MISHAP INVESTIGATION REPORT

1. This report is an investigation of a Class "B" Mishap.

However, the classification of this mishap is subject to change after the final totalization of damage and repairs.

2. **SUBJECT: Investigation of airframe stress, which exceeded operational limitations, and engine failure sustained by NOAA, Aircraft Operations Center Aircraft, N42RF (WP-3D) during operational penetration of Hurricane Hugo on September 15, 1989.**

3. **Equipment:** N42RF

4. **Flight Crew and Passengers:**

Aircraft Commander: (occupied right seat)
Pilot: (pilot at the controls - left seat)
Navigator:
Flight Engineer:
Radio Operator:
Flight Director:
AOC Hurricane Program Manager/Observer:

Systems Engineering Division:

Systems Engineer:
Flight Technician:
Flight Data Technician:

Hurricane Research Division:

Lead Scientist:
Cloud Physics Scientist:
Step Frequency Radiometer:
Drop Windsonde Scientist:
Radar Scientist:

Newsperson:

5. **Environment of Mishap**

a. Date: September 15, 1989
b. Time: 1728 (1328 Local)
c. Location: 14 31.4'N 054 38.0'W, 315 NM East of Barbados (S.E. Attachment 1)
d. Altitude: 1500' Absolute (Radar)
e. Weather: Hurricane Hugo:
   (1) Category 5 Hurricane - Saffir/Simpson Scale
   (2) Maximum Winds - 175 knots
   (3) Severe Turbulence

6. **Circumstances**

a. No injuries
b. Itemized Damage and Losses
   (1) Operational stress limitations (+3.0g to -1.0g) exceeded. Cockpit accelerometer indicated +5.8g and -3.5g following the subject flight. (S.E. Attachment 3). Damage assessment not yet determined. Aircraft damage assessment should be available following completion of scheduled depot level maintenance at NAS Jacksonville, FL.
   (2) Instrumentation damage: None
   (3) Torn overhead
   (4) Dented handrail
   (5) Jettisoned 15 AXBTs
c. Itemized Damage Cost

(1) Repair/Recovery of Aircraft at Barbados, U.S. Air Force Logistics Support, Per-Diem, Overtime, Ground Support, (L-100 support not included)	$41.0K
(2) U.S. Navy Inspection Team to Survey N42RF Structural Damage	20.0K
(3) Additional SDLM Cost	?
(4) Miscellaneous:	
(a) Fuel Dump: 1194 gal. at .62/gal.= $740	
(b) Fuel Control: Not applicable	
(c) Tire: $238	
(d) AXBTs: 15 @ $350 ea.= $5,250	
Subtotal: $6,228	
TOTAL:	**Not yet fully determined**

7. AOC Mishap Board (the Board)
   - Chairperson/Safety
   - Flight Operations/Pilot
   - Systems Engineering/Engineer
   - Science and Programs/Flight Director
   - Maintenance/Flight Engineer

8. Chronological Description of Events

The following description of events was compiled from the aircraft flight level data tape (FL), the radar data system tape (RT), the flight camera film, the AOC daily flight log (AOC Log), and the AOC Systems Engineering Division instrumentation Flight Performance Log (SED Log). When a time of a pertinent event could not be absolutely determined from factual data, the Board has made an estimate of the time of the occurrence based on the evidence available.

Approximately 1400Z pilots, navigators, flight directors, and scientists meet at Barbados Met office for pre-mission planning.

1555Z aircraft N42RF blocks out. (AOC Log)

161330Z, N42RF take-off. (FL)

1623Z, at enroute altitude of 9,500 feet. (FL)

1630Z, radar data system fails -- no tail or lower fuselage radar displays. (SED Log)

1655Z, radar data system back in operation. (SED Log)

1701Z, start descent. (FL)

1705Z, reached 1,500 feet, heading approx 070 degrees true (deg T) (FL)
172734Z, maximum wind speed of 175 Kts encountered. Heading 014 deg T (track 057 deg), absolute altitude 1330 ft. (FL)

172739Z, maximum downdraft of 9.5 M/S (19 Kts) encountered. Heading 027 deg T (track 057 deg), absolute altitude 1330 ft. (FL)

172756Z, maximum updraft of 21 M/S (41 Kts) encountered. Heading 018 deg T (track 053 deg), absolute altitude 1415 ft., pitch -9.2 deg. (FL)

172801Z, maximum true airspeed of 289 Kts reached -- roll is 3 degrees right, pitch is 8 degrees down. Heading 017 deg T (track 051 deg), absolute altitude 1360 ft. (FL)

172808Z, maximum down pitch of -13.2 degrees. Heading 038 deg T (track 042 deg), absolute altitude 1160 ft. (RT) (FL)

172814Z, right turn started. Heading 039 deg T (track 046), absolute altitude 910 ft. (FL)

Estimated 172815Z, #3 Engine failure noted after application of full power. (Board)

172818Z, minimum altitude of 883 feet reached. Heading 047 deg T, true airspeed 233 knots, pressure altitude 3241 ft. (FL)

Estimated 172830Z #3 Engine shut down. (Board)

172923Z, maximum up pitch of 11.9 degrees. Heading 199 deg T, true airspeed 203 knots, absolute altitude 1959 ft., pressure altitude 4320 ft., roll 29 deg. (FL)

173010Z, minimum true airspeed of 186 Kts reached (indicated airspeed of 169 knots) -- roll is 25 degrees right, pitch is 9 degrees up. Heading 345 deg T, absolute altitude 2330 ft., pressure altitude 4610 ft. (FL)

173050Z, out of right turn to left turn. Pitch 4.1 deg up, heading 110 deg T, true airspeed 205 knots, absolute altitude 2330 ft., pressure altitude 4610 ft. (FL)

1731Z-1822Z climb to 7,200 feet in left turn. (FL)

182520Z, start exit from eye, heading 060 deg T. (FL)

1825Z-1843Z, climb to 10,500 feet. (FL)

1959Z, start descent. (FL)

202130Z, land at Barbados. (FL)

2030Z, block in. (AOC Log)

The estimated time of engine failure and shutdown was set as primarily a result of the witness statements of and with supporting evidence from and . This timing was chosen after a great deal of investigation of the data tapes and study of the witness statements. The timing is based primarily upon the statements of and because their accounts most closely matched the actual events recorded by the flight level data tape. Much of the description of the sequence and timing in the statement from was discounted due to a great number of discrepancies between his statement and what the data tape shows the aircraft actually did. The discrepancies among the witness statements, while making the task much more difficult, are deemed understandable by the Board due to the fact that the crew had just been through what may be described as a

severe thrashing immediately followed by an emergency situation -- the #3 engine loss -- at the most critical time possible. Coupled with the engine loss was the tremendous concern about the possible additional problem of the "about a six foot piece of cloth rotating in the plane of the #4 prop." This concern was also stated by . "...it looked like the No. 4 prop boot had come loose and was flapping. We were concerned that it would be ingested in the engine which most certainly would be a shutdown." The board feels that when these factors are considered, it is not surprising that the recollections of the events and their timing do not all agree and further offer this situation as an explanation of why none of the crew recalls a major portion of the 410 degree turn to the right immediately after exiting the most severe turbulence.

Summary of Evidence

Preface

The Summary of Evidence section is compiled from Witness Statement extracts to provide the reader with a sequential description of the subject events in the words of the witnesses. The Summary of Evidence Section is also presented in outline form to provide a means for referencing pertinent witness statements for Mishap Board discussions in the **Analysis, Conclusions, and Recommendations** section.

9. Summary of Evidence:

Note: All personal references in the Summary of Evidence, as indicated by a name or names in parenthesis, refer to a written statement (s) provided by an individual (s) concerning his (their) experiences before, during, and after the subject Hurricane Hugo flight. These statements are considered evidence and are attached to this Section.

A. Preflight

(1) **Mission Requirements and Background**

(a) N42RF was tasked by HRD on September 15, 1989 to penetrate Hurricane Hugo as part of an energetics experiment to be accomplished in accordance with the Hurricane Field Program Plan (, Flight Schedule).

(b) Tasked flight altitudes for N42RF during the energetics experiment were 10,000 ft., 1500 ft. and 20,000 ft.

(c) Hurricane Hugo energetics experiment was the third attempt by HRD to complete the energetics experiment following two earlier unsuccessful attempts in Hurricane Dean on August 5, 1989 and Hurricane Gilbert on September 11, 1989 .

(2) **Mission Planning**

(a) Scheduled mission take-off time was 1600Z (local noon), .

