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SUBMARINE NAVIGATION UNDER THE NORTH POLE

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Abstract

Inertial navigation systems have played a critical role in the exploration of the Arctic Ocean by nuclear submarine. The USS Nautilus in its historic crossing of the Arctic Ocean from the Pacific to the Atlantic Ocean via the North Pole in 1958 used the earliest of these systems, Autonetics' N6A Autonavigator. The N6A was also used aboard the USS Skate and USS Sargo in subsequent exploration cruises of the Arctic Ocean.

This paper provides a brief description of the N6A Inertial Navigation System and its critical role in the Arctic exploration cruise of the USS Sargo in 1960.

Introduction

Exploration of the Arctic Ocean by nuclear submarine began in August of 1958 with the transpolar trip of the USS Nautilus. Two subsequent polar trips by the USS Skate in 1958 and 1959 demonstrated the capability of nuclear submarines to enter the Arctic Ocean from the Atlantic and operate for periods of up to 10 days. The cold war and the strategic importance of the polar region made it necessary for the US Navy to have the capability to conduct extended operations year around in the Artic Ocean and have access from both the Atlantic and Pacific oceans. This capability was clearly demonstrated in January and February of 1960 by the USS Sargo's historic thirty-one day exploration of the Arctic Ocean, entering and exiting the Arctic Ocean through the ice covered shallow waters of the Bering Sea, Bering Straits and Chukchi Sea during the season of heaviest ice pack.

Critical to the success of all three of these polar expeditions was the N6A Inertial Navigation System. This system, designed by the Autonetics division of North American Aviation Inc. in the early 1950s as the guidance system for the Navaho missile, proved the necessity of having inertial systems for polar navigation and provided the basis for the design of future Ships Inertial Navigation Systems.

The N6A Inertial Navigation System

The N6A Inertial Navigation System consisted of a local-level stabilized platform with two double integrating accelerometers that directly precessed the level axis gyros to produce a two-axis 84-minute pendulum. The operation of the platform was separate from the computer, which was used to solely solve the guidance equations. It was the development of digital computers that overcame the analog computers inability to perform angle resolution and integration to the accuracy required for navigation that led to the possibility of using a local-level platform mechanization. The local-level platform mechanization was preferred because it enhances the accuracy of both gyroscopes and accelerometers by maintaining them in a fixed orientation relative to gravity and it can be used as a precision attitude reference.

Figure 1. *N6A Navigation System installed on the USS Sargo* (Courtesy of US Navy)

Figure 1 is a photograph of the N6A Inertial Navigation System installation on the USS Sargo. The insulated spherical structure below the table and against the author's knee is the housing that covers the stable platform. Four gyros are mounted in the upper section of the platform with their output axes vertical. In this orientation any change in the center of gravity of the float of the gyroscope will not cause an error torque due to gravity. Two of these gyroscopes control motion about the level x-axis through the platform servo and two around the level y-axis. The two remaining gyros are mounted in the lower section of the platform along with two distance meters These gyros control motion about the azimuth axis and therefore are mounted with their output axes horizontal. Instead of controlling a particular axis of the platform continuously with one gyroscope; control is alternately switched between the gyro pairs on each axis. The rotor spin polarity is reversed for each gyro during its off-duty period. This effect is to cause the gyro drift to be alternately reversed from positive to negative instead of continuing in the same direction. This mode of operation was named NAVAN.

The distance meters consist of an electric motor that rotates about a vertical axis. The electric motor is contained within a cylinder or "float" suspended on frictionless bearings in a flotation fluid. The floated cylinder is unbalanced about the vertical axis. Acceleration acting on the unbalanced float causes it to rotate. A pick-off signal is sent to the distance meter servo, which generates a current in the electric motor inside the float. The acceleration of the electric motor reacts against the cylindrical float creating a torque that is equal and opposite to the acceleration induced torque. The acceleration of the electric motor is therefore proportional to the acceleration sensed by the distance meter, the angular velocity of the motor is proportional to velocity and the total angle that the motor rotates is proportional to distance. Thus the name distance meter.

