 nm) (scanning √ 45 degree from zenith) (fall 1998)
5) Broadband downwelling and upwelling irradiances (0.3-3 µm) (fall 1998),
6) Broadband downwelling and upwelling irradiances (~3-50 µm) (winter 1998)
7) Spectral downwelling and upwelling irradiances (Spectrometer) (Available now)
8) Upward and downward looking cameras (Available now).

Test Flights and Data Examples:

Our first test flights were carried out in early February 1998 in coordination with a SeaWifs initialization cruise being carried out by Dr. Dennis Clarke. The test flights were useful in that they allowed us to test our system and to collect some initial data sets. Example data sets are shown below for February 10 and 11, 1998. On the 10th of February, the Moana Wave R/V was near the west side of the big island (Kona coast) and was encountering volcanic aerosol (VOG, volcanic smog). On February 11, the Moana Wave R/V had moved just north of Maui and was in clean air at the time of the satellite overpass. The aircraft descent was planned to coincide with the overpass of the SeaWifs satellite to obtain coincident ship and aircraft measurements. Figure 2 shows the aerosol optical depths measured on these two days. On February 10th the aerosol optical depths were much greater than on February 11th, and are representative of the volcanic plume. These aerosol optical depth measurements were made with a hand held micro-tops sun photometer. Although we had carried out Langley plot calibrations with this sun photometer, we later found our Micro-tops sun photometer had developed a short in one of the capacitors which raises questions about the quality of these measurements. Comparing our optical depth measurements with those on the ship we find they measured 0.295 (at 520 nm) on February 10th and 0.018 (at 520 nm) on February 11th (courtesy of Dennis Clarke). This is in reasonable agreement with our measurements on February 10th but is smaller than measurements on February 11th. We can also compare out measurements with those made at the Mauna Loa observatory (courtesy of Ellsworth Dutton) when the plane is at height. On both February 10th and 11th the MLO optical depths were 0.009 (at 500 nm) and 0.003 (at 778 nm). These are in reasonable agreement with our measurements on February 11th but are lower than our measurements on February 10th. Now that our sun photometer has been repaired we expect more reliable measurements for future flights.

Upwelling and downwelling radiance measurements were made with a narrow field of view spectroradiometer (~4 degrees). The spectrometer covered the range of 400 to 1030 nm with ~200 channels (8 nm FWHM). For these test flights we mounted a pointable spectroradiometer on the aircraft rear door. The radiometer was either pointed upward or downward and auto scaling of the integration time was used to improve signal to noise and cover a large dynamic range. Figure 3 shows the upwelling and downwelling radiance measured on the aircraft as it descended from 4 km to the surface. For the periods labeled 1 and 3 the radiometer was pointed downward and the upwelling radiance was measured. The periods labeled 2 and 4 have the radiometer pointed upward to measure
Figure 2. Aerosol Optical Depth measured on February 10 and 11. The measurements made on the 10th were in volcanic haze and on the 11th they were in clean air.

Figure 3. Upwelling and downwelling radiance measured from the spectrometer as the plane descended and ascended. For the periods labeled 1 and 3 the spectrometer was looking down. For the period labeled 2 and 4 it was looking upward. The aircraft height is also shown.
sky radiance. Unfortunately the aircraft attitude GPS system was not operational so that it
is difficult to calculate viewing geometries. It can be seen that the variations in sky
radiance and surface reflection oscillate as the plane circled around the ship and change
systematically as the plane changes altitude. On certain occasions we measured the
aircraft attitude manually and we may be able to calculate the sensor viewing angles at
these times. After the experiment, we discovered the problem with the Ashtech GPS
system was a poor connection on one of the four antennas. The problem has since been
fixed and in the future we will also have a backup aircraft attitude system.

Several other radiometric measurements were made on the experiment and
include spectral downwelling irradiance and imaging of the surface with a scientific
camera. The spectral downwelling irradiance were made with a spectrometer covering the
range from 400-1020 nm with approximately 200 channels. These measurements should
be available in the near future once certain calibration issues are resolved. The scientific
camera we are using has a filter wheel with eight filters (only four were used on the
experiment), 14 bit digitization, mechanical shutter to take dark counts and flat field
correction. This data set will also be available in the near future. Once the data sets are
complete, they will be described on our web page (http://www.soest.hawaii.edu/~porter)
and turned into the SeaBass archive.

