Aviation Archeology of the Horten 229 v3 Aircraft

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Abstract: This paper is a report on the Radar Cross Section (RCS) design characteristics of the German World War II aircraft, the Horten 229 v3. The aircraft was designed by the Horten brothers who specialized in the development of flying wing aircraft. They were sponsored by the German Third Reich to develop an aircraft to defeat the American and British allied fighters and defense systems. An advanced batwing-shaped jet fighter was discovered by American troops in the final months of World War II at a top secret facility in Germany. If the Nazi engineers had had more time, would this jet have ultimately changed the outcome of the war? What, if any, RCS reduction characteristics were used by the designers to defeat the radar defense systems of the day? These questions have been the debate by historians for many years. Michael Jorgensen of Myth Merchant Films, a company that develops historical documentaries, collaborated with the stealth experts of Northrop Grumman Corporation to answer long debated questions regarding the stealth capabilities of the Horten 229 v3. Modern RCS tools were utilized to examine the one known Horten 229 v3 located at the Smithsonian facility in Washington, DC. A full-scale RCS model was fabricated with modern techniques to simulate the aircraft as it would appear to electromagnetic energy. The original aircraft structure was constructed of a steel tube truss design covered by wood skins. The RCS model was constructed of wood to replicate the original design and complex parts were fabricated by modern techniques such as stereo-lithography. Northrop Grumman tested the full-scale replica at its outdoor RCS test facility in California at electromagnetic frequencies equivalent to the allied radar systems of World War II. Imaging techniques were utilized to understand the main RCS scattering sources of the Horten 229 v3. The Horten 229 v3 was evaluated operationally. Radar detection ranges varied from 6 miles to 20 miles depending on the radar system. Speed also plays a major role in the Horten 229 v3 ability to outperform the conventional fighter/bomber of the day.

Nomenclature

°	=	degrees
CAD	=	Computer aided design
CH	=	Chain Home
dB	=	decibels
dBsm	=	decibels relative to one square meter
g	=	Acceleration due to gravity
GHz	=	Giga-hertz
ISAR	=	Inverse Synthetic Aperture Radar
kg	=	kilo-grams
km/h	=	kilometers per hour
lbs	=	pounds
MHz	=	Mega-hertz
mph	=	miles per hour
RADAR	=	RAdio Detection And Ranging
RCS	=	Radar Cross Section
RF	=	Radio frequency
UHF	=	Ultra-high Frequency
VHF	=	Very-high Frequency

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I. Introduction

During the final stages of World War II, the U.S. military initiated Operation Paperclip, which was an effort by the various intelligence agencies to capture advanced German weapon technologies, associated research materials, and keep them out of the hands of advancing Soviet troops. Among other prizes, the Americans managed to capture an intact Ho-229 v3 which was undergoing final assembly at the time. This was an exotic fighter/bomber prototype designed by Reimar and Walter Horten. It was a flying wing aircraft powered by jet engine propulsion and built almost entirely of plywood wrapped around a steel truss structure. The Ho-229 was easily one of the world's most advanced aircraft of the time.

When the captured Ho-229 v3 was brought to the United States at the end of World War II, the Northrop Corporation was involved in its evaluation. Northrop was chosen because of their own experience with flying wing aircraft designs. Jack Northrop had been independently building and testing flying wing aircraft since the N-1M in 1939.

One particular aspect of the Ho-229 has always been shrouded in mystery and speculation. Was it a true stealth aircraft? Many have speculated that this was indeed the world's first aircraft specifically designed to be difficult to detect by radar, the first aircraft to incorporate what is now called low observable or stealth technology. There is no doubt that a pure flying wing configuration with no vertical or horizontal tail surfaces would generally be expected to have a lower radar cross section as compared to a conventional aircraft design. But there is considerable evidence to suggest that such designs were initially pursued because of the inherent aerodynamic properties of the design, not because of stealth. Well after the end of World War II, Reimar Horten stated that the wood glue used to assemble the aircraft was mixed with charcoal dust in order to absorb electromagnetic energy from radar. He further stated that this technique could effectively shield the aircraft from detection by the British ground-based early warning radar known as Chain Home. Others have speculated that Horten made these claims decades after the end of World War II, only after he became aware of stealth technology.[4]

Figure 1. Full Scale Ho-229 RCS Pole Model

The goal of the collaborative effort between Myth Merchant Films, a company that produces historical documentaries, and today's stealth experts resident at Northrop Grumman Corporation was to explore and perhaps answer some of these tantalizing questions. The plan was to construct a full scale Radar Cross Section (RCS) model using plywood to replicate the original design and to fabricate complex parts using modern manufacturing techniques such as stereo-lithography. Northrop Grumman would test the full scale replica, at its outdoor RCS test facility located in California, at electromagnetic frequencies equivalent to the allied radar systems available during World War II. Imaging techniques would be employed to understand the primary RCS scattering sources of the aircraft. The Ho-229 v3 performance characteristics would then be modeled and evaluated operationally using Northrop Grumman's extensive simulation facilities.