The most significant features of the N6A navigation system were:

1. Local-level free-azimuth stable platform
2. Digital position computer
3. Paired reversing gyroscopes (NAVAN)
4. High-accuracy pulse torquing of the gyroscopes
5. Double integrating accelerometers (distance meters)
6. Automatic self-alignment

<u>Sargo's Arctic Exploration Cruise</u>

Sargo departed the submarine base at Pearl Harbor on Monday January 18, 1960 on a forty-five day cruise to explore the Arctic Ocean and to determine the feasibility of a submarine under-ice passage through the shallow waters of the Bering and Chukchi Seas during the arctic winter. The cruise began with the N6A Inertial Navigation System disassembled for the replacement of one of the distance meters. A complete set of spare parts was on board and it was decided that the repair could be made underway. The repair was completed within a few hours with the aid of the navy technicians assigned to the N6A. Following an at sea alignment the Latitude as determined the N6A disagreed with the Sargo's dead reckoned position derived from a Loran C fix. Attempts to resolve this discrepancy continued for several sleepless days and nights as the Sargo proceeded north toward the Aleutian Islands. Since the cruise could not proceed to the pole without the Inertial Navigation System it was a great relief when a radar position fix on St. Matthew Island validated the N6A's position and alerted the navigation officer to a malfunction of the Loran receiver. This would be the first of several instances in which the Inertial Navigation System would demonstrate its value. This uncertainty in the N6A's position was reported in the humorous cartoon publish in the Sargo's newsletter shown in Figure 2.

Sargo proceeded north into the Bering Sea to a rendezvous with the icebreaker Staten Island on the 25th of January. While steaming north in company with Staten Island she reported that she was stopped by solid pack ice three feet thick with six to eight foot pressure ridges and that it was snowing heavily in a 40 knot gale. As Sargo's commanding officer, Commander Nicholson wrote in his cruise report,"It was difficult to imagine the conditions on the surface as we comfortably orbited her at 120 feet.".

Continuing north Sargo surfaced through 17 inches of snow-covered ice 41 miles from St Lawrence Island on the 27th of January. The dawn was beautiful with a temperature of 23°F and a wind of 27 knots. Figure 3 is a photograph of the author on the ice with the Sargo in the background. By the 29th of January we were transiting the Bering Straits. The bow planes had frozen during an earlier surfacing. This became a serious problem when dodging pressure ridges in shallow water. It was in this condition that the Sargo encountered water depths of 120 feet that required sailing 10 feet off bottom. Overhead the ice was three and a half feet thick with pressure ridges 30 to 60 feet deep about every 80 yards. At one point the depth began to shoal and the submarine came within 5 feet of the bottom. This rise in the sea floor was named "Tall Gonzales". The Arctic Circle was

