THE T-28 THUNDER/HAILSTORM PENETRATION AIRCRAFT

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The purpose of my presentation this morning is to tell you about a unique aircraft--one almost literally designed to "go where angels fear to tread." The aircraft is a highly modified, former Air Force trainer--the T-28--originally built by North American Aviation (now Rockwell International) in 1949.

In the latter part of the 1960's, the idea of modifying an aircraft to take scientific measurements within active hailstorms emerged. As a result of studies conducted by Dr. Paul B. MacCready of Meteorology Research, Inc., under subcontract from the Institute of Atmospheric Sciences (IAS) of the South Dakota School of Mines and Technology (SDSM&T) and supported by the National Science Foundation (NSF), the decision was made to proceed with such a modification. The aircraft selected was the North American T-28 trainer used by the Air Force and Navy for pilot training (Figure 1). An aircraft was located and purchased on the commercial market. Analysis showed that armoring the wing, tail, canopy and cowling would permit the airplane to safely penetrate all but the severest of hailstorms. Accordingly, the following modifications[1] were made:

- The leading edges of the wings were armor plated with 0.090 inch heat-treated aluminum.
- The upper surfaces of the wings and tail were armor plated with 0.032 inch heat-treated aluminum.
- The leading edges of the engine cowling were armor plated with 0.125 inch aluminurn.
- The canopy was replaced with a much stronger unit constructed of 0.125 and 0.090 inch aluminum and having side panels of 0.60 inch stretched acrylic. The windshield was replaced with panels of 0.75 inch stretched acrylic (Figure 2).
- Heavy aluminum grills were installed over the air intakes of the carburetor and oil cooler to restrict hail from entering.
- The propeller governor and the push rod housings were armored to prevent hail damage.

[1] Most modifications were accomplished in the 1968-1971 time period and the rest as the need arose.

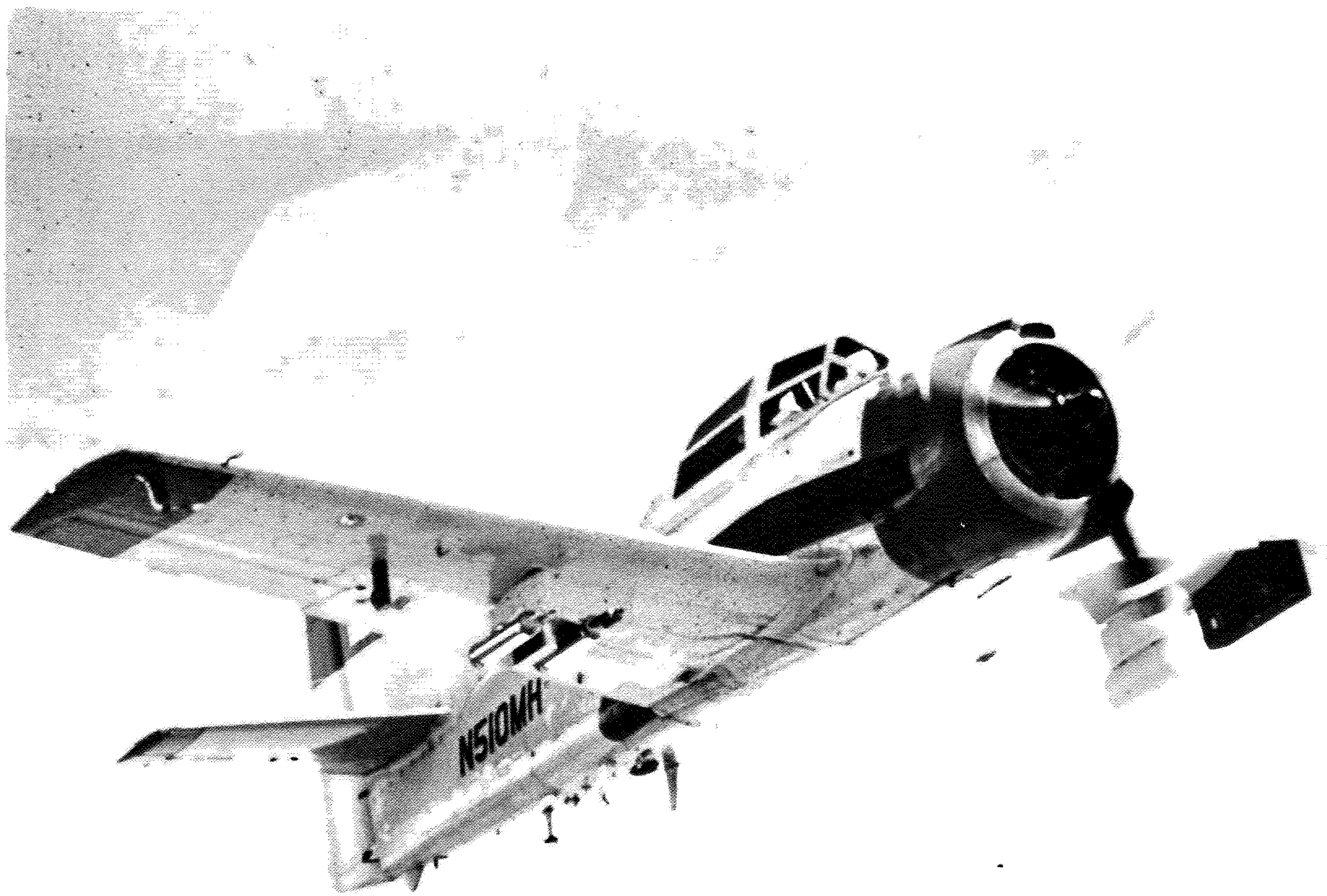

FIGURE 1 VIEW OF ARMORED T-28 AIRCRAFT IN FLIGHT. (PHOTO BY ROGER ROZELLE--AOPA PILOT MAGAZINE)

FIGURE 2. REDESIGNED T-28 CANOPY FOR HAIL PROTECTION

Along with armor plating the aircraft structure and strengthening the canopy, other modifications were made to enhance the performance and survivability of the airplane. These included:

- Propeller and carburetor alcohol anti-ice systems were installed.
- A Wright R-1820-86A engine delivering 1425 hp to a Hamilton Standard three-bladed propeller was installed.
- The fuselage structure was strengthened to support the larger engine (1425 hp vs. 800 hp from the original engine).
- An improved fuel system was installed.
- A new nose landing gear was installed along with the nose gear torque box.
- A larger oil cooler system was installed.
- A new oxygen system was installed.
- As a result of Air Force experience, wing spar caps were added to strengthen the wings for increased turbulence during storm penetrations.
- The horizontal stabilizer was replaced with one designed to withstand buckling under turbulent flight loads.
- The 100 volt-ampere inverters were replaced with 250 volt-ampere inverters.
- The rear cockpit controls and flight instruments were removed and replaced by the primary instrumentation recording system.
- PMS data processing equipment was mounted on an instrumentation platform in the baggage compartment area.
- The T-28 avionics were replaced with modern reliable equipment.