II. Background

The Battle of Britain proved to be the pivotal turning point in the air war between the allies and Germany. German aircraft built by companies like Messerschmitt, Heinkel and Junkers dominated the skies over Europe early in the war. In preparation for his invasion of Great Britain, Hitler ordered the Luftwaffe to destroy the Royal Air Force. With three times as many fighters as the British, Reichsmarshall Hermann Goring, was confident the Luftwaffe would make quick work of the RAF. Although out gunned, RAF pilots shot down more than a thousand Luftwaffe aircraft with only two hundred losses. What gave the British the defensive edge they needed was radar. This was a new technology that gave them the precise range, altitude and numbers of German aircraft approaching over the English Channel. The Germans also had radar but it was the British who under threat of invasion poured massive resources into building more advanced radars and deploying them as part of a fully integrated air defense system along the English Channel. The British were using radar controlled anti-aircraft guns with great success and it was becoming apparent to Goring that nothing the Luftwaffe put in the air was safe.

A. Capabilities of the Allied Defense System[5&6]

In September 1939 World War II began. By 1940 most of Europe was under the control of Hitler and the Nazi's. The British, just a short distance across the English Channel, looked on as more and more of France was taken over by Germany. Hitler wanted to destroy the British, but in order to do that he would have to control the English Channel. As the war between the British and German Navy's raged on, air superiority would be needed by the Nazi's. The Luftwaffe was Hitler's answer to beat the British in the Channel. The Luftwaffe was a fierce force and outnumbered Britain fighters by over 2.5 to 1. The British realized quickly that they needed an advantage over the German Luftwaffe. A brilliant radio researcher, Sir Robert Watson-Watt, conceived of an early warning system called RADAR.

The British RADAR system was called Chain Home (CH). The CH radar system evolved very quickly over time. It was not clear, at that time, if anyone understood the nature of aircraft RCS and how they it was affected by different frequencies. The CH radar was a family of systems that operated at different frequencies and power levels. This resulted in radar systems that had a wide variety of capabilities. We looked at four of the chain home systems: 1) Chain Home operated at various frequencies from 22 MHz to 50 MHz and detected targets at 80 mi at 10,000 ft altitude but could not detect targets below 1 degree elevation, 2) Chain Home Low operated at 200 MHz and detected targets at 110 mi as low as 500 feet in altitude, 3) Chain Home Low, Type 11 operated at various frequencies from 500 MHz to 600 MHz and detected a medium sized bomber target at 60 mi, 4) Chain Home Extra Low operated at 3 GHz and detected targets at 30 mi at 50 ft to 200 ft in altitude. The Chain Home Extra Low incorporated a type 13 moving elevation scan antenna and a type 14 rotating antenna.

The Chain Home radar system created a force multiplier effect for the British. Timely warning of the direction and range of incoming air raids allowed the British to focus their smaller numbers and thus defeat a larger strike force. Germany was never able to achieve air superiority and take control of the English Channel.

B. Horten Brothers[7]

Walter and Reimar Horten, also referred to as the Horten Brothers, were German aircraft designers, pilots, and enthusiasts. They were members of the Hitler Youth and Nazi party. They had little, if any, formal training in aeronautics or engineering, but they designed some of the most advanced aircraft of the 1940s, including the world's first jet-powered flying wing aircraft, the Ho-229.

As teenagers, the Horten brothers became involved in the civilian flying clubs that thrived in Germany between the World Wars. They earned practical experience and became admirers of German aircraft designer Alexander Lippisch. The Hortens moved away from the mainstream aircraft design trends of the 1920s and '30s, and began experimentation with alternative aircraft designs. Around 1933, the Hortens began to build and test their own flying wing glider designs, which were extremely simple and aerodynamically clean. The Horten airframe designs featured extremely low parasitic drag and were adaptable to high speed flight.

Following the outbreak of World War II in 1939, Walter and Reimar joined the Luftwaffe as pilots. Walter participated in the Battle of Britain, secretly flying as the wingman for Adolf Galland, and shot down seven British aircraft. Their brother Wolfram was killed while piloting a bomber over Dunkirk. The Hortens also served as aircraft design consultants to the Luftwaffe, though they were generally regarded as outsiders by the German aeronautical community. The Luftwaffe did not actually use many of the Hortens' designs until 1942, but gave enthusiastic support to their twin-turbojet-powered fighter/bomber design, the Ho-229.

C. Design Challenge given to the Horten Brothers

In 1943, Reichsmarschall Hermann Göring issued a request for design proposals to produce a bomber that was capable of carrying a 1,000 kg (2,200 lb) payload over 1,000 km (620 mi) range at a speed of 1,000 km/h (620 mph); the so called "3 x 1000 project".

At the time, there was no way to meet these aggressive goals. Conventional German bombers could reach Allied command centers in Great Britain, but were suffering devastating losses due to Allied fighters. The new Junkers Jumo 004B turbojets could provide the required speed, but suffered from excessive fuel consumption.