(b) Mission planning began at approximately 1400Z at the Barbados Met. Office.

(c) Mission planning was initiated by who "contacted Miami for the latest information on Hugo and the track forecasts for the next 72 hours."

(d) **Pilot:** "Satellite imagery was the only information available for flight and scientific planning.

(e) "Satellite images at the

first, it was decided that everyone would be fresh and we would get it over with early in the flight."

(r) With reference to (k) above, the Flight Director stated: "These were estimates from satellite images. and I agreed that we should try to fly the storm at 1500 ft. based on these estimates. After all we had flown into Hurricane Gabrielle at 1500 ft the previous week when it had winds of 125 kts, and a central pressure of 937 mb. also indicated that he wanted to change the plan for the Vortex Dynamics Experiment and do the first part of the flight at 1500 ft; the original plan called for this work to be done 2 hours into the flight. and I both agreed that we would try it at 1500 ft., and if it was too rough go up to 5000 ft."

(s) : "For this particular mission, the decision was reached to perform that part of the experiment initially to allow time for the Air Force aircraft to complete its mission at FL 100, the desired level for the remainder of the research mission. This was the approach used on a mission into Hurricane Gabrielle twelve days earlier, on 3 September, which was flown without incident."

(t) "Penetrations have been made into many storms over the years at 1500 ft. with no problem, and certainly we should not immediately abandon this altitude based on this one incident

(u) **Navigator:** "Preflight revealed that our time on station could be about 7.5 hours which could be more than enough time to completed the planned scenario."

(v) **Navigator:** "Preflight progressed normally with one update from the NHC saying everything remains the same."

(3) <u>AOC Flight and Hurricane Experience</u>

	AOC P-3	Hurr.Pen.	Tot.Time
(a).	3700 hrs.	248	6000 hrs.
(b).	270 hrs.	36	5100 hrs.
(c).	398 hrs.	16	7198 hrs.
(d).	N/A	7	N/A
(e).	N/A	30	N/A

f. The pilot stated "Only had extensive penetration experience among flight crew members."

g. In describing factors which contributed to N42RF's mishap in Hugo, the Flight Director lists one as being, Overconfidence brought on by having so many experts on board..."

B. Transit to Hugo

(1). **Takeoff/Climbout/Level-Off**

(a). ***Flight Engineer:*** *"Departed Barbados at 1610 Z* on 15 September, 1989."

(b). **Navigator:** "Takeoff, climb to about 18000 feet and initial cruise revealed nothing unusual. The course was set for the center and the nose radar revealed the outer rain bands already being painted while the belly radar was not yet operational and visibly the storm was evident out the cockpit windows."

(c). **Aircraft Commander:** "The storm was approximately one hour from Barbados. Transit was made at 15,000 feet and plans were to descend to 1500 feet by 80 miles to make two (2) penetrations at that altitude and then climb to 10,000 feet for more penetrations and then go to 20,000 feet to finish the experiment." (S.E. Attachment 7)

(2). Enroute - Belly Radar not Functioning

(a). : "Enroute to the storm the radar data system on NOAA 42, the inner aircraft, failed. The engineers worked for 15-20 minutes and succeeded in repairing the data system just before we reached the IP and started the

mission."

(b). **Flight Director:** "As N42RF ferried out to the storm at 9000 feet, the lower fuselage radar system went out. By the time we were 100 miles from the storm, the radar was still broken and we orbited for several minutes until it was fixed. At this time the nose radar could not get a good image of the eye of Hugo, so we did not know what it looked like yet."

(c). **Program Manager:** "Early into the flight we did experience a problem with the L.F. Radar, but this was quickly solved long before we reached the storm."

(3). <u>**Enroute - Belly Radar Functioning**</u>

(a). **Flight Director:** "When fixed the radar, we descended toward the storm, leveling out at 1500 feet, 80 nm miles from the storm. At this point we were about 50 minutes into the flight. I was still busy setting up graphics screens for the scientists and monitoring the behavior of the instruments. I had very little time to study the picture on the lower fuselage radar, as I was using my data screens for other things -- and eyewall penetration was less than 15 minutes away."

(b). **Aircraft Commander:** "An Air Force C-130 (Teal 57) was in the storm on a reconnaissance mission at 10,000 ft. He was contacted about 80 miles out by us and asked the conditions of the storm. He reported 40 knots of wind at 10,000 feet on entering from the South. I questioned him to verify that 40 knots of wind was encountered and it was confirmed."

(c). **Flight Director:** "In Hugo, I was so busy in those few critical moments before the eyewall penetration, that I relied on the scientists to study the strength of the storm... However, these guys were just as busy as I was. In addition, all but one of them were handicapped by having only a black-and-white monitor to study the lower fuselage radar."

(d). : "As we approached the IP some 80 miles southwest of Hugo's center, we descended to our operating altitude of 1500 and began the penetration on a track that would take us into the southwest portion of the eyewall.

(e). observed several minutes prior to penetration after the seat belt light was illuminated: "On the LF radar display I noted the entire eyewall in the northwest through the southeast quadrants of the storm had a wide band of white, indicating reflectivity in excess of 44 dBz. On the nose radar (Collins) display at that station (sta.#7) I noted that the entire arc of the eyewall shown, the color was magenta surrounded by yellow. I do not recall red showing on the display, but it may have been."

(f). No headset was provided for the inboard seat at station #7 where was sitting prior to and during the penetration.

(g). **Pilot:** As N42RF approached the storm the crew descended the aircraft to 1500 ft. absolute altitude at approximately 80 miles southwest of Hurricane Hugo. From that location the WP-3D was flown straight to the eye of the storm at 220 knots indicated airspeed.....During the aircraft approach to the eyewall, the cockpit weather radar indicated a well formed eye that appeared to be slightly less than 10 miles in diameter. The cockpit radar return was magenta and red in color. These two colors indicate that strong precipitation and/or wind shears may be present. A turbulent penetration flight of at least two minutes was anticipated."

(h). **Navigator:** "at about 20 miles out, the winds started to increase, and our heading was altered to the left to compensate. Then on the nose radar appeared a solid band of magenta about 5 miles thick.
stated to that if the ride became rough he would start to climb, agreed, before this time nothing has been stated by anybody over the ICS as to the nature or development of the storm"

(i). **Flight Data Tech:** "To the best of my recollection, which I believe to be accurate there was no discussion between the pilot/s and the flight director regarding the advisability of penetrating the severe weather indicated on both the nose and the lower fuselage radars."

(j). **Systems Engineer:** "Before descending from ferry altitude into the storm, I verified that all large equipment was stowed or tied down, After reaching our penetration altitude (1500 ft) I passed by the flight deck to see what the storm looked like on the nose radar. We were approximately 45 miles out from the leading edge of the eyewall at this time. The eyewall looked completely closed, very small (the eye diameter was not much large than the wall thickness) and displayed as solid yellow with flecks of red. I knew this would be a rough penetration, so I walked through the cabin, double checking that everything was tied down (although I did not check the port life raft). In the galley area I verified that all of the drawers and closets were closed and latched, then strapped in the forward galley seat."

(k). **Aircraft Commander:** "The closer we got to the eyewall, the nose radar was a solid donut of red with extensive magenta indicating turbulence. The nose radar did not indicate the area of entry any more severe than other guadrants of the storm. We discussed the magenta as maybe being seaspray we we've seen before. was occupying the Chief Scientist's seat in the cockpit and he conversed with the flight crew about the storm."

C. Penetration

(1). The first two thirds of the penetration was turbulent (moderate-) but "nothing extra ordinary."

(2). **Aircraft Commander:** "About two-thirds of the way through the eyewall, all hell broke loose. Winds to 165 knots were encountered and severe turbulence encountered."

(3). **Pilot:** "The cockpit weather radar scope gave no indication that the last third of the eyewall would be different than the first two thirds of the penetration."

(4). ": "When 42 entered the eyewall, it encountered severe turbulence. Just as the aircraft emerged from the precipitation at the inner edge of the eyewall, the flight engineer had to shut down the number three engine .

(5). Both the aircraft commander and pilot indicated that when severe turbulence was encountered the aircraft became uncontrollable for possibly as long as 15 seconds and both pilots were required on the controls to regain control of the aircraft

(6). **Flight Director:** "The last seven seconds in Hugo's eyewall, N42RF experienced a 40 kt updraft lasting 3 seconds, then a 15 kt downdraft lasting 2 seconds followed by a 25 kt updraft lasting 2 seconds. During the same time, the horizontal winds decreased from 160 kt to 40 kt. These wind shears were responsible for the +6/-4 gravity accelerations experienced in the nose of the aircraft." .