The net result of these modifications is that the T-28 can safely fly through thunderstorms and hailstorms with hail of up to 7.6 cm (3 in) in diameter. At the same time, the instrumentation and data gathering systems carried by the T-28 will take measurements of the internal characteristics of the storm that are of interest to research scientists.

At the present time, the T-28 has two instrumentation systems that allow measurement of the variables listed in Table 1. The primary recording system consists of a Precision Instruments Model 1387 computer-compatible magnetic tape recorder and a Monitor Labs Model 9100 multiplexer unit. This system is capable of recording 30 BCD digits of

Table 1

VARIABLES RECORDED BY T-28 INSTRUMENTATION SYSTEM

Variable	Instrument	Range of Measurement
State:		
Static Pressure (Altitude)	*Rosemount	0 to 15 PSI
	*Ball Engineering	0 to 27,000 ft (8.2 km) MSL
Total Temperature	Rosemount	-25 to +25°C
	*NCAR Reverse Flow	-25 to +25°C
Aircraft Navigation & Performance:		
Attitude	Servomechanisms angle-of-attack vane	-15 to +15°
	*Pitch (Humphrey vertically-stabilized accelerometer)	-50 to +50°
	*Roll (Humphrey vertically-stabilized accelerometer)	-50 to +50°
Navigation	Heading indicator	0 to 360" magnetic
	*CESSNA DME	0 to 200 n mi
	*NARCO DME	0 to 100 n mi
	NARCO COM/NAV (2 units)	0 to 360" from station
	*NARCO NAV	0 to 360° from station
Performance	Ball Engineering variometer (rate-of-climb)	-6000 to +6000 ft/min (-30 to +30 m/s)
	*Rosemount dynamic pressure (Ind. airspeed)	- 3 to +3 PSI
	*NCAR True Airspeed Computer	0 to 250 knots (128 m/s)
	*Humphrey vertically-stabilized accelerometer	-1 to +3 g's
	Giannini manifold pressure	0 to 50 in Hg
Hydrometeors:		
Cloud droplets	Johnson-Williams LWC	<50 μm dia (liquid only); 0 to 6 g/m^3
	*Particle Measuring Systems FSSP	3 to 45 μm dia; adjustable
Rain, graupel, snow	Williamson Foil Impactor	1 to 20 mm dia
	*Particle Measuring Systems OAP-2D	31 to 1000 μm
	*Cannon Particle Camera (alternates with hail spectrometer)	Approx. 50 μm up
Hail	Laser Hail Spectrometer (alternates with Cannon camera)	45 to 50+ mm dia

*Furnished by NCAR.

information plus 32 channels of analog data converted to digital form. The basic recording interval is once each second, although some of the variables are sampled twice during each one-second cycle to provide higher frequency response. In addition, a Pertec digital recorder, which is used to record particle size information from the PMS probes, serves as a backup recorder. It records all of the digital and some of the analog data that are recorded on the primary system.

A two-channel audio recorder records all communications transmitted and received by the T-28 along with the pilot's comments through a "hot mike" capability on one channel, and records precipitation and hail impact noises on the other channel. These comments and recorded impact noises are invaluable in subsequent data anlysis. A side-looking remote controlled 8 mm movie camera is used for qualitative pictures of the storm environment.

Data sensors are mounted on the underside of the wings (Figures 1 and 4). The basic wing structure is that of a T-28A and, as such, has one "hard point" external stores mounting location for each wing. The Johnson-Williams LWC sensor (Figure 3) is located on the right wing near the wing tip. Two total pressure sources are mounted on the right wing (Figure 4)--one for the pilot's airspeed indicator and the other for the data system. The angle-of-attack measuring vane is also mounted on the right wing. The PMS Forward Scattering Spectrometer Probe (FSSP), the PMS Optical Array Spectrometer Probe (OAP-2D), and the Williamson Foil Impactor are mounted on the right wing pylon (Figure 5). On the left wing pylon mount, the one unit of the Cannon Particle Camera (Figure 6) alternates with one for the Laser Hail Spectrometer. The remaining unit for each system is mounted just outboard of the pylon location, At the wing tip, two temperature probes are mounted (Figure 7) with the National Center for Atmospheric Research (NCAR) Reverse Flow instrument just inboard of the Rosemount instrument.

Data processing for the T-28 system is conducted in two phases. The first phase is the "quick look" reduction and provides "rapid recall" plots of the data. In this phase, the data tapes from the Monitor Labs 9100 and Pertec recorder units are sent to Rapid City, South Dakota, and Boulder, Colorado, by the most expeditious means available for immediate processing by the IAS and NCAR respectively. For example, in SESAME '79 air freight is used. Computer-generated plots (Figure 8) of the reduced data from the 9100 recorder are transmitted via telecopier to the field site--usually within a few hours after receiving the data tapes in Rapid City. The reduced PMS data from the Pertec recorder are reviewed at NCAR immediately and then sent to the field in microfilm form for comparison with the other data. This technique has been a key element in early detection of equipment malfunctions and minimizing lost research opportunities. A further advantage is availability of the data in the field for on-the-spot preliminary analysis while the conditions of observations are still fresh in everyone's minds.