Future Plans for Radiometric Instruments:

Currently we are working on FAA licensing of the spinning radiometer. Drawings
for the scanning radiometer are completed and initial verbal approval was given by the
FAA. We expect construction will be completed by the end of summer. This system will
be mounted on the rear door and will make measurements ∀45 degrees from zenith and
nadir with two separate spectrometers. The signal to noise will also be better than the one
used in Figure 3. Although we have several ideas, the final mounting of the broad band
irradiance sensors is not yet complete. We will be working closely with the owner, the
aircraft mechanic and the FAA on this.

We have also purchased Optronics NIST traceable radiance and irradiance
standards and will be setting up a dedicated calibration laboratory within the next few
weeks. We will maintain this facility with annual factory calibration and comparisons
with the Moby facilities and with NASA national comparisons (i.e. SIRREX-6). Our
current radiometric uncertainty is near 4% and we would like to reduce this to 2%. We
will also need to better characterize the stray light rejection of our systems and the
temperature dependance. As a test, we will occasionally fly with more precise
instruments with higher spectral resolution and stray light rejection better than 10⁻⁵.
These systems include a CVI spectrograph (.0.3-1 µm or 1-2.2 µm depending on the
detector used) and a Bomen FTIR configured to cover the range from 0.8 - 3.3 µm with
very high resolution (1 cm⁻¹). We have already ordered these systems with funds from
another grant and we expect they will be available for aircraft use during 1999.

As the EOS-AM1 launch has been postponed, we will carry out several specific
experiments. The first flight period will be during the July and August BARONS
Experiment. Further details of this experiment are given at
http://www.soest.hawaii.edu/~huebert/r.barons.html. During the fall of 1998 we will
carry out coordinated experiments over the Moana Wave R/V at the Hots site. Once the
EOS-AM1 satellite is launched, we expect to have a tightly coordinated experiment with Dennis Clarke for ocean color validation for the EOS-AM1 satellite.

**Aerosol Measurement Component**
*(Contact A. Clarke, 808-956-6215; tclarke@soest.hawaii.edu)*

Most proposed aerosol measurements for the Seneca (Fig 1) program have been implemented for the initial flights described here. Others that are under development are so noted below. The inboard aerosol package is integrated into a metal enclosure on the right side of the aircraft behind the passenger seat and close to the aerosol inlet (Fig 4.). Aspirated flow through the aerosol system is maintained by a venturi mounted on the front door near the inlet. A velocity probe in the inlet duct and valve in front of the venturi allows us to maintain isokinetic flow at the sampling tip.

![Aerosol inlet, venturi and temperature/humidity sensors are mounted atop Seneca passenger door. Aerosol enclosure is visible behind the passenger seat.](image)

**Fig 4.** Aerosol inlet, venturi and temperature/humidity sensors are mounted atop Seneca passenger door. Aerosol enclosure is visible behind the passenger seat.

**Instrumentation in the enclosure shown below in Fig. 5 include:**

- Radiance Research Nephelometers (NEPH) for aerosol light scattering extinction ($b_{sp}$) at 530nm. Two units are to be used, one for total (operational) and one for submicron aerosol (being tested)*. Each unit also record relative humidity and temperature in the instrument. (1Hz data output).
- Condensation Nuclei Number Concentration (CN) – total number concentration for aerosol diameters, Dp>0.01um. (1hz data output).
- 6 channel optical MET1-H particle counter (0.1-0.6um)- (30 sec. avg.)*
- 6 channel optical MET1-A particle counter (0.6-10um)- (30 sec. avg.)*
- velocity probe (KURZ)
- GPS (Garmin)

* The MET1 instruments are being upgraded to 40 size channels and improved computer interfaces. A 1um impactor cut is being added to one NEPH in order to isolate scattering due to aerosol above and below 1um.