(7). As the worst of the turbulence was being experienced, No. 3 engine "showed an overtemp of up to 1260 degrees C." ... "At the same time said over the intercom that flames were coming out of the No. 3 engine. The engine was immediately shutdown with the E-handle IAW NATOPS procedures."

(8). **Pilot:** "As the aircraft was nearing the end of the eyewall penetration the aircraft was uncontrollably pitched nosedown 15 degrees and right wing down 30 degrees. Both pilots were simultaneously applying pressure to the cockpit yoke to level the wings. At first all attempts to level the aircraft was unsuccessful, eventually the wings were leveled and the rate of descent was reduced. During this unscheduled maneuvering the number three engine decoupled and torched."

(9). **Flight Engineer:** "Then while attempting to maintain 220 kts IAS we began to suffer violent turbulence with the aircraft rolling right. A descent of approximately 500' occurred while <u>both</u> pilots on the controls were attempting to establish

a wings level condition... After leveling off at 1000 feet the plane commander instructed the copilot to climb. I advanced the power levers to full power for the climb. At this time the #3 engine was observed to lose all positive SHP and began to overtemp to 1250 C. At the same time was being notified of #3 torching over the IGS. I informed of the condition on #3 engine. He responded with instructions to shut down #3 engine with the emergency shutdown handle. An uneventful shutdown of #3 was accomplished. By this time we were breaking into the eye of the hurricane in a right bank into the shutdown engine. Altitude dropped further at this time."

(10). During the worst of the turbulence, the Flight Engineer stated, "All loose equipment was being thrown around during the maneuver."

(11). **Systems Engineer:** "As we hit the eyewall we went through a series of very sharp gusts, mostly in a horizontal direction. The worst hits came in quick succession. First the ice chest, stowed in the closet forward of the coffee pot, broke out into the aisle in front of me. At the same time the drawers under the microwave oven came out, somehow slipping their catches. The paper tray for the line printer also came free. On the next bump, the ice chest came off the deck, turned on its side, broke its catch and showered me with ice and soda cans. At that point I held the chest against the opposite wall with one foot, fending off a briefcase that had come out from under the coffee pot area at the same time. The turbulence ceased very soon after that as we entered the eye."

D. Recovery

(1). **Aircraft Commander:** "The engine was immediately shut down with the E-handle IAW NATOPS procedures. Very shortly afterwards, we broke out into the eye at approximately 1000 feet. The eye was 8-10 miles in diameter with little room for maneuvering. A right turn was made to stay in the eye which was down wind and into the dead engine. There was no other choice. Maximum power was on the three good engines and airspeed had dropped to 160 knots. N43RF was notified that we had an emergency and were in the eye with an engine feathered and would dump fuel... The fuel dump took about 10 minutes

(2). **Flight Technician:** "I overheard that we were dumping fuel. I looked toward Station 8 to make sure we had an aft observer. We had none. I manned that position."

(3). **Pilot:** As soon as the pilots regained control of the aircraft, it burst into the eye. The pilot noted the clouds appeared to be close to the left side of the aircraft and the eye was opening more on the right. Reluctantly, the pilot turned into the dead engine and increased the turn to approximately 40 degrees into the dead engine. Airspeed decelerated to 160 knots and altitude decreased to its lowest point during the flight, 880 ft. When sufficient turning airspace was observed to the left side of the aircraft, the turn into the dead engine was ended by leveling the wings and raising the right wing slightly. Airspeed increased to 175 knots... The aircraft was now in controlled flight, but trapped inside a very tight eye approximately 6 miles in diameter. Damage assessment activities were started throughout the aircraft..."

(4). **Pilot:** "The cockpit "G" meter read +5.6 G's and -3.5 G's. The crew damage report revealed that no personal injuries occurred. Almost everything that was not screwed to the floor came loose including a 100 lb. life raft, all kitchen drawers and most cabinets throughout the aircraft. Cockpit charts, logs, books, pencils and food items were thrown to the rear of the cockpit during the eyewall penetration."

(5). **Pilot:** "The aircraft would only maintain 190 to 195 knots in the constant 20-30 degree left hand turn with the three remaining engines operating at maximum power, 1060 to 1070 TIT. The aircraft weight was near 126,00 lbs at this point with approximately 8000 lbs. of fuel remaining in tank 5. Fuel dumping was commenced to reduce aircraft weight. During and after the fuel dump process the aircraft was able to accelerate to near 200 knots. A step climb procedure was initiated ... At the end of approximately 1 hour the aircraft reached 7000 ft. absolute altitude."

(6). **Aircraft Commander:** "After being in the eye about 40 minutes or so, the aircraft was at 9,000 feet pressure altitude...We were hesitant to exit the eye as we did not know what to expect on three

Barbados office were almost exclusively low quality facsimile products, so we were unable to estimate Hugo's intensity ourselves."

(f) **Navigator:** "The photos revealed the storm center to be about 300 miles on a true heading of about 040 degrees from Barbados." (S.E. Attachment 1).

(g) The reported minimum sea-level pressure for Hurricane Hugo was 938 mb.

(h) "The NHC satellite meteorologists estimated a minimum sea-level pressure of 948 mb and maximum low level winds of 115 kts. The hurricane forecaster indicated, however, that he thought Hugo was more intense than the satellite estimated."

(i) **Aircraft Commander:** "Predictions were about 100 knots of wind."

(j) **Pilot:** "Hurricane Hugo winds were reported to be near 100 miles per hour."

(k) **Flight Director:** "Before we took-off, our best information on the storm indicated that it had winds of 120 kts, a central pressure of 945 mb, and a 15 mile diameter eye."

(l) "was told that Hugo had a well-developed eye 15-16 nm across."

(m) "During flight planning for the Gilbert and Dean experiments HRD scientists and AOC pilots and flight directors agreed to follow the plan that is in the Hurricane Field Program Plan."

(n) "Based upon the experiences of the aircrews in these flights, the pilots of the inner aircraft for the Gabrielle experiment recommended changing the sequence of the components of the experiment and flying the 1500 ft. pattern before the 10,000 ft. and 20,000 ft. patterns."

(o) "The HRD lead scientist agreed."

(p) "The pilots of the inner aircraft in Hugo and HRD scientists also decided to do the 1500 ft.leg first."

(q) **Aircraft Commander:** "By doing the lower work

engines. The ideal thing was to burn off fuel to lighten up as long as we had no other engine problems.

(7). **Pilot:** "Both N43RF and Teal 57 assisted N42RF during the hour climbed in the hurricane eye. N42 and N43 pilots and meteorologists confirmed that the eyewall was weakest between 030 and 060 degrees."

(8). **Aircraft Commander:** "We had discussed with Teal 57 that the Northeast quadrant of the storm looked less solid. We requested that they exit to check it out. After their departure, they radioed that it was not too bad."

E. Hurricane Exit and Return to Barbados

(1). **Aircraft Commander:** "We exited in the same area at their (Teal 57) altitude on three engines and it was uneventful....N43RF joined up with us and escorted us back. A three engine overweight landing was made at Barbados."

(2). **Pilot:** "Teal 57 reported their flight at 8000 ft. (absolute) was uneventful and relatively smooth. Without hesitation N42RF completed the remainder of a turn in the eye before proceeding out of the eye on a heading of 040 degrees, at 8000 ft. absolute altitude and 220 knots...The aircraft proceeded northeasterly for approximately 25 minutes before turning to the left between two rainbands and proceeding back to Barbados. During the uneventful return to Barbados N43RF joined N42RF in a loose formation flight."

F. Crew Postflight Reflections and Recommendations

(1). **Aircraft Commander:**

(a) "...No one panicked and everyone acted professionally. Once we were into the situation, I can think of nothing that should have been done that wasn't. The aircraft was flown superbly by assisted in a very professional manner as always."

(b) "It is obvious that we had entered an area of the storm that we should not have been in. There will be a lot of second guessing on our getting into this situation. There should be no criticism on our actions after we got into the problem as all

areas were covered and every effort was made to keep the aircraft airborne in a very delicate situation."

(c) "Before I made recommendations, I think a thorough discussion should occur among parties involved and all data gathered as to what we encountered. Procedures should be changed accordingly as no one should get into this situation again."

(2). **Pilot:** "All crew members were at their assigned position when the aircraft penetrated the eyewall. No AOC crew member or HRD visiting scientist made any declaratory remark regarding the storm eyewall intensity or the selected path of penetration into the eye. The Hurricane penetration appeared to be routine in nature before the aircraft prepared to enter Hurricane Hugo's eyewall."