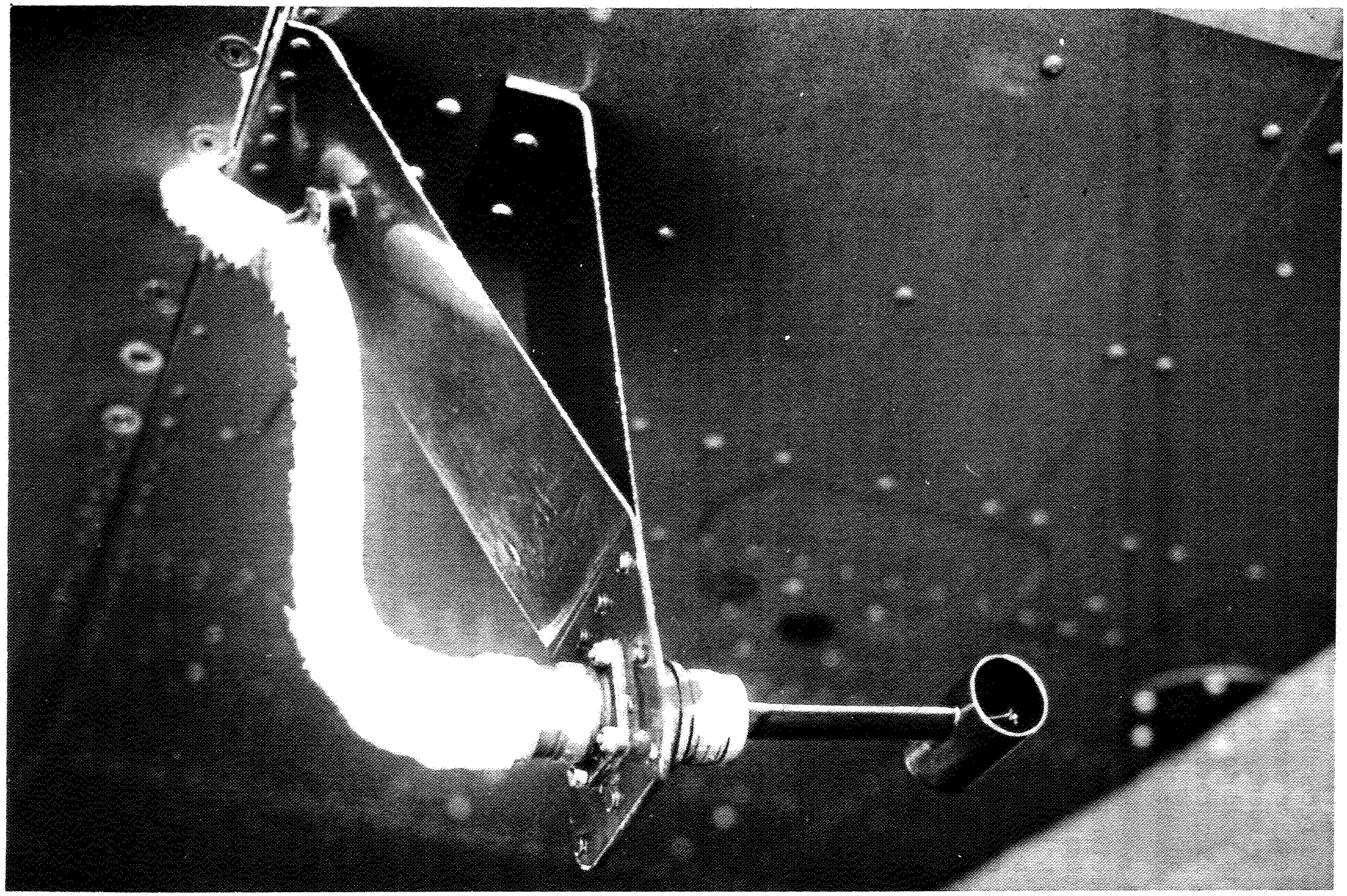

FIGURE 3 JOHNSON-WILLIAMS LIQUID WATER CONCENTRATION MEASURING INSTRUMENT

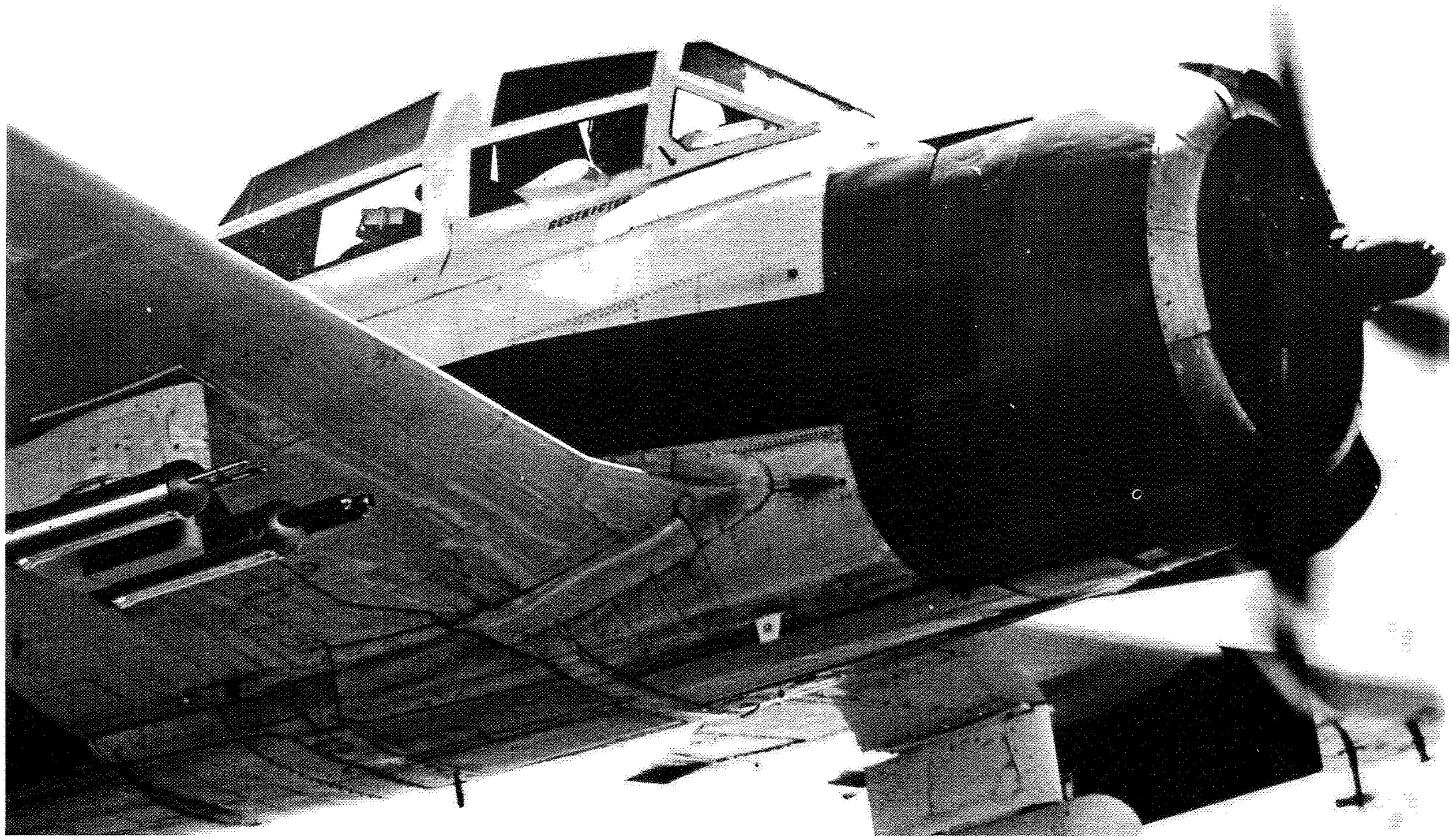

FIGURE 4 T-28 SENSORS WITH THE TOTAL PRESSURE HEADS ON THE LEFT OF THE ANGLE-OF-ATTACK VANE (SMALL POST). (PHOTO BY ROGER ROZELLE--AOPA PILOT MAGAZINE)