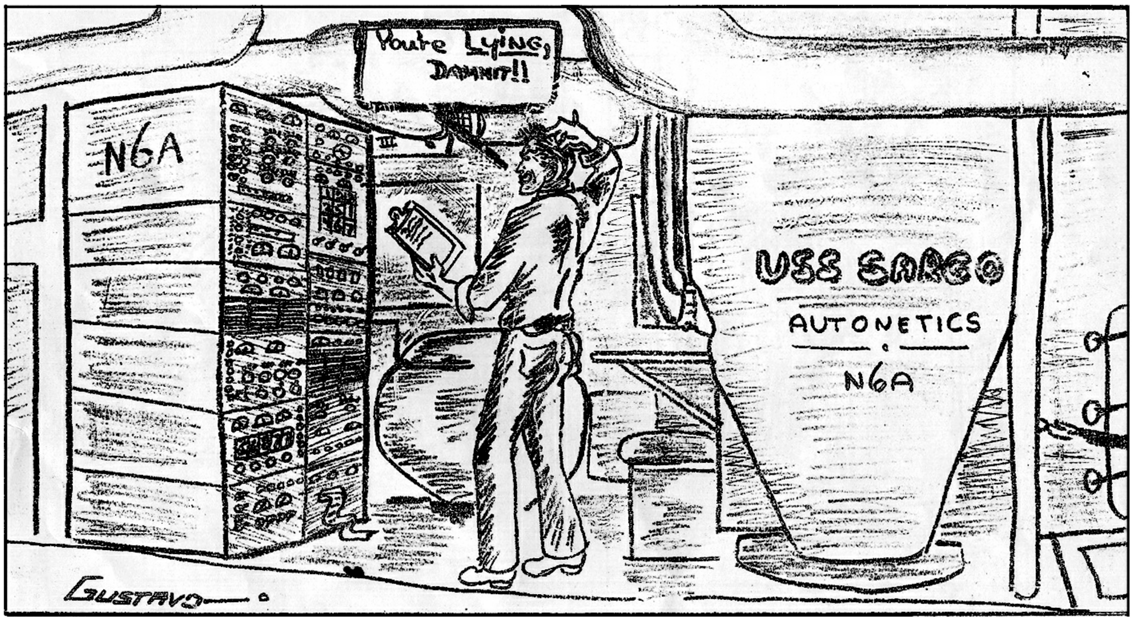

Figure 2. *Cartoon published in Sargo's Newsletter*

crossed without ceremony and the water depth continued to increase.

On the 1st of February after passing Herald Island and entering the Chukchi Sea, the iceberg detector stopped working due to a ground in the training motor. Five hours earlier we would have been in serious trouble. Now we must somehow make repairs before commencing the return transit. The problems which had to be overcome appeared staggering. The detector training mechanism weighs about 650 pounds with the

Figure 3. *Author on the ice with Sargo in the background* (Courtesy of US Navy)