The Hortens concluded that the low-drag flying wing design could meet all of the 3 x 1000 goals. By reducing the drag, cruise power could be reduced to the point where the range requirement could be met. They submitted their Ho IX design as the basis for the 3 x 1000 bomber. The German Air Ministry approved the Horten proposal, but felt that the aircraft would also be useful as a fighter due to its estimated top speed being significantly higher than that of any allied aircraft. So they ordered that two 30 mm cannons be incorporated into the design.

The Ho 229 was of mixed construction. The center section was fabricated from welded steel tubing with wooden wing spars. The wings were assembled from carbon-impregnated plywood panels boned together with a charcoal and sawdust adhesive mixture. The wings featured a single main spar, incorporating the jet engine inlets, and a secondary spar used for attaching the elevons. The aircraft was designed for a load factor of 7g's with a 1.8x safety factor yielding a 12.6g ultimate load rating. The wing's chord/thickness ratio ranged from 15% at the root to 8% at the wingtips.

Flight control was achieved using elevons and spoilers. The control system included both long span inboard and short span outboard spoilers. The smaller outboard spoilers were activated first, providing a smoother and more graceful control of yaw as compared to a single spoiler system.

The aircraft utilized retractable tricycle landing gear, with the nose gear on the first two prototypes obtained from the He 177's tailwheel system. An ejectable drogue parachute was incorporated to help slow the aircraft after landing. The crew station featured a primitive ejection seat. The aircraft was originally designed for the BMW 003 jet engine, but that engine was experiencing production problems which delayed its availability. The Junkers Jumo 004 engine was substituted. The turbojet-equipped Ho IX v2 prototype reached a speed of nearly 500 mph during flight trials.

The project was eventually transferred to the Gothaer Waggonfabrik aircraft company, with a production order for 40 aircraft from Goring. The war ended before any could be produced. The Ho 229 was a combat aircraft of enormous potential, but arrived too late to be produced and deployed and see any service prior to the end of the war.

III. Evaluation of the Horten 229

A. Physical examination of the actual Horten 229

Before beginning the construction of the RCS test model, Northrop Grumman engineers were given the opportunity to inspect the actual remaining Ho-229 in the Smithsonian Garber facility in the Washington DC area. The team approached this amazing artifact with great reverence. Physical dimension measurements were taken and subsequently compared to the Ho-229 layout drawings provided by Arthur Bentley. Portable electromagnetic equipment was used to test the multilayer wooden leading edge sections of the aircraft. These skins were approximately ¾ in. thick. The testing revealed that the skin exhibited electromagnetic properties not consistent with simple plywood, which might provide some electromagnetic masking of metal structures within the aircraft.

Figure 2. Ho-229 at Smithsonian

B. Materials used in original construction

The Ho-229 was constructed from a mix of the typical materials available to the Germans during the 1930's. The center section was made from welded steel tubing creating a space frame truss structure. The wings were made from wood with metallic fuel tanks in the left and right leading edges. The wooden spars of the wings were attached to the welded steel tubes in order to carry the loads of the aircraft. The leading edge of the center section was constructed from multiple layers of thin wood in order to create the complex airfoil contours. During our inspection of the Ho-229 at the Smithsonian museum, it appeared that a material similar to carbon black or charcoal was mixed in with the glue between the thin layers of the leading edge shape. Figure 2 shows the buildup of the leading edges of the Ho-229. One of the reasons that these older techniques were used was that aluminum and other materials were in short supply due to the war effort.

C. Reflectometer testing

Northrop Grumman utilized the Next Generation Sensor (NGS)[8] to determine how much electromagnetic energy was being reflected by the leading edge surface of the Horten 229. The NGS generates a frequency response across a 2 GHz to 18 GHZ bandwidth. The NGS system features a broadband dual polarization horn, a dielectric lens, a calibration methodology, and a unique set of data processing and extraction algorithms. The NGS horn is enclosed in an absorber lined cylindrical housing equipped with a collimating lens to achieve highly localized RF illumination. The estimated illumination footprint is 5" in diameter. The aperture of the NGS horn is exposed and the horn is suspended by four legs to minimize low frequency interference. The NGS software supports three standard calibration methods, 1) response and isolation, 2) three offset shorts, and 3) two offset shorts & one load. These error correction algorithms address the directivity, mismatch, and tracking errors associated with a one port device. Separate error correction is applied to both polarizations of the horn. The NGS data processing software includes time domain transformation, gating, windowing, weighting and de-weighting functions to enhance processing accuracy and minimize transformation artifacts.

The accuracy and compactness of the NGS make on vehicle inspection of microwave absorbers practical. The results of utilizing the NGS is shown in figure 3. The plywood test sample results exhibit a periodicity which is due to the ¾ inch thickness. The Ho-229 leading edge has the same characteristics as the plywood except that the frequency nulls are shifted and have a shorter bandwidth. This indicates that the dielectric constant of the Ho-229 leading edge is higher than the plywood test sample. The similarity of the two tests indicates that the design using the carbon black type material produced a poor absorber.