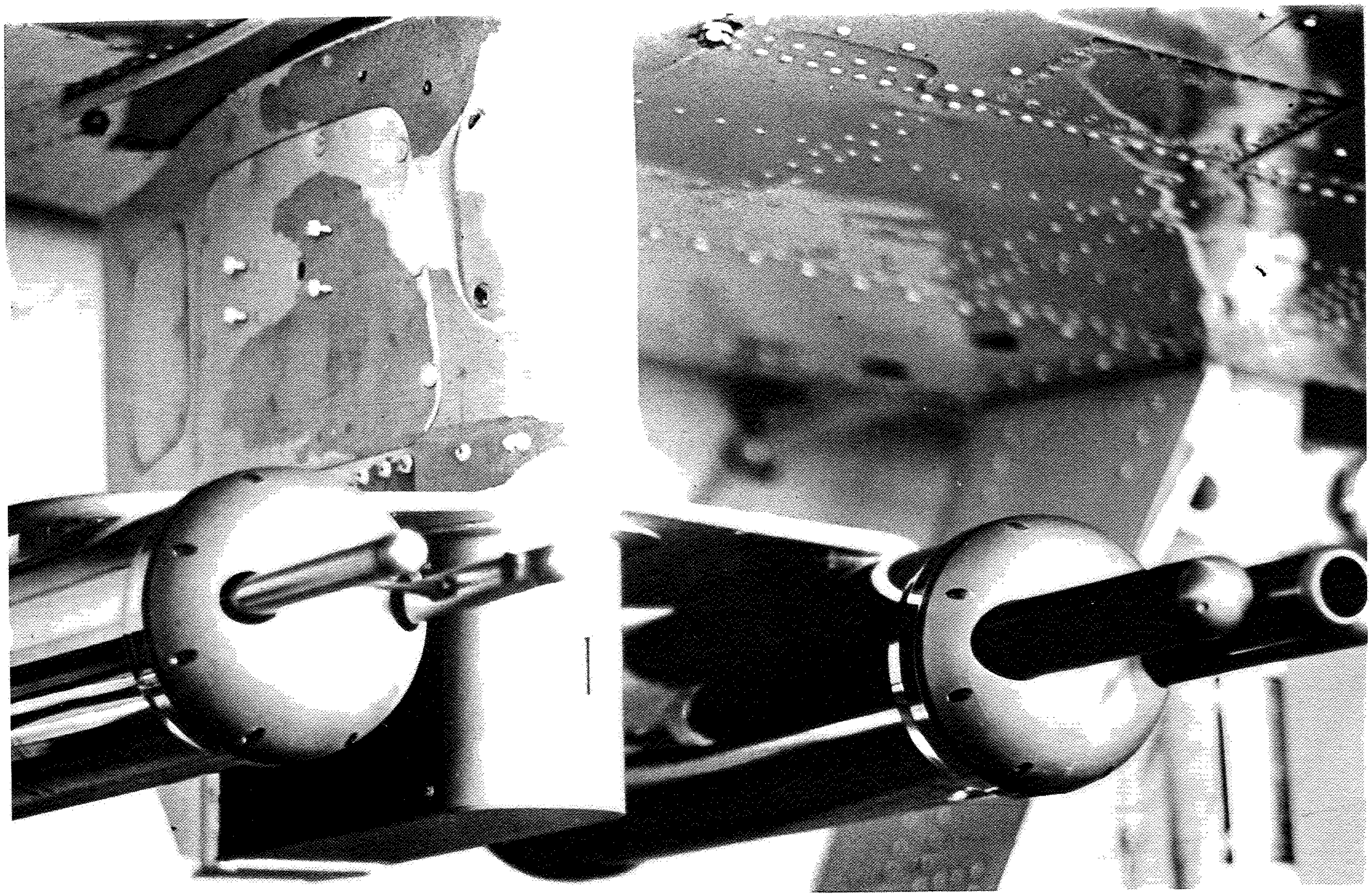

FIGURE 5 T-28 RIGHT WING PYLON WITH THE PMS PROBES (OAP-2D LEFT AND FSSP RIGHT) AND THE FOIL IMPACTOR (CENTER).

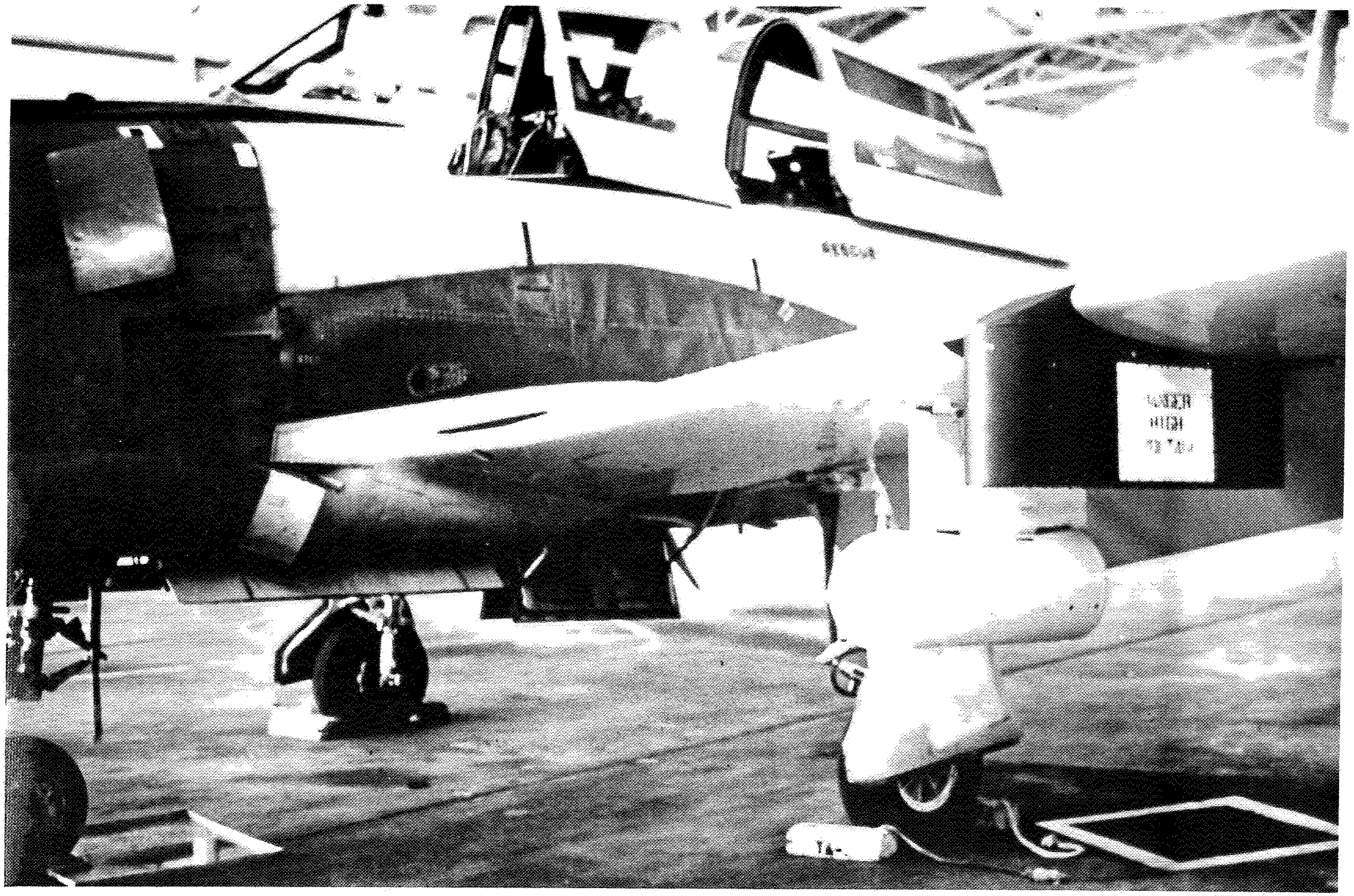

FIGURE 6 T-28 LEFT WING PYLON WITH THE CANNON PARTICLE CAMERA (WHITE POD) AND STROBE LIGHTING POD (BLACK).