(3). **Flight Engineer:**
(a) "I feel that the Flight Director should maintain constant recommendations to the flight station concerning possible turbulence while penetration of the storm is in progress."

(b) "All loose equipment must be stowed while penetrating the storm."

(c) "need Telexs for all Flight Engineers"

(4). **Flight Director:** "In summary, the following factors contributed to N42RF's accident in Hugo:

1) Inaccurate information on the storm's intensity during flight planning. Being the first plane out to the storm meant we had to rely on satellite information. If another plane had penetrated the storm at a higher level several hours before we did, the accident would not have occurred.

2) Overconfidence brought on by having so many experts on board and overconfidence due to the successful flight into Hurricane Gabrielle at 1,500 feet the previous week.

3) Insufficient time to study the radar image of the storm on the way in, caused by the short ferry and the temporary loss of the lower fuselage radar.

4) Had I taken the time to study the lower fuselage display for several minutes, I may have been able to figure out that this was no 120 knot storm! The evidence was there on the lower fuselage radar - - an eye that had contracted to 10nm, strong banding indicating concentric eyewalls were beginning to develop, and reflectivity exceeding 45 dbZ in the eyewall.

5) A plan that called for doing the low-level work first. In the future, HRD should design their experiments so that the first penetration into a storm is done at high level.

6) We hit the storm at the worst possible time--within a few hours of its peak, and in the strongest part of the eyewall. In all likelihood, the tremendous wind shears we encountered existed for only a few hours of the storm's 12-day lifetime."

(5). **HRD Participants:** "The five HRD participants in the flight have discussed their recollections of the eyewall penetration. We have the following suggestions for improvements in equipment and procedures that should help to ensure that we can recognize and avoid a similar situation in the future.

1) Every station should have a headset that is in good working condition for two-way communication.

2) The lead project scientist (or the cockpit area) should have a color monitor to display the lower fuselage radar.

3) The color displays of the nose and lower fuselage radar should be set so that the highest levels of reflectivity (turbulence) represent weather conditions that the aircraft should never penetrate. The display software should be modified to permit quick changes in the reflectivity scale that could help diagnose the reflectivity structure.

4) As the aircraft approaches potentially dangerous portions of flight patterns, the pilots and flight director, with possible

assistance from the lead project scientist, should be required to discuss the safety of that segment of the flight pattern before the pilots decide to continue the mission. The discussion should be on the headsets.

5) When recent reconnaissance information on a hurricane is unavailable and there is uncertainty about the strength or possible change of intensity of a hurricane, the first eyewall penetration of a mission should at 5000 ft or higher. In future years on these initial surveys, HRD scientists will be able to estimate the structure of the wind field at low flight levels from Doppler velocity data processed on its workstations.

6) Low-level penetrations of the eyewall should not be attempted until the aircraft has burned enough fuel to climb to safe altitudes in the eye on three engines.

7) Better procedures should be implemented for securing equipment and material before penetrations.

8) AOC and HRD should discuss radar reflectivity levels and patterns that are too dangerous to penetrate. Also, criteria (e.g., radius of the eye or rate of intensification of the storm) should be considered for low-level penetrations.

9) HRD needs to reevaluate the need for low-level penetrations in view of the current capabilities of the aircraft.

10) In bases of operations without local access to high quality satellite images, it would be useful for HRD/AOC to have the capability to obtain satellite images directly.

In addition, HRD scientists who participate on the hurricane research flights are concerned about the number of engine problems in 1989, the recent departure of three experienced hurricane pilots, and the reduction in the number of flight engineers.

I believe that we have enough knowledge of hurricane structure on the P-3;s to avoid a similar situation on future research flights. All of us are committed to continuing research flights in hurricanes. We appreciate the

dedicated efforts of AOC personnel and hope that our suggestions will contribute to many years of safe flights."

(6). :

(a) "REFLECTIONS

A few words about the role of the scientists are certainly appropriate here as it is their requirements that we trying to satisfy. An AOC team of pilots, navigator and flight director makes decisions on mission planning by pooling all of the knowledge and experience of the members of that team. The team may not abrogate its responsibility for mission safety once it accepts the request and plans the flight. During the planning session the team was firmly aware of the status of the storm, in that wind speeds were estimated to exceed 120 kts. and there appeared to be a closed eye, and that the request for 1500 ft. would place the aircraft into the storm while it was still heavy. While I was not present for this planning session, I am sure that the team and the lead scientist, , must have agreed that the low level penetration would not be attempted if conditions did not look favorable once they reached the storm. Even though may not have indicated a desire to break off the 1500 ft. pattern during the mission we may not lay any part of the responsibility for what occurred at his feet. Keep in mind that the lead scientist on N42RF does not have a color monitor, and the display of the lower fuselage radar on his black and white screen is essentially useless to him. Why is there no color monitor at one of the most important positions on the aircraft? I discovered recently that the flight deck station will not accommodate the larger Sony color monitor, and it will take money and time to rebuild the station to achieve this end. Neither was available prior to the hurricane season. Perhaps some emphasis should be placed on this accomplishing this task during the coming year.

So where does all of this leave us? "Blame" is an unsuitable word for this discussion as lots of small factors contributed to the problem. The fact that not each crew member was totally tuned in to what was transpiring is probably a given, and inarguably good judgement was not observed with the decision to stay at 1500 ft. But then one can argue that we just had bad luck in running into a meteorological event of a most unusual nature. Preliminary information from HRD is

telling us that the severe turbulence took place - NOT in the eyewall but in the eye itself perhaps a small vortex of some kind. It's possible that all of the tools in the world could not have forewarned us of that! Who is to say?

Assuredly we can use this to pull ourselves out of our stoic and self-confident feeling about hurricane flying. I think that there is sufficient knowledge within AOC and HRD to allow us to adequately quantify hurricanes in terms of eye size and shape, wind speed, observed radar signatures, expected turbulence, etc., and to familiarize pilots, flight directors, navigators and other crew members with such facts. Take, for example, the two l.f. radar figures attached which were obtained from comparable penetrations into Hurricanes Gabrielle and Hugo. Both were made at 1500 ft. into the southwest quadrant of the storm. The inner eye of each storm was about the same size, about 12 miles diameter, but there the similarity ends. Gabrielle's eye was not completely closed while Hugo's was. There was an outer eye wall in Gabrielle - but not in Hugo. This latter point is of particular significance when talking about storm strength.

And, of course, there is the "G" meter on the flight deck panel and what it displayed following the penetration compared with the "G" meters located in the load center and what they did or did not reveal. The enclosed picture of the former speaks for itself."

(b) "RECOMMENDATIONS":

While further review of this incident by the Safety Officer is in order, it must be followed by a presentation of the facts as we know them and a general discussion of procedures. Until such time as the latter can be accomplished I propose that no initial penetration be made into a hurricane below the altitude of 5000 ft., even though the NHC may be classifying it as a marginal storm. After the initial run, the crew may evaluate available information on storm conditions and then, if required, make subsequent penetrations at a lower altitude.

Prior to the season of 1990, and each subsequent year, I recommend that we include in our hurricane briefing a session on storm morphology and radar depiction. We have a number of new and/or not too experienced personnel working in AOC, and a short course by the Met. staff and, perhaps, some HRD people would be in order.

(7). **Systems Engineer:**

(a) The point is that, in my opinion, major hurricanes are too unpredictable and potentially violent to penetrate at very low altitude. There is no guarantee that higher altitude implies lack of turbulence (e.g. Hurricane Emily) but the combination of violent turbulence and lack of altitude automatically changes a somewhat serious problem (like an engine failure) into a life threatening situation.

(b) There was some discussion about misunderstood information from the Air Force C-130 that indicated that the storm was much weaker that it actually was. It may be necessary to institute a policy of always making a higher level pass on the first run through a storm before considering a very low altitude. Although this may impact the pattern and duration requested by the User, it may help avoid inaccurate information about a storm and give some hint as to the strength and quantity of turbulence while the aircraft is at a relatively safe altitude. This is not the absolute solution to the problem, because scientists will continue to request low level data runs and sometimes low level features do not show up at a higher altitudes, but it may help avoid another Hugo.

(c) A better (maybe best) solution centers on an improved radar system which can detect and quantify shear and turbulence ahead of the aircraft. Whether this can be done with upgrades to the current meteorological radar will need some study. Some of the provisions for a "Dopplerized" Lower Fuselage radar were included in the recently upgraded radar data system, but full implementation will take more development and substantial ($100-$300K) funds. Until then the best we can do is Be

Careful.