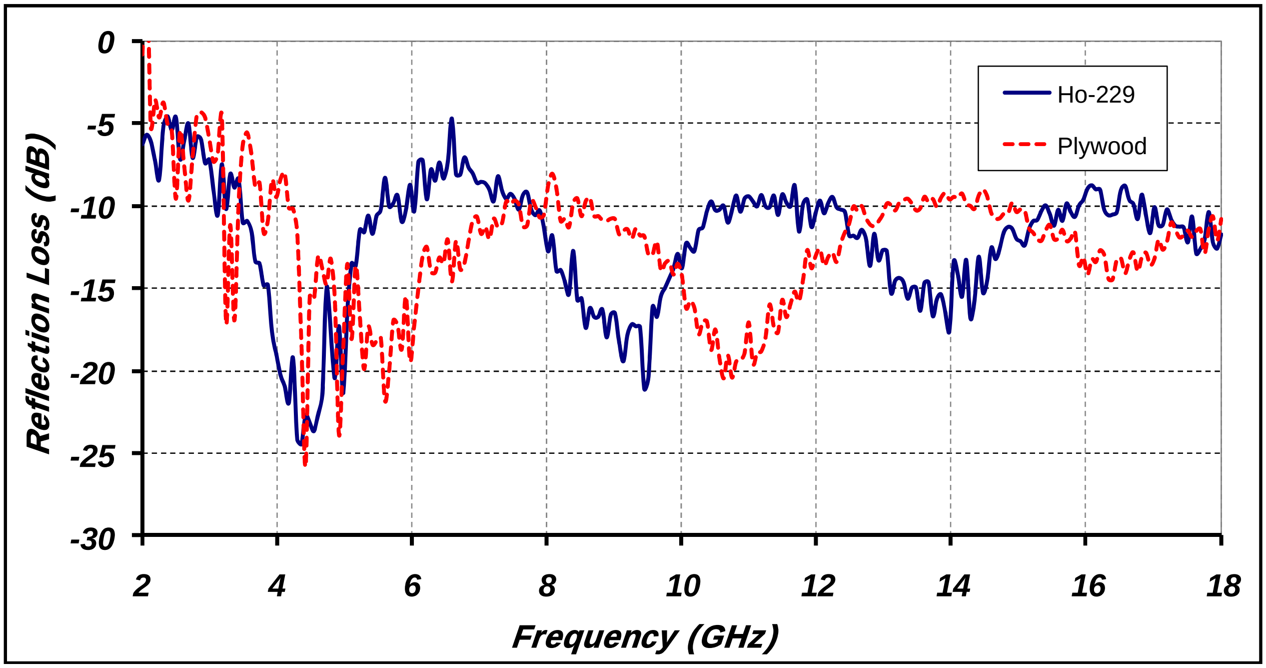

Figure 3. Ho-229 Leading Edge Reflection Loss

IV. Re-creation of the full scale Horten 229

A. Model Construction

Northrop Grumman's low observables engineering community has considerable experience under its belt. Over the decades, countless structures have been illuminated across all possible radar frequency ranges. This includes full-up aircraft and models, down to individual parts, representing all forms of aircraft construction methods and material utilization developed since the Wright Brothers. LO computational techniques have been considerably refined and validated in comparison to empirical testing results.

Prior to developing the strategy for model construction, Northrop Grumman engineers obtained a comprehensive package of wonderful Ho-229 layout drawings prepared by Arthur Bentley, and Mr. Bentley himself was a consultant to the project.

Given this information, the inspection of the actual aircraft, and the depth and breadth of observables experience, the engineering team was confident that it could figure out how to build the Ho-229 RCS test model. The team already had an excellent detailed technical understanding of this aircraft and how to effectively simulate it for the purpose of determining its electromagnetic properties.

The possibility of reconstructing the truss structure was discussed, but that would be cost prohibitive and the team's senior LO engineers determined that it wasn't really necessary. To obtain the desired first-order results, it would be sufficient to build the model from high-grade plywood with carefully targeted applications of various conductive coatings internally and externally to simulate the interior configuration. Specialized paints and coatings are the key and have been proven on numerous previous projects.

Engineering developed a 3D CAD model of the aircraft based on the Bentley drawings. The CAD model was used to develop the interior plywood structural layout. The various spars, bulkheads, and other structural elements were cut out using computer aided tooling. The aircraft was constructed in three major sections, the two wings and the center section. Fiberglass and carbon fiber techniques were used in certain areas for strength and to simulate complex contours. The canopy was formed from polycarbonate in several sections. The sections were heated and hand formed on a mold of the canopy shape after a number of trial and error attempts. Stereo lithography techniques were used to form complex assemblies such as the inlet lips and the turbojet engine compressor faces.

B. Test set-up

The Northrop Grumman Tejon RCS Test facility is located in Tehachapi Mountains of California. It is a ground bounce outdoor range designed for electromagnetic testing. Available RCS test frequencies range from 145 MHz to 18 GHz, with imaging capability provided in all bands. These ranges can handle targets up to 8,000 pounds on a 14 foot or 26 foot target support pole and range lengths of 1,500 feet or 3,000 feet. A model shop is available for target assembly and/or modification and target storage facilities are provided.