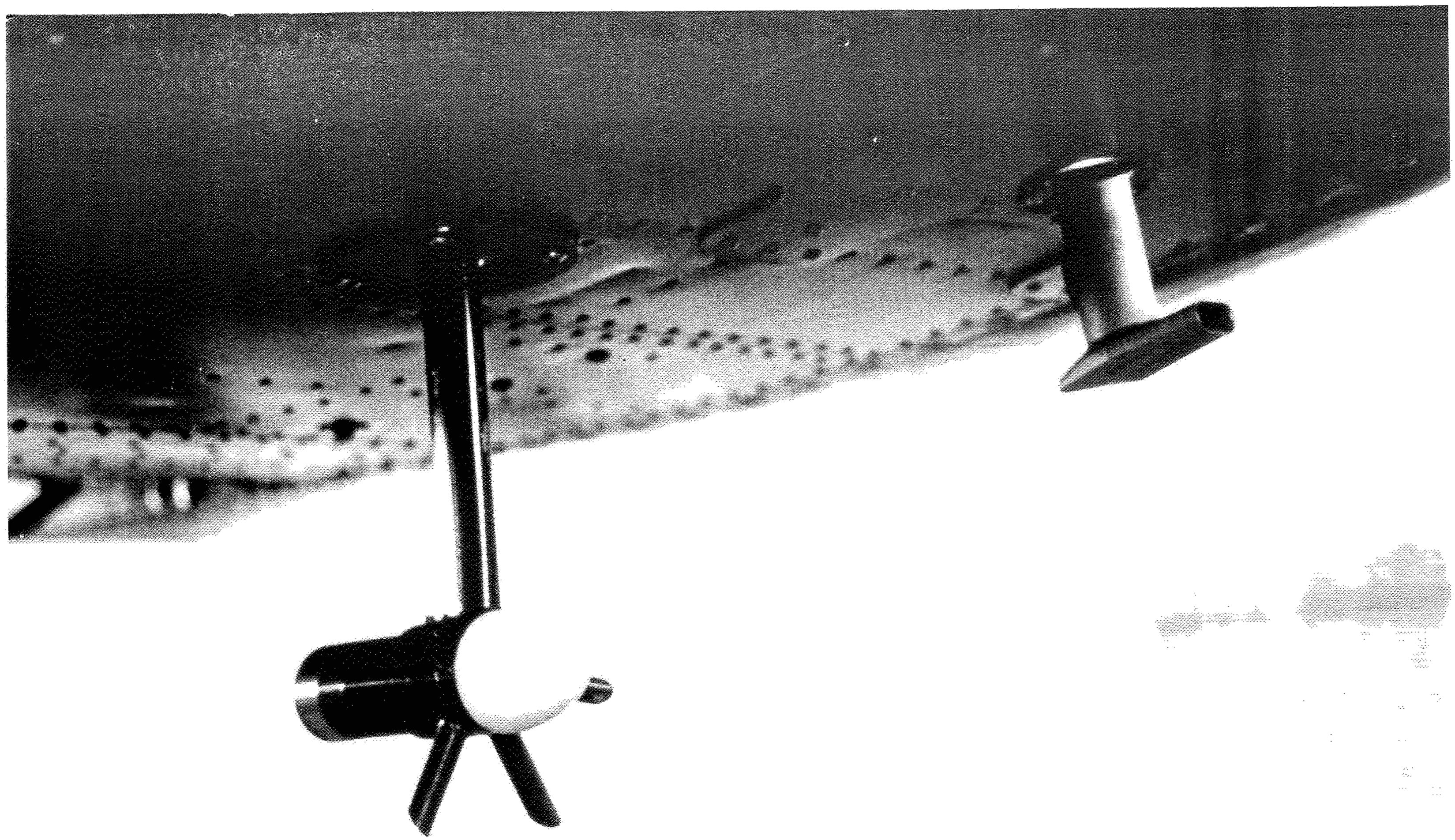

FIGURE 7 T-28 TEMPERATURE SENSORS--NCAR REVERSE FLOW (LEFT) AND ROSEMOUNT (RIGHT).