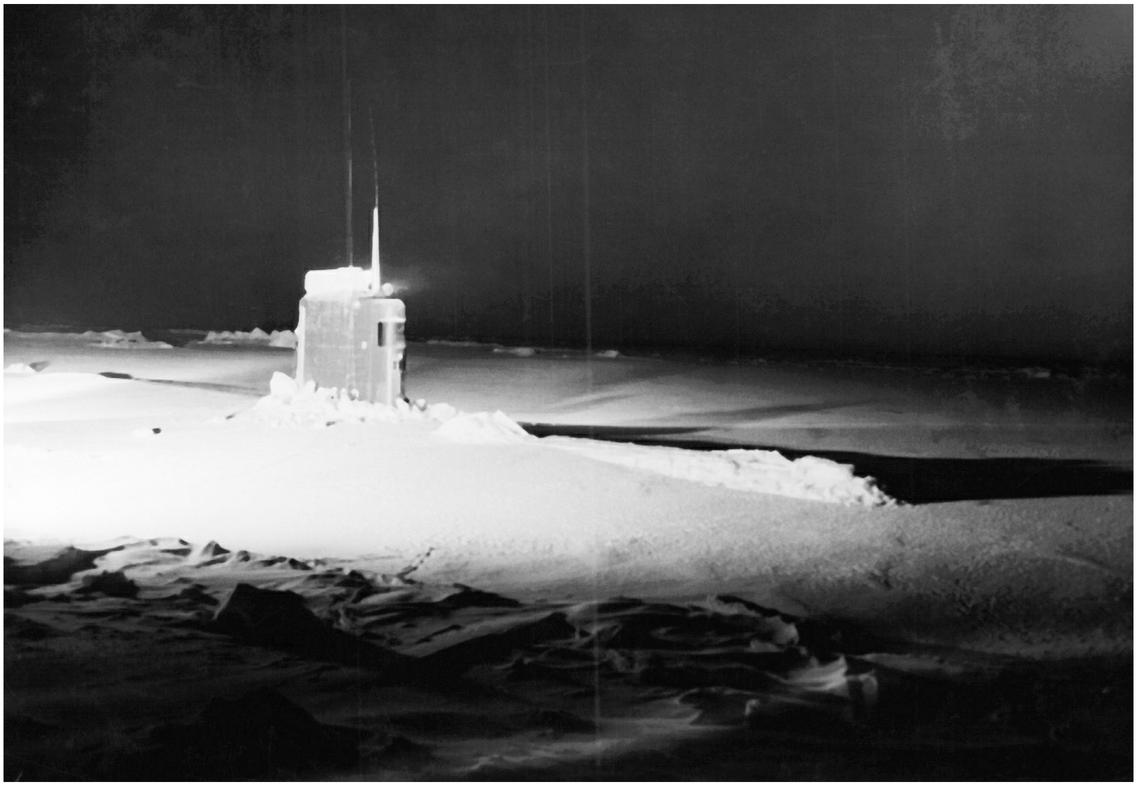

Figure 4. *Sargo surfaced at the North Pole — 9 Feruary 1960* (Courtesy of US Navy)

hydrophone attached. The removal of the training mechanism would have been difficult in any weather because of the weight and shape of the assembly. It was a real feat for two men wearing heavy winter clothing in cramped quarters in 20 below zero weather. By the 4th of February the training motor had been removed and brought below while the components of the iceberg detector, which remained topside, had been secured for sea and a stationary dive was made. There was some apprehension of the dive after having been surfaced for 40 hours where we were exposed to –20° weather and subjected to the tremendous forces of shifting ice. There was no cause for concern however and we continued to follow a zig-zag track generally along longitude 180°.

Radio communications continued to be a problem since it was too much to expect a submarine antenna to compete with better antennae three or four thousand miles closer to shore stations. A ham radio operator in San Francisco managed to get the circuit clear enough to receive several situation reports.

After passing 85° north latitude one of the gyros on the N6A platform failed. A spare gyro was installed and the Sargo retraced its course to below 85° in order to have a sufficient horizontal component of earth rate to gyro compass and realign the system. Once back on course to the pole the Mk 19 and Mk 23 gyrocompasses were placed in directional gyro mode and the N6A was shifted to the transverse coordinate frame. In the transverse coordinate frame the singularity of the Pole is moved 90° to the equator and the system navigates in grid coordinates. At 0934, Hawaiian time, Sargo passed the North Pole at a depth of 350 feet. We surfaced near the Pole through 37 inch thick ice. It was clear, calm and peaceful with a light breeze, a heaven full of stars and a bright half moon. The temperature was –33°F. Figure 4 is a photograph of the Sargo surfaced at the North Pole. A vapor trail of a high flying aircraft was sighted by our lookout. The pilot of the aircraft turned either because he observed us or because he was going to orbit the Pole. We shined our searchlight at him and he flashed his landing lights in reply, then continued on his way. He was too high to identify and radio was unable to contact him. The Sargo's navigator took sextant measurements

Figure 5. *Cake celebrating arrival at the North Pole* (Courtesy of US Navy)

to determine our position. Due to the high elevation of the visible stars his estimate of our position was within a ten mile diameter circle which included the Pole. Based on the display of the distance meter's speed of rotation we were with a quarter mile of the Pole. This was a second demonstration of the value of the Inertial Navigation System.

The next day after celebrating our arrival at the Pole with a cake (Figure 5) and raising the Hawaiian flag (Figure 6) Sargo departed from the Pole. The N6A was being used as the master heading reference and a comparison was made between the heading of the N6A and the heading of the Mk 19 after correcting for its drift in the free gyro mode. The initial result was a disagreement of 60°! An error of this magnitude would result in a position error of hundreds of miles in a short time. Confidence in the N6A heading and position information was supported by bottom contour data which included the Lomonosov Ridge. It was finally determined that the Mk 19's drift was being compounded rather than compensated for, which further demonstrated the necessity of having Inertial Navigation Systems on ships.