Data is acquired coherently with each target rotation capable of measuring eight frequencies simultaneously. Frequency sweeps can be set for 128, 256, 512, and 1024 frequencies per Chirp. Data output is available in numerous formats including hardcopy, magnetic, and optical. Various forms are available for data output which include rectilinear coherent plots, polar coherent plots, medianized coherent plots, sector statistics, ISAR images, Pixel dumps, image edit and reconstruct, and global plots.

Coherent RCS data, both magnitude and phase, was collected for over 200 discrete frequencies from 145 MHz to 2 GHz, both vertical and horizontal polarizations, and at conical elevations of 0° and -5° with respect to the aircraft.

C. Results and data summary

Today's technology has allowed us to collect sufficient data to answer some of the historical questions regarding the Ho-229. Many have speculated that this was indeed the world's first aircraft specifically designed to be low observable. Now we have RCS test data to answer some of these questions. First, the physical placement of a carbon black type substance in the leading edge plies could indicate that the Horten brothers attempted to build some kind absorber on the aircraft. This absorber proved to be unsuccessful and only increased the dielectric constant of the edge. This in the long run would be helpful in shielding the RF energy form the internal tubular structure and components. However, one must keep in mind that a pure flying wing configuration with no vertical or horizontal tail surfaces would generally be expected to have a lower radar cross section as compared to a conventional aircraft design. But there is considerable evidence to suggest that such designs were initially pursued because of the inherent aerodynamic properties of the design, not because of stealth.

The combination of speed and lower RCS, which contributes to a reduced detection range, was what would have given the Ho-229 a distinct advantage over typical fighter/bombers of the day. A summary of the results between detection range and speed are shown in figure 4 - Summary of Speed and Detection Range. Our model testing and analysis indicated that the detection range of the Ho-229 was reduced 17% to 20%. This would have significantly impacted the reaction times for the allied fighters. However, if the speed potential of the Ho-229 was achieved, it would have been much faster than the typical aircraft of the day, and the reaction time would have been decreased by approximately 47%.

	Typical detection range	Horten	
Chain Home Low	100mi to 110mi	80mi to 90 mi	
Chain Home Low Type 11	60mi	50mi	
Chain Home Extra Low	30mi	24mi	
	Time to target		
	Typical (500 km/hr)	Typical (1000km/hr)	Horten(1000 km/hr)
Chain Home Low	19min	10min	8min
Chain Home Low Type 11	12min	6min	5min
Chain Home Extra Low	6min	3min	2.5min

Figure 4. - Summary of Speed and Detection Range

The coherent RCS data collected was analyzed and figure 5 thru figure 8 represent typical linear RCS plots of the full scale Ho-229 RCS pole model. Each plot is at -5° elevation (relative to the aircraft) and for each frequency in the bands of concern, VHF, UHF, and L-Band for Horizontal polarization.

Data was collected at fine enough frequency steps to create pictures of the Ho-229 RCS target. These pictures are ISAR images and can be a useful tool in locating scattering regions of the Ho-229 RCS target. ISAR images are produced by rotating the target and processing the resultant phase changes of the scattering centers by using a Fourier transform algorithm. This operation is similar to the generation of a large synthetic aperture phased array antenna formed by the coherent summation of the receiver outputs for changing target / antenna geometries. For small angles, an ISAR image is the 2 dimensional Fourier transform of the received signal as a function of frequency and target aspect angle. Figure 9 is a 2 dimensional ISAR image. The intensity of the colors is correlated to the individual pixel RCS magnitudes. The nose and inlets of the Ho-229 are the major scattering mechanisms in the forward sector of the aircraft.