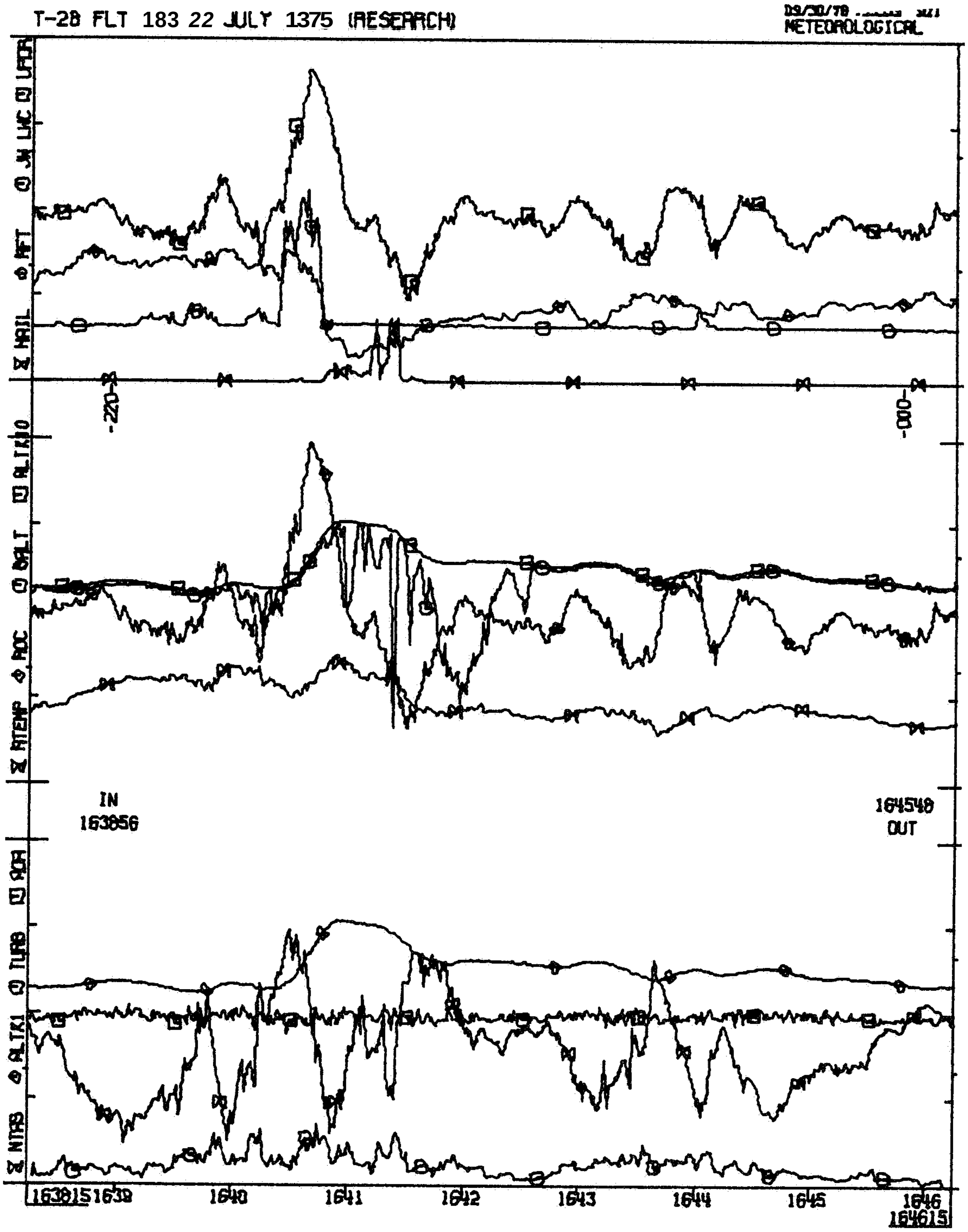

FIGURE 8. EXAMPLE OF REDUCED METEOROLOGICAL DATA FROM RAPID RECALL OUTPUT OF FLIGHT 183, 22 JULY 1976. THE TOPMOST TRACE INDICATES UPDRAFT SPEED (SCALE +25 TO -25 M/SEC), AND THE OTHER TRACES DEPICT VARIABLES INDICATED ALONG THE LEFT-HAND EDGE.

The second phase of data handling consists of detailed analyses by the principal investigators. In the past this has been done jointly at Rapid City and Boulder. The most useful form of presentation for the T-28 data has been in the form of computer listings and plots (Figure 9) showing the variables measured and computed as functions of time. Initial presentation of the PMS data is as is shown in Figures 10 and 11. There are numerical techniques which permit comprehensive description of the hydrometeor characteristics and allow various summarizations in terms of particle number and mass concentrations. A typical frame from the Particle Camera is shown in Figure 12.

Past operations of the T-28 are summarized in Table 2. For 1979, the T-28 will participate in the National Severe Storms Laboratory's Project SESAME at Norman, Oklahoma. It will be one of two storm penetrating aircraft--the other is an Air Force F-4--however, it will be the only one penetrating the high radar reflectivity areas of the storm (up to 55 dBz) where hail might be encountered. Operation during TRIP '79 at Socorro, New Mexico, has also been proposed.

Table 2

OPERATIONAL SUMMARY BY YEARS

Year	Flights	Cloud Penetrations	Program
1970	40	20	1. N.E. Colorado Hail Experiment (NECHE) 2. Hail Models - Rapid City
1971	21	--	Engine problem - no research flights
1972	54	83	NHRE
1973	38	27	NHRE
1974	8	--	No field program
1975	40	48	NHRE
1976	50	60	NHRE
1977	18	--	No field program
1978	47	108	1. Convective Storm Division (CSD) - N.E. Colorado 2. Thunderstorm Research International Program (TRIP) - Florida

The flights listed include research flights, maintenance flights, and equipment test flights, so the number of cloud penetrations is a better guide to the amount of data collected.

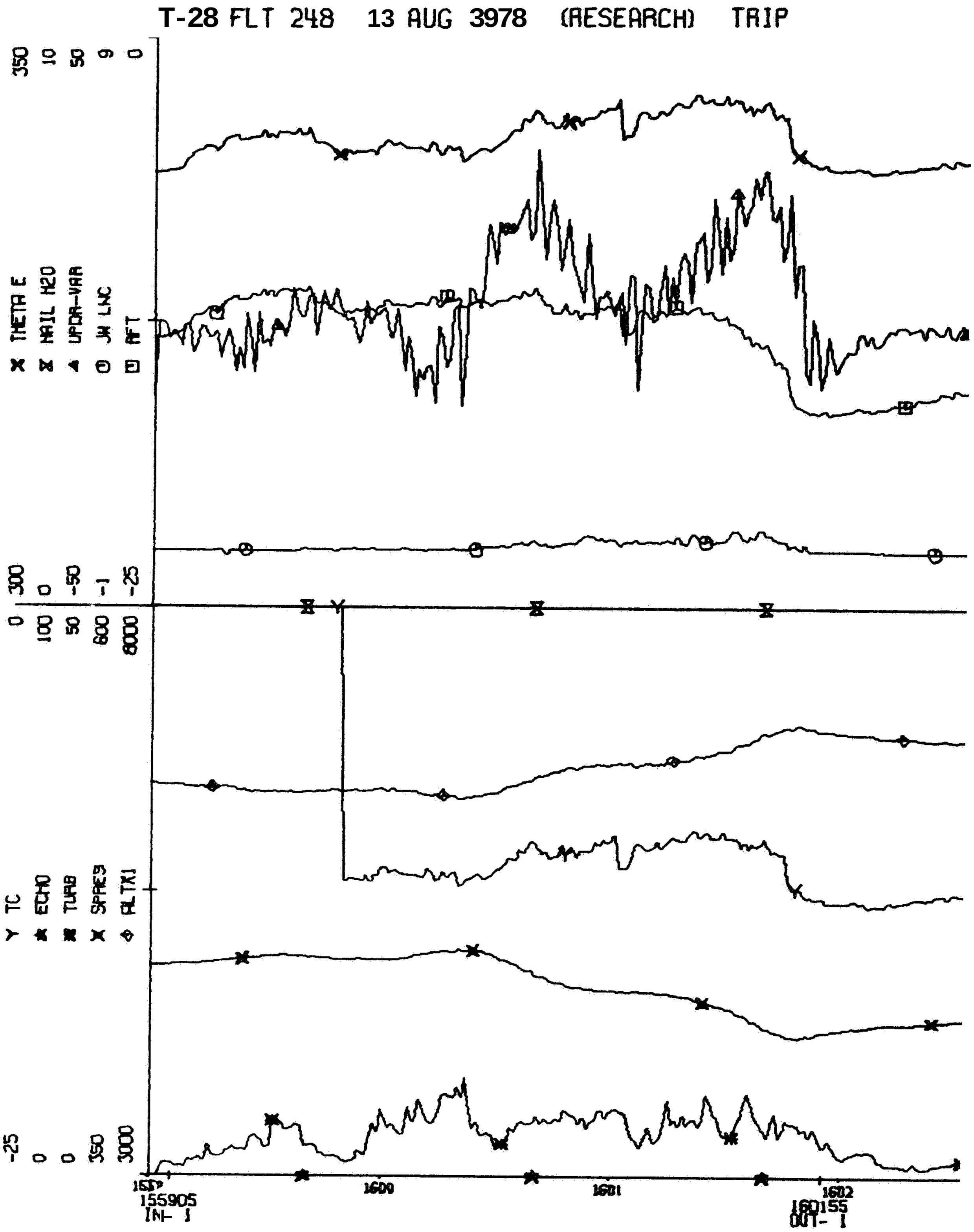

FIGURE 9. PLOT OF DATA FOR A 4-MIN SEGMENT OF THE T-28 FLIGHT ON 13 AUGUST 1978 IN FLORIDA. POINTS OF CLOUD ENTRY AND EXIT ARE INDICATED BY THE IN-1 AND OUT-1 MARKS ON THE ABSCISSA; THE TIME SCALE (EDT) CAN BE CONVERTED TO AN APPROXIMATE DISTANCE SCALE USING THE NOMINAL FLIGHT SPEED OF 6 KM/MIN. VARIABLES PLOTTED ARE INDICATED ALONG THE ORDINATE, WITH THE SCALE RANGE AND PLOTTING SYMBOL INDICATED FOR EACH CURVE.