![Image](image_url)

**Fig. 5** View of aerosol package during installation with inlet plumbing to two nephelometers to right of box, CN counters to their left and Met 1 particle counters below. Datalogger and microcomputer attach in front of box for operator use after installation is complete.

An external forward scattering spectrometer probe (FSSP-300x) is mounted below the fuselage and provides ambient size distributions (0.3-20um or an optional 0.5-40nm).

**Example Aerosol Data**

Sample data corresponding to the optical depth measurements shown below in Fig. 6 for Feb. 10 (left side of page) and for Feb. 11 (right side of page). NEPH light scattering data \( b_{sp} \) for Feb. 11 shows low values above about 2km even though CN are higher than in the marine boundary layer (MBL), indicating the dominance of small particles with little contribution to optical depth above that altitude. On Feb. 10 a layer of
enhanced scattering is present between 500m and 1,500m altitude corresponding to the peak aerosol layer from the volcanic plume. A separate layer between the surface and 700m is clearly evident in the CN data and also in the scattering extinction.

![Graph of scattering coefficient and aerosol number concentration](image1.png)

![Graph of scattering coefficient and aerosol number concentration](image2.png)

Fig. 6. Vertical profiles of light scattering ($b_{sp}$) and aerosol number concentration (CN) for volcanically influenced and clean marine cases.

Without correcting for differences in RH between the instrument and ambient (about 10%) the effective differential optical depth estimated from the Feb. 10 extinction profile is about 0.11. If we add a 15% correction for the difference in RH and an optical depth of about 0.009 measured above Mauna Loa (3,400m) we get about 0.13-0.14 as a column aerosol optical depth. This is about half of the ship and our aircraft optical depth values. Some of this could be due to the difficulty in aspirating aerosol larger than 3-4um into the inlet since significant aerosol surface area is out near 10um as seen in the surface area distributions. However, it is considered unlikely that these larger particles can account for much of the difference. Another possibility could be some cloud contamination in the photometric data from above flight altitude that would not show in the in-situ aerosol data. The observation of a lower shipboard optical depth of about 0.16 an hour or so earlier would be consistent with this.

The descent in much cleaner air on Feb 11 is evident in the scattering profile in Fig. 6 and in the more than order of magnitude lower aerosol surface area shown in Fig. 7. Except for the shallow layer between the surface and 400m the submicron aerosol contribute little to the surface area and scattering. Due to a 15s averaging used on the NEPH the increase in scattering appears to lag the CN for this descent and making the layer appear shallower than it is. This shallow layer could be the remnant of the previous nights drainage flow from Maui. The optical depth estimated from the NEPH below
about 3km is about 0.008 and, when added to the contribution measured above Mauna Loa, suggests a total optical depth of 0.017 and in agreement with the ship measured value of about 0.018. The aircraft photometer data suggests a value near 0.04.

Fig 7. The surface area size distributions above are averaged over the indicated altitude ranges for both days and reveal the significant differences for both days. Areas under curves are proportional to surface area.

Comparison of the column weighted average size distributions shown in Fig 8 below reveal the 25fold difference in submicron aerosol and only a five fold difference in supermicron aerosol compared to the nearly 10 fold difference in optical depth. This indicates a significant contribution of both size classes to the effective Feb. 10 column optical depth. Since the FSSP was operated on the 0.3-20um range, the relatively fast drop off for particles larger than 10um is probably exaggerated but because of the decreased relative scattering efficiency for these sizes we expect this to have a small effect.

Fig 8. Column weighted affective size distributions for below 4 km.
Ongoing improvements in the aerosol system:

We are currently making custom modifications to the electronics in our MET 1 optical particle counters to have greater size resolution and improved calibration capabilities. A differential mobility analyzer is also under development for better resolving smaller size particles in the 0.01 to 0.2um range. The tandem NEPH system, with and without an impactor size cut, is installed and being tested for final deployment. Improved GPS locations on the passenger door and software modifications are also underway. Plans also call for integrating a PVM100 (Gerber Probe) for the independent measurement of liquid water in particle sizes from 2-50um that will be used to detect clouds and measure cloud liquid water paths.