(8). **Navigator:**

"The available sophistication and scientific expertise on these flights is extensive, and the experience of the flight crews is high. This type of incident most likely is unavoidable at certain points in aviation. This is how new procedures are developed. Without any other information the flight crew flew into nothing that seemed unusual to them, until the magneta appeared on the nose radar. The flight station and navigator are only equipped with black and white tv screens which I have continuously requested be upgraded to color. Even with this info we may have still only asked for more specifics about what the scientists thought but may still penetrated. An initial eye penetration at 1500 feet into unknown conditions only increases one's chances of problems due to the lack of any altitude to lose.

1) Higher penetrations may be in order initially, working our way down; vice starting low and working up.

2) At the annual pre-season hurricane meeting about August a short display of radar images with associated data could be displayed. Covering info like a well defined eye is expected to have severe turbulence and other info that scientists could convey to the flight crews.

3) Up-to-date info from the NHC is critical. On a two hour transit a hurricane could change dramatically.

4) Better scientific coordination between all aircraft in and around the storm. Though as it has been determined, the Air Force aircraft experienced nothing alarming on their penetration at 10,000 feet only 20 minutes before ours.

(9). **Flight Data Technician:**

(a) "I'm relatively new to NOAA AOC however I had at the time of this flight over 120 hours in the WP-3D which included all flights for the North Dakota Thunderstorm Project and penetrations into hurricane Gabrielle at 1500 ft. Without exception on all my previous flights when radar showed high reflectivity on the planned aircraft flight track the pilot/s discussed with the flight director the advisability of penetrating the areas of high reflectivity. They carefully weighed safety against science and made calculated decisions."

(b) "I was at the data station for this entire flight, on the headset, monitoring all conversations as I normally would be....To the best of my recollection, which I believe to be accurate, there was no discussion between the pilots and the flight director regarding the advisability of penetrating the severe weather indicated on both the nose and the lower fuselage radars."

(c) "I feel that had the data displayed by our radars been considered properly a correct decision to avoid the eyewall at the point we penetrated, at least a 1500 ft., the incident and near fatal accident would have been avoided."

Analysis, Conclusions,and Recommendations

Preface

During N42RF's penetration of Hurricane Hugo at 1500 ft. on September 15,1989, an intense and severely turbulent small scale convective cloud was encountered near the eyewall. As a result of the severe turbulence, N42RF was subjected to vertical gravitational forces ("Gs") which exceeded the operational limits of the aircraft. Very strong lateral "Gs" were also encountered simultaneously. During the worst of the turbulence, No. 3 engine overtemped and torched requiring shutdown. The subsequent successful recovery and egress from Hugo on three engines required approximately one hour of maneuvering, climbing, and egress coordination with N43RF and the Air Force C-130. After returning to Barbados, a U.S. Navy P-3 inspection team was requested to determine the extent of structural damage. Because of damage found, the team recommended that N42RF be placed into SDLM for further structural evaluation and repairs.

The following Analysis, Conclusions, and Recommendations Subjects dicuss the cause factors leading to the mishap.

Subject 1: Airframe Stress

Analysis:

Background: During N42RF's penetration of Hurricane Hugo at 1500 ft. on September 15, 1989, severe turbulence was encountered in the last third of the eyewall. S.E. C(1&2), . The cockpit accelerometer ("G"-meter) indicated that the aircraft had sustained +5.8 and -3.5 G's. A subsequent inspection report to check the calibration of the "G"-meter revealed that the +5.8 reading was accurate. The -3.5 reading read low at -3.3 G's so in reality the aircraft was subjected to -3.7 G's. S.E. Attachment 3.

Discussion: The gravitational forces (G's) experienced by N42RF in the cockpit cannot be compared with the G's experienced at the pitch or vertical axis of the aircraft. N42RF's Inertial unit's Earth Vertical Accelerometer, which is located at the aircraft's center of gravity near the pitch axis, records filtered (slow rate) vertical acceleration. As a result, instantanous peaks such as those recorded on the cockpit "G" meter are not determined. Only two second interval vertical acceleration averages are recorded. As a result, one cannot determine if the whole aircraft was subjected to the same instantaneous "G's" that were experienced in the cockpit. , however, in his memorandum of February 21, 1990 provides, "-Possible Explanation of High G Meter Values." S.E.
Attachment 4.

Conclusions:

The Board concludes that explanation, as described in S.E. Attachment 4, is the most plausible explanation for the cockpit "G"-meter indications. The Board cautions, however, that due to the extreme attitudes experienced by N42RF during the last third of the eyewall penetration, the data measuring capabilities of the aircraft may have been reduced. All aircraft recorded measurements are compensated for attitude. The aircraft attitudes experienced during the extreme turbulence encountered in the eyewall penetration exceeded the limitations for which full measurement compensation is achieved. As a result, figures 1, 2, and 3 of memorandum, which were used to justify his discussion, may not be exact representations of actual events.

Recommendations:

1. Stress to hurricane pilots during training the importance of maintaining a reasonably constant nose attitude during turbulent flight. Excessive corrections to maintain mission desired altitude should be avoided.

2. During actual turbulent flight conditions, aircraft commanders are encouraged to openly discuss turbulent flight techniques to re-emphasize classroom discussions.

SUBJECT 2: Number Three Engine Malfunction and Subsequent Shutdown During Eyewall Penetration

ANALYSIS:

BACKGROUND: On 15 September 89 during initial penetration of Hurricane Hugo "about two-thirds of the way through the eyewall" "winds to 165 kts were encountered and severe turbulence encountered" "About this same time the No. 3 engine showed an overtemp of up to 1260° C." "At the same time, (Station 5) said over the intercom that flames were coming out of the No. 3 engine"

Flight Engineer account (C. [9]): "We began to suffer violent turbulence." The plane commander instructed the co-pilot to climb." "I advanced the power levers to climb." At this time #3 engine was observed to lose all positive SHP and began to overtemp to 1250° C." At the same time was being notified of #3 torching." "He responded with instructions to shutdown #3 engine with the emergency shutdown handle." "An uneventful shutdown of #3 engine was accomplished."

QUESTIONS TO BE ANSWERED:

1) What caused the loss of power, overtemp and torching?

2) Was this failure caused by the turbulence that was encountered?

3) Would the crew have had any advance warning that could have been recognized on the cockpit instruments to alert them of this impending failure?

CONCLUSIONS:

1) The cause of the loss of power, overtemp and torching: The main fuel control. After the main fuel control was replaced (during ground maintenance in Barbados) the engine ran normally with no evidence of torching, overtemp and/or compressor stall.

2) The specific failure within the fuel control was a malfunctioning compressor inlet temperature assembly. This was discovered by a bench test during an engineering investigation performed by NAVAVNDEPOT Norfolk, Va. (requested by AOC Safety office). The conclusion reached by the engineering investigation: "The failure reported was not caused by the severe turbulence experienced by the aircraft (letter [I.a.^{2}] attached)."

The board agrees with this conclusion.

3) During a phone conversation with , Engineering Technician at NAVAVNDEPOT Norfolk, he stated that this type failure was not uncommon in the NAVY over the years and every one is indicated by a torch, overtemp, and compressor stall. It could only be recognized when the failure occurs and the sensor is rendered inoperative. Being inoperative, it has the effect of providing an excessively rich fuel flow producing the indications which N42RF experienced in Hugo requiring engine shutdown.

RECOMMENDATIONS:

In view of the Navy's engineering investigation report,(S.E. Attachment 2), related information: "The failure mode of the CIT sensor is not uncommon on high time fuel controls (4158.4 hours since new). No repairs had been made to this fuel control since new," and the probability that the same condition exists on other currently installed fuel controls on our aircraft:

1. Determine the status of fuel controls on N42RF and N43RF.
2. Replace any fuel controls found to be in the condition described in the engineering report.

Subject 3: N42RF's Initial Penetration of Hurricane Hugo at 1500 ft. Absolute Altitude

Analysis:

Background: The Hurricane Energetics and Budgets Study, as described in S.E. Attachment 7 (an excerpt from the 1989 Hurricane Field Program Plan), calls for three separate flight levels to be flown by the inner aircraft for hurricane penetrations. These flight levels are to be flown in the order of 10,000 ft, 1500 ft and 20,000 ft. absolute altitude respectively. No scientific advantage is realized by flying the three flight levels in the established order. S.E. Attachment 9. With respect to flight safety, however, there are several distinct advantages gained by flying the 10,000 ft. flight level as the initial hurricane penetration altitude vs. the 1500 ft. flight level. These advantages include:

1. Real time hurricane strength estimates can be made before deciding to perform the lower penetration work where storm intensity is concentrated and is possibly greater.