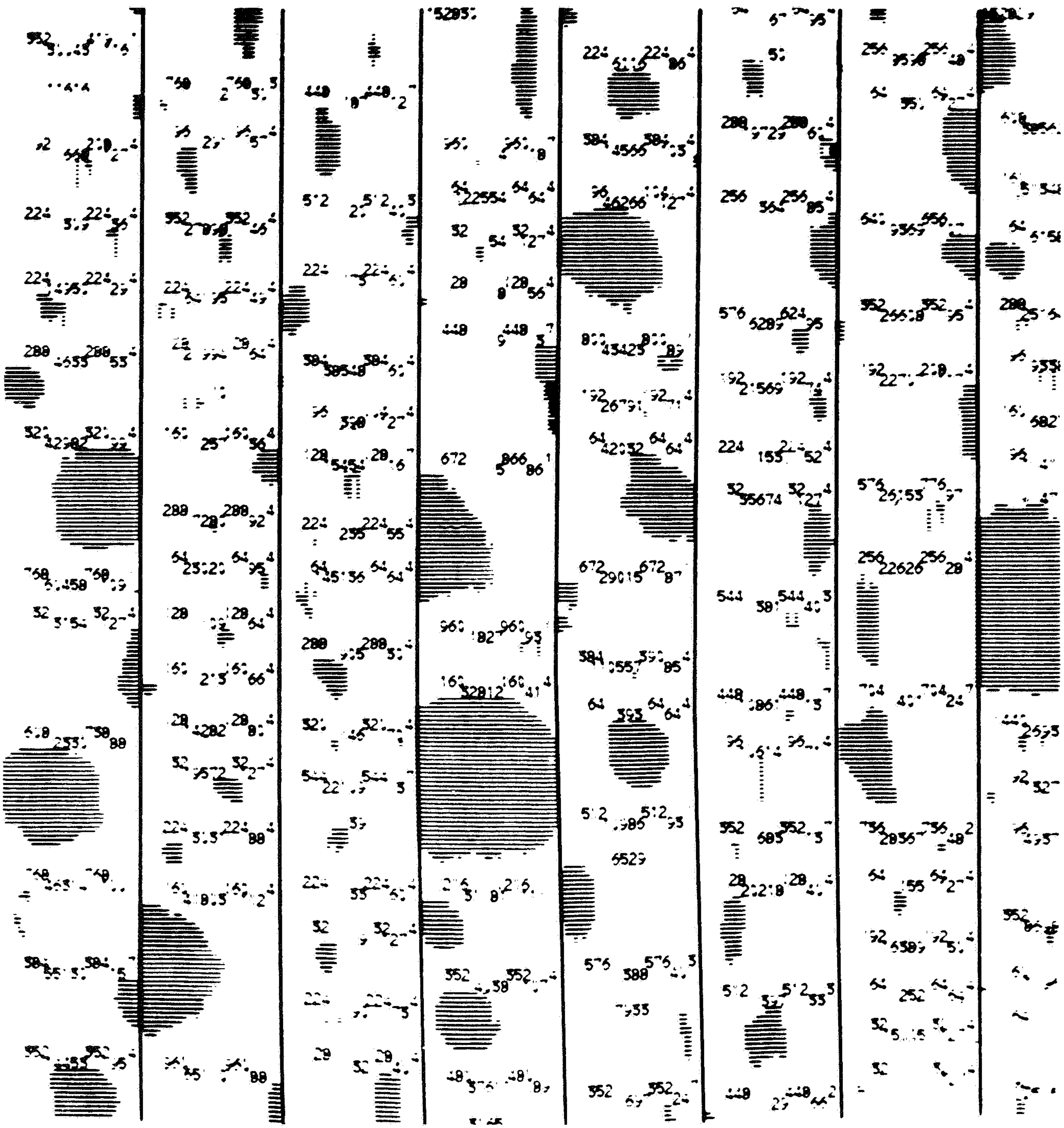

FIGURE 10. SAMPLE OF THE PARTICLE IMAGES OBTAINED BY THE PMS OAP-2D PROBE DURING A T-28 PENETRATION IN FLORIDA ON 13 AUGUST 1978. DISTANCE BETWEEN THE HEAVY BARS REPRESENTS APPROXIMATELY 1 MM, GIVING AN IDEA OF THE PARTICLE SIZES REPRESENTED. NUMBERS REPRESENT INFORMATION ABOUT PARTICLE CHARACTERISTICS, DISTANCE BETWEEN PARTICLES, ETC.