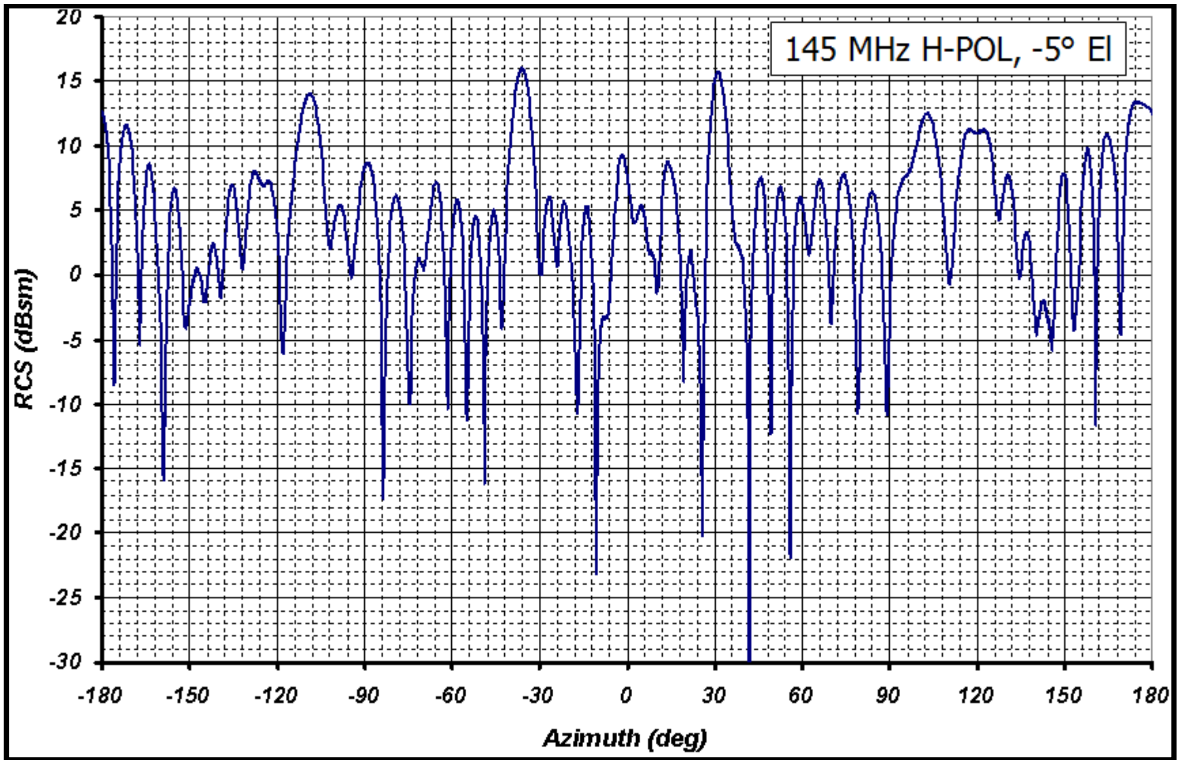

Figure 5. Linear RCS Plot of Ho-229

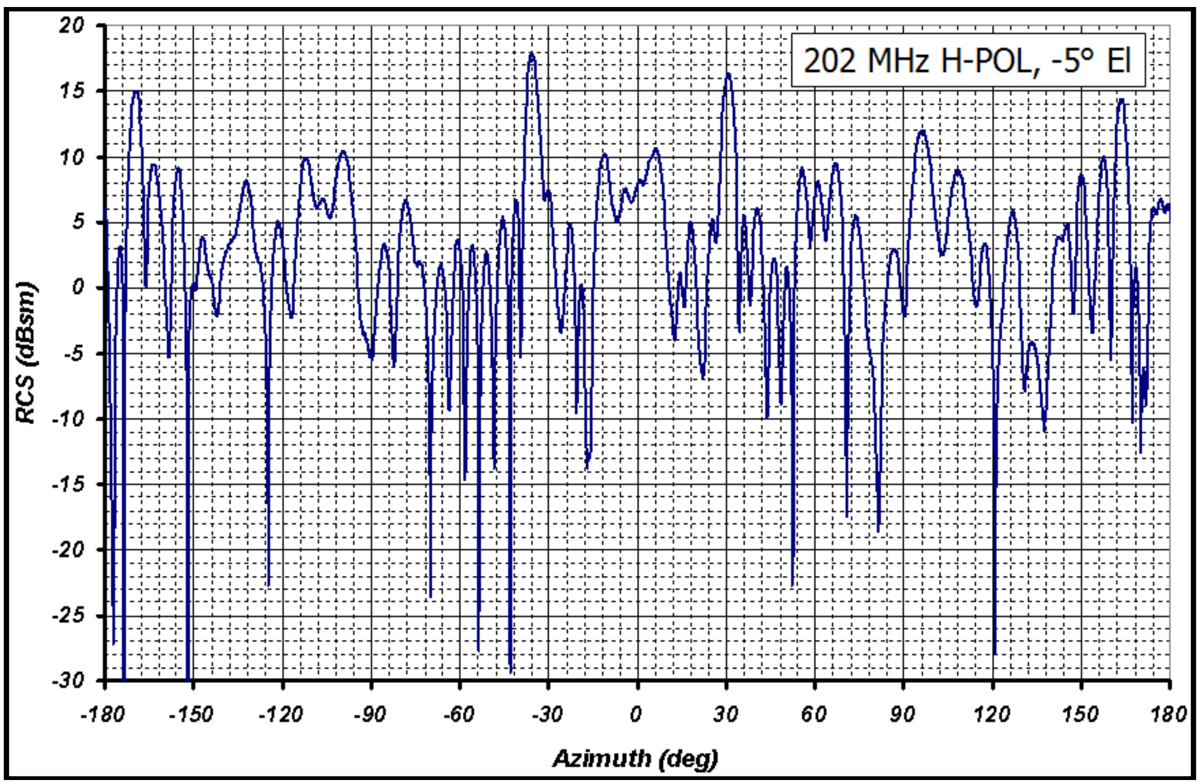

Figure 6. Linear RCS Plot of Ho-229

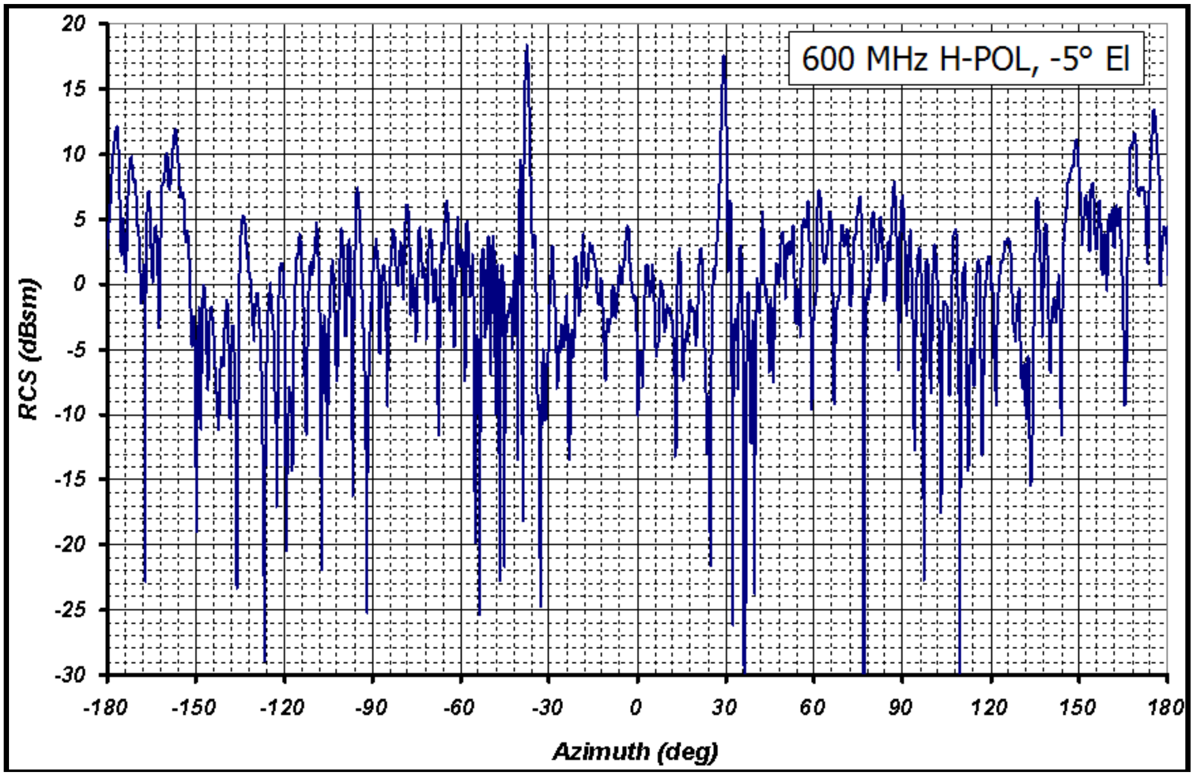

Figure 7. Linear RCS Plot of Ho-229

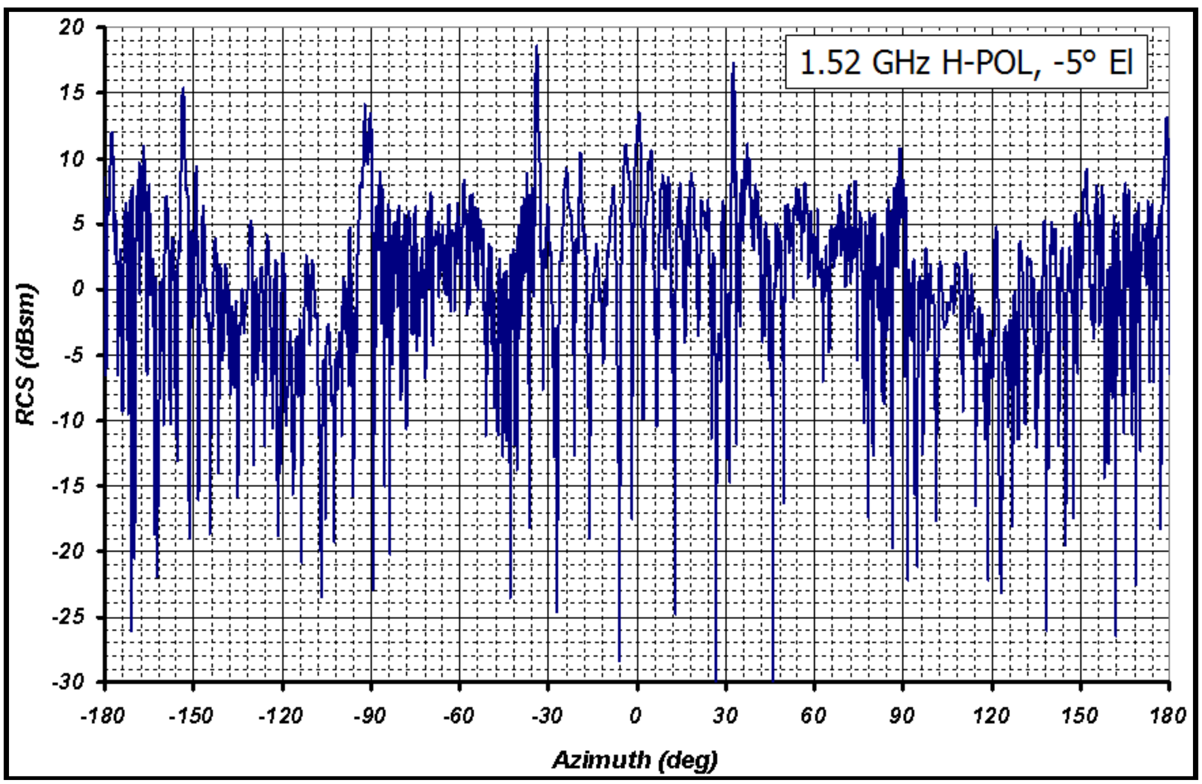

Figure 8. Linear RCS Plot of Ho-229

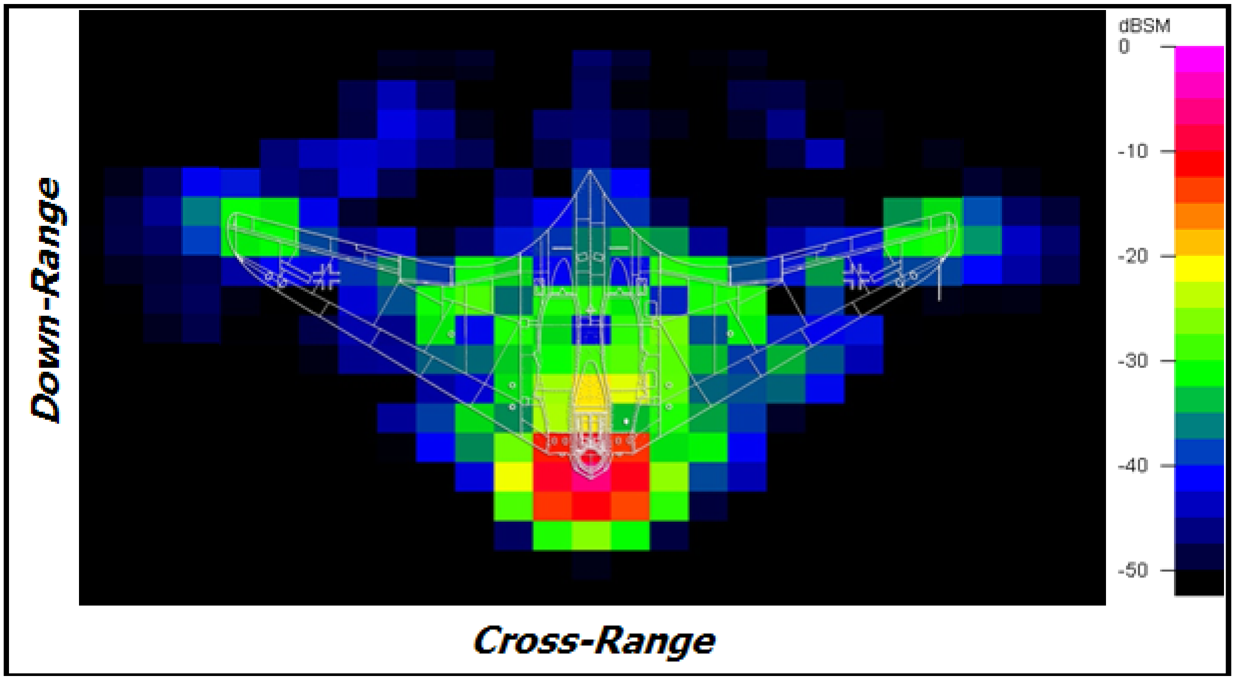

Figure 9. VHF ISAR Image of Ho-229

V. Conclusion

The Ho-229 was a very advanced vehicle for its time. Based on the examination of the original Ho-229 it is evident that the Horten brothers made some attempt to incorporate radar absorbing materials. Even though the material did not perform as an RF absorber, the increase in the dielectric constant of the outer mold line did help shield the inside of the platform from RF energy. Our testing and replication of the Ho-229 utilized conductive material to simulate the shielding effects on the fuselage leading edges and the wing panels. The Horten's, being experienced glider designers, did everything they could do to reduce drag. This includes blending the engines and exhausts into the body and removing the vertical tails from the fuselage. A significant contribution to the Stealth characteristics of modern day vehicles comes from the outer shape of the platform. The Ho-229 was better from a detection standpoint as compared to a typical fighter/bomber of the day. With the Ho-229 travelling at the same speed as a typical fighter/bomber the Horten gained ½ min to 2 min detection advantage. Speed was a large advantage for the Ho-229.

For its time, the Ho-229 is definitely a breakthrough in aircraft design. If the Germans had succeeded in deploying the Ho-229 in large numbers its increased speed and lower detection ranges may have been enough to defeat the radar systems and the allied aircraft of WW II.

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