Our course now was set for Nansen Sound and then to follow the 100 fathom curve to McClure Strait. Enroute the iceberg detector was modified to use a second sonar receiver. This appeared to work well, although not quite as well as it did with its own receiver. Evaluation of this modification continued during the exploration of the entrance of McClure Strait. The cruise continued with passage to the Ice Station T3 on the 17th of February. The plan was to surface near T3 and visit the Ice Station. No recently refrozen areas or Polynyas with thin enough ice were found so a sonar survey of the bottom contour of the Ice Station was performed. Leaving T3 we continued toward the Bering Straits. By the 19th of February we were cruising at seven knots keeping an indicated 30 feet off bottom in 155 feet of water when we entered another region of deep ridges and commenced radical maneuvers to avoid them. Detection and evasion of the ridges was a much different problem than on our north-bound transit. Two particularly deep ridges were detected ahead. Suddenly there was a jolt as the sail struck ice. At that moment we were at 123 feet with 32 feet under the keel, making seven knots. The boat was abruptly driven down 25 feet with a 6° down bubble. We heeled slightly to port and started to decelerate. All stop was rung up and the collision alarm sounded. The depth gage indicated 148 feet — almost on the bottom! Maneuvering was ordered to put the Emergency Bottoming Bill into effect and they shut down the port side of the steam plant to prevent silting-up the port side heat exchangers in case we bottomed. The fathometer

Figure 6. *Raising the Hawaiian Flag at the North Pole* (Courtesy of US Navy)

showed the depth under the keel and decreased into the zero to eight foot band. Blowing of the tanks with the vents open was effective and we came up. We were clear of the ridge and all compartments reported no damage. The port steam plant was put back on line and we resumed base course at five knots with 23 feet under the keel. Sensors indicated that the ridge we had hit was perhaps as deep as 108 feet. Figure 7 is a sketch, drawn by the author for the final trip report, illustrating the collision of the submarine with the ice ridge.

The N6A was found to be interfering with the iceberg detector and it was turned off on February 18th for several days until the 400 cycle inverter was relocated. The vital latitude information was sorely missed as the Bering Straits were being approached. When the N6A came back on line the initial read-out of latitude showed that we were 35 miles north of our estimated position. This seemed incredible but the N6A latitude had consistently been the best information of position. Apparently we had been in a one knot northerly current although the meager data available indicated that the currents should be very small at our cruising depth. After surfacing the navigator determined our position with a sun line and loran. The fix put us very close to the latitude determined by the N6A confirming the one knot northerly current. Dropping out of the Polynya we headed south. The iceberg detector once again was blanked out by interference. This time the cause proved to be the Mk 19 compass and not the N6A. There were no qualms about securing the Mk 19 as the N6A and the Mk 23 were giving reliable information.

On the 23rd of February the N6A went off line due to the failure of the NAVAN switch. After replacing the switch and realigning, the N6A indicated that we were well to the north of the estimated position. The current had increased to 1.7 knots rather than decreasing to 0.5 knots as had been predicted.

Open water was reached at last on the 25th of February. In the course of the polar exploration Sargo had steamed 6003 miles and spent 31 days under the ice. A total of 20 surfacings were made while in the ice pack including 16 ice breakthroughs.

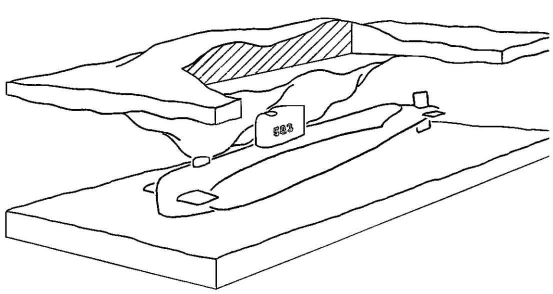

Figure 7. *Sketch of Sargo's collision with ice ridge*

The routine submerged transit from the edge of the Arctic ice pack to Pearl Harbor was interrupted by a brief stop at Adak, Alaska.

Bibliography

"Nautilus 90 North" by Commander William R. Anderson, U.S.N., World Publishing 1959

"Report of Under-Ice Cruise in Arctic Basin Which Included Surfacing at North Pole 9 February 1960"

USS Sargo Cruise Report Serial 012 3 March 1960

"Under Ice" by William M. Leary Texas A&M University Press College Station

"Submarines Under Ice" The U.S. Navy's Polar Operations by Marion D. Williams Naval Institute Press Annapolis, Maryland — 1988

"Through Bering Strait in Mid-Winter", pp 4–17, The Submarine Review, July 1984 Published by the Naval Submarine League