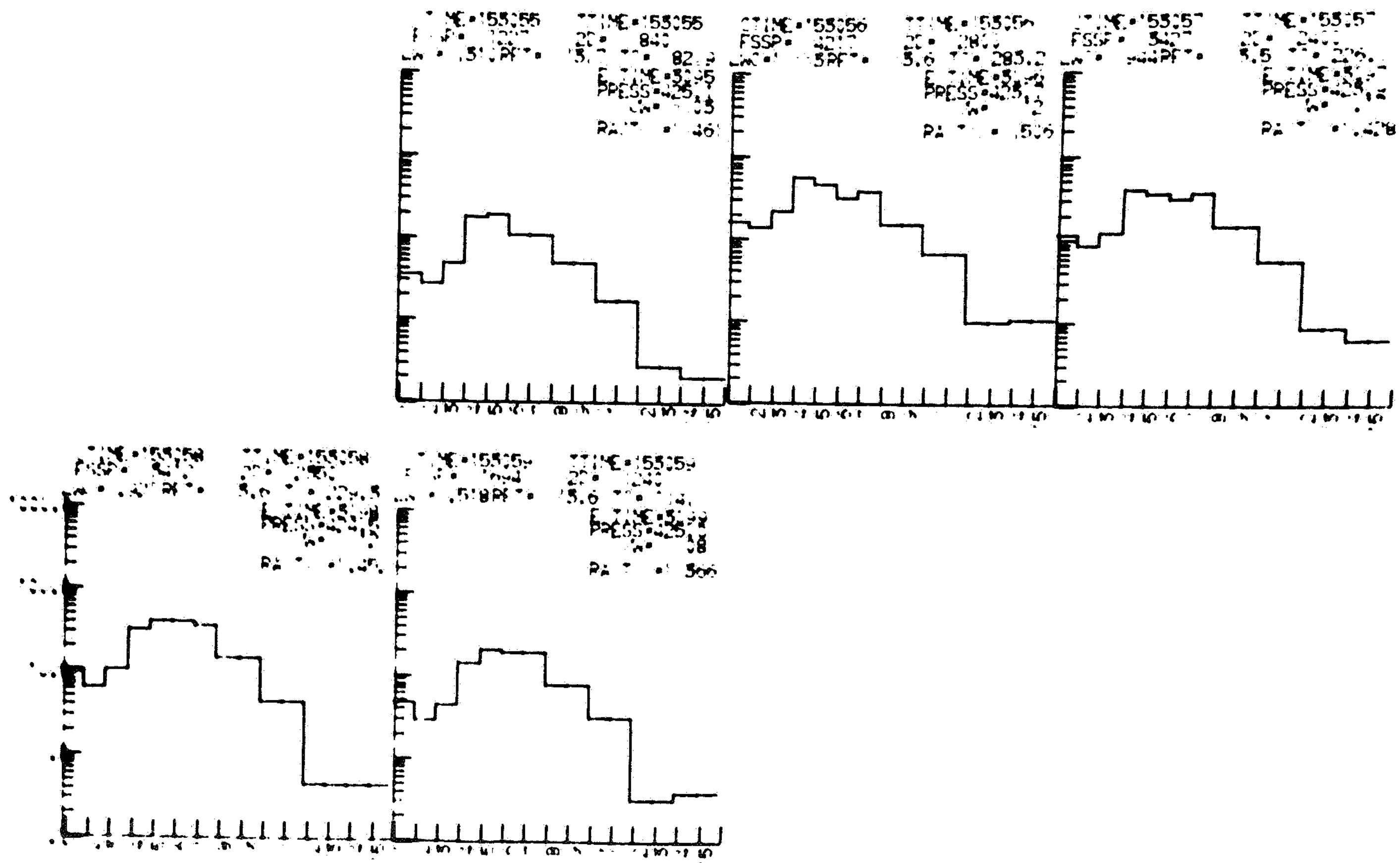

FIGURE 11. SAMPLE OF FSSP CLOUD DROPLET SPECTRA FOR A PORTION OF A T-28 CLOUD PENETRATION IN FLORIDA ON 13 AUGUST 1978. EACH HISTOGRAM REPRESENTS THE SPECTRUM OBSERVED DURING A 1-SEC SAMPLING PERIOD. THE ABSCISSA REPRESENTS DROPLET SIZE CHANNELS IN 3 μM DIAMETER INCREMENTS BEGINNING WITH 3 μM. THE ORDINATE REPRESENTS NUMBER CONCENTRATION (LOG SCALE) FOR EACH CHANNEL IN CM^{-3}. THE LEGEND WITH EACH HISTOGRAM CONTAINS A VARIETY OF RELATED INFORMATION.

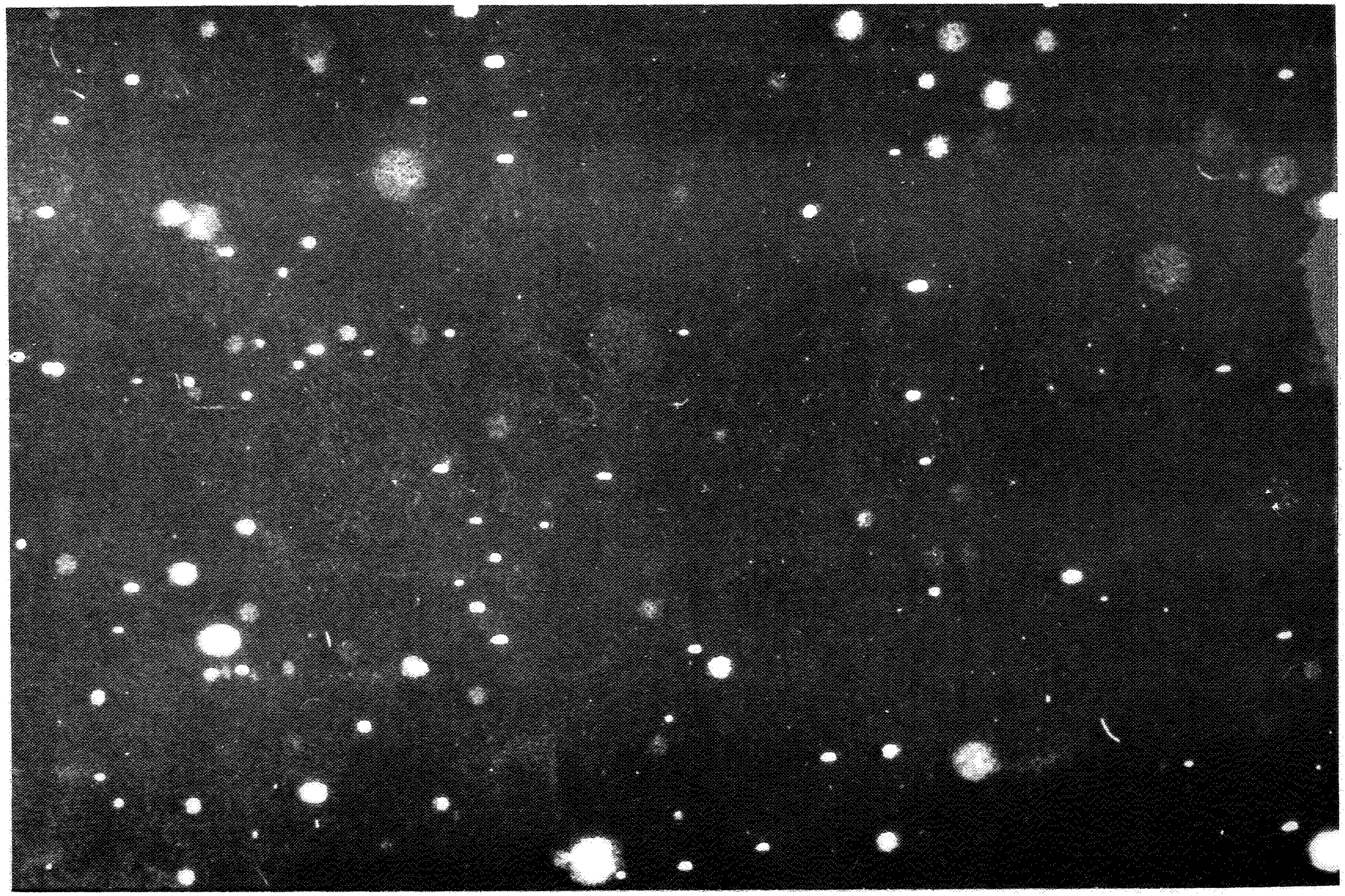

FIGURE 12 SAMPLE OF CANNON PARTICLE CAMERA IMAGES FROM A T-28 PENETRATION IN FLORIDA ON 9 AUGUST 1978. MOST OF THE PARTICLES VISIBLE ARE RAINDROPS (AS INDICATED BY THE DOT PAIRS) 1-2 MM IN DIAMETER, AND THEIR CONCENTRATION IS ABOUT 9000/^{3} THE VOLUME IN FOCUS IS ABOUT 10 LITERS.

Future plans for the T-28 system call for instrumenting the airplane to take measurements of the electrical conditions in the storm cells; redesigning the primary instrumentation system to include an on-board microprocessor which will allow data to be collected more efficiently and at a higher frequency; and installation of a flight test boom to give angle of yaw and more accurate angle-of-attack information.

In summary, the T-28 is a unique research platform for providing information about the interior characteristics of thunderstorms and hailstorms, Its full potential has yet to be reached. If you are interested in the use of the T-28 for any project or program, please feel free me at the IAS or Dr. Arnett S. Dennis, Director of the IAS.