2. Should aircraft power and/or control difficulties be experienced during the penetration wider hurricane eye space exists for maneuvering at the higher altitude than the lower altitude. More altitude is also available as a trade-off for airspeed,if necessary, to stay above Vmc air or to maintain best turbulence penetration airspeed.

3. Center tank fuel would be expended or nearly expended prior to the low penetration altitude. The aircraft configuration of full wing tanks and no center tank fuel enhances aircraft strength. Fuel dumping would not be necessary as part of an emergency recovery procedure in the event of a power loss. Airspeed would be more easily maintained where little trade-off altitude is available.

Flight Planning: A decision was made during flight planning at the Barbados Weather Office, by the N42RF flight crew, to change the initial penetration altitude of Hugo from 10,000 ft. to 1500 ft. absolute. This decision was based upon three considerations:

1. Hugo strength estimates by the National Hurricane Center (NHC) forecasters indicated that Hugo was similar to Hurricane Gabrielle which was flown at 1500 ft. absolute initial penetration altitude twelve days earlier. SE A(2) (c&r). The flight crew was unable to make Hugo strength estimates themselves because of poor facsimile products at the Barbados Weather Office. SE A(2) (d&e).

2. Aircrew experiences in hurricanes Gilbert, Dean and Gabrielle supported the decision to change the initial penetration altitude to 1500 ft. SE A(2)(m&n). These experiences revealed that the Energetics and Budgets Study inner aircraft flight requirements are especially demanding on the pilots. S.E. Attachment 9. Since the 1500 ft. flight level is potentially the most hazardous,
stated that "By doing the lower work first, it was decided that everyone would be fresh and we would get it over with early in the flight". SE A(2) (n,o,p,q). S.E. Attachment 9. had also suggested to , following a previous energetics flight, that the 1500 ft. flight level should be flown first for the same reason. S.E. Attachment 9. This fact was verified by in conversation with on January 22, 1990.

3. A third reason for not flying the 10,000 ft. penetration altitude first was offered by who stated that "For this particular mission, the decision was reached to perform that part of the experiment initially to allow time for the Air Force aircraft to complete its mission at FL 100...." SE A(2) (s).
The Board accepts this reason as a preflight consideration although not expressed in any other witness statement. Just because the Air Force's occupation of FL 100 is not mentioned by anyone other than does not mean that it was not considered. The fact that N42RF communicated with the Air Force plane (Teal 57), S.E. B.(3)(b), enroute indicates previous knowledge of the Air Force's presence. It is also common knowledge that the Air Force does reconnaissance at FL 100 in hurricanes.
The larger issue is the lack of understanding by AOC personnel that FL 080 or 120 would have sufficed scientifically. However, if the AOC flight crew was not aware of the flexibility of FL 100, then 1500 ft. was the only working altitude available. The aircraft was too heavy to work at FL 200.

Conclusions:

The three considerations discussed previously for changing the initial penetration flight altitude from 10,000 ft to 1,500 ft. absolute, although warranting some consideration for flight planning, do not offset the safety advantages previously listed for a 10,000 ft initial hurricane penetration altitude. More pertinent considerations for hurricane penetrations in Hugo should have included:

1. The possibility of engine loss at high aircraft weight and low operational altitude.
2. Possible inaccuracies of NHC hurricane strength estimates taken solely from satellite imagery.

3. The warning from NHC forecaster that Hugo may be more intense than what the satellite imagery indicated.
4. Past experience from AOC hurricane missions has shown that hurricane penetrations must be approached warily below 5000 ft absolute altitude.

These considerations are discussed in greater detail below:

1. Engine loss is possible during any flight evolution and should be considered as part of mission planning with respect to the environment in which the flight mission is conducted. Just as engine loss with respect to aircraft weight and runway length is considered for take-off abort, engine loss at critical weights and altitudes during hurricane penetrations must also be considered with respect to emergency hurricane egress. N42RF demonstrated the performance capability to make an emergency egress from Hugo on three engines. The egress was very difficult, however, due to high aircraft weight and the environmental combination of small hurricane eye diameter and hurricane eye thermodynamics which increases density altitude. SE D(1-8).

2. AOC flight crews, often, are required to rely solely on NHC hurricane strength estimates and forecasts for flight planning. Such was the case at the Barbados Weather Office where the facsimile products were of such poor quality, they were unusable SE A(2) (e). Satellite information is useful to the extent that the flight crew is provided with historical storm information permitting storm trend analysis. The accuracy of the information and thus the trend analysis, however, may be unreliable for the reasons given in S.E. Attachment 5. Trend analysis, also, does not provide the flight crew with accurate real time hurricane strength information needed for estimating low level penetration hazards and risk. Real time information is critical because of the potential inaccuracies of forecasting as well as for the possible vagaries of a hurricane. Hurricanes can quickly alter their historical trends by strengthening/weakening and/or changing directions. Hurricane Jerry was such an example during the 1989 hurricane season.

3. During flight planning at the Barbados Weather Office, was cautioned by the NHC forecaster that he thought Hugo was more intense than the satellite estimate. SE A(2) (h). Such a caution by a NHC forecaster confirms the unknown nature of a storm that has not been investigated by an aircraft.

4. description of closed eyewall hurricanes lists a number of reasons, based upon past AOC experiences flying hurricanes, why hurricanes must

the strong (magenta) nose radar return. S.E. B(3)(k).
also stated that he had never turned around before in a hurricane so turning around in Hugo was not seriously considered, only climbing if the flight became too rough. S.E. Attachment 10, S.E. A(2)(r).

The Board feels that the penetration should not have been continued at 1500 ft. Although, specifically speaking, the vigorous small scale (< 5nm horiz.) convective cloud encountered by N42RF on the inner edge of the eyewall was not discernible from other high radar reflectivity, the high reflectivity being painted on the nose radar, in general, should have indicated that continuing the penetration was not prudent. S.E. B(3)(h,i,j,k,), W.S. . The Board is concerned that if an AOC hurricane aircraft commander of
experience, S.E. A(3)(a), was not able to recognize and properly respond to the hazards of Hugo as indicated on radar, what then can be expected of an AOC hurricane aircraft commander with less experience?

The Board is more concerned, however, about the lack of crew communication from the Initial Point to the point of the mishap. While observing high reflectivity on the nose radar, neither belly radar information nor the Flight Director's opinion were requested by It should also be noted that belly radar information was not offered by anyone, most noteably the Flight Director, when maximum reflectivity was being indicated. Subject 4: Crew Communication Deficiencies is an expansion of the above discussion.

The Board cannot firmly establish why N42RF's crew did not use or properly interpret all of the assets at its disposal during the penetration of Hugo. Because of the hazardous environment of hurricane flight operations, it is essential for both flight safety and mission efficiency, that the capabilities and limitations of the WP3-D aircraft are known and utilized thru effective crew communication by AOC's hurricane flight crew's. Even though the Board recognizes that experience and training will not preclude misjudgement and misinterpretation by AOC hurricane flight crews in the future, a comprehensive hurricane flight operations training program is considered by the Board to be the proper method to provide the assurance to the Director, AOC that AOC hurricane flight crews are "mission ready." At AOC there exist no defined training program specifically for hurricane operations. What has sufficed, quite adequately for the most part in the past, is hurricane flight training by "word of mouth" and by lessons learned through actual hurricane in flight experience. Such training methods, however, no longer provide the assurance that all AOC hurricane flight personnel will be provided with all of the best hurricane flight information available for use in flight planning, hazard recognition, risk analysis, and subsequent operational decision making.

be carefully considered with respect to penetrations below 5000 ft. S.E. Attachment 5. Even working with the underestimated strength of Hugo provided by the NHC during flight planning, Hugo deserved these same considerations.

The preceding four considerations were fully applicable to N42RF's inner aircraft mission for Hugo. These considerations, however, were not an effective part of mission strategy established during the mission planning stage for Hugo. Instead "crew freshness," a comparison to Gabrielle, and possibly the Air Force's occupation of FL 100 were the only reasons used to lower the initial penetration altitude.

Even though the decision to penetrate Hugo at 1500 ft. initially was discussed and agreed upon during flight planning by the aircraft commander, HRD scientists, and the flight director, S.E. A(2) (n-r), the ultimate responsibility for the execution of that decision lies with the aircraft commander. He is the person who must weigh the scientific mission requirements or requests against the capabilities of the aircraft and aircrew to conduct the mission with the requisite prudence to accomplish the mission while preserving human and material assets.

decision to penetrate Hurricane Hugo at 1500 ft. initially was prudent. Even though not determined during flight planning (S.E. Attachment 10), N42RF's three engine performance capability was considered by the Board and demonstrated in the egress to be adequate. In addition, the Board considers that Hugo's strength, as estimated by NHC during flight planning, indicated that Hugo was workable using a 1500 ft. penetration altitude. The Air Force's presence at F100 and being too heavy to work FL 200 were added considerations. was not aware, nor was it stated in the Hurricane Energetics and Budget Study or volunteered by HRD personnel, that FL 080 or 120 were Air Force conflict alternatives. However, because Hugo was of hurricane strength, the Board strongly feels that Hugo warranted strength reevaluation enroute to reafirm the prudence of 1500 ft. as an initial penetration altitude. This, however, was not done.

Inbound to Hugo from the Initial Point, did converse with about the nose radar indications. S.E. B(3)(k). The Flight Director was not included in the discussion for which subsequently had no explanation. S.E. B(3)(h&i), S.E. Attachment 10. With N42RF's nose and belly radar systems indicating very rough weather ahead and a hurricane more intense than the NHC satellite estimates, the penetration was continued. S.E. B(3)(e,g,h,i,j,k).

The Board concludes that continued the penetration because he underestimated and misinterpreted the strength of Hugo from the radar indications. referred to "seaspray" as "maybe" being responsible for some of

Recommendations:

AOC's hurricane pilot experience level has been significantly reduced through retirements during the last five years. As a result, AOC pilots with limited hurricane experience (< 50 penetrations) will be assigned to hurricane aircraft commander duties in the future. Time and limited hurricane opportunity do not allow AOC to continue with empirical hurricane training methods with the expectation that less than 50 penetration aircraft commanders will have the knowledge needed to safely command a hurricane mission. A structured hurricane operations training program for new pilots and flight directors as well as an annual refresher program for the experienced personnel is recommended. The ultimate goal of such a program should be to provide hurricane flight personnel with a full understanding of the use of all the assets at their disposal for the decision making required to fly in a severe weather environment. A formal hurricane operations training program should be encapsulated in a document which can be easily referenced or changed as new lessons are learned or equipment is changed. As a minimum, a hurricane operations training program should include:

1. **Radar Use and Interpretation**
2. **Convective Meteorology**
3. **Crew Coordination**
4. **Flight Planning**
5. **Aircraft Capabilities**
6. **Lessons Learned**

The Board recommends that a committee be established as soon as possible comprised of a representative from each AOC Division and Safety and chaired by Flight Operations to develop a hurricane operations training program as described above.

Subject 4: Crew Communication Deficiencies Prior to Encountering Eyewall Turbulence.

Background:

The decision to make the initial penetration into Hurricane Hugo at 1500 feet was made during flight planning at Barbados. The ferry out to the IP, about 80 nm SW of the eye, was uneventful except for the failure of the Lower Fuselage radar enroute. It was repaired by about 100 miles out and fully operational. The people who had access to color LF radar displays were , , , and . Nose radar was available to , , , and . These two radars are the only look-ahead instruments on the aircraft.

Analysis:

Sufficient personal comments have been made about the lack of discussion on the ICS that the board can accept it as fact. reports, "At about 20 miles out, the winds started to increase, and our heading was altered to the left to compensate. Then on the nose radar appeared a solid band of magenta about 5 miles thick. stated to that if the ride became rough he would start to climb, agreed. Before this time nothing had been stated by anybody over the ICS as to the nature or development of the storm". reports the well-understood knowledge that, "The flight director or pilot has the option of instantly aborting the penetration at any time prior to reaching the eyewall...". Yet he also says, " and , who had a headset but no mike, reported to me that there was no discussion between the flight director and the pilot during the penetration". says, " Without exception on all my previous flights when radar showed high reflectivity on the planned aircraft flight track the pilot/s discussed with the flight director the advisability of penetrating the areas of high reflectivity. They carefully weighed safety against science and made calculated decisions". He then states, "To the best of my recollection, which I believe to be accurate, there was no discussion between pilot/s and the flight director regarding the advisability of penetrating the severe weather indicated on both nose and lower fuselage radars. The only conversation took place after we were already experiencing extreme turbulence as to whether to climb to 5000 feet. The pilot indicated it was too late".

Reasoning for lack of ICS communication:

states, "From the radar display, it was noted that it looked just like Hurricane Gabrielle which was flown in the same area a couple of weeks earlier for the same experiment with the same profile". He adds, "The closer we got to the eyewall, the nose radar was a solid donut of red with extensive magenta indicating turbulence. The nose radar did not indicate the area

of entry any more severe than other quadrants of the storm. We discussed the magenta as maybe being seaspray as we've seen before. was occupying the Chief Scientist's seat in the cockpit and he conversed with the flight crew about the storm". However, numerous accounts from the analysis section indicate this was not discussed over the ICS, so it was a closed conversation between , , and perhaps . clarifies who was directing the tracks when he reports, "Talking to the flight director, I believe that we determined that it was not a critical fix and that I could direct the aircraft into the eye." This decision was made 120 miles from the eye. had seven penetrations hurricane experience at the time. He and other crew members relate no further ICS communication about storm structure and radar presentation until just before (or at) eyewall impact. This is, in most cases, a point of no-abort. The safest route is the shortest track throught the eyewall.

Why was there so little discussion between the Aircraft Commander and the Flight Director? Here we refer extensively to updated statement of 20 February 1990. He states, "At this point (about 80-100 nm out), we were about 50 minutes into the flight. I was still busy setting up graphic screens for the scientists and monitoring the behavior of the instruments. I had very little time to study the picture on the lower fuselage radar, as I was using my data screens for other things - and eyewall penetration was less than 15 minutes away. Had I taken the time to study the lower fuselage display for several minutes, I may have been able to figure out that this was no 120 knot storm! The evidence was there on the lower fuselage radar - an eye that had contracted to 10 nm, strong banding indicating concentric eyewalls were beginning to develop, and reflectivity exceeding 45 dbZ in the eyewall". He then states that, in Gilbert the year before, he had seen the same evidence and made the correct decision to climb from 5K to 10K on the first inbound leg. In that storm, however, he had been advised by both and to not fly the rapidly-intensifying storm below 10K feet. He further clarifies, "In Hugo, I was so busy in those few critical minutes before the eyewall penetration, that I relied on the scientists to study the lower fuselage radar in detail and determine the strength of the storm. After all, we had most of the world's experts on hurricanes on board - , , , ".

Then, attempts to state a collective view of all on board of, "Everyone thought: "Well, if no one is saying we shouldn't go in at 1500 feet, it must be OK". In reality, everyone had misgivings about going in that low. When the big donut of fuchsia appeared on the nose radar, everyone thought, "Let's not go through that at 1500 feet." But nobody said anything." Earlier he notes two personal attitudes about hurricane flying with, "I held two attitudes which may have contributed to my decision to keep the plane at 1500 feet. One was a reckless "we can do that!" attitude, brought on by stubbornness and an eagerness to experience an exciting penetration. The other attitude was, "Boy, these scientists are sure stupid for wanting to go in at 1500 feet, but

we'll show them just how stupid it is!". He follows with, "If I had not had these attitudes, I still would have chosen to go in at 1500 feet; nevertheless, future flight directors and pilots must guard against letting such personal feelings causing unsafe decisions."

Thus, the initial penetration was likely handled by and discussing the radar structure on the flight deck, calling the inbound tracks from the nav station, and setting up data screens.

The only other possible contributors to the radar analysis aboard N42 were the HRD scientists at the radar station and station 7. Their role may be clarified by the phone conversation between and , where the question is asked of , " occupied a seat with a colored monitor. Why didn't he say something?". replies, " has a reputation for pushing the weather; however, in Gabrielle he expressed some reservations about one of the penetrations (the first one, at 1500 feet). at that point chastised for his reservation which seemed out of character. later apologized to , but still feels may have been "cowed" during the Hugo flight."

It should be noted that several station positions had either no headset available or a headset with no mike . However, we hesitate to add this to the reasoning for the lack of ICS comms, as these two individuals had no operational responsibility for the penetration.

Conclusion:

There was little communication about the upcoming eyewall penetration among the key AOC crewmembers on the inbound leg at 1500 feet. No discussion of the radar presentation took place over the ICS. No advisories of the likelihood of turbulence ahead were made by the flight director, and none solicited by the aircraft commander. These findings run completely contrary to the customary manner in which AOC normally penetrates severe weather.

felt he had sufficient weather and radar analysis from to continue the inbound leg. He was misled by as to the nature of the magenta seen ahead on the nose radar. also states that he had never turned around before, so he did not think it was necessary to turn around in this instance.

was apparently tasked by to call the track corrections on the inbound leg, thus assuming operational direction of N42RF.

lack of an operational or advisory role on the inbound leg was caused by two primary reasons: (1) The distraction of setting up data screens for scientific use instead of using the two sources of look-ahead information, the NOSE and LOWER FUSELAGE radars, to view the eyewall, and (2) his deferral of the eyewall radar analysis to HRD 'experts' on board. He was also less inclined to warn the A/C away from 1500 feet because of his anticipation of an 'exciting' eyewall penetration. Another reason may have been his desire to show HRD how 'stupid' a decision it was to penetrate at 1500 feet.

It is left as an open question why no HRD scientists commented on the radar intensity. It may have been that they were hesitant to comment after was chastised by for using caution during the Hurricane Gabrielle flight the week before.

Recommendations:

1. The safe execution of complex flight patterns near and sometimes through severe weather will only be accomplished successfully by the teamwork of all AOC flight crewmembers. This is because different types of expertise, all pertaining to safe flight, are reflected in the makeup of the AOC crew. Flight directors are not expert navigators, navigators are not qualified engineers, and pilots are not the best source of weather analysis. Each member of the team must make essential contributions to the mission accomplishment, and the entire mission suffers if all crewmembers are not doing their part. The concept of teamwork and communication cannot be overstressed in training sessions.

2. The first penetration of a hurricane at a given altitude, or any other first execution of a research pattern near possibly severe weather, is always a trip into the unknown to some degree.

With almost no exceptions, this first pass, coined an 'analysis run', is our greatest opportunity to gather all of the important indications of how the whole flight will go. This is the time to look hardest at the radar presentation and out the window, then make educated comments over the ICS to pilots, flight directors, and the rest of the crew. No other duties will be allowed to supersede the analysis of what we're about to fly through.

3. AOC crewmembers shall not abrogate the responsibility of flight safety to visiting scientists, regardless of their experience or knowledge. They may understand a certain atmospheric phenomenon better than anyone at AOC, but may also have a poor grasp on how best to fly a large aircraft in the vicinity of that same phenomenon. Visiting scientists oversee the accomplishment of research requirements, with much more of an observer's role than an advisory one. Past experience of research flying has shown that, (1) visiting scientists promulgate and push for the most complex patterns possible to maximize science gathered versus costs, and (2) always rely on AOC judgement to decide when a requested pattern becomes too hazardous. Experience also shows AOC is rarely if ever criticized for making too conservative of a decision involving aircraft safety. This is an important piece of knowledge to carry with us into severe weather, and will be highlighted in AOC training.

4. The aircraft ICS is the only common link with all AOC crewmembers. It is the required network for the flow of operational planning aboard AOC WP-3Ds. While both pilots and flight directors may agree on what's ahead, the only way to be sure is to discuss it over the ICS. The decision of a pilot to penetrate possible severe weather seen on radar is bound to be harder to make without some analysis from the flight director. As a side bonus, when this analysis is relayed over the ICS, the rest of the AOC crew is reassured that the people up front are looking and thinking ahead.

11. Summary of Recommendations

Subject 1: Airframe Stress

Recommendations:

1. Emphasize to hurricane pilots during training the importance of maintaining a reasonably constant attitude during turbulent flight. Excessive flight control corrections to maintain mission desired altitude should be avoided.
2. Aircraft commanders are encouraged to openly discuss turbulent flight techniques with their copilot and flight engineer when turbulent flight conditions are expected.

Subject 2: Number Three Engine Malfunction and Subsequent Shutdown During Eyewall Penetration

Recommendations:

1. Determine the high time status of the fuel controls on N42RF and N43RF.
2. Determine if the above fuel controls have received repairs since new.
3. Remove and replace any of the above fuel controls which are high time and have not received repairs as described in S.E. Attachment 2.

Subject 3: N42Rf's Initial Penetration of Hurricane Hugo at 1500 ft. Absolute Altitude

Recommendation:

1. AOC's Flight Operations Division, with the assistance of Maintenance, Science and Programs, Systems Engineering and Safety, should develop and implement a formal hurricane operations training program. The program should be encapsulated in a document which can be easily referenced or changed as new lessons are learned or equipment is changed. The ultimate goal of such a program should be to provide hurricane flight personnel with a full understanding of the use of all the assets at their disposal to support the decisions required to fly in a severe weather environment. As a minimum, a hurricane operations training program should include:

   (1) Radar Use and Interpretation
   (2) Convective Meteorology
   (3) Crew Communication
   (4) Flight Planning
   (5) Aircraft Capabilities
   (6) Lessons Learned

   The Board recommends that a committee be established as soon as possible comprised of a

representative(s) from each AOC Division and Safety and chaired by Flight Operations to develop a hurricane operations training program as described above.

Subject 4: Crew Communication Deficiencies Prior to Encountering Eyewall Turbulence

Recommendations:

1. During hurricane operations training sessions, stress the concept of teamwork and flight crew communications as being essential for the promotion of an efficiently and safely directed mission.
2. The first penetration of a hurricane at a given altitude, or any other first execution of a research pattern near possibly severe weather, is always a trip into the unknown to some degree. With almost no exception, this first pass, coined an "analysis run", is our greatest opportunity to gather all of the important indications of how the whole flight will go. This is the time to look hardest at the radar presentation and out the window, then make educated comments over the ICS to pilots, flight directors, and the rest of the crew. **NO** other duties will be allowed to supersede the analysis of what we are about to fly through.
3. AOC crewmembers **SHALL NOT** abrogate the responsibility of flight safety to visiting scientists regardless of their experience or knowkedge.
4. The ICS is the **only** common link with all AOC crewmembers aboard the aircraft. It is the required network for the flow of operational planning in flight.

Subject 5: Equipment Deficiencies

Recommendations:

1. Absence of internal communication equipment at specific seating locations is not considered to be a contributing factor in this mishap. Since there is adequate equipment on board the aircraft to meet the ICS communication requirements of the misson, the Board simply reiterates that one must check the equipment at the station one is occupying to ensure that the proper equipment is available well in advance of the anticipated need.
2. All radar operators should review the operation of the radar systems, and additional training should be provided for the operators in the area of radar interpretation. AOC should investigate the possibility displaying two levels of turbulence data on the nose radar indicators and/or the possibility of altering the turbulence threshold.

Subject 6: Satellite Estimation Deficiencies

Recommendation:

1. Stress th following points during hurricane operations training sessions:

   a. **All** satellite estimations are just that - estimations - with unknown error. For hurricane operations flight planning and operations, they should be treated as the most general of guidance.
   b. When with storms AOC has not yet flown, it is the flight director's responsibility to find out from CARCAH and NHC where the estimated storm strength comes from. If it comes from a satellite, the farther east the storm, the more one cannot trust the estimate. In this case, it is a good idea to talk with the Hurricane Specialist on duty to see how they feel about the satellite estimate.
   c. If the storm strength comes from an Air Force RECCO plane, the observation almost always comes from 10,000 ft. or higher if it is a hurricane. The Air Force uses dropsondes for surface pressure, and are usually fairly accurate, but 10,000 ft. winds do not always give good approximation of the lower altitudes. Turbulence at 10,000 ft., or lack thereof, is very poor guidance of what to expect at 5,000 ft. or 1,500 ft.

Subject 7: Emergency Recovery Procedures

Recommendations:

1. Emphasize during hurricane operations training the critical importance of strict attention to proper directional control.
2. During the Convective Meteorology portion of hurricane operations training, stress the eye characteristics associated with different types of hurricanes.

Subject 8: Inadequately Secured Objects

Recommendations:

1. 20 man life raft: Install additional tie down strap(s) to prevent the raft from slipping out during side loads.
2. Cabinet doors and galley drawers: Improve latching with a more positive means.
3. Paper tray: Secure properly in its mounting.
4. Loose Equipment: Manufacture and install cargo netting for the areas where equipment is stowed.

5. Briefcases/Flightbags: provide straps at each station to secure bags to seat tracks or other secure points.

Subject 9: Interpretation of Displayed Radar Information

Recommendations:

1. Provide training for and emphasize the importance of properly interpreting radar displays. The crew members aboard the WP3-D aircraft during hurricane missions must make full use of the aircraft's radar systems which are the best tools available for determining the characteristics of the weather ahead. Crew members must also be aware of the limitations of these tools.